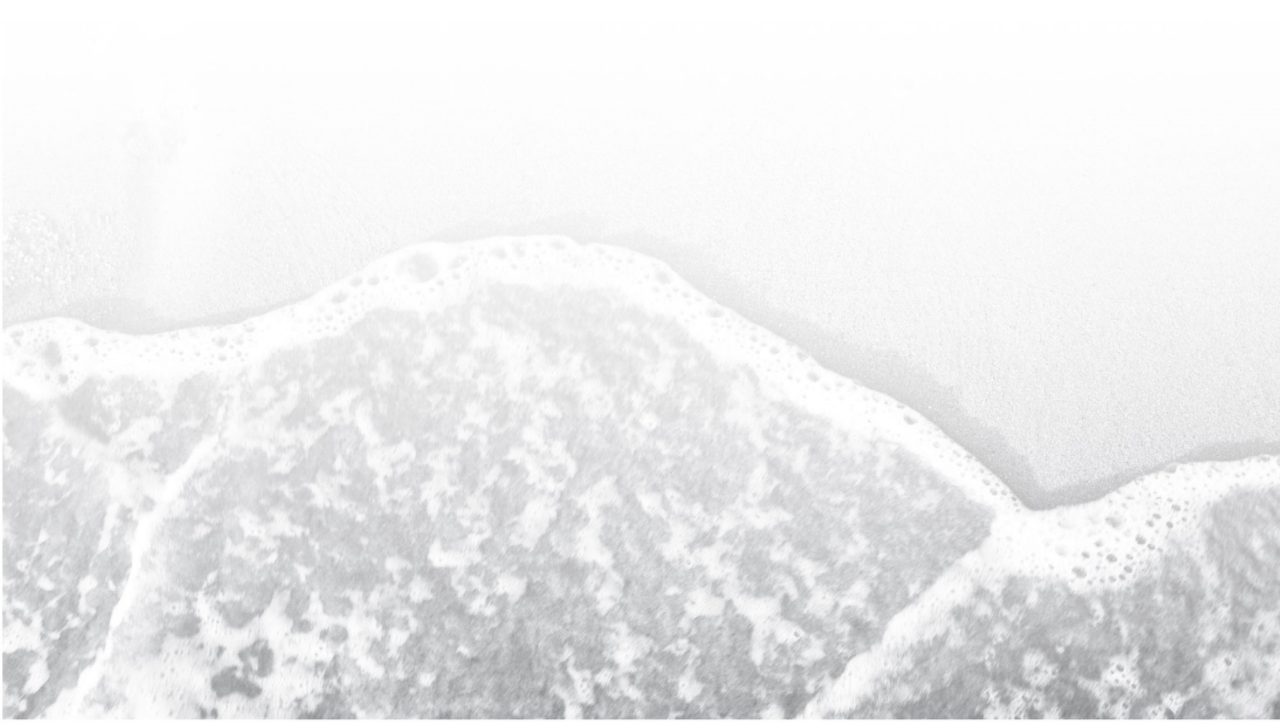
NSW GOVERNMENT | Marine Estate Management Authority

NSW Marine Estate Threat and Risk Assessment

BACKGROUND ENVIRONMENTAL INFORMATION



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More information

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Background

The NSW Marine Estate Management Authority (the Authority) was established by the NSW Government in 2013 to advise on policies, priorities and directions for the NSW marine estate.

The NSW marine estate includes marine waters, estuaries and the coast. It extends seaward out to three nautical miles and from the Queensland border in the north to the Victorian border in the south. The full definition and map can be found at www.marine.nsw.gov.au .

Acknowledgments

A great many people have contributed to our work over the last 18 months. The Authority acknowledges all of the ministers, government agencies, organisations and individual whose support, collaboration and input has made our work possible. Key contributors have been the Marine Estate Expert Knowledge Panel and officers from the following agencies in preparing this report:

- NSW Department of Primary Industries
- NSW Office of Environment & Heritage
- NSW Department of Transport
- NSW Department of Planning & Environment.

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1. INTRODUCTION

In 2013, the newly established N1SW Marine Estate Management Authority (the Authority) announced a project to develop a marine estate draft Strategy. The Authority states that the draft Strategy will aim to:

> Set the over-arching strategy for the NSW Government to co-ordinate the management of the marine estate with a focus on achieving the objects of the MEM Act.

The planned process for effective management of the NSW marine estate is outlined in MEMA (2013). The first step involves engaging with the community to identify the economic, social and environmental benefits they derive from the marine estate. The second step involves identifying current and future threats to the marine estate, and assessing the resultant risks. The management process will aid the Authority's vision of:

> A healthy coast and sea, managed for the greatest well-being of the community, now and into the future.

A key input into the draft strategy will be the outcomes from a threat and risk assessment of the entire marine estate. This project is being conducted in accordance with the principles developed by the Authority for such assessments (MEMA 2013), and is guided by the Authority's Threat and Risk Assessment Framework (MEMA 2015).

The purpose of threat and risk assessment, as set out in the *Marine Estate Management Act (MEM Act*), is to:

- identify threats to the environmental, economic and social benefits of the marine estate
- assess the risks those identified threats pose for the attainment of the Authority's objectives
- inform marine estate management decisions by prioritising those threats and risks according to the level of impact on the benefits derived from the marine estate.

1.1 AIM OF REPORT

This background report describes the environmental assets in the marine estate, and reviews the available scientific literature about threats to these environmental assets and associated benefits, referring to specific regional studies where relevant. Note that the report does not aim to include all literature that examines impacts and details about environmental assets in the regions. The reader is referred to several other publications for further detailed reviews and information at regional scales across NSW (Rule et al. 2007, Smith et al. 2009, Jordan et al. 2010, Roper et al. 2011, Hedge et al. 2014, Johnston et al. 2015, Mayer-Pinto et al. 2015, Stewart et al. 2015). Further background information specifically relating to threats to marine environments and fishery resources in NSW are presented in Kearney and Farebrother (2015). This included specific case studies on several NSW estuaries where the present condition and threats are detailed within several estuary types (e.g. barrier river, bay, drowned river valley, lake).

This background report provides the information on environmental assets and activities in the NSW marine estate to inform an assessment of threat and risk to these assets, which is presented in BMT WBM (2017). It also links to two other data collation projects that are running concurrently: statewide social and economic data about the marine estate (Vanderkooi 2015), and statewide information about Aboriginal cultural values (Feary 2015).

The highest priority threats identified from the marine estate assessment will be used to develop draft options for management responses within the NSW Marine Estate Management Strategy, which will be detailed in a subsequent report.

2. NEW SOUTH WALES MARINE REGIONS

The New South Wales (NSW) marine estate, as defined in the *Marine Estate Management Act 2014,* means:

- coastal waters of NSW within the meaning of Part 10 of the *Interpretation Act 1987*
- estuaries (any part of a river whose level is periodically or intermittently affected by coastal tides) up to the highest astronomical tide
- lakes, lagoons and other partially enclosed bodies of water that are permanently, periodically or intermittently open to the sea
- coastal wetlands (including saltmarsh, mangroves and seagrass), and lands immediately adjacent to, or in the immediate proximity of, the coastal waters of NSW that are subject to oceanic processes (including beaches, dunes, headlands and rock platforms).

The marine estate also includes any other place or thing declared by the regulations to be the marine estate, but does not include any place or thing declared by the regulations not to be the marine estate.

2.1 ENVIRONMENTAL ASSETS

Environmental assets are the physical and biological elements of the marine estate. These can be considered as a nested hierarchy of components, because they could be classified at several categorical levels. The Authority's vision identifies the two fundamental components in this hierarchy as:

- clean and safe waters
- biologically diverse and resilient ecosystems.

For the purposes of the statewide assessment project, assessment of clean and safe waters is restricted to the physio-chemical components of the **water column** only. Safety aspects are not considered, because these relate more to issues of public health than to marine biodiversity conservation.

The concept of biologically diverse ecosystems has been divided into two key categories: **habitat and associated diversity** and **threatened and protected species**.

Habitat diversity covers a range of important habitat types in the marine estate, and the flora and fauna typically associated with them. This includes planktonic assemblages that occur within the water column habitat. Thus, habitats are used as general surrogates for biodiversity in the same way as for previous bioregional assessments (e.g. Breen et al. 2005a, b). It also includes fish assemblages as a specific component of biological diversity as many of those that are harvested are not exclusively associated with a habitat type. The second category relates to marine species listed as threatened or protected under the *NSW National Parks and Wildlife Act*, *NSW Threatened Species Conservation Act* or the *Fisheries Management Act.* This report is restricted to these environmental assets within NSW state waters, which are within 3 nm (5.6 km) of the coast, because this is the area for which the NSW Government, guided by the Authority, has management responsibility.

These three basic components – water column, habitats and associated diversity, and threatened and protected species – will be used in the formal threat and risk assessment. The concept of resilient ecosystems will not be separately assessed, but will be taken into account when deciding the consequence levels assigned to each potential threat. A comprehensive discussion of resilience is presented in the Hawkesbury marine bioregion environmental report (MEMA 2016).

A further fundamental subdivision is needed to adequately assess the threats to the environmental assets in the marine regions. This involves separating the **estuaries** from the **open coast**, which is done by drawing a straight line across the two closest points on opposing headlands for those waterbodies listed as estuaries (Roper et al. 2011). Although this is an arbitrary separation in terms of marine ecological processes, it conveniently divides these two ecosystem types for threat and risk assessments. An example of the extent of estuarine and open coast areas in the central region is presented in Appendix 1.

Table 1. Main categories of environmental assets of the NSW marine estate and the broad benefits they support.

Ecosystem	Type	Key benefits	Key environmental assets
Estuarine	Tide-dominated drowned river valleys Wave-dominated estuaries, lagoons and inter-barrier estuaries; intermittently closed and open lakes and lagoons Brackish barrier lakes	Water quality	Estuarine waters
		Threatened and protected species	Fish (including marine plants), marine mammals, seabirds, shorebirds, reptiles
		Marine habitats and associated assemblages	Saltmarsh, mangrove, seagrass, mudflats, rocky shores, rocky reefs, beaches, soft sediments, planktonic assemblages, fish assemblages
Open coast and continental shelf	-	Water quality	Coastal waters
		Threatened and protected species	Fish (including marine plants), marine mammals, seabirds, shorebirds, reptiles
		Marine habitats and associated assemblages	Rocky shores, beaches, shallow soft sediments, deep soft sediments, shallow reefs, deep reefs, planktonic assemblages, fish assemblages

2.2 NSW MARINE ESTATE REGIONS

In this assessment, the NSW marine estate is divided into three regions: northern, central, and southern. This division follows the previous threat and risk assessment within the Hawkesbury Shelf bioregion, which is referred to in this report as the **central region**. The **northern region** (Tweed Heads to southern Stockton Bight) includes the Manning Shelf bioregion and the NSW component of the Tweed-Moreton bioregion. The **southern region** (Shellharbour to the Victorian border) includes the Batemans Shelf bioregion and the NSW component of the Twofold Shelf bioregion (Figure 1).

While the bioregions include all estuarine, coastal, and offshore waters to the edge of the continental shelf at the 200 m depth contour, this background report is restricted to the region within NSW coastal waters.

2.3 PREVIOUS BIOREGIONAL ASSESSMENTS

Between 2000 and 2005, the NSW Government, with support from the Commonwealth government, undertook bioregional assessments to report on the geomorphic and biodiversity features of each of NSW's five coastal marine bioregions (Breen et al. 2004, Breen et al. 2005a; b). The Authority's current project builds on these bioregional assessment reports to provide a contemporary and more comprehensive assessment of the regions as a basis for improved management.

2.3.1 ESTUARINE AND MARINE HABITATS IN PREVIOUS ASSESSMENTS

The previous bioregional assessments used estuarine and coastal and marine habitats as the primary units to examine the broadscale distribution of biodiversity. The current assessment used the same habitat classes as a starting point (Table 1). Many of these classes relate specifically to habitats that can be mapped, and represent those that can be interpreted or interpolated from the remotely sensed data. Such classes are often used as surrogates for the biodiversity that occurs within the regions. They are most effective as surrogates for species diversity when they are appropriately validated (Ward et al. 1999), and all representative habitats are included (Roff et al. 2003).

The effectiveness of a certain habitat as a surrogate for biodiversity partly depends on how well it reflects patterns of biodiversity (Gladstone 2005, Winberg et al. 2007, Williams et al. 2009). At present, most surrogates used across Australia are based on a range of abiotic (non-living) variables because spatial information on a wide range of assemblages or individual species is generally limited and such variables may provide effective surrogates at broad spatial scales (McArthur et al. 2010). However, the use of abiotic surrogates may result in the failure to differentiate between similar features that support different biological distribution.

Many of the estuarine habitats, principally saltmarsh, mangrove, and seagrass, have been mapped throughout NSW (Creese et al. 2009), and earlier versions of these habitat map layers were presented in the bioregional assessments. Since the previous bioregional assessments were completed, much more information is now available regarding the distribution, extent, and structure of seabed habitats on the open coast and continental shelf (Jordan et al. 2010). Both estuarine and continental shelf habitat map layers have been combined into a NSW seabed map series[1].

2.3.2 THREATENED AND PROTECTED SPECIES IN PREVIOUS ASSESSMENTS

In addition to a broadscale description, the previous bioregional assessments considered the issues relating to threatened and protected species. In this background report, these are separated into species administered under the *Fisheries Management Act 1994 (FMA)* and *Threatened Species Conservation Act 1995 (TSCA)*.

The *FMA* species include several threatened fish and shark species, the categories of which are:

- vulnerable species
- vulnerable ecological communities
- endangered species
- endangered populations
- endangered ecological communities
- species presumed extinct
- critically endangered species
- critically endangered ecological communities.

[1] http://www.seasketch.org/#projecthomepage/5196466a318415da55088370

The key fish species or species group included in this risk assessment are the grey nurse shark (*Carcharias taurus*) (critically endangered), white shark (*Carcharodon carcharias*), black rockcod (*Epinephelus daemelli*), and syngnathids (seahorse, pipefish, pipehorse, and seadragon), solenostomids (ghostpipefish), and pegasids (seamoths).

Several other rare fish are also protected from fishing or collecting. Although populations of these species may not be currently declining, they are protected to avoid becoming threatened in the future. Plant species that provide important fish habitat, such as mangroves, seagrasses and seaweeds, are also protected to maintain the health of aquatic communities and the productivity of our fisheries. A seagrass species that has also been classified as an endangered population in the waters of Port Hacking, Botany Bay, Sydney Harbour, Pittwater, Brisbane Waters, and Lake Macquarie is the seagrass, *Posidonia australis.*

The *TSCA* includes a large range of species, covering marine mammals, seabirds, shorebirds, and marine reptiles.

2.3.3 WATER COLUMN

The components of the water column were assessed in terms of the physio-chemical parameters (e.g. nutrients, turbidity, salinity), and are described separately for estuarine and continental shelf waters. Considerable background on characteristics of the water column in the NSW marine estate is presented in Roper et al. (2011).

Figure 1. The NSW marine estate showing the three regions used in this assessment and extent of coastal waters.

2.4 TOPICS EXCLUDED FROM THIS REPORT

Aspects of the marine environment that relate specifically to human health, such as pathogens (disease-causing microbes) that indicate suitability of water for human recreation, particularly swimming, are not included in this report. These aspects are discussed in the context of social and economic threat and risk assessment in BMT WBM (2017). Regular assessment of these risks are provided within the NSW Beachwatch[2] program, which provides information on beach water quality to enable people to make informed decisions about where and when to swim. A total of 130 swimming locations are monitored in the Sydney, Hunter and Illawarra regions, with a further 110 sites monitored in partnership with local governments along the NSW coast.

Risks associated with harmful substances in shellfish that affect seafood safety in NSW are also not considered in this report. This relates to both recreationally and commercially harvested seafood[3].

The assessment of seafood harvest relating to commercially harvested shellfish produced by oyster and mussel farmers, and fishers collecting shellfish such as pipis, is controlled through the NSW Shellfish Program administered by the NSW Food Authority.

[2] http://www.environment.nsw.gov.au/beach/

[3] http://www.foodauthority.nsw.gov.au/foodsafetyandyou/special-care-foods/recreational-harvest-of-seafood

3. ACTIVITIES AND ASSOCIATED THREATS TO ENVIRONMENTAL ASSETS IN THE NSW MARINE ESTATE

In this section, we describe the activities that threaten the benefits provided by the marine estate, and identify the threats that potentially arise from these activities.

Activities that threaten the benefits derived from the marine estate can be broadly characterised according to where they occur: i.e. either on or in the waters of the marine estate itself or on the land adjoining the marine estate.

This report uses these two primary divisions (**marine resource use** and **land based activities**) to examine activities that may create threats to the environmental assets within the NSW marine estate. **Climate change** is considered as a separate category, because the human activities that contribute to climate change – although primarily derived from land based activities – occur on a global scale, rather than regional (Table 2).

These categories are consistent with those used for the Marine Biodiversity Decline report (2008), commissioned by the Australian Natural Resource Management Ministerial Council to assess the state of Australia's marine biodiversity. That assessment included two additional major threat categories: **marine biosecurity** and **marine pollution**. We also consider these in our assessment, but as particular stressors, rather than primary activity categories. The categories are also based on reviews of previous assessments, supplemented by feedback received during community and stakeholder consultation as part of the Hawkesbury marine bioregion assessment. In this report, we describe how these activities might generate stressors (i.e. stimuli leading to a stress response) that threaten the described environmental assets.

3.1 IDENTIFYING THE THREATS

Threats to environmental, social and economic benefits of the marine estate potentially arise from human activities and interactions that may impinge on those benefits. The statewide assessment focuses on threats to environmental assets, and the human benefits derived from those assets. The health or quality of the environment provides most of the social and economic benefits. It follows that addressing the threats to the environmental assets will help to maximise related social and economic benefits.

Many activities can threaten the environmental, social and economic benefits of the marine estate. However, it is important to understand the mechanism by which an activity can be a threat. In this risk assessment, a wider range of activities that might degrade an environmental asset are included, as well as the elements of the activities that potentially change the environmental assets (defined as **stressors)**. In many cases, different activities might cause harm through similar stressors.

To avoid repetition when detailing activities, we have included a detailed description of each stressor, and explained why it is considered a threat to the environmental assets. The activity descriptions indicate which stressors are associated with each activity, and briefly describe the impacts they may cause.

The three primary threat categories (marine resource use, land based activities, and climate change) are further subdivided into a range of sub-components linked to specific human activities. In turn, these activities create stressors that harm the environmental assets (see Figure 2 for an example). The common stressors likely to be encountered in the NSW marine estate (see Table 3) are described in detail in this report (also see MEMA 2015).

ACTIVITY	STRESSOR	OBSERVED EFFECT
e.g. Vessel activities	e.g. Wildlife disturbance	e.g. Changes in dolphin behaviour

Figure 2. Example of dolphin watching as an activity, showing the relationship between activities, stressors, and effects.

In Figure 2:

- Human **activities** can pose a potential threat to environmental assets, and often contain multiple sub-activities; e.g. commercial fishing in NSW includes a wide range of specific methods and target species such as line and trap fishing, hauling and trawling.
- **Stressors** are elements of the activities that potentially change the environmental assets; e.g. wildlife disturbance is a stressor arising from tourism, and harvesting fish is a stressor from fishing.
- **Effects** are the outcomes or results of those stressors; e.g. disturbing wildlife may interrupt feeding or resting, reducing health and fitness.

Table 2. Primary activity categories used in this report and the activities[a] and sub-activities that may threaten environmental assets.

Primary threat category	Activities that result in sources of threats	Specific activities relating to these sources[a]
Marine resource use	Shipping	Large commercial vessels (trade ships, cruise ships) and major port facilities
		Small commercial vessels (ferries, charter boats, fishing vessels) and smaller port facilities
	Commercial fishing	*Estuary general fishery*
		Estuary prawn trawl fishery
		Ocean trap and line fishery
		Ocean trawl fishery
		Ocean haul fishery
		Lobster fishery
		Abalone fishery
		Sea urchin/turban shell fishery
	Charter fishing	Line fishing
	Recreational fishing	Shore based line and trap fishing
		Boat based line and trap fishing
		Hand gathering
		Fish stocking
	Cultural fishing	Line fishing, spearfishing, hand gathering, traditional methods
	Charter activities	Whale and dolphin watching
	Aquaculture	*Oyster aquaculture*
		Fish aquaculture
	Research and education	Collecting, sampling and tagging
	Recreation and tourism	Boating and boating infrastructure
		Snorkelling and diving
		Swimming and surfing
		Four-wheel driving
		Shark control measures on beaches
	Dredging	Navigation and entrance management and modification, harbour maintenance
	Mining	Oil, gas, minerals, sand, aggregate
	Modified freshwater flows	Extraction, artificial barriers to riverine and estuarine flow
	Service infrastructure	Pipelines, cables, trenching and boring
Land based activities	Land use intensification	Urban stormwater discharge
		Foreshore development (seawalls, reclamation, public access infrastructure, transport infrastructure)
		Beach nourishment and grooming
		Stock grazing of riparian and marine vegetation
		Clearing riparian and adjacent habitat, including wetland drainage
		Agricultural diffuse source run-off
		Deliberate introduction of animals and plants
	Point discharges	Industrial discharges
		Thermal discharges
		Sewage effluent and septic run-off
	Hydrologic modifications	Estuary entrance modifications
Climate change	Climate-change components	Altered ocean currents and nutrient inputs
		Climate and sea temperature rise
		Ocean acidification
		Altered storm and cyclone activity, flooding, storm surge, inundation
		Sea-level rise

a Activities in **bold** are exclusive to the open coast and continental shelf; activities in *italics* are exclusive to estuaries

3.2 ECOLOGICAL STRESSORS

This section provides a detailed review of the specific stressors defined within this background report. It is based on a broader analysis of the literature on the stressor compared to that provided within the chapters on activities (chapters 6.1 and 8.1) which focus more on Australian and/or regional literature.

Table 3. Stressors used in this report that may result in threats to environmental assets

Specific stressors
Reduction in abundances of species and trophic levels
Incidental bycatch
Incidental catch of species of conservation concern
Ghost fishing
Wildlife disturbance
Water pollution
Toxic contaminants
Nutrients and organic matter
Acid sulfate soils
Suspended sediments
Pathogens[a]
Pests and disease
Sedimentation
Sediment contamination
Thermal pollution
Groundwater pollution
Bank erosion
Physical disturbance
Litter and marine debris (including microplastics)
Changes to tidal flow velocity and patterns
Changes to tidal prism
Climate change components:
Altered ocean currents and nutrients
Climate and sea temperature rise
Ocean acidification
Sea-level rise
Altered storm and cyclone activity, flooding, storm surge, inundation

a Pathogens is used here to indicate suitability of water for human recreation. The risks associated with this are discussed in the context of social and economic threat and risk assessment in BMT WBM (2017).

3.2.1 REDUCTIONS IN ABUNDANCES OF SPECIES AND TROPHIC LEVELS

Harvesting of species during commercial and recreational fishing activities results in the reduction in the abundance of both target and non target species. The level of reduction in abundance can be highly variable between species and regions depending primarily on the specific characteristics of catch levels, gear type and relative abundance of the species. There is a considerable amount of published literature on the effect of such reductions in abundance, and these impacts are generally reflected in a defined explotation status for the species or species group (e.g. Fletcher et al. 2011, Georgeson et al. 2014, Stewart et al. 2015).

The effect that harvest may have on these species can also include reduced reproductive success and truncation of age and size structure which can affect life history traits such as growth rates and size at maturity (Stuart-Smith et al. 2008). Stewart (2011) found that 6 species commonly targeted by both recreational and commercial species had their age compositions truncated, meaning that there were more younger fish in the populations being harvested. In extreme scenarios, truncated age-class structure may result in populations being more susceptible to collapse as a result of poor recruitment of juveniles over several years. This effect lowers the resilience of populations to environmental change (Beamish et al. 2006).

Trophic structures depict the relationships between different groups of organisms within a food web and trace energy and nutrient pathways through an environment. These structures are very difficult to describe for estuarine and coastal ecosystems because they are open systems. In some marine environments harvesting has been shown to impact food webs and species interactions by causing changes to predator/prey relationships (Christensen 1996, Jennings and Kaiser 1998). The strength of the evidence for predator based control of prey species abundances varies in different aquatic environments and according to different spatial scales (Jennings and Kaiser 1998). The evidence for predator-prey coupling is strongest in some low diversity systems (e.g. freshwater) and weakest in high diversity systems (e.g. coral reefs).

There does not appear to be a tight coupling of predators and prey among fish communities of the south-eastern Australian continental shelf. Bulman et al. (2001) found that diets and trophic groups of 70 fish species on the continental shelf were very diverse. Overall, the diet of the fish community was equally split between benthic and pelagic prey species and there was no single apex predator species that played a key role in shaping the prey species assemblages.

In Australia, studies on trophic relationships within estuaries have primarily been done in the tropical regions associated with the northern prawn trawl fishery (Brewer et al. 1995, Lonergan et al. 1997, Robertson 1988, Sainsbury et al. 1997). Little work has been done on trophic structures within temperate estuaries, except for within Victoria’s Western Port Bay. This work focused on relationships between fish and seagrasses (Edgar and Shaw 1995a, b, c). Consequently, this assessment of the trophic impacts of reductions in top and lower-order trophic levels for coastal and estuarine ecosystems of NSW will be very limited and based more on inference than direct evidence.

Marine and estuarine species affected directly by reductions in abundance belong to feeding groups ranging from carnivores to planktivores. The prey of carnivores includes fish (e.g. silver trevally), molluscs, and crustaceans. Most of the planktivores (e.g. prawns) are preyed upon by fish. Except in a general sense (e.g. predator-prey relationships), interactions among these trophic groups are unknown for NSW estuaries. However, it has been found elsewhere that substantial removals of prey species can cause major shifts in trophic relationships through predators switching prey, possibly increasing pressure on the populations of newly targeted species, and leading to flow-on effects for other feeding groups (Dayton et al. 1995). Consequently, the potential direct effects of fishing (commercial and recreational) would primarily be associated with the depletion of species preyed upon by predatory fish and the flow-on effects on populations of these fish species.

Estuarine and coastal fish and shellfish communities have a complex array of interspecific relationships, such as competition and predation (Cappo et al. 1998, Hall 1999, Kaiser and de Groot 2000). Changes to any one component (e.g. through a reduction in the abundance of a particular species or size class) may have a range of consequences for other components, whether they are competitors, predators, or prey (Kennelly 1995a).

Fishing potentially has direct and indirect effects on trophic structures within estuaries and coastal ecosystems. Direct affects primarily revolve around the removal of species from food webs. These direct effects may include:

- a local decline in the abundance of an apex predator (e.g. tailor, dusky flathead, or even seabirds) caused by the selective removal of prawns (Cappo et al. 1998, Dayton et al. 1995)
- the favouring of opportunistic species (such as polychaete worms and seastars) that are able to regenerate quickly (e.g. Engel and Kvitek 1998)
- less efficient predator foraging due to the dispersal of prey aggregations, resulting in lower reproductive success and/or reduced populations among predator species (Dayton et al. 1995).

Indirect effects are more diverse and include:

- the favouring of mobile opportunists, better able to 'follow' food supplies created by trawling operations, at the expense of less mobile or less aggressive species (Dayton et al. 1995)
- decline in the abundance of certain benthic organisms (e.g. molluscs and crustaceans) through greater exposure to predators
- disappearance of certain species (particularly juvenile fish) due to loss of food and shelter arising from removal of epibenthos such as sponges and sea squirts (e.g. Sainsbury et al. 1997, Sainsbury et al. 1993)
- the favouring of species that prefer open less complex habitats (Watling and Norse 1998)
- unknown effects on benthic infauna due to removal of epibenthos (Hutchings 1990)
- changes to the condition of seagrasses or other marine vegetation through the removal of species (e.g. luderick and leatherjackets) likely to graze on epiphytic growth
- changes to benthic invertebrate communities through the removal of benthic invertebrate eating fish such as sand whiting
- short-term increases in the abundance of scavenger or predator species (fish, crabs, or birds) as a result of large numbers of dead or injured fish being made available as food during or after a trawling operation
- longer-term increases in the abundances of scavenger or predator species (fish, crabs or birds) as a result of large numbers of trapped, dead, or injured animals being made available in regularly fished areas (e.g. Blaber and Wassenberg 1989, Wassenberg and Hill 1990).

From these examples it is apparent that food web and community effects are complex and far reaching, and that their prediction in any given case would be very difficult (Cappo et al. 1998). Also, consequent cascading effects throughout the food web would also be likely (Kennelly 1995b). For example, scavengers or predators attracted to a fishing area may themselves become victims. In addition, it has been suggested that prawn trawl discards returned to Albatross Bay in the Gulf of Carpentaria fed mainly sharks, which then possibly ate more prawns due to a population expansion (Blaber and Milton 1990, Cappo et al. 1998). On the other hand, significant rates of predation by small fishes on prawns (Brewer et al. 1991, Salini et al. 1990) may be reduced by the incidental capture and subsequent mortality of these fish as a result of prawn trawling. If such an interaction was sufficiently large, bycatch from prawn trawlers may actually enhance the size of the target stock (Kennelly 1995b).

There remains a great deal of uncertainty in relation to trophic impacts associated with fishing (Cappo et al. 1998, Hall 1999, Jennings and Kaiser 1998). Despite specific evidence in a few cases (e.g. on temperate rocky reefs), Jennings and Kaiser (1998) argue that it is wrong to assume that most predator-prey relationships are so tightly coupled that the removal or proliferation of one species would result in detectable changes in ecological processes. They state that 'simplistic models of predator-prey interactions often take no account of prey switching, ontogenic shifts in diet, cannibalism or the diversity of species in marine ecosystems and thus often fail to provide valid predictions of changes in abundance'.

Most marine wildlife groups are higher order predators that occupy top trophic levels in the marine ecosystem. Competition between wildlife and fishers can occur when they take the same species (consumptive competition) or when wildlife feeds on lower trophic levels that harvested species use for prey (food web competition). The degree of such competition in an area is influenced by the: overlap between wildlife prey species and the species fished; level and distribution of fishing effort; size of the wildlife population and its foraging range and behaviour, dietary requirements and diversity of prey species; and availability of prey items (Baraff and Loughlin 2000, Harwood 1983, Harwood and Croxall 1988). This competition can result in increased foraging time, changes in dietary preferences, reduced breeding success and population declines for marine wildlife (Camphuysen and Garthe 2000, Monaghan et al. 1989, Shaughnessy 1985). Fishers, especially those operating in enclosed waters, can suffer economic losses when foraging wildlife decrease stock levels (Montevecchi 2002). It is the wildlife species that feed upon fish, which are most likely to compete for harvested stocks.

3.2.2 INCIDENTAL BYCATCH

Bycatch refers to the part of the catch that is 'taken incidentally in addition to the target species towards which fishing effort is directed'. Bycatch occurs in both commercial (Kelleher 2005) and recreational fishing (Cooke and Cowx 2004). In the latter it is usually referred to as catch and release if specific unwanted species, sizes, or sexes are released after capture (Arlinghaus et al. 2007, Cooke and Cowx 2004). Bycatch consists of two components, the component retained as catch and the component that is released or discarded (Kennelly et al. 1998). The latter component will be referred to as incidental bycatch for the purposes of this background document.

Incidental bycatch can consist of juveniles or small adults of targeted species, threatened and protected species, species of low commercial or social value, and portions of benthic biogenic habitats (e.g. sponges, seagrass). What is captured as incidental bycatch depends on the method of fishing, when, where, and depth fishing occurs, and taken incidentally in addition to the target species towards which fishing effort is directed. All of these factors are highly variable in space and time and therefore make understanding the extent of incidental bycatch in NSW marine and estuarine ecosystems difficult. Furthermore, all catch of incidental bycatch is released or discarded, the effect of release depends on the biological characteristics of the species, how it was caught and released, its condition, and environmental factors such as air temperature. These release factors are also highly variable in space and time, making monitoring and assessment of the effects of incidental bycatch complex in NSW marine and estuarine ecosystems.

Fishing methods that can capture juveniles or small adults of targeted species and species of low commercial or social value include demersal trawling, recreational angling, mesh nets, fish/crab traps, and line fishing. Methods that interact with threatened and protected species include droplines, gamefishing, beach meshing and trolling. Biogenic structures can be caught during demersal trawling but generally only in fishing grounds where trawling has not occurred before. Incidental bycatch can be derived from many different activities, and there are a number of specific stressors that can lead to this overall stressor.

The effects of release on juveniles or small adults of targeted species and species of low commercial or social value are lethal and sublethal. Juveniles and small adults can be more susceptible to lethal effects of release because their smaller size is not as able to deal with increased levels of stress caused by capture. The flow-on (secondary) effect of the mortality of these discarded species is that it can reduce the subsequent sizes of targeted fish stocks, deplete prey abundance for higher order predators, and influence other species interactions. However, for incidental bycatch to have this detectable effect requires that the mortality due to release is greater than the natural mortality they would have experienced without fishing (Kennelly 2014).

Determining the magnitude, duration, and frequency of these two types of mortality is very resource intensive and requires long-term data at multiple spatial and temporal scales. Sublethal effects on juvenile, small adults and species of low value include temporary and long-term damage to their physiology and reproduction. For example, fish that swallow hooks from line-fishing methods are released by cutting the line and leaving the hook embedded in their gut. Depending on the species and size of the fish this can affect their ability to feed and digest. Invertebrates, such as eastern rock lobsters, can suffer limb damage from traps and mishandling. Although they can recover they are vulnerable to predation in the intervening period and attain significantly smaller sizes post-moult than those not damaged.

Barotrauma, another effect of incidental bycatch, occurs when fish are caught at deep depths and brought to the surface quickly resulting in internal gas expansion. The occurrence and severity of barotrauma is species specific (Pribyl et al. 2011), and can result in >70 different injuries from the overexpansion of the swim bladder alone (Rummer and Bennett 2005). Common internal and external injuries include a distended coelomic cavity, stomach eversion, prolapsed cloaca, exophthalmia, corneal or subcutaneous gas bubbles, organ torsion, swim-bladder rupture and haemorrhaging (Broadhurst et al. 2012c, Rummer and Bennett 2005). The effects of these injuries varies and are not always lethal but can significantly impair reproductive organs (Hughes and Stewart 2013).

3.2.3 INCIDENTAL CATCH OF SPECIES OF CONSERVATION CONCERN

Threatened and protected species such as white and grey nurse sharks, cetaceans, turtles, and seabirds often have migratory routes, feeding areas, and/or life cycles that bring them into areas where they are more likely to interact with some fishing methods. For example, juvenile white sharks are known to migrate to inshore areas around Newcastle and Port Stephens where significant levels of boat and shore based recreational fishing occurs (Bruce et al. 2013). Many seabirds feed along the continental shelf and where this area comes within the NSW 3 nm (Sydney and areas of the south coast) there is potential interaction with fishers.

Effects of release after capture on threatened and protected species include sublethal effects of stress from entanglement in fishing gear, death from ingestion of hooks, impaired functioning from damage caused by hooks and fishing line remaining embedded in mouths, gills, fins, and feet (Ganassin and Gibbs 2005a). These types of injuries can lead to disease, morbidity, and death (Borucinska et al. 2002). For example, grey nurse sharks at Fish Rock, NSW, a designated critical habitat for the species, were found to have retained fishing gear or an attributed jaw injury in 29% of females and 52% of males (Bansemer and Bennett 2010). These injuries may impact their ability to feed and digest food reducing the population’s ability to recover.

3.2.4 GHOST FISHING

Ghost fishing occurs when fishing-related gear (nets, traps, lines, and debris) that is lost at sea continues to catch fish and other animals and hence causes mortality to those animal populations. Fishers, both commercial and recreational, can lose their gear as a result of unfavourable weather conditions, bottom snags, mobile methods that inadvertently tow the gear or remove marker buoys, human error, vandalism, and gear failure (Laist 1995, Matsuoka et al. 2005). Other fishing-related debris, such as fragments of nets, ropes, lines, floats, sinkers, bait bags and packaging (Jones 1995) may also be disposed of, deliberately or accidently, and find its way to the sea.

The potential for ghost fishing varies for different fisheries and different gear types. Three pieces of information are needed to assess the potential impacts of ghost fishing: (a) the quantity and type of gear lost; (b) the hazard-life of the gear (length of time that the gear is likely to continue fishing) (Jennings and Kaiser 1998, Laist 1995); and (c) the types of animals caught and their level of mortality. There are currently few studies in NSW investigating the level of ghost fishing from commercial or recreational fishing.

Gear loss in commercial fishing is not considered to be high in NSW, although this will vary by specific gear type. There have been no specific studies on gear loss from recreational fishing in NSW. The ghost fishing of intact traps and lines can affect fish and crustaceans in inshore waters, shore birds in the intertidal areas and marine mammals and turtles in offshore and estuarine waters. However, the extent of these interactions is currently unknown in NSW waters. Trap fishers indicate that traps have a maximum life of about a year and that this is often shorter when using escape panels. An Australian study based on the use of underwater video suggests that there is minimal potential for ghost fishing, as fish are able to readily swim in and out of fish traps (Moran et al. 1989). Those overseas commercial fisheries for which lost gear catches are high are primarily crustacean fisheries using crab pots, which are different to the large demersal traps used in NSW ocean trap fishery. Escape panels in commercial traps in NSW are mandatory.

Entanglement in or ingestion of marine debris of lost or discarded fishing gear by marine mammals, reptiles, and seabirds has been identified as a key threat to their survival (Laist 1997, NSW Scientific Committee 2003, Threatened Species Scientific Committee 2003). These species are attracted to floating debris as a source of food or shelter. There is limited information about the origin of fishing material that has entangled or been ingested by threatened and protected species in NSW. An analysis of data from around Australia (Ceccarelli 2009) found that discarded and active fishing gear is by the far the largest cause of impacts on marine wildlife, and in exceeds other forms of plastic by an order of magnitude. The majority of ghost fishing incidents are in the northern waters of Australia, but northern New South Wales and the Sydney region has some of the highest reported number of incidents in Australia (Ceccarelli 2009). This may reflect high rates of reporting in these areas by Taronga Zoo and Australian Seabird rescue.

The origin, magnitude, duration, frequency, and impacts of lost fishing gear on fish and threatened and protected species in NSW marine and estuarine waters is unknown but the relatively high number of reported incidents and the uncertainty in the amount of lost gear warrant further studies.

3.2.5 WILDLIFE DISTURBANCE

Wildlife disturbance can occur from a range of activities in estuarine and coastal waters, and can be a significant stressor on many species resulting from direct disturbance, noise, or indirect feeding through discards. It is mostly the colonial seabirds, shorebirds, and waders that are affected by disturbance from fishing and general boating activity, and shore based activities such as walking, four-wheel driving, and bait collecting. The degree to which these animals are affected by these disturbances is influenced by the number of people in the vicinity, the proximity of people to the birds, and the type and duration of activity they are undertaking (Thomas et al. 2003). Excessive disturbance at beach-nesting sites, intertidal feeding grounds and high-tide roosts is one of the five major threatening issues identified in relation to the conservation of waders at NSW wetlands (Smith 1991).

Avifauna move away from the disturbances considered under this section (Burger 1998, Kingsford 2009, Skilleter 2004). This avoidance can reduce their foraging time, increase their energy expenditure and disrupt incubation, leaving eggs exposed (Burger 1991, Roberts and Evans 1993). Human activities can also directly crush the eggs and chicks of avifauna. When human presence is frequent or it occurs for long periods of time around nesting avifauna, reduced breeding success and growth of avifauna and sometimes abandonment of breeding colonies can result. If energetic requirements cannot be met because of sustained disturbance from human presence in an area, avifauna can shift to alternative, perhaps less favourable, feeding grounds (Cayford 1993, Goss-Custard and Verboven 1993).

Migratory shorebirds are particularly susceptible to disturbance from human presence in the few months before their migration. They require undisturbed feeding areas at this time so as to accumulate sufficient energy reserves for the journey (Smith 1991). Avifauna can habituate to levels of disturbance from human presence in an area (Frederick 2002, Parsons and Burger 1982).

When at their breeding colonies, or hauling out on land, pinnipeds either tolerate or avoid disturbances from humans walking or driving vehicles or boats close to them (see references in Richardson et al. 1995). Tolerating behaviour results in pinnipeds becoming more alert, and exhibiting aggressive protective behaviour if breeding (Richardson et al. 1995). Pinnipeds avoid disturbance from humans by leaving the haul-out site temporarily (Richardson et al. 1995, Shaughnessy 1999). This avoidance can reduce breeding success as feeding activity may be disrupted or mothers may be unable to relocate their pups, increase juvenile mortality as pups may get squashed from larger fleeing animals or may not be strong enough to swim back to the colony, and interfere with the energy balance of seals (Richardson et al. 1995, Shaughnessy 1999). While pinnipeds may habituate to regular human activities in their vicinity, especially when not breeding or if they are not directly threatened by the disturbance, they may also abandon a haul-out site at least partly in response to human disturbance (Richardson et al. 1995).

Interactions that occur between fishing activities and marine wildlife include the effects of the noise from fishing vessels and gear operation, access to fishing sites, and physical presence of fishers. The effects of these disturbance sources are often considered cumulatively with other similar sources of disturbance that occur in coastal and oceanic areas (Leung Ng and Leung 2003, Paton et al. 2000, Thomas et al. 2003). Cetaceans can sometimes tolerate vessel or boat noise, for example baleen whales have been observed feeding in areas where large numbers of trawlers operate (Richardson et al. 1995) and dolphins actively approach boats to ride on bow waves and feed (Broadhurst 1998, Williams et al. 1992). However, they can also avoid this disturbance, especially if it is too lengthy, intrusive, or unpredictable (e.g. Janik and Thompson 1996, Lusseau 2003a).

Short-term responses of cetaceans to disturbance from vessel/boat activity or noise include spatial avoidance, increased dive time and swimming speed, changes in breathing patterns, group size and cohesion, and acoustic, foraging, socialising and resting behaviour (Lusseau 2003b, Richardson et al. 1995). Cetaceans have lower tolerance to approaching, increasing, or variable sounds than stationary, departing, or steady sounds (Richardson and Würsig 1997). For example, dolphins in Scotland frequently exposed to boating traffic showed no significant response to most of the traffic, which was either fishing or yachting related and usually occurred in a predictable straight line. However, these dolphins did show significant avoidance reactions to the unpredictable and approaching movement of dolphin-watching vessels (Janik and Thompson 1996). In the longer term, repeated exposure to human-induced noise including that from boats/vessels, can result in cetaceans avoiding areas where levels of this disturbance are high (Richardson et al. 1995). For example, in Hawaii, humpback whales have moved away from nearshore areas, a favoured resting site, apparently in response to disturbance from human activities (Salden 1988).

Activities that occur on or adjacent to shorelines, such as beach fishing, all-wheel driving, and boating, affect the successful nesting of sea turtles (Environment Australia 2003). Sea turtles reaction to disturbance from human-induced noise varies with different frequencies and intensities of sound (Environment Australia 2003). The available information on the potential effects of persistent noise, such as that from boating and shipping, on sea turtles is inconclusive (Environment Australia 2003).

The bycatch and offal discarded from fishing activities provide a food source for marine wildlife. Most records of this interaction occur on trawl discards (e.g. Martínez-Abraín et al. 2002). However, there are some accounts of wildlife foraging on the discards from lobster traps and various line and net-fishing techniques (e.g. Commonwealth of Australia 2003, Shaughnessy et al. 2003). In comparison to trawling discards, the discarding from other gear types can be quite irregular and may attract lower numbers of wildlife, as observed in the Mediterranean Sea (Arcos and Oro 2002).

3.2.6 WATER POLLUTION

Water pollution can be derived from many different activities, and there are a number of specific stressors that can lead to elevated levels of contaminants, nutrients organic matter, sediments and pathogens.

Toxic contaminants

Toxic contaminants include metals and metalloids, inorganic contaminants, and organic contaminants. Inorganic contaminants include, for example, cyanide, inorganic acids, and chlorine based disinfectants. Ammonia is an inorganic contaminant that can exert toxic effects but also can act as a nutrient stressor. Organic contaminants include chemicals used in plastics manufacture, pesticides, surfactants, dyes, and pharmaceuticals among many others. Contaminants can be present in the water column and accumulate in intertidal, shallow, and deep soft sediments.

Contaminants can have lethal and sub-lethal effects on all levels of the food chains including bacteria and algae, invertebrates, birds, reptiles, and mammals. Acute toxic effects are diverse, including narcosis (van Wezel and Opperhuizen 1995) and disrupting respiration (Bianchini and Wood 2003, Morgan et al. 1997). Significant spill events can lead to obvious fish kills (Department of the Environment 2011) particularly in closed waters where dilution or flushing is limited. Long-term effects could include oxidative stress (Valavanidis et al. 2006), cancers, reproductive abnormalities, endocrine disruption, and population declines (Kortenkamp et al. 2012).

Mercury and some organic contaminants (e.g. DDT and PCBs) can be biomagnified through food chains (Gray 2002). Biomagnification can in some cases result in adverse effects in higher organisms (e.g. large fish, birds, humans), even when concentrations in the water are far below those needed to cause direct toxicity. Some metals and metalloids are essential elements and therefore, are necessary at low concentrations but exert toxic effects at higher concentrations.

Contaminants enter waters from a variety of industrial, urban, and rural sources. Polycyclic-aromatic hydrocarbons (PAHs) come from car and truck exhausts and enter receiving waters from atmospheric deposition and stormwater. Pesticides, herbicides, and fertilisers routinely used in rural and urban areas are lifted away with the topsoil and enter the estuary via the creeks and the stormwater system. Metals come from discharges from smelters and chemical industries and dioxins are produced as by-products of industrial processes such as bleaching paper pulp, pesticide manufacture, and combustion processes such as waste incineration. Wastewater treatment plant effluents are sources of some contaminants to receiving waters.

Not surprisingly, the highest pressure from industrial and urban contaminants occurs around major population centres. National Pollutant Inventory data for 2012-2013 (Department of the Environment 2014) indicates that the majority of inorganic contaminants (including ammonia) are discharged to the coastal aquatic environment at or near Newcastle, Sydney (Botany Bay), and Port Kembla**.** Organic pollutants loads are highest at Sydney, but some high annual loads are reported on the far north coast. Metal and metalloid discharges to water are highest around Sydney, but generally reported on the coast from Newcastle, south to Nowra. There are also discharges of all contaminants to rivers, largely from mining and agriculture. Much of these contaminant loads will be transported to the coast where they will add to urban and industrial loads, particularly in estuaries. Recent data from the Great Barrier Reef lagoon indicates the possibility of agricultural chemicals in estuaries with extensive levels of cropping in their catchment. Cane growing was identified as a major source in Queensland. There are no data for presence of these chemicals in NSW waters.

Spilt oil and fuel can be a dramatic source of marine habitat degradation, especially if the spill is excessively large. While fishing vessels are not a major source of oil pollution in the sea, small spills do originate from these vessels. Oil can have a range of effects on benthic assemblages, determined primarily by the substrate and the type of oil. Impacts of oil spills on macroinvertebrates in (remaining) mangroves and saltmarshes are not considered to be long-term (McGuinness 1990), but if their habitat is removed this will likely have an effect. Similarly, an oil spill was found to alter the composition of intertidal rocky reef assemblages in Port Jackson, but there were signs of recovery after 12 months (MacFarlane and Burchett 2003).

Avifauna, pinnipeds, sea turtles, and cetaceans have varying responses to contact with oil spills, which are influenced by the type of oil spilt and the length of time the animals are in contact with the spill. The smothering of a bird's plumage with oil can reduce its insulation, waterproofing, buoyancy, and mobility, and often results in mortality from increased heat loss, metabolism, starvation, and drowning. Pinnipeds too are vulnerable to negative effects from oil spills, especially fur seals as they rely on clean fur for insulation (Shaughnessy 1999). Baleen whales do not appear to be directly affected by oil spills (Clapham et al. 1999), although studies have found baleen plates can become clogged by oil (e.g. Williams et al. 2011). However, general concerns about oil pollution, such as prey contamination, irritation of skin and eyes and destruction or pollution of feeding habitats, could affect this and the other marine wildlife groups (Geraci and St Aubin 1980, Geraci and St Aubins 1990).

Antifouling paints are applied to reduce the amount of organisms growing on vessel hulls, including barnacles and algae. Such growth has significant economic consequences in terms of reduced ship speeds and increased fuel use. Paints are typically formulated as a hard coating that slowly releases the active chemical(s) over time. In the past, sloughing or flaking paints were also used which wore off slowly, exposing fresh paint underneath and renewing exposure to the biocide.

Significant concerns over antifouling paints began when paints containing tributyltin (TBT) were linked with imposex in whelks (females developing male sex organs) and deformations in oysters. Shellfish deformities and reduced populations linked to TBT exposure have been observed in NSW waters (Batley et al. 1989, Roach and Wilson 2009, Wilson 2009) and overseas. TBT exerts effects at extremely low concentrations and the current Australian Water Quality Guideline (AWQG) trigger value for 95% protection of marine organisms is 6 ng/L (ANZECC/ARMCANZ 2000). The guidelines note that even this low value may not be protective of chronic toxicity. Bio-concentration factors (BCFs) of up to 7000 have been reported in laboratory investigations with molluscs and fish and higher BCF values have been reported in field studies. Biomagnification factors in marine mammals have been reported of 0.6–6.0.

It is worth noting that TBT is also used in plastics manufacture and as a biocide in cooling systems. Due to these current uses, TBT has been measured in freshwater systems in Europe and the UK (Chahinian et al. 2013, Jones et al. 2014). Such pollution may add to legacy pollution in estuaries and coastal zones from antifouling paints.

TBT breaks down to dibutyltin (DBT), monobutyltin (MBT) and ultimately inorganic tin. DBT and MBT are considered as less hazardous than TBT, but when assessing the overall threat from antifouling paints, the risk from these tin species should also be considered. There are no current AWQG trigger values for DBT, MBT or inorganic tin. TBT is also likely to adversely affect endocrine function in humans (Kortenkamp et al. 2012). Due to these concerns, TBT was banned as an antifouling paint by the International Convention on the Control of Harmful Anti-fouling Systems on Ships (2001) of the International Maritime Organization. There are 69 ratifying states to the treaty, including Australia.

It is assumed that TBT concentrations in NSW coastal waters and sediments would have dropped since 2008 when the treaty came into force. In response to the banning of TBT, other antifouling systems have increased in use, most notably containing copper and organic booster biocides. These are considered as being less hazardous than TBT, but harmful effects have been associated with products.

Copper has been used as an antifouling chemical for hundreds of years, notably on sailing ships by covering the wooden hull with thin plates of copper. Modern products either involve copper compounds such as copper oxide, copper thiocyanate, or use metallic copper powder or flakes incorporated into a paint or epoxy resin. In these products, copper ions (Cu^{2+}) are the biocidal agent.

Producers of copper based antifoulants claim that copper presents no problem as Cu_2+ ions once they leave the hull are complexed by organic matter and rendered non-bioavailable (http://www.copperantifouling.com/copper/). This claim is simplistic, as in situations of high boating activity such as marinas and industrial harbours, increasing copper loads and constant re-supply of copper ions are likely to mean that sufficient copper ions may be present to exceed toxic thresholds to aquatic organisms (USEPA 2011). Roberts et al. (2008) reported that abundance of marine amphipods was negatively correlated with copper concentration in one species of alga (but not another co-existing species) (Roberts et al. 2008). This suggests indirect effects of copper from antifouling paints may be possible.

Many antifouling systems combine the use of copper with organic based booster biocides. Organic biocides include (among others) Irgarol 1051, diuron, Sea-nine 211, chlorothalonil, and zinc pyrithione (Konstantinou and Albanis 2004). These chemicals cover a wide variety of structures and toxic mechanisms. Consequently they have a range of toxicities and other factors such as environmental persistence will also vary. For example, diuron is regarded as less toxic than many other booster biocides but is relatively persistent in the aquatic environment (Matthai et al. 2009). Organic biocides from antifouling paints may add to concentrations from other sources. For example, diuron is a widely used agricultural herbicide with inputs to estuaries from rivers. Not surprisingly, herbicide biocides such as Irgarol 1051 are extremely toxic to marine phytoplankton. Less is known about the fate and effects of degradation products of these biocides (Thomas and Brooks 2009).

Irrespective of the type of antifouling system, environmental effects are expected to be greatest in areas with the highest boating activity and in closed or semi-enclosed waters with poor flushing. With the replacement TBT antifouling paints with alternative systems, it is reasonable to expect that in areas of high boating activity, TBT concentrations will decrease and concentrations of copper and booster biocides may increase.

Due to copper's extensive use industrially and domestically, it is not always possible to definitively link aquatic copper concentrations with antifouling paints. Nevertheless, elevated copper concentrations have been observed in marinas (USEPA 2011). It is also important to note that copper from antifouling paints will add to concentrations from other sources, and therefore increase the risk of ecological consequences. Copper, being a metal, cannot be broken down. It will remain in the environment indefinitely although its bioavailability (and hence toxicity) will vary according to its chemical form (speciation). Any ongoing sources such as antifouling paints will add to the load of copper in sediments and biota. Even if copper occurs in sediments in a relatively non-bioavailable form, activities such as dredging can cause chemical changes that return the copper to a more available form (Hedge et al. 2009).

Some physically based systems are also used, such as Teflon or silicone coatings. These inhibit growth due to providing a very low friction surface which organisms struggle to adhere to. These products are considered comparatively environmentally benign compared to biocidal systems but have not yet achieved as widespread use. The risk from the long-term fate of Teflon and silicone coatings may also warrant consideration in light of concerns about microplastics and fluorinated chemicals.

Nutrients & organic matter

It is well established that catchment disturbance as well as fertiliser application, effluent discharges and urban stormwater can greatly increase the amount of nutrients and organic matter being exported to the receiving waterways (Cloern 2001, Davis and Koop 2006, Harris 2001, Scanes et al. 2007). Sewage in marine and estuarine waters associated with vessel usage, untreated sewage discharges, livestock, dogs and other sources can also result in elevated nutrients, and have human health implications if other water users are recreating in the area and faecal bacteria is ingested (e.g. swimming, diving, water-skiing, etc.). Visual aesthetics and use of an area can also be affected by the presence of sewage pollution and there is generally an expectation in NSW that such pollution should be appropriately managed.

Increased inputs of nutrients can cause excessive growth of micro- and macroalgae (eutrophication), leading to nuisance algal blooms (Davis and Koop 2006). If these blooms are composed of cyanobacteria (e.g. Peel Harvey WA, Myall Lakes NSW) or other toxic algae (Ajani et al. 2013) it can result in considerable loss of recreational and economic productivity.

Algal blooms can also result in increased metabolism in both the sediment and the water column. This can have profound effects on a number of key biogeochemical processes that are important in providing food to the system's broader food web as well as regulating carbon and nutrient cycling (Ferguson et al. 2004). Increased organic matter inputs from in-situ and ex-situ production can cause localised and broadscale depletion of oxygen (hypoxia and anoxia) and can greatly impact fish and invertebrates. Increased benthic respiration can also reduce important nutrient depuration processes such as denitrification (Eyre and Ferguson 2009) and lead to greater internal loading of inorganic nitrogen and phosphorus to the water column which further augments algal production.

The form of nutrient input is very important. Algae are only able to immediately utilise nutrients when they are present as the inorganic ions (e.g. phosphate, nitrate, nitrite, ammonia). Organic nutrients are far less bioavailable and generally need to be processed by microbes before they can be utilised by algae and other nuisance plants. For this reason, measures of 'total' nutrient inputs or concentrations are of very little use when evaluating eutrophication risk. Point source (e.g. sewage) and urban or intensive rural land uses tend to have a much higher proportion of inorganic nutrients than run-off from undisturbed catchments, even though the 'total' load can be the same. This means that systems receiving loads with large amounts of inorganic nutrients are at particular risk (Davis and Koop 2006, Eyre and Twigg 1997). Algae utilise the macro-nutrients nitrogen and phosphorus in a fixed ratio and a relative scarcity of one may mean that algal production is limited, despite the other nutrient being abundant. This condition is known as nutrient limitation (Howarth 1998). The traditional view is that freshwaters tend to be limited by phosphorus availability and marine waters (and estuaries) limited by nitrogen availability. Recent work in NSW estuaries (OEH unpub.) has shown that this generalisation is not supported and that some types of NSW estuary are severely limited by phosphorus (Scanes and Coade 2012).

NSW estuaries with disturbed catchments have greater inputs of nutrients and sediments and, on average, greater concentrations of pelagic algae and turbidity (Roper et al. 2011, OEH unpub. data). This is indicative that disturbances have already led to measurable levels of degradation in NSW estuaries.

Excessive production of epiphytic and pelagic algae can directly inhibit growth of seagrass by limiting light needed for photosynthesis. Loss of seagrass can impact on invertebrates, fish and some marine reptiles and mammals which use the seagrass as a habitat and food source. Such loss is also important as seagrasses are system engineers, decreasing water flows above their fronds, facilitating deposition and consolidation of both organic and inorganic sediments. Nutrient inputs can impact mangroves and saltmarsh because they stimulate growth of weeds and have been implicated in the invasion of saltmarsh by mangroves.

The majority of inputs are trapped within estuaries during low-flow conditions (Ferguson et al. 2004, Sanderson and Coade 2010) but some can be transported from the estuary to coastal waters through tidal exchange. This effect is exacerbated within estuaries with limited exchange such as coastal lagoons and wave-dominated estuaries (Sanderson 2010, Scanes et al. 2007). During flood conditions, the majority of nutrients can be exported to adjacent coastal waters (Eyre 1997, Eyre and Ferguson 2006, Ferguson et al. 2004), often forming large plumes. Pritchard et al. (2001) examined the relative influence of estuarine discharge, coastal upwelling and sewage discharge of the development of nearshore oceanic algal blooms. They concluded that slope water intrusions were the major factor leading to phytoplankton blooms along the Sydney coast.

Acid sulfate soils

In their natural state, acid sulfate soils (acid sulfate soils) are submerged, but when exposed or drained, they become oxidised and sulfuric acid is produced. This reduces soil fertility, kills vegetation, and run-off from acid sulfate soils areas can cause fish disease and fish kills, decreasing fish populations. The majority of NSW coastal catchments (~76%) have a high probability of occurrence of acid sulfate soils within the immediate vicinity of estuarine waters. There are numerous observations of impacts of acid sulfate soils in coastal and marine waters of NSW (e.g. Amaral et al. 2012, Corfield 2000, Nath et al. 2013, Wilson and Hyne 1997).

Suspended sediments

Sediment inputs are generated by soil erosion in catchments disturbed by human activity as well as riverbank and shoreline erosion. Bank erosion is often exacerbated in rural areas by clearing of riparian vegetation and damage to banks by stock access (see bank erosion). Sediment in estuaries can be resuspended by boat wakes and propeller wash from shipping. Wind and currents can also resuspend sediments in estuaries.

Sediments can be transported by urban stormwater or overland flow in less developed catchments. Coarse sediment settles out along river beds, floodplains and at tributary mouths while finer suspended sediment fills bays and central basins. Sediment inputs can reduce water clarity with implications for benthic plants (e.g. seagrass and algae) and can also smother sessile invertebrates and can cause gill irritation in fish. In extreme cases, sediments can lead to shoaling of estuaries and rivers.

Hossain and Eyre (2002) estimated that up to 99% of the suspended sediment input to the Richmond River estuary came from the catchment, and that 90% of this was transported in less than 5% of the year, during flood flows. Export of suspended sediments was dependant on the size of the flood, 47% was exported in a minor flood, but 88% was exported during a moderate flood.

Sediment resuspension can cause poor environmental outcomes in two ways. If sediments are not contaminated by toxic chemicals, it can lead to turbidity and smothering. If sediments are contaminated, then resuspension makes the contaminants significantly more bioavailable (Hedge et al. 2009). Sedimentation can lead changes in bed depth, physical smothering and changes in sediment size structure. All these outcomes can have severe and large-scale implications for benthic flora and fauna. The composition of benthic infauna is known to be strongly affected by sediment size and changes can have major implications for benthic communities.

Water turbidity from fine suspended sediments is a critical factor in the loss of aquatic plants such as seagrass. Reduction in light due to turbidity has been identified as a major cause of loss of seagrasses worldwide (Shepherd et al. 1989, Green and Short 2003). A less well recognised, but extremely important consequence of high turbidity, is the disruption of the function benthic microalgae which, in good light, intercept the majority of nutrients that flux from sediments; this reduces the nutrient sources that may support excessive amounts of pelagic algae.

Pathogens

This stressor considers pathogens as they relate to suitability of waters for human recreational use. The basis for assessment of risk is the National Health and Medical Research Council Guidelines for Managing Risks in Recreational Waters (NHMRC 2008). These guidelines recognise that a wide range of pathogenic microbial, algal, physical, and chemical biological factors impact on the suitability of waters for recreational use. The guidelines advocate the use of a combination of water testing and observations to assess suitability. In urban areas, the main source of harmful microbes is faecal contamination and the main source of faecal contamination is human sewage. When sewage is detected, water may not be safe for swimming.

NHMRC (2008) advocates enterococci as the single preferred indicator organism for the detection of faecal contamination in recreational waters. Enterococci is found in the intestines of warm blooded animals and is present in very high numbers in raw sewage (millions of enterococci bacteria can be present in just 100 mm of raw sewage). Studies have found a strong relationship between elevated levels of enterococci bacteria and illness rates in swimmers. While pathogens are the organisms that cause illness sampling programs don't test for these organisms directly because pathogens in sewage are generally present in lower numbers than the indicator bacteria and as there are very many pathogens that could be present in sewage, it would be very difficult to choose which pathogen(s) to test for. Indicator organisms are used to test for sewage contamination because they are easily detectable by simple laboratory tests, they are generally not present in uncontaminated waters and results are available relatively quickly. The levels of this stressor are reported in this background report, but the consequences are considered in the Social and Economic Threat and Risk Assessment.

3.2.7 PESTS AND DISEASE

Marine pests are plants or animals, transported to NSW from overseas or from other regions of Australia, that have a significant impact on marine industries and the environment. They can include mussels, crabs, seaweeds, sea stars and other marine species. Key sources include international and domestic shipping, aquaculture and the aquarium trade.

Marine pests have been introduced into NSW waters in various ways, including in ballast waters, attached to the hulls of international ships, or imported deliberately as aquarium or aquaculture species. Over 250 declared pest species have been introduced into Australia to date. Source: http://www.dpi.nsw.gov.au/fisheries/pests-diseases/marine-pests. A statewide mapping tool is provided on the NSW DPI website which maps the current status of pests and diseases in NSW, including within the NSW marine estate. See: http://www.dpi.nsw.gov.au/fisheries/pests-diseases/pest-disease-distribution

Marine pests can have severe ecological and economic impacts. For example, they can take over large areas of habitat to the detriment of native species. Some prey directly on native species or compete with them for food. Pest species can also cause considerable economic damage. Infestations of marine pests can impact on marine industries, such as aquaculture, commercial and recreational fishing and boating, tourism, and even international and domestic shipping. Some marine pests, such as toxic dinoflagellates, can threaten public health.

There are few invasive marine species currently in the NSW marine estate, compared to other states (i.e. Tasmania and Victoria). Surveys of major ports in NSW were done as part of a national management initiative in Newcastle (CSIRO 1999), Eden (Pollard and Rankin 2003), Port Kembla (Pollard and Petherbridge 2002b), Botany Bay (Pollard and Pethebridge 2002a), and Port Jackson (AMBS 2002). These surveys identified several non-indigenous species in most ports, but only very low numbers of any species listed on the national trigger list at the time. Although the presence of the European fan worm and green crabs were noted in Twofold Bay in (Pollard and Rankin 2003), this finding failed to trigger any management action.

An outbreak of the invasive green alga *Caulerpa taxifolia* in Port Hacking and Lake Conjola occurred in 2000. The outbreak led to considerable research on its possible ecological effects and ways of controlling it. Ongoing research is continuing to investigate the major presumed threat of *C. taxifolia* – the competitive displacement of native seagrasses. No effects of *C. taxifolia* on the seagrass *Posidonia australis* have been detected after more than six years of mapping and experimentation. Effects on the other common seagrass (*Zostera capricorni*), are less clear, largely because both species vary significantly in abundance at time scales of months to years.

Caulerpa taxifolia has been found in 14 estuaries in central to southern NSW, but it is consistently abundant only in a few of them. A control plan summarises the appropriate management responses to new incursions. This is the only marine pest in NSW for which a control plan has been developed and promulgated. The NSW control plan for the noxious marine alga *Caulerpa taxifolia* can be found at:

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0013/210712/NSW-control-plan-caulerpa-taxifolia.pdf

The European shore crab (*Carcinus maenas*) occurs in many south coast estuaries and has potential impacts on native molluscs (its prey) as well as on cultivated oysters. Some resources previously dedicated to surveys for *C. taxifolia* have now been redirected towards *C. maenas,* and research into its ecology and interactions with native biota has recently been initiated.

The most well documented marine pests in NSW are:

- Tilapia (Mozambique mouthbrooder – (*Oreochromis mossambicus*)
- Caulerpa (*Caulerpa taxifolia*)
- European fan worm (*Sabella spallanzanii*)
- European green crab (*Carcinus maenas*)
- Japanese goby (*Tridentiger trigonocephalus*)
- New Zealand screwshell (*Maoricolpus roseus*)
- Pacific oyster (*Crassostrea gigas*)
- Yellowfin Goby (*Acanthogbius flavimanus*)

Marine animals can also be affected by infectious diseases, which may be caused by pathogens such as viruses, bacteria, fungi, protozoa and parasites. Infection and disease in marine animals is normal, but can become severe under certain conditions. Such conditions can include the introduction of new diseases to a population; or conditions that promote disease, such as host animal stress or poor environmental conditions.

There are very few diseases of aquatic animals that are known to have implications for human health. Diseases can affect the sustainability of commercial and recreational fisheries, the productivity of aquaculture industries, access to international markets for Australian seafood industries, and aquatic environments.

Contamination of coastal waters with faecal material from animal and human sources can pose significant threats to recreational users of the NSW marine estate owing to the presence of pathogens (disease-causing micro-organisms) in the faecal matter. The most common groups of pathogens found in coastal waters are bacteria, protozoa and viruses.

Rainfall is the major driver of microbial pollution of coastal waters, generating stormwater run-off and triggering discharges from the wastewater treatment and transport systems. Microbial densities in coastal waters can reach high levels after rainfall if: treatment plants are overwhelmed (causing sewage to bypass treatment); animal wastes are washed from forests, pastures and urban land; sewage overflows directly into waterways or into stormwater because rainfall causes the capacity of the sewer system to be exceeded due to rain infiltrating cracks in the pipe and illegal connections from the stormwater system; and sediment-trapped pathogens are resuspended. Most changes in microbial water quality over time reflect rainfall patterns and the associated variation in the frequency and extent of stormwater and wastewater inputs. While much of these changes results in diseases relevant to human health, such aspects are not considered in the background report.

3.2.8 SEDIMENTATION

Sediment inputs occur mainly into estuaries as a result of soil erosion in catchments that is disturbed by human activity. It also occurs due to riverbank and shoreline erosion (Prosser et al. 2001). Sediments can be transported by urban stormwater or overland flow in less developed catchments. Coarse sediment settles out along river beds, floodplains and at tributary mouths while finer suspended sediment fills bays and central basins. Some of the sediment is exported from the estuary, often during flood events when much of it is resuspended (e.g. Eyre and Ferguson 2006). In extreme cases, sedimentation can lead to shoaling of estuaries and rivers, but this is not common. The main examples in NSW involve large sand masses that are slowly moving along south coast rivers such as the Bega River. These sand masses are usually attributed to extensive land clearing in the mid nineteenth century (Brierley et al. 1999).

It is important to distinguish between sedimentation, which is the deposition of sediments within the estuary and suspended sediments (or turbidity) which has significant impacts on ecology, but not on estuary geomorphology. Sedimentation can lead changes in bed depth (e.g. Brierley et al. 1999), physical smothering and changes in sediment size structure, all of which can result in impacts on benthic flora and fauna. The composition of benthic infauna is known to be strongly affected by sediment size, and sediment inputs can smother sessile invertebrates and can cause gill irritation in fish. Deposited fine sediments are also easily re-suspended by wind induced wave action, leading to chronic turbidity, even when there are no catchment inputs occurring (Scanes et al. 2017).

3.2.9 SEDIMENT CONTAMINATION

The seabed within estuaries and many areas of the open coast are dominated by soft-sediments that range from fine silts through to gravel. These sediments are the place where most of the contaminants that enter the coastal systems are deposited and stored. Sediment contamination can be derived from either point or non-point (or diffuse) sources of pollution. Point sources can include discharges primarily from sewage treatment, stormwater, or industrial activities. Non-point sources include diffuse land runoff that can be derived from urban, agriculture or industrial land-use, but can also be derived from atmospheric deposition.

Toxic contaminants include metals and metalloids, inorganic contaminants, and organic contaminants. Inorganic contaminants include, for example, cyanide, inorganic acids, and chlorine based disinfectants. Ammonia is an inorganic contaminant that can exert toxic effects but also can act as a nutrient stressor. Organic contaminants include chemicals used in plastics manufacture, pesticides, surfactants, dyes, and pharmaceuticals among many others. Contaminants can be present in the water column and accumulate in intertidal, shallow, and deep soft sediments. If sediments are contaminated, then resuspension makes the contaminants significantly more bioavailable (Hedge et al. 2009).

Sediment contamination is evident in many estuarine and coastal areas throughout the world, with much of this derived from past industrial discharges and urban runoff that has resulted in legacy contamination that is still at elevated levels. The sediments of many of the estuaries in New South Wales have elevated levels of contaminants, including metals and metalloids, petrochemicals, pesticides and fertilisers. Historically, industrial activities resulted in elevated metal and organic chemical concentrations in the water column and sediments in many estuaries, principally in the central region (e.g. Port Jackson, Port Kembla, Lake Macquarie, Lake Illawarra and the Hunter River (Birch and Taylor 1999, Dafforn et al. 2012, Hayes et al. 1998, Hedge et al. 2009, Jennings et al. 1996, Lottermoser 1998, Matthai and Birch 2000, Spooner et al. 2003). These sediment derived contaminants can impact biological pathways via re-suspension (Knott et al. 2009, Edge et al. 2015).

Elevated metal and organic chemical concentrations in sediments have been linked to significant risk to aquatic organisms (Gall et al. 2012, Hunt et al. 2010, Johnston and Roberts 2009). Fewer studies have been reported for other NSW locations. Bivalve surveys in NSW (Scanes and Roach 1999) have shown that measurable concentrations of organochlorine compounds, PAH and PCB, and significantly elevated levels of trace metals only occurred in a small number of industrialised estuaries along the NSW coast. The same industrialised estuaries can have elevated levels in fish tissues (Roach and Runcie 1998, Roach 2005). The often high spatial heterogeneity of both sediment grain size and contaminant distribution can result in considerable differences in the ecological effect on biota.

While much of the industrial pollution contamination is historical it should be noted that many pollutants will persist for many years (or will not degrade at all, in the case of metals). Further details on water and sediment pollution from industrial discharges within estuaries of the central region is presented in MEMA (2016) and (Hedge et al. 2014) and references within. A broader review of estuarine and coastal sediment contamination in relation to sediment characteristics, ecotoxicology, bioaccumulation and ecological assessment of impacts is presented in Simpson et al. (2005).

3.2.10 THERMAL POLLUTION

Thermal pollution is the addition of cold or heated water to the environment. Cold water pollution is primarily a consequence of releases from dams to rivers and not directly relevant to the NSW marine estate. Heated water plumes can affect the marine environment in diverse and sometimes unpredictable ways. Some effects include direct effects on photosynthesis (Chuang et al. 2009), particularly reducing the growth of seagrass (Robinson 1987) and other benthic cover and adversely affecting plankton and periphyton (Chuang et al. 2009). Discharged heated water can decrease fish species diversity (Teixeira et al. 2009). Thermal pollution can promote the occurrence of invasive species (Thomas et al. 1986) and has been associated with algal blooms and eutrophication, including toxic dinoflagellate blooms (Jiang et al. 2013). The heated water may also have indirect effects because it can alter the toxicity of certain pollutants (Bao et al. 2008, Cairns et al. 1975). Increases in temperature decrease the saturation concentration of oxygen, which in some instances has led to fish kills.

3.2.11 GROUNDWATER POLLUTION

Groundwater may be polluted by many of the same dissolved contaminants as surface water (see above). Groundwaters contaminated with toxicants have been demonstrated to be a significant source of pollutants to estuary systems (e.g. Penrhyn estuary, Botany Bay) (James 2009). High levels of oxidised nitrogen and phosphorus have been observed in groundwaters from urban catchments near estuaries (OEH unpubl.), and this may be a major source of nutrient enrichment in some circumstances.

3.2.12 BANK EROSION

Bank erosion occurs both naturally and as a result of anthropogenic activities. The dynamic nature of riverine and estuarine environments means they are constantly changing. Natural erosive forces such as riverine flow, wind-induced waves and tidal movements can produce productive floodplains with rich alluvial soils. Anthropogenic activities such as reclamation, land clearing and inappropriate boat use can exacerbate erosion. Bank erosion is a major source of sediment to rivers and estuaries. It can lead to the loss of riparian fauna and flora communities and intertidal organisms.

Vegetation, including grasses, shrubs and trees in the riparian zone has a major influence on the mass stability of riverbanks and thus the strength of bank sediments. Plants enhance bank strength by reducing pore-water pressures and by directly reinforcing bank material with their roots (Abernethy and Rutherfurd 2001). The direct removal of soil-binding riparian plants through intensification of land use exacerbates erosion and contributes to large losses of riverbank soils to the downstream environs. Further, the importance of an intact riparian zone to aquatic ecosystems is well recognised (see Pusey and Arthington's 2003 review) (Further detail available in Section: 6.2.1)

Erosion of natural river banks by boat-generated waves is an increasingly serious problem on the navigable reaches of many rivers, particularly on the middle and estuarine reaches (Bishop and Chapman 2004, Nanson et al. 1994). Nanson (1994) measured characteristics of a boat-generated wave train and most showed a high correlation with measured rates of bank retreat. Maximum wave height had a major threshold in erosive energy on unconsolidated sandy alluvium at wave heights of 30 to 35 cm. At maximum wave heights above 35 cm all but the most resistant bank sediments erode. Bishop and Chapman (2004) demonstrated that boat-generated waves significantly altered the structure of benthic infaunal communities and Bishop (2007) showed that the effect was due to wave action, not changes in grain size. Heatherington and Bishop (2012) noted that mangrove forests fronting artificial seawalls were narrower, had fewer saplings and less leaf litter, potentially as a result of bank erosion exacerbated by the presence of the seawalls.

Prosser et al. (2001) reviewed the available knowledge on stream erosion and found that, stream-bank erosion is the dominant source of sediments and that much of the sediments are stored within the river systems and will continue to affect estuarine ecosystems for decades.

3.2.12 PHYSICAL DISTURBANCE

Physical disturbance can be derived from many different activities to estuarine and continental shelf habitats, and there are a number of specific stressors that can lead to elevated levels of physical disturbance that result in impacts. These include such things are scouring of the seabed, compaction, physical habitat removal, habitat modifications, trampling and storm disturbance. Physical disturbance can also include activities that cause direct harm or injury to fauna (e.g. collision with vessels). These can be derived from many specific activities such as commercial and recreational fishing methods, vessel moorings and anchors, four-wheel driving, mining, dredging, beach grooming and foreshore development.

Activities associated with marine resource use that result in the primary impact of physical disturbance include: aquaculture (oyster aquaculture), charter fishing (line fishing), commercial fishing (e.g. estuary general, estuary prawn trawl, ocean trap and line, ocean trawl), dredging (navigation and entrance management and modification, harbour maintenance etc.), mining and extractive industries (oil, gas, minerals, sand, aggregate, coal), recreation and tourism (e.g. boating and boating infrastructure, four wheel driving), recreational fishing (e.g. boat based line and trap fishing, hand gathering), service infrastructure (pipelines, cables, trenching and boring), and shipping associated with large commercial vessels and associated port activities and industries (trade ships, cruise ships), and small commercial vessels (ferries, charter boats).

Activities associated with land based impacts that result in the primary impact of physical disturbance include: land use intensification (beach nourishment and grooming, clearing riparian and adjacent habitat including wetland drainage, foreshore development, stock grazing of riparian and marine vegetation, and the deliberate introduction of animals and plants), and hydrologic modifications (estuary entrance modifications).

Climate change results in physical disturbance as the primary stressors for both 20 and 50 year projections for altered storm, cyclone activity, flooding, storm surge, inundation and sea level rise

3.2.13 LITTER AND MARINE DEBRIS

Marine debris (or marine litter) is defined as any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment (UNEP 2009). Marine debris is harmful to marine life including to protected species of birds, sharks, turtles, and marine mammals. Marine debris may cause injury or death through drowning, injury through entanglement and internal injuries, or starvation following ingestion.

Marine debris constitutes a wide variety of items including as glass and plastic bottles, cans, bags, balloons, rubber, metal, fibreglass, cigarettes, and other manufactured materials. Debris is recognised globally as a threatening process for wildlife (Smith and Edgar 2014). CSIRO (2014) reported that approximately three-quarters of the rubbish along the Australian coast is plastic and most is from Australian sources. More debris was found near urban centres and within those centres was concentrated around stormwater drains (Duckett and Repaci 2015). In coastal and offshore waters, most floating debris is plastic. The density of plastic ranges from a few thousand pieces of plastic per square kilometre to more than 40,000 pieces of plastic per square kilometre (CSIRO 2014).

Plastic debris in particular has been identified to represent one of the top anthropogenic threats to estuarine environments (Kennish 2002), it is an emerging issue that may affect our ability to maintain biodiversity and community structure in these habitats (Weinstein et al. 2016).

While there have been no studies into the extent of gear loss by commercial or recreational fishers, studies of debris found on Australian beaches have recorded fishing-related items (Cunningham and Wilson 2003, Kiessling 2003, Slater 1991, Whiting 1998, Haynes 1997, Herfort 1997) A study of selected ocean beaches in NSW found 13% of the debris to be fishing related, 60% of which was from commercial origin and 40% recreational (Herfort 1997). Among the fishing debris recorded there was a dominance of fish trawl debris on the state's northern beaches, trap fishing on the central coast beaches and fish trawl gear on the southern beaches. Recreational fishing debris were dominant on beaches around urban centres, especially the central coast (Herfort 1997).

Debris also includes fishing gear such as line, ropes, hooks, buoys and other materials lost on or near land, or intentionally or unintentionally discarded at sea. Smith and Edgar (2014) reported on a survey of subtidal debris (primarily fishing-related items, but also including litter, bottles plastic etc.) at 120 sites over 1000 km of coasts. Estuaries and embayments were consistently the most contaminated sites. Different types of sites had different forms of litter, bays had relatively more plastic bags and plastic pieces (more mobile types of litter) and estuaries had relatively more fishing line. Sub-tidal coastal sites had some plastic and fishing line but relatively more glass and metal pieces (longer-lasting debris).

Turtles, seabirds, whales, dolphins, dugong, fish, crabs and many other taxa are affected by entanglement, ingestion or impalement on debris. Turtles, marine mammals and sea birds can be severely injured or die from entanglement in marine debris, causing restricted mobility, starvation, infection, amputation, drowning and smothering. Turtles and seabirds are particularly susceptible (Acampora et al. 2014, Schuyler et al. 2014a, Schuyler et al. 2014b). The propensity of turtles to ingest debris varies with habitat; marine turtles ingest more than coastal turtles and herbivores more than carnivores (Schuyler et al. 2014b). Green turtles and leatherback turtles are at the highest risk.

Sea turtles are threatened from actively ingesting plastic material they mistake for their preferred prey (Balazs 1985, Carr 1987). Plastic bags and rope are the debris items most frequently ingested, and other ingested items include monofilament line, net fragments, hooks, rubber, cloth, oil, tar and small pieces of hard plastic (e.g. Balazs 1985, Bjorndal et al. 1994). All sea turtle species, particularly pelagic juveniles, have been found with ingested debris (Carr 1987, Derraik 2002). Plastic bands or net fragments entangled around young animals' necks restrict their ability to feed properly, and as they grow, result in their strangulation and death. Derelict fishing gear, ropes, and other types of debris tangled around the bodies, flippers, tails or flukes of marine wildlife can lead to infections, restricted mobility, protracted amputation of limbs, and death through drowning, starvation or smothering.

The ingestion of floating plastic mistaken for food is a particular threat to seabirds (Wilcox et al. 2015). Birds that feed on plankton, squid and crustaceans are more likely to do this than birds that feed on fish. Also, surface feeding birds are likely to ingest more plastic than those that feed by diving below the surface (Azzarello and Van Vleet 1987). Once ingested, plastics can only be expelled from birds by regurgitation (Laist 1987). Acampora et al. (2014) reported that 43% of shearwaters had ingested plastics. Seabirds entangled in fishing lines, fragments of fishing nets, plastic packing straps or other marine debris may lose their ability to move quickly through the water, reducing their ability to catch prey and avoid predators; or they may suffer constricted circulation, leading to asphyxiation and death.

'Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris' has been listed as a key threatening process under the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).* Within Australian waters records of impacted wildlife tend to be limited to land based observations, and in many instances wildlife found negatively impacted by marine debris is not recorded. Marine debris may impact wildlife through entanglement and ingestion. Entanglement of marine wildlife tends to occur when animals feed on organisms attached to or associated with marine debris, or if they swim into marine debris floating at sea. Derelict fishing gear dominates the type of plastic observed entangling wildlife around Australia (Ceccarelli 2009). In NSW Francis (2007) analysed the Australian Seabird Rescue database. In 142 recorded strandings of wildlife 18 had ingested plastic, predominantly soft plastics, and 4 were entangled.

Microplastics

Plastics are generally resistant to degradation with estimates for the complete degradation of plastic debris in the environment ranging from decades to centuries (Browne et al. 2007). Extensively degraded plastics may eventually become brittle and disintegrate, fragmenting into progressively smaller microscopic particles, known as microplastics (Browne et al. 2007, Barnes et al. 2009, Ling et al. 2017). Some microplastics are deliberately manufactured, such as polyethylene microbeads added to facial scrubs.

Microplastics have been observed in marine waters and sediments, and are considered a major concern by many researchers (Cole et al. 2011, Wright et al. 2013, Ling et al. 2017). Microplastics can cause adverse effects to small aquatic fauna due to physical mechanisms (e.g. blocking feeding tubes) (Wright et al. 2013). Microplastics also can contain organic and metallic contaminants that may present a toxicity issue especially in the water column, or may concentrate such contaminants from the surrounding water (Cole et al. 2011). A few studies have reported contaminants in microplastics are able to be taken up by aquatic organisms that ingest the particles (Chua et al. 2014, Cole et al. 2011). Fish can ingest microplastics via food but also actively take up microplastics from the water column (Katzenberger and Thorpe 2015). These plastics did not adversely affect adult fish in the short term but led to poor body condition of larval fish. They also showed that microplastics partitioned organic pollutants from water and acted as a vector to move the pollutant into a food chain.

Some coastal ecosystems are more affected by microplastics than others, for example saltmarsh wetlands and tidal creek habitats serve as the hydrographic link between anthropogenic activities in the catchment and the adjacent estuary (Holland et al. 2004) and as such, higher levels of plastic debris have been associated with saltmarshes occurring near population centers (Viehman et al. 2011). Weinstein et al. (2016) demonstrated that due to the characteristics of saltmarsh, including the natural wetting and drying cycle, foraging behaviour of grazing animals and action of resident microbes; the degradation of plastic proceeds relatively quickly resulting in the production and release of microplastic particles during every tidal cycle.

In late 2014 the NSW Government called for a national ban on the sale and production of shampoos and other products containing microplastics. The NSW Government is convening an industry working group intended to eliminate the pollutant.

3.2.14 CHANGES TO TIDAL FLOW VELOCITY AND PATTERNS

Water flow is a major observable component for estuary and riverine systems. Flow related velocity is the underlying driver for many processes in these systems. Estuaries are an interface between catchment and coastal processes. The largest estuary flows are due to catchment events (floods) and the estuary geomorphology characteristics are generally dominated by catchment induced features. Coastal processes also influence the estuary entrance features, primarily as entrance bars and the marine delta which may extend as much as 5 km upstream from the entrance. At any one time, an estuary's behaviour will be a mix of features due to catchment and coastal processes. The water velocity is the critical factor for moving around anything in the water column. The water velocity can also move any material or object on the bed or bank of the estuary. The bed and bank material of an estuary is mostly sand or silt which is often erodible. This makes estuary geometries very dynamic, and means that the flow patterns can readily change. There are exceptions to this, where an estuary is formed from drowned valleys, with hard rock bed and banks. In these cases the geometry is still prone to depositional changes but erosion limits are fixed.

Changes due to current velocity can occur due to:

- Any changes to tidal prism.
- River bank hardening (training), designed to directly protect or move high velocity flows away from vulnerable areas – tends to maintain high velocities in that area but stops immediate erosion. Erosion often occurs at the ends of bank hardening.
- Hardening of the bed through riprap protection – stops the bed deepening through erosion under high velocities but maintains those high velocities.
- Dredge deepening and dredge disposal within active waterways – can concentrate flow into channels of lower resistance, may increase or decrease velocities locally.
- Jetty, wharf and groyne construction provide partial obstructions, changing local velocities
- Water discharge points and drainage channels can directly affect local velocities through sediment deposition or acting just like a hard structure by changing main channel flow patterns

- Manipulated dams flows (e.g. environmental flows) may change upper estuary velocities – changing short-term event high velocities into long-term small downstream velocities
- Water diversion from catchment for drinking or industrial use can remove the intermediate and larger sized events from a system, distorting long-term average behaviour by removing or decreasing the impact of these major downstream orientated processes.

The pattern of water flow is closely linked to the behaviour of the water levels in any system. In a purely tidal system, both water levels and flows fluctuate respectively between high and low tide and flood and ebb flows. A non-tidal system will generally only experience a downstream flow and a downstream water level gradient. An estuary with catchment inflow will behave as a mixture of the two. This also means that material in the water column or on the bed can be moved both upstream and downstream.

Tidal flows (extent) are limited in an estuary by the geometry of the system. The landward extent of tidal penetration is generally limited to where the bed level of the estuary is higher than the high-tide level. On longer estuaries without elevated gravel bars or barriers, frictional effects may damp the tidal amplitude below measurement levels (see Druery et al. 1983). Large lake systems can also exhibit this behaviour.

Tidal behaviour is determined by many things but the basic controlling feature is the estuary boundary. The boundary includes the estuary planform (shape) and the estuary bed geometry in conjunction with the bed material characteristics which determine the flow friction effects. Altering any of these can change the tidal behaviour. Tidal behaviour can also be changed by the changes to inflows from the catchment or water extraction from the system. Changes to tidal behaviour can occur due to natural events. In many of these cases, the tidal behaviour can return to a typical behaviour. However, larger-scale events can irrevocably change the system. Tidal behaviour can also be changed by human intervention. These are generally longer-term changes.

Because everything in the water column is transported by the system’s velocities, any changes to flow pattern affect anything that is transported within the system. From a nutrient and pollutant perspective, residence and flushing times and mixing characteristics can be changed. Areas that provide shelter via low velocities or suitable environment for vegetation growth can change distances between areas of relative calm for fish can make movement difficult creating isolation issues. Submerged vegetation (i.e. seagrass) and fish larval distribution depend implicitly on local velocity magnitudes. Riparian vegetation depends on the stability of the river banks which in term depend on local water velocities (in conjunction with bank material type).

Flow velocities directly impact on many other processes. It is the velocities that move water and material within an estuary. Sediment erosion, deposition and the capacity to carry sediment are directly linked to velocity magnitude. Spatial and longitudinal patterns of velocity magnitude determine the pattern of erosion and deposition.

Changing the natural equilibrium by changing velocities can have compounding effects on sediment transport that last for multiple decades. The changed prism and consequent changed tidal velocities (particularly on the ebb tide) of Wallis Lake and Lake Illawarra has resulted in a net loss of the flood-tide delta and existing entrance channel islands are eroding out to sea (Neilson and Gordon 2008).

Artificial opening of estuary entrances is an extreme form of change to tidal behaviour. It is most often done to prevent flooding of low-lying infrastructure, but also has perceived benefits for “flushing” contaminants from estuaries. There is very little evidence to support any significant long-term improvements of water quality from “flushing”. Artificial opening of intermittent estuaries has been shown to affect abundance and diversity of meiofauna (Dye and Barros 2005), macrobenthos (Gladstone et al. 2006) and fish (Griffiths 1999, Jones and West 2005).

Training walls are often added to entrances of wave-dominated and intermittent estuaries. This is commonly justified on the basis that it improves 'flushing'. The increased entrance channel sizes for small coastal lakes look good when considering initial increases in tidal prism and initial dilutions of catchment run-off however, the flushing times can actually increase as the entrance channel velocities decrease due to the depth and channel geometry. Increases in tidal ranges in an estuary can change the proportion of time that intertidal flats are exposed at low water effecting vegetation survival (e.g. Lake Illawarra seagrass). This can be despite increasing flushing characteristics. Training the entrances to coastal lakes and lagoons fundamentally changes the ecology from that of an intermittent estuary to a more marine-dominated ecology

3.1.15 CHANGES TO TIDAL PRISM

Tidal prism is effectively the volume of water that flows through a section over a tide cycle. It is location dependent, but the general use of the term refers to the flow volume nearest the entrance of the estuary. However, it is also applicable to talk about the tidal prism of a tributary or the tidal prism upstream of specific locations.

Estuary-wide impacts can occur due to changes to tidal prism. Any tidal prism change effects all of the system downstream. Changes to tidal prism effectively amount to changes in the tidal flood and ebb flow volumes. This directly translates into corresponding changes in the tidal flow velocities.

Training of river entrances along the NSW coast has modified tidal prism in many estuaries in NSW. In general, river entrance training increases entrance efficiency thereby increasing tidal range and discharge. In coastal lakes in particular, the time scale of response to entrance training is long. Ongoing effects to tidal range being observed in Lake Macquarie and Wallis Lake decades after training.

Tidal prism can be changed by numerous physical changes of the estuary including:

- obstacles across estuary channels including dams, levies, pipelines and culverts
- entrance training through breakwalls and training walls which can concentrate flow through restricted sections, make the system more hydraulically efficient, increasing tidal range and prism throughout an estuary. Wallis Lake has seen a 25% tidal range increase over 1990 to 2009 - there is an equivalent increase in tidal prism in this case (see MHL 2011).
- reclamation through infill, or intertidal areas fully or partially isolated with flood levies
- construction of ports, mariners or canal subdivisions
- changing the length of an estuary by meander bypassing through natural or flood mitigation works (aimed at 'straightening' a reach).
- dredging channels for navigation, thereby reducing channel friction effects and increasing tidal range upstream.
- dredging and/or channel re-alignment to mitigate catchment flood inundation
- catchment flood events can cause large-scale sediment movement resulting in changes to the bed geometry, and in extreme cases large-scale planform changes. In particular, larger catchment events can re-work entrance shoals and channels. Post-event tidal response can result in reshaped bed geometry over a longer term, returning the estuary to its pre-event geometry over time. Extreme events can lead to irrevocable changes, resulting in new long-term tidal behaviour. Likewise, ocean wave events can cause large sand movements in estuary entrances, sometimes resulting in complete closure for small systems but more likely resulting in reshaped entrance geometry (new channels and shoaling) that may cause tidal prism changes in larger estuaries.

The two primary impacts from changes in the tidal prism are:

- changes in salinity regime, larger tidal volumes tend to move systems from estuarine/brackish to a more marine salinity, with associated changes to flora and fauna
- changes in tidal inundation depth and frequency. The larger tidal range that is associated with increases in tidal prism can expose organisms and habitats at low tides (this occurred

to seagrasses in Lake Illawarra) and can inundate other habitats more frequently at high tide. This can have large impacts on the patterns of distribution of mangroves and saltmarsh, often leading to invasion of saltmarsh by mangroves.

3.2.16 CLIMATE CHANGE

A range of stressors are derived from the various components of climate change and these impact on specific environmental assets. Exposure to one stressor (such as warming) can affect the tolerance of an environmental asset to another stressor, and may act together to result in cumulative impacts (Laffoley and Baxter 2016). A recent review of the potential impacts of climate change under different emission scenarios (Gattuso et al. 2015) provides a concise summary of the potential changes in major forcing factors and indicates risk of impact on a variety of biological assets and ecosystem services provided by marine ecosystems. It predicts a very high risk of disruption if carbon dioxide emissions are not reduced.

Average global sea surface temperatures currently show a warming trend of ~0.13°C per decade since the beginning of the 20th Century (Laffoley and Baxter 2016). The last three decades have been warmer than at any time since regular instrumental records began (~1880) (Laffoley and Baxter 2016), and 2015 was globally the warmest year in this period, with +1.13°C relative to the 1880-1920 mean (Hansen et al. 2016). Accounting for interannual variability, Hansen et al. (2016) calculate that the recent increases in sea surface temperature meant that global warming has now reached ~1°C since the 19th Century (Hansen et al. 2016). Overall, climate modelling predicts that Australian waters will warm by 1–2°C by 2070. South-east Australia is considered a global hot spot for ocean warming, occurring at around four times the global average (~0.7°C · Century^{-1}), due to increased strength, southward penetration and separation point of the east Australian current (EAC) (Hobday et al. 2006, Ridgway 2007, Cetina-Heredia et al. 2014).

The impacts of climate change on the biophysical environment of NSW, and limitations associated with predictions, have been assessed at a regional level (DECCW 2010b). By 2050, the climate in the Sydney and central coast region is virtually certain to be hotter, with mean daily maximum and minimum temperatures increasing by an estimated 1.5–3^{o}C. Rainfall is likely to increase in all seasons except winter; increased evaporation is likely in spring and summer; the impact of the El Niño-Southern Oscillation is likely to become more extreme; and acceleration in global sea level is virtually certain (Clark et al. 2015).

Climate change components expected to impact the NSW marine environment include: altered ocean currents and nutrients, climate and sea temperature rise, ocean acidification, altered storm and cyclone activity, and sea level rise as well as associated indirect changes to species interactions. Each component and the associated stressors are described below.

Altered ocean currents and nutrients

In eastern Australia, the East Australian Current exerts a fundamental influence on the continental shelf circulation and therefore on the ecology and connectivity of the marine estate (Coleman et al. 2011). Changes in the EAC circulation and modes of variability could have significant implications for ecosystems of the marine estate (Coleman et al. 2017). Increased velocity in the EAC may bring about changes to coastal upwelling processes may affect ecosystems on the continental shelf and in estuaries.

Recent modelling by UNSW (M. Roughan pers. comm.) has indicated that there could be a poleward shift of the East Australian Current by 270 km. Continued global ocean warming will penetrate from the surface to the deep ocean and affect ocean circulation. There is a clear signal in decadal variability of the EAC associated with ENSO (Suthers et al. 2011).

Recruitment patterns and spawning aggregations of a number of fish species along NSW coast appear to be influenced by ENSO variability, so predicted changes in the intensity and frequency of El Nino, La Nina (Cai et al. 2014) may have significant implications for fisheries (Pecl et al. 2012). Connectivity between estuarine and marine environments may change under climate change scenarios. For example, strengthening of the EAC may afford increased tropical–temperate connectivity exposing the NSW marine estate to a greater diversity of subtropical and tropical species (Verges et al. 2014 2016). Whether the occurrence of these species translates into range expansions into NSW depends upon their ability to overwinter in our waters and therefore upon the increase in winter water temperatures rather than average increases (Booth et al. 2007). Estuarine circulation may also change due to alterations in water temperature, salinity and flow but long-term impacts have not been studied for Australian estuaries.

Altered nutrient and light availability have also been associated with changes in seaweed populations. Johnson et al. (2011) attributed a 95% decline in Australian giant kelp (*Macrocystis pyrifera*) forests in Tasmania to increasingly frequent incursions of warm nutrient poor water from the EAC.

Climate and sea temperature rise

Australia’s south-east region is recognised as a hotspot for rising sea surface temperatures resulting from global warming. Over recent decades, Australia’s south-east marine waters have warmed at almost four times the global average rate (Ridgway 2007). This increase is largely a result of a southward extension and separation point of the East Australian Current (EAC), which flows southward along the edge of the continental shelf, carrying tropical water south before moving towards New Zealand (Ridgway and Dunn 2003, Cetina-Heredia et al. 2014). Analyses of output from global climate models indicate that the south-east Australia hotspot will remain one of the fastest warming in the world (Hobday and Lough 2011, Anderson and Gledhill 2013). Australia’s temperate coast is predicted to continue warming, increasing by 1-3^{o}C over the next century. Long-term data from Port Hacking over the past 60 years indicate a warming trend of 0.746^{o}C per century. Further south at Maria Island in Tasmania, temperatures are increasing at the rate of 2.28^{o}C per century.

Temperature increases may influence the distribution and abundance of fishes (and other organisms) in estuaries and on the shelf through changes to recruitment and reproductive processes. For example, reef assemblages of macroalgae, corals and fishes in the Solitary Islands all show distinct relationships with temperature. This is seen in cross shelf distributions on nearshore reefs which are dominated by kelp through to shallow offshore reefs which are dominated by scleractinian corals. An intensifying EAC may bring increased temperatures which have the potential to cause bleaching of the sensitive temperate coral species in the region (Hughes et al. 2017) as well as to cause decline in kelp which is near its northern extent of its range in this location (Verges et al. 2016). An intensified EAC may also decrease inshore temperatures due to the increased bottom boundary layer uplift. The increased cross shelf gradients may have implications for fish assemblages (Hobday and Lough 2011). The extent of impacts will depend on whether species are at the extremes of their distribution and temperature tolerance (i.e. northern or southern boundary of geographic range).

For example, current winter temperatures act as key bottlenecks for long-term survival and population establishment of tropical fishes which settle along the south-east coast during summer. Current warming trajectories resulting from climate change predict that 100% of winters will be survivable by several tropical species as far south as Sydney by 2080, facilitating possible range expansions of these species into NSW waters. Overall, there is limited information on the response of marine organisms to climate and water temperature rises within estuaries (see relevant chapters in Poloczanska et al. (2012)).

Sea temperature rise has impacted, and is predicted to further impact populations of habitat-forming seaweeds in Australia's southeastern waters. The common kelp, *Ecklonia radiata* has declined from low latitudes in NSW (Verges et al. 2016) and marine heatwaves have precipitated similar declines in Western Australia (Smale and Wernberg 2013) leading to tropicalisation of these ecosystems (Wernberg et al. 2016, Verges et al. 2016). Global air temperatures are projected to rise 0.3-4.8˚C by 2100 (IPCC 2014). Warmer air temperatures are causing water bodies and soils to warm (Huang et al. 2000), which will have important implications for tidal marshes and highly organic soils (Laffoley and Baxter 2016).

Ocean acidification

Atmospheric concentrations of CO_2 were only 280 ppm prior to the industrial revolution, but have now reached 385 ppm. Half of this increase has occurred in the last three decades (Feely et al. 2009, Solomon et al. 2009), reaching the highest concentration in the Earth's atmosphere in 800,000 years (Lüthi et al. 2008). The IPCC predicts that by 2100 the atmospheric concentration of CO_2 will range between 730 and 1,020 ppm depending on the extent to which humans curb CO_2 emissions (Houghton 2001, IPCC 2013, Meehl et al. 2007).

The oceans are a sink for CO_2 and have absorbed one-third of all anthropogenically released CO_2 (Canadell et al. 2007, Feely et al. 2009, Raven et al. 2005, Sabine and Feely 2007). As CO_2 dissolves into the ocean it causes the 'other CO_2 problem', ocean acidification. CO_2 reacts quickly to form H_2CO_3 and like all weak acids, H_2CO_3 quickly dissociates to form HCO3- and H+, therefore reducing oceanic pH. Slowly the available H+ reacts with CO32- to form HCO3-, reversing the pH change, this process is known as the carbonate buffer. Previously in the Earth's history, the rate of increase in CO_2 concentrations has been so slow that the carbonate buffer has been able to buffer the oceans against any significant pH change (Caldeira and Wickett 2003). However, the current rate of CO_2 emission is 100 times greater than ever in the Earth's history (Siegenthaler et al. 2005), and the carbonate buffer cannot cope, resulting in the lowering of the pH of the Earth's oceans.

To date, the surface ocean waters of the globe have already decreased in pH by an average 0.1 units since the industrial revolution (Caldeira and Wickett 2003, Raven et al. 2005). The extent to which they will decrease in the future is dependent on future emission scenarios. Under a moderate reduction scenario (IPCC 5, Representative Concentration Pathway (RCP) 4.5) pH is expected to fall a further 0.3-0.5 units (pH 7.8-7.6) by 2100 (Gattuso et al. 2015) and another 0.7-0.77 units (pH 7.4-7.43) by 2300 (Caldeira and Wickett 2003; 2005, Raven et al. 2005).

The carbonate buffer is of benefit to the ocean because it protects to some degree against pH change. However, this process reduces the amount of vital CO3¬2- available to organisms. This carbonate is essential to organisms that calcify, such as the molluscs, plankton, corals, crustaceans, and echinoderms (Fabry 2008). The ability of these organisms to calcify their CaCO3 polymorphs (calcite and aragonite) relies heavily on the CaCO3 saturation state of seawater (Ω). As the pH of the oceans decreases, Ω decreases, eventually to a point where CO32 cannot exist alone in seawater, this is known as the saturation horizon. It is feared that in the near future, seawater will fall below this saturation horizon.

Studies into the impact of ocean acidification on marine organisms have mainly focused on the calcifying taxa which produce external shells. A wide variety of overwhelmingly negative responses haves been observed for marine organisms producing calcifying shells, including corals (cnidaria), echinoderms, molluscs, and crustaceans (Doney et al. 2009, Fabry 2008, Hendriks et al. 2010, Orr et al. 2005, Parker et al. 2013, Ross et al. 2011, Scanes et al. 2014a).

In addition to creating issues for externally calcifying organisms, decreased oceanic pH can have profound effects on the internal acid-base status of marine organisms (Melzner et al. 2009, Pörtner 2008). The impact of ocean acidification has been less severe as shown in cephalopods (Gutowska et al. 2010, Gutowska et al. 2008, Melzner et al. 2009) and fish but still has effects on and behaviour development (Ishimatsu et al. 2008, Munday et al. 2011). Due to their more complex physiology, fish, cephalopods, and other larger mobile marine organisms have a greater ability to regulate their internal acid-base balance compared to sessile organisms (Doney et al. 2009, Pörtner 2008).

Calcifying, sessile animals have been identified as the most vulnerable to ocean acidification (Parker et al. 2013, Ross et al. 2011). This vulnerability is most evident in their pelagic calcifying larval stages (Parker et al. 2010, Scanes et al. 2014a). Calcifying macro invertebrates form a large portion of the food chain. Not only do they provide food to higher organisms, but in many cases like, coral and oysters, are the backbone of the habitat on which ecosystems rely (Parker et al. 2013, Ross et al. 2011). Acidification related mortality is already known to be affecting the oyster culture industry on the east coast of the USA (Feely et al. 2010). This area is prone to CO_2 rich water upwelling from the deep ocean (Feely et al. 2010), but provides valuable insight to how future aquaculture industries may be affected in areas such as eastern Australia.

Research into the multi-generational capacity for adaptation to ocean acidification remains in its infancy. Studies have shown that parental exposure (Dupont et al. 2013, Parker et al. 2012) and selective breeding for traits (Parker et al. 2011) can have positive effects on larval development and survival under ocean acidification. However, the long-term ramifications of these potential physiological 'trade-offs' arising from extended parental exposure are still not entirely understood (Dupont et al. 2013). Some studies have shown that extended exposure to elevated CO_2 can cause negative carry over effects to their offspring in echinoderms (Dupont et al. 2013).

The potential for ocean acidification to interact additively or synergistically with other stressors is still being explored. Ocean acidification is known to increase the toxicity of heavy metals by changing their speciation and bioavailability (Zeng et al. 2015). There is overwhelming evidence that if global CO_2 emissions continue on their current trajectory there will be significant losses of biota in the world's oceans due to the subsequent pH decline (Doney et al. 2009, Fabry 2008, Orr et al. 2005).

Acidification will also impact non-calcifiers in complex ways. For example, under acidified conditions, kelp production is predicted to decrease (Britton et al. 2016) and kelp competitors (turfing algae) are predicted to do better, but increased consumption may negate this effect (e.g. Ghedini et al. 2015). Field studies at naturally acidified sites indicate that indirect effects may play a greater role in determining calcifying species abundance than direct physiological effects (Connell et al. 2017).

Sea level rise

Global mean sea levels are rising and this rise is expected to continue for centuries, even if greenhouse gas emissions are curbed and their atmospheric concentrations stabilised. As global temperature increases, rising ocean heat content causes ocean thermal expansion and sea-level rise. Other contributions to sea-level rise come from the melting of land ice, including glaciers and ice caps, as well as the major ice sheets of Antarctica and Greenland. The IPCC (2013) projections indicate global mean sea mean level rise under a business as usual scenario of between 0.52 m to 0.98 m, by 2100 relative to 1986 - 2005 or 0.28 m to 0.61 m with significant reduced emissions giving a range of between 0.28 m and 0.98 m by 2100 relative to 1986 – 2005. For NSW mean model predictions suggest sea level rise of 0-10% above the global average, i.e. approximately 0.5 m by 2050 and greater than 1 m by 2100.

Beyond 2100, the IPCC (2013) conclude that it is virtually certain that global mean sea level rise will continue for many centuries due to thermal expansion of the oceans. Assuming lower emission scenarios, global mean sea level rise above the pre-industrial level by 2300 will be less than 1 m. However, this significantly increases for higher emissions as the projected rise is from 1 m to more than 3 m.

Sustained warming greater than a threshold above 1°C (low confidence) but less than about 4°C (medium confidence) would lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of up to 7 m. Abrupt and irreversible ice loss from a potential instability of marine based sectors of the Antarctic ice sheet in response to climate forcing is possible, but current evidence and understanding is insufficient to make a quantitative assessment.

The impacts of sea level rise are likely to include the erosion of sandy beaches and the increased frequency, depth, and extent of coastal flooding. Increased ocean water levels during storms are virtually certain to result in more frequent coastal inundation, higher wave run-up levels, higher water levels in lakes and estuaries, and more flooding in coastal rivers. This suite of changes will have a progressively increasing impact on existing low-lying coastal development.

Altered storm and cyclone activity, flooding, storm surge, inundation

Rainfall is a key determinant of climate-driven changes to nutrients, sediments and freshwater inputs (e.g. Andersen et al. 2006, Fan and Shibata 2015, Hancock 2012, Hinsby et al. 2012, Howarth et al. 2006, Jeppesen et al. 2009, Jeppesen et al. 2011, Kaushal et al. 2008, Van Liew et al. 2012). Typically, inputs are projected to increase when the amount and intensity of rainfall increase but not necessarily in direct proportion. For example, small changes to rainfall may translate to greater changes in freshwater inputs (Chiew and McMahon 2002, Newton 2009). The overall extent of change will partly depend on land use (Bossa et al. 2014, Fan and Shibata 2015, Tu 2009, Wu et al. 2013). Urbanisation has the potential to amplify climate-driven exports of nitrate due to the increased hydrologic connectivity of impervious surfaces (Kaushal et al. 2008). Similarly, conversion of forest to agricultural land may promote greater nutrient and sediment exports under various climate scenarios, due to reductions in groundcover and soil water holding capacity (Bates et al. 1997).

Projections also indicate that current triggers or thresholds for managing water quality and ecosystem health will be exceeded under future climate scenarios (Alam and Dutta 2013, Tong et al. 2007), and that current best-management practices to mitigate nutrient, sediment, and freshwater inputs may be inadequate (e.g. Chiang et al. 2012).

Statewide projections on climate-driven changes to freshwater inputs, otherwise known as run-off, are described in the NSW Climate Impact Profile 2010 (DECCW 2010b). The projections were based on the IPCC SRES A1B global warming scenario for 2030, which represents a 0.9°C increase in global temperature relative to 1990 (Vaze et al. 2008). The projections indicate a shift in the seasonality of run-off patterns, with significantly more run-off in summer, significantly less in winter, minor increases in autumn and moderate to significant decreases in spring. The shift in seasonality has flow-on effects on the mean annual run-off patterns. Specifically, mean annual run-off is projected to increase slightly in northern NSW where rainfall and run-off is currently summer dominated. Mean annual run-off is projected to decrease in the southern regions, where rainfall and run-off is currently winter dominated.

The NSW Climate Impact Profile 2010 will soon be superseded by the outputs of the NSW and ACT Regional Climate Modelling (NARCliM) project, which provides more detailed climate projections to assist local government, businesses and communities to minimise the impacts of climate change. (http://www.ccrc.unsw.edu.au/sites/default/files/NARCliM/index.html). Rainfall projections from NARCliM generally show an increase in summer and autumn rainfall, and decrease in spring and winter rainfall in the near future (2030) for most of the NSW coast. Mean annual rainfall is projected to increase slightly (up to 3%) in the mid to northern parts of the coast, and decrease slightly (up to 3%) in the most southern parts by 2030. Rainfall erosivity, which considers the intensity of rainfall, can be used to indicate the risk of soil erosion under future land use and climate change (Meusburger et al. 2012). Preliminary projections from NARCliM indicate that annual rainfall erosivity will increase by up to 20% in the Hunter, central coast, and Sydney Metropolitan area (Yang unpublished data). In these areas, there is likely to be a high risk of sheet, rill and hillslope erosion, and increased delivery of sediment to adjacent waterways. Overall, the risk of impact of nutrients, sediments, and freshwater inputs on the marine estate is potentially high in areas where there is a coincident increase in rainfall, high erosivity and planned future urban expansion or intensification. The Hawkesbury–Nepean and the Hunter River catchment are likely to be at highest risk.

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The nature or type of impact of climate-driven changes to nutrients, sediments and freshwater inputs depends on the resilience of the ecosystem and the combined effects of a wide range of local and climate stressors (e.g. Russell et al. 2009). Generally, the types of impacts that have been projected in international literature include changes to the frequency and extent of flooding (Bates et al. 1997), changes to freshwater flushing times and biogeochemical processes in estuaries (Ahmadi et al. 2014, Statham 2012), increases in the frequency and magnitude of algal blooms (Moore et al. 2008), anoxia (Meier et al. 2012), loss in biodiversity (Mantyka-Pringle et al. 2014), and shifts in the distribution, phenology and community structure of plankton, invertebrates, fish, seagrass and mangroves (Cadol et al. 2014, Cardoso et al. 2008, Hallegraeff 2010, Hughes 2011, Jeppesen et al. 2009, Jeppesen et al. 2011, Laffoley and Baxter 2016, Meier et al. 2011, Newton 2009, Nicholson et al. 2008, Park et al. 2013, Poloczanska et al. 2007, Semeniuk 2013).

3.2 CUMULATIVE THREATS

Assessing the threats to the marine estate provides an effective tool for prioritising further assessment of risk and determining management responses and knowledge gaps. However, such assessments are often limited by scientific uncertainty, the quality of supporting data, the simplification of complex ecosystems and ecological processes, and the focus on individual threats in isolation. In many cases, impacts from two or more stressors on marine and coastal systems can be additive, and can multiply (synergistic) or or reduce effects (antagonistic) (Crain et al. 2008). Stressors are considered synergistic when their combined effect is greater than predicted from the responses to each stressor alone, and antagonistic when the cumulative impact is less than expected (Folt et al. 1999, Crain et al. 2008). Hence, it is important to understand the interactions between stressors.

In general, accurate prediction of the impacts of multiple stressors becomes more difficult as the number of stressors increases. For example, it is difficult to predict the impact of multiple stressors on complex ecosystems, such as those found within the NSW marine estate. In part, this is because it generally does not account for interactions among activities, or cumulative impacts over space and time.

To fully account for the cumulative threats impacting the marine estate scientists and managers must be able to understand: (1) which activities cause which stressors; (2) the magnitude, frequency, and spatial scale at which the activities occur; (3) what the resulting direct and indirect cumulative effects will be on the ecosystem; and (4) how multiple ecological components at different levels of organization. Some of the key activities that result in cumulative threats to the NSW marine estate are described in BMT WBM (2017).

4. ECOLOGICAL RESILIENCE

The concept of **ecological resilience** has been increasingly used across multiple disciplines (Standish et al. 2014), which has resulted in a confusing array of meanings (Brand and Jax 2007). In this section, we provide a basic, logical description that can be applied to the ecological values of the NSW marine estate in relation to human disturbances.

4.1 RESPONDING TO DISTURBANCES

In essence, ecological resilience is about a response to a disturbance. The disturbance could be generated either naturally, or by human activities (Glasby and Underwood 1996, Lake 2013).

The response of an ecological component or asset – that is, an organism, population, assemblage of species, habitat, or ecosystem – depends on the (Underwood 1989):

- size of the disturbance, described by its
  - magnitude
  - duration frequency
  - distribution
- type of disturbance, described by
  - how it occurs over time (i.e. pulse, press or ramp)
  - whether its origin is from a single or multiple stressors
  - capacity of the ecological component to respond to that disturbance.

The capacity of an ecological component to respond to a disturbance is described by its biological, ecological, hydrodynamic, and biogeochemical characteristics and processes. These combine to sustain the ecological component's abundance, distribution, form, and function within a natural range of variability in time and space (Underwood 1989).

4.2 MEASURING THE RESPONSE TO DISTURBANCES

The response of an ecological component to a disturbance is usually measured by changes in one or more of the following (Glasby and Underwood 1996):

- structure e.g. density, abundance, distribution, form
- function e.g. process rates
- time taken for the changes to return (or not) to their natural range of variability once stressors are removed, which may be decades.

The characteristics of an ecological component will determine the nature of the response, the trajectory of recovery, and the extent of its adaptation (or not) to new environmental conditions, if recovery to its natural range is unattainable (Glasby and Underwood 1996, Underwood 1989).

The question of whether a habitat is **resilient** relates to how it responds to changes in its structure or function after a disturbance. This involves examining whether it can:

- recover to its original natural variability
- retain its function, despite its changed structure
- reorganise and adapt its structure and function to a new environment.

An ecological component is resilient to a specified level of human disturbance if it has any of the above characteristics. If it is not resilient, then irreversible change has occurred, with a permanent loss of structure and function of the ecological component within that ecosystem.

Simple cases of interaction between a single ecological component and one human disturbance can easily be described. However, marine and estuarine ecosystems have highly complex interactions involving multiple human disturbances and ecological components (Astles 2015). Assessing the level of resilience of ecological components to human disturbances in complex ecosystems is very difficult without appropriately designed experiments and studies. Such studies need to simultaneously measure the size of human disturbances, and the responses of ecological components to these disturbances (Underwood 1989; 1996).

When such studies are unavailable, we can instead identify and examine the capacities of ecological components to respond to one or more human disturbances. As described above, these ‘capacities to respond’ are the ecological, biological, hydrological, geomorphic, and biogeochemical characteristics of ecological components that contribute to their ability to recover, persist, or reorganise and adapt their structure and function (Underwood 1989).

Ecological characteristics that contribute to the capacity of faunal assemblages to respond to human disturbance include:

- abundance
- distribution
- diversity
- quality and condition of habitat types
- distance between estuaries and the functioning nutrient, hydrological, and sediment dynamics that operate within the range of their natural variability.

The above characteristics are strongly influenced by season, latitude, catchment size and tidal currents. Furthermore, the complexity, quality, and condition of these ecological characteristics may be important for many faunal assemblages, rather than just their abundance and distribution.

Further discussion of the concept of resilience and examples relating to NSW marine environmental assets is provided in the Hawkesbury Shelf marine bioregion background environmental report (MEMA 2016).

5. ESTUARIES

This section defines estuaries and describes the three primary types of estuary used in this assessment:

- tide-dominated
- wave-dominated
- intermittent

The distribution of these estuary types is described in Section 5.5, while Section 5.7 describes the typical estuarine habitats and their distribution in the regions addressed in this report.

5.1 DEFINITIONS

An **estuary** is defined as a semi-enclosed coastal body of water that:

- is connected to the sea, either permanently or periodically
- has a salinity that is different from the adjacent open ocean due to freshwater inputs or evaporation
- includes a characteristic biota
- extends upstream to the limit of influence by the sea, including tidal rise.

The above definition has been adapted from Whitfield and Elliott (2011), with the addition of a reference to evaporation and extent.

Roper et al. (2011) recognised 184 estuaries along the NSW coast, although Williams et al. (1998) had previously identified more than 950 waterbodies with a connection to the NSW coast, most of which were small, ephemeral streams or springs. This section will concentrate on the 184 larger estuaries considered by Roper et al. (2011).

Of the 184 estuaries recognised by Roper et al. (2011) along the NSW coast, a small number dominate the total area of estuarine waters. These include the Richmond River, Clarence River, Wallis Lake, Port Stephens, Hunter River, Hawkesbury River, Sydney Harbour, Botany Bay, Jervis Bay, Batemans Bay, and Wallaga Lake (Figure 3). In total, 55 estuaries are found in the northern region, 40 in the central region and 89 in the southern region (Table 4). Their classification and location, and the indices of disturbance assigned in the first statewide assessments of estuarine condition were presented in Roper et al. (2011).

The three primary forms of estuary defined in this assessment (Scanes et al. 2016): tide-dominated, wave-dominated, and intermittent are based on the dominant forcing factors, including wave energy, tidal flow, and fluvial inputs (Dalrymple et al. 1982, Roy et al. 2001). They are a compression of the existing functional estuarine typology for NSW from Roper et al. (2011). Clear conceptualisations of the interactions between the influence of stressors and the main functional drivers for the formation of the three forms of estuary were developed in Scanes et al. (2016) (Figure 4-6). These interactions are readily applicable to the assessment of threat and risk.

The three primary estuarine forms have been further divided into estuary subtypes to allow more detailed assessment and reporting (e.g. Roper et al. 2011, OEH unpubl.). However, in this assessment, the data for each subtype have been pooled to the level of form (Table 4).

Figure 3. The New South Wales marine estate, showing the major estuaries, the extent of coastal waters and the marine bioregion within NSW.

5.2 TIDE-DOMINATED ESTUARIES

Tide-dominated estuaries are characterised by a funnel-shaped mouth, which gives way to channelised upper estuary and tidal river reaches (e.g. Hawkesbury River). The subtidal channels are generally flanked by an extensive, diverse array of intertidal and supratidal habitats (shoals, mangroves, saltmarsh: see Figure 4). Tidal inundation of flanking environments traps and deposits terrigenous (i.e. a marine deposit made of material eroded from the land) and resuspended particulate material.

Tidal currents are a major physical factor in tide-dominated systems, and significantly affect the resuspension and deposition of particulate material in the estuary. The net transport or accumulation of particulate material through the estuary is determined by residual currents, which vary along the estuarine gradient. In general, there is commonly a net downstream transport of suspended material from the upper estuary, accumulation within the middle estuary, and a net upstream transport of suspended material from the lower estuary (Chen et al. 2005). Constant disturbance of sediments can occur each tidal cycle, and disturbance can reach depths of >50 cm in some systems (e.g. the lower Scheldt estuary; Baeyens et al. 1998). Channel sediments of tide-dominated systems may therefore experience rates of disturbance that exceed rates of accumulation.

Large tides expose wide expanses of intertidal flats, and can inundate large areas of mangroves and marshes. The development of beds of subtidal macrophytes (i.e. mangrove, saltmarsh, and seagrass) is limited by strong currents and often high levels of turbidity. Most beds are located along margins, or in sheltered backwaters and bays.

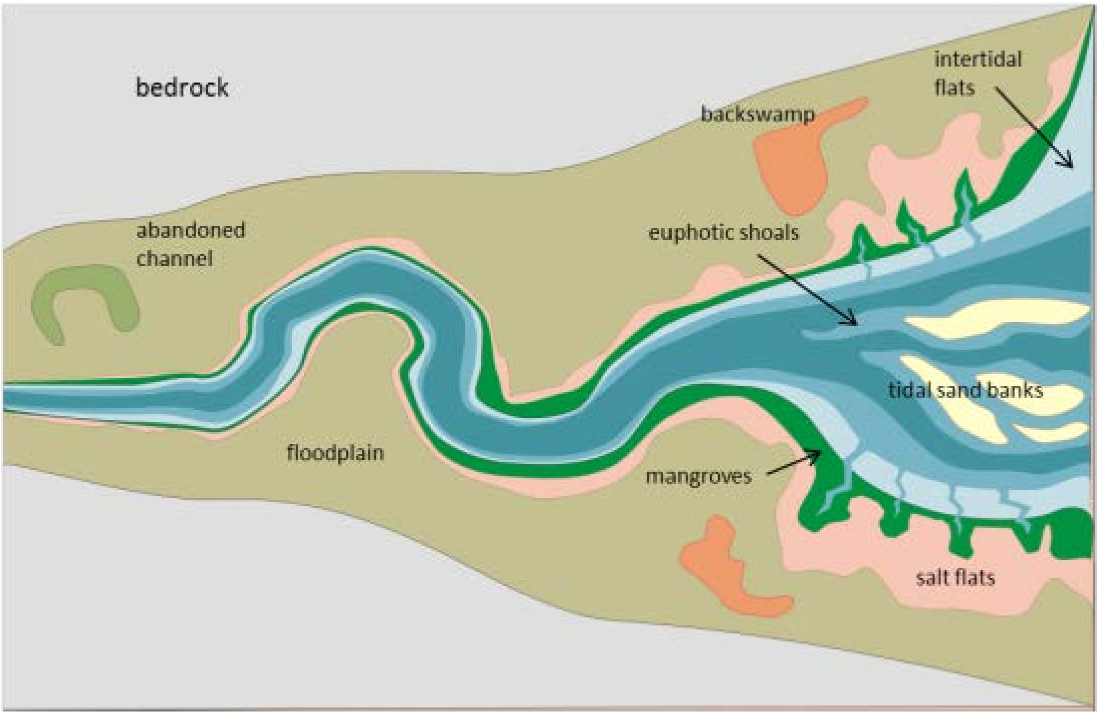

Figure 4. Typical morphology of tide-dominated estuaries (Scanes et al. 2016). The estuary is characterised by a funnel-shaped entrance that gives way to channelised middle and upper reaches. The main channel is flanked by extensive intertidal habitats that tend to trap particulate material. Elongate shoals and islands can form within the lower estuary reach. In tropical and warm-temperate latitudes, mangroves are common on upper parts of the intertidal flats.

Table 4. Location and categorisation of all estuaries within the northern, central, and southern regions of New South Wales.

Estuary	Latitude of estuary entrance (ºS)	Longitude of estuary entrance (ºE)	Form[a]	Estuary subtype[b]
Northern region				
Tweed River	–28.1693	153.5562	WD	BR
Cudgen Creek	-28.2564	153.5847	WD	BR
Cudgera Creek	–28.3596	153.5780	WD	BR
Mooball Creek	–28.3877	153.5700	WD	BR
Brunswick River	–28.5379	153.5581	WD	BR
Belongil Creek	–28.6251	153.5916	IE	CREEK
Tallow Creek	–28.6673	153.6216	IE	LAGOON
Broken Head Creek	–28.6968	153.6135	IE	LAGOON
Richmond River	–28.8766	153.5910	WD	BR
Salty Lagoon	–29.0771	153.4376	IE	LAGOON
Evans River	–29.1128	153.4373	WD	BR
Jerusalem Creek	–29.2145	153.3919	IE	LAGOON
Clarence River	–29.4268	153.3721	WD	BR
Lake Arragan	–29.5651	153.3383	IE	LAKE
Cakora Lagoon	–29.6007	153.3330	IE	LAGOON
Sandon River	–29.6728	153.3325	WD	BR
Wooli Wooli River	–29.8878	153.2683	WD	BR
Station Creek	–29.9494	153.2587	IE	LAGOON
Corindi River	–29.9805	153.2318	WD	BR
Pipe Clay Creek	–30.0223	153.2069	IE	CREEK
Arrawarra Creek	–30.0582	153.1973	IE	LAGOON
Darkum Creek	–30.0959	153.2004	IE	CREEK
Woolgoolga Lake	–30.0987	153.1993	IE	LAGOON
Willis Creek	–30.1286	153.2047	IE	CREEK
Hearns Lake	–30.1320	153.2025	IE	LAGOON
Moonee Creek	–30.2122	153.1614	WD	BR
Pine Brush Creek	–30.2516	153.1423	IE	CREEK
Coffs Creek	–30.2965	153.1391	WD	BR
Boambee Creek	–30.3546	153.1062	WD	BR
Bonville Creek	–30.3760	153.1004	WD	BR
Bundageree Creek	–30.4313	153.0758	IE	CREEK
Bellinger River	–30.5017	153.0313	WD	BR
Dalhousie Creek	–30.5232	153.0281	IE	LAGOON
Oyster Creek	–30.5633	153.0175	IE	LAGOON
Deep Creek	–30.6010	153.0116	IE	LAGOON
Nambucca River	–30.6483	153.0105	WD	BR
Macleay River	–30.8729	153.0259	WD	BR
South West Rocks Creek	–30.8831	153.0379	IE	LAKE
Saltwater Creek	–30.8831	153.0428	IE	LAGOON
Korogoro Creek	–31.0536	153.0561	WD	BR
Killick Creek	–31.1870	152.9784	IE	LAGOON
Goolawah Lagoon	–31.2093	152.9683	IE	BDL
Hastings River	–31.4259	152.9168	WD	BR

Estuary	Latitude of estuary entrance (ºS)	Longitude of estuary entrance (ºE)	Form[a]	Estuary subtype [b]
Cathie Creek	–31.5495	152.8598	IE	LAGOON
Duchess Gully	–31.5871	152.8403	IE	CREEK
Camden Haven River	–31.6357	152.8375	IE	LAKE
Manning River	–31.8767	152.6959	WD	BR
Khappinghat Creek	–32.0100	152.5656	IE	LAGOON
Black Head Lagoon	–32.0704	152.5449	IE	CREEK
Wallis Lake	–32.1734	152.5109	IE	LAKE
Smiths Lake	–32.3954	152.5196	IE	LAKE
Myall River	–32.6710	152.1457	IE	LAKE
Karuah River	–32.6656	151.9719	WD	BR
Tilligerry Creek	–32.7280	152.0519	IE	LAKE
Port Stephens	–32.7071	152.1953	TD	DRV
Central region				
Hunter River	–32.9143	151.8013	WD	BR
Glenrock Lagoon	–32.9627	151.7383	IE	CREEK
Lake Macquarie	–33.0855	151.6620	IE	LAKE
Middle Camp Creek	–33.1461	151.6368	IE	CREEK
Moonee Beach Creek	–33.1666	151.6328	IE	CREEK
Tuggerah Lake	–33.3447	151.5032	IE	LAKE
Wamberal Lagoon	–33.4299	151.4489	IE	BDL
Terrigal Lagoon	–33.4427	151.4436	IE	LAGOON
Avoca Lake	–33.4642	151.4365	IE	BDL
Cockrone Lake	–33.4939	151.4288	IE	BDL
Brisbane Water	–33.5225	151.3341	IE	LAKE
Hawkesbury River	–33.5644	151.3090	TD	DRV
Pittwater	–33.5799	151.3169	TD	DRV
Broken Bay	–33.5625	151.3410	TD	DRV
Narrabeen Lagoon	–33.7037	151.3081	IE	LAKE
Dee Why Lagoon	–33.7469	151.3037	IE	BDL
Curl Curl Lagoon	–33.7673	151.2992	IE	LAGOON
Manly Lagoon	–33.7864	151.2891	IE	CREEK
Middle Harbour Creek	–33.8188	151.2572	TD	DRV
Lane Cove River	–33.8427	151.1778	TD	DRV
Parramatta River	–33.8449	151.1873	TD	DRV
Port Jackson	–33.8283	151.2901	TD	DRV
Cooks River	–33.9494	151.1688	WD	BR
Georges River	–33.9975	151.1554	TD	DRV
Botany Bay	–34.0013	151.2337	TD	BAY
Port Hacking	–34.0725	151.1628	TD	DRV
Wattamolla Creek	–34.1379	151.1182	IE	CREEK
Hargraves Creek	–34.2297	150.9914	IE	CREEK
Stanwell Creek	–34.2328	150.9878	IE	CREEK
Flanagans Creek	–34.3156	150.9290	IE	CREEK
Woodlands Creek	–34.3251	150.9244	IE	CREEK
Slacky Creek	–34.3355	150.9251	IE	CREEK
Bellambi Gully	–34.3652	150.9228	IE	CREEK
Bellambi Lake	–34.3768	150.9223	IE	CREEK

Estuary	Latitude of estuary entrance (ºS)	Longitude of estuary entrance (ºE)	Form[a]	Estuary subtype[b]
Towradgi Creek	–34.3833	150.9165	IE	CREEK
Fairy Creek	–34.4099	150.9022	IE	CREEK
Allans Creek	–34.4638	150.9003	WD	BR
Port Kembla	–34.4648	150.9116	TD	BAY
Lake Illawarra	–34.5436	150.8750	IE	LAKE
Elliott Lake	–34.5606	150.8699	IE	CREEK
Southern region				
Minnamurra River	–34.6280	150.8611	WD	BR
Spring Creek	–34.6642	150.8545	IE	CREEK
Munna Munnora Creek	–34.6924	150.8538	IE	CREEK
Werri Lagoon	–34.7287	150.8394	IE	CREEK
Crooked River	–34.7728	150.8157	WD	BR
Shoalhaven River	–34.8979	150.7662	WD	BR
Wollumboola Lake	–34.9425	150.7772	IE	BDL
Currarong Creek	–35.0147	150.8215	IE	CREEK
Cararma Creek	–35.0020	150.7776	IE	LAKE
Wowly Gully	–34.9953	150.7287	IE	LAGOON
Callala Creek	–35.0067	150.7182	IE	CREEK
Currambene Creek	–35.0375	150.6714	WD	BR
Moona Moona Creek	–35.0499	150.6780	IE	CREEK
Flat Rock Creek	–35.1241	150.7041	IE	CREEK
Captains Beach Lagoon	–35.1264	150.7115	IE	CREEK
Telegraph Creek	–35.1363	150.7254	IE	CREEK
Jervis Bay	–35.1039	150.7872	TD	BAY
St Georges Basin	–35.1852	150.5938	IE	LAKE
Swan Lake	–35.2023	150.5598	IE	BDL
Berrara Creek	–35.2108	150.5484	IE	LAGOON
Nerrindillah Creek	–35.2276	150.5326	IE	CREEK
Conjola Lake	–35.2687	150.5078	IE	LAKE
Narrawallee Inlet	–35.3027	150.4740	WD	BR
Mollymook Creek	–35.3356	150.4743	IE	CREEK
Millards Creek	–35.3546	150.4757	IE	CREEK
Ulladulla Bay	–35.3556	150.4784	TD	BAY
Burrill Lake	–35.3950	150.4474	IE	LAKE
Tabourie Lake	–35.4427	150.4106	IE	BDL
Termeil Lake	–35.4623	150.3944	IE	BDL
Meroo Lake	–35.4829	150.3915	IE	BDL
Willinga Lake	–35.5006	150.3914	IE	BDL
Butlers Creek	–35.5522	150.3827	IE	CREEK
Durras Lake	–35.6418	150.3054	IE	LAKE
Durras Creek	–35.6576	150.2971	IE	CREEK
Maloneys Creek	–35.7094	150.2437	IE	CREEK
Cullendulla Creek	–35.7022	150.2095	WD	BR
Clyde River	–35.7069	150.1818	WD	BR
Batemans Bay	–35.7572	150.2500	TD	BAY
Saltwater Creek	–35.8122	150.2259	IE	CREEK

Estuary	Latitude of estuary entrance (ºS)	Longitude of estuary entrance (ºE)	Form[a]	Estuary subtype[b]
(Rosedale)				
Tomaga River	–35.8374	150.1852	WD	BR
Candlagan Creek	–35.8424	150.1802	WD	BR
Bengello Creek	–35.8679	150.1632	IE	CREEK
Moruya River	–35.9058	150.1518	WD	BR
Congo Creek	–35.9536	150.1601	IE	CREEK
Meringo Creek	–35.9785	150.1511	IE	BDL
Kellys Lake	–36.0065	150.1574	IE	BDL
Coila Lake	–36.0486	150.1416	IE	LAKE
Tuross River	–36.0667	150.1344	WD	BR
Lake Brunderee	–36.0935	150.1372	IE	LAGOON
Lake Tarourga	–36.1052	150.1356	IE	BDL
Lake Brou	–36.1280	150.1264	IE	BDL
Lake Mummuga	–36.1621	150.1266	IE	LAGOON
Kianga Lake	–36.1921	150.1330	IE	BDL
Wagonga Inlet	–36.2095	150.1348	IE	LAKE
Little Lake (Narooma)	–36.2243	150.1411	IE	BDL
Bullengella Lake	–36.2421	150.1447	IE	LAKE
Nangudga Lake	–36.2519	150.1444	IE	LAGOON
Corunna Lake	–36.2897	150.1312	IE	LAGOON
Tilba Tilba Lake	–36.3281	150.1156	IE	BDL
Little Lake (Wallaga)	–36.3396	150.1025	IE	LAGOON
Wallaga Lake	–36.3697	150.0799	IE	LAKE
Bermagui River	–36.4224	150.0731	WD	BR
Baragoot Lake	–36.4641	150.0668	IE	BDL
Cuttagee Lake	–36.4880	150.0551	IE	LAGOON
Murrah River	–36.5254	150.0581	WD	BR
Bunga Lagoon	–36.5402	150.0555	IE	LAGOON
Wapengo Lagoon	–36.6285	150.0209	IE	LAKE
Middle Lagoon	–36.6505	150.0092	IE	BDL
Nelson Lagoon	–36.6857	149.9940	WD	BR
Bega River	–36.7018	149.9830	WD	BR
Wallagoot Lake	–36.7900	149.9600	IE	BDL
Bournda Lagoon	–36.8202	149.9389	IE	CREEK
Back Lagoon	–36.8833	149.9307	IE	LAGOON
Merimbula Lake	–36.8957	149.9228	IE	LAKE
Pambula River	–36.9469	149.9170	WD	BR
Curalo Lagoon	–37.0469	149.9223	IE	LAGOON
Shadrachs Creek	–37.0768	149.8787	IE	CREEK
Nullica River	–37.0911	149.8729	IE	LAGOON
Boydtown Creek	–37.1029	149.8819	IE	CREEK
Towamba River	–37.1118	149.9132	WD	BR
Fisheries Creek	–37.1107	149.9289	IE	LAGOON
Twofold Bay	–37.0775	149.9481	TD	BAY
Saltwater Creek (Eden)	–37.1685	150.0030	IE	CREEK
Woodburn Creek	–37.1706	150.0052	IE	CREEK
Wonboyn River	–37.2497	149.9662	WD	BR

Estuary	Latitude of estuary entrance (ºS)	Longitude of estuary entrance (ºE)	Form[a]	Estuary subtype[b]
Merrica River	–37.2966	149.9519	IE	CREEK
Table Creek	–37.4063	149.9541	IE	CREEK
Nadgee River	–37.4381	149.9661	IE	CREEK
Nadgee Lake	–37.4688	149.9729	IE	BDL

a Estuary forms: IE = intermittent estuary; TD = tide-dominated; WD = wave-dominated.
b Estuary subtypes as described in Roper et al. (2011) and Scanes et al. (2014a): BDL = back-dune lagoon; BR = barrier river; DRV = drowned river valley.

5.3 WAVE-DOMINATED ESTUARIES

Wave-dominated estuaries constitute a wide spectrum of systems characterised by different rates of river inflow and geomorphic maturity. They mostly separate into two subforms: mature systems tend to be more riverine and confined (e.g. Richmond, Hunter Rivers), and less mature systems (Wallis, Wallis Tuggerah, Illawarra Lakes) are closer to coastal lakes. In the latter examples, ocean exchange is generally much greater than for intermittent estuaries (described in *Section 5.4 Intermittent estuaries*), due to entrance modifications.

Wave-dominated estuaries are formed on highly energetic microtidal coasts. On such coasts, oceanic wave regimes constantly bring unconsolidated sands towards the shore, but riverine flow is sufficient to maintain an open, albeit somewhat restricted, connection with the sea. Mature forms tend to be linear in shape, but may have significant side embayments, depending on their evolutionary stage (Figure 5). The entrance configuration of a wave-dominated estuary is usually somewhat constricted, with mobile sand shoals in the lower estuary and moderate tidal attenuation throughout the length of the estuary.

Although tidal currents can be strong in some locations, they are less important drivers in wave-dominated estuaries. This is due to the largely microtidal range and high attenuation at the mouth and lower estuary reaches (Dalrymple et al. 1992). The net transport of material in wave-dominated estuaries is similar to tide-dominated systems, with net accumulation of material in the middle-estuary mud basin (Heap et al. 2004). Net export of material may occur due to flood scour of sediments. The magnitude of flood scour generally varies as a function of flood size relative to the shape of the system (i.e. bed shear stress) (Hossain et al. 2002). Wind-driven resuspension becomes more important in less mature, shallow systems, such as coastal lakes.

Like tide-dominated estuaries, wave-dominated estuaries have a broad range of habitats, ranging from near marine at the entrance to freshwater in upper reaches. Emergent aquatic macrophyte communities are generally well developed in riverine systems, with mangroves and saltmarshes in more saline reaches, and reed beds and riparian forests in upper reaches. Micro tidal regimes (<2 m daily) mean that the lateral extent of the emergent vegetation is moderate. Intertidal habitats, such as sand and mud flats, are mostly located in the lower and middle reaches. Subtidal vegetated habitats, such as seagrasses, may also be present. However, mobile sediments and strong currents can limit their ability to colonise and survive, therefore limiting their distribution to sheltered bays and shoreline fringes.

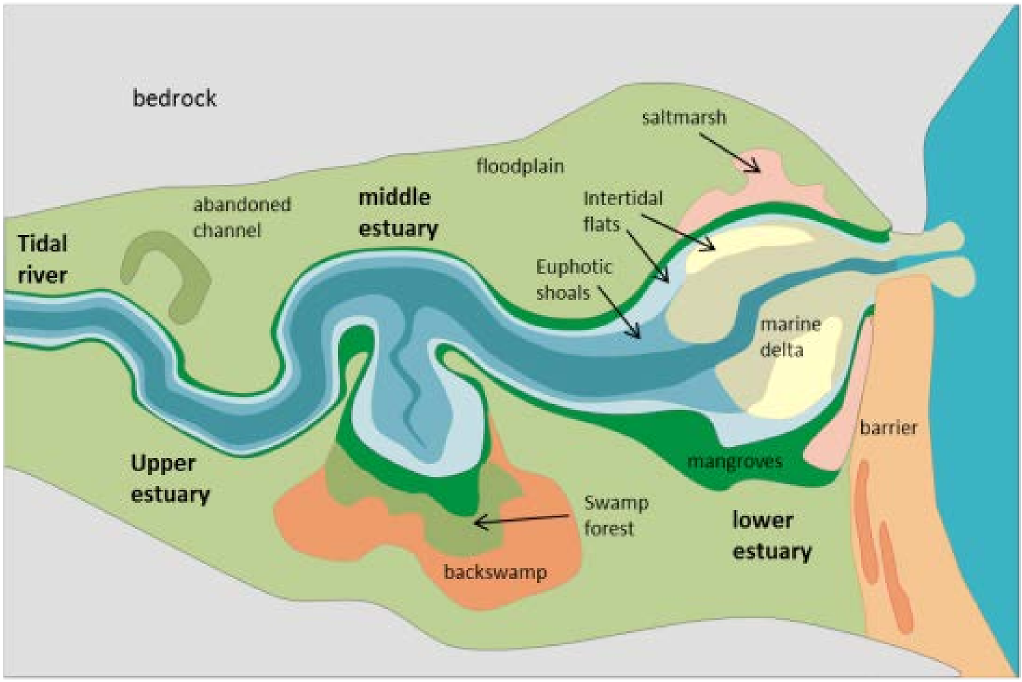

Figure 5. Typical morphology of wave-dominated estuaries (Scanes et al. 2016). The tidal river and upper estuary tend to have a confined channel, with little branching. The middle estuary has a mostly confined main channel, but can also have side arms or basins. The lower estuary is defined by large intertidal and shallow subtidal shoals, with a branching main channel through the marine flood-tide delta. In tropical and warm-temperate latitudes, mangroves are common on upper parts of the intertidal flats.

5.4 INTERMITTENT ESTUARIES

Intermittent estuaries are extreme, immature forms of wave-dominated estuaries that are characterised by an intermittently open or closed entrance. These systems occur where ocean processes act on mobile sand to form a barrier at the estuary entrance, and the rate of barrier formation or reforming is generally greater than the capacity of freshwater inputs to breach that barrier (Figure 6). Intermittent estuaries are only exposed to small tidal currents for short periods (days to weeks) when the entrance is breached, with high attenuation at the mouth (Haines et al. 2006). Wind-driven resuspension constitutes the main form of energy acting on bed sediments in these systems.

Habitats within intermittent estuaries are generally less diverse than those within estuaries with greater tidal influence. Habitats with an obligate tidal range requirement (e.g. mangroves, rocky intertidal communities, intertidal flats, sandy beach communities) are either absent or greatly reduced in abundance and composition. The exception is extensive saltmarshes, which can form on flats that are submerged when water levels rise before the opening of intermittent estuaries that are frequently closed.

Submerged benthic habitats can be extensive, with large shallow subtidal flats and deeper mud basins allowing the development of diverse benthic assemblages. Sediments tend to be spatially sorted: coarser sediments are deposited around the margins where wave energy is greater, and finer sediments dominate the deeper central basins. There is little longitudinal variation in habitats, except in the immediate vicinity of the entrance channel where a flood-tide delta of marine sands can form. Small deltas of riverine sands and muds can form, but are less common, because intermittent estuaries are characterised by minimal fluvial inputs.

Subtidal vegetated habitats, such as seagrasses, are present in some intermittent estuaries. They are confined to areas with sufficient light when the estuary is closed, but are not exposed when water levels drop after the estuary opens.

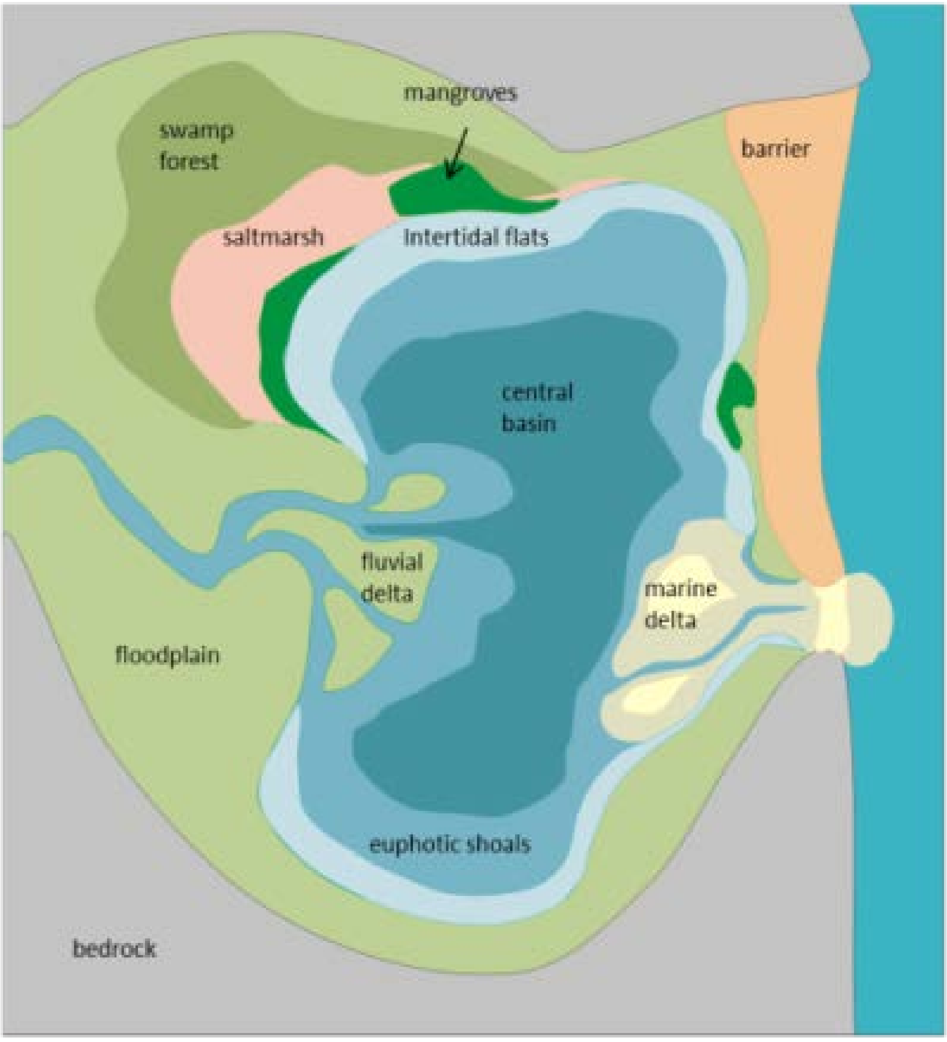

Figure 6. Typical morphology of intermittent estuaries and coastal lagoons (Scanes et al. 2016). These estuaries are an immature form of wave-dominated estuaries, where catchment flows are insufficient to maintain an open entrance. In tropical and warm-temperate latitudes, mangroves may be present on some upper intertidal flats, but the small tidal range often excludes them from establishing.

5.5 DISTRIBUTION OF ESTUARY TYPES

The three different types of estuaries described above are not equally abundant on the NSW coast, nor are they equally distributed among regions on the coast (Figure 7, Table 4). The northern region is dominated by almost equal amounts of wave-dominated (riverine) and intermittent estuaries, while the central region is dominated by wave-dominated (riverine) and a smaller proportion of tide-dominated estuaries. The southern region has the highest proportion of wave-dominated (riverine) estuaries.

The physical characteristics of NSW's estuaries are detailed in Table 5, which includes an estimate of catchment disturbance.

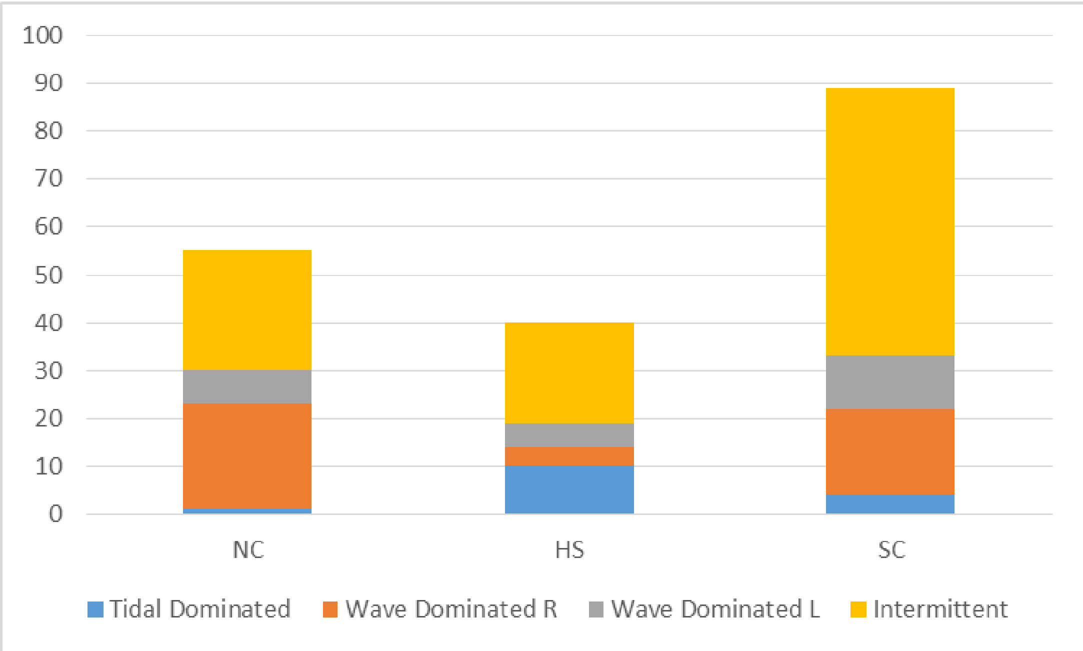

Figure 7. Abundance and type of estuaries in each statewide region of New South Wales (NC = northern; HS = central; SC = southern).

Table 5. Characteristics of estuaries within the northern, central, and southern regions of New South Wales.

Estuary	Catchment disturbance[a]	Open water (km^2)	Total estuary area (km^2)	Average depth (m)	Tidal limit (km)
Northern region					
Tweed River	H	17.16	22.72	2.59	42.00
Cudgen Creek	VH	1.95	2.15	1.13	13.70
Cudgera Creek	VH	0.23	0.48	0.61	5.80
Mooball Creek	H	0.39	0.53	0.67	10.60
Brunswick River	H	2.01	3.59	1.30	14.00
Belongil Creek	H	0.12	0.27	0.46	3.50
Tallow Creek	H	0.12	0.12	0.39	2.80
Broken Head Creek	M	0.05	0.05	0.29	
Richmond River	H	31.43	38.38	3.16	114.10
Salty Lagoon	VL	0.16	0.16	0.43	2.10
Evans River	H	1.89	2.66	1.15	15.40
Jerusalem Creek	VL	0.32	0.32	0.56	5.00
Clarence River	M	120.94	132.32	2.19	109.50
Lake Arragan	VL	0.97	0.97	0.84	
Cakora Lagoon	VL	0.22	0.36	0.50	2.10
Sandon River	VL	1.48	2.62	1.12	14.70
Wooli Wooli River	VL	2.12	3.75	0.85	17.00
Station Creek	VL	0.25	0.26	0.52	6.40
Corindi River	M	0.93	1.90	1.18	12.30
Pipe Clay Creek	H	0.01	0.01	0.16	0.85
Arrawarra Creek	M	0.10	0.12	0.39	2.40
Darkum Creek	VH	0.03	0.06	0.30	2.60
Woolgoolga Lake	VH	0.15	0.16	0.43	2.70
Willis Creek	VH	0.02	0.02	0.21	-
Hearns Lake	VH	0.10	0.15	0.37	2.00
Moonee Creek	H	0.16	0.41	1.49	7.30
Pine Brush Creek	VH	0.02	0.02	0.19	1.00
Coffs Creek	VH	0.26	0.46	0.64	6.80
Boambee Creek	VH	0.57	0.99	0.84	7.10
Bonville Creek	H	1.27	1.66	0.98	10.40
Bundageree Creek	M	0.00	0.00	0.10	3.60
Bellinger River	L	6.71	8.16	1.80	26.10
Dalhousie Creek	H	0.06	0.08	0.32	2.30
Oyster Creek	M	0.14	0.14	0.41	2.70
Deep Creek	H	1.04	1.72	1.28	9.30
Nambucca River	M	9.31	12.64	2.04	30.70
Macleay River	M	20.73	31.64	2.56	56.70
South West Rocks Creek	H	0.18	0.94	0.79	3.10
Saltwater Creek (Frederickton)	H	0.28	0.28	0.29	4.30
Korogoro Creek	M	0.19	0.28	0.51	6.40
Killick Creek	M	0.24	0.29	0.84	2.90
Goolawah Lagoon	VL	0.13	0.13	0.40	-
Hastings River	M	23.20	29.96	1.88	35.80
Cathie Creek	M	7.86	13.75	1.07	8.90
Duchess Gully	H	0.02	0.02	0.22	1.60
Camden Haven River	M	19.73	32.16	3.63	25.90

Estuary	Catchment disturbance[a]	Open water (km^2)	Total estuary area (km^2)	Average depth (m)	Tidal limit (km)
Manning River	M	26.71	34.72	2.98	53.90
Khappinghat Creek	M	1.03	1.19	0.86	9.30
Black Head Lagoon	M	0.01	0.01	0.15	-
Wallis Lake	M	59.43	98.70	2.35	32.10
Smiths Lake	M	7.05	10.01	2.35	5.90
Myall River	L	107.32	115.20	3.98	61.50
Karuah River	M	8.99	17.88	2.21	47.70
Tilligerry Creek	H	8.26	20.45	2.53	35.90
Port Stephens	M	102.50	134.38	14.07	-
Central region					
Hunter River	H	22.61	47.03	3.28	63.50
Glenrock Lagoon	H	0.05	0.05	0.29	1.00
Lake Macquarie	M	97.33	114.10	5.71	24.00
Middle Camp Creek	L	0.01	0.01	0.18	-
Moonee Beach Creek	VH	0.00	0.00	0.09	0.48
Tuggerah Lake	M	63.31	80.76	2.40	19.50
Wamberal Lagoon	H	0.08	0.52	1.70	2.90
Terrigal Lagoon	H	0.28	0.28	0.54	2.50
Avoca Lake	H	0.67	0.67	0.44	2.20
Cockrone Lake	M	0.04	0.33	0.57	2.00
Brisbane Water	H	19.56	28.34	3.09	21.20
Hawkesbury River	M	100.88	114.50	13.81	138.50
Pittwater	M	16.33	18.39	9.90	11.30
Broken Bay	M	17.11	17.14	9.78	-
Narrabeen Lagoon	M	1.69	2.32	2.27	6.50
Dee Why Lagoon	VH	0.24	0.30	0.05	1.40
Curl Curl Lagoon	VH	0.07	0.07	0.31	1.20
Manly Lagoon	VH	0.10	0.10	0.36	2.80
Middle Harbour Creek	H	5.91	6.11	13.40	16.80
Lane Cove River	H	2.60	2.98	4.23	23.30
Parramatta River	H	12.19	13.74	5.07	30.30
Port Jackson	H	28.72	29.06	12.99	-
Cooks River	VH	1.09	1.20	0.90	21.90
Georges River	VH	20.00	26.59	10.54	49.30
Botany Bay	VH	31.14	39.55	11.36	-
Port Hacking	L	10.27	11.70	9.09	14.10
Wattamolla Creek	VL	0.03	0.03	0.25	1.10
Hargraves Creek	H	0.00	0.00	0.11	0.28
Stanwell Creek	M	0.01	0.01	0.15	0.40
Flanagans Creek	H	0.00	0.00	0.09	
Woodlands Creek	M	0.00	0.00	0.11	0.18
Slacky Creek	H	0.00	0.00	0.12	0.60
Bellambi Gully	H	0.02	0.02	0.19	1.00
Bellambi Lake	H	0.03	0.03	0.24	0.71
Towradgi Creek	H	0.04	0.04	0.27	1.90
Fairy Creek	H	0.11	0.11	0.38	2.60
Allans Creek	H	1.14	1.17	0.89	-
Port Kembla	H	1.37	1.37	6.14	-

Estuary	Catchment disturbance[a]	Open water (km^2)	Total estuary area (km^2)	Average depth (m)	Tidal limit (km)
Lake Illawarra	H	27.56	35.83	2.09	11.50
Elliott Lake	H	0.07	0.08	0.34	2.00
Southern region					
Minnamurra River	H	0.54	1.86	0.99	9.60
Spring Creek	H	0.05	0.05	0.29	1.00
Munna Munnora Creek	H	0.00	0.00	0.11	0.50
Werri Lagoon	H	0.14	0.14	0.44	2.10
Crooked River	H	0.21	0.28	0.54	3.10
Shoalhaven River	M	21.42	31.89	2.90	50.20
Wollumboola Lake	L	4.99	6.33	0.79	-
Currarong Creek	L	0.03	0.03	0.25	1.70
Cararma Creek	VL	0.04	2.39	1.16	17.30
Wowly Gully	M	0.07	0.16	0.44	15.30
Callala Creek	M	0.01	0.01	0.14	15.10
Currambene Creek	M	0.76	2.22	1.13	29.60
Moona Moona Creek	M	0.05	0.14	0.42	14.30
Flat Rock Creek	VL	0.01	0.01	0.18	8.20
Captains Beach Lagoon	VL	0.05	0.05	0.28	-
Telegraph Creek	VL	0.01	0.01	0.13	6.90
Jervis Bay	M	118.27	123.89	16.16	-
St Georges Basin	L	37.31	40.91	5.28	21.90
Swan Lake	M	4.41	4.68	2.35	-
Berrara Creek	VL	0.20	0.26	0.52	3.80
Nerrindillah Creek	L	0.04	0.07	0.33	-
Conjola Lake	L	6.53	6.72	4.00	12.20
Narrawallee Inlet	M	0.36	1.04	0.74	7.10
Mollymook Creek	H	0.01	0.01	0.13	0.80
Millards Creek	H	0.00	0.00	0.12	0.65
Ulladulla	H	0.09	0.09	3.74	-
Burrill Lake	M	3.38	4.38	4.26	10.00
Tabourie Lake	L	1.23	1.49	0.78	6.60
Termeil Lake	M	0.57	0.57	0.69	4.30
Meroo Lake	M	0.61	1.37	0.95	-
Willinga Lake	M	0.14	0.31	0.30	3.30
Butlers Creek	H	0.02	0.03	0.23	1.00
Durras Lake	L	3.10	3.77	1.40	9.30
Durras Creek	L	0.02	0.02	0.21	1.10
Maloneys Creek	L	0.03	0.03	0.23	-
Cullendulla Creek	H	0.11	1.29	0.88	4.14
Clyde River	L	12.92	17.55	2.98	43.65
Batemans Bay	L	34.29	34.48	11.12	2.54
Saltwater Creek (Rosedale)	H	0.00	0.00	0.09	0.15
Tomaga River	M	0.71	1.81	1.04	11.50
Candlagan Creek	M	0.04	0.20	0.40	3.40
Bengello Creek	M	0.01	0.01	0.16	-
Moruya River	L	3.68	6.14	1.90	20.80
Congo Creek	M	0.11	0.13	0.39	4.80
Meringo Creek	M	0.07	0.08	0.33	-

Estuary	Catchment disturbance[a]	Open water (km^2)	Total estuary area (km^2)	Average depth (m)	Tidal limit (km)
Kellys Lake	M	0.06	0.06	0.31	1.10
Coila Lake	L	5.41	7.12	2.28	7.80
Tuross River	L	11.86	15.50	1.24	25.00
Lake Brunderee	L	0.17	0.21	0.47	-
Lake Tarourga	VL	0.33	0.33	0.57	-
Lake Brou	L	2.37	2.45	1.16	4.60
Lake Mummuga	L	1.29	1.65	1.01	3.60
Kianga Lake	M	0.06	0.17	0.37	-
Wagonga Inlet	L	5.91	6.94	5.66	11.50
Little Lake (Narooma)	H	0.10	0.10	0.36	2.00
Bullengella Lake	M	0.15	0.15	0.42	-
Nangudga Lake	H	0.39	0.74	0.65	3.40
Corunna Lake	M	1.92	2.13	1.10	4.30
Tilba Tilba Lake	H	0.92	1.17	0.85	3.60
Little Lake (Wallaga)	H	0.12	0.13	0.39	1.00
Wallaga Lake	M	8.06	9.31	3.66	11.10
Bermagui River	M	1.24	2.16	1.09	10.40
Baragoot Lake	L	0.47	0.55	0.64	-
Cuttagee Lake	L	0.85	1.35	0.91	3.70
Murrah River	M	0.57	0.84	0.74	4.90
Bunga Lagoon	L	0.11	0.14	0.38	-
Wapengo Lagoon	L	2.19	3.67	1.29	7.60
Middle Lagoon	M	0.30	0.56	0.66	-
Nelson Lagoon	VL	0.69	1.35	0.90	3.40
Bega River	M	3.05	3.84	1.93	14.60
Wallagoot Lake	L	3.09	3.98	1.38	-
Bournda Lagoon	L	0.08	0.08	0.34	-
Back Lagoon	L	0.14	0.38	0.60	2.90
Merimbula Lake	M	3.00	5.58	2.59	6.80
Pambula River	L	3.07	4.72	2.24	9.80
Curalo Lagoon	L	0.53	0.80	0.89	2.40
Shadrachs Creek	VL	0.01	0.01	0.15	0.60
Nullica River	VL	0.30	0.33	0.56	3.00
Boydtown Creek	M	0.02	0.02	0.19	1.00
Towamba River	L	1.80	2.04	1.07	12.30
Fisheries Creek	VL	0.05	0.09	0.29	2.70
Twofold Bay	L	29.99	30.73	10.89	-
Saltwater Creek (Eden)	VL	0.06	0.06	0.30	1.70
Woodburn Creek	VL	0.05	0.05	0.29	2.40
Wonboyn River	VL	2.88	4.21	2.66	11.40
Merrica River	VL	0.12	0.12	0.40	2.00
Table Creek	VL	0.06	0.06	0.30	1.10
Nadgee River	VL	0.19	0.27	0.47	3.70
Nadgee Lake	VL	1.17	1.20	0.91	-

a The catchment disturbance category is an indicator of the degree of catchment disturbance based on changes to nutrient and sediment inputs, where VH = very high; H = high; M = medium; L = low; and VL = very low.

5.6 ESTUARINE WATERS

The estuarine waters habitat refers to the water column between habitats on the seafloor and the surface. Waters in estuaries are generally more variable than ocean waters, and may be strongly affected by short-term factors such as wind and weather. Other factors influencing the water column within estuaries include:

- heat
- hydrology
- circulation
- flushing
- ocean exchange
- inputs of foreign materials, such as toxicants
- suspended solids and nutrients from diffuse and point sources
- pathogens from sewage
- agricultural run-off
- stormwater and septic systems.

The assessment of the estuarine waters habitat relates specifically to the physio-chemical attributes of the water column. While this is generally related to the objective of clean waters, this does not imply that all waters, at all times, are crystal clear. The natural state of waters can vary from clear and colourless to turbid, clear or tannin-coloured. This state is often variable over time, and is often dependent on weather, rain, and winds.

Any reference condition for clean waters needs to take such variation into account. It also needs to account for factors that may not be visible, such as pollution, temperature and acidity. The National Water Quality Management Strategy (ANZECC 2001) provides guidance on what constitutes clean waters. It uses the concept of trigger values, which provide guidance about the expected status of many water-quality variables based on reference site data. If measurements do not meet the trigger values, further investigation may be needed to determine why.

NSW has had a rigorous process to establish locally relevant trigger values for water quality. The process recognises intrinsic differences between different types of estuary. These new triggers will be included in the next update of the National Water Quality Management Strategy. NSW has also developed a standardised process for using trigger values to assess condition of estuaries[4].

5.7 ESTUARINE HABITATS

The following habitat descriptions are, of necessity, general. They focus mainly on the typical habitats and assemblages found in the various types of estuaries in each of the regions addressed in this report. If some aspects of a habitat or its distribution are particularly significant, it has been highlighted where it is known. For each individual habitat type, the features of the habitat and the species generally closely associated with this habitat are provided where possible. However, many estuarine species are not restricted to particular habitat types, and may occur across a range of habitats, including within the water column itself (e.g. planktonic organisms). Therefore, for the sake of completeness, the final component in this section contains a broad description of the major species groups found in estuaries.

The first scientific mapping of broadscale marine vegetation for NSW was published in 1985 (West et al. 1985) and was based on aerial photos from the previous 5–7 years. The mapping techniques of the time (hand-drawn maps using camera lucida) mean that the areas indicated in West et al. (1985) are approximate compared with those generated by modern GIS mapping methods.

[4] http://www.environment.nsw.gov.au/soc/130125esthlthprot.htm

Many of the estuarine habitats in NSW have been mapped or remapped since then (Creese et al. 2009). Meehan and Williams (2005) assessed the potential errors arising from changes to mapping techniques and consequences of temporal comparisons. They found that hand-drawn maps consistently overestimated areas of seagrass (in comparison to GIS methods) by 8–20%.

In this report, the information from Creese et al. (2009) has been combined into a NSW map series, and the relevant sheets for NSW waters are presented in Appendix 1. Mapped spatial layers are available statewide for saltmarsh, mangrove and seagrass habitats, with other identified habitats mapped in only a few estuaries, including Sydney Harbour, Botany Bay, and Port Stephens. For the purpose of this assessment, these additional habitats are defined as beach and mudflat, rocky shores, subtidal rocky reefs, and subtidal soft sediments.

5.7.1 SALTMARSH

Saltmarsh refers to species of herbaceous plants and low shrubs that can tolerate high soil salinity and at least occasional flooding by seawater (Morrisey 1995). An example of saltmarsh habitat is given in Figure 8.

Saltmarsh provides habitat and food for fishes, birds, mammals, insects, and invertebrates, and contributes to the base of estuarine food chains through decomposition of vegetation. Many wetland plants actively regulate hydrology through mechanisms such as transpiration, water shading and sediment trapping. Saltmarsh also has other important ecosystem functions, including:

- acting as a buffer and filter of nutrients
- reducing erosion and controlling floods
- maintaining water quality
- acting as a ‘carbon sink’ by storing large quantities of carbon within plants and sediment.

Saltmarshes occur within 81% of the mapped NSW estuaries, but are typically absent in small intermittently open lagoons or creeks (Table 6). They usually grow between the mean and maximum (highest astronomical tide) high-tide levels (i.e. landward of mangroves) in areas too salty and dry for mangroves, and adjacent to shorelines dominated by soft sediment.

Most saltmarshes contain a diverse range of grasses, saltbushes, rushes and sedges, although a small number of species often dominate at a particular site. There is often distinct zonation of species across the habitat, with two main zones: the low or high saltmarsh. The number of low saltmarsh species increases from north to south in NSW, with the dominant species being *Sarcocornia quinqueflora* (samphire), *Suaeda australis* (salt-couch), *Sporobolus virginicus,* and *Paspalum vaginatum* (Sainty et al*.* 2012).

The habitat can also contain considerable small-scale patchiness, with zones often consisting of a mosaic of species. This is influenced by elevation, salinity and frequency of inundation. The high saltmarsh typically consists of numerous species and is more prone to invasion by weeds, such as the introduced rush (*Juncus acutus),* starwort (*Aster squamatus*), and pennywort (*Hydrocotyle bonariensis*). The common high native saltmarsh species include *Juncus kraussii*, *Baumea juncea,* and the reed *Phragmites australis*, which is most common in coastal lakes.

Saltmarsh distribution

There are considerable regional differences in the extent, distribution and composition of saltmarshes. However, mapping by NSW Department of Primary Industries (DPI) does not discriminate saltmarsh species. The distribution of saltmarshes has been mapped at least twice in most estuaries in NSW, with some being mapped three or four times from 1985 to 2013. Here, we only discuss changes over this recent period, although we acknowledge the large losses of this habitat in the early parts of the 20th century.

The distribution of saltmarsh habitats throughout NSW are represented in the seabed habitats layers on the Fisheries NSW Spatial Data Portal:

https://www.dpi.nsw.gov.au/about-us/science-and-research/spatial-data-portal

The **northern region** of NSW (Tweed River to Port Stephens) contains 30% of the state's estuaries, yet these estuaries contain 64% of the state's saltmarsh. Since 1985, saltmarshes have been recorded from all but two estuaries (Saltwater Creek and Blackhead Lagoon) in the northern region, although they were absent from an additional four lagoons or lakes at the last time of mapping (Table 6). Significant areas of saltmarsh occur within Port Stephens (25% of the northern region), Wallis Lake (12%), Clarence River (10%), and Macleay River (8%). Not surprisingly, Port Stephens and Wallis Lake also have the largest areas of saltmarsh of all estuaries in the state (15% and 8% of the state's total, respectively).

Differences in mapping methods between 1985 and recently are likely to lead to an overestimation of cover in the 1985 data (Meehan and Williams 2005). Small declines from the 1985 data in the following discussions should therefore be treated with caution. Between 1985 and 2013, the area of mapped saltmarsh has declined in nine of the 43 northern region estuaries (Table 6). Of these, the majority of declines were observed over the first two times of mapping (1985 – mid 2000s). Note that saltmarsh is extremely difficult to map at the scale of an entire estuary. It can often be obscured in aerial photos by trees, such as mangroves and *Casuarina* spp., and field validation is often compromised by difficulties accessing saltmarsh areas. Nevertheless, the most noteworthy declines of saltmarsh (in terms of area) in the northern region occurred in Lake Cathie (292 ha lost between 1985 and 2011), the Karuah River (115 ha) and Cudgen Creek (50 ha).

Saltmarsh habitat in the **central region** is present within 17 estuaries, with the largest areas found in the Hunter River (17% of the state's total), Hawkesbury River, Botany Bay and Brisbane Water (1.5% of the state). The only known recent decline in saltmarsh in the central region occurred in Botany Bay, where 25 ha were apparently lost between 1985 and 2008. Further specific details on saltmarshes within individual estuaries in the central region are presented in MEMA (2015).

Saltmarsh plant species diversity is greatest in the **southern region** of NSW, with Jervis Bay being the northern limit for many species. Saltmarsh has been mapped in 63 estuaries in this region. The largest area is in the Shoalhaven River (212 ha, 15% of the region, or 2% of the state), followed by Jervis Bay (148 ha, 10% of region), Clyde River (92 ha, 6.5% of the region), Moruya River (80 ha, 5.6% of region), and Tuross Lake (79 ha, 5.5% of region).

Within Jervis Bay, the vast majority of saltmarsh is found within Cararma Inlet. This is one of the most diverse and pristine saltmarsh environments in New South Wales, and is an important reference site for statewide monitoring of saltmarsh. The Moruya, Tuross, Clyde, and Tomaga Rivers support the largest saltmarsh communities. Smaller areas of saltmarsh are found in most intermittently closed estuaries, such as Coila and Corunna Lakes. They represent the primary intertidal vegetation type in these estuaries, because mangroves are generally absent. The saltmarsh plain is wide, and contains extensive stands of the vulnerable species *Wilsonia backhouseii* (Schedule 2 of the NSW *TSCA*), and the northernmost stand of the saltmarsh shrub *Tecticornia* (ex. *Sclerostegia arbuscular)*.

Declines in mapped saltmarsh area have been documented in 13 of the 63 southern region estuaries that contain saltmarsh. The most substantial declines (in area) have occurred in Lake Brunderee (23 ha lost between 1985 and 2005), the adjacent Lake Brou (16 ha lost over the same period) and Wallaga Lake (13 ha lost).

Figure 8. Typical saltmarsh habitat in New South Wales.

Table 6. Areas of saltmarsh (hectares) in New South Wales estuaries mapped between 1985 and 2013 (mapped two to four times, depending on estuary).

Estuary	Type[a]	Times mapped	Change[b]	Area lost[c]	Latest area	% of region	% of state
Northern region							
Tweed River	BR	2	Increase		76.25	1.60	1.05
Cudgen Creek	BR	2	Decrease	–50.89	5.21	0.11	0.07
Cudgera Creek	BR	2	Increase	-	7.43	0.16	0.10
Mooball Creek	BR	2	Increase	-	0.80	0.02	0.01
Brunswick River	BR	3	Increase	-	38.55	0.81	0.53
Belongil Creek	CREEK	2	Increase	-	8.32	0.18	0.11
Tallow Creek	LAG	2	Decrease	–0.30	0.00	0.00	0.00
Broken Head Creek	LAG	2	Decrease	–3.60	0.00	0.00	0.00
Richmond River	BR	2	Increase	-	59.94	1.26	0.83
Evans River	BR	2	Decrease	–1.74[d]	35.76	0.75	0.49
Jerusalem Creek	LAG	2	Decrease	–2.10	0.00	0.00	0.00
Clarence River	BR	3	Increase	-	438.05	9.22	6.04
Cakora Lagoon	LAG	1	NA	-	12.86	0.27	0.18
Sandon River	BR	2	Increase	-	47.74	1.00	0.66
Wooli Wooli River	BR	2	Increase	-	66.86	1.41	0.92
Station Creek	LAG	2	Increase	-	0.40	0.01	0.01
Corindi River	BR	3	Increase	-	88.94	1.87	1.23
Arrawarra Creek	LAG	3	Increase	-	1.35	0.03	0.02
Darkum Creek	CREEK	3	Variable	-	0.03	0.00	0.00
Woolgoolga Lake	LAG	3	Increase	-	0.11	0.00	0.00
Hearnes Lake	LAG	3	Variable	-	4.31	0.09	0.06
Moonee Creek	BR	3	Variable	-	11.72	0.25	0.16
Coffs Creek	BR	3	Increase	-	1.36	0.03	0.02
Boambee Creek	BR	3	Variable	-	10.50	0.22	0.14
Bonville Creek	BR	3	Increase	-	17.66	0.37	0.24
Bellinger River	BR	3	Increase	-	28.35	0.60	0.39
Dalhousie Creek	LAG	3	Variable	-	0.52	0.01	0.01
Oyster Creek	LAG	2	Increase	-	0.30	0.01	0.00
Deep Creek	LAG	2	Increase	-	63.87	1.34	0.88
Nambucca River	BR	2	Increase	-	127.67	2.69	1.76
Macleay River	BR	3	Variable	-	388.90	8.18	5.36
South West Rocks Creek	LAKE	3	Variable	-	29.91	0.63	0.41
Saltwater Creek	LAG	2	None	-	0.00	0.00	0.00
Korogoro Creek	BR	2	Increase	-	3.98	0.08	0.05
Killick Creek	LAG	2	Increase	-	0.91	0.02	0.01
Hastings River	BR	3	Increase	-	234.75	4.94	3.24
Lake Cathie	LAG	3	Decrease	–291.65	176.04	6.43	4.21
Camden Haven River	LAKE	3	Decrease	–3.18[d]	74.82	1.57	1.03
Manning River	BR	2	Increase	-	244.70	5.15	3.37
Khappinghat Creek	LAG	2	Increase	-	15.89	0.33	0.22
Black Head Lagoon	CREEK	1	NA	-	0.00	0.00	0.00

Estuary	Type[a]	Times mapped	Change[b]	Area lost[c]	Latest area	% of region	% of state
Wallis Lake	LAKE	2	Increase	-	592.91	12.47	8.18
Smiths Lake	LAKE	2	Decrease	−0.30	0.00	0.00	0.00
Lower Myall River	LAKE	2	Increase	-	189.07	3.98	2.61
Karuah River	BR	2	Decrease	−115.71	367.09	7.72	5.06
Port Stephens	DRV	2	Increase	-	1149.64	24.19	15.86
Central region							
Hunter River	BR	4	Variable	-	520.43	42.40	7.18
Lake Macquarie	LAKE	4	Variable	-	69.25	5.64	0.96
Tuggerah Lake	LAKE	2	Increase	-	12.92	1.05	0.18
Wamberal Lagoon	LAKE	2	None	-	0.00	0.00	0.00
Terrigal Lagoon	LAG	2	None	-	0.00	0.00	0.00
Avoca Lake	LAG	2	None	-	0.00	0.00	0.00
Cockrone Lake	LAG	2	None	-	0.00	0.00	0.00
Brisbane Water	LAKE	3	Variable	-	112.39	9.16	1.55
Broken Bay	BR	1	NA	-	0.00	0.00	0.00
Hawkesbury River	DRV	3	Increase	-	287.75	23.45	3.97
Pittwater	DRV	3	Variable	-	2.68	0.22	0.04
Narrabeen Lagoon	LAKE	4	Variable	-	0.36	0.03	0.00
Dee Why Lagoon	CREEK	4	Variable	-	7.60	0.62	0.10
Curl Curl Lagoon	LAG	4	None	-	0.00	0.00	0.00
Manly Lagoon	CREEK	4	Variable	-	0.00	0.00	0.00
Port Jackson	DRV	2	Increase	-	9.49	0.77	0.13
Cooks River	BR	1	NA	-	0.27	0.02	0.00
Botany Bay	BAY	3	Decrease	−25.49	134.61	10.97	1.86
Georges River	DRV	3	Variable	-	25.67	2.09	0.35
Port Hacking	DRV	3	Variable	-	12.83	1.05	0.18
Towradgi Creek	CREEK	2	None	-	0.00	0.00	0.00
Allans Creek	BR	1	NA	-	0.76	0.06	0.01
Port Kembla	BAY	2	None	-	0.00	0.00	0.00
Lake Illawarra	LAKE	2	Increase	-	30.24	2.46	0.42
Elliott Lake	CREEK	2	Increase	-	0.07	0.01	0.00
Southern region							
Shellharbour Creek	CREEK	1	NA	-	0.00	0.00	0.00
Minnamurra River	BR	3	Variable	-	29.82	2.35	0.41
Spring Creek	CREEK	2	None	-	0.00	0.00	0.00
Werri Lagoon	CREEK	2	Decrease	−0.01	0.00	0.00	0.00
Crooked River	BR	2	Increase	-	1.74	0.14	0.02
Shoalhaven River	BR	3	Increase	-	212.81	16.75	2.93
Lake Wollumboola	LAKE	2	None	-	0.00	0.00	0.00
Wowly Gully[e]	LAG	1	NA	-	9.37	0.74	0.13
Cararma Creek[e]	LAKE	1	NA	-	108.89	8.57	1.50
Currambene Creek[e]	BR	1	NA	-	26.62	2.10	0.37
Moona Moona Creek[e]	CREEK	1	NA	-	0.00	0.00	0.00
Jervis Bay[e]	BAY	2	NA	-	2.84	0.22	0.04

Estuary	Type[a]	Times mapped	Change[b]	Area lost[c]	Latest area	% of region	% of state
Flat Rock Creek[e]	CREEK	1	NA	-	0.63	0.05	0.01
Captains Beach Lagoon[e]	CREEK	1	NA	-	0.00	0.00	0.00
Jervis Bay (total)	BAY	2	Decrease	−84.66	148.34	11.68	2.05
St Georges Basin	LAKE	2	Increase	-	14.93	1.18	0.21
Swan Lake	LAKE	2	None	-	0.00	0.00	0.00
Berrara Creek	LAG	2	Increase	-	0.51	0.04	0.01
Nerrindilah Creek	CREEK	2	None	-	0.00	0.00	0.00
Lake Conjola	LAKE	2	Increase	-	2.71	0.21	0.04
Narrawallee Inlet	BR	2	Increase	-	17.55	1.38	0.24
Mollymook Creek	CREEK	2	Increase	-	0.08	0.01	0.00
Ulladulla	CREEK	2	Increase	-	0.14	0.01	0.00
Burrill Lake	LAKE	2	Increase	-	23.68	1.86	0.33
Tounouree Lake	LAG	2	Increase	-	3.95	0.31	0.05
Termeil Lake	LAG	2	None	-	0.00	0.00	0.00
Meroo Lake	LAG	2	None	-	0.00	0.00	0.00
Willinga Lake	LAG	2	None	-	0.00	0.00	0.00
Kioloa Lagoon	CREEK	2	Decrease	−0.48	0.12	0.01	0.00
Durras Lake	LAKE	2	Increase	-	17.06	1.34	0.24
Cullendulla Creek	BR	3	Variable	-	10.57	0.83	0.15
Clyde River	BR	3	Variable	-	92.05	7.25	1.27
Maloneys Creek	CREEK	1	NA	-	0.00	0.00	0.00
Batemans Bay	BAY	3	None	-	0.00	0.00	0.00
Tomaga River	BR	3	Increase	-	47.13	3.71	0.65
Candlagan Creek	BR	3	Variable	-	6.90	0.54	0.10
Bengello Creek	CREEK	2	None	-	0.00	0.00	0.00
Moruya River	BR	3	Increase	-	79.74	6.28	1.10
Congo Creek	CREEK	2	Increase	-	1.12	0.09	0.02
Meringo Creek	LAG	2	Increase	-	1.16	0.09	0.02
Kellys Lake	LAG	1	NA	-	0.00	0.00	0.00
Coila Lake	LAKE	2	Increase	-	34.27	2.70	0.47
Tuross Lake	BR	3	Variable	-	78.73	6.20	1.09
Lake Brunderee	LAG	2	Decrease	−22.91	1.69	0.13	0.02
Lake Brou	LAG	2	Decrease	−16.18	8.82	0.69	0.12
Lake Dalmeny	LAG	2	Decrease	−3.35	2.15	0.17	0.03
Kianga Lake	LAG	2	Decrease	−3.30	0.00	0.00	0.00
Wagonga Inlet	LAKE	2	Decrease	−3.27	2.33	0.18	0.03
Little Lake (Narooma)	LAG	1	NA	-	0.00	0.00	0.00
Bullengella Lake	LAKE	1	NA	-	0.00	0.00	0.00
Nangudga Lake	LAG	2	Increase	-	14.64	1.15	0.20
Nargal Lake	LAG	1	NA	-	0.00	0.00	0.00
Corunna Lake	LAG	2	Increase	-	4.92	0.39	0.07
Tilba Tilba Lake	LAG	2	Increase	-	15.64	1.23	0.22
Little Lake (Wallaga)	LAG	2	Decrease	−3.04	1.66	0.13	0.02
Wallaga Lake	LAKE	2	Decrease	−13.34	16.16	1.27	0.22

Estuary	Type[a]	Times mapped	Change[b]	Area lost[c]	Latest area	% of region	% of state
Bermagui River	BR	2	Increase	-	16.77	1.32	0.23
Barragoot Lake	LAG	2	Increase	-	7.90	0.62	0.11
Cuttagee Lake	LAG	2	Increase	-	11.25	0.89	0.16
Murrah Lake	BR	2	Increase	-	16.11	1.27	0.22
Bunga Lagoon	LAG	2	Increase	-	2.99	0.24	0.04
Wapengo Lake	LAKE	2	Increase	-	50.59	3.98	0.70
Middle Lake	LAG	2	Increase	-	5.22	0.41	0.07
Nelson Lake	BR	2	Increase	-	15.55	1.22	0.21
Bega River	BR	2	Increase	-	53.31	4.20	0.74
Wallagoot Lake	LAKE	2	Increase	-	11.76	0.93	0.16
Bournda Lagoon	CREEK	2	Increase	-	0.46	0.04	0.01
Back Lagoon	LAG	2	Increase	-	2.21	0.17	0.03
Merimbula Lake	LAKE	2	Decrease	–3.75[d]	59.15	4.66	0.82
Pambula Lake	BR	2	Increase	-	36.56	2.88	0.50
Curalo lagoon	LAG	2	Decrease	–2.64	8.96	0.71	0.12
Shadrachs Creek	CREEK	1	NA	-	0.00	0.00	0.00
Twofold Bay	BAY	2	Decrease	–0.80	0.00	0.00	0.00
Nullica River	LAG	2	Increase	-	1.82	0.14	0.03
Boydtown Creek	CREEK	1	NA	-	0.51	0.04	0.01
Fisheries Creek	LAG	2	Increase	-	3.46	0.27	0.05
Towamba River	BR	2	Increase	-	12.52	0.99	0.17
Wonboyn River	BR	2	Increase	-	51.76	4.07	0.71
Merrica River	CREEK	2	None	-	0.00	0.00	0.00
Table Creek	CREEK	1	NA	-	0.09	0.01	0.00
Nadgee River	CREEK	2	Increase	-	8.21	0.65	0.11
Nadgee Lake	LAKE	2	Increase	-	0.10	0.01	0.00

a BR = barrier river; DRV = drowned river valley; LAG = lagoon.
b Consistent declines in area are classified as a decrease; fluctuating areas over time are classified as variable. No change indicates area estimate was consistently zero. If estuary has been mapped only once, change is not applicable (NA). This occurs primarily for the creeks within Jervis Bay, which were grouped for the 1985 estimate. Given the difficulty in mapping saltmarsh, estuaries that have been mapped only twice are considered to be the least reliable estimates of change.
c Area loss estimates calculated as latest mapped area minus earliest (1985) mapped estimate.
d Comparisons between areas that have been mapped only two times and show small losses should be treated with caution, due to errors resulting from differences in mapping methods (Meehan and Williams 2005).
e Included in Jervis Bay total.

Associated biota

Saltmarshes are an important ecological community that provide key habitat for many fish species and a range of other fauna, including many bird species (Harvey et al. 2010; 2014). When saltmarsh and mangroves are inundated during spring high tides, they provide habitat and shelter for fish, especially juveniles and smaller fish species, which move between seagrass, mangroves and saltmarsh (Saintilan et al. 2007). It provides a temporary refuge or nursery for the smaller fish, because larger fish predators often avoid entering the shallow water and dense vegetation. Higher salinity areas near the lower end of the estuary have been shown to be most important for Eastern king prawn, and marsh systems in the lower estuary need good connectivity with oceanic water in order to be utilised as habitat by this species. Saltmarsh has also been shown to be important for juvenile School Prawn, with their numbers increasing as the distance along the estuary increases (Taylor et al. 2017). Further, Taylor et al. (2017) highlighted that a substantial number (approximately 90%) of emigrating prawns are associated with putative nursery sites, such as shallow embayments and mangrove-lined creeks.

Studies have recorded more than 40 species of fish inhabiting tidal saltmarsh areas. These include commercially and recreationally important species, such as yellowfin bream, sand whiting, mullet, garfish, eels, and crabs. Many smaller fish, such as perchlets, glassfish, hardyheads, blue-eyes, and gobies, are also commonly found in saltmarsh.

Saltmarshes also provide shelter for delicate, developing crab larvae as well as for prawns. Juvenile and adult crabs directly consume the fallen leaves of the saltmarsh and mangrove plants, with crab droppings providing a vital source of nutrients for the receiving waterways and their dependent aquatic life. Crabs and prawns also provide food for birds, mammals, insects, and invertebrates, and contribute to the base of estuarine food chains through decomposition of vegetation. Saltmarshes bind together the carbon-rich sediments, keeping the estuary clear and clean. The amount of carbon sequestered by marine vegetation communities (mangrove, saltmarsh, and seagrass) far outweighs that locked up by an equivalent area of any terrestrial ecosystems, including woodlands and rainforests (Lawrence et al. 2012).

5.7.2 MANGROVES

Mangroves are located mostly on soft-sediment areas within sheltered parts of estuaries, forming an important component of estuarine wetlands that occupy the fringe of intertidal shallows between the land and the sea (Figure 9). They are characterised by the presence of water, either permanently or periodically. In most places, mangroves occur in the intertidal area seaward of the saltmarsh, but variations in local topography often results in a highly patchy mosaic of the two habitats within a small area.

Six mangrove species are found in NSW. The two most common are the grey mangrove (*Avicennia marina*), which is found along the entire coast, and the river mangrove (*Aegiceras corniculatum*), which occurs from the Tweed River in the north to Merimbula on the south coast. The other four species are confined to the north coast. Their southernmost limits are the Clarence River (*Acrosticum speciosum*), Moonee Creek (*Bruguiera gymnoorhiza*), South West Rocks (*Rhizophora stylosa*), and the Manning River (*Excoecaria agallocha*).

The mangrove habitat provides important ecosystem functions. The plant's air-breathing roots (pneumatophores) help stabilise the sediments in which they grow. They supply organic matter to the soil, and act as a buffer between the sea and land, reduce erosion, and maintain water quality. Mangroves form key habitats for many terrestrial, estuarine and marine animal species, and are therefore high in biodiversity. Mangrove forests protect coastlines under everyday circumstances by reducing wave energy. Further, the value of these ecosystems in reducing storm surge height and flooding during extreme events is becoming more widely recognised (Narayan et al. 2016).

Mangrove distribution

The distribution of mangroves has been mapped at least twice in most NSW estuaries. Some have been mapped three or four times (from 1985–2013), with mapping not discriminating between species. Here, we only discuss changes over this recent period, although we acknowledge the large losses of this habitat in the early parts of the 20th century.

Mangroves occur in 60% of mapped estuaries in NSW, with their absence usually associated with intermittently open lagoons, lakes, or creeks (Table 7). The area of mangroves in NSW estuaries tends to decrease from north to south. The distribution of mangrove habitats throughout NSW are represented in the seabed habitats layers on the Fisheries NSW Spatial Data Portal:

https://www.dpi.nsw.gov.au/about-us/science-and-research/spatial-data-portal

Since 1985, mangroves have been found in all but five estuaries in the **northern region** of NSW. This region contains 55% of the mapped mangrove forest in NSW, despite containing only 30% of the state's estuaries. As noted above, more mangrove species are found in the northern region than elsewhere in the state. The most extensive mangrove forests in the northern region are found in Port Stephens (30% of the region, 17% of the state), followed by Clarence River (12% of region, 7% of state), Richmond River (9% of region, 5% of state), and the Macleay River (8% of region, 5% of state). Since 1985, declines in mangrove area have been documented in just two estuaries in the northern region: Port Stephens (197 ha lost) and Lake Cathie (0.1 ha lost).

Differences in mapping methods between 1985 and recently are likely to lead to an overestimation of cover in the 1985 data (Meehan and Williams 2005), so small declines from the 1985 data in the following discussions should be treated with caution. However, there have been significant increases in mangroves since 1985 in many estuaries, most notably the Clarence River (340 ha gained), Hastings River (176 ha gained), Richmond River (108 ha gained), and Karuah River (108 ha gained). The spread of mangroves (especially *Avicennia marina*) may be related to human activities, and is often associated with declines in saltmarsh (Mitchell and Adam 1989, Saintilan and Williams 1999). But, of the four northern region estuaries with the largest increases in mangroves, declines in saltmarshes have been documented in only one (Karuah River).

Mangrove habitat in the **central region** is present within 72% of estuaries, again tending to be absent from small intermittently open lagoons or creeks. The largest areas of mangroves in the central region occur in the Hunter River (47% of the region, 15% of the state) followed by Hawkesbury River (24% of the region, 8% of the state) and Botany Bay (11% of the region, 3% of the state). Declines in mangroves have been documented in Port Hacking (3 ha lost between 1985 and 2008) and Lake Illawarra (0.004 ha lost between 1985 and 2005) only. Increases in mangrove area have been documented for Brisbane Water (44 ha between 1985 and 2005), Port Jackson (37 ha between 1985 and 2002) and Botany Bay (35 ha between 1985 and 2008). Of these estuaries, there were declines in saltmarsh over this same period, which have been attributed to increases in mangrove extent (Mitchell and Adam 1989).

The majority (62%) of the mapped estuaries in the **southern region** do not contain mangroves, with these again tending to be the intermittently open lagoons and creeks (Table 7). The estuaries with by far the most area of mangroves in this region are Shoalhaven River (27% of region, 3% of the state), Clyde River (20% of region, 2.5% of the state), and Jervis Bay (12% of region, 1.5% of the state). Declines in mangrove area have been documented in four southern region estuaries, with the greatest decline being in the Towamba River (7 ha lost between 1985 and 2004). Increases in areal extent of mangroves have generally been small, with the exception of the Clyde River, where there was an apparent increase of 110 ha between 1985 and 2005. Although there was an apparent decline in saltmarsh in the Clyde between 1985 and 2005, by 2012, the area of saltmarsh was estimated to be similar to the 1985 area.

Figure 9. Typical mangrove habitat in New South Wales.

Table 7. Areas of mangrove (hectares) in New South Wales estuaries mapped between 1985 and 2013 (mapped two to four times, depending on estuary).

Estuary	Type [a]	Times mapped	Change [b]	Area change	Latest area	% of region	% of state
Northern region							
Tweed River	BR	2	Increase	89.14	398.24	5.61	3.09
Cudgen Creek	BR	2	Increase	4.49	13.89	0.20	0.11
Cudgera Creek	BR	2	Increase	0.97	14.77	0.21	0.11
Mooball Creek	BR	2	Increase	6.14	11.44	0.16	0.09
Brunswick River	BR	3	Increase	46.49	128.09	1.81	0.99
Belongil Creek	CREEK	2	Increase	1.97	6.97	0.10	0.05
Tallow Creek	LAG	2	None	-	0.00	0.00	0.00
Broken Head Creek	LAG	2	None	-	0.00	0.00	0.00
Richmond River	BR	2	Increase	107.65	602.55	8.49	4.68
Evans River	BR	2	Increase	7.87	40.87	0.58	0.32
Jerusalem Creek	LAG	2	None	-	0.00	0.00	0.00
Clarence River	BR	3	Increase	340.16	860.96	12.14	6.69
Cakora Lagoon	LAG	1	NA	-	0.46	0.01	0.00
Sandon River	BR	2	Increase	4.13	57.43	0.81	0.45
Wooli Wooli River	BR	2	Increase	36.71	86.01	1.21	0.67
Station Creek	LAG	2	Increase	0.04	0.04	0.00	0.00
Corindi River	BR	3	Increase	22.42	41.32	0.58	0.32
Arrawarra Creek	LAG	3	Increase	1.59	1.60	0.02	0.01
Darkum Creek	CREEK	3	Variable	-	0.66	0.01	0.01
Woolgoolga Lake	LAG	3	Increase	0.61	0.81	0.01	0.01
Hearnes Lake	LAG	3	Variable	-	0.76	0.01	0.01
Moonee Creek	BR	3	Increase	7.03	10.63	0.15	0.08
Coffs Creek	BR	3	Increase	3.37	20.07	0.28	0.16
Boambee Creek	BR	3	Increase	28.26	34.86	0.49	0.27
Bonville Creek	BR	3	Increase	9.09	14.39	0.20	0.11
Bellinger River	BR	3	Increase	50.86	135.56	1.91	1.05
Dalhousie Creek	LAG	3	Variable	-	0.86	0.01	0.01
Oyster Creek	LAG	2	Increase	0.02	0.02	0.00	0.00
Deep Creek	LAG	2	Increase	2.71	3.51	0.05	0.03
Nambucca River	BR	2	Increase	67.56	145.46	2.05	1.13
Macleay River	BR	3	Increase	75.85	595.95	8.40	4.63
SW Rocks Creek	LAKE	3	Increase	26.31	79.11	1.12	0.61
Saltwater Creek	LAG	2	None	-	0.00	0.00	0.00
Korogoro Creek	BR	2	Increase	4.47	5.77	0.08	0.04
Killick Creek	LAG	2	Increase	4.51	4.52	0.06	0.04
Hastings River	BR	3	Increase	176.42	384.22	5.42	2.98
Lake Cathie	LAG	3	Decrease	–0.10	0.00	0.00	0.00
Camden Haven River	LAKE	3	Increase	58.70	146.00	2.06	1.13
Manning River	BR	2	Increase	32.32	390.52	5.51	3.03
Khappinghat Creek	LAG	2	Increase	0.01	0.01	0.00	0.00
Black Head Lagoon	CREEK	1	NA	-	0.03	0.00	0.00
Wallis Lake	LAKE	2	Increase	62.07	140.67	1.98	1.09

Estuary	Type [a]	Times mapped	Change [b]	Area change	Latest area	% of region	% of state
Smiths Lake	LAKE	2	None	-	0.00	0.00	0.00
Lower Myall River	LAKE	2	Increase	28.06	130.16	1.83	1.01
Karuah River	BR	2	Increase	107.50	455.40	6.42	3.54
Port Stephens	DRV	2	Decrease	–197.42	2128.58	30.01	16.53
Central region							
Hunter River	BR	4	Variable	-	1921.74	46.90	14.92
Lake Macquarie	LAKE	4	Variable	-	126.63	3.09	0.98
Tuggerah Lake	LAKE	2	Increase	0.08	0.08	0.00	0.00
Wamberal Lagoon	LAKE	2	None	-	0.00	0.00	0.00
Terrigal Lagoon	LAG	2	Increase	0.12	0.13	0.00	0.00
Avoca Lake	LAG	2	None	-	0.00	0.00	0.00
Cockrone Lake	LAG	2	None	-	0.00	0.00	0.00
Brisbane Water	LAKE	3	Increase	44.30	207.80	5.07	1.61
Broken Bay	BR	1	NA	-	0.00	0.00	0.00
Hawkesbury River	DRV	3	Variable	-	983.04	23.99	7.63
Pittwater	DRV	3	Variable	-	17.48	0.43	0.14
Narrabeen Lagoon	LAKE	4	Increase	0.01	0.01	0.00	0.00
Dee Why Lagoon	CREEK	4	None	-	0.00	0.00	0.00
Curl Curl Lagoon	LAG	4	None	-	0.00	0.00	0.00
Manly Lagoon	CREEK	4	Variable	-	0.02	0.00	0.00
Port Jackson	DRV	2	Increase	37.20	184.70	4.51	1.43
Cooks River	BR	1	NA	-	10.82	0.26	0.08
Botany Bay	BAY	3	Increase	35.32	434.92	10.61	3.38
Georges River	DRV	3	Variable	-	177.58	4.33	1.38
Port Hacking	DRV	3	Decrease	–2.88	29.92	0.73	0.23
Towradgi Creek	CREEK	2	Increase	0.03	0.03	0.00	0.00
Allans Creek	BR	1	NA	-	2.05	0.05	0.02
Port Kembla	BAY	2	None	-	0.00	0.00	0.00
Lake Illawarra	LAKE	2	Decrease	–0.004	0.01	0.00	0.00
Elliott Lake	CREEK	2	Increase	0.51	0.51	0.01	0.00
Southern region							
Shellharbour Creek	CREEK	1	NA	-	0.00	0.00	0.00
Minnamurra River	BR	3	Increase	46.16	94.56	5.60	0.73
Spring Creek	CREEK	2	None	-	0.00	0.00	0.00
Werri Lagoon	CREEK	2	Increase	0.001	0.00	0.00	0.00
Crooked River	BR	2	Increase	0.81	0.81	0.05	0.01
Shoalhaven River	BR	3	Increase	100.99	448.59	26.58	3.48
Lake Wollumboola	LAKE	2	None	-	0.00	0.00	0.00
Wowly Gully [c]	LAG	1	NA	-	0.00	0.00	0.00
Cararma Creek [c]	LAKE	1	NA	-	99.35	5.89	0.77
Currambene Creek [c]	BR	1	NA	-	94.26	5.59	0.73
Moona Moona Creek [c]	CREEK	1	NA	-	5.46	0.32	0.04
Jervis Bay [c]	BAY	2	NA	-	6.22	0.37	0.05
Flat Rock Creek [c]	CREEK	1	NA	-	0.00	0.00	0.00

Estuary	Type [a]	Times mapped	Change [b]	Area change	Latest area	% of region	% of state
Captains Beach Lagoon [c]	CREEK	1	NA	-	0.02	0.00	0.00
Jervis Bay (total)	BAY	2	Increase	80.32	205.32	12.16	1.59
St Georges Basin	LAKE	2	Increase	2.38	27.58	1.63	0.21
Swan Lake	LAKE	2	None	-	0.00	0.00	0.00
Berrara Creek	LAG	2	None	-	0.00	0.00	0.00
Nerrindilah Creek	CREEK	2	None	-	0.00	0.00	0.00
Lake Conjola	LAKE	2	Increase	0.06	0.07	0.00	0.00
Narrawallee Inlet	BR	2	Increase	3.82	41.62	2.47	0.32
Mollymook Creek	CREEK	2	None	-	0.00	0.00	0.00
Ulladulla	CREEK	2	Increase	0.10	0.11	0.01	0.00
Burrill Lake	LAKE	2	Decrease	–0.01	0.00	0.00	0.00
Touburee Lake	LAG	2	None	-	0.00	0.00	0.00
Termeil Lake	LAG	2	None	-	0.00	0.00	0.00
Meroo Lake	LAG	2	None	-	0.00	0.00	0.00
Willinga Lake	LAG	2	None	-	0.00	0.00	0.00
Kioloa Lagoon	CREEK	2	None	-	0.00	0.00	0.00
Durras Lake	LAKE	2	None	-	0.00	0.00	0.00
Cullendulla Creek	BR	3	Variable	-	106.50	6.31	0.83
Clyde River	BR	3	Increase	109.83	341.63	20.24	2.65
Maloneys Creek	CREEK	1	NA	-	0.00	0.00	0.00
Batemans Bay	BAY	3	Variable	-	0.52	0.03	0.00
Tomaga River	BR	3	Increase	23.36	44.36	2.63	0.34
Candlagan Creek	BR	3	Increase	3.54	5.64	0.33	0.04
Bengello Creek	CREEK	2	None	-	0.00	0.00	0.00
Moruya River	BR	3	Increase	21.40	59.40	3.52	0.46
Congo Creek	CREEK	2	None	-	0.00	0.00	0.00
Meringo Creek	LAG	2	None	-	0.00	0.00	0.00
Kellys Lake	LAG	1	NA	-	0.00	0.00	0.00
Coila Lake	LAKE	2	None	-	0.00	0.00	0.00
Tuross Lake	BR	3	Variable	-	41.02	2.43	0.32
Lake Brunderee	LAG	2	None	-	0.00	0.00	0.00
Lake Brou	LAG	2	None	-	0.00	0.00	0.00
Lake Dalmeny	LAG	2	Increase	1.34	1.34	0.08	0.01
Kianga Lake	LAG	2	None	-	0.00	0.00	0.00
Wagonga Inlet	LAKE	2	Decrease	–5.19	19.71	1.17	0.15
Little Lake (Narooma)	LAG	1	NA	-	0.00	0.00	0.00
Bullengella Lake	LAKE	1	NA	-	0.00	0.00	0.00
Nangudga Lake	LAG	2	None	-	0.00	0.00	0.00
Nargal Lake	LAG	1	NA	-	0.00	0.00	0.00
Corunna Lake	LAG	2	None	-	0.00	0.00	0.00
Tilba Tilba Lake	LAG	2	None	-	0.00	0.00	0.00
Little Lake (Wallaga)	LAG	2	None	-	0.00	0.00	0.00
Wallaga Lake	LAKE	2	None	-	0.00	0.00	0.00
Bermagui River	BR	2	Increase	3.91	47.31	2.80	0.37

Estuary	Type [a]	Times mapped	Change [b]	Area change	Latest area	% of region	% of state
Barragoot Lake	LAG	2	None	-	0.00	0.00	0.00
Cuttagee Lake	LAG	2	None	-	0.00	0.00	0.00
Murrah Lake	BR	2	Increase	1.70	1.70	0.10	0.01
Bunga Lagoon	LAG	2	None	-	0.00	0.00	0.00
Wapengo Lake	LAKE	2	Increase	14.61	55.51	3.29	0.43
Middle Lake	LAG	2	None	-	0.00	0.00	0.00
Nelson Lake	BR	2	Increase	21.96	49.06	2.91	0.38
Bega River	BR	2	None	-	0.00	0.00	0.00
Wallagoot Lake	LAKE	2	None	-	0.00	0.00	0.00
Bournda Lagoon	CREEK	2	None	-	0.00	0.00	0.00
Back Lagoon	LAG	2	None	-	0.00	0.00	0.00
Merimbula Lake	LAKE	2	Decrease	–2.78	34.92	2.07	0.27
Pambula Lake	BR	2	Increase	13.12	58.02	3.44	0.45
Curalo lagoon	LAG	2	None	-	0.00	0.00	0.00
Shadrachs Creek	CREEK	1	NA	-	0.00	0.00	0.00
Twofold Bay	BAY	2	None	-	0.00	0.00	0.00
Nullica River	LAG	2	Increase	0.75	0.76	0.05	0.01
Boydtown Creek	CREEK	1	NA	-	0.00	0.00	0.00
Fisheries Creek	LAG	2	None	-	0.00	0.00	0.00
Towamba River	BR	2	Decrease	–7.31	1.69	0.10	0.01
Wonboyn River	BR	2	Increase	0.01	0.02	0.00	0.00
Merrica River	CREEK	2	None	-	0.00	0.00	0.00
Table Creek	CREEK	1	NA	-	0.00	0.00	0.00
Nadgee River	CREEK	2	None	-	0.00	0.00	0.00
Nadgee Lake	LAKE	2	None	-	0.00	0.00	0.00

a BR = barrier river; DRV = drowned river valley; LAG = lagoon.
b Consistent declines in area are classified as a decrease; fluctuating areas over time are classified as variable. No change indicates area estimate was consistently zero. If estuary has been mapped only once, change is not applicable (NA). This occurs primarily for the creeks within Jervis Bay, which were grouped for the 1985 estimate. Given the difficulty in mapping saltmarsh, estuaries that have been mapped only twice are considered to be the least reliable estimates of change. Changes in area are listed for estuaries where there have been consistent declines or increases over time. Increases in mangroves have been identified given that they can be caused by human disturbances.
c Included in Jervis Bay total.

Associated biota

Mangroves provide important habitat for many fish, birds, and invertebrates (Bell et al. 1984, Hutchings and Saenger 1987, Chapman and Underwood 1995). The most visible species are the larger snails and crabs, including the mud periwinkle (*Littoraria luteola*), mudwhelk (*Bembicium auratum*), and the semaphore crab (*Heloecius* sp.). Mangrove sediments also host a diverse assemblage of invertebrate infauna, including polychaete worms and burrowing animals.

Similar to seagrasses, mangroves are nursery areas for many commercially important species of fish, crabs and prawns, providing shelter among their submerged roots and trunks (Clynick and Chapman 2002). They are also important as habitat for adult fish, such as some species of whiting. These areas also provide feeding, nesting and roosting areas for birds, insects, mammals, and reptiles.

Recent studies in the eastern Pacific indicate that adult hawksbill turtles (*Eretmochelys imbricata*) may use mangrove areas in estuarine habitats. Some individuals use inshore mangrove estuaries, while others, to a lesser extent, use open-coast rock and coral reefs. These findings suggest that *E. imbrica* may also use these habitats in northern NSW waters.

5.7.3 SEAGRASSES

Seagrasses are found mainly in shallow waters of protected estuaries and bays, where they form a prominent feature of shallow subtidal and intertidal areas of NSW's subtropical and temperate estuaries. They provide important ecosystem functions, including contributing to coastal productivity through high levels of primary production. They also stabilise sediments, and therefore affect water clarity. In addition, seagrass beds act as carbon stores, regulate nutrients within estuaries and are important habitats for algae, invertebrates and fishes. Vegetated soft sediments (seagrass and charophytes) are an important habitat for juvenile stages of many commercial and recreational species, with different seagrass species often having distinct fish assemblages.

The species of seagrass in NSW are:

- *Posidonia australis* (strapweed)
    - mainly in marine-dominated areas, where sediments are stable
    - extends south from Wallis Lake to the NSW/Victorian border (Figure 10)
- *Zostera muelleri ssp. capricorni* (hereafter *Z. capricorni*)
    - occurs extensively in NSW estuaries (Jacobs et al. 2006)
- *Zostera nigricaulis* – less common, often scattered amongst *Z. capricorni*, found from Eden to Port Stephens
- *Halophila ovalis*
    - occurs as sparse beds in NSW estuaries
- *Halophila decipiens*
    - occurs along the NSW coast, but common near Sydney
- *Halophila spinulosa*
    - only in far north coast estuaries (Tweed region)
- *Halodule uninervis and Halodule tridentata*
    - uncommon
    - known only in Port Stephens, Wallis Lake and Broughton Island
- *Ruppia maritima, R. megacarpa, R. polycarpa*
    - typically found in lagoons and lakes.

Mapping by NSW DPI discriminates *P. australis* and *Z. capricorni* wherever possible. However, in many cases, these species are found mixed either with each other or with other species of seagrass. The distribution of seagrasses has been mapped at least twice in most NSW estuaries, with some being mapped three or four times (from 1985–2013). Here, we discuss only changes over this recent period, although we acknowledge the large losses of this habitat in the early parts of the 20th century (Larkum and West 1990, Williams and Meehan 2004) (see Box 1 for further information). Historical mapping and change in distribution of estuarine macrophytes including seagrass has been from the 1940's in northern NSW estuaries (Russell 2005) showing an overall loss in seagrass area to 2000.

Figure 10. *Posidonia* seagrass habitat.

Box 1 Historical losses of marine vegetation

The majority of information about trends in the area of marine vegetation has come from analysis of aerial photos since 1985. However, most of the major stressors that resulted from significant changes in land use and poor pollution practices occurred in the decades before this time.

Larkum and West (1990) analysed aerial photographs of Botany Bay dating back to 1930. They showed that *Posidonia australis* had undergone a steady decline in distribution in Botany Bay between the earliest photos and the 1980s. Between 1942 and 1984, 58% (257 ha) of *Posidonia* was lost from the bay's southern foreshores. Other beds of *Posidonia,* once continuous, consisted of only fragmented patches by 1984. The losses were attributed to industrial and residential development in the catchment, including dredging of the bay's entrance. Over the same period (1930–1987), *Zostera capricorni* showed cyclical fluctuations in area throughout the bay, and had colonised many sites that were previously vegetated with *Posidonia*.

Williams and Meehan (2004) used a similar approach to assess trends in areas of saltmarsh, mangrove and seagrass in Port Hacking. They showed a minimum area of seagrass in 1977, which represented a 60% loss. Similar trends were seen for *Posidonia*, which experienced a 25% loss in area prior to 1977, but a slight increase since then. Concurrently, 30% of saltmarsh was lost since the 1930s, at a rate that has not abated. The area of mangrove has doubled over the same period.

Seagrass distribution

Seagrasses are not equally distributed among NSW estuaries. All tidally dominated estuaries (drowned river valleys and bays) and the majority of wave-dominated estuaries (rivers and lakes) have seagrass, but only 30–50% of intermittent estuaries have seagrass (Table 8). Four of the main wave-dominated estuaries account for more than 50% of the total area of seagrass in NSW: Wallis Lake (30%), Clarence River (15%), Lake Macquarie (10%), and Tuggerah Lakes (7%). Jervis Bay, which is a tide-dominated, open ocean embayment, also has a significantly large area (6%).

Most NSW estuaries have some cover of seagrass, apart from intermittently closed and open lakes and lagoons. These are common on the NSW coast, but generally contain little or no seagrass.

Table 8. Proportions of different estuary types where seagrass (*Zostera, Posidonia*) has been observed in NSW Department of Primary Industries and NSW Office of Environment & Heritage sampling.

Estuary type	Catchment disturbance level[a]			
	High	Medium	Low	Overall
Drowned valley	1.00	1.00	1.00	1.00
Bay	1.00	1.00	1.00	1.00
River	0.82	0.94	1.00	0.91
Lake	1.00	0.91	0.75	0.86
Lagoon	0.31	0.50	0.62	0.47
Creek	0.62	0.23	0.17	0.30

a Explanation needed here for the values of disturbance level

Patterns of seagrass distribution also differ across NSW, with *Z. capricorni* abundance tending to decrease from north to south, and *P. australis* abundance tending to increase from north to south. The distribution of seagrass habitats throughout NSW are represented in the seabed habitats layers on the Fisheries NSW Spatial Data Portal:

https://www.dpi.nsw.gov.au/about-us/science-and-research/spatial-data-portal

Since 1985, seagrasses (all species combined) have been recorded in 80% of mapped estuaries in the **northern region**. Estuaries that have not contained seagrass have been small intermittently open lagoons or creeks. Seagrass was not found in an additional three estuaries during the most recent time of mapping (Table 9).

The greatest areas of seagrass in the estuaries of the northern region are found in Wallis Lake (48 ha, 21% of state total), Port Stephens (23 ha, 10% of state total), and Camden Haven (12 ha, 5% of state total). All three estuaries contain mixtures of seagrass species, but *P. australis* is present in just two estuaries in the northern region: Port Stephens and Wallis Lake (Table 10). Port Stephens contains the second-largest area of *P. australis* of any estuary in the state (18% of the state's total). Wallis Lake and Port Stephens (including Broughton Island) also contain species of *Halodule*. These species have not been documented in many NSW estuaries, although they may be present in many northern region estuaries. Broughton Island also has areas of *P. australis* in several sheltered embayments, but these have not been mapped.

Differences in mapping methods between 1985 and recently are likely to lead to an overestimation of cover in the 1985 data (Meehan and Williams 2005), so small declines from the 1985 data in the following discussions should be treated with caution. There have been consistent declines since 1985 in the total area of seagrass in 11 of the 47 mapped estuaries of the northern region. These declines have been documented over three mapping times for most estuaries, and so are likely to represent real changes. However, in four estuaries (Killick Creek, Khappinghat Creek, Lower Myall River, and Karuah River), the declines have occurred over just two times of mapping. Given that *Z. capricorni* is extremely temporally variable, changes in total seagrass area over just two times of mapping should be interpreted with caution. There has also been an apparent loss of *P. australis* in Wallis Lake (87 ha from 1985 to 2002), but work currently underway suggests that this is a large overestimate.

Seagrass is present in 84% of mapped estuaries in the **central region**, and some *Z. capricorni* is present in Terrigal Harbour (not defined as an estuary). The largest areas of seagrass (all species combined) occur in Tuggerah Lake (32% of the region, 11% of the state), Lake Macquarie (22% of the region, 8% of the state), Lake Illawarra (15% of the region, 5% of the state), Brisbane Water (10% of the region, 4% of the state) and Botany Bay (9.5% of the region, 3% of the state).

The seagrass in Botany Bay is dominated by *P. australis*, with this estuary containing the state's third largest amount of this endangered seagrass (14% of the state's total). Losses of seagrass have been documented in eight central region estuaries, most of which were intermittently open lagoons or creeks (Table 9). Two of these are in the Hunter River, where small beds of *Ruppia* spp. were lost on Kooragang Island since 1985. This could be due to increasing tidal flow in this area by removing floodgates, or might simply reflect the ephemeral nature of *Ruppia* spp. Losses of total seagrass were also documented for Port Jackson (77 ha from 1985 to 2002), but this was driven primarily by losses of the temporally variable *Z. capricorni*. The abundance of *P. australis* increased in Port Jackson over the same period (Table 10).

Seagrass occurs in 85% of estuaries in the **southern region**, with *P. australis* present in only eight of these (i.e. 32% of the region's estuaries). The largest areas of seagrass occur in Jervis Bay (primarily *P. australis*). The Shoalhaven River (primarily *Z. capricorni,* no *P. australis* present) and St. Georges Basin (mixture of *Z. capricorni* and *P. australis*). Jervis Bay contains the largest area of *P. australis* of any estuary in the state (~23% of the state's total). There are small beds of *P. australis* along the open coast in the Batemans Bay region (including Tollgate Island and Broulee Bay) and in Bittangabee Bay in Ben Boyd National Park.

Losses of seagrass (all species combined) have been documented for many estuaries in the southern region since 1985, but again most losses occurred in intermittently open lagoons or creeks (Table 9). The main exceptions are losses in the permanently open St Georges Basin, Wagonga Inlet, Bermagui River, Merimbula Lake and Pambula Lake. In these five permanently open estuaries, losses of seagrass have been due to *Z. capricorni* in all except Wagonga Inlet where there have been losses of both *Z. capricorni* and *P. australis* (29 ha of *P. australis* lost between 1985 and 2002). In the other four estuaries, the area of *P. australis* has increased since 1985. The other noteworthy losses of *P. australis* in the southern region were in Jervis Bay (175 ha between 1985 and 2004) and Twofold Bay (2 ha between 1985 and 2004). This apparent large loss of *P. australis* in Jervis Bay seems to be an overestimate, in part related to differences in mapping methods between to the two times.

Table 9. Areas of seagrass (hectares) in New South Wales estuaries mapped between 1985 and 2013 (mapped 2–4 times, depending on estuary).

Estuary	Type[a]	Times mapped	Change[b]	Area lost[c]	Latest area	% of region	% of state
Northern region							
Tweed River	BR	2	Increase	-	80.63	1.22	0.52
Cudgen Creek	BR	2	Increase	-	0.89	0.01	0.01
Cudgera Creek	BR	2	Increase	-	3.38	0.05	0.02
Mooball Creek	BR	2	Increase	-	2.42	0.04	0.02
Brunswick River	BR	3	Variable	-	2.61	0.04	0.02
Belongil Creek	CREEK	2	None	-	0.00	0.00	0.00
Tallow Creek	LAG	2	None	-	0.00	0.00	0.00
Broken Head Creek	LAG	2	None	-	0.00	0.00	0.00
Richmond River	BR	2	Increase	-	32.01	0.48	0.21
Evans River	BR	2	Increase	-	0.63	0.01	0.00
Jerusalem Creek	LAG	2	None	-	0.00	0.00	0.00
Clarence River	BR	3	Variable	-	115.87	1.75	0.75
Cakora Lagoon	LAG	1	NA	-	0.00	0.00	0.00
Sandon River	BR	2	Increase	-	8.59	0.13	0.06
Wooli Wooli River	BR	2	Increase	-	9.42	0.14	0.06
Station Creek	LAG	2	None	-	0.00	0.00	0.00
Corindi River	BR	3	Decrease	–2.75	0.55	0.01	0.00
Arrawarra Creek	LAG	3	Decrease	–0.30	0.00	0.00	0.00
Darkum Creek	CREEK	3	Variable	-	0.00	0.00	0.00
Woolgoolga Lake	LAG	3	None	-	0.00	0.00	0.00
Hearnes Lake	LAG	3	None	-	0.00	0.00	0.00
Moonee Creek	BR	3	Variable	-	1.87	0.03	0.01
Coffs Creek	BR	3	Decrease	–1.61	0.19	0.00	0.00
Boambee Creek	BR	3	Variable	-	4.21	0.06	0.03
Bonville Creek	BR	3	Variable	-	0.99	0.01	0.01
Bellinger River	BR	3	Variable	-	3.99	0.06	0.03
Dalhousie Creek	LAG	3	Decrease	–1.19	0.01	0.00	0.00
Oyster Creek	LAG	2	None	-	0.00	0.00	0.00
Deep Creek	LAG	2	Increase	-	0.96	0.01	0.01
Nambucca River	BR	2	Increase	-	62.61	0.95	0.40
Macleay River	BR	3	Decrease	–22.10	87.60	1.32	0.56
SW Rocks Creek	LAKE	3	Decrease	–2.25	0.15	0.00	0.00
Saltwater Creek	LAG	2	None	-	0.00	0.00	0.00
Korogoro Creek	BR	2	Increase	-	0.04	0.00	0.00
Killick Creek	LAG	2	Decrease	–1.09	0.01	0.00	0.00
Hastings River	BR	3	Variable	-	99.56	1.50	0.64
Lake Cathie	LAG	3	Decrease	–0.70	0.00	0.00	0.00
Camden Haven River	LAKE	3	Variable	-	783.90	11.85	5.05
Manning River	BR	2	Increase	-	165.43	2.50	1.07
Khappinghat Creek	LAG	2	Decrease	–1.57	0.33	0.00	0.00
Black Head Lagoon	CREEK	1	NA	-	0.00	0.00	0.00
Wallis Lake	LAKE	2	Increase	-	3189.69	48.20	20.54

Estuary	Type[a]	Times mapped	Change[b]	Area lost[c]	Latest area	% of region	% of state
Smiths Lake	LAKE	2	Increase	-	295.99	4.47	1.91
Lower Myall River	LAKE	2	Decrease	−128.41	153.09	2.31	0.99
Karuah River	BR	2	Decrease	−38.00	0.00	0.00	0.00
Port Stephens	DRV	2	Increase	-	1509.95	22.82	9.73
Central region							
Hunter River	BR	4	Decrease	−15.30	0.00	0.00	0.00
Lake Macquarie	LAKE	4	Variable	-	1194.46	22.10	7.69
Tuggerah Lake	LAKE	2	Increase	-	1731.75	32.04	11.15
Wamberal Lagoon	LAKE	2	Increase	-	43.60	0.81	0.28
Terrigal Lagoon	LAG	2	Decrease	−4.60	0.00	0.00	0.00
Avoca Lake	LAG	2	Decrease	−16.10	0.00	0.00	0.00
Cockrone Lake	LAG	2	Increase	-	28.91	0.53	0.19
Brisbane Water	LAKE	3	Variable	-	561.67	10.39	3.62
Broken Bay	BR	1	NA	-	0.14	0.00	0.00
Hawkesbury River	DRV	3	Variable	-	91.72	1.70	0.59
Pittwater	DRV	3	Decrease	−7.89[d]	185.51	3.43	1.19
Narrabeen Lagoon	LAKE	4	Variable	-	49.15	0.91	0.32
Dee Why Lagoon	CREEK	4	Decrease	−3.40	0.00	0.00	0.00
Curl Curl Lagoon	LAG	4	None	-	0.00	0.00	0.00
Manly Lagoon	CREEK	4	Variable	-	0.12	0.00	0.00
Port Jackson	DRV	2	Decrease	−76.74	51.86	0.96	0.33
Cooks River	BR	1	NA	-	0.00	0.00	0.00
Botany Bay	BAY	3	Variable	-	523.01	9.68	3.37
Georges River	DRV	3	Variable	-	45.52	0.84	0.29
Port Hacking	DRV	3	Variable	-	100.23	1.85	0.65
Towradgi Creek	CREEK	2	Decrease	−3.60	0.00	0.00	0.00
Allans Creek	BR	1	NA	-	0.00	0.00	0.00
Port Kembla	BAY	2	None	-	0.00	0.00	0.00
Lake Illawarra	LAKE	2	Increase	-	796.60	14.74	5.13
Elliott Lake	CREEK	2	Decrease	−2.09	0.71	0.01	0.00
Southern region							
Shellharbour Creek	CREEK	1	NA	-	0.08	0.00	0.00
Minnamurra River	BR	3	Variable	-	18.42	0.53	0.12
Spring Creek	CREEK	2	Decrease	−0.30	0.00	0.00	0.00
Werri Lagoon	CREEK	2	Decrease	−1.62	0.08	0.00	0.00
Crooked River	BR	2	Increase	-	4.56	0.13	0.03
Shoalhaven River	BR	3	Increase	-	538.89	15.38	3.47
Lake Wollumboola	LAKE	2	Increase	-	134.01	3.83	0.86
Wowly Gully[e]	LAG	1	NA	-	0.00	0.00	0.00
Cararma Creek[e]	LAKE	1	NA	-	26.36	0.75	0.17
Currambene Creek[e]	BR	1	NA	-	25.09	0.72	0.16
Moona Moona Creek[e]	CREEK	1	NA	-	3.32	0.09	0.02
Jervis Bay[e]	BAY	2	NA	-	553.44	15.80	3.56
Flat Rock Creek[e]	CREEK	1	NA	-	0.00	0.00	0.00

Estuary	Type[a]	Times mapped	Change[b]	Area lost[c]	Latest area	% of region	% of state
Captains Beach Lagoon[e]	CREEK	1	NA	-	0.00	0.00	0.00
Jervis Bay (total)	BAY	2	Decrease	–297.90	608.20	17.36	3.92
St Georges Basin	LAKE	2	Decrease	–536.7[d]	317.04	9.05	2.04
Swan Lake	LAKE	2	Decrease	–32.57	26.13	0.75	0.17
Berrara Creek	LAG	2	Increase	-	5.23	0.15	0.03
Nerrindilah Creek	CREEK	2	Increase	-	2.96	0.08	0.02
Lake Conjola	LAKE	2	Decrease	–36.10	16.60	0.47	0.11
Narrawallee Inlet	BR	2	Increase	-	8.65	0.25	0.06
Mollymook Creek	CREEK	2	Decrease	–0.90	0.00	0.00	0.00
Ulladulla	CREEK	2	Decrease	–0.94	0.06	0.00	0.00
Burrill Lake	LAKE	2	Increase	-	76.43	2.18	0.49
Tabourie Lake	LAG	2	Decrease	–97.99	21.91	0.63	0.14
Termeil Lake	LAG	2	Decrease	–6.42	0.58	0.02	0.00
Meroo Lake	LAG	2	Increase	-	75.45	2.15	0.49
Willinga Lake	LAG	2	Increase	-	17.28	0.49	0.11
Kioloa Lagoon	CREEK	2	Increase	-	0.73	0.02	0.00
Durras Lake	LAKE	2	Decrease	–1.32[d]	49.58	1.42	0.32
Cullendulla Creek	BR	3	Variable	-	11.92	0.34	0.08
Clyde River	BR	3	Increase	-	154.31	4.40	0.99
Maloneys Creek	CREEK	1	NA	-	0.00	0.00	0.00
Batemans Bay	BAY	3	Variable	-	29.20	0.83	0.19
Tomaga River	BR	3	Increase	-	39.25	1.12	0.25
Candlagan Creek	BR	3	Increase	-	4.94	0.14	0.03
Bengello Creek	CREEK	2	None	-	0.00	0.00	0.00
Moruya River	BR	3	Increase	-	130.39	3.72	0.84
Congo Creek	CREEK	2	Increase	-	0.22	0.01	0.00
Meringo Creek	LAG	2	None	-	0.00	0.00	0.00
Kellys Lake	LAG	1	NA	-	0.00	0.00	0.00
Coila Lake	LAKE	2	Decrease	–49.48	136.72	3.90	0.88
Tuross Lake	BR	3	Variable	-	104.35	2.98	0.67
Lake Brunderee	LAG	2	Decrease	–3.83	2.57	0.07	0.02
Lake Brou	LAG	2	Decrease	–7.80	0.00	0.00	0.00
Lake Dalmeny	LAG	2	Increase	-	32.54	0.93	0.21
Kianga Lake	LAG	2	Increase	-	11.28	0.32	0.07
Wagonga Inlet	LAKE	2	Decrease	–67.49	80.91	2.31	0.52
Little Lake (Narooma)	LAG	1	NA	-	0.00	0.00	0.00
Bullengella Lake	LAKE	1	NA	-	0.00	0.00	0.00
Nangudga Lake	LAG	2	Increase	-	20.19	0.58	0.13
Nargal Lake	LAG	1	NA	-	0.00	0.00	0.00
Corunna Lake	LAG	2	Decrease	–1.77[d]	16.13	0.46	0.10
Tilba Tilba Lake	LAG	2	Increase	-	9.50	0.27	0.06
Little Lake (Wallaga)	LAG	2	Decrease	–0.30	0.00	0.00	0.00
Wallaga Lake	LAKE	2	Decrease	–25.77	108.53	3.10	0.70
Bermagui River	BR	2	Decrease	–6.69[d]	27.11	0.77	0.17
Barragoot Lake	LAG	2	Decrease	–4.29	0.61	0.02	0.00

Estuary	Type[a]	Times mapped	Change[b]	Area lost[c]	Latest area	% of region	% of state
Cuttagee Lake	LAG	2	Decrease	–4.52[d]	38.48	1.10	0.25
Murrah Lake	BR	2	Increase	-	9.68	0.28	0.06
Bunga Lagoon	LAG	2	Increase	-	0.02	0.00	0.00
Wapengo Lake	LAKE	2	Increase	-	41.78	1.19	0.27
Middle Lake	LAG	2	Increase	-	21.07	0.60	0.14
Nelson Lake	BR	2	Decrease	–10.40	1.00	0.03	0.01
Bega River	BR	2	Decrease	–4.28[d]	26.12	0.75	0.17
Wallagoot Lake	LAKE	2	Increase	-	77.44	2.21	0.50
Bournda Lagoon	CREEK	2	Decrease	–4.27	0.03	0.00	0.00
Back Lagoon	LAG	2	Increase	-	21.54	0.61	0.14
Merimbula Lake	LAKE	2	Decrease	–65.84	163.86	4.68	1.06
Pambula Lake	BR	2	Decrease	–16.22	70.58	2.01	0.45
Curalo lagoon	LAG	2	Increase	-	18.48	0.53	0.12
Shadrachs Creek	CREEK	1	NA	-	0.36	0.01	0.00
Twofold Bay	BAY	2	Increase	-	73.99	2.11	0.48
Nullica River	LAG	2	Decrease	–0.85	1.15	0.03	0.01
Boydtown Creek	CREEK	1	NA	-	0.00	0.00	0.00
Fisheries Creek	LAG	2	Decrease	–2.72	0.58	0.02	0.00
Towamba River	BR	2	Increase	-	9.69	0.28	0.06
Wonboyn River	BR	2	Increase	-	80.63	2.30	0.52
Merrica River	CREEK	2	Decrease	–0.01	0.00	0.00	0.00
Table Creek	CREEK	1	NA	-	0.00	0.00	0.00
Nadgee River	CREEK	2	Increase	-	0.00	0.00	0.00
Nadgee Lake	LAKE	2	Decrease	–4.27	3.23	0.09	0.02

a BR = barrier river; DRV = drowned river valley; LAG = lagoon.
b Consistent declines in area are classified as a decrease; fluctuating areas over time are classified as variable. No change indicates area estimate was consistently zero. If estuary has been mapped only once, change is not applicable (NA). This occurs primarily for the creeks within Jervis Bay, which were grouped for the 1985 estimate. Given the difficulty in mapping saltmarsh, estuaries that have been mapped only twice are considered to be the least reliable estimates of change.
c Area loss estimates calculated as latest mapped area minus earliest (1985) mapped estimate.
d Comparisons between areas that have been mapped only two times and show small losses should be treated with caution, due to errors resulting from differences in mapping methods (Meehan and Williams 2005). The very large loss in St Georges Basin was attributed by Meehan and Williams (2005) to error associated with the original mapping by West et al. (1985), and hence due to large difference this value should not be considered.
e Included in Jervis Bay total.

Table 10. Areas of *Posidonia australis* (hectares) in New South Wales estuaries mapped between 1985 and 2013 (mapped 2–4 times, depending on estuary). The northern extent of *Posidonia australis* is Wallis Lake.

Estuary	Type[a]	Times present	Change since 1985[b]	Area lost since 1985[c]	Latest area	% of region	% of state
Northern region							
Wallis Lake (most northern estuary)	LAKE	2	Decrease	–86.99	242.91	37.22	10.69
Smiths Lake	LAKE	0	-	-	-	-	-
Lower Myall River	LAKE	0	-	-	-	-	-
Karuah River	BR	0	-	-	-	-	-
Port Stephens	DRV	2	Increase	-	409.70	62.78	18.03
Central region							
Hunter River	BR	0	-	-	-	-	-
Lake Macquarie	LAKE	4	Variable	-	98.24	13.87	4.32
Tuggerah Lake	LAKE	0	-	-	-	-	-
Wamberal Lagoon	LAKE	0	-	-	-	-	-
Terrigal Lagoon	LAG	0	-	-	-	-	-
Avoca Lake	LAG	0	-	-	-	-	-
Cockrone Lake	LAG	0	-	-	-	-	-
Brisbane Water	LAKE	3	Variable	-	95.87	13.54	4.22
Broken Bay	BR	1	NA	-	0.14	0.02	0.01
Hawkesbury River	DRV	1	NA	-	0.67	0.10	0.03
Pittwater	DRV	3	Variable	-	124.51	17.58	5.48
Narrabeen Lagoon	LAKE	0	-	-	-	-	-
Dee Why Lagoon	CREEK	0	-	-	-	-	-
Curl Curl Lagoon	LAG	0	-	-	-	-	-
Manly Lagoon	CREEK	0	-	-	-	-	-
Port Jackson	DRV	2	Increase	-	10.42	1.47	0.46
Cooks River	BR	0	-	-	-	-	-
Botany Bay	BAY	3	Increase	-	315.12	44.49	13.86
Georges River	DRV	0	-	-	-	-	-
Port Hacking	DRV	3	Increase	-	63.35	8.94	2.79
Towradgi Creek	CREEK	0	-	-	-	-	-
Allans Creek	BR	0	-	-	-	-	-
Port Kembla	BAY	0	-	-	-	-	-
Lake Illawarra	LAKE	0	-	-	-	-	-
Elliott Lake	CREEK	0	-	-	-	-	-
Southern region							
Shellharbour Creek	CREEK	0	-	-	-	-	-
Minnamurra River	BR	0	-	-	-	-	-
Spring Creek	CREEK	0	-	-	-	-	-
Werri Lagoon	CREEK	0	-	-	-	-	-
Crooked River	BR	0	-	-	-	-	-
Shoalhaven River	BR	0	-	-	-	-	-
Lake Wollumboola	LAKE	0	-	-	-	-	-
Wowly Gully[d]	LAG	0	-	-	-	-	-

Estuary	Type[a]	Times present	Change since 1985[b]	Area lost since 1985[c]	Latest area	% of region	% of state
Cararma Creek[d]	LAKE	1	-	-	14.16	1.55	0.62
Currambene Creek[d]	BR	0	-	-	-	-	-
Moona Moona Creek[d]	CREEK	0	-	-	-	-	-
Jervis Bay[d]	BAY	2	-	-	498.96	54.71	21.95
Flat Rock Creek[d]	CREEK	0	-	-	-	-	-
Captains Beach Lagoon[d]	CREEK	0	-	-	-	-	-
Jervis Bay (total)	BAY	2	Decrease	–175.45	513.12	56.27	22.58
St Georges Basin	LAKE	2	Increase	-	140.12	15.36	6.16
Swan Lake	LAKE	0	-	-	-	-	-
Berrara Creek	LAG	0	-	-	-	-	-
Nerrindilah Creek	CREEK	0	-	-	-	-	-
Lake Conjola	LAKE	0	-	-	-	-	-
Narrawallee Inlet	BR	0	-	-	-	-	-
Mollymook Creek	CREEK	0	-	-	-	-	-
Ulladulla	CREEK	0	-	-	-	-	-
Burrill Lake	LAKE	0	-	-	-	-	-
Tounbouree Lake	LAG	0	-	-	-	-	-
Termeil Lake	LAG	0	-	-	-	-	-
Meroo Lake	LAG	0	-	-	-	-	-
Willinga Lake	LAG	0	-	-	-	-	-
Kioloa Lagoon	CREEK	0	-	-	-	-	-
Durras Lake	LAKE	0	-	-	-	-	-
Cullendulla Creek	BR	0	-	-	-	-	-
Clyde River	BR	0	-	-	-	-	-
Maloneys Creek	CREEK	0	-	-	-	-	-
Batemans Bay	BAY	4	Variable	-	10.14	1.11	0.45
Tomaga River	BR	0	-	-	-	-	-
Candlagan Creek	BR	0	-	-	-	-	-
Bengello Creek	CREEK	0	-	-	-	-	-
Moruya River	BR	0	-	-	-	-	-
Congo Creek	CREEK	0	-	-	-	-	-
Meringo Creek	LAG	0	-	-	-	-	-
Kellys Lake	LAG	0	-	-	-	-	-
Coila Lake	LAKE	0	-	-	-	-	-
Tuross Lake	BR	0	-	-	-	-	-
Lake Brunderee	LAG	0	-	-	-	-	-
Lake Brou	LAG	0	-	-	-	-	-
Lake Dalmeny	LAG	0	-	-	-	-	-
Kianga Lake	LAG	0	-	-	-	-	-
Wagonga Inlet	LAKE	2	Decrease	–28.69	60.51	6.64	2.66
Little Lake (Narooma)	LAG	0	-	-	-	-	-
Bullengella Lake	LAKE	0	-	-	-	-	-
Nangudga Lake	LAG	0	-	-	-	-	-
Nargal Lake	LAG	0	-	-	-	-	-

Estuary	Type[a]	Times present	Change since 1985[b]	Area lost since 1985[c]	Latest area	% of region	% of state
Corunna Lake	LAG	0	-	-	-	-	-
Tilba Tilba Lake	LAG	0	-	-	-	-	-
Little Lake (Wallaga)	LAG	0	-	-	-	-	-
Wallaga Lake	LAKE	0	-	-	-	-	-
Bermagui River	BR	2	Increase	-	19.91	2.18	0.88
Barragoot Lake	LAG	0	-	-	-	-	-
Cuttagee Lake	LAG	0	-	-	-	-	-
Murrah Lake	BR	0	-	-	-	-	-
Bunga Lagoon	LAG	0	-	-	-	-	-
Wapengo Lake	LAKE	0	-	-	-	-	-
Middle Lake	LAG	0	-	-	-	-	-
Nelson Lake	BR	0	-	-	-	-	-
Bega River	BR	0	-	-	-	-	-
Wallagoot Lake	LAKE	0	-	-	-	-	-
Bournda Lagoon	CREEK	0	-	-	-	-	-
Back Lagoon	LAG	0	-	-	-	-	-
Merimbula Lake	LAKE	2	Increase	-	115.67	12.68	5.09
Pambula Lake	BR	2	Increase	-	52.33	5.74	2.30
Curalo lagoon	LAG	0	-	-	-	-	-
Shadrachs Creek	CREEK	0	-	-	-	-	-
Twofold Bay	BAY	2	Decrease	–1.66	0.14	0.02	0.01
Nullica River	LAG	0	-	-	-	-	-
Boydtown Creek	CREEK	0	-	-	-	-	-
Fisheries Creek	LAG	0	-	-	-	-	-
Towamba River	BR	0	-	-	-	-	-
Wonboyn River	BR	0	-	-	-	-	-
Merrica River	CREEK	0	-	-	-	-	-
Table Creek	CREEK	0	-	-	-	-	-
Nadgee River	CREEK	0	-	-	-	-	-
Nadgee Lake	LAKE	0	-	-	-	-	-

a BR = barrier river; DRV = drowned river valley; LAG = lagoon.
b Significant loss occurred prior to 1985 in Botany Bay and Port Hacking and can be assumed to have occurred in other highly modified estuaries. Consistent declines in area are classified as a decrease; fluctuating areas over time are classified as variable. No change indicates area estimate was consistently zero. If estuary has been mapped only once, change is not applicable (NA). This occurs primarily for the creeks within Jervis Bay, which were grouped for the 1985 estimate.
c Area loss estimates calculated as latest mapped area minus earliest (1985) mapped estimate. Comparisons between areas that have been mapped only two times and show small losses should be treated with caution, due to errors resulting from differences in mapping methods (Meehan and Williams 2005).
d Included in Jervis Bay total.

Associated biota

Seagrass beds are widely recognised for their role in providing habitat for a diverse assemblage of flora and fauna, including algal epiphytes, crabs, shrimps, fishes, hydroids, sponges, bryozoans, ascidians, amphipods, polychaetes, gastropods, bivalves, and holothurians (Barnes et al. 2013, Bell and Pollard 1989, Ferrell et al. 1993, Hannan and Williams 1998, Howard and Edgar 1999).

The beds contain a significantly higher diversity and abundance of fish than unvegetated areas, and are an important habitat for juvenile stages of commercial and recreational species such as snapper, yellowfin bream, tarwhine, and luderick (Hannan and Williams 1998). The fish communities in beds of different seagrass species are also often distinct, with many species or life-history stages only found in that particular habitat (Middleton et al. 1984, Rotherham and West 2002). There is also evidence to indicate that small seagrass beds can contain a high diversity of juvenile fish, and that the proximity of a seagrass bed to a mangrove forest is correlated with greater diversity of juvenile fish (Jelbart et al. 2007a;b). In several areas of Australia, up to 65% of fishes in seagrasses could be juvenile (Bell and Pollard 1989).

While vegetated areas generally support a greater diversity and abundance of fish, many studies have shown that significantly different assemblages of fish occur in unconsolidated habitats (Ferrell and Bell 1991, Connolly 1994, West and King 1996). Recent research of fish assemblages in Wagonga Inlet using baited, remote underwater video recorded a fish assemblage of 35 species in seagrass and subtidal unconsolidated soft sediments (Gladstone et al. 2010).

5.7.4 BEACHES AND MUDFLATS

Large areas within estuaries are often dominated by unconsolidated habitats devoid of vegetation. These are caused by the dynamic input and movement of sediments from marine and fluvial sources, as well as depth, turbidity and disturbance conditions that do not allow seagrasses to grow. Such habitats largely occur as beaches and mudflats. The sediment within these habitats is a varying mixture of: sand, silt and clay-sized particles from the catchment; organic detritus; phytoplankton and bioclastic material (i.e. skeletal fossil fragments of once living marine or land organisms that are found in sedimentary rocks laid down in a marine environment).

Estuarine beaches are distributed across wave exposures that range from open-ocean swell (closer to the heads) to those completely protected from waves (upper estuary). Mudflats occur primarily in the lower tidal reaches of NSW estuaries. In all regions, the extent of beaches and mudflats is a function of estuary type and tidal range. The most extensive areas occur within middle and lower zones of wave-dominated estuaries and some tide-dominated estuaries (e.g. the Tweed, Brunswick, Evans, Richmond, Clarence, Wooli, Corindi, Nambucca, Macleay, Hasting Rivers, Port Stephens, Hawkesbury, Brisbane Waters, Clyde River, Shoalhaven River, Jervis Bay, and Tuross River). Beaches and mudflats are also present in the most of the smaller creeks and arms of the larger rivers. They can be extensive in intermittent estuaries when open, and virtually not present when the estuaries are closed.

Upper reaches and tributaries of tide dominated and wave dominated estuaries often have well defined river banks. In many cases these are composed of erodible sediments laid down on the floodplain.

The intertidal foreshore has only been mapped for seven estuaries in the state (Port Stephens, Lake Macquarie, Hawkesbury River, Pittwater, Port Jackson, Port Hacking, and Batemans Bay). Port Stephens and Batemans Bay have the highest percentage of soft-sediment shoreline of the mapped estuaries (Table 11). Artificial structures are common at many estuarine beaches, and include jetties, boat ramps and netted swimming enclosures.

Table 11. Foreshore type of New South Wales estuaries presented as percentage of total shoreline; no mapping data are available for other estuaries.

Estuary	% of total shoreline			Total length (km)
	Natural soft	Natural hard	Artificial	
Port Stephens	81.37	13.58	5.06	281.33
Lake Macquarie	64.72	11.56	23.72	335.40
Hawkesbury River	44.60	50.58	4.81	510.80
Pittwater	20.12	34.05	45.83	54.69
Port Jackson	21.41	29.67	48.92	288.88
Port Hacking	21.12	46.43	32.45	72.97
Batemans Bay	76.59	17.30	6.11	149.47

Associated biota

The underlying biological structure of mudflats is provided by bacteria, which occur in high densities. The surface is often densely coated by mats of filamentous plants. Beaches and mudflats are important habitats for a diverse range of epifauna and infauna, including crabs and prawns, molluscs, polychaetes, and other larger mobile animals, such as fish, sharks and rays. Different beach types support characteristic faunal assemblages. A diverse range of invertebrate species occurs below the sand surface (e.g. bivalves, beach worms, crustaceans), forming an important part of the marine food chain. Shallow subtidal areas are spawning, nursery or feeding areas for many fish species. Beaches are foraging, roosting and nesting sites for shorebirds and seabirds, including threatened species and populations such as the little penguin, little tern, pied oystercatcher, and beach stone-curlew.

Crabs and ghost shrimp are among the most abundant macrofauna of intertidal sand and mud flats. These include burrowing crabs, such as the soldier crab (*Mictyris longicarpus*) and semaphore crab (*Heloecius cordiformis*). The ghost shrimp (*Trypaea australiensis*) is highly sought after by fisherman for bait. Burrowing animals, including the ghost shrimp, are important bioturbaters and bio-irrigators of marine sediments (Contessa and Bird 2004). Their burrows increase sediment porosity and the penetration of oxygen into otherwise usually anoxic conditions (Katrak and Bird 2003). Their extensive sediment turnover during burrow construction and feeding influences both the physical and chemical environment of the sediment. For instance, the effects of soldier crabs over sediment biogeochemistry is mainly attributed to its intensive sediment working and surface grazing activities, whereby dense ‘armies’ emerge to swarm and feed on the sediment surface.

These sediment 'cleansing’ activities also significantly affect benthic primary productivity and are likely to have a strong influence over assemblages of other detrital organisms in the same habitat (Webb and Eyre 2004). Some meiofaunal and macrofaunal species also favour the sediments inhabited by these burrowing animals (Dittmann 1996). Further, the bioturbators’ burrows create larger pore spaces than those naturally occurring in the sediment matrix and thus can have more pronounced governance on pore water exchange (seawater recirculation) (Tait et al. 2016)

Molluscs are abundant on unconsolidated tidal flats. These include predatory gastropods, such as the moon snail (*Polinices sordidus*) and club whelk (*Pyrazus ebeninus*), which are commonly seen sliding over the sediment as they search for prey. Bivalves may be found in the soft sediments, and include the burrowing pipi, cockle (*Anadara* spp.) and occasional mud oyster (*Ostrea angasi*). Mud oysters were once abundant in NSW estuaries and inlets, before they were severely depleted by overfishing in the early 1900s (Nell 2001).

The intertidal sand and mudflats of many estuaries are feeding and roosting sites for migratory shorebird communities, many of which are listed in international migratory species agreements (e.g. China Australia Migratory Bird Agreement, Japan Australia Migratory Bird Agreement). Endangered species that rely on these habitats to survive include the critically endangered eastern curlew, (*Numenius madagascariensis*), curlew sandpiper (*Calidris ferruginea*), pied oystercatcher (*Haematopus longirostris*), red knot (*Calidris canutus*), golden plover (*Pluvialis fulva*), and the little tern (*Sterna albifrons*).

5.7.5 ROCKY SHORES

Rocky shores are present in many NSW estuaries, with their structure and extent determined by the regional geomorphology, local geology and exposure. Many are dominated by cobbles and boulders, resulting in a complex habitat structure (Figure 11). Weathering produces cracks, crevices and pools that increase the structural complexity of the habitat, influencing the diversity of organisms.

Rocky shores are generally more common in drowned river valleys, such as Sydney Harbour, Hawkesbury River and Port Stephens than in barrier rivers, creeks or lagoons. A number of bays such as Jervis Bay and Batemens Bay also have significant areas of rocky shores. The regional distribution of these estuary types influence the extent and distribution of estuarine rocky shores across the state. However, their extent has been mapped only in a few selected estuaries.

The foreshores of most urbanised estuaries within the regions have been modified in a variety of ways (Figure 12). Structures have been erected in the form of seawalls, wharves, jetties and pontoons. These areas are now used as habitat by a range of marine organisms, although assemblages can differ from those on natural habitats (see Foreshore development under Section 6.2.1).

Figure 11. Typical estuarine rocky-shore habitat in New South Wales.

Figure 12. Modified rocky shore.

Associated biota

Rocky-shore assemblages in estuaries contain a similar range of species to that found on this habitat type on the open coast (see Section 7.2.4). There are often distinct patterns of marine invertebrates, rock pool fishes and algae within this habitat, which are determined by a suite of physical and ecological processes (Courtnay et al. 2005, Shokri and Gladstone 2013).

Macroalgae inhabiting rocky shores include encrusting, foliose (leafy) and low turf-forming species, with representatives of the red, green and brown algae all adapted to growing in this environment. Species often found on intertidal rock platforms all year include the brown alga, Neptune's necklace (*Hormosira banksii*), green algae *Ulva* spp., *Codium* spp., and a variety of red algae that largely comprise the coralline mats and algal turfs covering rocks on the lower shore. These provide an important habitat for a diverse assemblage of small and cryptic fauna. Underwood and Chapman (1995) provide a comprehensive review of rocky shore ecology.

Many of the migratory shorebirds that use the beaches and tidal mud flats use rocky shorelines for roosting. These habitats are feeding sites for species such as the Pacific golden plover (*Pluvialis fulva*) and ruddy turnstone (*Arenaria interpres*). The sooty oystercatcher (*Haematopus fuliginosus*), listed as vulnerable in NSW under the *Threatened Species Act*, makes extensive use of rocky shores for nesting and foraging.

5.7.6 SUBTIDAL ROCKY REEFS

Subtidal rocky reefs are primarily found in estuaries of the central region, and some within the southern region, particularly embayments such as Jervis Bay. Rocky reefs are primarily found in drowned river valleys, and are less common in barrier rivers, bays or some of the large lakes. The distribution of subtidal reefs has been mapped in Port Jackson and several of the larger embayments, including Port Stephens and Batemans Bay (Table 12).

Subtidal rocky reefs are uncommon in coastal lagoons. If any do exist, they are typically very shallow and narrow. No reefs have been mapped in the coastal lagoons of the northern region.

Oyster reefs were once a dominant structural and ecological component of estuaries around the globe, fuelling coastal economies for centuries (Beck et al. 2011.) and forming complex structure and habitat that supported many other species (Russell and Lebrault 2015). Since European settlement, the effects of increasing urbanisation, industrialisation and agricultural development have led to significant changes to Australia's coastal sedimentary environments (Gillies et al. 2015, Russell and Lebrault 2015). In Australia, it is estimated that 99% of natural oyster reefs are functionally extinct (Beck et al. 2011) with most of the reefs remaining around NSW comprising several little patches of oysters (Russell and Lebrault 2015).

The extirpation of oyster reefs has contributed to significant declines in richness and diversity of reef-associated species including key recreational and commercial fish species (Airoldi et al. 2008, Alleway and Connell 2015, Cranfield et al. 2001) and the intensification of coastal water quality problems (Lotze et al. 2006).

The limited information available on the role of these very high-density mollusc populations in Australia has allowed their very existence to be largely lost to living memory (Clark and Johnston 2017). This paucity in knowledge, or changed baseline of natural habitats, could not only undermine progress towards their recovery, but also reduce our expectations of these coastal ecosystems (Alleway and Connell 2015).

Table 12. Areas of subtidal rocky reefs that have been mapped in selected New South Wales estuaries.

Estuary	Mapped reef (km^2)
Port Stephens	0.41
Hawkesbury River	0.69
Pittwater	0.11
Port Jackson	1.58
Port Hacking	0.22
Batemans Bay/Clyde River	2.27

Associated biota

Subtidal rocky reefs in estuaries provide attachment space for a wide range of sessile species (algae and invertebrates) which in turn create further habitats for numerous species of fish. Rocky reefs are made up of habitats such as fringe, turf, macroalgal beds, urchin-grazed barren areas and, in deeper water, ascidian or sponge gardens. Rocky reefs provide habitat, food and shelter for a diverse assemblage of sharks and rays, fishes, and invertebrates, from reef-associated species to transient species that move between reef systems. A diverse range of demersal and pelagic fish species are common residents on estuarine reefs or visit reefs intermittently (see Section 5.7.8).

Large, brown algae (e.g. *Ecklonia radiata*, *Sargassum* spp., *Cystosiera* spp) are common in the lower reaches of many wave-dominated estuaries. There is generally a gradient in the structure of assemblages on and associated with rocky reefs within the estuary. This is mostly determined by light availability (due mostly to turbidity), sedimentation, recruitment and habitat availability (Morton and Gladstone 2014). Rocky reef habitats are important sites for juvenile and adult marine turtles, especially in the north of the state. Green turtles are known to frequent these habitats, and are commonly observed in the Port Stephens estuary.

5.7.7 SUBTIDAL SOFT SEDIMENTS

The majority of the total area of all NSW estuaries consists of non-vegetated, soft-sediment habitats. Many immature (as used in Roy et al. (2001)) intermittent and wave-dominated estuaries, which have not yet in-filled, have a relatively large central basin. The floor of the basin is often unvegetated, and the sediments may receive little light. Soft-sediment habitats are dominated by muddy sediments, but commonly also contain sand, pebbles, and cobbles.

Sediments in basins perform essential biogeochemical processes such as mediating the breakdown of organic matter, release of nutrients to the water column and removal of nitrogen via denitrification, whilst providing an important habitat for an array of fauna and flora (Banks 2011).

The distribution of estuarine, subtidal, unvegetated soft-sediment habitats are represented in the current seabed habitat maps as the areas that are not mapped as seagrass. Further analysis of their spatial extent is currently underway to develop a specific layer for this habitat type.

Associated biota

Marine assemblages associated with these habitats are influenced by sediment type and size, organic content, the depth at which the habitat occurs, and the degree of fine-scale habitat structuring (ripples, pits, mounds). Many animals live within the sediment, including amphipods, bivalves, and marine worms.

Subtidal soft sediments are important habitats for many fish, crab, sharks and ray species, including the mudcrab, *Scylla serrata*. A diverse range of demersal and pelagic fish species are commonly occur on subtidal soft sediment habitats (see Section 5.7.8). The species present often differ between sandy and muddy areas, contributing to estuarine diversity. Research is demonstrating that certain species of fish display strong site attachment to these soft sediment areas (Fetterplace et al. 2016). Dominant fishes include ambassids, atherinids, bream, flatheads, leatherjackets, girrellids and mullets. Both adults and juveniles are caught in these habitats, indicating that these areas serve more than just a nursery function. Deeper (>10 m) unvegetated habitats are often dominated by leatherjackets, gurnards, sharks, skates and stingarees. This habitat provides foraging and nursery areas for much of the higher trophic levels.

A diverse range of macroinvertebrates species are also found in subtidal, unvegetated habitats. The dominant species include brittle stars and dog whelks. In shallow, sandy sites, the dominant species are often polychaete worms, ghost shrimps, amphipods, and molluscs, whereas the dominant species generally differ in the deeper, muddy sediments.

Unconsolidated habitats can also contain large, sessile macrofauna (e.g. sponges, ascidians, bryozoans, seawhips) that increase the diversity and complexity of the habitat. These are particularly prevalent in areas of higher current flows in adjacent to channels. Some biota are restricted in their distribution in estuaries, such as the soft coral (*Dendronephthya australis*), which colonises soft sediments in Port Stephens, and provides habitat for a large range of associated biota (Poulos et al. 2013). Charophyte algae (e.g. *Lamprothamnion* spp.) are also limited in their distribution, but in places may form large and dense beds with a similar function in many intermittent estuaries. They are believed to be critical to water quality and ecosystem function in the subset of intermittent estuaries known as back-dune lagoons (Scanes et al. 2014b).

Similarly to bioturbators associated with intertidal beach and mudflat habitat, the burrowing and tube-building by deposit-feeding benthic invertebrates (bioturbators) helps to mix the subtidal sediment and enhances decomposition of organic matter (Bird 1994, Nixon 1998).

Further, these soft sediment habitats and deep subtidal reef of between 2 and 20 m in depth are potentially an important zone for direct interaction between estuary and marine fauna, with a range of consequences for intertidal habitat use and nursery ground functioning. Research is showing that the interface between marine areas and the shallow-water estuary may be richer and more complex than previously recognised (Bradley et al. 2017).

5.7.8 FISH ASSEMBLAGES

Fish assemblages within estuaries are dominated by those that occur principally on soft-sediment habitats due to the dominance of this type of habitat. Bony fish are a diverse and abundant group, which includes small site-attached fish which live in seagrass (e.g. pipefish), up to large transient species such as yellowtail kingfish and snapper. Bony fishes are a key component of estuarine food webs, and many species spend their entire lives within the estuary or use them as nursery areas before moving to the coast (e.g. snapper, blue groper). For example, most snapper (89%) caught in the adult fishery in central NSW, originated from local nursery estuaries including Sydney Harbour, Hawkesbury River, Botany Bay, and Port Hacking (Gillanders 2002).

Sampling of fish assemblages of estuaries within the central region undertaken for the NSW Monitoring, Evaluation and Reporting (MER) program (Roper et al. 2011) recorded 132 species of finfish and elasmobranchs and 36 species of invertebrates in either seagrass (vegetated) or subtidal unvegetated soft-sediment habitats. Glassfish and several species of gobies were the most ubiquitous non-commercial species occurring in 16-17 estuaries in the central region. The most common commercial finfish species was yellowfin bream, occurring in 18 estuaries in the region.

Seagrass beds can often contain a significantly higher diversity and abundance of fish compared to unvegetated areas and they are an important habitat for juvenile stages of commercial and recreational species such as snapper (*Chrysophrys auratus*), yellow-fin bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*) and luderick (*Girella tricuspidata*) (Hannan and Williams 1998). Dominant fish species in unvegetated habitats include flounders, leatherjackets, atherinids, flatheads, mullets and salmon, and both adults and juveniles are caught in these habitats indicating that these areas serve more than just a nursery function.

In some estuaries, particularly drowned river valleys (e.g. Port Jackson) or coastal embayments (e.g. Jervis Bay), there are areas of mostly shoreline fringing rocky reefs that are dominated by a further range of fish species, such as eastern hulafish (*Trachinops taeniatus*), yellow-tail scad (*Trachurus novaezelandiae*), mado sweep (*Atypichthys strigatus),* eastern pomfret (*Schuettia scalaripinis*), with one-spot puller (*Chromis hypsilepis*), small-scale bullseye (*Pempheris compressa*), white-ear (*Parma microlepis*), Maori wrasse (*Opthalmolepis lineolata*) and crimson-banded wrasse (*Notolabrus gymnogenis*).

The apex predators at the top of the food chain are the top order sharks which play an important role in the ecosystem functioning of the estuary. Common species are bull sharks (*Carcharhinus leucas*), whalers (*Carcharhinus* spp.) and wobbegongs (Family Orectolobidae). Top order sharks generally occupy estuarine and oceanic habitats and can travel large distances. However, they may also use estuaries intermittently, particularly for breeding or as nursery habitats. For example, Port Jackson is an important seasonal area for bull sharks (Smoothey et al. 2016). Other top order sharks such as tiger sharks (*Galeocerdo cuvier*), and white sharks (*Carcharodon carcharias*) are transitory within the lower reaches of many estuarine embayments such as Batemans Bay, Jervis Bay and Twofold Bay.

Lower order sharks and rays occupy the middle of the food chain, prey on other species (e.g. small fishes, crustaceans, and worms) and are consumed by predators such as pelagic sharks, dolphins and seals. Some of these are seasonally abundant; such as adult Port Jackson sharks (*Heterodontus portusjacksoni*), which primarily occur in coastal embayments during winter when they aggregate at specific sites to breed (O'Gower 1995). As juveniles they utilise shallow waters as nursery areas before moving to offshore habitats as adults. Other species such as wobbegong sharks regularly occur in both estuarine and coastal waters throughout NSW (Huveneers et al. 2009).

For the purpose of this assessment, fish assembages also includes invertebrates that are harvested or landed as bycatch. Within estuaries this includes a number of important species including blue swimmer crab (*Portunus armatus*), giant mud crab (*Scylla serrata*), Eastern king prawn (*Melicertus plebejus*), school prawn (*Metapenaeus macleayi*), ghost nipper (*Trypaea australiensis*) and Loligo squid (*Uroteuthis* species).

Many species of fish are harvested or caught as bycatch within estuaries as part of a number of commercial fisheries (principally the estuary general fishery and estuarine prawn trawl fishery) (see Stewart et al. 2015), and the recreational fishery (see West et al. 2015). Specific details of these fisheries and their catch composition are presented in sections 6.1.2 and 6.1.4, respectively. There are regional and often estuary specific catch compositions that reflect both local conditions and target species, although harvested species generally make up between 40-50% of all species. Further specific details on estuarine fish assemblages in the central region is presented in the Hawkesbury marine bioregion background environmental report (MEMA 2016).

5.7.9 PLANKTONIC ASSEMBLAGES

Estuarine pelagic habitat refers to the water column between habitats on the seafloor and the surface. This habitat is influenced by chemical, physical and biological parameters that influence all marine and estuarine organisms. It contributes greatly to population connectivity by transporting organisms with a pelagic life-history phase.

Microscopic passive plants and animals, collectively known as plankton, are key components of open waters and are fundamental to estuary structure and function. They include plants (phytoplankton), animals (zooplankton) and microbes (bacteria and protists) that range in size from microbes to jellyfish. They are an important component of food webs, fundamentally supporting primary and secondary production. There is limited understanding of plankton and microbe communities within the region’s estuaries. Many marine organisms in estuaries have a planktonic larval stage (e.g. fishes, crabs, urchins) which is important for dispersal and population connectivity.

However, as most are relatively passive particles they are generally unable to move away from the sources of stressors, such as toxins. Early life stages of organisms are well recognised to be the most vulnerable to the effects of stressors, but also to less well-recognised changes, such as temperature, acidity, salinity and turbidity. Changes in currents may transport the organisms to unsuitable habitats, disrupting their life cycles. Pelagic ecosystems can contribute a significant amount to primary productivity, unless waters are shallow or particularly clear.

5.8 ESTUARINE THREATENED AND PROTECTED SPECIES

This section details threatened and protected species found in estuaries. Such species include fish and sharks, marine reptiles and mammals, shorebirds, seabirds and little penguins.

5.8.1 THREATENED AND PROTECTED FISH AND SHARKS

The *Fisheries Management Act 1994* lists threatened fish in NSW, including shark species. Several threatened fish and shark species may occasionally occur in estuaries, including the critically endangered grey nurse shark (*Carcharias taurus*), white shark (*Carcharodon carcharias*) and black rockcod (*Epinephelus daemelli*). This is particularly the case in the lower reaches of marine-dominated drowned river valleys, and within the embayments of the Hawkesbury River, Jervis Bay, Batemans Bay and Twofold Bay. White sharks occasionally occur at locations such as Lake Macquarie. For further details on threatened and protected fish and shark species, see Section 7.3.

Sygnathiformes (seahorses, seadragons, pipefish, pipehorses) are listed as protected under the *NSW Fisheries Management Act 1994*. Up to 31 syngnathids (seahorse, pipefish, pipehorse and seadragon), four solenostomids (ghost pipefish) and two species of pegasids (seamoths) currently exist in NSW waters. Three of these species are endemic to NSW: White's seahorse (*Hippocampus whitei*), Coleman's seahorse (*H. colemani*), and the pygmy pipehorse (*Idiotropiscis sp*). The weedy seadragon (*Phyllopteryx taeniolatus*) is the only known seadragon in NSW waters. Pipefish species are the most common within the group, and are strongly associated with seagrass habitat in all estuaries throughout NSW.

NSW coast sygnathiform habitat ranges from deep reefs and coastal algae to weed and seagrass, or artificial structures, such as jetties or mesh nets. There is evidence of a localised decline in sygnathiformes within the central region (Harasti et al. 2010), but long-term monitoring data are scarce. Six of the protected sygnathid species group occurred in nine of the estuaries sampled in the central region, although the sampling program was not designed to detect rare or unique species of finfish. Weedy seadragons occur within estuaries with marine habitat (e.g. Port Jackson and Botany Bay) and along the open coast. They are generally found within kelp or at the sand-reef interface.

5.8.2 THREATENED AND PROTECTED MARINE MAMMALS, REPTILES, AND BIRDS

Marine mammals

As whale and seal populations on the east coast of Australia recover from years of overexploitation, they are more commonly encountered in the rivers, bays, estuaries, harbours, and offshore waters of NSW. Humpback and southern right whales accompanied by calves are regularly seen in winter, entering and remaining for short periods within sheltered estuaries such as Twofold Bay, Jervis Bay, Sydney Harbour, Botany Bay, and the Hawkesbury River.

The bottlenose dolphin is regularly observed along the NSW coast, usually close to shore and often in bays, estuaries and the lower reaches of rivers. Separate inshore and offshore forms of this species complex occur in many regions, with the inshore forms typically occurring as resident groups with a limited home range in very shallow water near the coast. Resident, breeding populations are found at Port Stephens, Jervis Bay, Twofold Bay, and many other sites along the NSW coast. The individuals within Port Stephens make up a small population of the inshore Indo-Pacific bottlenose dolphins, *Tursiops aduncus,* consisting of around 121–160 individuals (Möller and Beheregaray 2001), with around 90 commonly seen within the Port (Möller et al. 2002). There is evidence that these dolphins are genetically distinct from the adjacent offshore dolphins (*T. truncates*), with females of *T. aduncus* returning to their birthplace to breed (Möller and Beheregaray 2004, Möller et al. in review). The two forms differ morphologically as well as in habitat preferences.

The dolphin population within the Port display distinct social structuring, with four main female bands and several male alliances identified (Möller et al. 2001, Möller et al. 2006). They have been found to use all habitats from shallow sand flats and seagrass beds to deep channels (<1 to 30+ m), including the rivers that flow into the Port and the open coastal beaches outside the headlands (Allen and Moller 1999). However, there is also evidence that female bands (and associated calves and juveniles) show spatial structuring in the Port, with three of the bands using the section of the Port east of the Soldiers Point region (Möller et al. 2006). These unique set of behaviours make dolphin populations that reside in estuaries and bays susceptible to overexploitation from recreational and commercial whale-watching activities, and expose them to a litany of threats created by the ever-increasing urbanisation of coastal zones.

Australian fur seals (*Arctocephalus pusillus*) and long-nosed (formerly New Zealand) fur seals (*A. forsteri*) are the most commonly occurring pinniped species in NSW (Shaughnessy 1985). Their distributional range is throughout NSW, although they are concentrated in southern NSW waters. Fur seal haul-out colonies, in which many non-breeding adults congregate, are known at: Montague Island Nature Reserve, Narooma; Steamers Beach, Jervis Bay; and, Five Islands Nature Reserve, Wollongong. The recent observation of pups at both Montague and Five Islands suggests a transition from haul-out to breeding colonies at these locations (McIntosh et al. 2014).

With the recovery of seal populations in Australia and the re-establishment of breeding colonies in NSW, the abundance of fur seals within estuaries will increase. Fur seal sightings are increasing in NSW estuaries, especially in Newcastle Harbour, Sydney Harbour, Botany Bay, and Port Kembla.

Threats to cetaceans

The increased use of estuaries by urban human populations for tourism and other recreational and industrial pursuits imposes increasing interactions with whales and dolphins, including:

- collisions with commercial and recreational boating traffic
- entanglement in nets and other fishing gear
- exposure to underwater noise
- ingestion of marine debris, such as plastics, which can cause abrasions, infection, suffocation or blockages if swallowed.

Exposure of marine wildlife to effluent and urban run-off containing persistent organic pollutants and microplastics poses a significant, yet unknown, level of threat.

In a recent paper on marine wildlife incidents from 1790–2013, Lloyd and Ross (2015) found more cases of injury or mortality from anthropogenic causes, such as those given above, than from natural causes (e.g. disease, calf mortality). The number of cetacean incidents (carcasses ashore, strandings, entanglements, vessel strike etc.) has also increased significantly since the 1960s (Figure 13).

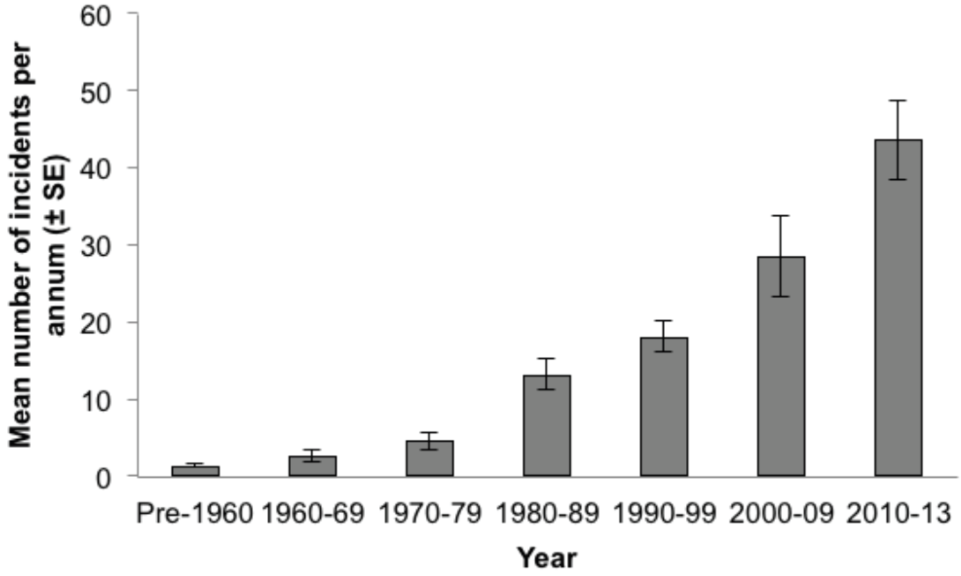

Figure 13. Mean number of cetacean (whales, dolphins and porpoises) incidents reported annually in New South Wales for each decade since 1960, compared to pre-1960 levels. *Source: Lloyd and Ross (2015).*

Short-term responses of cetaceans to disturbance from vessel activity or noise include spatial avoidance, increased dive time and swimming speed, and changes in breathing patterns, group size and cohesion, and acoustic, foraging, socialising and resting behaviour (Leung Ng and Leung 2003, Lusseau 2003b, Richardson et al. 1995). However, some marine mammals are more susceptible to vessel strike, because they are difficult to detect and cannot avoid fast-moving vessels. This includes females with calves, or sperm whales recovering from dives. Ensuring that commercial and recreational vessel users are aware of their presence and the approach distance regulations may significantly reduce the risk to vessels, crew, and whales.

Cetaceans can sometimes tolerate vessel or boat noise. For example, baleen whales have been observed feeding in areas where large numbers of trawlers operate (Richardson et al. 1995) and dolphins actively approach boats to ride on bow waves and feed (Williams et al. 1992, Broadhurst 1998).

Cetaceans have lower tolerance to approaching, increasing or variable sounds than stationary, departing or steady sounds (Richardson and Würsig 1997, McCauley et al. 2003). For example, dolphins in Scotland frequently exposed to boating traffic showed no significant response to most of the traffic, which was either fishing or yachting related, and usually occurred in a predictable straight line. However, these dolphins did show significant avoidance reactions to the unpredictable and approaching movement of dolphin-watching vessels. In the longer term, repeated exposure to human-induced noise, including that from boats/vessels, can result in cetaceans avoiding areas where levels of this disturbance are high (Richardson et al. 1995). For example, in Hawaii, humpback whales have moved away from nearshore areas, a favoured resting site, apparently in response to disturbance from human activities (Glockner-Ferrari and Ferrari 1990, Salden 1988).

Threats to seals

The depleted populations of NSW seals, caused by earlier commercial sealing, has increased the species' vulnerability to many threats. The greatest threat in NSW appears to be bycatch in specific fisheries, and entanglement in marine debris (Jones 1995). Secondary threats include:

- habitat degradation
- human disturbance to colonies
- deliberate killings
- disease
- pollution and oil spills
- noise pollution
- prey depletion
- climate change.

When at their breeding colonies, or hauling out on land, seals either tolerate or avoid disturbances from humans. Tolerating behaviour results in seals becoming more alert, and exhibiting aggressive protective behaviour if breeding (Richardson et al. 1995). Pinnipeds avoid disturbance from humans by temporarily leaving the haul-out site. This avoidance can reduce breeding success (Richardson et al. 1995, Shaughnessy 1999).

Marine reptiles

Seventeen species of marine reptiles have been recorded in NSW waters, many of which are vagrants carried on ocean currents and beach-washed in NSW.

Turtles

Four turtle species are regarded as regular visitors, while the green turtle may be regarded as a year-round resident (Cogger 2001). Only one species is listed as endangered under the NSW *Threatened Species Act*. All marine reptiles are protected under NSW legislation.

Five species of marine turtle are reported from the NSW regions:

- one endangered species – the loggerhead turtle (*Caretta caretta*)
- one vulnerable species – the green turtle (*Chelonia mydas*)[5]
- three protected species – hawksbill turtle (*Eretmochelys imbricata*), flatback turtle (*Natator depressus*), leatherback turtle (*Dermochelys coriacea*).

There is limited information in the literature regarding the population densities of marine turtles in the estuaries of the various bioregions. However, data extrapolated from stranding events, which can be regarded as an indirect measure of abundance (Williams et al. 2011), suggests that NSW has a large resident marine turtle population in estuaries and shallow offshore reefs. A study in Lake Macquarie and Tuggerah Lakes recorded 125 sightings of marine turtles over 12 months (Mead 2003).

C. mydas is the most reported marine turtle species along the NSW coast and sightings are relatively common as far south as Wollongong. Though its abundance is relatively high, there are significant concerns regarding its long-term viability, unless the key threats are removed (Limpus 2008b). Although data is anecdotal, the nesting of green turtles is increasing on beaches in northern NSW (Ross pers. obs.). A large number of reported sightings of adult *C. mydas* in Lake Macquarie also suggests that a stable population of non-breeding adults may be present within the lake system.

Populations of *C. caretta* are said to have declined by as much as 80% within its range and population modelling suggesting that the species faces a high risk of extinction (Limpus and Reimer 1994). There is a continuing decline in the size of the *C. caretta* nesting population at all monitored sites in eastern Australia (Limpus 2008a).

[5] Note that Cogger (2001) suggests that the green turtle should be re-listed as endangered

A recent analysis of hawksbill turtle stranding events by latitude showed that they stranded more frequently towards the north of NSW between 1996 and 2011 (Ferris 2016) (Figure 14). This suggests that *E. imbricata* favours northern locales, where important populations may be resident. A lack of knowledge on the distribution and abundance of marine turtle species in NSW waters severely constrains conservation management decision-making.

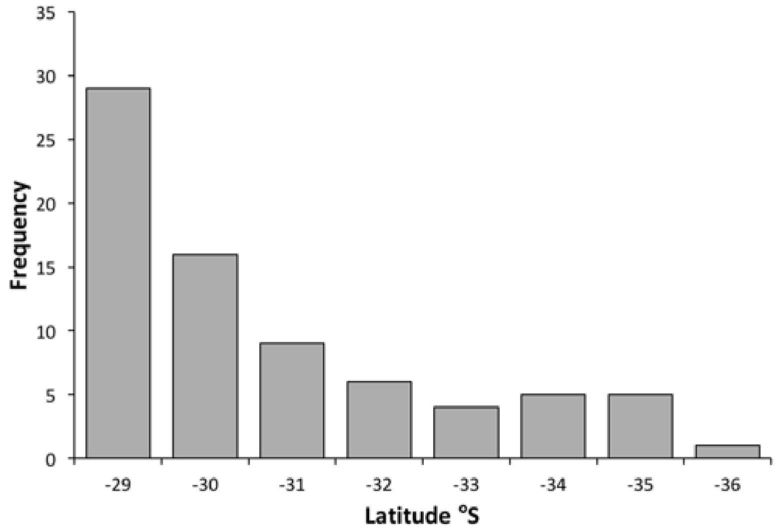

Figure 14. Latitudinal spread of 173 hawksbill turtle stranding events in New South Wales between 1996 and 2011. Source: Ferris (2016).

All marine turtle species face high risk of death as bycatch from some recreational commercial methods. The adoption of turtle exclusion devices in the northern Australian commercial prawn trawl has significantly reduced the human impact on this species (Brewer et al. 2006). However, turtle exclusion devices are not mandatory in NSW.

Other factors contributing to the decline of marine turtle populations include:

- vessel strike (see shipping sections *6.1.1 Shipping and 8.1.1 Shipping*)
- disturbance of nest sites and feeding grounds by human activities
- mortality from recreational and commercial fishing activities, such shark netting and prawn trawling (Limpus 2008a)
- increased predation on nests by introduced predators, such as pigs and foxes.

Mortalities from entrapment in crab traps is also a major issue in some NSW estuaries (Gallen and Harasti 2014). The DPI has proposed modifications to recreational crab traps to reduce bycatch in NSW.

Activities that occur on or adjacent to shorelines, such as beach fishing, all-wheel driving and boating, affect the successful nesting of sea turtles (Environment Australia 2003). The reactions of sea turtles to disturbance from human-induced noise vary with different frequencies and intensities of sound. Current information on the potential effects of persistent noise, such as that from boating and shipping is inconclusive (Environment Australia 1998a).

Sea snakes

Approximately 33 species of sea snake occur in Australian waters, and are generally found in warm, tropical water (Ganassin and Gibbs 2005a). Twelve species are recorded in NSW (Cogger 2000) (Table 13). They occur primarily in open coastal waters, but may enter some of the marine-dominated systems, such as Port Stephens.

All sea snakes in NSW are protected under legislation. However, because of their wide distribution, no marine snakes are currently listed on either Schedule 1 or Schedule 2 of the *TSCA*, although all are protected under the *National Parks and Wildlife Act* 1974.

Table 13. Sea snakes recorded within New South Wales waters

Family Hydrophiidae (viviparous sea snakes)	Family Laticaudidae (oviparous sea kraits)
Acalyptophis peronii	*Laticauda colubrine*
Aipysurus duboisii	
Aipysurus laevis	
Astrotia stokesii	
Disteira kingii	
Disteira major	
Emydocephalus annulatus	
Hydrophis elegans	
Hydrophis inornatus	
Hydrophis ornatus/ocellatus complex	
Pelamis platurus	

Shorebirds

Shorebirds form a large proportion of the vertebrate fauna within estuarine, ocean beach, and rocky-shore environments, which they use for roosting and foraging activities. Preferred roosting locations are generally above the high-water mark, and frequently include saltmarsh, sandy ocean beaches, sand bars and spits, mangroves, rock walls, rock platforms, and oyster racks. Common foraging habitats are intertidal flats, beaches, rocky headlands and along the fringes of wetlands (DECCW 2010a).

Shorebirds are particularly common in wetlands and marshes of estuaries across the Hawkesbury Shelf region, with groups including oystercatchers, plovers, sandpipers, herons and members of the suborder Charadrii.

The endangered little tern (*Sterna albifrons* subspecies sinensis) nests along the NSW coast during spring on habitats on the open coast, including sand spits, sand islands and beaches, and feeds in nearby waters (NSW NPWS 2003). Prior to management by the NSW National Parks and Wildlife Service (NSW NPWS), the Little Tern suffered a major decline in distribution and abundance across coastal NSW. This was primarily related to poor breeding success caused by a combination of natural and anthropogenic threats. Rising concerns for the survival of the species in NSW triggered a number of conservation actions in the late 1970s on the north coast, which were later broadened to incorporate its statewide distribution. Nesting in NSW has been recorded at 70 sites along the coast (compared with 75 in Garnett and Crowley 2000), but at only 44 sites since 1977, and only 31 sites since 1987 (NSW National Parks and Wildlife Service 2003). During the mid- to late 1990s, nesting was recorded at 12 sites in 1995–96, 16 sites in 1996–97, eight sites in 1997–98 and 11 sites in 1998–99 (NSW National Parks and Wildlife Service 2003). Several other key threatened and protected shorebird species present on the open coast include the critically endangered beach stone-curlew and hooded plover, and endangered pied oystercatcher.

Threats to shorebirds

The majority of shorebirds are classified as vulnerable. This is in part a reflection of their overall low resilience to disturbance. Compared with many other marine vertebrates, shorebirds continue to experience a disproportionately high level of threat, especially due to human disturbance and urban development.

Many species of shorebirds are protected under international (migratory bird) agreements such as the China Australia Migratory Bird Agreement and Japan Australia Migratory Bird Agreement, Republic of Korea-Australia Migratory Bird Agreement, the Bonn Convention, and under Australian state and federal legislation. Highly important habitats have been protected under the Convention on Wetlands of International Importance (the Ramsar Convention) and within the national parks and wildlife estate. Disturbance of foraging or roosting can be a significant stressor on many species, and can result from direct disturbance, noise or indirect feeding through discards. Disturbances can include fishing and general boating activity, and shore based activities such as walking, four-wheel driving and bait collecting.

Birds often move away from disturbances, which can reduce their foraging time, increase their energy expenditure and disrupt incubation, leaving eggs exposed (Burger 1991, Roberts and Evans 1993, Weston 2000). Human activities, such as bait harvesting, can reduce food resources and affect the feeding behaviour of wildlife (McPhee et al. 2002) and can also affect nesting success by destroying the eggs and chicks of nesting shorebirds.

Migratory shorebirds are particularly susceptible to disturbance from human presence in the few months before their migration. Overseas studies have linked declines in shorebird populations to the disturbance or loss of roosting sites (Mitchell et al. 1988, Tubbs et al. 1992, Pfister et al. 1992); the recent decline in shorebird populations in NSW (Nebel et al. 2008) may be related to high levels of disturbance in coastal estuaries and oceanic beaches. Kirby et al. (1993) found that shorebird abundance may increase at sites where disturbance factors are controlled.

Seabirds

Fifty-six species of seabird from the Family Oceanitidae (Petrels), Diomedeidae (Albatrosses) and Procellaridae (Shearwaters) are recorded from NSW. Many inhabit those zones between coastal waters and those off the continental shelf. Several species forage within the bays, estuaries and harbours. These sea birds tend to nest on offshore islands, including Montague Island, the Lord Howe Island group and the Solitary Islands.

Plastic ingestion and entanglement are rated as the highest threat to seabird populations. For example, Wilcox et al. (2015) found the number of seabird species ingesting plastic has increased from 20% in the 1960s to 90%. As for shorebirds, excessive disturbance at beach-nesting sites, intertidal feeding grounds and high-tide roosts is another major threat to seabirds (Smith 1991).

Little penguins

The little penguin (*Eudyptula minor*) is the smallest species of penguin and is often encountered in NSW coastal waters. Little penguins occur in temperate marine waters in southern Australia and New Zealand (Priddel et al. 2008). They are the only penguin species to breed on mainland Australia, with the only breeding colony on mainland NSW located in Manly, Sydney Harbour (Priddel et al. 2008). The issues affecting the little penguin are described in detail in the Hawkesbury environmental background report (MEMA 2016), and further details are provided in Section 7.3.

6. ESTUARINE ACTIVITIES AND USES

Activities that threaten the benefits derived from the NSW marine estate's estuarine environmental assets include **resource-use activities** and **land based activities**. These can either occur on, or in, the waters of the estuaries themselves, or are derived from the land adjoining the marine estate. **Climate change** is considered as a separate major category of threats (see Table 2).

This section details the characteristics of these activities in estuaries, the key stressors that are derived, and how these activities might threaten the environmental assets described in the previous sections. Historical data and any existing management arrangements are also presented.

6.1 RESOURCE-USE ACTIVITIES

Resource-use activities cover shipping, boating, fishing and aquaculture; recreation and tourism; and effects from dredging, mining and changes to freshwater flows.

6.1.1 SHIPPING

This section includes impacts from both large and small commercial shipping vessels.

Large commercial vessels (e.g. trade ships, cruise ships)

For the purposes of this report, large commercial vessels include all international and domestic vessels carrying cargo or passengers transiting though the NSW marine estate, including coal ships, container ships, oil tankers, cruise ships, and naval vessels. Thousands of these large commercial vessels transit through the NSW marine estate every year.

In the financial year 2015-2016, approximately 6,013 trading vessels and cruise ships visited NSW ports, with 5,926 (98.5%) in the central region, 18 (0.4%) in the north and 69 (1.1%) in the south (Port Authority of New South Wales, Annual Report 2015-16):

https://www.parliament.nsw.gov.au/la/papers/DBAssets/tabledpaper/webAttachments/69937/Attachment%20H%20-%20Port%20Authority%20of%20NSW%202015-16%20Annual%20Report.pdf

Shipping in the estuaries in the **northern region** occurs primarily in the Port of Yamba, which is located at the mouth of the Clarence River, and is the only official port in the northern region. It is home to the state's second-largest commercial fishing fleet, and services the Northern Rivers district and provides a link to Norfolk Island and the south-west Pacific region. The port exports goods such as timber and hardwood logs, explosives and general cargo. Yamba Cargo operations occur mainly at Goodwood Island, which has a 70 m long wharf and a minimum depth of 3.4 m at low tide. In 2015–16, there were 18 ship visits to the Port of Yamba.

Shipping in the estuaries in the **central region** occurs primarily in Sydney Harbour, Port Botany, Port Kembla and the Port of Newcastle. Together, Port Botany and Newcastle account for more than 98.5% of all ship visits to NSW.

A brief trade profile for each Port follows:

- Sydney Harbour
    - primarily used for the importation of bulk products such as cement, salt, soda ash, lubrication oil and petroleum products
    - the only port in Australia with two dedicated cruise facilities (Circular Quay and White Bay); can host up to three cruise ships concurrently
- Port Botany
    - Australia's second-largest container port
    - has a significant role in the importation of bulk liquids and gases
- Port Kembla
    - NSW's leading port for car importation
    - one of Australia's largest grain export ports

  - other major trades include coal, iron ore, various dry and liquid bulk products and steel
- Port of Newcastle
  - one of the world's largest coal export ports
  - other major trades include cruise ship visits, alumina, petroleum, fertilisers, grains, cement, woodchips and steel
  - ships servicing the export coal trade are predominantly Panamax (65,000 DWT) and Cape Size with some minor shipments in Handy class vessels
  - developments from 2015–2020 include the development of 12 additional berths alongside the existing shipping channel on the Hunter River South Arm, and upgrades to existing berth infrastructure on the western side of Walsh Point to enhance operational and environmental performance.

In 2013, the NSW Government entered into a long-term lease for the Ports of Botany and Kembla, and in 2014, for the Newcastle Port. The state retained responsibility for all port safety aspects via the Ports Authority of New South Wales, which was established through the amalgamation of the state's former ports corporations and commenced operations on 1 July 2014.

The Ports Authority is responsible for:

- harbour masters and pilotage
- navigation services (including vessel traffic services)
- marine pollution and emergency response
- dangerous goods management
- management of Sydney Harbour, Yamba and Eden
- management of the Hunter Valley Coal Export Framework.

Transport for NSW is responsible for improving efficiency to and from NSW's ports. It is also responsible for regulating port safety and marine pollution response in all ports under the *Marine Safety Act*, the *Ports and Maritime Administration Act* and the *Marine Pollution Act*, and ensuring appropriate mechanisms are in place to maintain high standards of marine safety and environmental protection in the trading ports and coastal waters of NSW.

NSW Ports, a private entity, is responsible for managing, maintaining, and developing the Ports of Botany and Kembla to cater for trade demand. In its five-year port development plan, released in March 2014, NSW Ports notes that that the majority of container ships servicing Port Botany have a capacity of less than 4,000 TEUs (twenty-foot equivalent units). However, due to the long-term international trend of increasing container ship sizes, vessels with a carrying capacity of up to 6,000 TEUs are beginning to visit the Port. NSW Ports also notes that container terminal capacity is expected to be sufficient to accommodate the growth in total containers at Port Botany over the next five years.

NSW Ports identified the following projects of relevance to the NSW marine estate:

- maintenance dredging of Brotherson Dock at Port Botany to remove sediment build-up and restore the dock to its original dredged depth, for improved vessel access (project commencement: 2014)
- installation of sediment traps in the Bunnerong Stormwater Canal to capture sediment before it is deposited in Brotherson Dock (project commencement: 2016)
- berth and shipping channel maintenance dredging at Port Kembla to restore the depth of the harbour and improve vessel access, including reclamation to create new berth facilities (ongoing project).

Small commercial vessels (ferries, charter boats, fishing vessels)

Domestic commercial vessels include any of the following, which are used for commercial, governmental or research activity in Australian territorial waters (exclusive economic zone), including of the NSW marine estate:

- passenger vessels (carrying more than 12 passengers)

- trading vessels (e.g. tugs, barges, dredgers and other vessels carrying no more than 12 passengers)
- fishing vessels
- hire-and-drive vessels (e.g. cruisers, houseboats and powered dinghies).

These vessels are termed domestic, because their place of departure and first place of arrival are within Australia. They do not undertake international voyages, even though they may travel outside Australian territorial limits.

An estimated 8,748 registered commercial vessels operate in the NSW marine estate. These include commercial fishing vessels, including prawn and ocean trawlers, ocean trap and line fishing vessels and estuarine punts. Other commercial vessels provide harbour cruises, water taxis, estuarine and marine charters and ferry services (Transport for NSW is responsible for the contracting of passenger ferry services in NSW). Nature based tourism charters operate out of most NSW ports to undertake whale and dolphin watching, fishing charters, scuba diving and snorkelling, while some operators also offer adventure sports such as paragliding, jet boats and water-skiing. Vessels such as commercial catamarans and yachts can also be hired for holiday, sightseeing or private functions.

Table 14. Number of registered commercial vessels operating in the New South Wales (NSW) marine estate.

	NSW (excl. Sydney)	Sydney		Total
		Number	% of NSW vessels	
Survey vessels	1,864	507	21	2,371
Non-survey commercial vessels	1,732	1,167	40	2,899
Small hire-and-drive vessels	3,014	464	13	3,478
Total	6,610	2,138	24	8,748

Government agencies operate domestic commercial vessels for compliance, surveillance and research purposes, including the NSW Water Police, Roads and Maritime Services (RMS), Fisheries NSW, NSW Office of Environment & Heritage, and the Ports Authority of NSW. Research and other non-government organisations also operate domestic commercial vessels to undertake research, education and environmental awareness activities. There are also a large number of volunteer rescue boats (e.g. surf lifesaving, marine rescue).

DPI Crown Lands Division operates 25 coastal harbours along the NSW coast, which currently berth 588 commercial vessels. Of these, 276 are commercial fishing trawlers, and 312 are charter vessels (DPI Crown Lands 2014).

In the **northern region**, private passenger ferry operations run in the Clarence River. Other domestic commercial vessels include dredges used for maintenance dredging of estuaries and ports, and vehicle ferries to cross tidal waters (e.g. Clarence and Richmond River estuaries).

In the **central region**, much of the small commercial vessel activity occurs in and around Sydney Harbour (~20% of vessels statewide).

In the **southern region**, whale and dolphin watching and charter fishing mainly operates from the Crookhaven River, Currambene Creek and Jervis Bay, Clyde River and Batemans Bay, Wagonga Inlet, Bermagui, Merimbula Lake and Twofold Bay (Eden).

Current vessel management

All domestic commercial vessels used for commercial, governmental or research activity in Australia are regulated by the Australian Maritime Safety Authority (AMSA) under the *Marine Safety (Domestic Commercial Vessels) National Law Act 2012* (National Law). As delegates of AMSA, RMS is responsible for the effective day-to-day delivery of the National System for Domestic Commercial Vessels in NSW.

The National Law, which commenced on 1 July 2013, specifies requirements for:

- safe operation of domestic commercial vessels
- certificates of operation and survey
- vessel identification
- certificates of competency for crews and masters of commercial vessels.

All vessels require a certificate of operation, which specifies the type of operation, vessel use category and operational area for each type of operation. The certificate requires operators to have a Safety Management System to ensure that the vessel and its operations are safe.

High-risk vessels are required to have a certificate of survey to ensure that the vessel has been surveyed by an accredited surveyor and meets specified national standards for design, construction, stability, and safety equipment.

Crew on commercial vessels must hold a certificate of competency appropriate to the vessel length, complexity and area of operation. Delegated RMS examiners conduct final assessments before issuing certificates of competency. National system certificates are issued by RMS as a delegate of AMSA. Attested surveyors also conduct vessel survey inspections.

Commercial vessels must comply with state waterway management requirements including navigation requirements, speed and wash limits, restrictions on operating in certain areas and drug and alcohol laws. RMS and the NSW Police are responsible for compliance and enforcement activity both of the National Law and NSW marine safety legislation.

In June 2013, the Standing Council on Primary Industries endorsed the *Anti-fouling and in-water cleaning guidelines*[6]. These replace the *Australian and New Zealand Environment and Conservation Council Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance, 1997*.

RMS boat licence and boating handbook-*Marine Safety Regulation 2016* – rules associated with recreational boating in the Regulation are contained within the RMS Boating Handbook (Safety and Rules). To ensure recreational boaters understand the approach distance guidelines, RMS have incorporated education of boaters into the boat licence training and examination.

The *Protection of the Environment Operations Act 1997 (POEO Act)* is the main piece of NSW environmental legislation covering water, land, air and noise pollution and waste management. Under section 120 of the POEO Act it is illegal to pollute or cause or permit pollution of waters. Under the Act, 'water pollution' includes introducing anything, including litter, sediment, fuel, oil, grease, wash water, debris, detergent, paint, etc. into waters or placing such material where it is likely to be washed or blown into waters or the stormwater system or percolate into groundwater.

RMS are primarily responsible for regulation of small commercial vessels. DPI lands operates coastal harbours that berth commercial vessels.

Potential impacts of shipping

Water pollution - toxicants

Water pollution is possible from oil and chemical spills or ship accidents. A major spill can harm or kill organisms due to either acute toxicity from volatile components, or physical coating by oil. Significant instances of water pollution are rare in NSW. Only three significant oil spills were recorded in the last four decades, all of which were in the central region. The most recent event was in 2010 in Newcastle. However, each year sees numerous minor incidents or reports of oil or sheens, on the water or ashore, arising from shipping activities. For example, the then Sydney Ports Corporation's Annual Report for 2013–14 notes that staff responded to 225 pollution events, although there are no details on the scale or environment impact of these events.

[6] http://www.agriculture.gov.au/biosecurity/avm/vessels/anti-fouling-and-inwater-cleaning-guidelines

Oil spills have resulted in impacts to foreshore habitats in Port Jackson and Botany Bay. Such spills have killed mangroves around Towra Point in Botany Bay (Allaway 1982), and depending on the type of oil, can also kill mangrove seedlings (Grant et al. 1993). The effects of oil spills on macroinvertebrates in the remaining mangroves and saltmarshes are not considered to be long-term (McGuinness 1990), but if their habitat is removed, this will likely have an effect. Similarly, an oil spill altered the composition of intertidal rocky reef assemblages in Port Jackson, but there were signs of recovery after 12 months (MacFarlane and Burchett 2003).

Vessel pollution management: international

The MARPOL Convention (International Convention for the Prevention of Pollution from Ships), administered by the International Maritime Organization (IMO), is the main international instrument addressing marine pollution. Annex 4 of the convention applies to ships greater than 400 gross tonnes on international voyages, as well as to ships of less than 400 gross tonnes that are certified to carry more than 15 persons on international voyages.

The annex prohibits the discharge of sewage from ships within 3 nm of the nearest land, unless two conditions are met:

- the discharge must be carried out through a sewage-treatment plant that is certified to meet certain standards
- the discharge must not produce visible solids or discolouration of surrounding waters.

To meet these treated sewage standards, ships must have equipment on board to control sewage discharge. Sewage remaining in holding tanks on board ships may be discharged at waste reception facilities, which Annex 4 requires ports to provide. NSW ports already have, or can provide, sewage reception facilities in accordance with these requirements.

Vessel pollution management: NSW

The Port Authority of NSW provides the emergency response and clean up in each port for maritime incidents, such as oil and fuel spills. Oil and chemical spills are dealt with in accordance with the NSW State Waters Marine Oil and Chemical Spill Contingency Plan. The combat agencies include the relevant Port Authority if the incident occurs within the port boundary or AMSA for spills beyond 4 nm.

Transport for NSW maintains the NSW Oil Spill Response Atlas. This geographic information system stores environmental, resource and textual data that can assist planning and decisions during a response to a marine incident. Under the NSW arrangements, the NSW Environment Protection Authority (EPA) and the NSW Office of Environment & Heritage (OEH) provide an Environment and Science Coordinator to provide high-level environmental advice to the spill controller. The protection of the environment in connection with the use of trading vessels is regulated by Transport for NSW, RMS and the Port Authority of NSW under the *Marine Pollution Act 2012*. Transport for NSW has overall responsibility for ensuring that maritime oil and chemical spills are responded to, but the initial responsibility differs throughout the region, with assistance provided by other agencies as required. Fire and Rescue NSW, the Royal Australian Navy and the AMSA are responsible for incidents in inland waters, declared naval waters and Australian territorial sea and high sea (outside 3 Nm state limit), respectively.

If an oil or chemical spill incident requires a significant and complex response by multiple agencies, a position of Marine Pollution Controller (pre-appointed by the NSW Minister with responsibility for Ports) may be required to provide overall coordination. RMS is the appropriate regulatory authority responsible for the management of on-water pollution from all vessels (not just commercial vessels) in NSW waters, whether in the form of litter, sewage, greywater, bilge water, hull scrapings or chemicals, under the *Protection of the Environment Operations Act 1997*. Vessel owners are requested to promptly report any pollution events, either observed while on the water, or arising from their vessel.

If the pollution appears to be coming from a marina or land based facility, or from a vessel on a slipway being serviced or out of water on land, the EPA or the local government are the appropriate regulatory authority under the same Act. RMS requires vessel operators to store garbage on board and dispose of it responsibly once they're back in port or on shore.

Under the *Protection of the Environment Operations Act 1997* (*POEO Act*), pollution of waters is an offence. This includes, but is not limited to, water pollution in the form of litter, sewage, greywater, bilge water, hull scrapings, or chemicals. Vessel owners should report any pollution events either observed while on the water or arising from their vessel. In NSW waters, RMS is generally the appropriate regulatory authority (ARA) responsible for regulation of pollution from non-pilotage vessels while on the water. However, in some situations, DPI, the local government or the EPA may be the ARA, depending on the location of the spill. The EPA is the ARA for water pollution arising from activities and premises subject to an environment protection licence (e.g. some marinas and boat construction and maintenance facilities) and from activities carried out by, or premises owned by, a state or public authority. Excluding these situations, DPI is the ARA if a water pollution incident occurs in a marine park, while the local government is the ARA if it occurs within a local government area. The EPA is the ARA in all other situations.

The Marine Pollution Regulation 2014 prohibits the discharge of untreated sewage from any vessels into any navigable waters, or onto the bank or bed of any navigable waters, unless the sewage is discharged or deposited into a waste collection facility. Pump-out facilities are available for many boating areas across NSW[7]. Vessel owners are encouraged to make their own inquiries on pump-out facilities if visiting an unfamiliar area. Facilities listed may be privately owned (e.g. by marinas, boating clubs) and may have restrictions (e.g. 'members only', staff are required to operate the equipment) and may be subject to fees. Vessel owners are encouraged to report any difficulties, faults or vandalism to the owner of the pump-out facility. RMS requires vessel operators to store garbage on board and dispose of it responsibly once they are back in port or on shore.

Table 15. Area of control for oil and chemical incident responses in New South Wales and the response agency.

Jurisdiction or area	Response agency
NSW state waters	Transport for NSW
Queensland border to Fingal Head (Port Stephens)	Roads and Maritime Services
Port of Yamba	Port Authority of New South Wales (Sydney resources)
Fingal Head to Catherine Bay, including the Port of Newcastle	Port Authority of New South Wales (Newcastle resources)
Catherine Hill Bay to Garie Beach, including Sydney Harbour and Port Botany	Port Authority of New South Wales (Sydney resources)
Garie Beach to Gerroa, including the Port of Kembla	Port Authority of New South Wales (Port Kembla)
Gerroa to the Victorian border	Roads and Maritime Services
Port of Eden	Port Authority of New South Wales (Sydney resources)
Australian territorial sea and high sea (outside 3 nautical mile state limit)	Australian Maritime Safety Authority
Declared naval waters	Royal Australian Navy

[7] http://www.rms.nsw.gov.au/about/environment/environmental-compliance/vessel-waste-disposal/pumpout-facilities.html

The response to oil and chemical spills is integrated into the NSW emergency management arrangements set out in the NSW State Waters Marine Oil and Chemical Spill Contingency Plan[8], a sub-plan of the NSW Emergency Management Plan[9].

Major NSW oil-spill response exercises involving all agencies are held regularly, the most recent exercise being held in Port Macquarie in 2013 and Sydney in 2016. During 2012–2013, contingency plans for responding to oil spills were drafted for the north coast and south coast. These plans have been endorsed by the relevant regional emergency management committees and are available on the RMS website[10].

Fees collected from shipping, via the Port Authority of NSW, are used to pay the majority of costs incurred for maintaining the state's marine pollution response capability. This is supplemented by other revenue derived from general boating, which results in smaller marine pollution response activities each year.

Marine debris

Debris from international shipping has been found along the South Australian coastline (Edyvane et al. 2004), but studies of NSW have not identified shipping as a key source (Smith 2010, Taffs and Cullen 2005).

Risks to the NSW marine estate are reduced by existing regulations that state no garbage from shipping may be discharged within 12 nm from the nearest land. Under MARPOL Annex 5, garbage includes all kinds of food, domestic and operational waste – excluding fresh fish – generated during the normal operation of a vessel.

Annex 5 also:

- prohibits the disposal of all plastics anywhere into the sea
- requires all ships of 400 gross tonnes and above, and every ship certified to carry 15 persons or more, to keep a garbage record book and have a garbage management plan in place
- requires every ship of 12 m or longer to display placards notifying passengers and crew of the garbage disposal requirements on board the vessel
- requires signatory governments to ensure the provision of facilities at ports and terminals for the reception of garbage.

In NSW, garbage facilities are already available, or can be provided, at each port in the central region. Overall, the impact from marine debris from shipping in the NSW marine estate is expected to be low, but greatest in the central region, where vessel activity is at highest. Recent surveys by Smith (Poole 2015) have found that up to 50% of bottles washed up on beaches is of foreign origin. The lack of fouling suggests that these have been thrown from ships within our water.

Water pollution - Antifouling toxicants

Antifouling toxicants include organotins such as tributyltin (TBT), a chemical that was once used in antifouling paints, but that is now banned worldwide; and booster biocides, which were introduced as alternatives to organotin compounds. In Australia, coatings containing biocides must be registered by the Australian Pesticides and Veterinary Medicines Authority.

Under some conditions, the TBT half-life in sediments may be years (Cruz et al. 2014). It is likely that in some harbours in the **central region**, particularly near large dry-docking facilities (e.g. Garden Island) there may still be significant concentrations of organotins, including TBT and its breakdown products.

[8] http://www.maritime.nsw.gov.au/docs/ports/NSWMarineOilPlan.pdf

[9] http://www.emergency.nsw.gov.au/media/84.pdf

[10] http://www.rms.nsw.gov.au/about/environment/environmental-compliance/oil-chemical-spill-response.html

Sediment TBT concentrations of >5 µg/L were reported for several locations in the lower Hawkesbury River as recently as 2009 (Matthai et al. 2009). Two locations had concentrations that exceed ANZECC/ARMCANZ (2000) sediment-quality guideline values. This demonstrates the persistence of TBT and suggests that despite the ban on TBT antifouling paints, it may be many years before TBT presents no threat to the bioregion's marine fauna.

In Sydney Harbour, however, recoveries of wild populations of oysters have been reported (Birch et al. 2013a, Birch et al. 2013b). The ban on TBT was proposed to be a major factor in these recoveries. In a study of imposex (the masculinisation of females of certain marine snails in response to TBT) in aquatic snails from coastal NSW sites, a decline in TBT effects over time was reported (Wilson 2009). According to the study, 17 sites had a high frequency of imposex, with the conclusion that: 'low to moderate impact sites will have zero to low effects by 2025 and this will extend out to 2040 for high impact sites'.

Far fewer monitoring studies have been reported of booster biocides in Australian waters than for TBT. A study of sediments in the lower Hawkesbury–Nepean (Matthai et al. 2009) failed to detect Irgarol 1051 or chlorothalonil, but did detect diuron at concentrations up to 40 µg/kg (concentrations in a reference location were <1 µg/kg). The concentrations reported were below values reported in overseas studies.

Pests and diseases

Shipping is a key vector for the potential introduction of pests and diseases into the NSW marine estate, either via fouling of marine pest organisms on the ship's hull (including sea-chests) or via ballast water. To date, 58 marine pest species have been declared in NSW waters (NIMPIS 2009).

Major ports in the central region were surveyed as part of a national management initiative in Newcastle (CSIRO 1999), Port Kembla (Pollard and Pethebridge 2002b), Botany Bay (Pollard and Pethebridge 2002a), and Port Jackson (AMBS 2002). The surveys identified several non-indigenous species in most ports, but only very low numbers of any species listed on the national trigger list of the time.

One marine pest, *Caulerpa taxifolia,* has received significant interest since it was first detected in NSW in 2000. This alga is now known to occur in 14 estuaries in NSW, and both research findings and observations now consider it to fluctuate in density due to natural factors, including salinity and temperature. Due to the nature of *C. taxifolia,* and its ability to spread through natural dispersal mechanisms, management focus of this pest has shifted to education that encourages activities to minimise its spread to unaffected estuaries.

There were reports of the pest crab *Carcinus maenas* in Botany Bay (Ahyong 2005), but subsequent surveys have failed to detect the species (NSW DPI unpubl. data). The European fanworm *Sabella spallanzanii* was discovered in Botany Bay (Murray and Keable 2013), but again subsequent surveys failed to detect any more individuals (NSW DPI unpubl. data).

A risk assessment for marine pests for the Sydney region (Glasby and Lobb 2008) identified several high-risk vectors for a suite of new marine pests, including shipping. Modelling work in collaboration with the University of NSW then determined the likelihood of these species spreading to other NSW estuaries. Of the pests considered, the Asian bag mussel (already in Australia, but not in NSW) was by far the most likely to invade Sydney ports.

Pest and disease management

Australia is a signatory to the International Convention for the Control and Management of Ships' Ballast Water and Sediments (May 2005). Australia has applied ballast water management requirements in Australian waters since 2001. The Department of Agriculture and Water Resources is the lead agency.

The *Biosecurity Bill 2014* provides a framework for Australia to manage risks associated with ballast water and to work towards ratification of the Convention. AMSA plays an operational role in implementing the convention.

Smaller commercial vessels moored within the NSW marine estate are encouraged to reduce the risk of being a vector for pests and disease through actions such as:

- following the 'make clean' part of your routine guidelines[11]
- slipping and cleaning boats regularly (at least annually or when fouling is evident) and check for fouling every month on the boat, propeller, anchor and gear
- removing any weeds, animals or sediment from boats, trailers and gear and disposing of it on land in a bin
- draining all water from the boat and gear on land and preventing the water from re-entering coastal and marine areas.

Commercial vessels travelling out of NSW waters and then returning to NSW waters, or visiting commercial vessels from other jurisdictions, may be subject to quarantine under the *Quarantine Act 1908*. This Act is administered by the Department of Agriculture and Water Resources, which undertakes regulation of all vessels arriving in Australian ports or waters. These vessels may or may not come into contact with overseas ports, international vessels or installations.

All vessel stores and waste are subject to quarantine. If the Department of Agriculture and Water Resources considers a vessel subject to quarantine, Masters must decide if they wish the vessel to remain in international status or request a Release from Quarantine (Coastal stripping)[12].

Australian vessels may include, but are not limited to:

- commercial fishing vessels
- Australian customs and border protection vessels
- Royal Australian Navy vessels
- cargo carriers
- commercial tugs
- rig tenders
- non-commercial fishing vessels
- tour and charter vessels
- research vessels
- privately owned yachts and cruisers
- any Australian registered vessel.

The Department of Agriculture and Water Resources undertakes measures to control and limit the possibility of any pest or disease incursion. Vessels, crew, and passengers that have come into contact with any overseas ports, vessels or installations are subject to quarantine. Ships Masters are required to submit a Quarantine Pre Arrival Report prior to arrival. Private yachts and cruisers must contact Australian Customs and the department prior to arrival. All vessels are also required to manage their ballast water with a department-approved method. All disembarking crew and passengers must have their personal effects available for inspection by a department officer prior to leaving the vessel.

Large commercial vessels can be a key vector for the introduction and spread of pests and diseases within the NSW marine estate. This can occur via fouling of marine pest organisms on the vessel hull, or from related vessel equipment (e.g. trailers, ropes, anchors). Advisory information has been provided via Commonwealth and NSW Government agencies to vessel owners to attempt to reduce the risk of marine pest introduction and spread at state and national levels.

For larger commercial vessels, the risk of spreading marine pests is greatest when the vessel is:

- heavily biofouled with organisms such as mussels, oysters, seaweeds and seasquirts
- has been inactive or operating at low speeds (<5 knots/hour) for extended periods prior to relocating
- has a worn, aged or ineffective antifouling coating
- has areas where an antifouling coating hasn't been applied.

Large commercial vessels are encouraged to:

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[11] http://www.dpi.nsw.gov.au/fishing/pests-diseases/marine-pests/stop-the-spread/clean-routine

[12] http://www.agriculture.gov.au/biosecurity/avm/vessels/commercial-vessels/inspection/stripping

- manage ballast water according to Australia's mandatory *Ballast Water Management Requirements*[13]
- minimise the amount of biofouling through a high standard of cleaning and maintenance.

Operators are referred to the *National biofouling management guidance for non-trading vessels*[14] for guidance on specific maintenance practices for particular vessel types.

Key maintenance actions recommended to reduce the risk of large commercial vessels spreading marine pests include:

- slipping or dry-docking vessels before relocation to thoroughly clean and remove biofouling and to repair or replace the antifouling coating
- conducting an in-water inspection and where necessary, removing the vessel from the water to be cleaned or completing an in-water clean (noting the latest guidance for in-water cleaning in Australia[15])
- inspecting internal seawater systems, cleaning strainer boxes and dosing or flushing these systems
- inspecting and cleaning all above-water equipment and areas that may accumulate sediments and biofouling.

Large commercial vessels are also encouraged to:

- inspect antifouling coatings and repair any damaged areas, even if coating replacement isn't scheduled for that docking
- work closely with antifouling suppliers to identify the most appropriate coating(s) for the operating profile of the vessel, taking into account maximum and typical operating speeds, duration and frequency of periods of inactivity and maintenance and docking cycles
- consider applying different coatings to different areas of the vessel to match performance and longevity requirements with wear and water flow
- apply coatings to the accessible inner portions of intake/outlet ports
- consider coating areas not normally treated, such as main and thruster (auxiliary) propellers and log prober.

Smaller commercial vessels moored within the NSW marine estate are encouraged to:

- slip and clean boats regularly (at least annually or when fouling is evident) and check for fouling every month on the boat, propeller, anchor and gear
- select an antifouling paint suited to the vessel's activity and renew it when damage to the coating or persistent fouling occurs
- treat internal seawater systems regularly by flushing with freshwater or other treatment
- disposing of sewage and bilge water at an approved pump-out facility.

Smaller commercial vessels stored on trailers are also encouraged to reduce the risk of spreading marine pests and diseases by:

- removing any weeds, animals or sediment from boats, trailers and gear and disposing of it on land in a bin
- rinsing the boat and trailer and gear with fresh water at home or at a carwash

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[13] http://www.agriculture.gov.au/biosecurity/avm/vessels/biosecurity-concerns/ballast/australian-ballast-water-management-requirements-version6

[14] http://www.marinepests.gov.au/marine_pests/publications/Documents/Biofouling_guidance__NTV.pdf

[15] http://www.daff.gov.au/animal-plant-health/pests-diseases-weeds/marine-pests/anti-fouling-and-inwater-cleaning-guidelines

- draining all water from the boat and gear on land and not allowing the water to re-enter coastal and marine areas
- drying the boat and gear, including ropes and anchor.

Wildlife disturbance

Boats and ships impact the health of marine fauna populations by increasing noise, water pollution, and marine debris. Noise from shipping traffic is one of the most persistent sources of anthropogenic noise in oceans (Wright et al. 2007, Soto et al. 2006). The intensity of noise can impede the ability of marine animals to navigate, hunt, and communicate, with negative consequences for life-history behaviours (Southall 2005). Shipping can lead to separation of individuals from pods and calves from mothers, as well as displacement from critical habitat areas and migratory pathways (Van Waerebeek et al. 2007, Wright et al. 2007). Extreme consequences of noise disturbance from shipping activities include hearing damage and strandings (Wright et al. 2007). Increased concentration of vessel noise in coastal waters and near ports has the greatest consequences for nearshore species such as resident bottlenose dolphins.

Increases in vessel traffic have been shown to permanently displace animals from foraging areas and lead to complete shifts in habitat use (Tyack 2008). Most commercial shipping vessels including container ships and tankers emit low frequency noise, which interferes with baleen whale vocalisations (Soto et al. 2006, Southall 2005). Modern cargo ships and small vessels that have faster travel speeds emit mid to high frequency noise that can disturb toothed whale and dolphin communication and echolocation (Soto et al. 2006, Southall 2005). Seals are affected by a large range of mid frequency sound on both land and in water (Southall 2005). Vessel noise can mask the vocalisations of marine fauna (Southall 2005, Wright et al. 2007). Low frequency shipping noise has potentially reduced the communication range of baleen whales by tens to hundreds of kilometres (Tyack 2008), which can limit ability to locate mating partners (Tyack 2008).

Toothed cetaceans are also impacted and high frequency shipping noise can lead to an 82% reduction in communication range and a 58% reduction in echolocation clicks for some species. In response to noise animals may change their dive patterns, dive depth, direction, speed, and cease resting and foraging behaviours. In addition to affecting animal behaviour and communication, vessel noise can lead to stress in marine fauna which has consequences for physiological processes. Persistent stress can suppress reproductive success and compromise overall health and is likely to exacerbate the impact of other threats (Wright et al. 2007). Animals at greatest risk to noise-related stress include migrating whales with low energy reserves, resident marine fauna populations, and lactating females and their calves (Wright et al. 2007).

In October 2008, the 58th session of the IMO Marine Environment Protection Committee (MEPC) approved the inclusion of a new item on ‘noise from commercial shipping and its adverse impacts on marine life’. The basis for the new item was a proposal by the United States to develop non-mandatory technical guidelines to minimise incidental noise from commercial shipping operations in the marine environment, thereby reducing potential adverse impacts on marine life. Draft guidelines were approved by MEPC 66 in April 2014, and AMSA will oversee the implementation of these guidelines in Australian waters.

Physical disturbance

Shipping can result in physical damage to marine habitats, including (but not limited to) rocky reefs, sponge gardens, sand beds and beaches via anchoring and accidental grounding of vessels. Damage to these habitats will have flow-on effects on marine biodiversity, including fish and invertebrates that rely on these habitats for shelter and as a source of food. Vessel strike is recognised as significant global threat to marine wildlife and Australia accounts for approximately 17% of vessel strikes with whales worldwide (Peel et al. 2016). Globally in the past 50 years, the commercial shipping vessels has tripled; coupled with advances in tonnage and speed during that period has led to 3 times more collisions with ships and whales (Vanderlaan et al. 2009). Increased vessel traffic from commercial and recreational vessels in Australia is increasing the risk collisions between wildlife and vessels (Peel et al. 2016). Whales, dolphins, seals and turtles are at risk of vessel collision when they surface to breathe, as are sperm whales when they lie on the surface recovering from a dive. Incidents are more likely to occur near ports and areas with high commercial vessel traffic (Kemper et al. 2008). The relative risk to threatened and protected species across all three regions is highly localised, and varies from minimal in the north, to high in the south.

This reflects the relationship between the number of shipping activities within the estuary or port, and the increasing abundance of marine fauna – especially large whales – as well as the type and behaviour of the whale species present in these regions (e.g. endangered southern right whales occur more commonly in southern bays and estuaries). For example, in 2012 at Jervis Bay a vessel struck one of only two southern right whale calves born in the state that season.

The risk of shipping-related incidents with marine fauna is seasonal. Large whales, including humpback whales and southern right whales, migrate through NSW waters between June and November each year. During the southern migration, mothers with calves occasionally shelter in coastal bays and harbours. Marine turtles are present year-round, but are more likely to be sighted in NSW during warm water periods. Seals are also present year-round, but are associated with cooler water temperatures in southern NSW. Species that spend more time near the surface are more prone to vessel strike. For example, southern right whales often rest near the surface in coastal waters with only part of their head exposed, making them inconspicuous and highly prone to vessel strike (Van Waerebeek et al. 2007). Cetaceans with calves are also more prone to vessel strike.

Collisions between marine fauna and large vessels (>80 m long) and fast-travelling vessels (>14 knots) are more likely to result in animal mortality (Kemper et al. 2008). When ship speed exceeds 10 knots, animals can be dragged towards the hull, bow and propellers by hydrodynamic forces (Laist et al. 2014). The probability of a lethal collision doubles at speeds greater than 11.8 knots (Laist et al. 2014). The most effective measures to manage the threat of vessel strike include modifying the speed, routes and concentration of vessel traffic, while accounting for seasonal variation in the presence of marine fauna (Laist et al. 2014, Van Waerebeek et al. 2007).

More research has been published on vessel collisions with whales than other marine fauna. However, reports of marine turtles struck by vessels in NSW waters are reported in significantly greater numbers than are collisions with whales, dolphins and seals. The incidence of vessel strike in marine turtles is determined by the presence of visible injuries, such as fractures in the carapace or parallel cuts that are consistent with propeller strike (Hazel and Gyuris 2006). However, in many cases, vessel strike injuries are internal, or cannot be attributed to vessel strike alone. To determine cause of death in these cases, a necropsy (post-mortem examination) must be conducted. As necropsies are only performed on a small percentage of animals encountered, the incidence of vessel strike within the bioregion is likely to be under-reported.

Though NPWS does not have a systematic program for collecting vessel strike data, collisions are occasionally reported to NPWS. The NPWS Elements database has 80 records of marine mammals, reptiles, and birds that were struck by vessels since 1971. Vessel strike occurs across all regions and 48 of those animals were struck in the north region, 17 in the central region, and 11 in the south region (four of those were from an unknown location). During this period, 10 seals, eight dolphins, nine whales, and 52 turtles were reported as struck. Over the past 10 years (2007-16) 58 strikes were reported to NPWS (average 5.8 each year). The NPWS penguin mortality database has 28 records of boat strike from the Manly penguin colony in the past 20 years, with 12 of those occurring in the past five years. An additional 18 animals died of blunt force trauma, which is commonly associated with vessel strike, 12 of those were in the past five years. Some of these strikes are also attributed to non-commercial boating.

Quantifying the magnitude of vessel strike injury and mortality is problematic (Van Waerebeek et al. 2007). In some cases, when a boat collides with an animal, those on board may not be aware of the collision. Where vessel crew are aware of a collision, only a small number are reported to the OEH or other relevant organisation, because no formal reporting mechanisms are available. Of the beach-washed carcasses reported, only a subset show obvious injuries that are classified as vessel strike. This low reporting effort impedes an accurate assessment of the threat of vessel strike to marine fauna populations (Van Waerebeek et al. 2007). Mechanisms to improve this reporting could include community and industry education and developing an online web portal or phone app that facilitates the reporting process.

Sediment resuspension or disturbance

Sediment resuspension occurs when ships generate water movement of sufficient velocity to lift sediments off the seafloor. Generally this occurs when ships, or tugs manoeuvring ships, apply high propeller thrust in shallow waters, particularly at low tide. The consequences of this are dependent on the characteristics of the sediment. In estuaries where the sediment is contaminated, resuspension increases the likelihood that the contaminants can affect organisms living in the water. It also creates high levels of suspended sediments in the water column, which can harm organisms directly (e.g. smothering, clogging gills) or reduce water clarity and inhibit photosynthesis (e.g. in algae, seagrasses, benthic microalgae). Sediment disturbance can also reduce the biodiversity of benthic invertebrates that live in the sediments, which can have consequences further up food chains.

In the **central region**, in estuaries where the sediment is contaminated (e.g. Port Kembla), resuspension increases the likelihood that the contaminants can harm organisms living in the water. In the **northern and southern regions**, the level of activity is likely to result in limited and localised impacts.

Bank erosion

Waves generated by passing boats can erode river banks (Nanson et al. 1994), with waves higher than 35 cm causing serious erosion of unconsolidated sediments. Bank erosion can send significant amounts of sediment to estuaries and increase the turbidity of estuarine waters. Boat wash can also increase turbidity by resuspending sediments. This can have important consequences for a wide range of ecological processes. In the **central region**, vessel wakes in the Parramatta River have led to significant changes in benthic infaunal communities (Bishop and Chapman 2004). In the **northern and southern regions**, the level of activity is likely to result in limited and localised impacts, because most operations take place in coastal waters.

6.1.2 COMMERCIAL FISHING

Three share-managed fisheries currently operate in NSW estuarine waters: Estuary General Fishery (EGF), Estuary Prawn Trawl Fishery (EPTF), and to a lesser extent, Ocean Hauling Fishery (Table 16). Because fishery activities and their controls generally occur at a statewide level, rather than regional or local, the descriptions of these fisheries given below are necessarily generic. However, aspects specific to individual regions are highlighted where appropriate. Most of the effort in the Ocean Hauling Fishery occurs along ocean beaches; only a small amount takes place in the lower parts of estuaries.

Commercial fishing is permitted in only 86 of the 184 estuaries defined along the NSW coast (Roper et al. 2011). According to the separate regions, these include 41 of 55 estuaries in the northern region, 7 of 40 in the central region and 38 of 89 in the southern region (Table 17). Of these, 18 estuaries account for >95% of the total estuarine commercial catch. A large number of estuaries do not allow commercial fishing activity; many of these are defined as Recreational Fishing Havens (see Figure 15).

Commercial fishing catch and effort data (and recreational estimates) are used to monitor the condition of fish stocks, and to assess the economic contribution of fishing to the NSW economy. Estuarine commercial fisheries often catch a large range of species; hence, the assessment of specific fisheries is determined by the condition of harvested species. Fish species or species groups are assigned an exploitation status according to an assessment process. This includes the amount of knowledge held on the species, any long or short-term estimates, changes to harvest and changes to relative harvest effort. Over time, the level and proportion of species subject to detailed assessment continues to increase. A lack of knowledge increases the risk of overfishing for species that have not been subject to a full assessment. However, detailed assessment is usually deferred if a species shows no initial signs that would prompt a prioritised assessment of the exploitation status (Stewart et al. 2015).

In this current assessment process, stock exploitation categories (e.g. overfished, fully fished) contribute to the assessment of overall risk. Details of the exploitation status definitions are provided in Appendix 2. A selection of these species were also assessed in 2016 according to the Status of Australian Fish Stocks (SAFS) framework, and those determinations can be found on the SAFS website (http://fish.gov.au/). The SAFS reports are based on a consistent national reporting framework developed collaboratively by fisheries scientists across Australia. NSW DPI are currently transitioning to the SAFS framework for all of our NSW stock status assessments, which will next be completed in early 2018 for a reduced number of priority species.

Table 16. Commercial fisheries operating in estuarine waters of New South Wales and their occurrence in the Hawkesbury bioregion.

Fishery	Gear types used	Occurrence in the Hawkesbury bioregion	Comments
Estuary general	Multiple	Occurs in 76 estuaries distributed across all three regions	Includes mesh netting and use of crab traps
Estuary prawn trawl	Otter nets	Three estuaries only (Clarence, Hunter and Hawkesbury rivers), all in northern and central bioregions	Targets school prawns
Ocean haul	Multiple	Some activity in lower parts of some estuaries	Majority occurs along ocean beaches

Table 17. Estuaries in each region of the New South Wales marine estate where commercial fishing is currently permitted.

Northern region		
Tweed River[a]	Arrawarra Creek	Korogoro Creek
Cudgen Creek	Darkum Creek	Killick Creek
Cudgera Creek	Woolgoolga Lake	Lake Innes
Mooball Creek	Hearnes Lake	Lake Cathie
Brunswick River	Moonee Creek	**Camden Haven River**
Richmond River	Coffs Creek	**Manning River**
Evans River	Boambee Creek	Khappinghat Creek
Jerusalem Creek	Bonville Creek	**Wallis Lake**
Clarence River	Dalhousie Creek	**Smiths Lake**
Lake Wooloweyah	Oyster Creek	**Lower Myall River**
Sandon River	**Nambucca River**	Lake Booloombayte
Wooli Wooli River	**Macleay River**	Karuah River
Station Creek	SW Rocks Creek	**Port Stephens**
Corindi River	Saltwater Creek	
Central region		
Hunter River	**Pittwater**	Towradgi Creek
Tuggerah Lake	Port Hacking	**Lake Illawarra**
Hawkesbury River		
Southern region		
Minnamurra River	Durras Lake	Little Lake (Wallaga)
Spring Creek	Batemans Bay	**Wallaga Lake**
Werri Lagoon	Cullendulla Creek	Barragoot Lake
Crooked River	Candlagan Creek	Cuttagee Lake
Shoalhaven/Crookhaven River	Moruya River	Murrah Lake
Lake Wollumboola	Congo Creek	Bunga Lagoon
Jervis Bay	Meringo Creek	Wapengo Lake
Swan Lake	Coila Lake	Middle Lake
Berrara Creek	Lake Brou	Wallagoot Lake
Nerrindilah Creek	Kianga Lake	Merimbula Lake
Termeil Lake	Nangudga Lake	Curalo lagoon
Willinga Lake	Nargal Lake	Twofold Bay
	Corunna Lake	
	Tilba Tilba Lake	

a Estuaries in **bold** account for >95% of the total estuarine commercial catch

Figure 15. Location of recreational fishing havens along the New South Wales coast.

Overall, DPI manages the each Fishery in accordance with the *Fisheries Management Act 1994*, the relevant regulations and the Fishery Management Strategy. Access is limited to shareholders in the fishery, and/or their nominated fisher, who hold shares the minimum (or above) shareholding.

Daily cultural fishing needs are currently provided for by the *Aboriginal Cultural Fishing Interim Access Arrangement* which allows for extended bag and possession limits, as well as other special arrangements, for cultural fishing activities. Special provisions also exist under the Act to accommodate access to fisheries resources beyond what the current cultural fishing rules provide for (for events such as for a large cultural gathering or ceremonies).

Management actions to address potential threatened species interactions include:

a) mandatory reporting of threatened and/or protected species interactions for all commercial fisheries, including distribution of a waterproof threatened and protected species identification brochure; and,

b) scientific observer work. A number of performance indicators included in the FMS, used as part of the FMS performance monitoring process, relate to resource sharing.

The purpose of these performance indicators is to detect large shifts in catch of key species, over time, between:

a) the commercial and non-commercial sectors;
b) among each commercial fishery in NSW; and,
c) among methods or endorsement types within a fishery.

The Ministerial Fisheries Advisory Council (MFAC) has developed a policy - *Fisheries Resource Sharing in NSW* - to assist decision-making on sharing the State's sustainably exploitable fisheries resources between the various commercial, recreational, charter and Aboriginal cultural fishing sectors in accordance with the objects of the Act.

Active compliance regime including:

- Overt and covert compliance operations.
- Dedicated compliance effort across each sector.
- Enforcement policy and procedure and prosecution system.
- Monitoring and reporting of results.

Estuary General Fishery

The EGF operates in 76 estuaries of NSW. It includes all forms of commercial estuarine fishing (other than estuary prawn trawling) in addition to gathering pipis and beachworms from ocean beaches. The most frequently used fishing methods are mesh and haul netting. Other methods used include trapping, hand lining and hand gathering.

More than 80 species or species groups of fish are caught in this fishery, although five species make up more than 75% of statewide landings by weight: sea mullet (*Mugil cephalus*) (50%); luderick (*Girella tricuspidata*) (8%); school prawn (*Metapenaeus macleayi*) (8%); yellowfin bream (*Acanthopagrus australis*) (7%); and dusky flathead (*Platycephalus fuscus*) (3%) (Figure 16).

The overall catch from the fishery within NSW coastal waters was 4,109 tonnes in 2013–2014 (Figure 16). The catch of the main species, sea mullet, declined between 2009–2010 and 2012–2013 by 661 tonnes, but increased by about the same amount between 2012–2013 and 2013–2014. Luderick showed the opposite trend over the same periods, increasing by 97 tonnes and then decreasing by 36 tonnes. Catches of yellowfin bream have increased by 71 tonnes between 2011–2012 and 2013–2014, while those of dusky flathead have decreased in the same period by 54 tonnes. The combined catch of other species has declined slowly by 11% over the last five years.

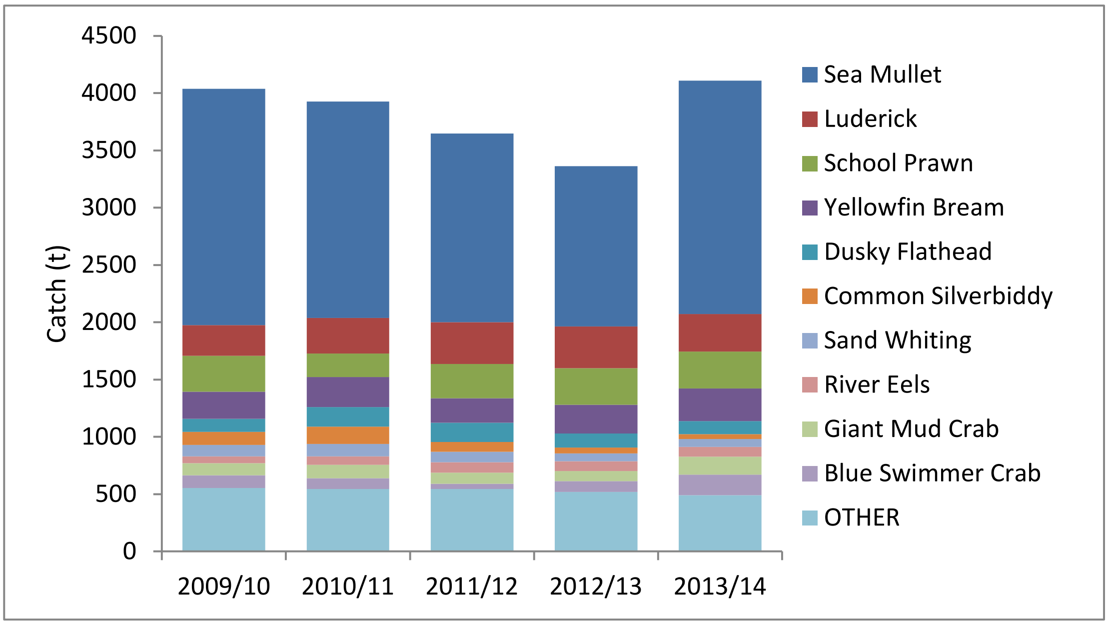


Figure 16. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the Estuary General Fishery in New South Wales estuarine waters (catch is reported by the top 10 species, with the remainder classified as 'other'). *Source: DPI Fisheries catch records database.*

The proportion of the EGF catch taken in NSW estuarine waters is largest in the northern region and smallest in the southern region: ~65% and 8%, respectively (Figure 17). In the **northern region**, 70% of the catch came from five estuaries – Clarence (31%), Wallis Lake (17%), Port Stephens (8.6%), Richmond (8%), and Myall Lakes (6%). In the **central region**, 97% of the catch is taken from four estuaries – Hawkesbury (40%), Tuggerah Lake (30%), Hunter (14%), and Lake Illawarra (14%). In the **southern region**, two estuaries contributed 64% of the catch – Shoalhaven (53%) and Wallaga Lake (11%).

There is considerable variation in the level and composition of catch between estuaries in different regions. Sea mullet dominates the catch composition in the north and central regions (51 and 56% of the total catch, respectively). In the southern region, luderick is the dominant species taken, followed in equal proportions by sea mullet and yellowfin bream at 22 and 17%, respectively (Figure 18).

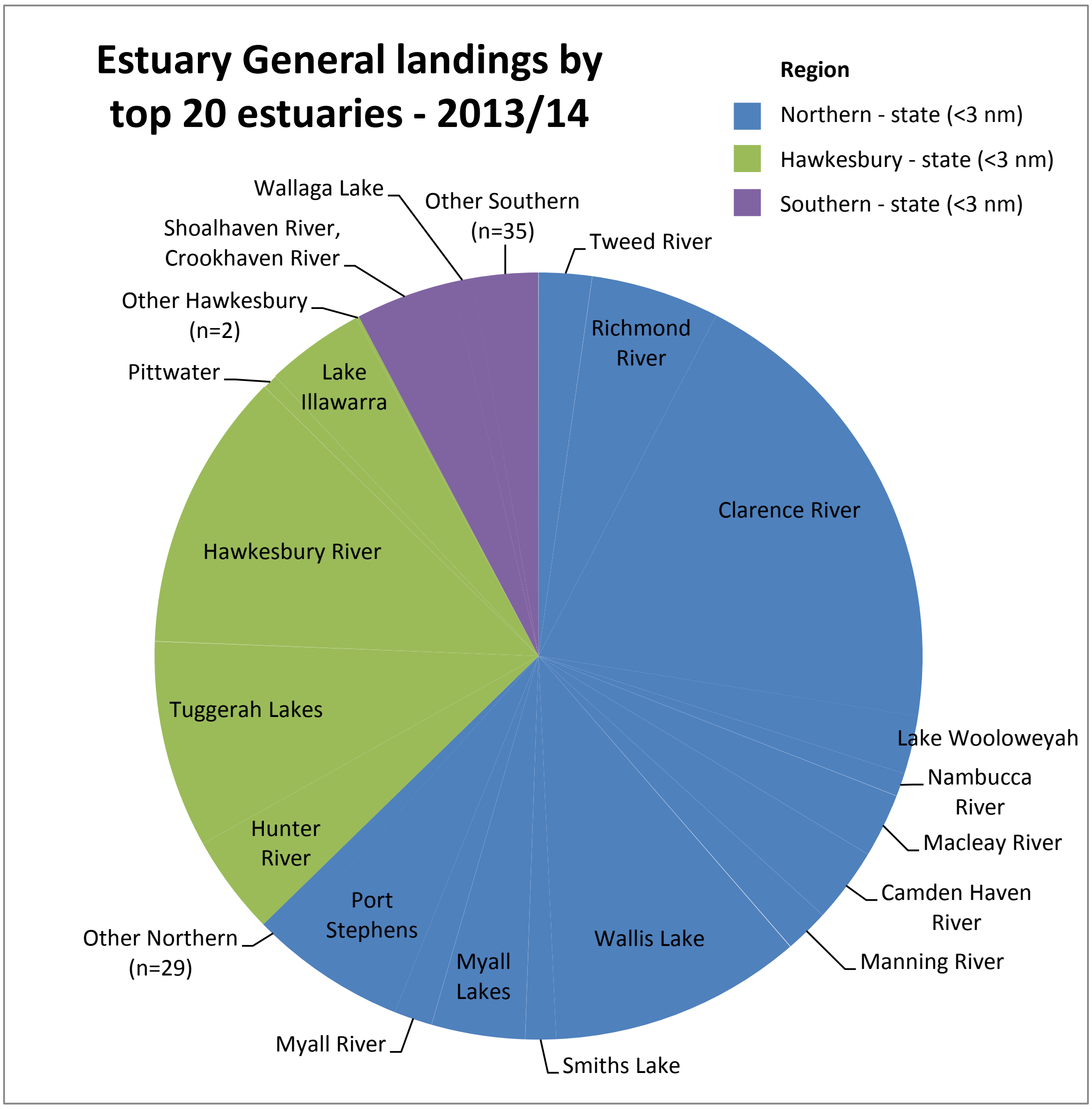


Figure 17. Proportion of landings for the top 20 estuaries in the Estuary General Fishery by region in 2013/14. *Source: DPI Fisheries catch records database extract 26 November 2015.*

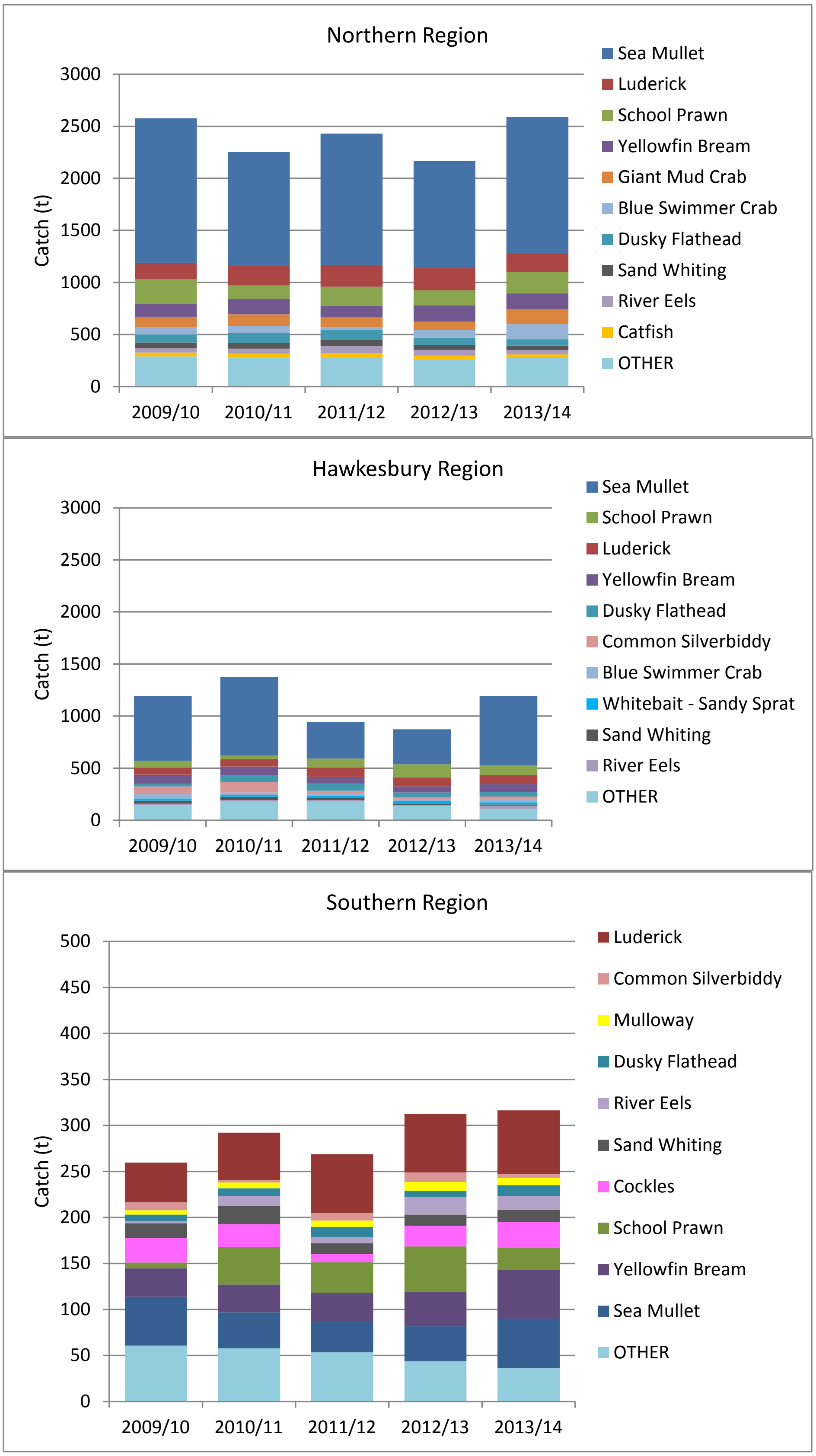


Figure 18. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the Estuary General Fishery (inshore 3 nm) for the top 10 species in each coastal region of New South Wales. *Note: Maximum value on y-axis of the southern region is different from the other two graphs. Source: Source: DPI Fisheries catch records database extract 26 November 2015.*

Current management arrangements of the Estuary General Fishery

The EGF is a share-management fishery divided geographically into seven regions, from the far north coast to the far south coast of NSW. The primary management controls used to assist in the long-term sustainability of the fishery include:

- a limit on the number of fishers authorised to operate in each region of the fishery
- temporal and spatial closures
- gear restrictions (i.e. mesh sizes and net lengths)
- daily and possession limits
- species restriction
- minimum size limits.

The NSW estuarine waters available to this fishery have decreased over the past 15 years. In part, this is due to the implementation of recreational fishing havens and specific marine park zones throughout NSW. In May 2002, 30 areas along the NSW coast became recreational fishing havens to improve recreational fishing opportunities. The re-allocation of the fisheries resources in the selected areas, from the commercial sector to the recreational sector, involved a licence buy-out program. This has meant the removal of all EGF activity from Lake Macquarie, Botany Bay and many estuaries in the northern and southern regions. More recently, Sydney Harbour was closed to all commercial fishing, including EGF, because of dioxin contamination issues (SIMS 2014). Of the remaining regions, not all NSW estuarine waters and ocean beaches are open to the EGF. The Fisheries Management (Estuary General Share Management Plan) Regulation 2006 outlines waters in which EGF is permitted to operate, noting that additional time and area closures may exist within these waters. Restrictions also apply to the EGF prohibiting operating on weekend and public holidays in given areas.

In marine parks, fishing activity within the EGF is not allowed within sanctuary zones. However, it is partially allowed in many habitat-protection zones, and is unrestricted within general-use zones. The extent of estuaries within marine parks varies considerably along the NSW coast. For example, there is little estuarine habitat within the Cape Byron Marine Park, mostly within the Brunswick River. Similarly, the estuaries within the Solitary Islands Marine Park are small, the largest being the Wooli Wooli River. The 15 estuaries within the Marine Park are of two main types: barrier lagoons, and intermittently closed and open lakes and lagoons. In contrast, the large estuaries of Port Stephens, Myall Lakes ,and Smith Lakes are within the Port Stephens-Great Lakes Marine Park. For the purpose of this assessment, Jervis Bay is considered an estuary, and makes up a significant part of Jervis Bay Marine Park.

A suite of management arrangements have been implemented in the EGF to manage the impacts of the fishery on species abundance, including a limited entry regime, controls on fishing gear and boats, temporal and spatial fishing closures, size limits, commercial catch limits and restrictions.

A recovery program and associated management arrangements for mulloway, covering all stakeholder groups, were implemented in 2013 to rebuild the population to a sustainable level in NSW. The current management arrangements include:

- a reduction to the recreational bag limit from five (with only two over 70 cm) to two;
- an increase to the minimum legal length from 45 to 70 cm;
- a by-catch allowance of 10 fish between 45 and 70 cm for mulloway incidentally caught in estuarine meshing nets; and
- a 500 kg possession limit per ocean hauling endorsement holder.

The minimum mesh size in flathead nets has been increased to minimise the capture of dusky flathead that are below the minimum legal length.

Management remains adaptive and able to modify fishing gear or the use of gear when necessary to reduce impacts on non-retained organisms. The minimum mesh size in overnight set meshing nets (set during the winter months only) has been selected to reduce the catch of unwanted fish and/or fish below the minimum legal length.

To reduce the impacts of the EGF on non-retained fish, invertebrates, reptiles, mammals and birds; the use of discard chutes has been implemented for methods meshing nets and flathead nets during the period one hour before official sunrise to one hour after official sunset. Discard chutes facilitate the return of fish removed from mesh nets.

DPI has completed several research projects on improving the selectivity of prawn catching gear and reducing unwanted bycatch. As a result of this research implementation of square mesh codends (highly effective at retaining targeted species and reducing bycatch) in the EG prawn fisheries has been approved.

Potential impacts of the Estuary General Fishery

Reductions in abundance of species and trophic levels

This stressor relates specifically to the harvest of fish assemblages from the EGF. Overall, the stock status of exploited marine species assessed using available data from 2013–2014 is presented in Appendix 3. Further details are provided in the Status of Fisheries Resources in NSW 2013–2014 report (Stewart et al. 2015)[16]:

Approximately 65% of recent statewide landings are taken in the **northern region**, and are dominated by three species that make up around 60% of landings and are primarily commercially taken in the EGF. Approximately 70% is taken from five estuaries, which is likely to result in higher risks associated with this activity for these estuaries. Overall, recent landings are dominated by five fully fished (sea mullet, luderick, yellowfin bream, school prawn, sand whiting) and five uncertain or undefined species (giant mud crab, blue swimmer crab, dusky flathead, river eels, catfish) in the top 10, and intermediate (I) or higher risk as defined in the EGF environmental impact statement (EIS).

In the **central region**, the range of species taken is similar to the northern region. However, the quantities removed are much smaller, and the catch is taken from far fewer estuaries (seven of 40), which increases the risk associated with this activity for some estuaries. Approximately 27% of recent statewide landings are taken from this region. These are dominated by five species that make up approx. 80% of landings, and are primarily commercially taken in the EGF. Overall, recent landings are dominated by five fully fished (sea mullet, luderick, yellowfin bream, school prawn, sand whiting) and five uncertain or undefined species (common silverbiddy, blue swimmer crab, dusky flathead, river eels, whitebait) in the top 10, and which have intermediate or higher risk as defined in the EGF EIS.

In addition, mulloway is a key secondary species in the EGF that is identified as overfished. Mulloway have been subject to a recovery plan since 2013, which includes increased recreational and commercial size limits, reduced recreational bag and commercial trip limits, and a small allowance for estuarine commercial slot limit bycatch.

Harvest of nippers in Port Hacking was identified as a low level of impact. However, their undefined status shows that the effect of this harvest, particularly at a local scale, is unknown.

In the **southern region**, the overall harvest is considerably lower, at approximately 8% of recent statewide landings. This is dominated by three species that make up approx. 60% of landings. These species are primarily commercially taken in the EGF. While landings are principally taken from one estuary (Shoalhaven and Crookhaven Rivers), overall catch is spread over 37 estuaries. Recent landings are dominated by one overfished (mulloway), five fully fished (luderick, yellowfin bream, school prawn, sand whiting, sea mullet) and four uncertain/undefined species (common silverbiddy, cockles, dusky flathead, river eels) in the top 10, and which have intermediate or higher risk as defined in the EG EIS.

[16] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/566652/status-fisheries-resources-NSW-2013-14-Final.pdf

Overall, the fishery is characterised by the dominance of sea mullet, luderick, yellowfin bream, and school prawns in the northern and southern regions in all years (generally making up >60% of landings), significantly lower catches in the southern inshore region compared to the other regions in all years, the recognition that the landings and length distribution of sea mullet and yellow fin bream has remained relatively stable through time, lack of evidence that current school prawn harvest levels are not sustainable, the dominance of fully fished species and absence of overfished species in the dominant landings, and a very small contribution of mulloway to the landings.

Bycatch

Unwanted species are often caught by EGF methods, particularly in mesh and haul nets. These species are generally returned to the water, whether dead or alive. Observer based studies have examined discards from components of the EGF, particularly those derived from the use of meshing nets (Gray et al. 2004 2005). Following these studies, modifications were made to reduce bycatch: for example, by increasing mesh size and net height. However, because mesh and haul netting are the most frequently used fishing methods, there are ongoing uncertainties about the level of bycatch for many species, and hence the overall impact of these methods on the fish assemblage.

This stressor is principally associated with fish assemblages in shallow soft sediment and seagrass habitats in estuaries. The overall levels of bycatch are likely to be higher in the **northern** and **central regions**. This reflects the greater EGF activity in these regions, much of which comes from the large estuaries, including the Clarence River, Wallis Lake, Port Stephens (northern) and Hawkesbury River and Tuggerah Lakes (central). However, the estuary-specific impacts are expected to be similar in the many smaller estuaries of the **southern region**. In addition, bycatch levels have been reduced due to introduction of changes in mesh sizes, and bycatch while using seine nets have been shown to be low.

Incidental catch of species of conservation concern

Marine mammals, reptiles and birds are at risk of entanglement and capture in the EGF including in passive and active net methods (Ganassin and Gibbs 2005). Sinkers and hooks can also cause mortality if accidently ingested (Ganassin and Gibbs 2005). Gillnet fisheries are known to capture marine mammals, turtles and birds (Beeson 1998, Cox et al. 1998, Julian and D'agrosa et al. 2000, Kinas 2002, Oesterblom et al. 2002, Quinn 1988, Trippel et al. 1996). However, their impact to marine wildlife in the EGF is not clear, though an observer study in NSW detected the capture of a cormorant (Gray et al. 2005). The NPWS Elements database captures data on wildlife that are entangled in fishing gear. Many entanglements are reported each year in gear types used by the EGF (see section 6.2.1 for details). However, low reporting effort and a lack of information on gear or fishery type associated with entanglements impedes an accurate assessment of the threat of the EGF to marine fauna populations.

The EIS found that the EGF was not currently having a direct or adverse impact on any threatened species. The lifecycles and preferred habitats of many threatened species, combined with the techniques used in the fishery, suggest that there is limited scope for the fishery to significantly affect these species. However, the EIS noted that a high degree of uncertainty was associated with this assessment, due to the small amount or absence of quantitative data and the reliance on anecdotal information.

Wildlife disturbance

Birds, marine mammals and marine reptiles can be disturbed during meshing and hauling activities and disturbance of shorebird nesting, foraging, and roosting habitat can occur when EGF fishers access sites. Marine wildlife including birds, dolphins, and seals have been observed feeding off discards in NSW fisheries using hand/drop line and trapping methods (Ganassin and Gibbs 2005). Competition between fishers and wildlife can occur when prey items and foraging grounds overlap with fishing, reducing overall population health for those species (Ganassin and Gibbs 2005). No studies have been done in NSW to specifically assess these interactions with the EGF.

Marine debris

Derelict and active fishing gear is by far the greatest cause of entanglement of marine wildlife around Australia (Ceccarelli 2009). Much of this occurs in the nation's northern waters. Data from NSW are a bit sparse with most incidents being recorded in northern NSW and Sydney regions (Ceccarelli 2009). There are no data on rates of loss of commercial fishing gear in NSW.

Estuary Prawn Trawl Fishery

The EPTF uses otter trawl nets to target school prawns and eastern king prawns in three NSW estuaries: the Clarence (northern region), Hunter and Hawkesbury rivers (central region). The usual length of boats in the EPTF is 8–10 m. Effort in the fishery across the state has been gradually increasing since 2009–2010 to 4,876 days per year (an increase of 24%). Note that this reflects a short period, and that significant floods in 2009–2010 in the Clarence River resulted in very low levels of fishing effort during that year.

The total annual NSW catch from the EPTF has remained around 400 tonnes for the past four years (Figure 19). The catch of the main species, school prawns (89% of the catch), has remained steady over the last four years at around 360 tonnes. Loligo squid, the second-largest catch in the fishery, has increased since 2010–2011 by 6 tonnes. Incidental catches of blue swimmer crab decreased by 50% to 1.4 tonnes between 2009–2010 and 2012–2013, but 2013–2014 catches returned to higher levels of 2.9 tonnes. The combined catch of other species has declined since 2011–2012 by 51% to 4.4 tonnes.

The proportion of the EPTF catch taken in NSW estuarine waters is largest in the **central region** (60%), with the remainder in the **northern region** (Figure 20). There is no estuary prawn trawling in the **southern region**. School prawns dominates the catch composition in both the north and central regions: 98 and 83%, respectively, of the total catch. In the central region, loligo squid makes up 8% of the catch (Figure 21).

There is considerable variation between estuaries within regions in the level and composition of catch in the EPTF (Figure 21). In the northern region, 74% of the catch came from the Clarence estuary and the remainder from Lake Wooleyweah. In the Hawkesbury region, 71% of the catch came from the Hawkesbury estuary and 29% from the Hunter (Figure 21). School prawn catches in the northern region have declined since 2010–2011 by 24%, but in the central region they have increased since 2009–2010 by 61% (Figure 21). In the central region, only 19 species or species groups are authorised to be taken as byproduct species, although four species form the dominant component of the non-target catch. There are obviously more species caught (i.e. bycatch) that are not reported by fishers. Apart from the squid species, the most dominant bycatch species are trumpeter whiting and silverbiddy (Figure 21).

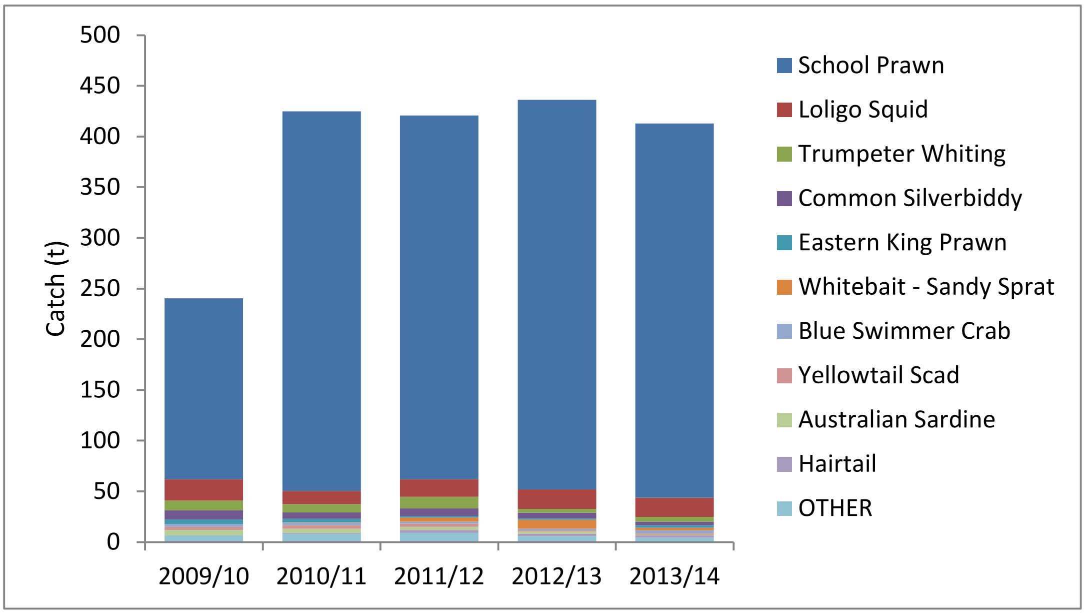


Figure 19. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the Estuary Prawn Trawl Fishery for New South Wales; catch is reported by the top 10 species, with the remainder classified as 'other'. *Source: DPI Fisheries catch records database extract 26 November 2015.*

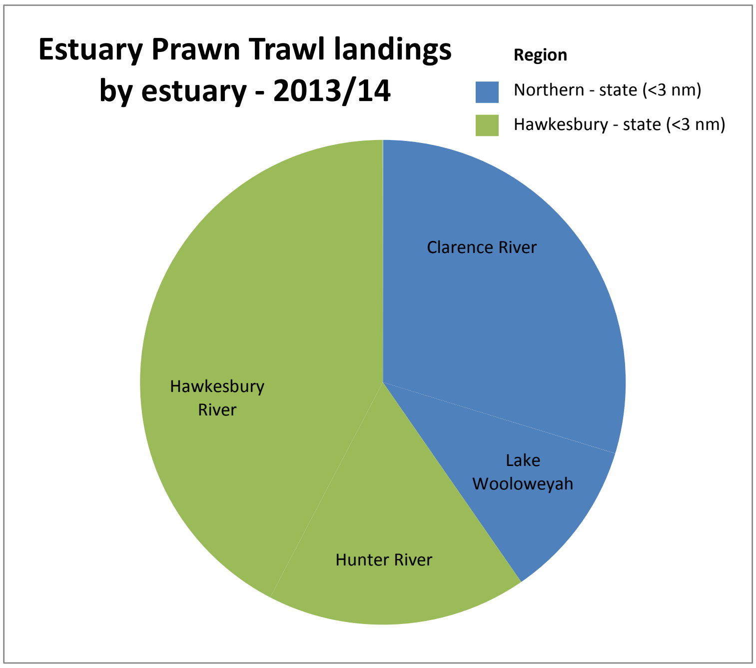


Figure 20. Proportion of landings in each estuary for the Estuary Prawn Trawl Fishery by region in 2013/14. *Source: DPI Fisheries catch records database extract 26 November 2015.*

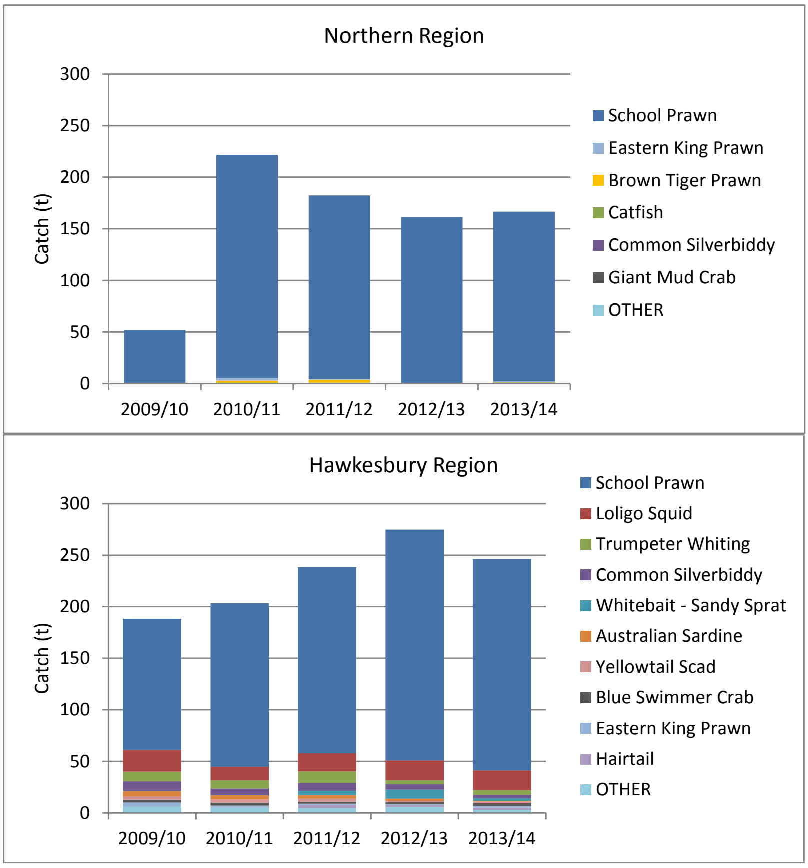


Figure 21. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the New South Wales Estuary Prawn Trawl Fishery inshore 3 nm for the top 10 species by region. *Source: DPI Fisheries catch records database extract 26 November 2015.*

Current management arrangements

The EPT Fishery is managed under the *Fisheries Management Act*, and the regulations made under this Act. The EPTF is a share-management fishery that is managed predominantly by limiting the amount of effort commercial fishers put into their fishing activities. These input controls include restrictions on:

- the numbers of fishers endorsed to operate in each estuary
- a range of seasonal, time and area fishing closures
- the number and size of vessels permitted
- the size and dimensions of the fishing gear used.

In recent years, fishers have reduced the volume of bycatch (marine turtles and other non-commercial fish species) in their nets by using bycatch reduction devices. The use of these devices is now mandatory in all areas of the EPTF. There are also fishing closures to approximately 50% of each of the two estuaries where the EPTF occurs (in the upper reaches of the Hunter River, and upper and some lower sections of the Hawkesbury River). The Clarence and Hunter Rivers are closed during winter to conserve prawn stocks and stocks of juvenile fish.

Several strategies are applied in the EPTF to minimise any bycatch issues, including:

- keeping only target and byproduct species
- implementing permanent temporal and spatial closures
- defining operating hours during the season and restricting boat capacity
- enforcing maximum prawn counts per ½ kilogram
- enforcing maximum net lengths
- prohibiting the keeping of fish below the legal size limit

- compulsory use of bycatch reduction devices
- closing areas where catch ratios indicate high abundance of incidental species
- using best-practice fishing techniques.

Potential impacts of the Estuary Prawn Trawl Fishery

Reductions in abundance of species and trophic levels

This stressor relates specifically to the harvest of fish assemblages from the EPTF. Overall, the stock status of exploited marine species assessed using available data from 2013–2014 is presented in Appendix 3. Further details are provided in the Status of Fisheries Resources in NSW 2013–2014 report (Stewart et al. 2015)[17]. The risk to retained species was previously assessed as high where their exploitation status was unknown (NSW Fisheries 2002b).

In the **northern region**, approximately 40% of recent statewide landings taken from this region were dominated by school prawns, which make up around 80% of landings. School prawns are identified as fully fished and have a high overall risk defined in NSW Fisheries (2002b). In addition, eastern king prawns are caught in small numbers in the EPTF, which is growth-overfished and has a high overall risk rating in NSW Fisheries (2002b).

In the **central region**, around 60% of recent statewide landings taken from this region were dominated by school prawns, which make up around 98% of landings. School prawns are identified as fully fished and have a high overall risk defined in NSW Fisheries (2002b). In addition, eastern king prawns are caught in small numbers in the EPTF, which is growth-overfished and has a high overall risk rating in NSW Fisheries (2002b).

The EPTF does not operate in any estuarine waters in the **southern region**.

Incidental bycatch

The trawling methods used in this fishery are a relatively non-selective method of fishing that can catch non-targeted species or juveniles of commercially and recreationally important species. For this reason, bycatch reduction devices are compulsory; when installed onto trawl nets, they significantly reduce the capture of bycatch species. Most byproduct species (e.g. octopus, whiting, crabs, flounder, mantis shrimp) are economically important and can be marketed.

However, there are ongoing uncertainties about the level of bycatch in the fishery across a large number of species, and hence the overall impact on this bycatch component of the fish assemblage. This stressor is principally associated with fish assemblages in shallow soft-sediment habitats within the Clarence River.

Incidental catch of species of conservation concern

The EPTF is unlikely to interact with any threatened fish species, because very few are likely to occur in the areas targeted by EPTF fishers. The EPTF EIS noted that the risk of the EPTF to threatened or protected species of seabirds, marine mammals and reptiles was also low. However, threatened turtles and seals have been reported as entangled in the EPTF in NSW (Ganassin and Gibbs 2005). Marine turtles in the northern region are vulnerable to capture in trawls in shallow water estuaries. When turtles are caught in trawl nets they are likely to die of drowning and smaller animals, which are most common in NSW, are more likely to drown or asphyxiate than larger animals (Ganassin and Gibbs 2005). Turtles are most likely to suffer mortality during long trawls as found in the Australian Northern Prawn Fishery, which frequently catches turtles during trawls over 90 minutes.

[17] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/566652/status-fisheries-resources-NSW-2013-14-Final.pdf

In Australia, dolphins and seals are most commonly recorded as captured in trawl gear (Ganassin and Gibbs 2005). Otter trawls are known to pose a threat to marine wildlife and are listed as a key threatening process to turtles in Qld (Ganassin and Gibbs 2005). Marine wildlife including birds, dolphins, and seals have been observed feeding off discards in NSW fisheries using trawling methods and are at greater risk of entanglement, capture, vessel strike, or ingestion of fishing gear when doing so (Ganassin and Gibbs 2005). In recent years, fishers have reduced the volume of bycatch (marine turtles and other non-commercial fish species) in their nets by using bycatch reduction devices. The use of these devices is now mandatory in all areas of the EPTF. The extent to which this has reduced interactions is not known as bycatch reporting not required.

Wildlife disturbance

Indirect impacts on wildlife can occur from noise, collision with vessels and behavioural modifications arising from fishing activities. Wildlife that could be affected by the EPTF may include marine turtles, sea snakes, seabirds, terrestrial mammals, marine mammals and non-target fish. The adoption of turtle-excluding devices, such as those deployed elsewhere in Australia, may significantly reduce the probability of capturing and drowning marine turtles. Disturbance of shorebird nesting, foraging, and roosting habitat can occur when EPTF fishers access sites or conduct near shore activities. Competition can occur when prey items and foraging grounds overlap with fishers, reducing population health (Ganassin and Gibbs 2005).

Physical damage

Trawling estuarine habitats can cause physical damage to estuarine habitats as a consequence of direct net contact. Trawling is prohibited over sensitive habitats, such as seagrass and rocky reefs, and closures have been implemented to protect these key habitats. In NSW Fisheries (2002b) it was noted that there was insufficient information about the distribution of key estuarine habitats and the impact of trawling on these habitats to categorise the risk of damage to these habitats. The EIS also noted that trawling has taken place in the three EPTF estuaries for more than 60 years, and that therefore any changes would no longer be discernible.

In the **northern region**, no statistically significant differences in soft-sediment biota were found in a detailed comparison of areas of the Clarence River subjected to harvesting by prawn trawlers and those not trawled (Underwood 2007). No such studies have been done in the Hunter or Hawkesbury rivers in the central region, but it is reasonable to assume that similar results would be found. An updated risk assessment for the Hawkesbury River (Astles et al. 2010) concluded that the EPTF represents a low-risk activity to benthic habitats, because of the effective management controls in place (including fishing closures).

In NSW Fisheries (2002b) it was noted that sediment resuspension caused by trawling in estuaries can increase turbidity in the trawl area. This can lead to the release of heavy metals, which might shift benthic flora and fauna and community composition.

6.1.3 CHARTER FISHING

Charter fishing activities provide opportunities for recreational anglers to undertake estuarine or marine fishing and for adventure tourism for visitors to the NSW marine estate. Well-equipped boats and localised fishing expertise helps recreational anglers to fish successfully across a range of fishing types and species, and to access areas not normally available to them. Operators derive a profit from the use of fishery resources by hiring out their knowledge and equipment to recreational fishers.

In May 2012, the total number of estuary seats (i.e. places) for active operators was 2,887 for 203 licences, 162 of which had an estuary endorsement. Thus, 2,887 is the maximum number of people that can go charter fishing in NSW estuaries on a given day if every charter fishing boat went estuary fishing. In practice, more than half of charter fishing operators are ocean based and do not often fish in estuaries.

Current Management Arrangements

Fisheries Management Act 1994 regulations establish the legislative framework governing fishing activities consistent with Act objectives. Fisheries regulations apply to the recreational fishery including controls on:

- species that may be taken
- bag and size limits
- waters closed to fishing
- lawful fishing gear

Regulations limit recreational fishers to small amounts of gear restricting potential catch for an individual. Major reviews of bag and size limits undertaken every five years, last being in 2013. The *FMA 1994* also established a series of recreational fishing havens to provide for improved recreational angling opportunities, free of commercial fishing.

Marine Estate Management Act 2014 and regulations influence recreational fishing activities (and a range of other activities), primarily through spatial closures. Permits (licences – no cost) are also required for organised activities in marine parks including fishing competitions and for commercial activities including charter fishing operations in marine parks.

Charter boat licensing was implemented in 2000. There is a cap on the total number of charter boats that may operate and there are currently approximately 200 active boats fishing in NSW waters. The boats are constrained by a wide suite of bag and size limits and gear restrictions, which significantly reduce the overall catch capacity. Tournament Management Program provides advice and guidance on sustainable practices with regard to fishing competitions.

Potential impacts of the charter fishery

Reductions in abundance of species and trophic levels

Recent studies, which include the analysis of voluntary logbook data, have shown that the charter fishing boat sector involves a large number of boats and many thousands of anglers annually. This level of activity has the potential to take large numbers of fish and reduce the abundance of some fish species. However, it is not currently possible to obtain an accurate estimate of this catch, especially at a regional scale. Further assessment of the charter fishery is currently underway and is likely to provide details on catch and levels of activity.

Physical disturbance

Only minor impacts were considered likely to occur from this activity at a local scale, principally related to anchor damage on both seagrass and subtidal rocky reef habitats at a local scale.

Incidental catch of species of conservation concern

There is no specific information is available on the level of charter fishing interactions with threatened and protected fish, marine mammal, reptile or bird species. However, seabird entanglements are common in estuaries with species such as the Australian pelican and sinkers and hooks can cause mortalities in birds if accidently ingested (Ganassin and Gibbs 2005). The literature suggests a capture rate of 0.36 (95% confidence interval: 0.09 to 0.66) birds per 100 fisher hours (Ferris and Ferris 2004). The NPWS Elements database captures data on wildlife that are entangled in fishing gear. Many entanglements are reported each year in gear types used by charter fishers (see section 6.2.1 for details). However, low reporting effort and a lack of information on gear or fishery type associated with entanglements impedes an accurate assessment of the threat of the charter fishing to marine fauna populations.

Wildlife disturbance

Marine wildlife including birds, dolphins, and seals have been observed feeding off discards in NSW fisheries using hand line methods among others (Ganassin and Gibbs 2005) and competition can occur when prey items and foraging grounds overlap with fishers, which may have consequences for population health (Ganassin and Gibbs 2005).

Marine debris

No specific information is available on the level of marine debris resulting from charter fishing activities. Fishing gear, particularly monofilament line entangled on reefs, represents a high proportion of marine debris in subtidal reefs (Smith and Edgar 2014). Generally, densities of marine debris in offshore areas are low by world standards, but increase within estuaries and embayments. It is not known how much marine litter can be attributed to the charter fishing.

6.1.4 RECREATIONAL FISHING

Recreational fishing is broadly defined as the capture of aquatic fauna by anglers without a commercial licence, for personal use or for the purpose of catch and release (Crowder et al. 2008). Recreational methods include traditional hook-and-line angling, trapping, jigging, netting, spearfishing, and hand collecting (Crowder et al. 2008). Recreational fishing occurs throughout estuarine and marine waters of NSW, with the exception of general and location fishing closures that can range from weekdays, seasonal or permanent, and which can be specific to particular gear types (e.g. hoop or lift nets, traps), or total no-take (e.g. marine park sanctuary zones). In addition to general non-targeted fishing, mostly with hook and line, there are a wide range of methods that target specific species, such as mud crabs (traps), saltwater nippers (hand pump), prawns (dip or push net), and lobsters (traps).

There are also a number of specialist components of the fishery that target specific species with hook and line, such as Australian bass, black marlin and tuna. There are also several components of the sector that target a specific range of species, such as that through structured game fish tournaments (Ghosn et al. 2015). The environments that are fished range from creeks, coastal lakes and embayments, and offshore areas on the continental shelf. Thirty estuaries along the NSW coast are defined as Recreational Fishing Havens, which are areas largely free of commercial fishing[18].

The diversity of fishing methods and areas fished results in a wide range of harvested species, and the details of these are presented in the following sections for landings from both estuarine and coastal and marine waters, followed by details specific to the estuarine catch. Analysis of the catch specific to coastal and marine waters in presented in section 8.3.1.

Overall recreational landings

A telephone and diary based survey of recreational activity in NSW conducted in 2013–2014 estimated that 79% of all recreational fishing activity occurred in saltwater – primarily estuaries, followed by coastal inshore and then offshore waters (West et al. 2015). Shore based fishing accounted for 59% of all fisher days; line fishing (with bait or lures) was the dominant fishing method, at 93% of the total effort (Figure 22). The use of pots or traps (baited, passive use) was relatively minor, along with nets (including scoop and drag or seine nets); dive collection (underwater spearfishing and hand collection by snorkel, scuba or hookah); and other methods (e.g. other hand collection, pumps, and spades).

[18] For more information, see http://www.dpi.nsw.gov.au/fisheries/recreational

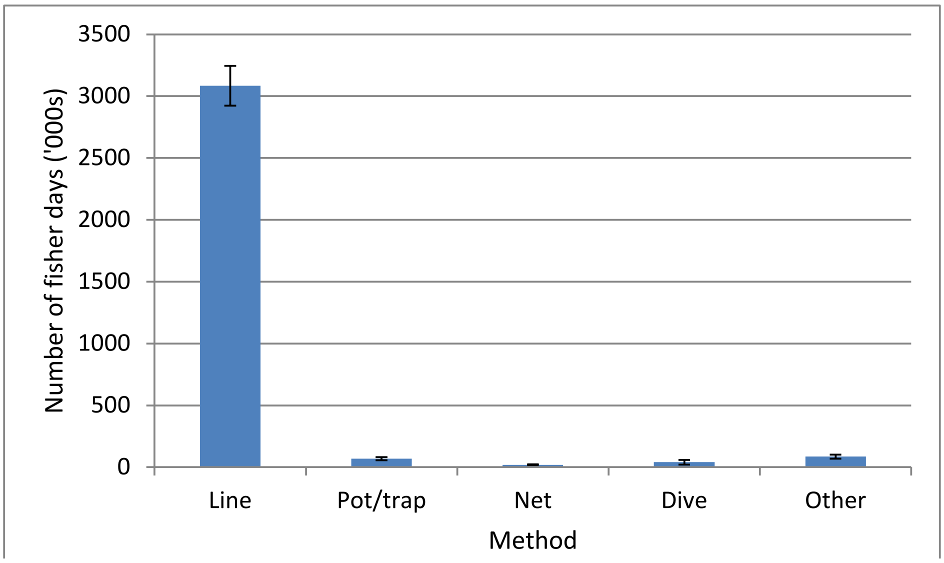


Figure 22. Annual recreational effort (number of fisher days, ± standard error) by fishing method during 2013–2014, by New South Wales and Australian Capital Territory residents aged five years and older. *Source: West et al. (2015).*

The total recreational effort expended in coastal and estuarine waters was approximately evenly distributed between the three regions, ranging from 37–28% north to south (924,132 to 699,678 fisher days) (Figure 23).

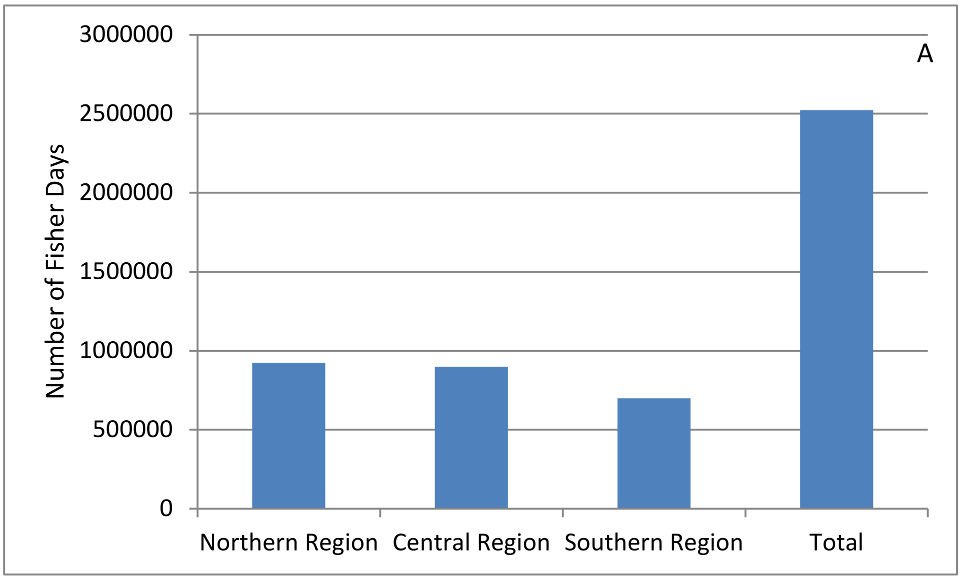


Figure 23. Annual recreational effort of the number of fisher days during 2013–2014, by New South Wales and Australian Capital Territory residents aged five years and older. *Source: West et al. (2015).*

The overall catch composition of species across both estuarine and open coastal waters indicates that recreational fishers captured a diverse range of scalefish, elasmobranchs (sharks and rays), crustaceans, molluscs and other taxa. In estuarine and marine waters, bream was the most common finfish species group caught and kept (estimated at 614,434), followed by the various flathead species (dusky, 481,164; sand, 440,763), snapper (185,590) and sand whiting (247,470). The smaller crustacean species dominated the remainder of the total catch kept (by numbers) – saltwater nippers (1,319,066) followed by saltwater prawns (724,756). Blue swimmer crab (50,637) accounted for the majority of the larger crustaceans, followed by mud crab (30,052) and rock lobster (23,216) (West et al. 2015). Squids (105,308) and pipis (87,760) were the most common mollusc species caught and kept (Figure 24).

The largest proportion of total recreational catch was taken in the northern region, but was only 10% larger than the total catches in the central and southern regions; 40% (473,1467) in the northern region, 30% (360,5475) in the central and 30% (359,6598) in the southern (Table 18). In the northern region, the species with the largest total harvest was saltwater nipper, followed by bream and dusky flathead. In the central region, bream had the largest total harvest, followed by snapper and mixed other scalefish. In the southern region, bream again had the largest harvest, followed by dusky flathead and saltwater prawns.

The proportion of total recreational harvest of each species group varied substantially among regions (Figure 25). For example, bream was taken least in the southern region but approximately equally in the north and central regions. Six species groups (school whiting, mud crab, pipis, swallowtail dart, trumpeter whiting, undefined baitfish) had the greatest proportion of their recreational harvest (>70%) taken in the northern region. Four species groups (silver trevally, mulloway, leatherjackets and snapper) had the largest proportion of their catch taken in the central region (>50%). Another four species groups (tiger flathead, luderick, tunas and yellowtail kingfish) had the largest proportion of their catch taken in the southern region (>60%).

Table 18. Harvest of key species or species group and proportion of harvest per species by region, 2013–2014. *Source: West et al. (2015).*

Region	Species group	Total harvest (No. individuals)	Proportion of harvest per species	Rank
Northern	Nippers, saltwater	971574.2	0.69	1
	Bream	793588.7	0.36	2
	Flathead, dusky	371048.4	0.35	3
	Other small baitfish	304796.6	0.96	4
	Whiting, sand	264481.7	0.46	5
Central	Bream	886356.6	0.40	1
	Snapper	402964.1	0.53	2
	Scalefish, other salt freshwater	343771.1	0.46	3
	Flathead, sand	320174.1	0.33	4
	Nippers, saltwater	267192.8	0.19	5
Southern	Bream	524255.5	0.24	1
	Flathead, dusky	442042.2	0.42	2
	Prawns, saltwater	431192	0.59	3
	Flathead, sand	403708	0.42	4
	Luderick	297977.1	0.70	5

Recreational catches exceeded commercial landings for five of the 10 species (71% of the total harvest of dusky flathead; 67% for sand flathead; 63% for both mulloway and tailor; and 52% for yellowtail kingfish). The recreational catches of bream, sand whiting and snapper were slightly lower than commercial landings (ranging from 40–49% of the total harvest), whereas the recreational catch of Australian salmon and silver trevally were substantially smaller than the commercial harvest, both at 14% of the overall total (Table 19) (West et al. 2015). The greatest number of individuals and the highest proportion of the catch of the key species was kept rather than released in the northern region (Figure 26). Overall, the proportion of the catch released across all regions ranged from around 25 to 40%.

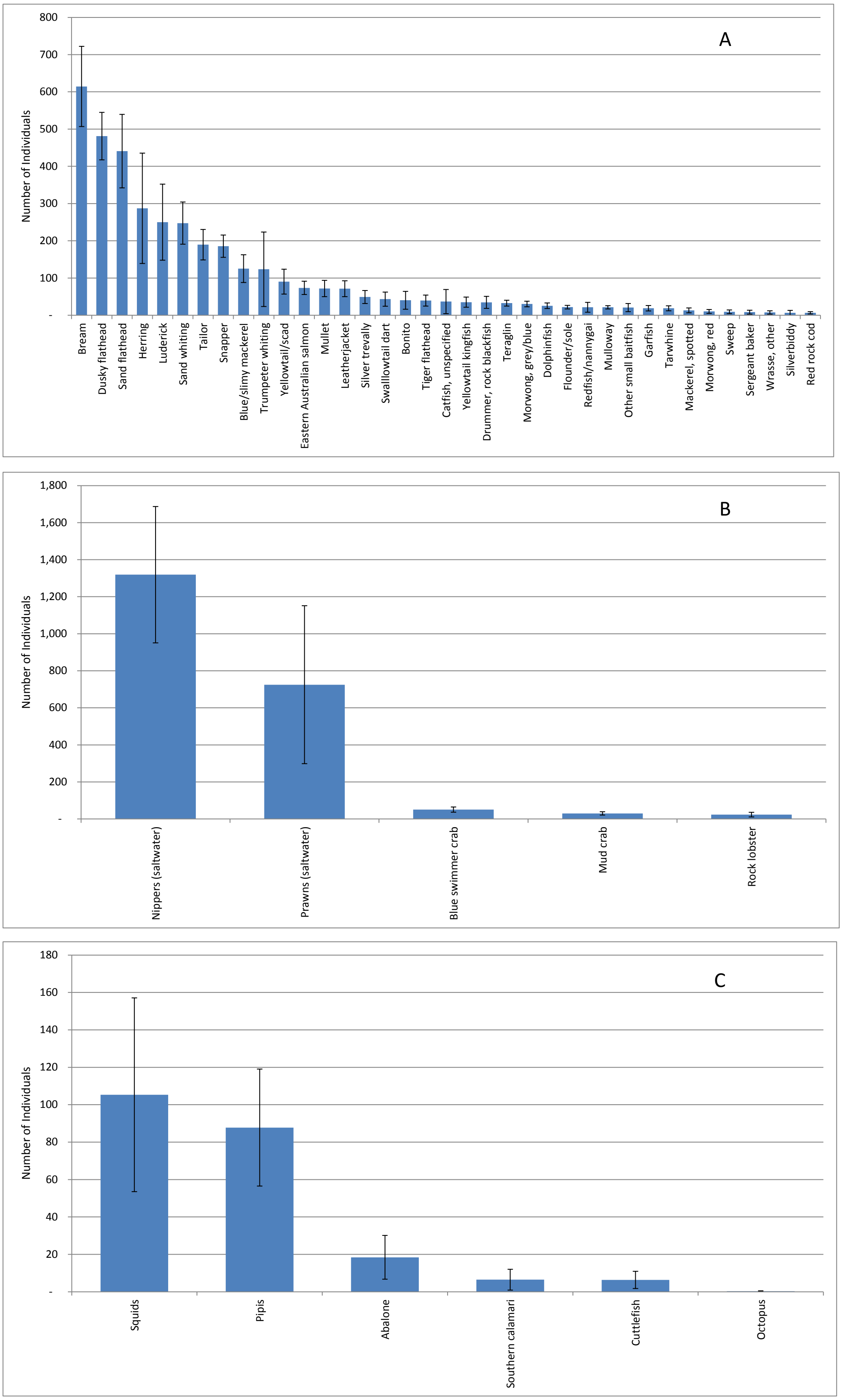


Figure 24. Annual recreational catch (kept numbers, '000s) by species group during 2013–2014, by New South Wales and Australian Capital Territory residents aged five years or older; (A) scalefish, (B) crustaceans, (C) molluscs. *Source: West et al. (2015).*

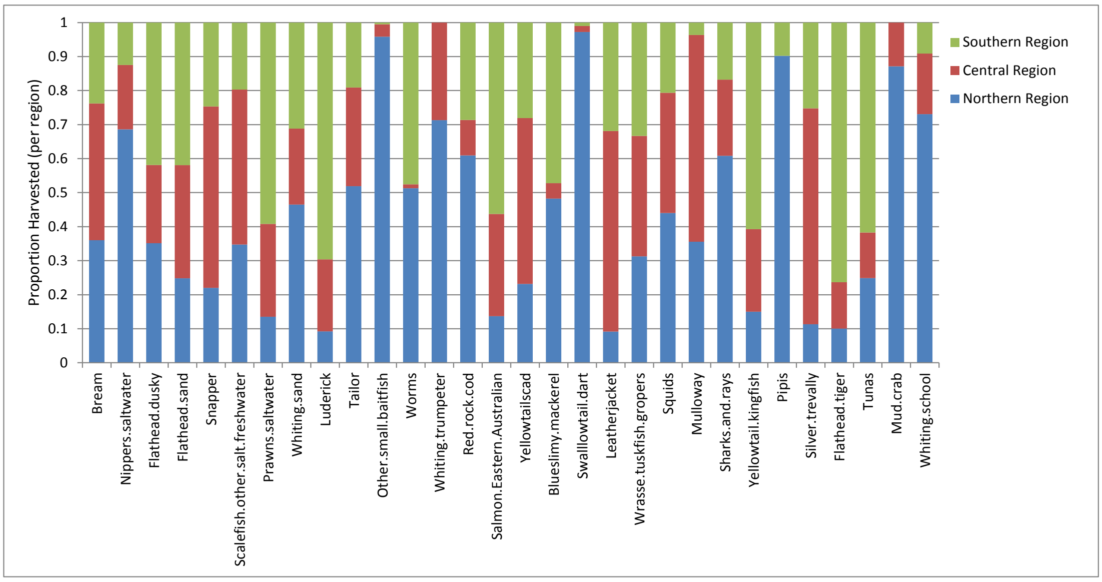


Figure 25. Relative proportion of harvest of key species by region. *Source: West et al. (2015).*

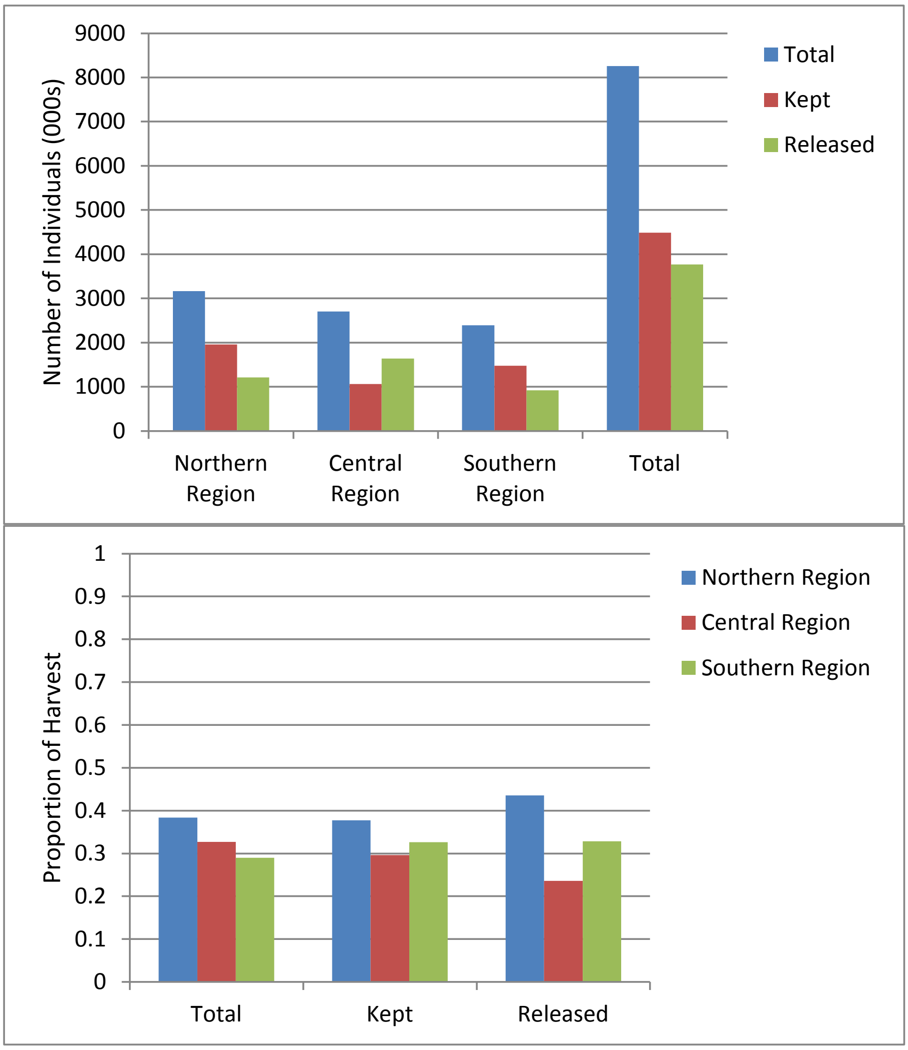


Figure 26. Number of individuals fish kept and released in each region, and proportion of overall harvest in each region. *Source: West et al. (2015).*

Table 19. Recreational harvest of key species in New South Wales waters by New South Wales and Australian Capital Territory residents aged five years and older, by water body types; indicative estimates of the total weight (tonnes), compared with estimates for the commercial fisheries sector during 2013–2014. *Source: West et al. (2015).*

	Recreational estuarine harvest			Recreational marine harvest			Total harvest (t)			% Recreational
Species/ group	Number	Average weight (g)	Total weight (t)	Number	Average weight (g)	Total weight (t)	Recreational (t)	Commercial (t)	Grand total (t)	
Bream	497,270	525	261	117,164	589	69	330	343	672	49.1
Flathead, dusky	468,978	593	278	9,691	1,023	10	288	115	404	71.4
Flathead, sand	61,715	409	25	379,048	488	185	210	101	311	67.5
Mulloway	14,181	2,530	36	7,181	2,897	21	57	59	116	49
Salmon, Australian	24,759	2,870	71	48,776	2,283	111	182	1,112	1,294	14.1
Silver trevally	23,036	543	13	26,046	558	15	27	168	195	13.9
Snapper	39,544	564	22	146,046	860	126	148	220	368	40.2
Tailor	52,933	499	26	136,681	593	81	107	62	169	63.5
Whiting, sand	180,864	278	50	66,606	278	19	69	79	148	46.5
Yellowtail kingfish	2,046	3,223	7	33,088	3,434	114	120	109	229	52.5

Statewide, 58% of recreational fishing was exclusively shore based, while 42% was exclusively boat based (Figure 27) (West et al. 2015). Total recreational harvest statewide was slightly skewed towards shore based platforms, with 54% of the kept harvest taken exclusively by shore based platforms and 46% taken exclusively by boat based platforms (Figure 28). However, this distribution varies considerably among species, with larger harvests for some species taken from boat based platforms. Ten species taken from boat based platforms had kept harvests of >80% of the state recreational total, whereas only seven species had kept harvests >80% of the state from shore based platforms. A greater number of species had harvests >50% of the state recreational total taken from boat based rather than shore based platforms (22 and 18, respectively) (Figure 28) (West et al. 2015).

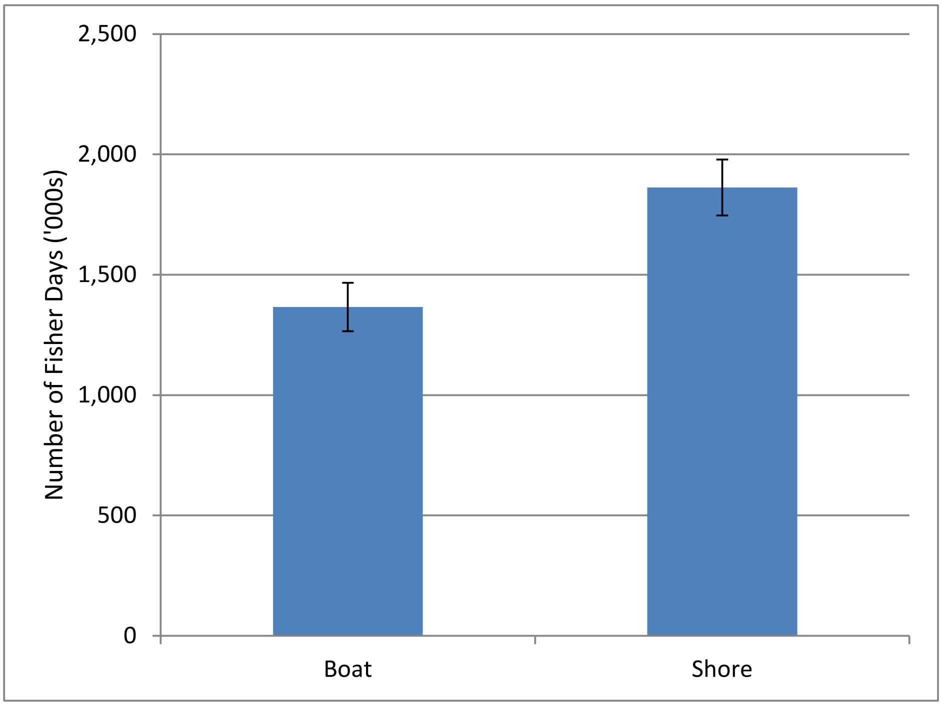


Figure 27. Annual recreational effort (numbers of fisher days, ±SE) in New South Wales waters by fishing platform during 2013–2014, by New South Wales and Australian Capital Territory residents aged five years and older. *Source: West et al. (2015).*

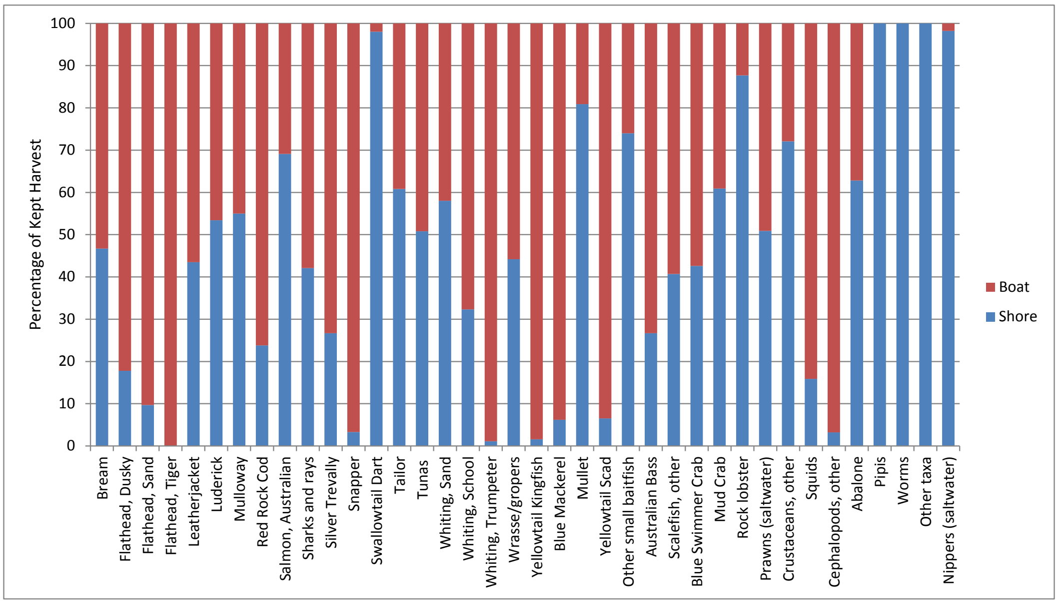


Figure 28. Proportion of recreational kept harvest taken from New South Wales waters by species group on different fishing platforms during 2013–2014, by New South Wales and Australian Capital Territory residents aged five years and older. *Source: West et al. (2015).*

Estuarine recreational landings

Recreational fishing occurs within all estuaries of NSW where anglers fish from both boat and shore based platforms using hook and line, netting, trapping, spearfishing or hand-collecting methods (Steffe and Murphy 2011). Between 2013 and 2014, estuarine recreational fishing effort and harvest accounted for 70% and 69%, respectively, of the recreational fishing activity across the state (Figure 29) (West et al. 2015). During this period, the estimated total effort (± standard deviation, SE) expended by anglers within estuaries was 1,795,958 (±125,190) fisher days, and the total number of fish harvested within estuaries was 4,489,951. Five species (trumpeter whiting, Australian bass, mud crab, saltwater prawns and saltwater nippers) were harvested exclusively from estuaries. Another five species (blue swimmer crab, baitfish (unspecified), dusky flathead, cephalopods (unspecified) and school whiting) had estuarine harvests of >90% of the state recreational catch (Figure 30, Table 20).

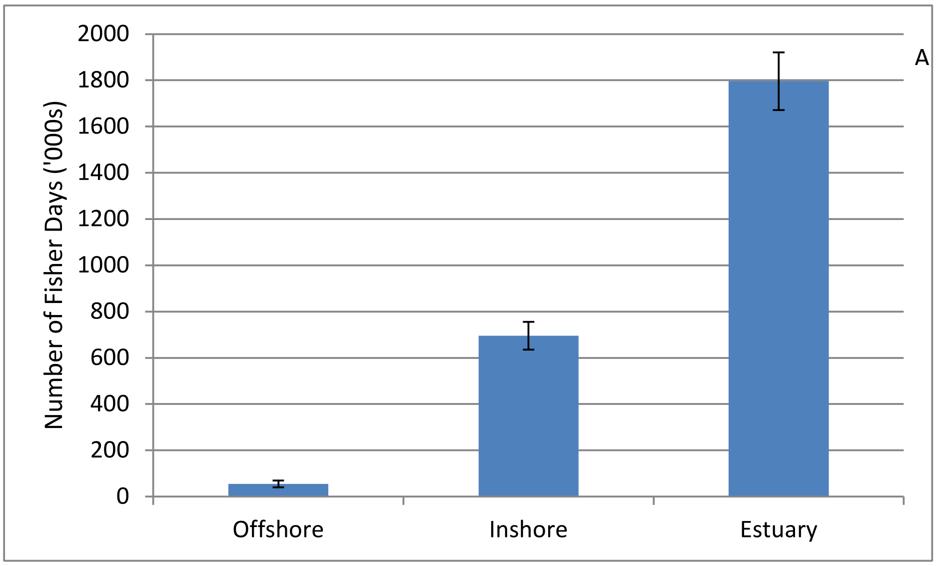


Figure 29. Number of fisher days expended by recreational fishers in New South Wales waters by water body type during 2013–2014 by New South Wales and Australian Capital Territory residents aged five years and older. *Source: West et al. (2015).*

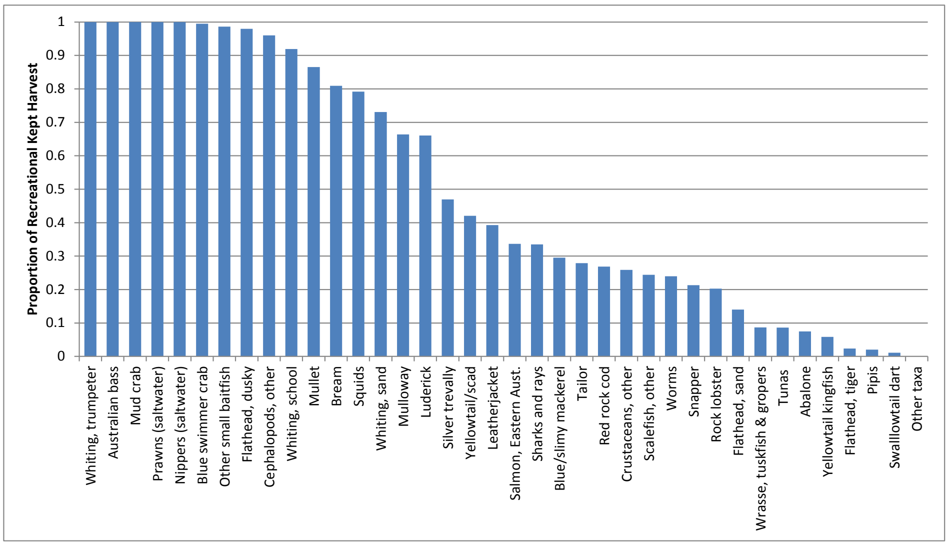


Figure 30. Proportion of recreational kept harvest for each species group in New South Wales estuarine waters relative to total recreational harvest during 2013–2014 by New South Wales and Australian Capital Territory residents aged five years and older. *Source: West et al. (2015).*

Table 20. Annual recreational harvest (kept numbers) within estuarine waters of the state of key species during 2013–2014, by New South Wales and Australian Capital Territory residents aged five years or older. *Source: West et al. (2015).*

Species or group[a]	Annual recreational harvest (kept)[b]	Standard error (+/–)	Proportion of statewide harvest[c]	NSW stock status[d]
Nippers (saltwater)	1,319,066	367,909	1	Undefined
Prawns (saltwater)	***724,756***	***426,343***	1	Growth-overfished (eastern king prawns) or fully fished (school prawns)
Whiting, trumpeter	***123,580***	***100,107***	1	Uncertain
Mud crab	*30,052*	*8,865*	1	Uncertain
Australian bass	***803***	***573***	1	Not determined
Blue swimmer crab	*50,387*	*14,218*	0.995	Uncertain
Other small baitfish	***309,229***	***150,006***	0.986	Undefined (whitebait)
Flathead, dusky	481,164	63,864	0.979	Uncertain
Cephalopods, other	***13,136***	***9,871***	0.960	Fully fished (southern calamari) or undefined (other species)
Whiting, school	***4,995***	***2,078***	0.919	Not determined
Mullet	*47,081*	*13,681*	0.865	Fully fished (sea mullet)
Bream	614,434	107,686	0.809	Fully fished

a Species groups shown are those that were among the most commonly harvested species groups within the state by number.
b Values in **bold** indicate relative standard error >40%; values in *italics* indicate fewer than 30 households recorded catches of the species.
c Proportion of fish harvested recreationally for the period between June 2013 and May 2014.
d Current exploitation status for each species group based mainly on the assessment of NSW commercial data (see Appendix 2 for description of each exploitation status category).

In estuaries, the **northern region** had the largest total harvested recreational catch, followed by the central then southern regions. In the northern region, the largest estuarine harvests were saltwater nippers (971,574 individuals), bream (638,196), dusky flathead (361,393), baitfish (300,935), and sand whiting (226,091) (Figure 31). Four species (baitfish, mud crab, school whiting and tunas) had >80% of their estuarine harvest taken in the northern region (Figure 31). In the **central region**, the largest estuarine harvests were bream (829,323 individuals), snapper (355,946), saltwater nippers (267,193), and dusky flathead (235,789). Four species (abalone, other crustaceans, leatherjackets and silver trevally) had >70% of their estuarine harvest taken in the central region. In the **southern region**, the largest estuarine harvests were bream (479,540), saltwater prawn (431,192), dusky flathead (421,140), and luderick (262,076). Six species (worms, pipis, tiger flathead, red rock cod, blue mackerel and luderick) had >80% of their estuarine harvest taken from the southern region (Figure 32).

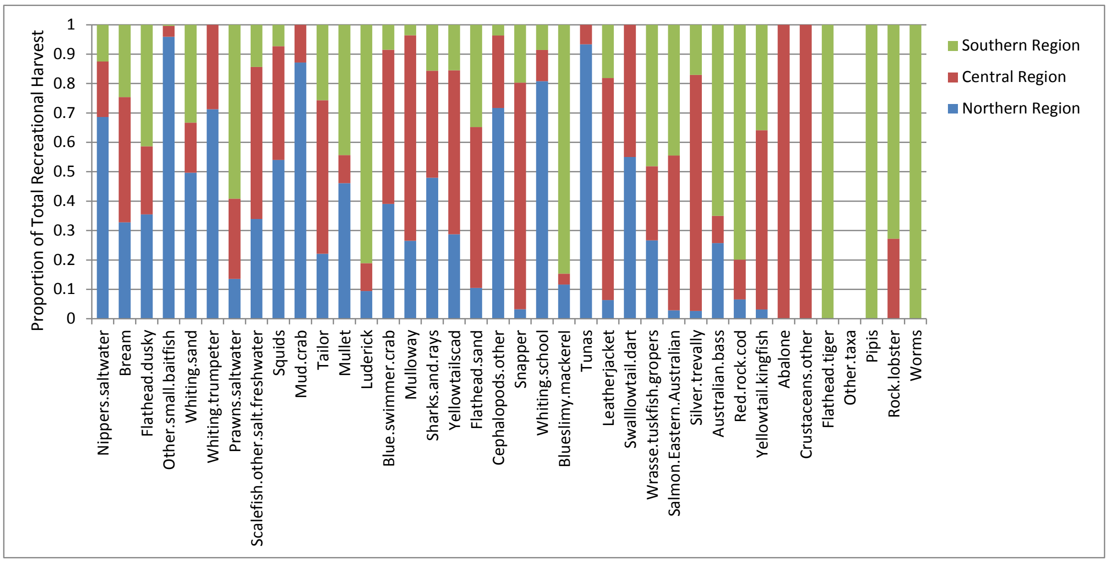


Figure 31. Proportion of total harvested recreational catch of each species taken in estuaries across the three regions of New South Wales. *Source: West et al. (2015),*

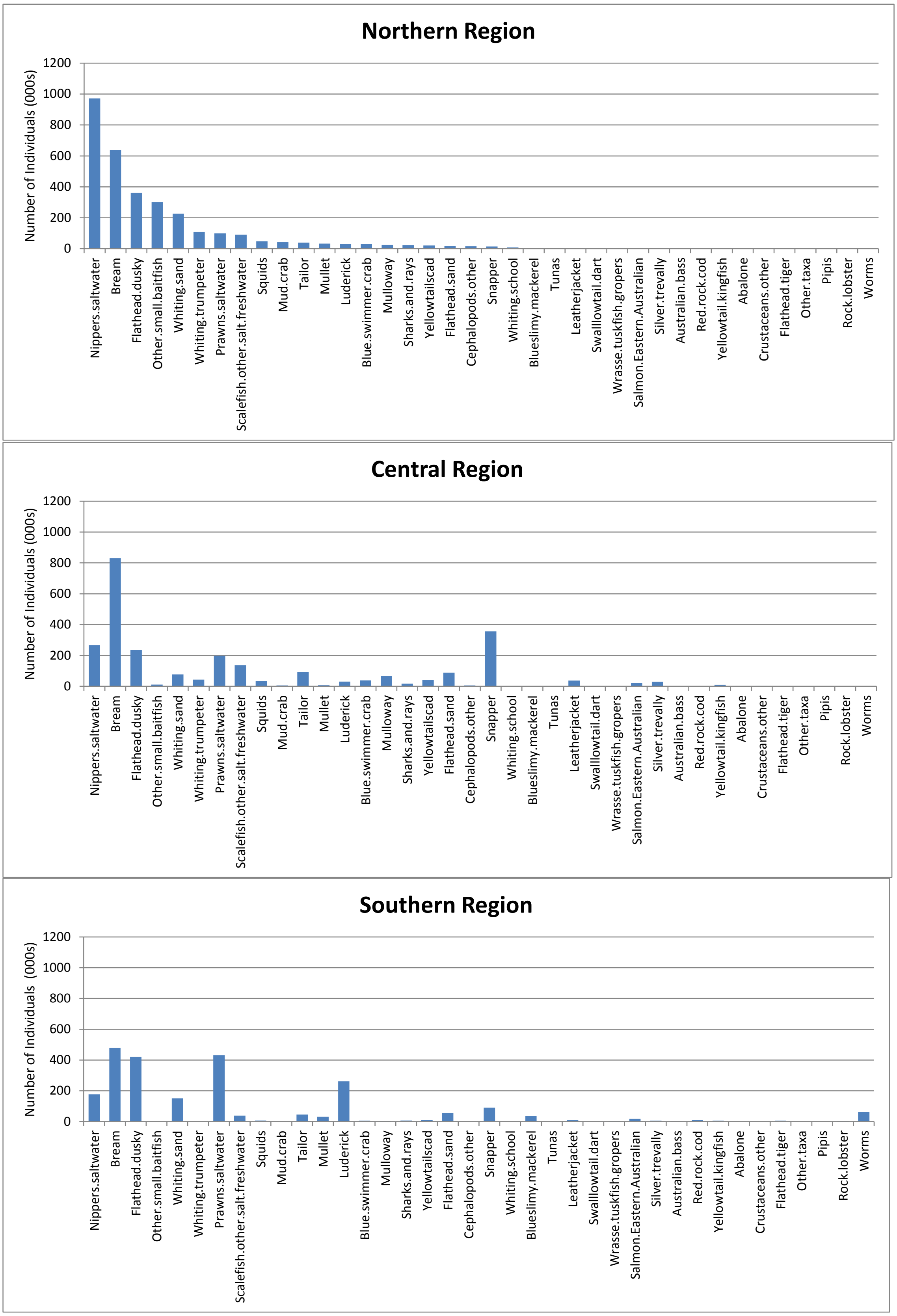


Figure 32. Total harvested recreational catch in estuaries by species in each of the three regions of New South Wales. *Source: West et al. (2015).*

The proportion of recreational fishing effort in estuaries is greatest in the central region (717,995 fisher days, 40%) followed by the northern (614,361 fisher days, 34%) and southern regions (463,603 fisher days, 26%) (Figure 33).

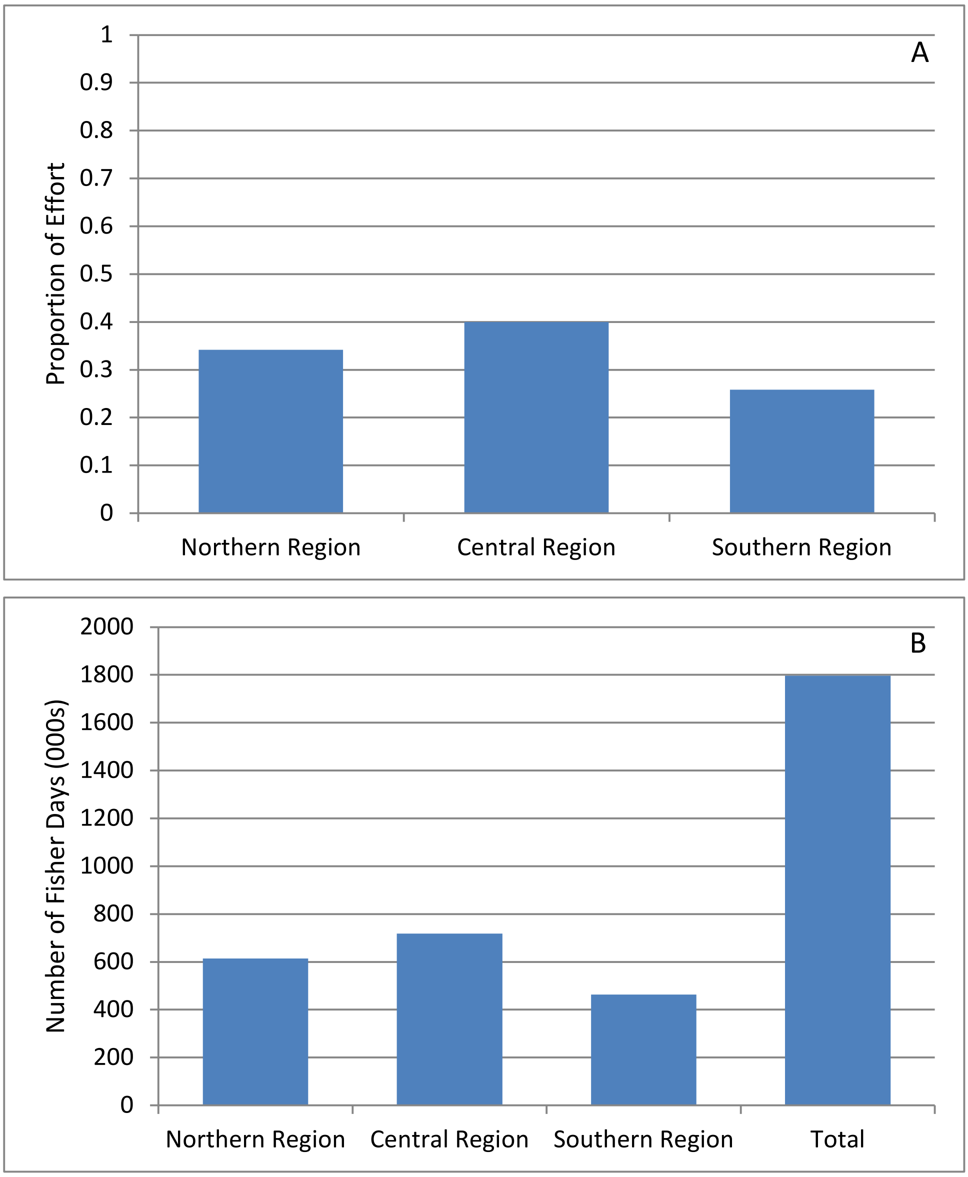


Figure 33. Recreational fishing effort in New South Wales estuaries; A) proportion of effort across regions, B) number of fishing days per region and total. *Source: West et al. (2015).*

Although recreational fishing is known to occur in each of the estuaries within the state, recent (post-2000) published information on site-specific recreational fishing is only available for Lake Macquarie, the Hawkesbury River, Port Jackson, Botany Bay, and Port Hacking. For these estuaries, Table 21 summarises the estuarine shore and boat based activity as quantified by on-site recreational fishing surveys. Among these five estuaries, the highest total levels of effort and harvest have been recorded for Lake Macquarie.

The distribution of fishing activity within Port Jackson is also being assessed by researchers at the Sydney Institute of Marine Science. They have reported that shore based fishers accounted for 63.9% of total observations, with 36.1% fishing from vessels. Fishing hot spots had up to 75 fishers per square kilometre (Hedge and Johnston, in prep). Shore based fisher intensity was greatest on wharves and piers around Port Jackson.

Table 21. Summary of estuary-specific results from various on-site recreational fishing surveys within New South Wales.

Estuary	Average annual boat based harvest (numbers)	Average annual shore based harvest (numbers)	Average annual boat based effort (angler hrs)	Average annual shore based effort (angler hrs)	Dominant species in boat based harvest	Dominant species in shore based harvest	Survey period
Lake Macquarie (1)	378,181	119,271	769,251	224,029	Trumpeter whiting, blue swimmer crab, yellowfin bream, dusky flathead & tailor	Luderick yellowfin bream, trumpeter whiting, common squid & dusky flathead	2003 to 2004
Hawkesbury River (2)	99,174	35,288.5	517,650	144,150	Dusky flathead, yellowfin bream, yellowtail, blue swimmer crab & tailor	Yellowfin bream, dusky flathead, river garfish, tailor and sand whiting	2007 to 2009
Port Jackson (3)	33,189	51,397	84,935	88,529	Yellowtail scad, kingfish, yellowfin bream, dusky flathead & tailor	Yellowtail scad, yellowfin bream, snapper, tailor & trumpeter whiting	2007 to 2008
Botany Bay (4)	2,892[a]	Not assessed	Not assessed	Not assessed	Yellowfin bream, silver trevally, dusky flathead, trumpeter whiting & snapper	Not assessed	Autumn of 2000 and 2007
Port Hacking (5)	30,603.5	49,338.5	92,700	125,700	Common squid, yellowfin bream, Australian sardine, southern calamari & sand whiting	Yellowtail, sand mullet, silver trevally, luderick & tailor	2007 to 2009

a Three-month estimate of harvest

Sources: (1) Steffe et al. (2005), (2) Steffe and Murphy (2011), (3) Ghosn et al. (2010), (4) Bogg (2007), (5) Steffe and Murphy (2011).

Current management

The *Fisheries Management Act 1994* and regulations establish the legislative framework governing fishing activities consistent with Act objectives. The Recreational Fishing NSW Advisory Council (RFNSW) has been established to provide advice to the Minister for Primary Industries on key recreational fishing issues in NSW. The new Advisory Council is based around a modern representative model, ensuring the views of regional fishers from right across the State are communicated. RFNSW includes eight regional members, two members with expertise in spearfishing and charter boat fishing and other representatives that significantly benefit the function of the Advisory Council. The Council has replaced the Advisory Council on Recreational Fishing.

Fisheries regulations apply to the recreational fishery including controls on:

- species that may be taken
- bag and size limits
- waters closed to fishing
- lawful fishing gear.

Regulations limit recreational fishers to small amounts of gear restricting potential catch for an individual. Major reviews of bag and size limits undertaken every five years, last being in 2013. The *FMA 1994* also established a series of recreational fishing havens to provide for improved recreational angling opportunities, free of commercial fishing.

Marine Estate Management Act 2014 and regulations influence recreational fishing activities (and a range of other activities), primarily through spatial closures. Permits (licences – no cost) are also required for organised activities in marine parks including fishing competitions and for commercial activities including charter fishing operations in marine parks.

These restrictions are designed to ensure the ongoing sustainability of fish stocks, which is assessed annually by NSW DPI. When assessing the status of harvested fish species, the estimated take by recreational fishers is considered, along with the reported catch from commercial fisheries.

Licencing

When fishing in NSW waters, unless exempt, you are required by law to pay the NSW Recreational Fishing Fee.

This applies when:

- spear fishing
- hand lining
- hand gathering
- trapping
- bait collecting
- prawn netting
- in possession of fishing gear in, on or adjacent to waters.

Education programs are in place to improve the sustainability of practices in the recreational fishery[19]. This includes the publication of responsible fishing guidelines that aim to minimise impacts on the environment. The guidelines include the following relevant information:

- Reduce wildlife injuries by attending lines and avoid bird-feeding areas.
- Only catch sufficient fish to meet immediate needs. Release all others using best-practice catch and release techniques.
- Dispose of all litter and fish waste responsibly.
- Use environmentally friendly fishing tackle, such as lead-alternative sinkers, biodegradable line and non-stainless hooks where possible.
- Act responsibly when the bag limit has been reached and ensure any additional fish caught have the best chance of survival on release. If fishing in deep water, consider moving to a different location to reduce potential discard mortality.

In response to specific impacts on turtles in estuaries from recreational fishing activities, the NSW Government has produced educational information on the appropriate deployment of crab pots in the Port Stephens area. NSW DPI has also modified trap design and restricted the use of witches-hat traps[20], and banned wide-mouthed crab traps in Lake Macquarie.

[19] For more information, see http://www.dpi.nsw.gov.au/fisheries/recreational

[20] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/539180/Discussion-paper-crab-traps-final.pdf

Potential impacts of recreational fishing in estuaries

Reductions in abundances of species and trophic levels

Recreational fishing within NSW estuaries can reduce the abundance and change the size structure of fish such as bream, dusky flathead, blue-spotted flathead, snapper, salmon, silver trevally, and species of leatherjacket, all of which dominate harvests from the area. Since these species are known to be lower-order predators, recreational fishing may also affect estuarine and coastal food webs.

Recreational fishing may also reduce the abundance and alter size structure of omnivores, particle feeders and detritivores, such as saltwater nippers and prawns, blue swimmer crabs and yellowtail scad. Since these species are important sources of food for organisms that occupy higher tiers of the food web, their removal can affect estuarine and coastal food webs within NSW estuaries.

The most dominant herbivore harvested recreationally within NSW estuaries is luderick. The numbers of luderick harvested by the shore and boat based sectors of Lake Macquarie increased, though not significantly, between 1999 and 2000, and therefore do not provide any evidence of a measured decrease in species-specific abundance (Steffe et al. 2005). However, in Botany Bay, numbers of luderick harvested by the boat based fishery declined between 2000 and 2007 (Bogg 2007).

Few quantitative studies have investigated the long-term impacts of fishing in both estuarine and coastal systems. A lack of historical baseline data on the unfished ecosystem impedes our understanding of the full extent of fishery effects. Shifting baselines in perceptions of what constitutes unaffected stock size and species composition is a global issue in fisheries science (Pauly 1995). Historical evidence suggests that fishing impacts were evident within the central region during early European settlement. Knowledge of fishing impacts has also been advanced through the use of marine protected areas (MPAs) as scientific reference sites where fishing is excluded (Edgar et al. 2014). Further details of the effects of this stressor are presented in the Hawkesbury marine bioregion environmental report (MEMA 2016).

In addition to legal harvest of fishes, illegal fishing can occur, which includes all fishing activities that do not comply with current fisheries regulations (e.g. exceeding bag limits, keeping undersize fish or protected species, using illegal gear and poaching from protected areas). Illegal fishing undermines the effectiveness of management and conservation efforts, and thus the ecological sustainability of the fishery. However, the quantitative data on illegal fishing in NSW estuaries is limited.

Data for Sydney Harbour provides some insight into the potential scale and impact of this activity. Retention of undersized fish by recreational fishers is common in the harbour and is reportedly much higher than from other NSW estuaries (Ghosn 2010, Henry 1984). In 1980–1982 surveys, 93% of snapper and 30% of bream harvested by recreational fishers were below the minimum legal size limit. Similar trends were reported in 2007–2008, with 51% of kingfish, 97% of snapper, 76% of tailor, and 11% of bream in harvests being undersized.

Overharvesting of small fishes within estuaries may influence adult stocks, because estuarine habitats are important nursery areas for many species. For example, most snapper (89%) caught in the adult fishery in central NSW originated from local nursery estuaries, including Sydney Harbour, Hawkesbury Estuary, Botany Bay and Port Hacking (Gillanders 2002). Non-compliance in Sydney Harbour occurs particularly during the warmer months, and by fishers from culturally and linguistically diverse communities. Non-compliance hotspots include mudflats around the harbour and the Parramatta River, and the intertidal protected areas, aquatic reserve or fishing closures (e.g. Port Jackson shellfish closure).

Incidental bycatch

Individuals of many species are incidentally captured and released by fishers. Within the whole central region, 57% of the total recreational catch, by number, was discarded during the 2013–2014 fiscal year. Bream, snapper, blue-spotted flathead, and dusky flathead were among the most discarded species, by number, and they respectively accounted for 34%, 18%, 11%, 8%, and 6% of the total discarded catch within the bioregion.

At a finer spatial scale, high discard rates for important species have also been recorded at specific sites within the central region. For example, 292,800 individuals, or 56.6% of the total recreational catch by number, was discarded in Port Jackson during 2007–2008 (summer). Around 94% of the discarded catch across the estuary was accounted for by snapper (43.2%), bream (17.1%), scad (9.1%), sweep (6.9%), flathead (3.8%), tailor (3.8%), leatherjacket (3.2%), kingfish (2.4%), mado (2.4%), and whiting (2.2%). High rates of discard may represent a significant risk to sustainability of stocks if associated mortality is high, because current assessments and management regulations assume that discard mortality is negligible (Stewart 2008). The survival rate of discards within most areas remains largely unknown.

Incidental catch of species of conservation concern

Limited quantitative data is available on incidental catch of species of conservation concern by recreational fishers within NSW estuaries. The NPWS Elements database captures data on wildlife that are entangled in fishing gear. Many entanglements are reported each year in gear types used by recreational fishers (see Section 6.2.1 for details). However, low reporting effort and a lack of information on gear or fishery type associated with entanglements impedes an accurate assessment of the threat of recreational fishing to marine fauna populations.

Shorebirds and seabirds are most at risk of entanglement or capture in line fishing methods and of ingestion of fishing gear. Ferris and Ferris (2004) reported that active recreational fishing, both from attended handlines and unattended set lines, was the primary cause of this interaction. Within estuaries, jetties, wharves, pontoons, boat ramps, fish cleaning tables and narrow watercourses were the most likely areas for this interaction to occur. Australian Seabird Rescue (ASR) has reported several species of birds (e.g. pelicans, silver gulls, cormorants, crested terns, osprey, Australasian gannets, darters, brahminy kites, white-faced herons, great egrets and oystercatchers) as entangled and hooked in recreational fishing gear (e.g. fishing tackle, set lines, and fishing debris) in NSW (Ferris and Ferris 2004, Ganassin and Gibbs 2005). Given the level of shore and boat based recreational fishing activity in both estuaries and open coast, considerable interaction is likely between fishing line methods and these species. Seals entangled and caught on lures are also reported to NPWS.

Marine turtles are under significant threat from incidental capture or entrapment in illegal, discarded or ghost crab or fishing pots, especially in the north and central regions of the state. Since 2007, more than 1,500 traps were removed from Port Stephens (from December 2012 to April 2013, 177 traps were removed) (Gallen and Harasti 2014). Since 2011, 13 turtles have been found drowned in the port as a result of entanglement, mostly in recreational witches-hats traps and some in rectangular collapsible traps (based on NSW DPI and National Parks and Wildlife Service monitoring data). Unreported drownings in crab gear in other estuaries are also expected (DPI 2014).

Wildlife disturbance

Disturbance at intertidal feeding grounds and high-tide roosts is one of the five major threats to the conservation of shorebirds in NSW (Smith 1991). Disturbance of shorebird nesting, foraging, and roosting habitat can occur when recreational fishers access sites or fish near foraging sites. Many species of threatened and protected shorebirds are affected by shore and boat-fishing activity in estuaries. The degree to which they are disturbed is influenced by the number of people in the vicinity, the proximity of people to the birds and the type and duration of activity (Thomas et al. 2003). Human activities can also directly crush the eggs and chicks of avifauna. When human presence is frequent, or occurs for long periods around nesting avifauna, reduced breeding success and growth of avifauna can result, along with abandonment of breeding colonies (see references in Burger 1998, Weston 2000).

Disturbance can result in birds shifting to alternative, less favourable feeding areas (Cayford 1993, Goss-Custard and Verboven 1993). Migratory shorebirds, such as endangered little terns are particularly susceptible to disturbance from human presence in the few months before their migration. They require undisturbed feeding areas at this time to accumulate sufficient energy reserves for their journey (Paton et al. 2000, Smith 1991). Disturbance to beach nesting species such as oystercatchers and hooded plovers is an issue for population health in some areas including the south region (NPWS observations). Competition can also occur when prey items and foraging grounds overlap with fishers, reducing population health (Ganassin and Gibbs 2005).

Marine wildlife including birds, dolphins, and seals are prone to entanglement or ingestion of fishing gears when feeding off discards and have been observed doing so in NSW fisheries using line and trap methods (Ganassin and Gibbs 2005). Marine mammals are also affected by physical disturbance and underwater noise from vessels.

Marine debris

Marine debris arising from recreational fishing (e.g. discarded fishing gear, bait bags, general litter) can affect wildlife within estuarine waters. Floating debris poses the greatest threat to surface-dependent species that are attracted to the debris as a food source or shelter.

Many threatened and protected species such as turtles, marine mammals and seabirds can be severely injured or die from entanglement in marine debris, causing restricted mobility, starvation, infection, amputation, drowning and smothering. Turtles and seabirds are particularly susceptible (Acampora et al. 2014, Schuyler et al. 2014 a; b), and marine debris (particularly plastic and synthetic debris) is a key threat to the survival of marine reptiles (Environment Australia 2003, Laist 1987). For instance, fishing line debris, nets and ropes can cut into the skin of marine turtles or mammals, leading to infection or the amputation of flippers, tails, or flukes (Meagher et al. 2015).

Limited quantitative data is available on recreational fishing debris derived from recreational fishing in the regions. Herford (1997) recorded a dominance of commercial trap fishing gear on central NSW beaches and recreational fishing gear on beaches around urban centres, especially those on the central coast of NSW. In particular, wharves can be laced with monofilament line and fishing hooks and lures.

Hertford (1997) also found 13% of the debris to be fishing related, 40% of which was derived from recreational fishing activities. Meagher et al. (2015) found a significant increase in the number of annual admissions to Taronga Veterinary Hospital from 2003–2013 that were attributed to recreational fishing debris (Figure 34). A large proportion of the marine turtles affected by entanglement or recreational fishing debris in that study were subadult or juvenile.

The propensity of turtles to ingest debris varies with habitat. Coastal or oceanic turtles ingest more than estuarine-living turtles, and herbivores more than carnivores (Schuyler et al. 2014b). Green turtles and leatherback turtles are at the highest risk.

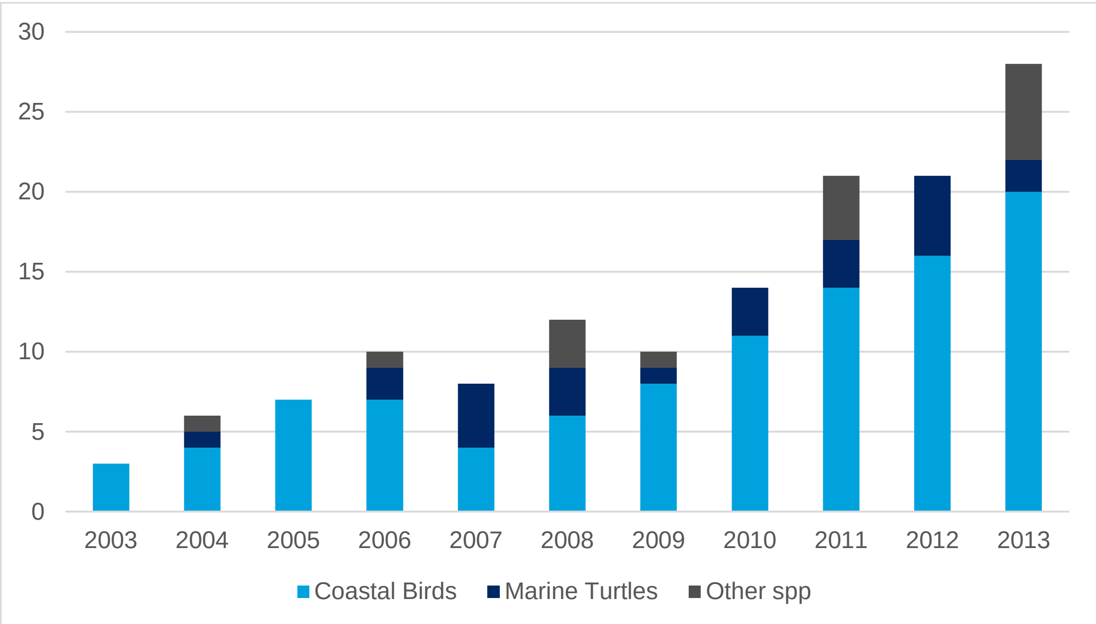


Figure 34. Number of admissions to Taronga Veterinary Centre with recreational fishing debris injuries, 2003 to 2013. *Source: Meagher et al. (2015).*

The impact of recreational fishing debris on estuarine avifauna, particularly shorebirds and waterbirds, has largely gone unreported. Before 1992, the number of birds injured by fishing tackle along the coast of NSW was considered to be minimal. Therefore, the impact of fishing activities posed little cause for concern, and the small number of reported incidents did not prompt investigation by management agencies. A study focused on estuaries between the central coast and north coast of NSW found that 537 pelicans had life-threatening or debilitating conditions, and entanglement in fishing line was found to be the major cause of debilitation (94%) (Ferris and Ferris 2004). Birds may lose their ability to move quickly through the water, reducing their ability to catch prey and avoid predators; or, they may suffer constricted circulation, leading to asphyxiation and death. A recent study of ingestion of plastics in offshore waters of Eastern Australia found that Suliformes were the most susceptible order to ingestion of fishing line (Roman 2016). NPWS has recorded 10 fishing gear injuries with the little penguin colony at Manly since 1995 including ingestion of or entanglement in fishing line, hooks, and nets.

Given the high level of shore and boat based recreational fishing activity that occurs in NSW estuaries and the presence of many of threatened and protected bird, mammal and reptile species, considerable ongoing interaction between fishing-derived debris and protected and endangered species is likely.

Physical disturbance

Physical disturbance from recreational fishing includes trampling of foreshore habitats, operation and anchoring of boats and impacts of marine debris. These stressors are discussed further in Section *8.1.8 Recreation and tourism.*

Spearfishing

Spearfishers comprise a small fraction of recreational anglers in NSW (Lowry and Suthers 2004, West et al. 2016). Spearfishing in estuaries is considerably less common than on the open coast; but note that the definition of estuary in this assessment includes areas such as Broken Bay, Batemans Bay, Jervis Bay, and Twofold Bay, which are areas where spearfishing would occur. Spearfishing is more constrained spatially than line fishing, as it is limited to breath-holding (free-diving), and is therefore restricted to shallower depths, such as marine-dominated areas of drowned river valleys.

Recreational spearfishers are generally highly selective (Neville 2006), especially those that are more experienced and skilled, often targeting larger or specific fish species. These include red morwong, luderick, rock blackfish, yellowfin bream, various leatherjackets, and dusky flathead. With a paucity of data on the potential impacts of recreational spearfishing on species populations (Young et al. 2014), scientists are increasingly reliant upon anecdotal evidence (Gledhill et al. 2013; 2015). A more detailed description of spearfishing is presented in Section *8.1.3 Recreational fishing.*

Current management

Spearfishers and divers (harvesting) in NSW are generally required to have a current recreational fishing licence, unless they are fishing from a charter boat, hire boat or under the supervision of a fishing guide. The charter or hire boat operator or guide is required to hold a current recreational fishing fee exemption certificate; otherwise, the spearfisher or hand gatherer will need to hold a current recreational fishing licence.

Spearfishers and those taking invertebrate species underwater by hand are generally subject to the same rules and regulations regarding bag and size limits as other recreational fishers. They are permitted to use a snorkel when taking fish, scuba gear for scallops and sea urchins only, and bare or gloved hands only when taking lobsters (Recreational Fisheries Management 2011).

They are prohibited from using:

- hookah apparatus
- a light with a spear or speargun
- a spear or speargun to take blue, brown or red groper, or any other protected or threatened fish species listed under state or Commonwealth legislation
- a spear or speargun in spear fishing closures

- power heads or other explosive devices.

Spearfishing is restricted in more than 40 estuaries and coastal rivers in NSW. These restrictions are largely for safety reasons, to avoid conflicts and unsafe interactions between spearfishers and recreational boats, commercial vessels, swimmers, surfers, recreational line fishers and other users of these waterways and beaches.

In estuaries, spearfishing sites are generally around headlands and nearshore subtidal rocky reefs for reef species: the beach side of river entrance-training walls for beach and estuarine-associated species, and open waters for pelagic species. The prohibition of spearfishing using scuba gear provides a depth refuge from spearfishing for some species (Lindfield et al. 2014). The Australian Underwater Federation is a volunteer organisation that self-regulates the growing sport, along with 'Spear Safe', a national management initiative to provide information and raise awareness on the risks associated with the sport[21]. The federation has a spearfishing code of conduct that promotes sustainable and safe spearfishing[22].

Potential impacts of spearfishing

Reductions in abundances of species and trophic levels

For a detailed description of this stressor as it relates to recreational fishing, see Section *8.1.3 Recreational fishing.* Given the small amount of spearfishing activity in estuaries, its impact is expected to be low.

Incidental bycatch

Bycatch from spearfishing can occur when fish are speared and then discarded, because they are undersized or have been misidentified. Death can also occur when fish are wounded but escape. Given the small amount of spearfishing activity in estuaries, the impact of this is expected to be low.

Incidental catch of species of conservation concern

Incidental spearing of threatened and protected species (e.g. grey nurse sharks, blue groper, and black rock cod) by non-compliant and inexperienced fishers has been observed in NSW. Given the small amount of spearfishing activity in estuaries and the low abundance of these species in these regions, these impacts are expected to be low.

Wildlife disturbance

Spearfishing can alter the behavioural responses of targeted species. However, no data is available on this potential impact in NSW. Disturbance of roosting or nesting seabirds and shorebirds by spearfishers accessing the water from land can disrupt nesting, increase risk of nest predation by other species, cause trampling or force migratory species into increased vigilance behaviour, which decreases feeding time (Blumstein et al. 2003).

Marine debris

The primary source of marine debris associated with spearfishing is similar to that for general recreation and tourism (see section 6.1.9). The loss of spearfishing equipment contributing to marine debris is minor.

Hand gathering

Hand gathering of invertebrates and algae for food and bait occurs in intertidal and subtidal habitats in all regions (Gladstone and Sebastian 2009, Kingsford et al. 1991, Underwood 1993). Harvested species in estuaries are dominated by crustaceans (ghost nippers), and to a lesser extent, molluscs (e.g. limpets, turbo, periwinkles, whelks, octopus) and ascidians (e.g. cunjevoi). Hand gathering for direct consumption tends to be more prevalent among culturally and linguistically diverse communities (Underwood 1993).

[21] http://auf.com.au/sports/spearfishing/

[22] http://auf.com.au/wp-content/uploads/2012/08/Spearfishing-Code-of-Conduct.pdf

The ghost nipper (*Trypaea australiensis*) are the key species harvested recreationally through hand gathering, and are commonly harvested for use as bait. The annual recreational harvest of this species in NSW was estimated to be about 1,320,000 individuals in 2013/14, with about half of those individuals harvested between December and February (West et al. 2015). Although there is limited information on the distribution of catch within an estuarine system, anecdotal evidence suggests their harvest is often within a relatively small area of intertidal sandflats.

Current management

Hand gathering is managed through the NSW saltwater recreational fishing regulations. Within estuaries these specifically relate to limits (e.g. bag limit) on species, of which the Ghost Nipper is the dominant species by number.

The NSW Government has set up 14 intertidal protected areas (IPAs), mostly on the open coast within the central region. IPAs are temporary fishing closures, renewable every five years, in which the collection of seashore animals is prohibited from the mean high-water mark to 10 m seaward from the mean low water mark. The main objectives of IPAs are to:

- protect intertidal community habitat, biodiversity and structure
- provide biological reservoirs of breeding stock from which nearby exploited areas can be recolonised or sustained
- help ensure that intertidal invertebrates are harvested at ecologically sustainable levels.

Potential impacts of hand gathering

Reductions in abundances of species and trophic levels

Hand gathering can reduce harvested populations and indirectly change the structure of associated assemblages (Thompson et al. 2002). There is potential for impact of harvest of nipper populations, particularly at a local scale at key harvest locations. However, while the overall effect of fishing activity on populations is unknown, particularly at local scale, their demography and population dynamics indicate high resilience to the numbers of individuals harvested. Further details are provided in Stewart et al. (2015) and references therein.

A study by Fisheries NSW commenced in early 2016 to identify key locations that support the harvest of nippers throughout NSW and investigate the main biological parameters at a broad scale. The study will also examine environmental and fishery-related factors affecting the productivity of important populations at these locations. Fisheries NSW expects that the study will reduce the uncertainties of the level of impact of hand gathering on nippers.

Wildlife disturbance

Disturbance at intertidal feeding grounds and high-tide roosts is one of the five major threats to the conservation of shorebirds in NSW (Smith 1991). The prey items of foraging shorebirds are directly targeted in hand gathering fisheries. The disturbance of critically endangered beach stone curlews may impact population status in the northern region. Competition for space and food between yabby or nipper pumpers and shorebirds is extremely high during peak holiday periods, which coincide with nesting time of shorebird species. For example, in the Brunswick River Estuary 1/11 breeding pairs of resident beach stone curlews in NSW occur and face displacement by yabby pumpers and soldier crab collectors on mud flats (DPI Cape Byron Marine Park unpublished data). Disturbance of roosting, nesting, and foraging seabirds and shorebirds during hand gathering or when accessing sites can disrupt nesting, increase nest predation, cause trampling, force migratory species into increased vigilance behaviour (Blumstein et al. 2003), or result in abandonment of breeding colonies (Burger 1998, Weston 2000) and feeding areas (Cayford 1993, Goss-Custard and Verboven 1993). Further details on disturbance by recreational fishers is outlined in section *6.1.4 Recreational fishing Wildlife disturbance.*

Physical disturbance

Physical disturbance from hand gathering includes trampling of foreshore habitats and impacts of marine debris. These stressors are discussed further in Section *8.1.8 Recreation and tourism.*

Fishing stocking

A marine fish stocking program commenced in NSW in 2014 following completion of a comprehensive Environmental Impact Statement (EIS) and Fishery Management Strategy (FMS). The EIS and FMS provides for effective enhancement of saltwater fish stocks and recreational and Aboriginal cultural fishing opportunities in NSW; supports conservation outcomes for fish and fish habitat; and is undertaken within a clear management framework consistent with the principles of ecologically sustainable development and ecosystem management. The marine stocking program is subjected to highly controlled review guidelines and conditions to ensure sustainability and responsibility in the application of the program. This includes limitations on species, set stocking locations, genetics, stocking density, suitable habitat requirements and frequency of stocking events.

The FMS provides guidelines for the strategic development and implementation of releases of marine fish to enhance recreational fishing. A key element of the FMS is a comprehensive research and monitoring plan, and provisions for feedback to facilitate adaptive management of future releases. This ensures that sufficient information exists to ensure marine stocking is undertaken in a responsible fashion, and that targeted monitoring is conducted on all released species to provide data to improve future releases.

The current program commenced with targeted releases of Eastern king prawn (*Melicertus plebejus*) in intermittently closing lakes in the central and southern bioregions. Ten estuaries were stocked in 2014 and two estuaries were stocked in 2015. Releases in both years have been monitored (including a pre-stocking monitoring component), with the research program examining the progression of the stocked animals to the fishery, the contribution of stocked animals to the fishery, and also monitoring of the species assemblages in stocked estuaries relative to unstocked estuaries (unstocked estuaries being monitored are located within the Batemans Marine Park). Also, data is collected to underpin additional modelling of stocking density and trophic impacts in stocked systems.

The current program will commence releases of mulloway (*Argyrosomus japonicus*) over the next few years, and pre-stocking surveys to support future releases of mulloway have commenced.

6.1.5 CULTURAL FISHING

Line fishing, spearfishing, hand gathering and traditional fishing methods

Aboriginal people have a long association with the marine environment, and have used line fishing, spearfishing, hand gathering and other traditional techniques for thousands of years. These are described in more detail in the companion reports by Feary (2015) and Cox Inall and Ridgeway (2015) and are not considered further here. There is considered to be only a very low level of this activity in NSW currently, and the risks posed by it are likely to be negligible.

Aboriginal cultural fishing is defined in the Act as “fishing activities and practices carried out by Aboriginal persons for the purpose of satisfying their personal, domestic or communal needs, or for educational or ceremonial purposes or other traditional purposes, and which do not have a commercial purpose”. Daily cultural fishing needs are currently provided for by the Aboriginal Cultural Fishing Interim Access Arrangement which allows for extended bag and possession limits, as well as other special arrangements, for cultural fishing activities. Special provisions also exist under the Act to accommodate access to fisheries resources beyond what the current cultural fishing rules provide for (for events such as for a large cultural gathering or ceremonies). For the years 2012/13, 2013/14 and 2014/15 22 cultural fishing permits were approved.

Aboriginal cultural fishing activity and possession of fish and/or fishing gear must comply with the current fisheries legislation i.e. size limits of fish as prescribed in the FM (G) Regulation apply to Aboriginal cultural fishing activities.

The Aboriginal Fishing Advisory Council (AFAC) has been established under Section 229 of the *Fisheries Management Act 1994* to provide strategic level advice to the Minister for Primary Industries on issues affecting Aboriginal fishing. The Council will continue to play an important role in the development of cultural fishing policy as well as exploring commercial opportunities for Aboriginal communities associated with fishing activities.

6.1.6 CHARTER ACTIVITIES

Whale and dolphin watching

NSW waters contain 36 cetacean (whale and dolphin) species, including both resident and vagrant populations (Smith 2001). Dolphins are sighted throughout the year in offshore, coastal and estuarine waters. Sustainable whale and dolphin watching is a valuable industry that has measurable benefits for the economy, environment and the community.

In Australia, the industry is well established, with commercial operators in all states (Knowles and Campbell 2011). In 2008, the industry generated $264 million in tourism, with $47 million attributed to direct sales (Knowles and Campbell 2011), supporting 617 jobs (O'Connor et al. 2009). This includes activities both within estuaries and coastal and open waters. Whale and dolphin watching represents a growing tourism industry, with the number of people participating in tours in Australia growing from 9 million in 1998 to 13 million in 2008 (O'Connor et al. 2009, Prideaux 2012). NSW has the largest whale and dolphin watching industry in Australia, comprising 58% of the sector (Stamation et al. 2007). In 2008, over 800,000 people participated in cetacean watching in NSW, this contributed over $65.3 million to the economy, with $12.9 million from direct sales (O'Connor et al. 2009). The most popular tourism location in Australia is in Port Stephens, NSW. In Port Stephens, 80% of tours focus on dolphin watching. The area attracted over 270,000 people for cetacean watching in 2008 (O'Connor et al. 2009).

The key areas for cetacean watching within NSW estuaries are Sydney, Port Stephens, Jervis Bay, Narooma and Eden, with several of these areas classified as estuaries for the purpose of this assessment (O'Connor et al. 2009). Charters in NSW are primarily directed towards Indo-Pacific bottlenose dolphins, which occur year-round, and humpback whales during their annual migration. Southern right whales are less common, but also targeted on their annual migration (O'Connor et al. 2009). Cetacean-watching tours opportunistically target other wildlife and any of the cetacean species present in NSW may be viewed, as well as seals, seabirds, turtles, and other marine fauna species.

Whale and dolphin watching provides an opportunity for the public to view animals in the wild and develop an understanding and appreciation of the marine environment. There is a strong link between the satisfaction of observers on tour boats and the level of wildlife education provided to them during their trip (Stamation et al. 2007). However, whale and dolphin watching can disturb the normal behaviour of cetaceans, reducing the breeding and foraging success of individuals and local populations (Jenkins et al. 2009, Markowitz 2011). It must therefore be managed to ensure the industry is sustainable and to minimise impacts to wildlife.

Current management

Whales and dolphins are protected in NSW waters under the *National Parks and Wildlife Act 1974* (*NPW Act*) and in Commonwealth waters under the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) (*Smith 2001*)*.

Commercial and recreational whale and dolphin-watching activities in NSW operate in accordance with the standards and regulations outlined in the *NPW Act*, the *National Parks and Wildlife Regulation 2009* (*NPW Regulation*) and the *Australian National Guidelines for Whale and Dolphin Watching 2005*. The regulation and guidelines were developed to educate the public about appropriate behaviour around whales and dolphins and to manage harm to marine mammal populations from land and vessel based watching. However, the effectiveness of these regulations in the protection of cetaceans is limited by compliance rates; over a two year period, Kessler and Harcourt (2013) noted regular breaches of regulations by commercial and recreational whale watching vessels based off Sydney, suggesting further management and enforcement measures be considered. Risks to marine wildlife and behavioural changes are likely to increase with tourist interaction and the expansion of the whale and dolphin watching industry.

In NSW marine parks charter operators are currently licenced under the marine estate legislation to operate and conditions can be set. Outside marine parks, there is no commercial compliance based management licensing or permit system. No licensing system for operators exists in NSW; the approach distance regulations outlined in the *NPW Act* and *NPW Regulation* are used to manage this activity. A person who approaches a marine mammal any closer than the approach distances prescribed in the *NPW Regulation* is guilty of an offence punishable by a maximum penalty of 1,000 penalty units or imprisonment for two years, or both. In contrast to some other states, NSW does not licence 'swim with' activities that permit swimming and diving with whales and dolphins. However, charters that operate within the approach distance regulations for swimming with cetaceans are allowed as they are not committing an offence under the NPW Regulation. Feeding or touching cetaceans in the wild is prohibited in NSW.

Seals and sea lions are protected in NSW under the *NPW Act* and in Commonwealth waters under the *EPBC Act* (Smith 2001*)*. Both New Zealand and Australian fur seals are listed as vulnerable in NSW under the *TSCA*. Tourism interactions with seals and sea lions are managed using the approach distance guidelines.

RMS boat licence and boating handbook-*Marine Safety Regulation 2016* – rules associated with recreational boating in the Regulation are contained within the RMS Boating Handbook (Safety and Rules). To ensure recreational boaters understand the approach distance guidelines, RMS have incorporated education of boaters into the boat licence training and examination.

Approach distances ensure adequate protection is given to whales and dolphins in NSW. The following distances are prescribed in the *NPW Regulation*:

- 300 m from a cetacean when on a prohibited vessel
- 100 m from a whale when on a vessel other than a prohibited vessel
- 50 m from a dolphin when on a vessel other than a prohibited vessel
- 30 m from a cetacean when swimming.

To minimise disturbance, the manner in which boats may approach cetaceans is specified in the *NPW Regulation* to ensure vessels do not restrict the path of cetaceans, or pursue them. The regulations also outline how to minimise disturbance if an adult cetacean approaches a vessel (e.g. disengage gears, maintain a constant slow speed, minimise noise, don't drift close to cetaceans). Closer approach distances may be permitted by NPWS to an individual or group if required for scientific research, educational programs or commercial filming (Harcourt 2013).

In addition to the approach distances, a caution zone is used to protect marine mammals when vessels are in close proximity. The caution zone includes a radius of 150 m around a dolphin and 300 m around a whale, with a maximum of two vessels allowed in the zone at one time. Entering the caution zone of a calf is also prohibited, and if a calf approaches a vessel within the caution zone, the person in charge of the vessel must take action to minimise disturbance as described above. Harcourt (2013) and Allen et al. (2007) highlighted concerns regarding the ability of tour boats to distinguish between pods of dolphins with and without calves, suggesting greater protection may be required for dolphin calves. Within the caution zone, if a cetacean shows signs of being disturbed, vessels must immediately withdraw.

An important regulation used to protect vulnerable individuals or groups of marine mammals is the declaration of special-interest marine mammals. This clause can be used to protect rare species, such as dugongs, physically unique animals (e.g. white whales), a female that has recently given or is about to give birth, a lone calf or a sick or injured animal. This clause has been useful in protecting the health and welfare of predominantly white whales that migrate through NSW each year, including the famed white whale '*Migaloo*'.

The approach distance for seals and sea lions are used to manage disturbance to seals from tourism in NSW. The *NPW Regulation* specifies a minimum approach distance of 10 m when a seal is in the water, 40 m if a seal is hauled-out on land, and 80 m from a pup at all times.

The *Protection of the Environment Operations Act 1997 (POEO Act)* is the main piece of NSW environmental legislation covering water, land, air and noise pollution and waste management. Under section 120 of the *POEO Act* it is illegal to pollute or cause or permit pollution of waters. Under the Act, 'water pollution' includes introducing anything, including litter, sediment, fuel, oil, grease, wash water, debris, detergent, paint, etc. into waters or placing such material where it is likely to be washed or blown into waters or the stormwater system or percolate into groundwater.

Potential impacts of whale and dolphin watching

Physical disturbance

Humans can affect marine mammal behaviour directly, by feeding or touching them, or indirectly, while observing them from land, boats, aircraft or when swimming and diving. Whales and dolphins are particularly sensitive to noise from vessels, aircraft and people. High-volume or persistent sound can interfere with the ability of marine mammals to navigate, communicate and hunt.

Vessel strike is a major threat to marine mammals worldwide, causing injuries such as propeller cuts that are often severe and can be life threatening. The approach distances for marine mammals are used to reduce the possibility of vessel strike from whale-watching vessels. Prior to the introduction of these regulations, collisions between whales and whale watching vessels had been reported at Coffs Harbour (Smith 2001). Certain vessels are prohibited from whale watching due to the higher risk of collision with animals, and must remain 300 m away from marine mammals at all times. These vessels include personal water craft (e.g. jet skis, parasails, hovercrafts motorised diving aids (e.g. motorised underwater scooter) and remotely operated craft (e.g. remote controlled speed boats). For all other vessels, collision risk is managed by the *NPW Regulations.* These require slow and constant vessel speeds in close proximity to cetaceans, as outlined in the previous section, and a lookout to be posted for cetaceans on boats with more than one person. A higher vessel strike risk is posed by skippers who are less experienced in navigating around cetaceans, including recreational boaters.

There are no specific regulations on how to operate a vessel around seals. To ensure recreational boaters understand the approach distance guidelines, they have been incorporated by RMS into the boat licence training and examination. RMS's promotion of the approach distance guidelines is a valuable part of NSW's public education strategy on appropriate behaviour around marine mammals.

Vessel strike from commercial activities other than whale, dolphin and seal watching is covered in sections 6.11 and 8.1.1.

The continuing increase in anthropogenic noise in the estuaries and coastal seas may be affecting marine wildlife in different ways. Many marine animals have evolved to use sound as their main means to communicate, sense their surroundings, and find food underwater (Hatch and Wright 2007). Loud, persistent noise can cause stress and hearing loss in cetaceans, indirectly affecting individual and population health (Erbe 2002), including reduced reproductive success.

Avoidance and other behavioural changes have been observed in killer whales when more than 200 m away from fast-travelling boats, and 50 m from slow-travelling boats. In addition, noise impacts are greater when multiple boats are present and when pods are viewed multiple times per day (Erbe 2002). Strategies for minimising noise impacts from whale and dolphin watching therefore include travelling slowly around cetaceans, and minimising the number of boats watching a pod. Noise from whale and dolphin-watching activities in NSW is managed using the *NPW Regulations* on approach distances as described in the previous section.

Noise from boats and aircraft can affect the ability of seals to communicate, interfering with important social and reproductive behaviours. Boat noise can also lead to increased vocalisation and avoidance behaviours, which affect seal energy budgets (Tripovich et al. 2012). The *NPW Regulations* for noise are not as prescriptive for seals as for cetaceans. Noise is managed by ensuring vessels are no closer than 40 m to a seal that is hauled-out on land. Seals are more sensitive when on land than in the water, and noise or other disturbance can cause a seal colony to stampede into the water, sometimes crushing pups (Tripovich et al. 2012). While seal watching is concentrated on Montague Island, seal populations are predicted to increase, and breeding colonies may establish in NSW (McIntosh et al. 2014). As a result, tour operations are likely to expand, meaning that greater protection for seals from noise disturbance may be required.

Viewing marine mammals from aircraft with high noise levels can also disturb animals. Noise from aircraft is managed using the approach distance guidelines, which state that an aircraft must not fly closer than 500 m to a marine mammal if in a helicopter or gyrocopter, or 300 m if in any other airborne craft.

Wildlife disturbance

Watching whales and dolphins can change their behaviour. Under the *NPW Regulation,* behavioural changes that indicate a whale or dolphin is distressed include 'regular changes in direction or speed of swimming, hasty dives, changes in breathing patterns, changes in acoustic behaviour or aggressive behaviour such as tail slashing and trumpet blows.'

Short-term behavioural changes in response to vessel presence are well studied. Cetaceans have been observed to modify their pod composition (Gulesserian et al. 2011), energy budgets (Williams et al. 2006), swim speed and vocalisation (Erbe 2002), and movement and diving patterns, surface behaviour and habitat use (Gulesserian et al. 2011). Humpback whales passing Sydney have been observed changing their breathing patterns by reducing time spent deep diving, and either remaining near the surface or employing a short, shallow diving pattern when vessels are present (Gulesserian et al. 2011). High levels of cetacean watching occur in Port Stephens, Byron Bay, Jervis Bay, and Twofold Bay, and are a cause for concern for resident dolphin populations. In particular, the population of Indo-Pacific bottlenose dolphins located within the Port Stephens Great Lakes Marine Park, which is the subject of the largest dolphin watching industry in Australia, have exhibited significant decreases in time spent feeding, socialising, and resting in the presence of dolphin watching vessels (Steckenreuter et al. 2012). These effects were correlated with an increasing number of boats and decreasing boat distance to dolphin pods.

Long-term behavioural changes in response to vessel presence include animals becoming sensitised, habituated to human activities (Constantine 2001), or avoiding areas where vessels are present (Erbe 2002) to the extent of abandoning habitat areas (Bejder et al. 2006). Long-term reductions in the time animals spend socialising, breeding, feeding, and resting decreases reproductive success (Bejder and Samuels 2003), which may have consequences for individual health and the viability of cetacean populations.

The presence of tourists also leads to behavioural changes in seals. Seals are more likely to change their behaviour when hauled-out on shore than when swimming. Signs of disturbance include animals changing from resting to becoming alert and watching onlookers (Shaughnessy et al. 2008), and displaying aggressive behaviour, such as charging and biting (Constantine 1999). More significant signs of disturbance include one or more animals moving to the water. Seal pups are particularly sensitive to disturbance from onlookers (Shaughnessy et al. 2008). Behavioural changes associated with long-term disturbance include animals becoming habituated to humans, relocating haul-out sites, and females neglecting their pups (Constantine 1999).

Disturbance to cetaceans from whale and dolphin watching can have short and long-term consequences to their health and viability. Disturbance has been reported in a large number of cetacean species including humpback whales, killer whales, bottlenose dolphins, fin whales, grey whales, common dolphins, dusky dolphins, Hector's dolphins, and sperm whales (Gulesserian et al. 2011). Critically, disturbance can affect the energy budgets of cetaceans by limiting time spent hunting, feeding, resting, and caring for young (e.g. suckling), and persistent disturbance is known to shift animals from their preferred habitat (Gulesserian et al. 2011). Lower reproductive success has been observed in female dolphins frequently exposed to whale and dolphin watching in Australia (Higham and Bejder 2008).

In Shark Bay in Western Australia, commercial tourism charters are tightly regulated. Research into the impacts of dolphin watching when tour operators increased from one to two vessels found a decline in the local dolphin population of one in seven individuals (Higham and Bejder 2008). This research demonstrates the cumulative impact of tour boat operators in a well-studied and closely monitored environment.

Approach distance regulations are the primary tool used to manage disturbance to cetaceans in NSW. However, experimental approaches of vessels in Jervis Bay found that short-term changes in the surface behaviour and travel direction of inshore bottlenose dolphins occurred at an exposure distance of ~100 m, outside the minimum approach distance stipulated within the NPW Regulation (Lemon et al. 2006). As noted above, the level of disturbance can be cumulative, so other factors that need further consideration when managing disturbance include:

- the cumulative time spent watching a pod by one or multiple vessels in a day and how much time a pod needs to recover between approaches
- whether there are temporal exclusion zones that would benefit the population (i.e. feeding and resting periods)
- whether there are spatial exclusion zones that would benefit the population (i.e. critical habitat areas)
- whether there are restrictions related to the biology, behaviour, or seasonal and habitat requirements of the species that would minimise disturbance.

There is less research on the impacts of tourism on seals than on cetaceans. However, the disturbance of seals has similar consequences to those reported in cetaceans. For example, the short-term disturbance of seals can alter energy budgets by restricting time spent resting when hauled-out (Constantine 1999, Shaughnessy et al. 1999). The impact of persistent disturbance is likely to reduce the reproductive success of the colony, especially when summer breeding seasons coincide with high visitor numbers; female seals have been observed neglecting their pups and reducing suckling time when tourists are present (Constantine 1999). The risks to seals from disturbance are high, because they are accessible to tourists when hauled-out on shore. This impact is well managed on Montague Island, where visitor numbers are limited and based on ongoing monitoring and research (Shaughnessy et al. 1999; 2008). Additional management may be required as seals establish more haul-out sites on mainland NSW.

6.1.7 AQUACULTURE

Oyster aquaculture

Oyster aquaculture is conducted in 37 estuaries along the NSW coast, using around 3,000 ha of leases (Figure 35). More than 300 shellfish businesses in NSW depend upon the quality of the environment in the marine estate to remain viable. They are reliant on a combination of natural larval spatfall and hatchery stock, and high-quality estuarine water for growth and product food safety. In NSW, approximately 49.5% of leases granted to conduct aquaculture are located in MPAs. In most cases, these leases have been in operation for more than 50 years, with many dating back to the early 1900s.

Oyster species cultured in NSW include the native Sydney rock oyster (*Saccostrea glomerata)*, the introduced Pacific oyster (*Crassostrea gigas)*, the native flat oyster (*Ostrea angasi),* and the Akoya pearl oyster (*Pinctada imbricata)*. The Sydney rock oyster is the mainstay of the NSW oyster industry (contributing 85% of the total production value of $40.6 million in 2014–2015) followed by Pacific oysters.

Most production occurs in estuaries in the northern region, followed by the southern region and then central (Figure 36). Production has been in decline in both the northern and central regions for at least the past decade, although there has been some recovery in the north since around 2012–2013. In contrast, production in the southern region has consistently increased since around 2009–2010.

In recent years, the key estuaries in the **northern region** in terms of production are Wallis Lake, Port Stephens, Camden Haven and the Hastings River. The key **southern region** estuaries are the Clyde River, Merimbula Lake, Wagonga Inlet, Pambula River and Crookhaven River. Historically, the most productive estuary in the **central region** was the Georges River, followed by the Hawkesbury River, with Brisbane waters and the Hunter River a distant third and fourth, respectively. Today, the Hunter River no longer produces oysters. The region's remaining estuaries have dwindled, and now produce only approximately 2.5% of the NSW oyster production.

A typical oyster farm is shown in Figure 37. Further details on oyster aquaculture are available on the DPI website, including production methods and health and disease issues[23], and oyster production by estuaries across NSW[24].

[23] http://www.dpi.nsw.gov.au/fishing/aquaculture/publications/oysters

[24] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/595260/aquaculture-production-report-2014-2015.pdf

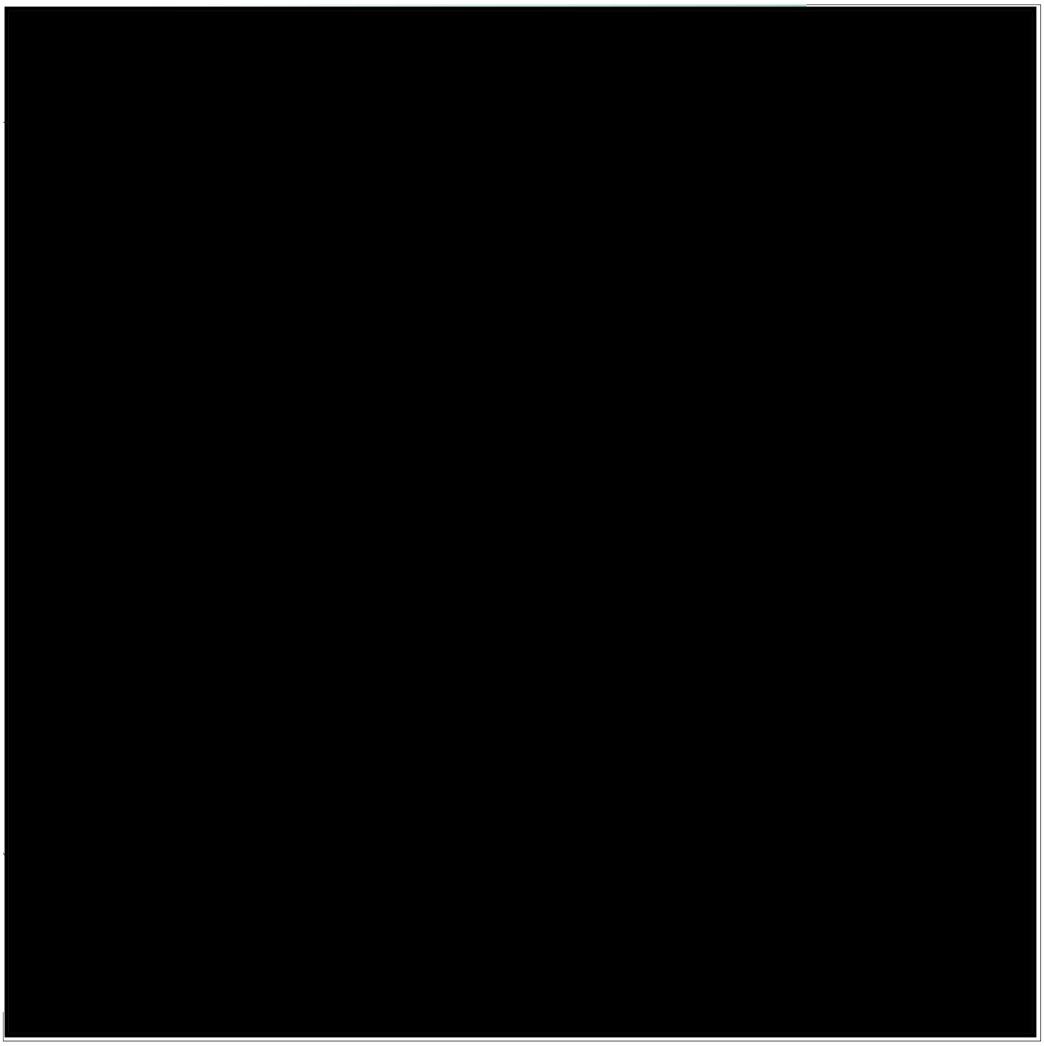


Figure 35. Location of the 37 estuaries used for oyster production in New South Wales. *Source: NSW DPI 2015.*

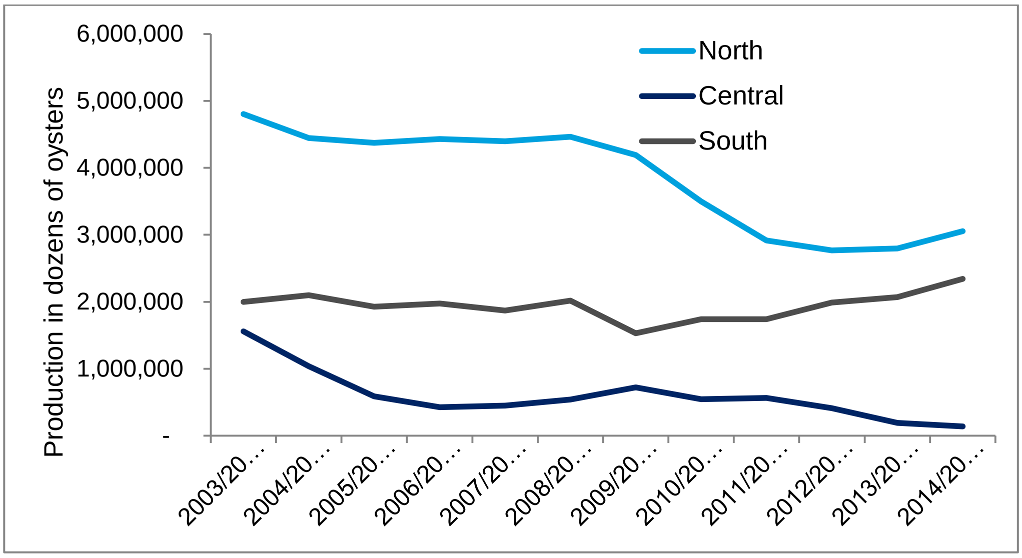


Figure 36. Production of oysters in the three New South Wales regions, 2003–2004 to 2014–2015. *Source: NSW DPI 2015.*

Figure 37. Oyster aquaculture in New South Wales. *Source: NSW DPI 2016.*

Other species

Farmed tiger prawns and mulloway are produced in the **northern region** in earthen ponds. There are a number of freshwater and marine hatcheries along the coast, as well as silver perch and barramundi farms. Three prawn, one mulloway, one Balmain bug and several aquaculture hatchery operations draw saline water for operation from estuarine or marine waters and discharge it after treatment. In 1999, the first marine finfish aquaculture in sea pens was established in NSW off Port Stephens. Two finfish sea pen farms are approved off Port Stephens (one 30 ha commercial snapper lease and one 20 ha research lease). The former is currently unused, while negotiations are underway with a commercial operator for kingfish production to occur on the research lease.

Details of aquaculture in the **central region** are presented in the Hawkesbury marine bioregion environmental report (MEMA 2016). In addition, in 2001, a polychaete production facility was constructed on the shores of Lake Macquarie to produce *Diopatra* sp., predominantly for use as bait and aquafeeds.

In the **southern region**, the subtidal culture of shellfish, predominantly blue mussel, has occurred in NSW since the mid-1970s. Between 1977 and 2008, blue mussel aquaculture was undertaken in Jervis Bay, and three new lease areas were approved within the Bay in November 2014 for extensive aquaculture of shellfish (excluding abalone) and marine algae. Early indications suggest blue mussels are the species most likely to be cultivated on these leases, although scallops, pearl oysters and flat oysters have been discussed. Currently, 50 ha of lease area in Twofold Bay is approved for subtidal aquaculture using long-line systems.

Current management

NSW aquaculture industries are highly regulated to prevent adverse environmental impacts and to maximise socioeconomic benefits. Approval of aquaculture activities under the *Environmental Planning and Assessment Act 1979 (EP&A Act)* requires that environmental impacts be assessed, and where necessary, mitigated. *State Environmental Planning Policy 62 – Sustainable Aquaculture* provides approval pathways tailored to address the potential impacts of aquaculture.

The operation of aquaculture businesses is regulated under the provisions of the *Fisheries Management Act 1994 (FMA)* and the Fisheries Management (Aquaculture) Regulation 2012 (the FMA Regulation) through aquaculture permit conditions, import and broodstock collection permits, and lease conditions for aquaculture on public water land. The *FMA* and FMA Regulation also mandate shellfish translocation procedures, a regular compliance inspection regime and penalties for breaches of permit and lease conditions.

During the past 15 years, the NSW Government has implemented a whole-of-government approach to the development of aquaculture in NSW, to promote environmentally sustainable development and provide an alternative source of seafood production to wild caught fisheries. NSW oyster and land based sustainable aquaculture strategies detail best-aquaculture practice for species and site selection, design and operation, and outline the environmental impact assessment pathway. These strategies take effect under State Environmental Planning Policy 62-Sustainable Aquaculture (SEPP 62) and as aquaculture industry development plans under the *FMA*.

The NSW Oyster Industry Sustainable Aquaculture Strategy (OISAS) identifies those areas within NSW estuaries where oyster aquaculture is a suitable and priority outcome (NSW DPI 2014). These areas are known as Priority Oyster Aquaculture Areas (POAA). POAA were identified from a site inspection and evaluation against a list of locational, environmental and socioeconomic suitability criteria. Where POAA occurs within marine parks, the OISAS assessment has been recognised and is zoned within these areas as Special Purpose Zones.

The main aims and roles of OISAS are to:

- secure resource-access rights for present and future oyster farmers throughout NSW
- document and promote environmental, social and economic best practice for NSW oyster aquaculture
- ensure that the principles of ecological sustainable development, community expectations and the needs of other user groups are integrated into the management and operation of the industry
- formalise industry’s commitment to environmentally sustainable practices and a duty of care for the environment on which the industry relies
- implement measures that will lead to the protection and improvement of water quality in NSW estuaries, including referral of all Development Applications that may impact shellfish harvest water quality to Fisheries NSW for assessment under SEPP 62.

The NSW Land Based Sustainable Aquaculture Strategy (NSW Industry & Investment 2009) is made up of two interlinked sections – a best-management section and an integrated approvals section – so that projects can be established and operated to meet sustainability objectives.

The best-management section provides the basis for the Aquaculture Industry Development Plan for land based aquaculture in NSW under the provisions of the Act. The plan identifies best management for business planning, species selection, site selection and design, and planning and operation of the land based aquaculture facilities. It also includes performance requirements for relevant environmental regulations.

The shellfish industry routinely monitors water quality in oyster-growing areas, as well as shellfish meat quality, to ensure that it meets stringent food safety standards under the NSW Shellfish Program. In recent years, oysters have been considered to be the ‘canaries’ of the waterways, detecting poor water quality that may arise from human activities. Many coastal local governments and local land services recognise the important role the shellfish industry plays in monitoring the environment, and work with industry to remedy estuarine pollution sources.

The integrated approvals section of the strategy contains a project profile analysis that guides an up-front preliminary assessment of the likely level of risk to the environment from aquaculture proposals. The outcome of the analysis determines the level of assessment: low-risk proposals require a Statement of Environmental Effects, while high risk proposals require an EIS. The project profile analysis is given effect under SEPP 62.

Some of the criteria used in the project profile analysis include:

Locational criteria	Operational criteria
• conservation exclusion zones • heritage or native title interest areas • presence of acid sulfate soils • presence of floodways • water supply availability and adequate hydrology • soil suitability • nearby ecology • presence of riparian buffers • adjacent land use • excess water disposal	• species selection that is appropriate to the region • biosecurity and health management • feed management • waste management • discharge water management • predation and stock management • screening and prevention of stock loss

The complete list of locational and operational criteria are detailed in the NSW Land Based Sustainable Aquaculture Strategy (NSW Industry & Investment 2009).

Hatcheries wishing to participate in stocking programs for estuarine or marine species must be accredited under the NSW Hatchery Quality Assurance Scheme. The scheme audits facilities to ensure that minimum operational standards in the form of infrastructure, equipment and breeding techniques are met to ensure that fish destined for stocking comply with genetic guidelines and meet health standards.

Independent environmental monitoring undertaken as part of the aquaculture permit conditions for the original marine aquaculture farming activities identified that the activity had no significant impacts on the sediments in Providence Bay off Port Stephens (Underwood and Hoskin 1999).

For the deep water marine shellfish leases in Jervis Bay, a total of 22 risk issues were identified. Nineteen issues were assessed as of low or negligible risk. No issues were identified as representing a high or extreme risk, but three were classified as moderate. These were water quality and sedimentation; genetics, disease and introduced pests; and entanglement and ingestion of marine debris. These issues and their required mitigation measures are summarised in the environmental management plan that must be implemented as a requirement under the project approval[25] issued via the *EP&A Act.*

[25] https://majorprojects.affinitylive.com/public/8f9148dc471f4639fc3b966d9370df49/Jervis%20Bay%20Aquaculture%20Project%20SSI%205657%20Instrument%20of%20Approval.pdf

Independent environmental monitoring undertaken as part of the aquaculture permit conditions for mussel farming activities identified that the activity has had no significant impacts on the sediments in Twofold Bay. Following approval of these two applications, the NSW Government is now looking to develop a NSW Marine Waters Sustainable Aquaculture Strategy for inshore and offshore coastal waters that will reflect best-practice requirements.

Aquatic pest and disease issues are also regulated and managed under the *FMA* and FMA Regulation. Farms follow health management plans to routinely screen farmed stock health. Juvenile prawn stock is disease tested prior to entry to the farm. Marine finfish stock are currently being supplied by a hatchery accredited under the NSW Hatchery Quality Assurance Scheme to ensure stock is pest and disease free. There is an exemption to requiring a permit for the production of ornamental fish in a total water capacity of less than 10,000 L.

The oyster industry has specific permit conditions and quarantine orders that deal with relevant pests and diseases[26]. In brief, the Sydney rock oyster endemic disease, QX, and the Pacific oyster exotic disease, Pacific oyster mortality syndrome (known as POMS), are controlled through quarantine orders that restrict the movement of oysters and infrastructure between some estuaries. The risk of importation of POMS from interstate increased in 2016 with an outbreak in Tasmania, and border restrictions were implemented to prohibit movement of oysters from Tasmanian waters into NSW waters. Generally, import of oyster spat from hatcheries is controlled through specific hatchery and importation protocols developed and approved by Biosecurity NSW. The spread of Pacific oysters is also controlled through movement restrictions that are mandated in Division 2A of the FMA Regulation.

Division 2A of the FMA Regulation also mandates that all oyster shipments are recorded in the oyster shipment logbook system. This system facilitates trace back and control should a biosecurity event occur and also assists compliance with movement restrictions. This type of control and trace back information is not available for many of the other main vectors of aquatic pests and diseases, including recreational and commercial vessels.

Application for the cultivation of new species includes a thorough assessment of potential pest and disease issues as required under OISAS (2014). Similarly, any import of stock into NSW by the oyster industry is assessed and regulated for pest and disease issues under s.217 of the *FMA*.

Potential impacts associated with aquaculture

Water pollution

Land based aquaculture in NSW is undertaken using freshwater (surface and subsurface) as well as saline waters (marine, estuarine, and inland saline). The NSW EPA regulates aquaculture activities (excluding oyster production) that involve supplemental feeding in tanks or artificial waterbodies and discharges to waterways using environmental protection licences. Freshwater aquaculture is not permitted to discharge any waters directly into waterways, except for a small number of historic salmonoid farms based in inland NSW. Excess freshwater and any nutrients it contains are used on farm, primarily for irrigation purposes. For example, the Port Stephens Barramundi Farm integrates fish production with a hydroponics operation. Saline water based farms are unable to reuse wastewater for irrigation; they require other options, such as evaporation (inland saline systems) or other predisposal treatments. All Australian prawn farms use environmental management practices, including discharge treatment systems, to meet world best-practice discharge water quality. These progressive advances in treatment systems and practices have enabled some farms to increase their total production area with no net increase in sediment and nutrient loads discharged into receiving waters.

[26] http://www.dpi.nsw.gov.au/biosecurity

Antifouling and other toxicants

Since the advent of intertidal farming practices in the early 1900s, the NSW oyster industry used the traditional marine antifouling practice of coating timbers with coal tar to protect the timbers from marine boring organisms. The rising cost of marine grade timber, occupational health and safety issues, disposal costs associated with the use of tar and the advent of new composite materials has seen the industry move away from tar over the last 15 years. They now use plastic-coated timber, composite posts and plastic baskets and trays, and rarely use tar. However, a small amount of legacy tarred timber infrastructure is still present on some oyster lease areas.

An assessment of sediment contamination from tar-treated infrastructure in the Port Stephens and Georges River estuaries found polycyclic aromatic hydrocarbons (PAH) consistent with those found in coal tar within and adjacent to lease areas (Umwelt Australia Pty Ltd 2000). In Port Stephens, PAH was at background levels 5 m from the leases tested, while in the Georges River, PAH remained elevated 10 m from some of the leases tested. A highly variable vertical distribution of PAH through the sediment profile was observed. The associated biological sampling and habitat surveys undertaken at the Port Stephens sites indicate that there are no ecological differences between lease and non-lease areas for benthic fauna, epiphytes and seagrass. This supports the evidence that PAH in sediments near leases has caused no significant impact.

Prawn and marine finfish hatcheries primarily use chemicals to disinfect culture apparatus. The chemicals are only used in small quantities and wiped or sprayed onto surfaces, and may include methylated spirits, sodium sulfate and sodium hypochlorite. In the event of disease outbreak in a hatchery, very small quantities of oxytetracycline may be used in accordance with Australian Pesticides and Veterinary Medicines Association requirements, which outline dosage rates, withholding periods and user safety advice. Oxytetracycline is a broad-spectrum synthetic antibiotic that rapidly degrades in seawater, and further breaks down in hatchery wastewater-settlement ponds.

Prawn and marine finfish ponds undergo lime treatments during fallowing. The lime is scarified into the pond base to manage pH levels, and as a health management strategy before filling the pond.

Once prawn ponds are filled, urea may be applied to stimulate natural algae blooms before stocking the pond with juveniles. Molasses may be added during the growing season to act as a biofloc as required. If large amounts of fresh water enter the ponds, salt may be added to maintain salinity. Occasionally, marine finfish farms may use formalin to treat stock for disease.

The use of settlement pond systems in both prawn and marine fishpond culture ensures that chemicals are mostly broken down by processes such as biodegradation, chemical degradation, photo-chemical degradation and reaction with other organic compounds in the settlement pond environment.

Litter and marine debris

Currently, 458 ha of oyster lease area is abandoned in NSW (as at February 2015, from the Fisheries NSW oyster lease database). The majority of these areas are in Botany Bay and Georges River (194 ha), Port Stephens (156 ha) and the Hawkesbury River (49 ha). Abandonment has resulted from the introduction of a noxious species (Pacific oyster) in Port Stephens and the oyster disease QX (Georges and Hawkesbury rivers).

Derelict or abandoned oyster cultivation materials, such as tarred sticks, trays, poles and racks, can pose a navigational safety risk and look unsightly. This reflects poorly on the oyster industry as a legitimate user of the state’s estuarine water resources. Fisheries NSW has a statutory responsibility to manage oyster lease areas to ensure derelict cultivation is not left on public water land.

Since 2001, an aquaculture lease security arrangement (environmental performance bond) has been in place. This bond system ensures that industry shares responsibility for problems arising from lease management and maintenance. All lease holders are required to contribute to the lease security trust account.

Several large-scale clean-ups of derelict leases have occurred in NSW. In 2000, the NSW Government supported a derelict oyster clean-up program following a severe industry downturn in the 1990s. This resulted in 433 ha rehabilitated and 2000 tonnes of waste removal from Port Stephens, and 84 ha rehabilitated, 67 ha of stick cultivation removed, and 520 tonnes of waste removed from the Georges River. Between 2004 and 2008, the Hawkesbury River industry also removed dead stock and 8000 tonnes of redundant oyster infrastructure following an outbreak of the oyster disease QX.

In 2009, Fisheries NSW embarked on an active management and compliance program to ensure that permit holder and lessee obligations are upheld, and to facilitate the removal and environmentally sustainable disposal of derelict oyster materials from the state's waterways. This program ensures that new leases are not added to the derelict lease estate through compliance and administrative sanctions against former and current permit and lease holders. Where non-compliance occurs, contractors are employed to remediate the previously leased area. Costs are either recovered from the permit holder or lessee, or where deemed unrecoverable, are recovered from the lease security trust account. This program has seen the rehabilitation of 319 leases covering 385 ha.

The NSW oyster industry is also actively involved in land based clean-ups of current and former oyster land based depot sites in conjunction with Crown Lands and the NPWS. The industry also participates in community clean-ups, particularly Clean-up Australia Day. Many of these activities are undertaken in line with the industry's individual, estuary based environmental management systems. Of 32 oyster-producing estuaries in NSW, 16 are committed to an estuary-wide environmental management system[27]. These activities are also consistent with the industry's commitment to environmentally sustainable practices, including the good neighbour and estuarine stewardship policies detailed in OISAS (2014).

Physical damage

Unlike many areas in the world, lease based oyster farming activity in NSW is conducted almost exclusively from within flat-bottomed punts, due to the deep muddy nature of most oyster-growing areas. In shallow seagrass areas, the punts are poled, rather than driven.

Traditional tray-and-stick cultivation of oysters in NSW has been observed to affect seagrass present on oyster lease areas. In most cases, this is largely confined to the areas directly beneath the cultivation in shallow areas. Aerial photographic evidence suggests that on removal of the infrastructure, seagrass quickly recolonises the area beneath the cultivation, particularly where the underlying seagrass is *Zostera* spp. In the case of *Posidonia australis*, evidence suggests that the rate of re-establishment is linked to the presence of a network of viable rhizomes remaining beneath the infrastructure, and that the observed effect is associated with defoliation due to light attenuation, rather than death.

Modern post-supported and floating-basket oyster cultivation techniques are now replacing traditional tray-and-stick cultivation techniques in many areas, particularly in southern NSW. These are proving to be more seagrass friendly, and healthy beds of *P. australis* and *Zostera* spp. can be found under this cultivation type. In some cases, the presence of the oyster leases has restricted damage to seagrass established on and behind oyster lease areas, due to unregulated boat access and reduced wave action. While there is little published quantitative evidence to support these observations in NSW, evidence is growing internationally to support these observations. Several current research projects are aiming to clarify the nature of seagrass and oyster lease interactions in NSW waters.

As a mitigation measure, Fisheries NSW does not allow any new oyster leases over seagrass. Specific seagrass-protection measures are outlined in the OISAS best-practice standards (OISAS 2014). An assessment of the potential impacts associated with oyster aquaculture in NSW is presented in Ogburn (2011).

[27] http://www.oceanwatch.org.au/our-work/ems-nsw-oysters/

Wildlife interactions

The construction of oyster leases involves two to four people installing posts and infrastructure from punts. The work is undertaken intermittently over about one to two months, fitting around weather conditions, other oyster farming tasks and tidal fluctuations. Outboard motors are generally only used for transport to the lease area. Poles are then used to manoeuvre the punt around the lease.

The cultivation of oysters on each lease involves irregular stock management (averaging six weekly for baskets, and annually for sticks) and maintenance. This involves one to two people moving around the lease in a flat-bottomed punt to ensure all infrastructure is appropriately attached and in good condition. Stock may be removed and taken back to the land base for grading. The work is generally undertaken over one tide.

The above activities may discourage birds and migratory or other estuarine and marine species from approaching the immediate area, potentially disrupting the behaviour, feeding and movement of some species. However, given that these disturbances are short and irregular, the potential for ongoing disturbance is negligible. In some areas, oyster lease infrastructure may be a safe haven for migratory and wading birds, providing roosts that cannot be accessed by predators, such as foxes, dogs and cats.

Land based aquaculture, such as fin fish and prawn farms, have reported issues with sea birds, such as cormorants and darts, preying on their stock while in ponded areas. This issue is cyclical and dependent on the availability of prey associated with drought conditions affecting inland breeding areas (Ian Lyall pers. comm.). The industry is encouraged to use non-lethal methods to control predatory birds, such as motion-sensored watering systems, laser scarers, line scarers strung across ponds or gas guns.

OISAS (2014) considers threatened species and wildlife interactions as one of seven conservation-specific assessment criteria for POAA (see Table 5 in OISAS (2014)). This means that all areas currently designated POAA have been assessed as not affecting significant (SEPP14) coastal wetlands, matters of national environmental significance listed under the *EPBC Act*, listed threatened species and their habitats under state and federal legislation, or MPAs in NSW. All new lease applications are similarly assessed against these criteria.

Two other relevant assessments[28] of the potential impacts of oyster leases on listed threatened species and MPAs found no significant impacts. The proposals were approved, with the main mitigation measures being the adoption of the best-practice standards for oyster aquaculture published in OISAS. OISAS includes specific threatened species protection measures (see Chapter 7.8 in OISAS (2014)).

Fish and mussel farming infrastructure can interact with marine fauna such as whales, seals and dolphins. However, there have been no reports of entanglement impacts or other interactions with marine mammals from the farming infrastructure in Twofold Bay since the mid-1970s, or in the sea pen infrastructure off Port Stephens.

Water extraction

Prawn farms operate seasonally (eight months per year) and extract water to fill and exchange grow-out ponds. Low volumes of estuarine water (2–20,000 megalitres per year per facility) are extracted annually to support prawn aquaculture operation and hatcheries. Marine fish grown in earthen ponds operate year-round, and extract water at the lower end of the prawn farm range. Operators do not have to be licensed for estuarine and marine water extraction.

[28] Industry and Investment NSW (2010) Review of Environmental Factors for Proposed Oyster Leases Within Towra Point Aquatic Reserve, and NSW Department of Primary Industries (2012) Review of Environmental Factors for Oyster Leases within Comerong Nature Reserve

6.1.8 RESEARCH AND EDUCATION

Estuarine flora and fauna is sampled for a wide range of research and educational activities within the northern, central and southern regions. This includes sampling from both intertidal and subtidal habitats, which is generally targeted at individual taxonomic groups. Some limited sampling also provides specimens for educational programs, primarily university undergraduate studies.

The use of passive observational techniques in marine research is rising, reflecting recent developments in underwater video and acoustic techniques. This also reflects the increasing use of marine park sanctuary zones for understanding changes in marine populations where extractive sampling is generally not allowed. This activity is more common in the northern and southern regions, due to the presence of sanctuary zones in the Cape Byron, Solitary Islands and Port Stephens-Great Lakes Marine Parks (northern), and Jervis Bay and Batemans Marine Parks (southern).

Current management

Assessments are made of all proposed research and educational sampling that requires specific harvesting of flora and fauna. A scientific collection permit is required for individuals who intend to collect fish or marine vegetation for scientific research. This permit can be issued under Section 37 of the *FMA* to allow the taking or possession of fish or marine vegetation that would otherwise be unlawful. As part of issuing permits, NSW DPI has a statutory responsibility under Section 111 of the *EP&A Act* to assess the environmental impacts of activities authorised by permit. To assess these impacts, NSW DPI requires the applicant to consider the potential impacts of their proposed research.

Further details on current management arrangements for research and education are presented in *Section 8.1.7 Research and education.*

6.1.9 RECREATION AND TOURISM

Boating and boating infrastructure

Of the 7.2 million Australian households, an estimated 789,000 (11% of total) owned at least one recreational vessel as at April 2000. The total number of vessels (including personal watercraft, canoes, sailing boats, row boats and power craft) owned by Australian residents at that time was about 925,000 vessels. Not unexpectedly, the level of boat ownership was higher for households containing recreational fishers, with approximately 574,000 (32%) of the 1.8 million Australian fishing households owning a boat. Not all recreational vessels are used for fishing. Of the total, more than 511,000 (55%) were identified as having been used for recreational fishing in the 12 months before May 2000.

Vessels are categorised according to their primary mode of propulsion: personal watercraft, powered vessels, sailing vessels and paddle or row boats. While all types were used for recreational fishing, the vast majority (93%) of recreational fishing vessels were powered. Approximately 5% of the recreational fishing fleet were paddled vessels. Sailing boats and jet skis were of negligible significance as recreational fishing platforms.

The primary storage location of fishing boats was another feature that may be used to categorise the recreational fleet. The survey established that the majority (80%) of recreational fishing vessels were stored on trailers (trailer boats). The balance was distributed almost equally between moorings or marinas (Figure 38), on the shore or carried as 'car toppers'.

Depth-sounding and global positioning system (GPS) electronic aids were also used to characterise the fishing fleet. These electronic devices are generally used to assist fishers in the location of fish and with navigation. Depth-sounding and GPS equipment was present on 45% (232,000 vessels) and 19% (100,000 vessels) of the recreational fishing fleet, respectively.

There are more than 2 million recreational boaters along the NSW coastline and on inland lakes, rivers and estuaries. Recreational boating is a popular social and leisure activity, and a significant driver of domestic tourism, contributing an estimated $3.8 billion to the NSW economy.

Recreational boating includes:

- paddle sports (canoes, kayaks, rowing, dragon boat racing, dinghies)
- sailboarding and kite boarding
- sailing (small sailboats, skiffs, day sails, catamarans, cruisers, racing and regattas)
- ski boats (tow boats for water-skiing, wake boarding, parasailing)
- personal watercraft (jet skis)
- powerboats (open runabouts, cabin runabouts, motor cruiser)
- fishing from vessels
- swimming, spearfishing and snorkelling or diving from vessels.

For the purposes of this report, recreational vessels are those used purely for pleasure, and not in connection with a business (see section on domestic commercial vessels). There are approximately 230,000 registered recreational vessels in NSW, and more than 485,000 people hold a licence to drive a recreational powerboat. Operation of passive craft, such as canoes, kayaks, sailboats and paddlecraft, does not require a recreational boating licence (estimated at a further 100,000 vessels).

The most popular areas for boating in terms of vessel registrations and boat driver licences are in the central region, in the Hunter River, Hawkesbury (Pittwater–Brisbane Water), Sydney Harbour, and Botany Bay (Georges River and Port Hacking).

Figure 38. A typical marina in New South Wales

Current management of recreational boating

RMS boat licence and boating handbook-*Marine Safety Regulation 2016* – rules associated with recreational boating in the Regulation are contained within the RMS Boating Handbook (Safety and Rules).To ensure recreational boaters understand the approach distance guidelines, RMS have incorporated education of boaters into the boat licence training and examination.

The *Protection of the Environment Operations Act 1997 (POEO Act)* is the main piece of NSW environmental legislation covering water, land, air and noise pollution and waste management. Under section 120 of the *POEO Act* it is illegal to pollute or cause or permit pollution of waters. Under the Act, ‘water pollution’ includes introducing anything, including litter, sediment, fuel, oil, grease, wash water, debris, detergent, paint, etc. into waters or placing such material where it is likely to be washed or blown into waters or the stormwater system or percolate into groundwater.

RMS are primarily responsible for regulation of small commercial vessels. DPI lands operates coastal harbours that berth commercial vessels.

RMS requires recreational vessel owners to pay a registration fee based on the length of their vessel, and a fee for a boat driver licence to navigate a vessel able to travel greater than 10 knots. Through the operation of the Waterways Fund, these fees fund delivery of boating services and facilities, such as on-water patrols, education and compliance campaigns and management initiatives, navigational aids and harbour cleaning services. The fund is administered by RMS and is established under section 42 of the *Ports and Maritime Administration Act 1995.* It accounts for all revenues and expenditures associated with the boating safety, property management and infrastructure functions delivered by RMS and Transport for NSW in accordance with NSW marine legislation.

A Maritime Advisory Council established under the *Ports and Maritime Administration Act 1995* advises the Minister on maritime matters, including recreational boating and boating infrastructure.

NSW Boating Now and Regional Boating plans

The NSW *Boating Now* boating infrastructure program, announced in August 2014, consists of $70 million over the next five years to support the delivery of projects and actions identified in Regional Boating Plans[29], which are divided into 11 regions (Figure 39).

The plans include details about the boating safety, access and infrastructure actions to be implemented in each region over the next five years to improve recreational boating across NSW. The number of vessel registrations and boat licences by coastal region in 2014 are detailed in Table 22. Specific details about the 10 Regional Boating Plans that relate to areas with the NSW marine estate are presented in Table 23.

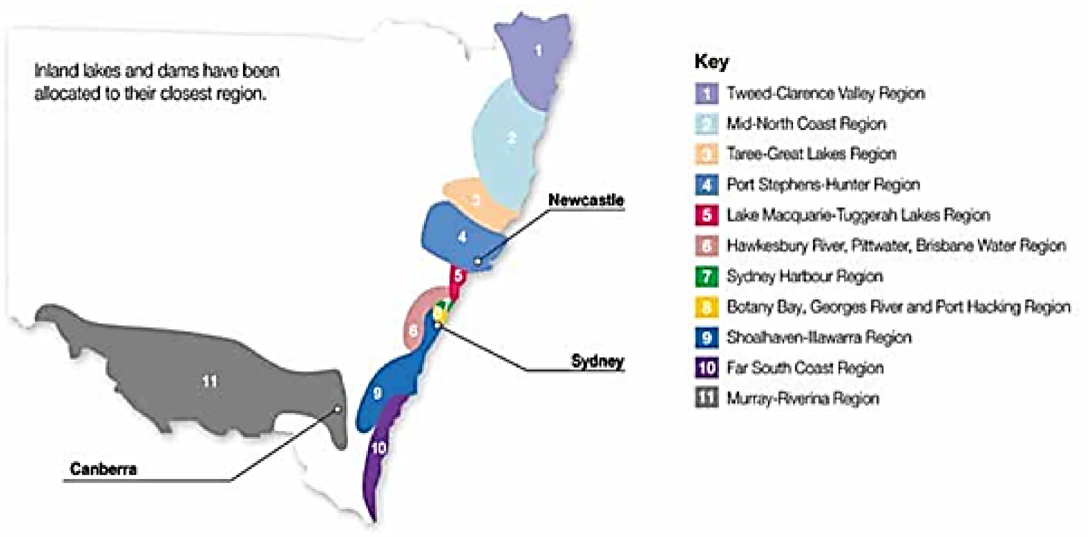


Figure 39. Regional boating plans across all New South Wales regions, 10 of which relate to areas with the marine estate.

[29] http://maritimemanagement.transport.nsw.gov.au/projects/regional-boating-plans/index.html

Table 22. Vessel registrations and boat licences by New South Wales coastal region in 2014, all figures are approximate.

Region	Local government areas	Boat licences	Registered vessels
Tweed / Clarence Valley	Tweed, Byron, Richmond Valley, Ballina, Lismore, Clarence Valley, Kyogle	25,000	14,000
Mid-north coast	Armidale Dumaresq, Bellingen, Coffs Harbour, Nambucca, Kempsey, Port Macquarie-Hastings, Narrabri, Gunnedah, Tamworth, Gwydir, Guyra, Inverell, Moree Plains, Liverpool Plains, Lord Howe Island Board, Lake Keepit State Park Trust, Tareelaroi Weir Reserve Trust, Yarrie Lake Flora, Fauna and Recreation Reserve Trust, Bowling Alley Point Recreation Reserve Trust (Chaffey Dam)	42,000	20,000
Taree – Great Lakes	Greater Taree, Great Lakes, Gloucester	15,000	8,700
Port Stephens/ Hunter	Port Stephens, Great Lakes, Maitland, Newcastle, Cessnock, Singleton, Dungog, Muswellbrook, Upper Hunter, Wellington, Mid-Western, Oberon, Lithgow, Blayney, Boorowa, Cowra, Bogan	64,000	27,000
Lake Macquarie – Tuggerah Lakes	Lake Macquarie, Wyong	41,000	19,000
Hawkesbury – Pittwater – Brisbane Water	Gosford Council, Hawkesbury, Camden, Pittwater, Ku-ring-gai, Hornsby, The Hills, Penrith, Warringah	103,000	41,000
Sydney Harbour	Auburn, Canada Bay, Ryde, City of Sydney, Lane Cove, Leichhardt, Manly, Mosman, North Sydney, Parramatta, Hunters Hill, Willoughby, Woollahra	52,000	20,000.
Botany Bay, Georges River and Port Hacking	Kogarah, Marrickville, Randwick, Rockdale, Fairfield, Bankstown, Botany Bay, Hurstville, Liverpool, Sutherland	77,000	28,700
Shoalhaven – Illawarra	Shellharbour, Shoalhaven, Kiama, Wollongong	50,000	24,000
Far south coast	Shoalhaven, Eurobodalla, Bega Valley	7,000	4,400

Table 23. Recreational boating activity and infrastructure per New South Wales region

Area	Recreational boating activities	Recreational boating infrastructure
Northern region		
Tweed	Fishing from vessels and the shoreline with designated recreational fishing havens. Popular areas: downstream from Boyd’s Bay Bridge, Wommin Lake and Crystal Waters Water-skiing and wake boarding: adjacent to the Fingal Head Boat Harbour, between Chinderah and The Piggery, and Tumbulgum to the Commercial Road Boat Ramp Personal watercraft popular: especially ‘wave-zone’ adjacent to the Jack Evans Boat Harbour Rowing: near Boyds Bay Bridge and between Condong and Murwillumbah. Non-powered boating activities such as canoeing, sailing and kayaking	69 boat ramps 55 public access points including wharves, jetties, pontoons and landings Courtesy moorings at Julian Rocks and Cook Island Aquatic Reserve Around 1,300 on-water and on-land storage spaces Fewer than 250 private moorings; just over 20 are commercial mooring licences administered by RMS, and some are administered by Crown Lands Much less on-water storage available in this region compared with other areas of NSW
Brunswick	Power boating, sailing, canoeing and kayaking	
Richmond	Ballina: caters for cruising vessels on ‘day sails’ along the NSW coast Evans River: mostly recreational fishing from powerboats and popular for canoeing, kayaking and swimming	
Clarence	White water rafting and canoeing, still-water canoeing and kayaking in the upper reaches of the Clarence, rowing, sailing, dragon boat racing, recreational fishing, and water-skiing and wakeboarding	
Bellinger and Nambucca and Coffs Harbour	Canoeing, sailing, fishing, boating and water-skiing, tubing and wakeboarding. Motorised boating: dinghies, ski boats, small trailer boats, wake boats and jet skis on the Bellinger Corindi River: boating activities, fishing and aquaplaning, canoeing and kayaking, small sail craft Coffs Creek: recreational fishing, canoeing and kayaking Coffs Harbour: commercial marina for large recreational and commercial/fishing vessels and to a slipway Nambucca River: boat trips between centres, fishing and water sports (e.g. water-skiing) Deep Creek: recreational fishing, non-powered and powered	68 boat ramps 44 public access points including wharves, jetties, pontoons and landings 26 courtesy moorings around the Solitary Island Marine Park 1,200 vessels stored on-water or associated land facilities 150 private moorings, 105 commercial mooring licences administered by RMS, and some administered by NSW Trade and Investment (Crown Lands)
Macleay	Macleay River: recreational boating, concentrated in Kempsey, Smithtown, Jerseyville, Matty’s Flat, Fishermans Reach, Stuarts Point and South West Rocks (commercial dive and fishing charter vessels, recreational fishing)	
Hastings	Sailing, canoeing, rowing, power boats, water-skiing, personal watercraft Dry dock and slipway on the Hastings River Camden Haven River is frequented by personal watercraft	
Manning	Power boating, recreational fishing, rowing, sailing and kayaking	26 boat ramps 38 public access points including wharves, jetties, pontoons and landings
Wallis Lake	Recreational fishing, paddling, power boating and jet skiing. Coolongolook, Wang Wauk and Wallingat Rivers: fishing and water-skiing	

Area	Recreational boating activities	Recreational boating infrastructure
Smiths Lake	Water-skiing, canoeing, kayaking, kite-surfing, fishing and personal water craft Ski Cove to Bull Island: most intensively used section of Smiths Lake windsurfers, sail craft, canoes, catamarans, powerboats and personal water craft, power boats used for towing purposes	600 vessels stored on-water or associated land facilities 130 private moorings, 10 commercial moorings administered by RMS, some commercial and private licences by Crown Lands Small boat harbours at Crowdy Head and Forster
Central region		
Hunter	Boating, water-skiing and rowing focused around Newcastle, Raymond Terrace, Morpeth rowing, dragon boats and outrigger operations: Throsby Creek, Throsby Basin and Newcastle Harbour Vessel based fishing popular in lower reaches of river	54 boat ramps 56 public access points including wharves, jetties, pontoons and landings 40 courtesy moorings 1,700 vessels stored on-water or at associated land facilities 690 private and 189 commercial moorings administered by RMS, some licences managed by Crown Lands
Karuah (northern)	Karuah River: boating Port Stephens: popular for recreational boating, especially for fishing, sightseeing and cruising, most popular recreational boating areas are Nelson Bay, Salamander Bay and Shoal Bay Myall River estuary: sailing, power boating, canoeing, house boating and fishing, commercial hire-and-drive vessels within the estuary Broughton Island: popular for boating	
Lake Macquarie	Popular for recreational fishing, sailing, water skiers, wake vessels, rowers, kayakers, yacht racing and other regattas; hosts numerous sporting events Lake dominated by trailered boats (generally <6 m), few larger vessels access the waterway, larger vessels mostly stored on water at private moorings, jetties or marinas Number of bays dominated by sail vessels (e.g. close to 80% of private moorings in Toronto occupied by sailing vessels, similar in Sunshine and slightly lower in Belmont) Popular areas: Murrays Beach, Pulbah Island, Kilaben Bay and Crangan Bay. Narrow channel between Wangi Wangi peninsula, the sand bars at Swansea Flats and the Swansea Channel provides lake-wide access. Water ski and jet ski (personal watercraft) activities, primarily in southern lake, personal watercraft also frequent Swansea Bar and offshore beach	55 boat ramps 70 public access points including wharves, jetties, pontoons and landings 12 courtesy moorings 3,300 vessels stored on-water or at associated land facilities
Tuggerah Lakes	Popular for recreational boaters, especially small vessels used for sailing: power, passive craft and hire vessels Commercial operations: hire-and-drive vessels, kayaks and canoes, smaller sail craft and stand up paddle boarding, fishing from vessels is popular	
Hawkesbury and Nepean Rivers	Hawkesbury River, lower reaches: power boating, recreational fishing, water-skiing and wakeboarding, personal watercraft, house boating, sailing, kayaking and canoeing	45 boat ramps 117 public access points including wharves, jetties,

Area	Recreational boating activities	Recreational boating infrastructure
	Hawkesbury River, upper reaches: water-skiing and wakeboarding, particularly near Wisemans Ferry, which together with its tributaries, is also popular for canoeing and other non-powered craft Nepean River: popular for rowing, Sydney International Regatta Centre at Penrith, also power boaters Tench Reserve, and wakeboarding at cable wake park in Penrith	pontoons and landings 19 courtesy moorings Access facilities at private clubs and commercial marinas: boat ramps, jetties, wharves and pontoons, trailer parking and visitor berths and moorings 8,500 storage spaces on-water or associated land facilities 4,000 private moorings and 1,500 commercial moorings, administered by RMS ~50% of commercial moorings associated with marinas, clubs or related boating facilities Numerous wetland leases administered by Crown Lands
Pittwater	Sailing, kayaking, fishing, sailboarding, kite-surfing, water-skiing, dragon boating and shore fishing, personal watercraft use becoming popular	
Narrabeen Lagoon	Narrabeen Lagoon: kayaking and canoeing, rowing, small motorised vessels, small sailing dinghies, kite-surfing and both shore fishing and fishing from small dinghies Minimal use of the lagoon by larger sailing and motorised vessels; the use of small sailing dinghies, kite boarders and sailboarders mostly restricted to the SW side of the lagoon	
Brisbane Water	Power boating, fishing, water-skiing, sailing, paddling, kayaking and rowing Typically, large vessels predominantly found downstream of the Rip Bridge and smaller vessels found upstream The use of sail craft is predominantly located in The Broad Water, north of Saratoga	
Outer Sydney Harbour **Bordered by entrance to the Heads, the Opera House and Admiralty House**	Sailing and yachting, leisure boating, non-powered craft use such as kayaking in the sheltered bays, recreational fishing typically in the sheltered bays Major events such as New Year's Eve, Australia Day and start of the Sydney-to-Hobart yacht race	16 boat ramps 137 public access points including wharves, jetties, pontoons and landings 4850 private moorings, 2840 commercial moorings, 1680 domestic berths, moorings and other associated storage attached to private land-all, RMS administered 480 private marina berths or structures-privately (usually strata) administered Dry boat storage: 670. 26 courtesy mooring and 23 emergency moorings
Sydney Harbour North **Borders the outer harbour; the area between Cannae Point and Dobroyd Head to Manly**	Recreational fishing, especially around Cannae Point Vessels are often launched from the boat ramp in Little Manly Cove Non-powered craft in Little Manly Cove, Spring Cove and Fairlight	
Middle Harbour **Borders Outer Harbour and connects Middle Head and Grotto Head; and extends north past the Roseville Bridge to near 'Bungaroo' in the Garigal National Park**	Rowing between Pearl Bay and the Roseville Bridge Water-skiing and wakeboarding upstream of the Spit Bridge Sailing typically between Hunters Bay and The Spit General cruising, kayaking and canoeing throughout the waterway, especially near Roseville Bridge	

Area	Recreational boating activities	Recreational boating infrastructure
Parramatta and Lane Cove rivers	Parramatta River: rowing (e.g. Homebush Bay, Hen and Chicken Bay and Iron Cove), other non-powered craft including sailing, dragon boating and kayaking, general cruising by small and large vessels Lane Cove River: non-powered recreational activities dominate – rowing, sailing and paddling with cruising and boat fishing	
Inner Harbour **Area between outer harbour and Parramatta River**	Pleasure craft and cruising, only limited power boating near Harbour Bridge, Sydney Cove and the Opera House due to the 15-knot zone Dragon boating and rowing in Blackwattle Bay, and cruising during major events	
Botany Bay and Georges River (including tributaries such as Woronora and Cooks rivers)	Recreational boating popular: including water-skiing, personal watercraft operation, sailing, canoeing, kayaking, rowing, dragon boating and other non-powered boating activities Fishing from vessels also popular Regattas using various boat types Sailboarding and kite-surfing popular in Botany Bay Georges River: sailing and motor boats with main channel utilised by all vessel types, protected bays popular for non-powered craft and water-skiing; upper reaches commonly used by personal watercraft, towing vessels and non-powered craft Lower reaches of Woronora River popular for non-powered craft and personal watercraft; small craft launching areas Cooks River: rowing and kayaking and the lower reaches, from the mouth of the river to the Princes Highway Bridge at Tempe, used to access Botany Bay	28 boat ramps 45 public access points including wharves, jetties, pontoons and landings 22 courtesy moorings 4,000 vessel storage spaces on-water or at associated land facilities 1,800 private moorings and 430 commercial moorings (300 with marinas, clubs or associated boat facilities) administered by RMS Dry storage spaces in the region Numerous facilities administered by NSW Crown Lands
Port Hacking	Less boating on Port Hacking than Botany Bay and Georges River Popular for activities such as boating, recreational fishing, personal watercraft and sailing	
Wollongong	Lake Illawarra: boating, fishing and prawning, rowing, water-skiing, personal watercraft, wind surfing and sailing Paddling of non-powered craft occurs throughout most of the waterways	
Southern region		
Shoalhaven catchment	Shoalhaven River: water-skiing, wakeboarding, sailing, rowing, canoeing, kayaking and cruising, aquatic events (wakeboarding competitions, rowing and sailing regattas) Inshore commercial vessels operate within the estuary: houseboats, hire-and-drive craft and small tinnies that use both the Lower and Upper Shoalhaven Lake Wollumboola: sailboarding, windsurfing, non-powered craft and fishing	64 boat ramps 41 public access points including wharves, jetties, pontoons and landings One courtesy mooring at the entrance to Sussex Inlet

Area	Recreational boating activities	Recreational boating infrastructure
	Lake Yarrunga: canoeing and kayaking	NSW DPI administers 16 moorings across the Jervis Bay Marine Park at four sites 1,550 vessels on-water or at associated land facilities 700 private moorings and 160 commercial mooring licences administered by RMS Numerous wetland leases administered under licence with NSW Crown Lands, some of which are included in the total storage spaces quoted above Relatively less on-water storage available compared with some other regions, partly due to the number of small boat harbours, Kiama Wollongong, Jervis Bay, Ulladulla, and river systems
Jervis Bay	Jervis Bay: inshore and offshore fishing, sailing (including disabled sailing activities), canoeing, kayaking and cruising Commercial operators provide whale watching, day cruise, fishing and diving charters St. Georges Basin: power boating, towing activities, sailing and canoeing; Sussex Inlet allows smaller vessels to access the ocean waters for offshore recreational boating and fishing Lake Conjola: power boating, water-skiing, wake boarding, fishing and personal watercraft; upper reaches: canoeing and kayaking Burrill Lake: cruising and water sports Tabourie Lake entrance protected water for swimming, canoeing and fishing	
Clyde catchment	Recreational fishing, cruising and sailing in Batemans Bay and the lower Clyde River, personal watercraft, non-powered craft including kayaks, canoes and surf-skis on the Clyde River, Tomaga River and Durras Lake, tow sports in the Clyde River, houseboating on the Clyde River around Nelligen	38 boat ramps 20 public access points including wharves, jetties, pontoons and landings 1,000 storage spaces on-water or at associated land facilities 400 private moorings and 65 commercial mooring licences issued and administered by RMS Numerous wetland leases administered by NSW Crown Lands, some of which are included in the total storage spaces quoted above
Moruya catchment	Fishing, water-skiing, wakeboarding and cruising on small runabouts, personal watercraft, sailing, non- powered craft (kayaks, canoes, surf-skis)	
Tuross catchment	Recreational fishing, tow sports and personal watercraft in Tuross River and adjoining lakes (excluding Tuross Lake due to eight knot speed restriction), Wagonga Inlet and Corunna Lake Personal watercraft, non-powered craft use on Tuross Lake, Coila Lake, Lake Mummuga, and Wagonga Inlet Sailing around the Wagonga Inlet, but limited on Tuross Lake and Coila Lake	
Bega catchment	Fishing on Wallaga Lake, Bega River, Bermagui River and south of Wallagoot Lake, Brogo Dam Water-skiing in Bega River and certain channels of Wallaga Lake Non-powered craft use on Wallaga Lake, Wallagoot Lake, Brogo Dam and Bega River Personal watercraft and sailboarding in Bega River and Wallagoot Lake	
Towamba	Recreational fishing on the Wonboyn River, Towamba River,	

Area	Recreational boating activities	Recreational boating infrastructure
catchment	Merimbula Lake, Pambula Lake, Twofold Bay, Cocora Beach, and Asling Beach Sailboarding in Merimbula Lake Sailing in Twofold Bay Personal watercraft, wakeboarding and water-skiing in Pambula River Non-powered craft on the Merimbula Lake, Pambula River and in Twofold Bay	

Current management of new or upgraded boating infrastructure

Local government are involved in consent to install or upgrade boating infrastructure, including sewage management facilities. Some areas require consent from RMS, DoI Lands, OEH Heritage Division and/or aquatic environment (if in a marine park). New or upgraded private boating infrastructure (e.g. jetties, pontoons, moorings, boat ramps) is generally subject to integrated development assessment and approval under Part 4 of the *EP&A Act*. Local governments are generally the consent authority for integrated developments. Where public or private boating infrastructure is to be located on or over public land, consent of the landowner is required before approval can be sought under the *EP&A Act*. In Sydney Harbour, Botany Bay, Newcastle Harbour, Port Kembla Harbour and the ports of Yamba and Eden, landowner consent is required from RMS. In other estuaries and marine waters out to 3 nm, landowner consent is required from DPI Crown Land Division. RMS will also generally assess any boating infrastructure applications to ensure that they do not affect public navigation safety.

Under the integrated development assessment process, Fisheries NSW assess boating infrastructure development applications to ensure they do not affect marine vegetation or threatened species and their habitat, which are protected under the *FMA*. Local governments will also ensure the development is consistent with their local environmental plan and development control plans, coastal zone management plan and the requirements of any relevant domestic foreshore infrastructure strategy.

DPI Fisheries NSW's Policy and Guidelines for Fish Habitat Conservation and Management (Update 2013)[30] outlines requirements for boating infrastructure to avoid, mitigate or offset impacts on aquatic habitats. Integrated developments will generally not be granted general terms of approval or subsequent permits under the *FMA* unless they are undertaken in accordance with these policies and guidelines. Under the policies and guidelines, Fisheries NSW will generally not provide general terms of approval or permit any boating infrastructure that is likely to harm *Posidonia australis* seagrass or other species of seagrass, *Ruppia* spp. or coastal saltmarsh that is greater than 5 m^2 in area, or where such infrastructure will restrict access for commercial and recreational fishing (NSW DPI 2013). Fisheries NSW will also generally not approve boating infrastructure that shades marine vegetation (seagrasses) unless mitigation measures, such as mesh decks, are implemented. New, replacement or relocated moorings will only be considered in patches of seagrass less than 5 m^2 (except in *Posidonia* sp.) where habitat mitigation or compensation measures are employed or environmentally friendly mooring designs are used (NSW DPI 2013).

DPI Crown Lands Division's Domestic Waterfront Facility Policy (2014)[31] outlines key policy objectives when assessing applications for private domestic waterfront facilities to be located on or over Crown land or for issuing licences to occupy such land for these facilities. These objectives note that domestic waterfront facilities are not to:

[30] http://www.dpi.nsw.gov.au/fishing/habitat/publications/pubs/fish-habitat-conservation

[31] http://www.crownland.nsw.gov.au/__data/assets/pdf_file/0011/645959/Domestic_waterfront_facility_policy_2014.pdf

- adversely impact the natural environment, including water flow, water quality, marine vegetation and the effect of natural coastal processes
- obstruct, restrict or discourage existing and future safe and practical public access along and adjacent to this land
- adversely impact the cultural environment (any existing structures and localities of cultural heritage importance are to be recognised).

Fish Friendly Marinas- is an information campaign and accreditation system developed by the NSW Department of Primary Industries (Fisheries) in collaboration with the Marina Industries Association (MIA) and the NSW Boating Industry Association (BIA). Fish Friendly Marinas provides advice and supporting material to help marina operators incorporate beneficial outcomes for native fish into their existing operational plans (such as ensuring their marina is free from marine pests, providing habitat for native fish, managing stormwater, managing chemical/oil/fuel spills, reduce impacts to seagrass and other sensitive fish habitat, and educating boaters).

Other management tools:

- RMS mooring fields (geospatial mapping)
- Local Environment Plans
- Estuary Management Plan.

Boat houses, jetties, other marine structures are governed by DCP's (Development Control Plans).

Environmental Actions for Marinas, Boatsheds and Slipways *(DECC 2007)* – This guide is designed to help owners of marinas, boatsheds and slipways understand the environmental risks and responsibilities associated with their operations and to manage these effectively.

Prevention of Contamination of Marina Sites (DECC 2007) – This document provides a guide to marina owners to prevent soil, including a checklist for prevention of contamination from general marina activities as well as contamination by fuel and waste oil storage and dispensing.

Boat based contamination

AMSA - Australia is a signatory to the *International Convention on the Control of Harmful Anti-Fouling Systems on Ships 2001* and in Australia, anti-fouling paint is federally governed by the Australian Maritime Safety Authority (AMSA). The *Protection of the Sea (Harmful Anti-fouling Systems) Act 2006* is the commonwealth legislation that governs the treatment of anti-fouling paint nationally. The regulation of anti-fouling paint is the responsibility of AMSA and is consistent across Australia. MEMA as the representative of the NSW Government is not able to consider any management initiatives that would contradict or contravene the work of the Commonwealth

Moorings and on-water vessel storage

Roads and Maritime Services (RMS) have responsibility for the management of private moorings and on-water storage in NSW excluding Lord Howe Island. RMS requires a registration fee from vessel owners. Waterways fund delivers boating services and facilities. Regional boating plans and boat storage plans are being developed under the Boating Now banner.

Moorings are defined by RMS as:

> 'a structure or an apparatus used to secure any floating object or apparatus in navigable waters whether or not that structure or apparatus is itself beyond the shores of the water, and whether or not that structure or apparatus is, or is proposed to be, used for any other purpose'.

RMS is responsible for the management of moorings in NSW, although some courtesy moorings within NSW marine parks are managed by DPI (Fisheries NSW).

The types of moorings and on-water vessel storage in the NSW marine estate include:

- Private moorings
- RMS issues licences that allow holders to install a mooring and moor their vessel This licence is renewable annually but is not a lease and is not transferable

- There are approximately 15,800 private moorings in NSW
- Commercial moorings
- RMS issues mooring licences to business entities, such as marina and boat shed operators, who install moorings and rent them out to boaters
- There are approximately 4,900 commercial mooring sites in NSW
- Club moorings
- Throughout NSW there are several hundred moorings associated with boating and sailing clubs
- Emergency and courtesy moorings
- RMS provides courtesy moorings throughout the state to provide a short-term mooring opportunity for vessels. This may be required for refuge in foul weather or by holiday makers in national parks or high-vessel-use areas
- Emergency moorings are also available for short-term use by RMS and NSW Water Police
- Commercial marinas
- RMS administers leases for commercial marinas on its lands
- Private marinas
- RMS administers leases for private marinas on its lands
- Private marinas are often associated with private residences and are for the exclusive use of the occupants
- Private landing facilities
- Private infrastructure facilities include jetties, ramps, pontoons, slipways, steps, landing platforms and boatsheds for the exclusive use of the occupants of the adjacent dry land property.

Off-water vessel storage options include:

- Commercial dry stack storage
- involves vessels being removed from the water (usually using forklift trucks) and stored in multilevel covered stacks
- viewed as one of the more feasible methods of storing small to medium size vessels
- Trailer storage
- the most popular method of vessel storage; in July 2009 there were over 195,000 registered boat trailers in NSW
- Commercial marinas
- a group of pontoons, jetties, piers or similar structures designed or adapted to provide berthing for vessels used primarily for pleasure and recreation
- may include ancillary works such as slipways, facilities for the repair and maintenance of vessels and the provision of fuel, provisions and accessories.

Marinas provide services to the general public, social benefits (e.g. community events, such as 'try sailing' days), and economic benefits. Larger-scale developments, such as commercial marinas, are generally determined by the local government or a joint regional planning panel.

Potential threats from boating and boating infrastructure

Water pollution

Pollution from boating activities occurs primarily in the major and minor ports and urbanised estuaries of NSW, but can occur anywhere large numbers of vessels are moored. Pollution can result from accidental (or deliberate) spills of chemicals, fuel or oil, leaching of copper from anti-fouling paints and the day-to-day operation of vessels and associated infrastructure. Water pollution arising from oil and chemical spills from vessel accidents can cause localised, significant impacts on estuarine and marine environmental assets, generally within estuaries of the NSW marine estate.

Significant instances of water pollution are rare, with only three major oil pollution incidents from shipping having been reported in the last two decades. However, each year there are numerous minor incidents or reports of oil or sheens on the water or ashore arising from vessel activities. For example, Sydney Ports Corporation's Annual Report 2013–2014 notes that they responded to 225 instances of pollution, but no data is provided on the vessels involved or the scale or impact of this on the environment. There is some possibility of cumulative effects on organisms from minor inputs of oil and chemicals, but little evidence. In 2013–2014, RMS reported that they responded to five marine oil pollution incidents in NSW, but no additional details were provided. AMSA reported no major pollution incidents within Australian waters for the same period.

A total of 114 safety-related incidents involving commercial vessels in NSW waters were recorded in 2013–2014. The vast majority of these incidents were reported as relatively minor (83.3%)[32]. The same period saw 112 recreational vessel incidents involving collision with a vessel, capsizing and grounding. For both commercial and recreational vessels, no data is provided about whether these resulted in oil or chemical pollution.

Oil spills and leaks from vessels can occur via:

- poorly maintained engines
- spills during refuelling or engine maintenance activities
- leaking fuel tanks or lines
- unburnt fuel in engine exhaust gases, which can vent from the engine below the waterline (Byrnes 2011).

Leaks and spills can enter the water directly or via the vessel's bilge, which is pumped overboard (Byrnes 2011). Sewage and greywater from vessels entering the NSW marine estate can occur in all waters. The risk is likely to be higher in estuarine areas where:

- pump-out facilities for use by commercial and recreational vessel operators are not provided
- there are restrictions on facility operation (e.g. time of operation, or vessel operators may not be allowed to use them and have to rely on marina or wharf staff)
- facilities are in disrepair, or difficult to access and use
- a fee is charged.

Instances of releases of sewage and greywater from vessels can go undetected unless incidents are immediately observed and reported.

A review of the list of available pump-out facilities and locations in NSW on the RMS website indicates that very few services are available in estuaries between Tweed Heads and Yamba, except at major marinas in these two towns. No services are listed for the Brunswick or Richmond Rivers. Similarly, on the south coast, pump-out facilities are only reported at five locations south of Wollongong.

Sewage-related impacts from vessels can generally be expected to be cumulative. They can contribute to increases in nitrogen, phosphorous and faecal coliforms, particularly in semi-enclosed coastal lakes and lagoons, or in areas of estuaries that have limited tidal circulation or flushing (Byrnes 2011). Commercial vessel impacts on water pollution can also be problematic in areas of high use, when carrying large numbers of passengers, or where people are also entering the water (e.g. snorkelling, spearfishing, scuba diving). Sewage releases can be either at continuous low rates (e.g. via direct release from on board toilets) or via larger peaks (e.g. pump-out of holding tanks while at sea). The size of the release is dependent on the number of people on board and the sewage-treatment facilities available (Byrnes 2011).

[32] http://maritimemanagement.transport.nsw.gov.au/documents/nsw-boating-incidents-statistics-13-14.pdf

Copper pollution is a direct consequence of the use of copper based antifouling paints. These paints reduce the settlement of unwanted organisms by slowly leaching low levels of toxic copper into the water, killing or repelling larvae that might settle on the vessel. When vessels are moored at high densities the load of copper can be large enough to bioaccumulate in near-by organisms such as oysters (Dafforn et al. 2011, Scanes and Roach 1999).

Water quality issues in marinas (higher turbidity, temperature, pH, higher concentrations of lead and copper in suspended sediments, reduced flow rates and trapped sediment loads) contribute to significantly altered biological communities inside marinas. These communities are dominated by taxa with short-lived larvae (e.g. bryozoans, spirorbids and sponges) (Rivero et al. 2013).

Sediment contamination

Heavy metals can be released into the estuarine environment from antifouling paints that are used on commercial and recreational vessels (Dafforn et al. 2011). They can also leach from wooden structures that have been treated to resist marine borers. Pollutants (from vessels or run-off from the land) can accumulate in marinas, which tend to be less well flushed than other parts of estuaries. Contaminants can be elevated adjacent to areas of boating infrastructure (e.g. slipways, boat ramps, jetties, marinas), but these can be highly localised (Sim et al. 2015).

Heavy metals can concentrate in soft sediments, bioaccumulate in species such as oysters and seagrasses, and reduce the diversity of invertebrates in soft sediments (Morrisey et al. 1996, Scanes and Roach 1999, Stark 1998). The colonisation of hard surfaces by marine invertebrates is affected by heavy metals, and in general, assemblages of marine organisms can differ greatly between heavily urbanised (and contaminated) estuaries and less-contaminated estuaries (Dafforn et al. 2012).

Physical disturbance

Human activities, such as dredging, boat moorings and the construction of ports and related infrastructure, can physically remove estuarine habitats. Dredging of shipping channels or marinas has considerably disrupted soft sediments and seagrasses (Larkum and West 1990, West 2012). Seagrass can be affected directly, by removal, or indirectly, via smothering by sediments.

The construction of breakwalls and other port infrastructure has also removed estuarine habitats, such as mangroves and saltmarshes. Such infrastructure often replaces the naturally soft substrata with hard surfaces, which affects estuarine biota (Dafforn et al. 2015). Artificial, hard surfaces create habitats that are ecologically distinct from natural, hard surfaces (Bulleri and Chapman 2010), and tend to promote colonisation of introduced species (Glasby et al. 2007). Breakwalls can also affect water flow, which can affect seagrasses and soft-sediment invertebrates (Barros et al. 2001).

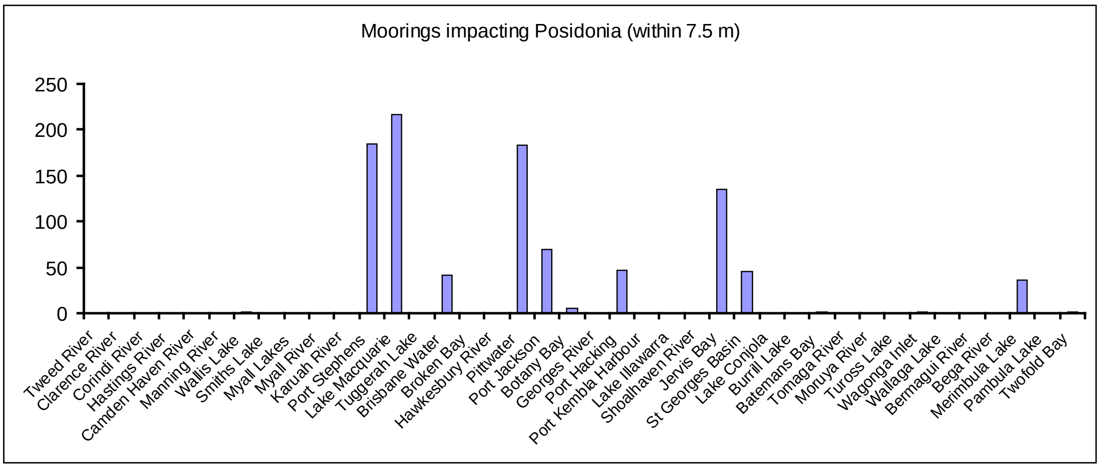
There are also clear differences in the fish assemblages of marinas and natural rocky reefs in Sydney Harbour (Clynick et al. 2008). The targeting of marinas by boat based recreational fishers also points to an effect on the distribution and abundance of particular species.

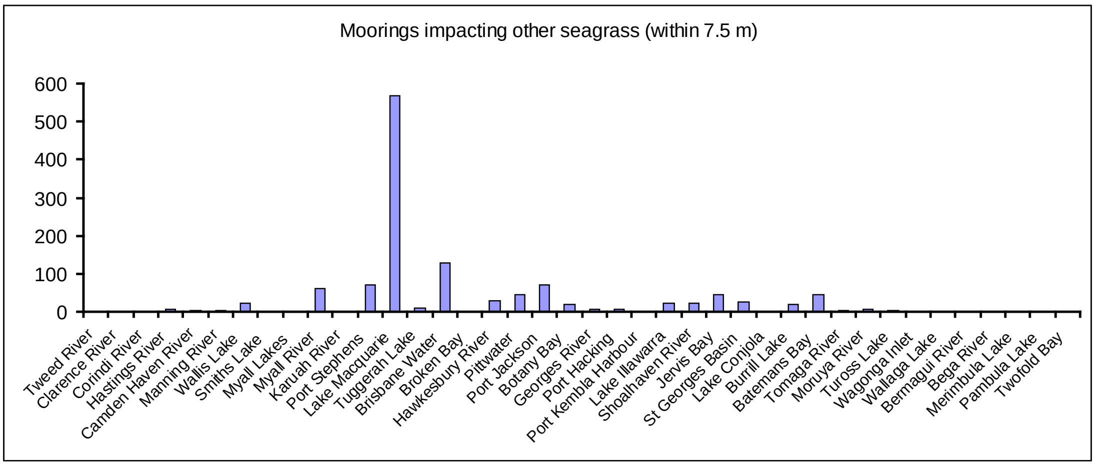
Many of these disturbances are related to large ports and estuaries with heavily populated catchments. However, disturbances related to recreational boating are common in numerous estuaries (except perhaps small coastal lagoons), and are not restricted to heavily populated areas. Large areas of seagrass have been and continue to be lost due to block-and-chain swing moorings and boat propellers (West 2012). The habitat can also become fragmented (Montefalcone et al. 2010), meaning there is less connectivity between habitat patches, which is likely to affect ecological functions.

Block-and-chain swing moorings can scour the seabed (Walker et al. 1989), removing any obvious biota that was growing within the radius of the chain (~7.5 m) around the mooring block. The biota most commonly affected includes seagrasses, algae and invertebrates living either on or in the sediments (Herbert et al. 2009).

The damage to seagrass can be either complete removal, or a decrease in density in close proximity to the mooring (La Manna et al. 2015). Losses of the large seagrass *Posidonia australis* (now listed as threatened ecological communities in the Manning–Hawkesbury Bioregion) due to moorings were estimated at 76,467 m^2 in Lake Macquarie and 19,846 m^2 in Port Stephens, primarily in water <3.5 m deep where there would typically be unbroken beds of seagrass (Glasby and West 2015). The size of a mooring scar varied with depth and between estuaries, being larger in Port Stephens (305 ± 45 m^2) than in Lake Macquarie (167 ± 12 m^2). If all seagrass species are considered together, the loss of seagrass in Lake Macquarie due to moorings alone increases to 114,875 m^2.

There is considerable variation among estuaries in the numbers of moorings affecting different marine habitats (*P. australis*, other seagrasses and soft sediments) (Figure 40). In total, there are ~19,000 moorings in NSW estuaries.





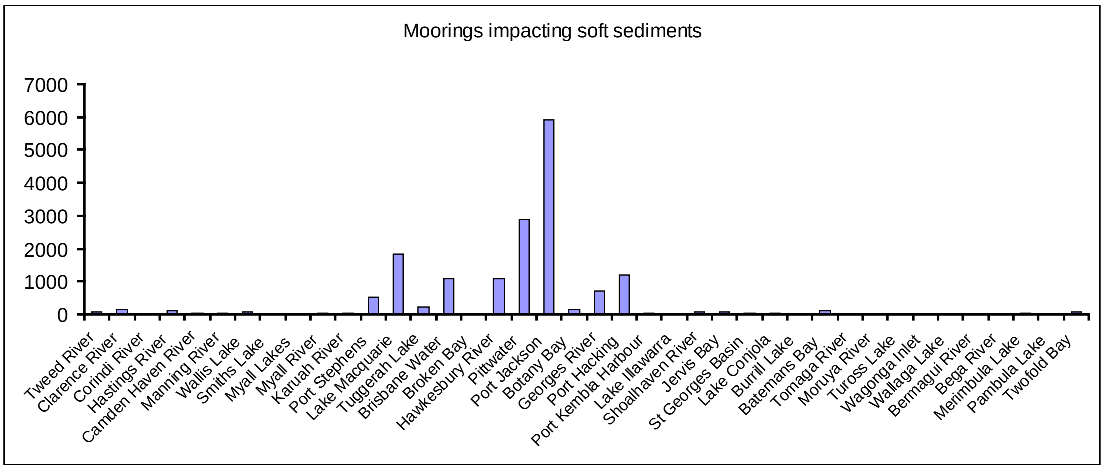


Figure 40. Number of boat moorings likely to be affecting marine habitats in New South Wales estuaries. *Top, any seagrass bed containing Posidonia australis; middle, any seagrass bed containing Zostera capricorni or Halophila spp; bottom, soft sediments. Moorings within 7.5 m of seagrass were considered to be affecting seagrass in some way (based on Glasby and West 2015).*

Boat anchors can also remove species from rocky reefs and soft sediments, but these impacts have been far less well studied than impacts on seagrasses. The ecological consequences of removing organisms from rocky reefs are likely to be greater for slow-growing species, such as sponges and corals (Dinsdale and Harriott 2004) than for species of algae that can often recolonise bare areas relatively quickly. As such, short-term disturbances from anchors can have long-term ecological consequences, even though the scale of the impacts might be small. Impacts on soft-sediment invertebrates are less likely to be long lasting, given the ability of these assemblages to recover quickly (Backhurst and Cole 2000).

Collision with a vessel may result in injury or death of marine organisms, with surface-breathing animals such as whales, dolphins, turtles and dugongs being particularly vulnerable (Hazel et al. 2007, Van Waerebeek et al. 2007). The risk of collisions is more likely in areas where intense vessel activity overlaps with key habitats or migration pathways, and with vessels that operate at higher speeds or are large and less manoeuvrable (Hazel et al. 2007, Laist et al. 2014). The risk of vessel-related incidents with marine fauna is spatial and seasonal for some species. Humpback and southern right whales intermittently enter NSW waters from late April to November during their annual migrations. For example, a humpback was injured in the Hawkesbury River in 2001 (Van Waerebeek et al. 2007). Marine turtles are present year-round, but are more likely to be encountered in the northern and central regions. Seals are also present year-round, but are associated with cooler water temperatures in southern NSW. Species that spend more time near the surface are more prone to vessel strike. For example, southern right whales often rest near the surface in coastal waters with only part of their head exposed, making them inconspicuous and highly prone to vessel strike (Van Waerebeek et al. 2007). Mothers with calves are also at greater risk from collision due to greater time spent on the surface. Some vessels also pose a greater threat, such as jet skis, which were banned in the harbour in 2001, and were reportedly responsible for the death of several resident little penguins at Manly in 1997.

NPWS records data on vessel strikes with marine fauna in NSW and reports of vessel-struck marine fauna are increasing (see Section 6.1.1 Shipping). The NPWS Elements database has 80 records of marine mammals, reptiles, and birds that were struck by vessels since 1971. Vessel strike occurs across all regions and 48 of those animals were struck in the north region, 17 in the central region, and 11 in the south region (4 of those were from an unknown location). During this period, 10 seals, eight dolphins, and 52 turtles were reported as struck. Nine whale collisions were also reported, though these are generally from commercial vessels. Over the past 10 years (2007-16) 58 strikes were reported to NPWS (average 5.8 each year). The NPWS penguin mortality database has 28 records of boat strike from the Manly penguin colony in the past 20 years, with 12 of those occurring in the past five years. An additional 18 animals died of blunt force trauma, which is commonly associated with vessel strike, 12 of those were in the past five years. As many animals are encountered after the event, it is difficult to determine the vessel that caused the event, as such some of these strikes are attributed to commercial vessels. Quantifying the magnitude of vessel strike injury and mortality is problematic (Van Waerebeek et al. 2007). Where vessel crew are aware of a collision, only a small number are reported to NPWS. Of the beach-washed carcasses reported, only a subset show obvious injuries that are classified as vessel strike. This low reporting effort impedes an accurate assessment of the threat of vessel strike to marine fauna populations (Van Waerebeek et al. 2007).

The approach distances prescribed in the NPW Regulation are the primary regulatory tool for managing the risk of collisions. The approach distances require slow and constant vessel speed in close proximity to cetaceans, and require that boats with more than one person post a lookout for cetaceans. There are no specific regulations on how to operate a vessel around seals. To ensure recreational boaters have an understanding of the approach distance guidelines, NSW Maritime has incorporated them into the boat licence training and exam. Promotion of the approach distance guidelines by NSW Maritime is a valuable part of NSW's public education strategy on appropriate behaviour around marine mammals. In addition, media reports about whale season remind boaters to show extra caution when operating between June and November. For details on the approach distance guidelines, see Section 6.1.6 Charter activities.

Bank erosion

The wash from recreational and commercial vessels can contribute to the erosion of the banks of rivers and creeks and change the composition of soft-sediment invertebrates in non-vegetated and vegetated areas (Bishop 2004). These impacts are most widespread in the larger estuaries where there are many moored boats, but can also be significant where boating activities are concentrated (e.g. Wallamba River, Wallis Lake, Tweed River), and where narrow channels provide flat water for skiing (e.g. Shoalhaven River, Clyde River). Boat wash can also increase turbidity by resuspending sediments. The rising popularity of wakeboarding over the last 10 years has significantly increased the risks associated with bank erosion caused by boating. Wakeboarding is generally conducted behind a boat that employs water ballast to create a large wake.

Shading

Boating infrastructure, such as jetties and pontoons, can affect seagrasses by reducing light levels. Jetties typically reduce the density of seagrasses that are directly below them. Gladstone and Courtney (2014) demonstrated reduced *Z. capricorni* biomass in Lake Macquarie in shallow water (~1 m); wooden jetties were worse than mesh jetties, presumably because more light being transmitted through the latter. Similar effects have been documented for the density of *P. australis* at depths down to 4 m (Fyfe and Davis 2007), and these structures can affect the distribution of fishes.

Pests and diseases

The most common vectors for the spread of invasive marine species are ship ballast water and biofouling on vessel hulls or niches. The dumping of ballast water is now tightly regulated, meaning this vector is unlikely to be as great a risk for transporting species as is hull fouling (Glasby and Creese 2007). Hull fouling is of concern for spreading invasive species within Australia, because the hygiene of vessels travelling shorter distances is typically not as great as those travelling long distances. Moored vessels, including barges, are more likely to transport species on their hulls than are trailer boats. Thus, threats from invasive fouling species are likely to be greatest in estuaries with large numbers of moored vessels, which tend to be the estuaries with the greatest commercial shipping activity. Recreational vessels also transport invasive species among estuaries, most likely algae in anchor wells and on trailers (West et al. 2007).

There are large numbers of marinas, sailing clubs, jetties and pontoons in estuaries, particularly in the central region. Hull fouling of recreational vessels (particularly moored vessels) is of particular concern for spreading invasive species within Australia. In addition, boating infrastructure (especially floating structures such as pontoons) facilitate the secondary spread on invasive species once they are in an estuary (Glasby et al. 2007, Glasby and Creese 2007). Although there are many introduced fouling species in several estuaries, there are none of major concern that have invaded rocky reefs. The invasive subtidal green alga *Caulerpa taxifolia* is present in Lake Macquarie, Brisbane Water, Pittwater, Port Jackson, Botany Bay and Port Hacking, but there is little evidence that it is having direct impacts on seagrasses (Glasby 2013). The distribution of the species has not changed greatly over this time and its abundance has declined (Glasby 2013). Sediments that have been colonised by *C. taxifolia* can have significantly greater rates of primary productivity than non-vegetated sediments, but the rates of productivity and nitrogen cycling are similar to those in adjacent *Z. capricorni* beds (Eyre et al. 2011). At present, there is no active control program for *C. taxifolia*.

Boating infrastructure, especially floating structures, such as pontoons, facilitate the secondary spread of invasive species once they are in an estuary (Glasby et al. 2007). Copper antifouling paints also facilitate non-indigenous invasive taxa that are either tolerant of the copper and attach to hulls, or where copper infers a competitive advantage over similar native taxa (Piola et al. 2009, Dafforn et al. 2009).

Wildlife disturbance

Boating can affect the health and behaviour of marine and terrestrial wildlife (e.g. reduce fitness to feed, breed, migrate, nest and rest) (Higham and Shelton 2011, Whitfield and Becker 2014). Increased vessel traffic has permanently displaced animals from foraging areas and led to complete shifts in habitat use in coastal waters (Tyack 2008). Powerboats have affected the surface behaviour and direction of travel on dolphins in Jervis Bay (Lemon 2006).

Noise from vessels is a key threat to marine mammals, which rely on sound to communicate, navigate and hunt (Southall 2005). Behavioural changes resulting from noise exposure include changes in vocalisation and changes in swim patterns and resting and foraging behaviours. High levels of noise from boats can mask vocalisations and reduce the range at which individuals can communicate with a member of the same species (Southall 2005, Wright et al. 2007). Small vessels that travel at high speeds tend to emit high-frequency sound, which interferes with the communication and echolocation of toothed cetaceans (Soto et al. 2006, Southall 2005). In some countries, underwater noise from vessels is now an important consideration in habitat quality assessments and marine spatial planning. Further information on wildlife disturbance from vessels is outlined in Section 6.1.1.

Marine debris

Litter and debris is common in the marine environment, including that on the shore and subtidal reefs (Smith 2010). In the northern rivers region of NSW, 67% of the debris found in the marine environment was derived from fishing-related activities, some of which was associated with boating (Smith 2010). Debris and litter can affect marine ecosystems in a variety of ways, although the primary impacts are due to entanglement and ingestion of plastic (Derriak 2002). Floating debris can also transport invasive species. Debris has been identified as a key threatening process to marine habitats and organisms in Australia (Department of the Environment & Heritage 2003), especially to threatened and endangered species.

Snorkelling and diving

Snorkelling and diving within estuaries is primarily restricted to specific sites within the larger marine embayments, including Sydney Harbour (e.g. Camp Cove, Clifton Gardens), Botany Bay (e.g. Bare Island), Port Hacking (e.g. Shiprock Point), Port Stephen (e.g. Fly Point), Jervis Bay (e.g. Bowen Island), Batemans Bay (e.g. Tollgate Island) and Twofold Bay. Most of the activity is restricted to shallow rocky reef habitats in these areas. There is little information on the level of activity, because much of it occurs as a private recreational activity, rather than through commercial operations.

Potential impacts of diving and snorkelling

Snorkelling and diving are infrequent activities in most estuaries, are generally passive, and are unlikely to have any impact on biodiversity or habitats. However, scuba divers can potentially damage delicate benthic communities if they approach too closely, and can interfere with marine wildlife. There is no information available to assess the level of impacts, but the overall level of the activity in these areas is expected to be low in most locations.

Further specific details are provided in the Hawkesbury marine bioregion environmental report (MEMA 2016).

Swimming, surfing, walking and other passive use including dog walking

These activities are generally passive, but in many locations they can be the dominant activities within the intertidal habitats and adjacent coastal areas. They can potentially interfere with marine wildlife and generate marine debris in specific locations. The level of activity is generally related to the size of the local population, and hence are higher in estuarine areas with adjacent urbanised areas, such as Port Jackson, Botany Bay, Lake Macquarie and parts of Port Stephens. The exception is during peak holiday periods where many other areas in the northern and southern regions have high levels of activity.

In a number of estuaries there is also infrastructure associated with swimming, such as swimming enclosures or nets and the potential localised effects on the composition and distribution of fish assemblages, including seahorses (see papers by Harasti and Clynick).

Wildlife disturbance

Popular recreation areas and habitat areas for threatened shorebirds frequently overlap in NSW (Glover et al. 2011). Dog walking in coastal areas is a popular activity that has social benefits for the community. However, dog walking on beaches can cause significant disturbance to foraging, roosting, and nesting seabirds and shorebirds (Glover et al. 2011). Direct predation or mortality of eggs and chicks by domestic dogs, and trampling by humans are both listed as key threats to the four endangered/critically endangered shorebirds in NSW (Lane and Harris 2013, Department of Environment, Climate Change and Water NSW 2010, NSW National Parks and Wildlife Service 2003, OEH NSW 2017; Appendix 5). Both people and dogs can elicit an anti-predator response in birds, displacing them from key habitat and reducing their time spent resting, feeding, and caring for young (Banks and Bryant 2007). Disturbance by domestic dogs is more acute and can have a range of impacts including death, injury, avoidance or permanent displacement from habitat areas, nest or habitat disturbance, and behavioural disturbance resulting in reduced fitness, breeding success, and neglect of chicks (Holderness-Roddam 2011, Glover et al. 2011). Shorebirds and seabirds that nest and burrow in coastal areas are particularly vulnerable to domestic dogs (e.g. hooded plovers, little penguins; Holderness-Roddam 2011). Disturbance levels increase during summer when more people are present on the coast, this coincides with the nesting time of threatened species.

Dog walking outside the bioregion has been shown to cause a 41% reduction in bird abundance and a 35% reduction in the number of bird species, whereas people without dogs have approximately half the disturbance impact (Banks and Bryant 2007). Human disturbance to foraging and roosting areas in south-eastern Australia has been attributed to declines in some shorebird species (Kingsford 1990). In Qld, human disturbance has been shown to affect habitat selection by threatened shorebirds on beaches at local and landscape scales including endangered pied oystercatchers and endangered little terns (Meager et al. 2012). In Victoria, 33% of the time critically-endangered hooded plovers spent away from nests was due to human disturbance with potential consequences for incubation and breeding success (Weston and Elgar 2007). In south-eastern Australia, on-leash domestic dogs were shown to cause a significantly higher shorebird flight response than that of people alone (Glover et al. 2011). In the Shoalhaven River estuary, human disturbance has had significant impacts on threatened shorebirds including pied oystercatchers and little terns (Kingsford 1990).

NPWS monitoring of endangered pied oystercatchers in NSW found a 7% loss of eggs and chicks to predation by domestic dogs and a 2% loss to human interference during surveys where the cause of loss was identified. However, 50% of eggs and chicks were lost to unknown causes, and nests abandoned due to disturbance by dogs and humans could not be accounted for (NPWS Saving our Species unpublished data 2017). The NPWS monitoring program found lower numbers of egg and chick losses to humans and domestic dogs for little terns, likely because of greater management effort at tern colonies. Rapid declines in the number of breeding pairs of pied oystercatchers on Crown Land in northern NSW have also been observed over the last 10 years, potentially reflecting reduced management of human disturbance and domestic dogs relative to other tenures, such as National Parks (NPWS Saving our Species unpublished data 2017). In NSW, localised impacts have also been observed on beach-stone curlews and oyster catchers in Moonee Creek and Moonee Beach and shorebirds have been observed to abandon beaches with dog exercise areas, such as Tallow Beach and Belongil Beach. Off-leash dog walking is restricted on many beaches in NSW and is not-permitted in sensitive areas such as National Parks. However, as this activity is common and widespread, non-compliance is difficult to manage by land managers. The risk posed to shorebird species from recreational beach users, particularly people walking dogs, can be expected to increase over time in line with development pressures and population increase.

Disturbance of marine mammals is also an issue in NSW. The NPW Regulation prescribes approach distances for marine mammals for vessels, swimmers, aircraft, and people on land (seals only). Detailed information on threats to mammals from vessels are outlined in the commercial vessel and boating sections. People approaching mammals when swimming or on land can have negative impacts on marine mammals, which can result in avoidance of habitat areas and disruption from normal life-history behaviours (Constantine 2001). Seals are more sensitive to disturbance when on land than in the water and noise or other disturbance can cause a seal colony to stampede into the water, sometimes crushing pups (Tripovich et al. 2012). Increased disturbance tends to occur when animals come into shore in populated areas or are of special interest (e.g. southern-right whales, white whales, or when calves/pups are present). Marine mammals may also rest close to shore when they are in poor health or nursing young and are more vulnerable to human disturbance when doing so. As these situations are irregular and widely dispersed, the approach distances are difficult to enforce and non-compliance with the regulations is common.

Four-wheel driving

Four-wheel driving occurs primarily on intertidal habitats (mostly saltmarsh), which are often associated with adjacent recreational four-wheel-drive tracks on private and public lands. Local regulations by national parks or local government restrict driving in most locations in NSW estuaries, but some amount of illegal activity is expected to occur. There is no specific information on the level of activity and level of associated stressors. The key stressors associated with four-wheel driving in estuaries are physical and wildlife disturbance.

Physical disturbance

Four-wheel driving in estuaries and adjacent coastal wetlands may directly and indirectly impact threatened and protected species, including migratory and resident shorebirds (Sargent et al. 2012). This is principally through disturbance of, and injury to nesting, foraging, or roosting shorebirds and degradation of shoreline habitat. Vehicular intrusion into beach nesting sites may result in crushed nests, eggs, and chicks (Sargent et al. 2012). Such damage may be extensive if not regulated and monitored; a 1989 study of the potential impact of off-road vehicles on the nesting success of hooded plovers in South Australia estimated that 81% of nests on studied beaches were likely to be crushed during the incubation period, while 31% of chicks were likely to be killed after hatching (Buick and Paton 1989). Human activity from four-wheel driving can degrade and erode habitat and subsequently decrease resilience to other stressors such as sea level rise, storm surge, and extreme weather (Kingsford 1990, Sargent et al. 2012).

Wildlife disturbance

Disturbance from four-wheel driving at foraging sites has been found to have a significant energetic cost to shorebirds (Goss-Custard et al. 2006, Weston et al. 2012). Disturbed foraging sites and consequent reduced feeding times may be exacerbated by declines in the availability of invertebrates to foraging birds due to compacted sand (Kingsford 1990, Sargent et al. 2012). Behavioural changes and compacted feeding areas have been observed among wader populations on Comerong Island at the mouth of the Shoalhaven River, an important habitat for shorebirds in NSW (Kingsford 1990). Migratory birds are particularly susceptible to disturbance, as they require undisturbed feeding and roosting grounds to acquire sufficient energy reserves for their migration (Department of the Environment 2015, Sargent et al. 2012). Disturbance of nesting sites may also affect the recovery of threatened resident species.

While many of the impacts of four-wheel driving on beaches are short-term and localised, there is evidence to suggest that frequent and prolonged periods of disturbance by human activity result in long-term declines in populations of migratory shorebirds, rather than habituation to human presence (Martín et al. 2015). High levels of disturbance may ultimately lead to temporary or long-term abandonment of critical habitat in favour of low quality foraging, breeding, or roosting habitat (Goss-Custard et al. 2006, Sargent et al. 2012).

6.1.10 DREDGING

Coastal waterways are dynamic sedimentary systems, and dredging is often required to ensure that they are safe and navigable. This is particularly critical for shipping in working harbours such as Newcastle and Botany Bay. Similarly, safe navigation of coastal rivers and harbour entrances is essential for recreational boating and vital for NSW's regional economy, the operations of industry, commercial fishing fleets and tourism charter vessels.

Dredging has two aspects: the removal of material and the disposal of material. Dredging activity includes:

- navigation and entrance dredging within estuaries
- port and harbour maintenance dredging
- dumping of dredge spoil in offshore marine waters
- obtaining fill material.

Specific details of dredging activities in the central region are presented in the Hawkesbury bioregion environmental background report (MEMA 2016).

Current management

Outside the major commercial ports of Newcastle, Sydney, Port Botany and Port Kembla, all submerged land in NSW is Crown Land managed by the division of Land and Natural Resources within DPI. Thus, DPI is responsible for all dredging activities in most coastal waterways, which is managed under several sections of legislation (Table 24).

Table 24. Dredging activities in New South Wales estuaries and current legislation.

Legislation	Related activities
Environment Protection (Sea dumping) Act 1981 (Commonwealth) (Cth. Department of the Environment, Water, Heritage and the Arts)	Commonwealth permits are required for all sea dumping operations in marine park areas. Examples include artificial reefs and dredging operations. Permits have also been issued for dumping of vessels, platforms or other man-made structures and for burials at sea. The Australian Government also manages the loading and dumping of waste at sea (such as dredge spoil), as well as international obligations under the London Protocol to prevent marine pollution by controlling dumping of wastes and other matter. Ocean disposal of waste and the sinking of vessels, aircraft and platforms in all Australian waters, including most areas of NSW marine parks are determined by the Commonwealth. Commonwealth legislation also protects underwater cultural heritage in Australia. Management is also guided by the Code of Ethics of the Australasian Institute for Maritime Archaeology.

DPI Fisheries considers dredging and reclamation proposals for impacts on key fish habitats, harm to marine vegetation, and blockage of fish passage in accordance with Part 7 of the *FM Act* and the Commonwealth Government's Policy and Guidelines for Aquatic Habitat Management and Fish Conservation 2013 to ensure the sustainable management and "no net loss" of fish key habitats in NSW.

NSW Coastal Dredging Strategy: The Department of Industry – Lands works with Transport for NSW, Roads and Maritime Services, local governments and communities to improve access to State owned regional ports and harbours. Development long term dredging plans for local waterways and enable local governments to undertake their own dredging works to address the needs of their local communities. Dredging of entrance bars and navigation dredging occurs in the major ports of Hunter, Port Jackson, Botany Bay and Port Kembla. Periodic entrance dredging and dredging within the estuary occurs in the majority of trained estuaries. Dredging has been undertaken to improve navigation and increase flushing to improve water quality. Dredged material has been used to nourish ocean and estuarine beaches. Sediment (uncontaminated dredge spoil) dumped at sea in designated spoil grounds requires Commonwealth approval.

Other management mechanisms include;

- *Fisheries Management Act 1994 (Part 7)*
- *Fisheries Management General Regulation 2010 (Part 14)*
- Policy and Guidelines for Aquatic Habitat Management and Fish Conservation 2013 update.

Potential impacts of dredging

Physical disturbance

Potential stressors resulting from physical disturbance due to dredging include:

- mechanical removal of sediments
- dumped sediment
- increased turbidity
- pollutants from the dredge
- vectors for invasive species
- altered bathymetry
- altered flows
- erosion and sediment deposition.

These can destroy habitat, smother communities through disposal of dredge spoil, and reduce water quality. Other consequences include the accumulation of organic material and the potential release of toxic substances and nutrients. Studies of the ecological impacts of dredging are limited; however, the actual impacts are likely to be site specific, depending on the physical and habitat characteristics of the sites and adjacent area.

Dredging activities can result in the physical damage and loss of seagrass, either directly or indirectly (Larkum and West 1990, West 2012). For example, seagrass can be directly removed, or affected indirectly via smothering by sediments. Opening of entrances to intermittent estuaries disrupts many ecological processes, and permanent openings can result in artificially saline estuaries and altered biological assemblages.

Plankton, benthic organisms associated with soft and hard substrata, marine mammals and seabirds are most likely to be affected by dredging (Nairn et al. 2004). Impacts on pelagic organisms would be confined to areas affected by suspended sediment plumes, and dependent on plume scale and duration. Impacts on hard substrata could be minimised by avoiding direct impacts and using wide buffers to minimise smothering.

Reductions in species richness of 30-70% and biomass of 40-95% associated with dredging has been estimated in muddy embayments, oyster shell deposits, coastal lagoons and sand and gravel deposits (Newell et al. 1998). Recolonisation of dredged areas by opportunistic species is rapid (months), but recovery to pre-dredging assemblages can take 2-4 years or even longer in some locations (Newell et al. 2004). Infilling of deeper areas with finer sediment than that extracted can lead to different biological communities (van Dalfsen et al. 2000).

Water pollution: resuspension of sediment and contaminants

The consequences of dredging-related sediment resuspension are dependent on the characteristics of the sediment. If the sediments are contaminated (e.g. at Port Kembla), then resuspension increases the likelihood that the contaminants can harm organisms living in the water. Resuspension of sediments also creates high levels of suspended sediments in the water column, which can directly harm organisms (e.g. smothering, clogging gills) or reduce water clarity and inhibit photosynthesis by plants (algae, seagrasses, benthic microalgae).

Sediment resuspension is of particular consequence in estuaries and harbours. It is regulated by government for most medium-to-large dredging operations. Disturbance of sediments can also reduce the biodiversity of benthic invertebrates that live in the sediments, with consequences further along food chains.

Wildlife disturbance

The movement of vessels associated with either dredging or sand extraction would create the same pressures and potential impacts as discussed previously for shipping activities in Section 6.1.1 Shipping. Loss of habitat and disturbance of dune areas by dredging entrances to intermittent lagoons can have implications for nests of shorebirds.

6.1.11 MINING

Oil, gas, minerals, sand, aggregate and underground coal

The extractive industries considered in this section are limited to on-land activities, such as open-cut and underground coal mining, which occur in many NSW estuary catchments. Much of state's mining occurs within the central region, particularly at its northern (Hunter Valley coal fields) and southern (Illawarra coalfields) boundaries. The other region of catchment risk is in the northern region, in the area immediately to the north of Port Stephens (Figure 41). Mining activities potentially affect adjoining streams and rivers, and these may ultimately influence the quality and quantity of freshwater flow into estuaries. The EPA regulates discharges to waters from mines within coastal catchments using environmental protection licences.

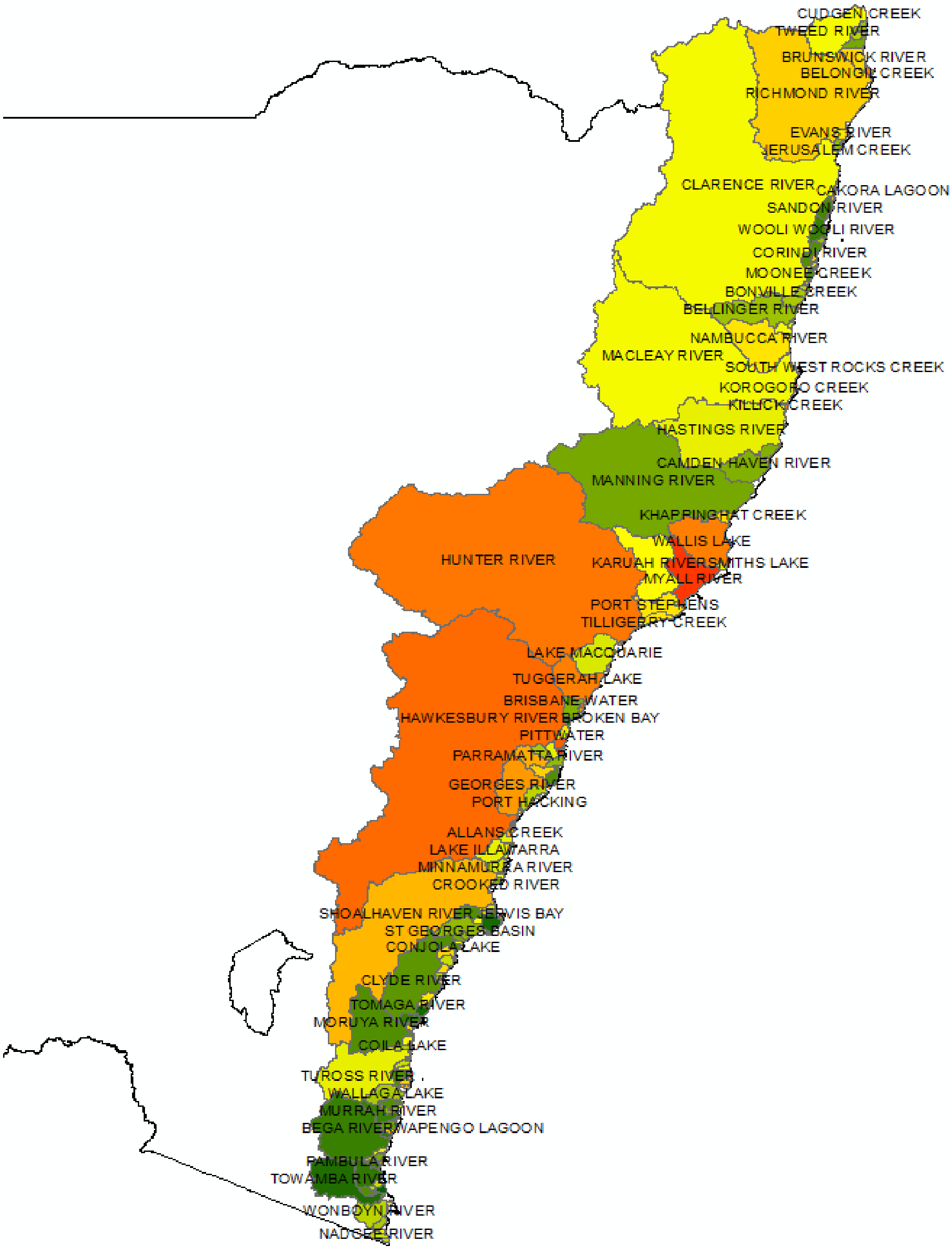


Figure 41. Risks to New South Wales estuarine catchments from industrially or mining-derived inorganic acids, cyanide, fluoride, sulfide, some metals and metalloids; risk is a combination of pollutant load and the potential to mobilise metals via low soil pH. Catchments with highest risks are shown in red, lowest in dark green. *Source: OEH.*

Potential impacts of mining

Water pollution

Risks from mines in catchments are dependent on the volume of pollutants that are being discharged, and the potential for acidic soils to facilitate metal mobilisation. Little information is available to assess this risk in NSW. Mine waste waters are often saline, acidic and have elevated concentrations of heavy metals. This has consequences for freshwater tributaries to estuaries and for the receiving waters of estuaries.

Physical disturbance

There is little information on the physical disturbance on NSW estuarine environmental assets as a result of mining. Long-wall coal mining can have adverse impacts due to subsidence, particularly around the edges of estuaries where seagrass beds can be submerged below light compensation depth and riparian vegetation inundated. This has already occurred to some extent in Chain Valley Bay, Lake Macquarie.

6.1.12 MODIFIED FRESHWATER FLOWS

Extraction and artificial barriers to flow

Two related anthropogenic activities can affect the flow of water into the upper reaches of estuaries: water extraction, and physical barriers such as dams, weirs, road crossings and floodgates.

Water extraction reduces (potentially dramatically so, in times of drought) the quantity of water flowing into an estuary. Dams and weirs regulate river flows to allow the efficient extraction of large amounts of water on a regular basis. They are therefore likely to disrupt the natural connectivity between fresh and saline waters.

Extraction of freshwater flows from NSW’s **northern region** rivers is relatively low, with only one catchment having >10% of flow extracted, and a further 30 out of 55 with some level of extraction (Table 25). There is considerable extraction of flow from **central region** estuaries, with four having between 20 and 32% of flow extracted, another two with >10% extracted, and 16 of 40 others with some extraction. The **southern region** has one estuary with 26% extraction and one with 12%, but a further 36 out of 89 estuaries have some level of extraction.

An analysis of hydrologic stress (Healy et al. 2012) shows the relationship between extraction volumes and 80th-percentile flows. The greatest stress is evident in Warragamba and central coast, but some smaller catchments on north and south coast also show high hydrological stress.

Table 25. Percentage of surface flow extracted from each estuary catchment in New South Wales[a]

North coast estuary	% surface flows extracted	Central estuary	% surface flows extracted	South coast estuary	% surface flows extracted
Hearnes Lake	10.1	Hawkesbury River	31.7	Shoalhaven River	25.7
Pine Brush Creek	9.2	Tuggerah Lake	24.1	Bega River	11.7
Tweed River	6.7	Georges River	22.0	Mollymook Creek	5.7
Richmond River	4.5	Hunter River	21.6	Bermagui River	5.0
Darkum Creek	4.0	Botany Bay	18.1	Murrah River	4.5
Manning River	3.5	Stanwell Creek	15.0	Little Lake (Narooma)	3.9
Camden Haven River	3.3	Manly Lagoon	4.9	Tilba Tilba Lake	3.7
Coffs Creek	3.3	Narrabeen Lagoon	3.2	Back Lagoon	2.1
Woolgoolga Lake	3.2	Towradgi Creek	2.6	Wallaga Lake	2.0
Deep Creek	2.9	Lake Macquarie	2.3	Tuross River	1.8
Boambee Creek	2.8	Pittwater	1.9	Minnamurra River	1.6
Clarence River	2.3	Lake Illawarra	1.7	Pambula River	1.6
Hastings River	2.3	Parramatta River	1.5	Bournda Lagoon	1.5
Cudgen Creek	2.1	Cockrone Lake	1.4	Moruya River	1.4
Mooball Creek	1.8	Lane Cove River	1.1	Saltwater Creek (Rosedale)	1.3
Arrawarra Creek	1.3	Port Jackson	0.9	Congo Creek	1.2
Macleay River	1.2	Cooks River	0.6	Wapengo Lagoon	1.0
Brunswick River	1.2	Bellambi Gully	0.6	Narrawallee Inlet	0.8
Bonville Creek	1.1	Port Hacking	0.5	Towamba River	0.8
Karuah River	1.0	Middle Harbour Creek	0.4	Twofold Bay	0.7
Moonee Creek	1.0	Brisbane Water	0.3	Clyde River	0.5
Cudgera Creek	1.0	Terrigal Lagoon	0.3	Batemans Bay	0.5
Nambucca River	1.0			Wagonga Inlet	0.4
Port Stephens	0.7			Burrill Lake	0.3
Wallis Lake	0.7			Cuttagee Lake	0.2
Willis Creek	0.6			Tomaga River	0.2
Bellinger River	0.4			Corunna Lake	0.2
Myall River	0.3			Currambene Creek	0.2
Corindi River	0.3			Crooked River	0.2
Khappinghat Creek	0.2			Merimbula Lake	0.1
Duchess Gully	0.1			St Georges Basin	0.1
				Conjola Lake	0.1
				Cullendulla Creek	0.1
				Wallagoot Lake	0.1
				Jervis Bay	0.1
				Lake Mummuga	0.1
				Meroo Lake	0.1
				Coila Lake	0.1

a Any diversions of less than 3% are probably negligible
Source: Roper et al. (2011)

A national workshop on the impacts of reducing freshwater inflow in estuaries identified the following list of potential consequences (Peirson et al. 2002).

Low magnitude inflows (Low-):
Low-1: increased hostile water-quality conditions at depth

Low-2: extended durations of elevated salinity in the upper–middle estuary adversely affecting sensitive fauna
Low-3: extended durations of elevated salinity in the upper–middle estuary adversely affecting sensitive flora
Low-4: extended durations of elevated salinity in the lower estuary allowing the invasion of marine biota
Low-5: extended durations when flow-induced currents cannot suspend eggs or larvae
Low-6: extended durations when flow-induced currents cannot transport eggs or larvae
Low-7: aggravation of pollution problems
Low-8: reduced longitudinal connectivity with upstream river systems

Middle and high magnitude inflows (M/H-):
M/H-1: diminished frequency that the estuary bed is flushed of fine sediments and organic material (physical habitat quality reduction)
M/H-2: diminished frequency that deep sections of the estuary are flushed of organic material (subsequent water quality reduction)
M/H-3: reduced channel-maintenance processes
M/H-4: reduced inputs of nutrients and organic material
M/H-5: reduced lateral connectivity and reduced maintenance of ecological processes in waterbodies adjacent to the estuary

Across all inflow magnitudes (All-):
All-1: altered variability in salinity structure
All-2: dissipated salinity or chemical gradients used for animal navigation and transport
All-3: decreases in the availability of critical physical habitat features, particularly the component associated with higher water velocities.

Current management

The construction of works which impact on flows within waterways are managed by the *Fisheries Management Act 1994* (Part 7). They may also fall under 'controlled activities' in the *Water Management Act 2000* and local government Development Approvals in cases where the proponent is not a public authority. Floodplain management (floodgates, levees etc.) provisions within the *Water Management Act 2000* have not been 'turned on'. The *Water Management Act 2000* requires water-sharing plans to:

- improve the health of rivers
- provide security of access for water users
- meet the social and economic needs of regional communities
- facilitate water trading.

Water-sharing plans reflect the following priorities:

- environmental health of rivers
- basic landholder rights – domestic and stock rights and native title rights
- town water and licensed domestic and stock use
- other extractive uses, including irrigation, farming, industry, Aboriginal cultural, education and research purposes in certain rivers, mining, and recreation, such as watering playing fields.

Plans have commenced for Hunter regulated and unregulated waters, and greater metropolitan groundwater and unregulated rivers.

The importance of free fish passage for native fish is recognised under the *FMA*, in which specific provisions deal with the blockage of fish passage. The installation and operation of instream structures that alter natural flow regimes has been recognised as a key threatening process under this Act and the *TSCA*. These legislative tools, and associated NSW Government policies on fish passage, regulate the construction of structures that may be barriers to fish passage. In addition, reinstating connectivity between upstream and downstream habitats and adjacent riparian and floodplain is an essential part of aquatic habitat management and rehabilitation programs in NSW.

Potential impacts of modified freshwater flows

Freshwater flows have a great impact on the physical and biological aspects of coastal environments (Gillanders and Kingsford 2002). The flow regime is often regarded as the key driver of river and floodplain wetland ecosystems. Aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes (Bunn and Arthington 2002). Changes to natural flow regimes can create adverse water quality conditions with major changes in nutrient loading. Sediment loads, pH, temperature, salinity, clarity, oceanography and nutrients are affected. Habitats and organisms within estuaries and coastal environments are impacted. The effects include mortality, changes in growth and development, and in some cases movement of organisms (Gillanders and Kingsford 2002).

In the context of fishes, the impacts of freshwater inflow to estuarine systems is often classified into either pulse or press effects (Gillanders and Kingsford 2002). Pulse effects are caused by freshwater pulses, and usually result from large, short-term freshwater inflows which occur as a result of storms and associated run-off, environmental releases of water from storages, unintended over-topping of storages or opening of floodgates. Press effects usually operate over a longer time period, and can arise in response to protracted periods of elevated discharge into estuaries, such as seasonal variation in annual discharge.

The impacts of pulse and press events can be either essential or detrimental to fishes life histories. (Taylor et al. 2014). For example, seasonal freshwater flows may provide a cue to trigger a life history event, such as spawning in key recreational and commercial fish species (Gillison et al. 2008) including Estuary Perch (Walsh et al. 2002) and Mulloway (Taylor et al. 2014), and recruitment, including in Yellowfin Bream, Dusky Flathead, Luderick, Sea Mullet, and Sand Whiting (Gillison et al. 2008).

In the context of shorebirds, hydrological regimes are significant factors in determining estuarine species distribution by influencing prey distribution and habitat availability and quality (e.g. productivity, sedimentation, pollutant transport, nutrient cycling) (Lee et al. 2006). As such, modification of the natural flow regimes of rivers and streams connected to coastal floodplains and wetlands is recognised as a major cause of the loss of bird diversity in affected areas (Kingsford et al. 2009). As such, alterations to hydrological regimes and associated impacts have been identified as a key threatening process affecting both resident and migratory shorebirds in Australia (Nebel et al. 2008, Department of the Environment 2015).

Species with high site fidelity are likely to be more vulnerable to the impacts of altering freshwater flows, however, as noted in the Australian Government's *Wildlife Conservation Plan for Migratory Shorebirds 2015* the assumption that migratory shorebirds may easily move to other habitats as their normal feeding, breeding, or roosting areas become unusable does not account for increases in overcrowding, competition for food, depletion of resources, and increased risks of disease transmission at remaining habitats (Department of the Environment 2015).

Regulation of freshwater flows and flooding may involve diversion; reducing or increasing volume and velocity; modifying seasonality, frequency, duration, predictability and variability, and timing; and altering surface and subsurface water levels, and their rate of rise and fall. These effects can result from building dams, levees, and other structures including detention basins and gross pollutant traps, as well as through surface and groundwater extraction due to increasing water demand (Department of the Environment 2015). Subsequently, altering the hydrology of estuarine wetlands and floodplains (e.g. flow regime, water depth, and water temperature) (Department of the Environment 2015).

Given the lateral connectivity of wetlands, rivers, floodplains, and estuaries, changes to flows may cause permanent loss or degradation and fragmentation of shorebird breeding, roosting, or foraging habitats through inundation, drying, erosion, sedimentation, and physical barriers (Department of the Environment 2015). For instance, altered water flows along the Bega, Tuross, Nullica, and Wonboyne rivers, and for all ICOLLS along the South Coast of NSW – particularly during years of lower than average rainfall – are predicted to cause modifications of flow rates and subsequent reductions in habitat quality for shorebirds.

Additionally, changes in water regulation may alter the geochemical profile and water quality of these environments, changing salinity, exposing acid sulfate sulphate soils, increasing sediment and nutrient loads, and transporting and dispersing pollutants including pesticides, trace metals, and hydrocarbons (Lee et al. 2006, Department of the Environment 2015). This may result in eutrophication, the trophic accumulation of toxins, and infilling due to sedimentation, not only altering both habitat availability and type, but also disrupting trophic systems that support resident and migratory shorebirds (Lee et al. 2006).

As of 2008, resident and migratory shorebirds in eastern Australia had declined by 81% and 73%, respectively, over a period of 24 years (Nebel et al. 2008). This was largely attributed to significant reductions in wetland area – including coastal Lake Denison/Jack Smith Lake in Victoria, and the Coorong in South Australia - possibly caused by water extraction and river regulation (Nebel et al. 2008). Wetland ecosystems are thought to be particularly susceptible to changes in the timing and quantity of water received due to the impacts on plant communities and subsequently habitat quality and food availability for estuarine wildlife (Lee et al. 2006). Mapping of floodplain vegetation in 2005 by the Northern Rivers Catchment Management Authority was indicative of a large-scale loss of vegetation cover in these areas (NRCMA 2005). In NSW, major estuary and floodplain areas are associated with the Manning, Macleay, Nambucca, Clarence, Richmond, and Tweed Rivers.

Historical drainage and flood mitigation works have resulted in habitat fragmentation from reduced wetland and floodplain area, particularly in the backswamps along the north coast of NSW and on the Tweed, Richmond, Clarence, and Macleay River coastal floodplains (Tulau 2011). Addressing these legacy impacts are likely to be problematic, particularly near areas that are heavily farmed, industrialised, or urbanised. Modification of hydrological regimes and associated affects (e.g. mobilisation of acid sulfate sulphate soils, degradation of water quality, expansion of aquatic weeds, eutrophication, sedimentation, changes in salinity, and habitat fragmentation) have been identified as threats to the intertidal wetlands and floodplains in the Clarence Lowlands bioregion (Department of Environment and Climate Change NSW 2008). This includes the Broadwater, Clarence Estuary, and Richmond Estuary, all of which provide important refuge for migratory and resident shorebirds, including species listed within international treaties such as the greater sand-plover, lesser sand-plover, white-bellied sea-eagle, whimbrel, Terek sandpiper, broad-billed sandpiper, sharp-tailed sandpiper, and little tern (Department of Environment and Climate Change NSW 2008).

Effects on these estuarine systems due to modification of hydrology have already been seen. In 2001, flooding in the upper catchment of the Richmond River resulted in a major fish kill, with the greatest and longest impact occurring at the upper and mid-reaches of the Richmond Estuary (Walsh et al. 2004). This event was attributed to extremely low levels of dissolved oxygen in the river, as a consequence of the death of pasture grasses inundated by floods and rapid drainage of the floodplain water into the river. Additionally, drainage of acid sulfate sulphate soil sediments contributed to the eutrophic conditions (Lee et al. 2006). The areas that were the most greatly affected were those that had been extensively drained and flood gated, allowing the rapid transport of highly anaerobic backswamp water into the estuary (Walsh et al. 2004).

Previously, estuaries, wetlands, and floodplains in the Clarence lowlands such as Cudgen lake had been identified as priority areas for the management of acid sulfate sulphate soils, as the engineered drainage and flood mitigation schemes in place in the region were predicted to increase the risk of soil acidification, degradation of water quality, loss of estuarine habitat, and wildlife population declines (Tulau 1999). Fish die-offs and changes to aquatic plant communities associated with acid sulfate sulphate soils and black water both degrades shorebird habitat and has upward cascading trophic affects by reducing prey availability.

Alteration of water flows and subsequent changes to estuarine geomorphology may also allow increased access for recreational beachgoers, fishers, and terrestrial predators to shorebird nesting areas that were previously less accessible on island sites. Further, fragmentation of estuarine wetlands exacerbates edge effects, creating greater opportunities for the introduction and establishment of invasive species, and rendering wetland communities more vulnerable to disturbance (Lee et al. 2006).

Water extraction

There is limited information regarding an assessment of current activities on the attributes listed by Peirson et al. (2002). Where large dams are present in catchments (Wyong, Hawkesbury, Georges, Hunter, Shoalhaven, Bega Rivers), large quantities of water are extracted and do not reach estuaries downstream. The NSW Office of Water provides detailed report cards for factors that were assessed during the implementation of water-sharing plans[33].

River regulation by dams and weirs and the capture of flood pulses (water extraction) for consumptive use have the potential to alter estuarine salinity gradients and their location in the estuary, affecting both the intensity of cues experienced by fishes, and their physicochemical habitats. Such regulation may result in a decrease in the frequency of years with high seasonal discharges, which may affect spawning and recruitment success (Taylor et al. 2014) of estuary-dependent species. Recruitment may be affected via a number of mechanisms (see Gillison et al. 2008) including:

- modified nutrient input influencing the trophic cascade in the estuarine food chain,
- changes to food resources affecting growth rates,
- modification of habitat quality and quantity altering density-dependent mortality,
- advection (negative effect) or retention (positive effect) of eggs and larvae in nursery habitats and
- increased predation (negative effect) of young-of the-year.

Further, river regulation and reduced freshwater inflows may also result in a compression of estuarine salinity gradients, reducing the spatial extent of brackish water habitat used by juveniles of estuary-dependent fish species such as Mulloway (Taylor et al. 2014).

Increased freshwater input

Large increases in flow can also have a major impact on estuarine and coastal systems. Freshwater run-off is a function of numerous environmental variables, depending primarily on climate (precipitation and evaporation) and the physical characteristics of the drainage basin (Gillanders and Kingsford 2002). Large volumes of freshwater flows can reduce the viability and vigour of estuarine habitat: particularly saltmarsh, and to a lesser degree, mangroves. An excess of freshwater from increased catchment stormwater inputs, or reduced estuarine flow penetration due to floodgates, can alter vegetation and facilitate weed infestation. This is a particular risk to rehabilitation projects in the Hunter, such as Tomago wetland.

Changes to tidal flow, drainage and the hydrology of estuaries to reclaim land and mitigate flooding can have major impacts on saltmarsh leading to their decline. Inundation with freshwater for extended periods can kill many succulent saltmarsh species such as samphire. In areas where freshwater becomes too dominant, saltmarsh plants can be replaced by brackish and freshwater reed species such as the common reed (*Phragmites australis*). Developments or activities (such as floodgates, flood mitigation works and artificial openings of estuary entrances to the sea) which have the effect of permanently draining water from a saltmarsh or which impede normal drainage and tidal influence are likely to degrade saltmarsh and lead to the loss of the habitat.

Potential impacts of modified freshwater flows – instream barriers and associated infrastructure

Instream structures that span the whole channel (e.g. weirs, causeways) can impede natural flows and act as physical and hydrological barriers to fish movement, thus isolating upstream and downstream habitats (Figure 42). Even structures such as road culverts and piped crossings can block fish passage if they are not designed correctly or adequately maintained.

The extent to which waterway crossings reduce the migration of fish in waterways can depend on the:

- design of the waterway crossing structure

[33] For example, see http://www.water.nsw.gov.au/water-management/water-sharing/plans_commenced/water-source/hunter-unregulated-and-alluvial

- nature of flow, debris and sediment movement in the waterway
- swimming capabilities of resident fish (Industry and Investment 2009).

Bridges that are built too low, or whose piers and footings constrict the channel, can affect hydrological flows (e.g. excessive velocity) or collect debris that creates physical blockages. Poorly constructed culvert crossings can significantly modify channel bed form and flow conditions due to increased flow velocities, turbulence and reduced flow depth through the structure. Fish passage at culverts is inversely related to flow velocity (Warren and Pardew 1998), with velocities as low as 0.35 m/s significantly reducing migration success (MacDonald and Davies 2007). Additionally, culvert crossings often display perched outlets, which result in excessive head differential (i.e. >100 mm) at base flows that acts as a physical migration barrier.

These impacts can be severe for diadromous fish (e.g. sea mullet, eels), which need to migrate between the two systems to complete their natural lifecycles. Additional motivation for species to disperse includes the search for food and shelter, and the avoidance of predation and competition pressures. Altered flows can also affect habitat-forming vegetation, such as saltmarsh (Laegdsgaard et al. 2009) and mangroves.

Figure 42. Example of modified freshwater flows

Structures located in tidal areas or that artificially create the tidal limit in the catchment often drown out several times a year, when rising water levels overcome head differential barriers. This enables fish to pass through periodically. Despite higher frequencies of drownout, these downstream structures are generally viewed as a higher priority for remedial action, due to the increased impact they have on juvenile fish. After spawning in the estuary, juvenile catadromous species such as Australian bass (*Macquaria novemaculeata*) will attempt to move upstream into freshwater habitats. When they encounter an instream structure, they are forced to accumulate below the structure until flow conditions permit migration past the overtopped barrier. However, such drownout events rarely coincide with a species' migrational timing, thereby increasing exposure to predation and the potential loss of a population cohort.

Changes in habitat features associated with instream structures may also present behavioural barriers to migrating fish. Species that are able to pass into weir reservoirs may find the pooled, still-water system unsuitable, due to the loss of critical riverine habitat features such as riparian vegetation cover, aquatic macrophytes and large woody debris.

Structures installed in-channel banks and floodplains, such as levees, floodgates and other off-stream structures (e.g. detention basins and gross pollutant traps) can disrupt the longitudinal and lateral connectivity of floodplain wetlands.

This connection between wetland units including seasonal or ephemeral habitats, and between wetlands and adjacent habitats is among the most important functional component of an estuarine wetland as it maintains the ecosystem's integrity and allows fish to access them as nurseries. Maintenance of these connections are critical to metapopulation dynamics (Sheaves and Johnston 2008) of many riverine species (Bunn and Arthington 2002).

Disconnecting and isolating these habitat units has had pronounced, far-reaching impacts on estuarine fauna and flora. For example, there has been a general degradation in the overall quality of available fish habitat, particularly in terms of reductions in natural fringing vegetation (mangroves in the more estuarine-dominated areas and overhanging terrestrial trees in the more freshwater-dominated areas often being replaced by grasses and rushes), impeded access to large areas of previously available estuarine fish nursery and feeding habitat and to increase the intensity of surrounding land use (natural forest often being cleared and wetlands drained for cattle grazing and sugarcane growing) (Pollard and Hannan 1994).

The major cause of mangrove stress at many sites globally is often linked to reduced tidal flows and exchange. Once seemingly innocuous hydrological modifications such as road crossings and blocked tidal channels can often manifest stress in mangrove forests over decades with little incremental change signalling their future demise (Lewis 2016).

Floodgates are one-way hinged flap structures that seal against a near-vertical face. They are commonly found on coastal floodplain drainage systems that were constructed to promote agricultural opportunities. Many natural creek systems have also been floodgated. Floodgates prevent saline tidal water from inundating low-lying agricultural land, and avert river rises from backflooding urban and rural areas (Johnston et al. 2003).

The passive design of the majority of floodgate structures presents an obvious physical barrier that directly reduces fish passage between estuaries and tidal tributaries, especially when the hinged flap is closed. Even when gates are opened, water quality attributes, such as including low pH, temperature differentials and low dissolved oxygen levels, can further deter migrating fish from entering a drain (Kroon 2005) and have severe impacts on species diversity and abundance across the full range of macro fish and invertebrates in a system (Heath and Winberg 2010). Additional impacts of floodgates and associated drainage works include the fragmentation and degradation of wetland habitat, the reduction of water quality, and the potential exposure of acid sulfate soils (Walsh and Copeland 2004), see Section 6.2.1 for further detail.

6.1.13 SERVICE INFRASTRUCTURE

This activity includes laying infrastructure pipelines and cables on the bed of estuaries and the seafloor, or into the seabed via trenching and boring techniques. A considerable amount of service infrastructure occurs within estuarine waters in the various regions, reflecting the level of urban development adjacent to the marine estate. These pipes and cables cross intertidal and subtidal areas, and vary in size and extent. The infrastructure is usually protected by a protection zone, which excludes or limits a wide range of other activities.

6.2 LAND USE IMPACTS

6.2.1 LAND USE INTENSIFICATION

More than 85% of the NSW population lives within 50 km of the coast. As a consequence, development of foreshores and coastal floodplains has occurred all along the coastline. Most of the coastal catchments in the marine estate have some level of land use activity or development. Only 12 of the 184 main catchments in NSW remain undeveloped, and these are mostly catchments in the south towards the NSW and Victorian border. The most developed catchments (where >80% of land is developed) are predominantly urbanised. Typically, urban areas are adjacent to main waterways, while agricultural areas, forestry and mining operations are in the upper parts of the catchment (Figure 43).

The extent of land use activity in all coastal catchments has been summarised by a catchment disturbance index, which ranges from very low to very high disturbance (Figure 44). The index was derived for the NSW Monitoring, Evaluation and Reporting Strategy 2010–2015 (Roper et al. 2011), and reflects a ratio of pre- and post-European diffuse pollution loads modelled using OEH's Coastal Eutrophication Risk Assessment Tool[34].

Roper et al. (2011) analysed characteristics of catchments and shores of all NSW estuaries to develop catchment pressure indices. Populations are increasing faster on the north and south coasts (36–40% catchments with population increases >20%), compared with 10% in the central region (Table 26). The central region has 70–85% of estuary catchments in the highest population density and nutrient export categories; the north coast has 45% of estuary catchments in these categories, and the south coast has just 17–18%. Broadly, the central region has greatest levels of urbanisation and nutrient and sediment export to estuaries, followed by the north coast. Populations are increasing at about the same rate on the north and south coast, which is relevant to considerations of the impacts of land use intensification. Hydrological modification of estuary function is greatest on the north coast.

[34] www.ozcoasts.gov.au/nrm_rpt/cerat/index.jsp

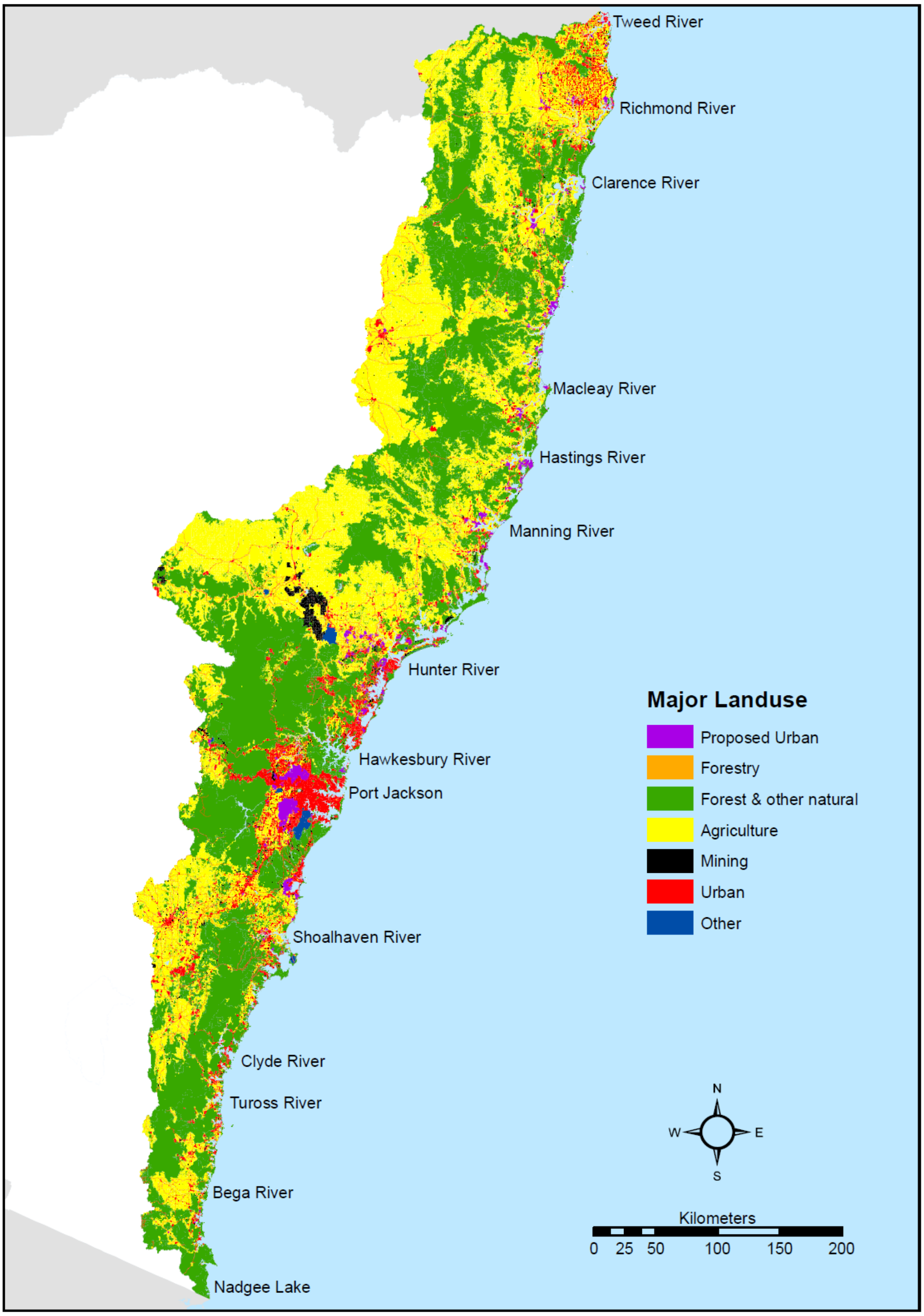


Figure 43. Major land use within the catchments influencing the New South Wales marine estate. *Source: OEH unpublished land use data; disturbance index from Roper et al. (2011).*

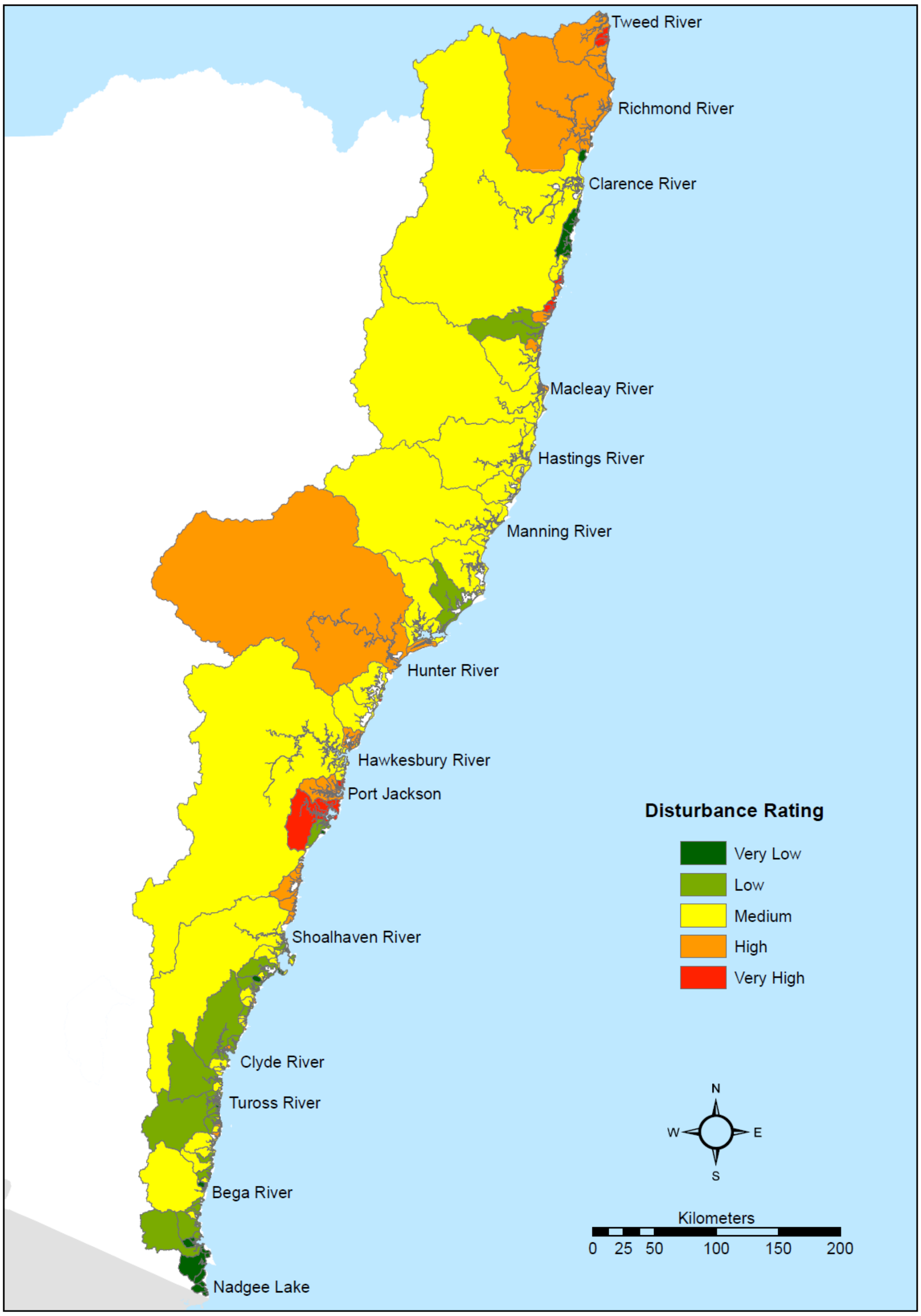
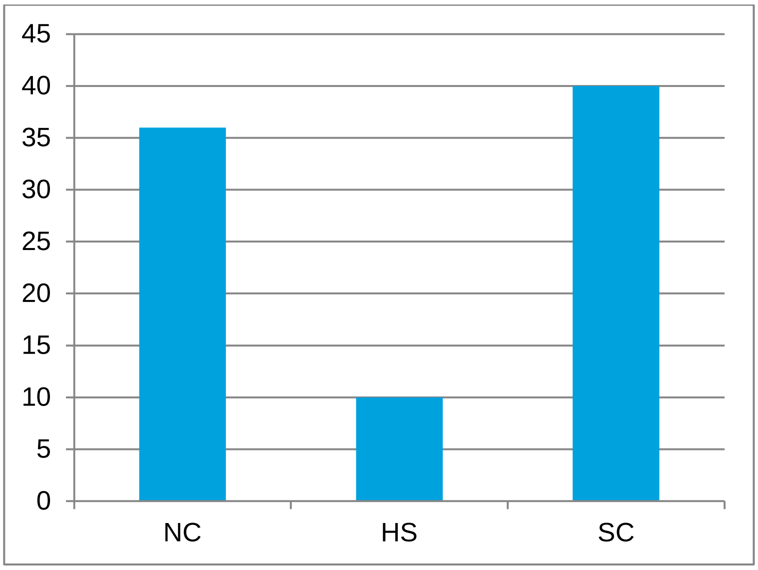


Figure 44. Catchment and estuary disturbance rating in New South Wales. *Source: OEH unpublished land use data; disturbance index from Roper et al. (2011).*



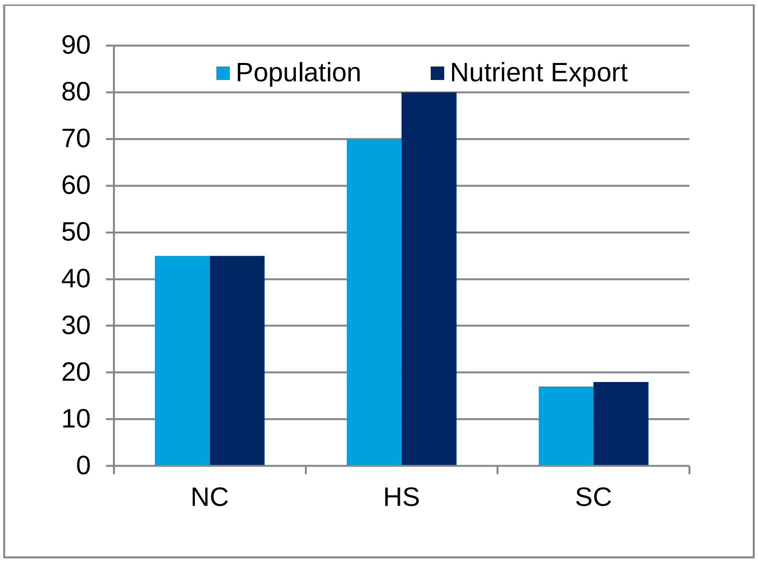


Figure 45. A, Proportion of estuary catchments with greater than 20% increase in population; B, percentage of estuary catchments with greater than 50 persons/ha of catchment and nitrogen catchment export ratios (current load/pre-European load) greater than 2.5. *HS = Hawkesbury Shelf; NC = north coast; SC = south coast.*

Current management

Australia has international obligations to protect the marine environment from land based activities under the United Nations Environment Programme Global Programme of Action for the Protection of the Marine Environment from Land Based Activities (UNEP GPA). The Australian Government meets its obligations under the UNEP GPA through its Framework for Marine and Estuarine Water Quality Protection. The framework builds upon the National Water Quality Management Strategy and National Principles for the Provision of Water to Ecosystems[35]. It guides development of Water Quality Improvement Plans (WQIP) for key coastal waterways (‘hotspots’) threatened by pollution.

[35] www.environment.gov.au/resource/framework-marine-and-estuarine-water-quality-protection-reference-document

Table 26. Proportion of New South Wales estuary catchments in the two highest disturbance ranks (statewide) for population density, nutrient increase and commercial fish catch.

Region	Factor	No. of Estuaries with Disturbance Rank 1 and 2	Number of estuaries	Proportion[a]
Northern				
	Population density	24	55	0.44
	Nutrient increase	25	55	0.45
	Commercial catch	5	55	0.09
	Population increase (>20%)	20	55	0.36
Central				
	Population density	34	40	0.85
	Nutrient increase	28	40	0.70
	Commercial catch	1	40	0.03
	Training walls	7	40	0.18
	Population increase (>20%)	4	40	0.10
Southern				
	Population density	16	89	0.18
	Nutrient increase	15	89	0.17
	Commercial catch	3	89	0.03
	Training walls	9	89	0.10
	Population increase (>20%)	36	89	0.40

[a] proportion of estuaries with training walls and proportion of estuaries with >20% increase in population (1996 – 2006) in each of the northern, central, and southern regions.
Source: All data from Roper et al. (2011).

A WQIP has been developed and implemented for Wallis and Myall Lakes on the northern region, and in the Botany Bay catchment in the central region. In both cases, land based targets for pollution load reduction have been developed to protect the quality and health of the waterway. A WQIP is now being developed for the Sydney Harbour Catchment (Freewater et al. 2014). In addition, Lake Macquarie Council and Wyong Council all have sophisticated linked catchment and estuary response models to help management of diffuse source pollution from catchments.

Outside these hotspot areas, diffuse source water pollution is managed by different levels of government, industry and community. No single authority is responsible for managing diffuse source water pollution in NSW.

The OEH has developed a NSW Diffuse Source Water Pollution (DSWP) Strategy in a joint management initiative by the state's natural resource managers (state, regional, and local governments). The DSWP Strategy aims to reduce diffuse source water pollution inputs into all NSW surface and ground waters and contributes towards the community-agreed NSW Water Quality Objectives[36].

The DSWP Strategy coordinates efforts to reduce diffuse source water pollution across NSW by promoting partnerships, providing guides for investment and a means to share information on projects and outcomes across the state. The DSWP Strategy is non-statutory and does not provide funding to help implement the proposed priority action plan that underpins it[37].

[36] www.environment.nsw.gov.au/ieo/

[37] www.environment.nsw.gov.au/water/dswppap.htm

The first annual report for the DSWP Strategy was published in 2010, indicating good progress towards meeting priority actions. There have been no reports since, although the effectiveness of the DSWP Strategy is currently being evaluated by OEH and potentially revised to ensure that it remains relevant and useful. In addition to the Framework for Marine and Estuarine Water Quality Protection and the DSWP Strategy, other non-statutory strategies, guidelines, objectives, plans and programs collectively aim to reduce pollutant inputs to the state's waterways. For example, OEH also administers the Lower Hawkesbury–Nepean Nutrient Management Strategy (DECCW 2011), various regional growth strategies, and the Beachwatch programs[38].

Office of Local Government provides guidelines to local government on stormwater management and levying a stormwater management service under the *Local Government Amendment (Stormwater) Act 2005*. Local government authorities have specific plans for target areas within the catchments that they manage. The stormwater levy and other funding sources have supported the construction of a wide range of gross pollution traps (GPT) that are administered by local government.

Local governments have a responsibility to carry out stormwater management and control activities within their local area, including managing stormwater run-off and stormwater harvesting and reuse. Local governments administer strategic, implementation and compliance role under the *Local Government Act 1993, POEO Act*, *Environmental Planning & Assessment (EP&A) Act 1979*. Regulation role of water pollution under the *POEO Act*.

Local government authorities have specific plans for target areas within the catchments that they manage. Stormwater industry groups also produce their own guidance material for managing diffuse source water pollution[39]. Recent directions for improving diffuse source run-off management have concentrated on spatially explicit assessments of downstream risk and tailoring catchment management to degree of downstream risk in estuaries[40]. This process has also resulted in a revised list of NSW estuaries that have been identified as sensitive to land use intensification (Table 27).

The *Coastal Protection Act 1979* provides statutory requirements for managing the coastal region and associated ecosystems and water quality. The objects of the Act are partly implemented through the development of coastal zone management plans. OEH administers coastal and estuary management programs to facilitate preparation of the plans, along with supporting studies to help assess and manage the health of estuaries. This includes assessments of pressures arising from land based activities that cause diffuse source water pollution. The *Coastal Protection Act 1979* is currently being replaced by a new *Coastal Management Act*, as part of the NSW government's coastal reforms[41].

Under the *Protection of the Environment Operations Act 1997*, the EPA is the regulatory authority for:

- activities listed in Schedule 1 to the Act and the premises where they are carried out
- activities carried out by a State or public authority
- other activities in relation to which a licence regulating water pollution is issued.

In nearly all other cases, the regulatory authority is the relevant local government. The *POEO Act* contains a list of activities that require an environment protection licence. These are listed in Schedule 1 of the *POEO Act*. Environment protection licences are a central means to control the localised, cumulative and acute impacts of pollution from these activities.

[38] www.environment.nsw.gov.au/beach/

[39] e.g. www.wsud.org/

[40] e.g. http://www.planning.nsw.gov.au/Plans-for-Your-Area/Regional-Growth-Plans/Illawarra

[41] www.environment.nsw.gov.au/coasts/stage1coastreforms.htm

The *Environmental Planning and Assessment Act 1979* has provisions for reducing diffuse source water pollution in special areas, namely the State Environmental Planning Policy (2011) for Sydney's drinking water catchment. There are also provisions for minimising disturbance and managing developments on acid sulfate soils (Part 4, *EP&A Act 1979*). Broader statutory requirements for reducing diffuse source water pollution are met through environmental planning instruments and development control plans of local government areas. However, these controls relate mostly to stormwater, and not all local government areas specify controls.

There is also a lack of consistency in the type of controls or management targets adopted. For example, some local government areas apply a one-size-fits-all target for reducing stormwater pollution irrespective of the sensitivity of the waterway. Others (e.g. Great Lakes Shire) have more stringent controls, which are based on management targets aiming for no net increases in the discharge of pollutants from new developments. An increasing trend to urban stormwater management involves slowing down and filtering stormwater through techniques known as water sensitive urban design. This typically involves on-site water retention, routing through porous surfaces (e.g. grassed swales) and constructing wetlands for biofiltration.

The clearing and development of agricultural land is governed by a range of state policies and legislation[42]. These include state environmental planning policies on rural lands and intensive agriculture, Fisheries Management Act (which protects marine vegetation, including saltmarsh and mangroves from grazing and trampling by livestock on public water land), *EP&A Act*, *Native Vegetation Act, Soil Conservation Act, Protection of Environment Operations Act* and *Pesticides Act*. Unless specifically controlled through the aforementioned acts, the management of the environmental and off-farm impacts of agriculture is primarily through best-management guidelines (Haine et al. 2011).

Potential impacts of land use intensification

Non-urban disturbance

Water pollution

Across NSW, past land use practices (urban development, forestry, agriculture, and mining) and other soil disturbances have greatly accelerated natural rates of soil erosion by reducing vegetation cover. Erosion is the largest contributor to turbidity and nutrient pollution in water bodies. Agricultural land use changes have accelerated soil erosion by 1–2 orders of magnitude, with rates 5–25 times greater than natural levels common in southern Australia (Hughes et al. 2001). Soil erosion can affect downstream creeks, rivers, reservoirs, lakes, and estuarine and marine environments, while waterborne erosion increases the supply of sediment to rivers.

High concentrations of suspended sediments in waterways can:

- reduce stream clarity (increasing turbidity)
- inhibit respiration and feeding of stream biota
- diminish light needed for photosynthesis
- cause eutrophication of rivers and wetlands
- make water unsuitable for irrigation
- require treatment of water for human use
- smother the stream bed
- increase land flooding.

Large-scale historical erosion has resulted in sediment slugs in many locations (e.g. Bega River). These are likely to take generations to move through a river system, even if upstream sediment supply is returned to natural levels. Dealing with sediment slugs is difficult, because works can easily be smothered.

[42] http://www.dpi.nsw.gov.au/agriculture/resources/lup/legislation

Table 27. Estuaries identified as sensitive to impacts from land use through Office of the Environment and Heritage assessment of estuary sensitivity for New South Wales planning reforms.

Northern region	Central region	Southern region
Belongil Creek	Glenrock Lagoon	Wollumboola Lake
Tallow Creek	Middle Camp Creek	Currarong Creek
Broken Head Creek	Tuggerah Lake	Wowly Gully
Salty Lagoon	Wamberal Lagoon	Moona Moona Creek
Lake Arragan	Terrigal Lagoon	Captains Beach Lagoon
Cakora Lagoon	Avoca Lake	St Georges Basin
Station Creek	Cockrone Lake	Swan Lake
Pipe Clay Creek	Narrabeen Lagoon	Berrara Creek
Arrawarra Creek	Dee Why Lagoon	Nerrindillah Creek
Darkum Creek	Curl Curl Lagoon	Narrawallee Inlet
Woolgoolga Lake	Manly Lagoon	Tabourie Lake
Willis Creek	Wattamolla Creek	Termeil Lake
Hearnes Lake	Bellambi Gully	Meroo Lake
Pine Brush Creek	Bellambi Lake	Willinga Lake
Dalhousie Creek	Towradgi Creek	Butlers Creek
Oyster Creek	Fairy Creek	Durras Lake
Deep Creek	Lake Illawarra	Durras Creek
Saltwater Creek (Frederickton)	Elliott Lake	Maloneys Creek
Killick Creek	Spring Creek	Cullendulla Creek
Goolawah Lagoon	Werri Lagoon	Congo Creek
Cathie Creek	Shoalhaven River	Meringo Creek
Duchess Gully		Kellys Lake
Khappinghat Creek		Coila Lake
Black Head Lagoon		Lake Brunderee
Wallis Lake		Lake Tarourga
		Lake Brou
		Lake Mummuga
		Kianga Lake
		Little Lake (Narooma)
		Bullengella Lake
		Nangudga Lake
		Corunna Lake
		Tilba Tilba Lake
		Little Lake (Wallaga)
		Wallaga Lake
		Baragoot Lake
		Cuttagee Lake
		Bunga Lagoon
		Middle Lagoon
		Wallagoot Lake
		Bournda Lagoon
		Back Lagoon
		Curalo Lagoon
		Boydtown Creek
		Fisheries Creek
		Saltwater Creek (Eden)
		Woodburn Creek
		Merrica River
		Table Creek
		Nadgee River
		Nadgee Lake

As land use changes from undeveloped to various forms of development, community pressure can increase the risk of other environmental threats to meet the needs of the new land use. Such threats can include:

- removal of (or damage to) riparian or marine vegetation
- increased boating or recreational infrastructure
- increased stormwater, industrial and effluent discharge
- pressure to increase drainage and reduce habitat connectivity, due to the need (or perception of need) for flood protection
- pressure to change estuary entrance openings and regimes, increase in-channel dredging or foreshore protection
- reduced carbon sequestration potential due to land clearing
- change of freshwater flows (both ground and surface water) due to increased water demand for urban, industrial or agricultural uses.

Additionally, historical land use change and intensification has left us with legacy environmental problems. An example is historical drainage of estuarine wetlands for agricultural land use, which now cause problems such as acid sulfate soils and blackwater (high levels of dissolved organic carbon in the water column). These pose difficult community decisions regarding the appropriateness and cost of maintaining the current land use and its consequent impacts, or reverting to a less harmful land use.

A recent contamination issue identified from specific sites in NSW relates to the presense of per- and poly- fluoroalkyl substances (PFAS), which are a group of chemicals that include perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS). These range of chemicals are used for many specific applications and are widely used in a range of products in Australia and internationally. PFAS are an emerging contaminant, which means that their ecological and/or human health effects are unclear.

PFOS and PFOA are both very stable chemicals that bioaccumulate in the ecosystem, and because they do not break down they can persist for a long time in the environment. Their widespread use in a range of industrial and consumer products over many decades PFAS contamination means that they are commonly found in the environment at low levels.

The NSW Environment Protection Authority (EPA) is undertaking an investigation program to better understand the extent of PFAS use and contamination in NSW. The EPA is investigating sites where there is a likelihood that large quantities of PFAS have been used in the past, to better understand the extent of PFAS use and contamination in NSW.

The initial focus is on sites where there has been known use of PFAS-containing fire-fighting foams, primarily where fire training exercises were conducted. This includes sites managed by NSW Fire and Rescue (FRNSW), Rural Fire Service (RFS), Airservices Australia and other airports. Further details are available at:

http://www.epa.nsw.gov.au/working-together/community-engagement/pfas-investigation-program

In relation to nutrient inputs into estuarine waters, the NSW Monitoring Evaluation and Reporting Strategy 2010–2015 (Roper et al. 2011) provided estimates of nitrogen and phosphorus exports from all coastal catchments in NSW (Figure 45). Some estuaries are particularly sensitive to nutrients, because they have limited connections to the ocean. These estuaries will be poorly flushed, and may retain almost all the nutrients derived from stormwater discharge and/or rural run-off.

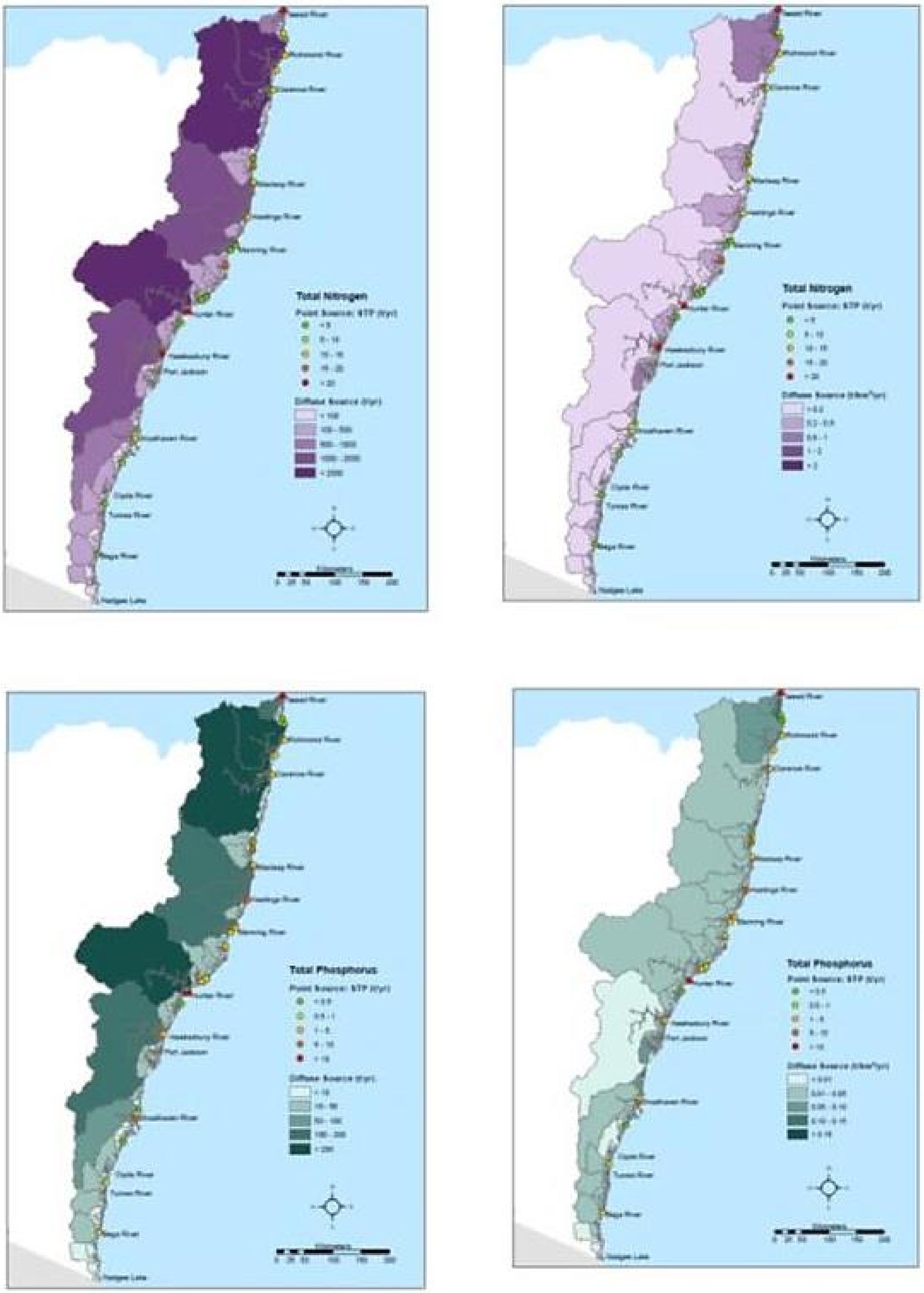


Figure 45. Total nitrogen and phosphorus export and export rates from all New South Wales estuary catchments. *Source: Roper et al. (2011).*

Increases in the amount of nutrients and organic matter being exported to receiving waterways can profoundly affect the biogeochemical processes that provide food to the system's broader food web, and regulate carbon and nutrient cycling. Nutrient enrichment in mangrove forests will favour the growth of shoots relative to roots, thus enhancing growth rates but increasing the mangroves vulnerability to environmental stressors that adversely affect plant-water relations (Lovelock et al. 2009).

Increased inputs of nutrients can cause excessive growth of micro and macroalgae, leading to nuisance algal blooms and increased metabolism in both the sediment and the water column. Increased organic matter inputs from in-situ and ex-situ production can cause localised and broadscale depletion of oxygen (hypoxia and anoxia), and can greatly harm fish and invertebrates.

Water pollution can also increase turbidity (decrease water clarity), with consequent implications for growth of primary producers, such as seagrass, (Carruthers et al. 2002, Green and Short 2003, Shepherd et al. 1989, Waycott et al. 2005,), habitat-forming algae and microalgae (Figure 46). Many associated ecological processes, such as nutrient interception by benthic microalgae, are also disrupted by water pollution.

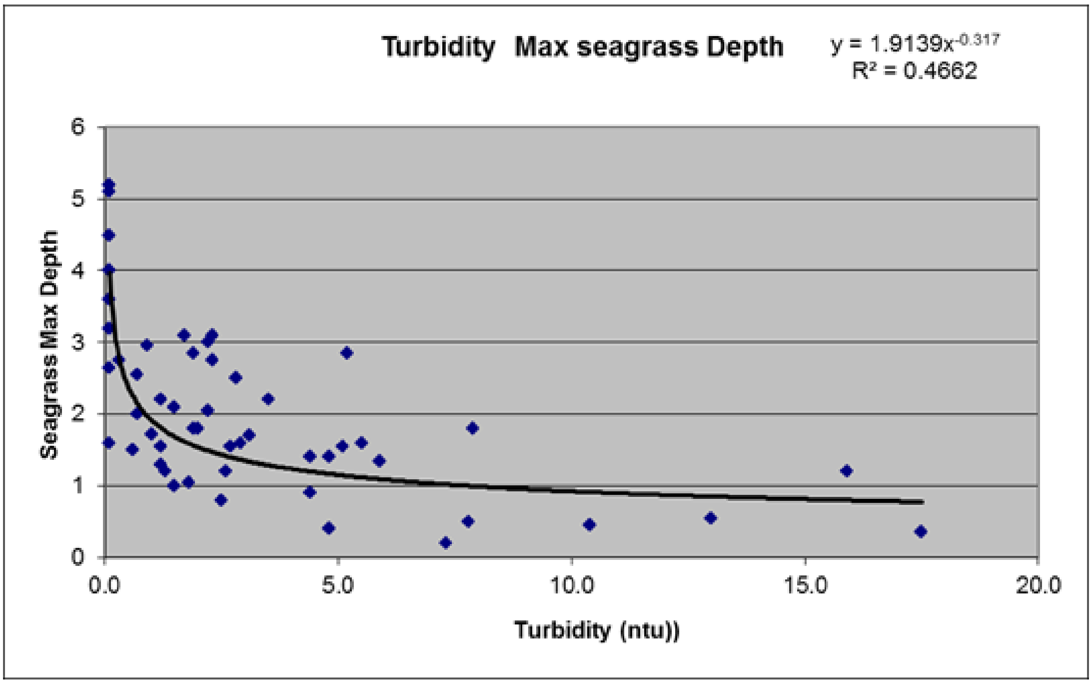


Figure 46. Seagrass depth decreases with measured turbidity in 18 New South Wales estuaries. *Source: Scanes and Coade (2012).*

Recent monitoring of microalgal biomass (chlorophyll *a*) (Figure 47) and turbidity (Figure 48) shows that some of the state's sensitive estuaries are already exceeding management triggers (i.e. Australian and New Zealand Environment and Conservation Council guidelines). These estuaries are distributed near large population and industrial centres and those with large levels of agricultural intensification.

Condition scores for NSW estuaries (based on water clarity and algal abundances) have been calculated for 50 north coast estuaries, 28 Hawkesbury Shelf estuaries and 71 south coast estuaries (Table 28; OEH data).

Southern region estuaries showed the lowest level of overall disturbance, with 25% of estuaries in Grade 1 and a further 40% in Grade 2. The north coast was next, with 4 and 64%, respectively, while the central region had only 7 and 18% in the top 2 grades. The central region had the greatest percentage of poor scores, with 25 and 7% in the lowest two grades, followed by the south coast (6 and 4%) and northern regions (2 and 0%). The relatively high percentage of poor scores on south coast reflects the vulnerability of intermittent estuaries to catchment-derived pollution (Figure 49).

The central and northern region estuaries are most affected by nutrient pollution (high chlorophyll). The central region is also most affected by turbidity, with the northern and southern regions having the same percentage of poor grades, though the south has the greatest proportion of very good grades (Figure 49).

Urban stormwater discharge

As urbanised areas tend to have a large proportion of hard surfaces there is little filtration of rainfall resulting in increased volume and velocity of run-off. The stormwater run-off in urban areas is primarily managed by rapid direction into pipes and canals which do little to reduce volume, velocity, or pollutant loads. The greatest impacts are observed in estuarine habitats where changes to the salinity and hydrodynamic regimes can have systemic effects, and input loads of nutrients and sediments can affect habitats and associated biota. Large run-off events can cause scouring and redepositing of sediment, smothering habitats, and resuspending sediments, affecting water column clarity. There are also potential effects from pollutants in the stormwater.

Potential impacts of urban stormwater discharge

Waterways in urban areas are particularly prone to impacts from stormwater run-off. In addition to the generalised impacts of nutrient and sediment from urban stormwater discharge (as described above), oil and toxic chemicals leaching from rubbish, or washing into waterways from roadways impact a range of estuarine habitats, particularly saltmarsh, seagrass, beaches and mudflats, and shallow soft sediments.

Low lying saltmarsh areas also act as depositional sinks which accumulate various pollutants and litter from both the water and land. The increased volumes of freshwater can lead to loss of saltmarsh due to water-logging. Stormwater drains often directly empty into intertidal areas discharging various pollutants (especially litter, sediment, nutrients) altering salinity levels, and spreading weeds.

Flow volumes and velocities from urban stormwater can be particularly large, resulting in scouring and erosion of urban waterways and estuaries.

Further details on nutrient pollution from urban stormwater discharge are presented in the Hawkesbury bioregion background environmental report (MEMA 2016).

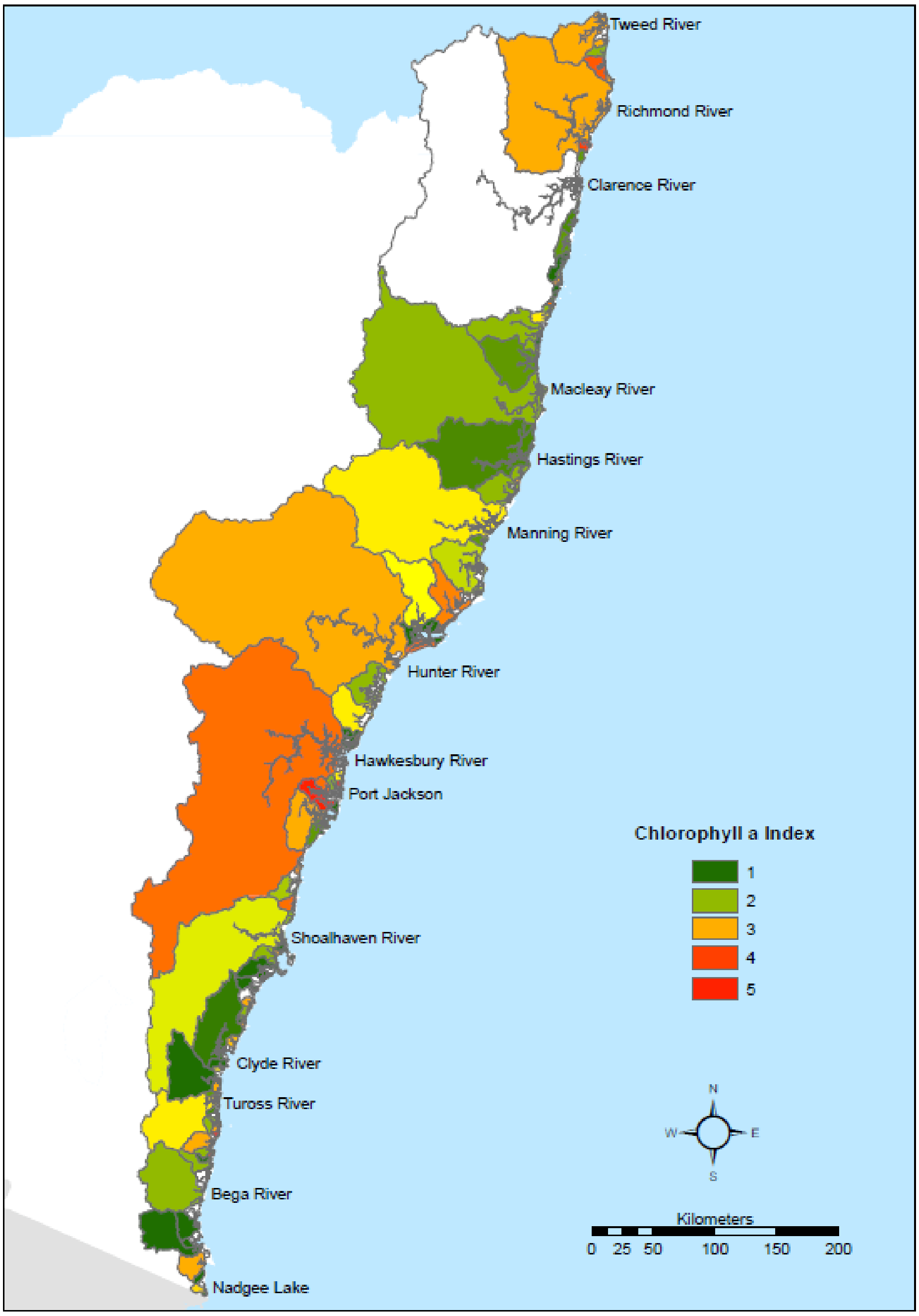


Figure 47. Chlorophyll index indicating New South Wales catchments where nutrient discharges are resulting in excessive concentrations of microalgae. *Source: OEH.*

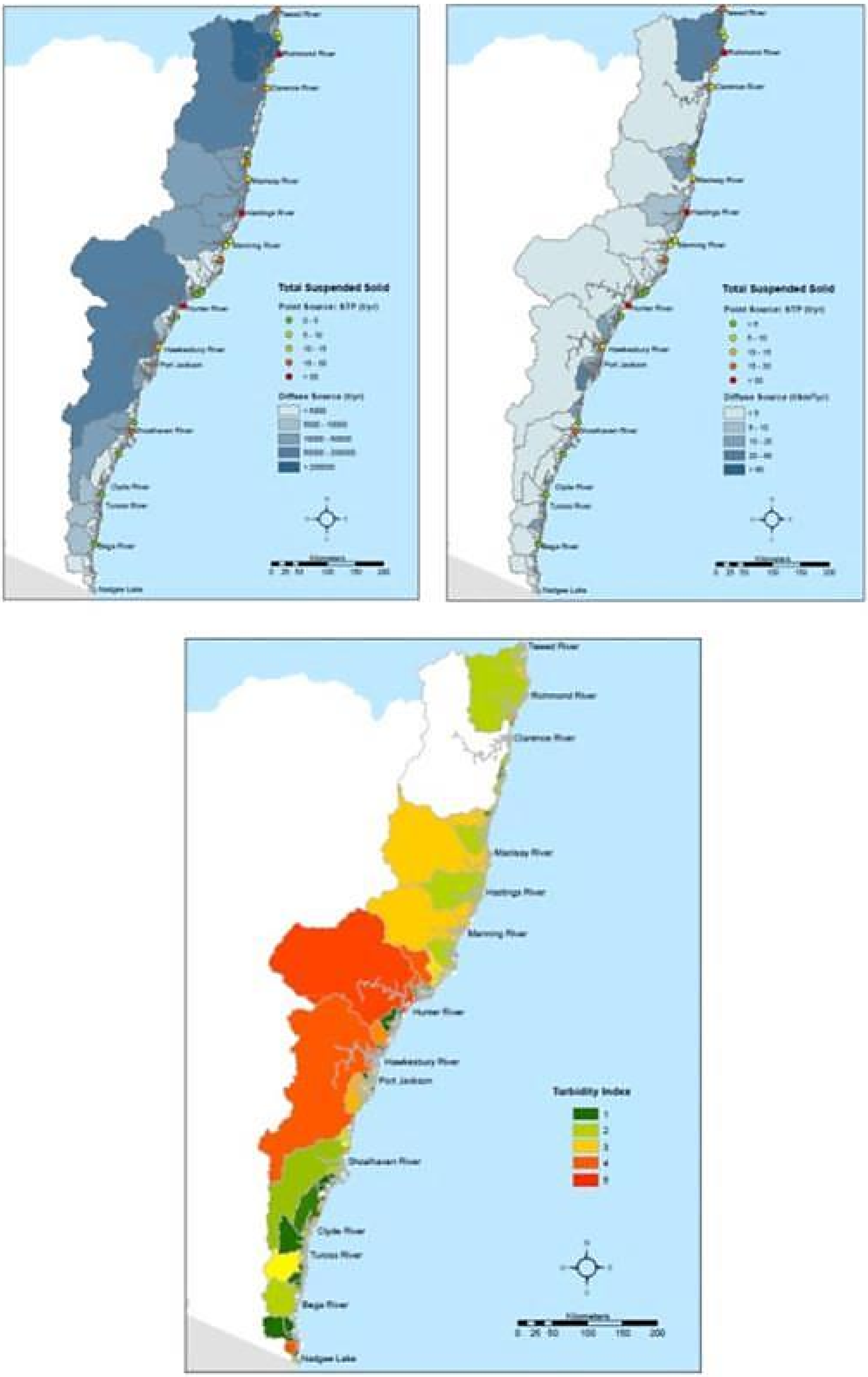


Figure 48. Loads and generation rates of sediments from coastal catchments and turbidity index in New South Wales estuaries. *Source: OEH.*

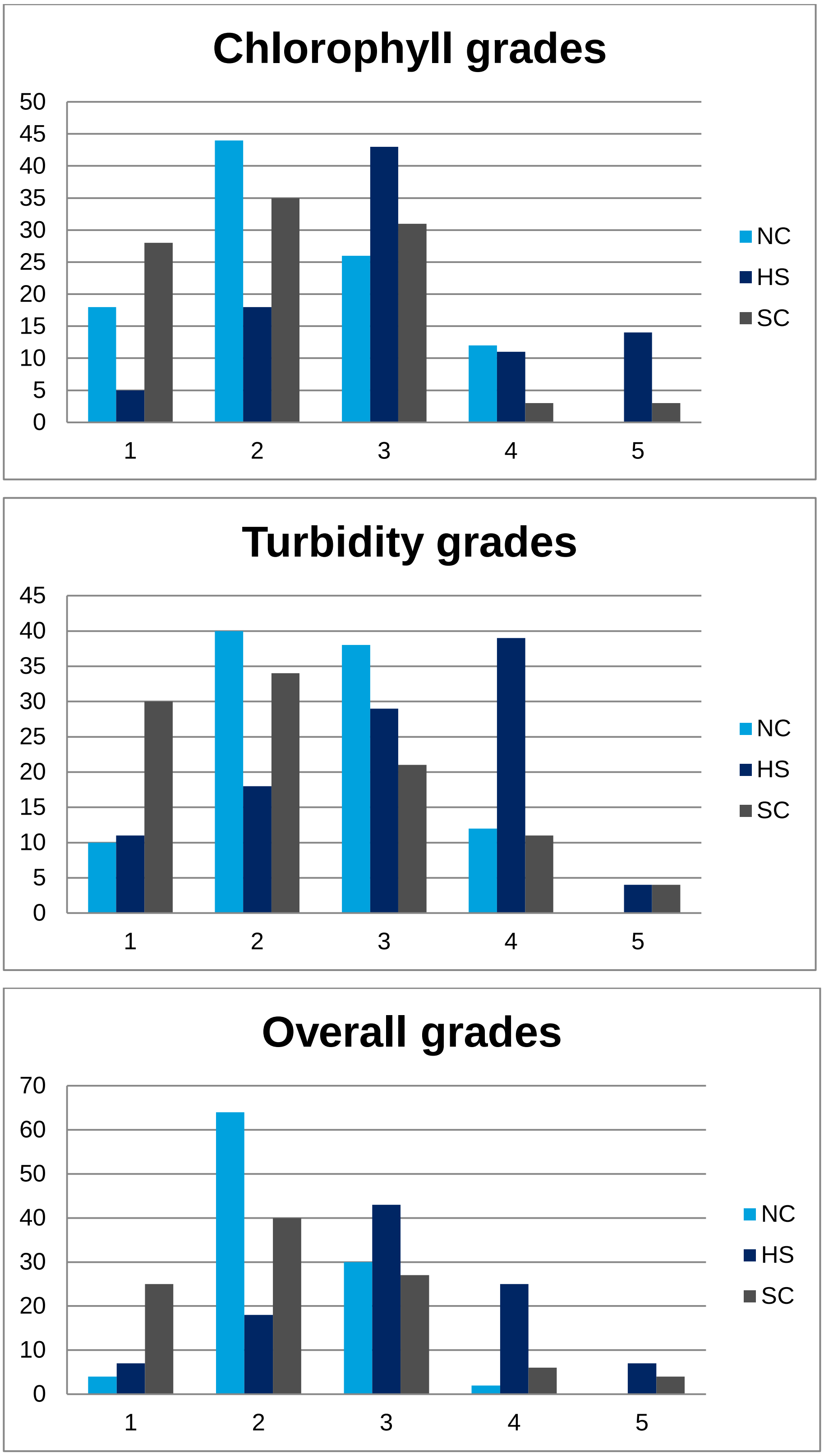


Figure 49. Percentage of estuaries in each New South Wales region in each condition grade for chlorophyll, turbidity and overall (1 = best condition, 5 = very poor condition).

HS = Hawkesbury Shelf; NC = north coast; SC = south coast

Table 28. Condition of New South Wales estuaries: Score of 1 = water is consistently below state trigger values for that type of estuary; score of 5 = water is consistently above state trigger values by a large amount.

Estuary	Turbidity[a]	Chlorophyll[b]	Overall[c]
Tweed River	2	3	2
Cudgen Creek	1	2	2
Cudgera Creek	3	4	3
Mooball Creek	2	2	2
Brunswick River	3	4	3
Belongil Creek	3	3	3
Tallow Creek	1	2	2
Richmond River	2	3	2
Salty Lagoon	1	1	1
Evans River	4	4	4
Jerusalem Creek	2	2	2
Lake Arragan	3	2	2
Sandon River	2	1	2
Wooli Wooli River	2	2	2
Station Creek	2	1	2
Corindi River	2	1	2
Pipe Clay Creek	2	1	2
Arrawarra Creek	4	2	3
Darkum Creek	3	1	2
Woolgoolga Lake	2	3	2
Willis Creek	4	3	4
Hearnes Lake	3	3	3
Moonee Creek	3	1	2
Pine Brush Creek	3	2	3
Coffs Creek	3	4	4
Boambee Creek	3	2	2
Bonville Creek	2	3	2
Bellinger River	3	2	2
Dalhousie Creek	1	1	1
Oyster Creek	3	1	2
Deep Creek	2	2	2
Nambucca River	2	2	2
Macleay River	3	2	2
South West Rocks Creek	3	2	2
Saltwater Ck Frederickton	1	2	2
Korogoro Creek	2	3	3
Killick Creek	4	3	3
Hastings River	2	1	2
Cathie Creek	2	2	2
Duchess Gully	2	3	3
Camden Haven River	3	2	2
Manning River	3	3	3
Khappinghat Creek	2	2	2
Black Head Lagoon	3	3	2
Wallis Lake	2	2	2
Smiths Lake	2	2	2
Myall River	3	3	3
Karuah River	4	2	3
Tilligerry Creek	4	4	4
Port Stephens	2	1	2
Hunter River	5	3	4
Glenrock Lagoon	4	3	3
Middle Camp Creek	3	3	3
Tuggerah Lake	4	3	3
Wamberal Lagoon	3	2	3
Terrigal Lagoon	3	3	3
Avoca Lake	2	3	3

Estuary	Turbidity[a]	Chlorophyll[b]	Overall[c]
Cockrone Lake	3	2	3
Brisbane Water	1	1	1
Hawkesbury River	4	4	4
Narrabeen Lagoon	3	3	3
Dee Why Lagoon	3	2	2
Curl Curl Lagoon	2	3	3
Manly Lagoon	2	5	4
Middle Harbour Creek	2	2	2
Lane Cove River	1	4	3
Parramatta River	3	5	5
Cooks River	3	5	4
Georges River	3	3	3
Botany Bay	1	1	1
Port Hacking	2	2	2
Wattamolla Creek	2	1	2
Bellambi Gully	4	5	5
Bellambi Lake	2	3	3
Towradgi Creek	4	3	4
Fairy Creek	4	3	4
Lake Illawarra	2	2	2
Elliott Lake	4	1	2
Minnamurra River	2	3	3
Spring Creek	2	2	2
Werri Lagoon	4	2	3
Crooked River	3	3	3
Shoalhaven River	2	2	2
Wollumboola Lake	3	1	2
Currarong Creek	1	1	1
Cararma Creek	2	2	2
Wowly Gully	1	1	1
Callala Creek	4	3	4
Currambene Creek	2	2	2
Moona Moona Creek	2	2	2
Flat Rock Creek	1	2	2
Captains Beach Lagoon	1	2	1
St Georges Basin	1	1	1
Swan Lake	2	1	1
Berrara Creek	1	2	1
Nerrindillah Creek	4	2	3
Conjola Lake	1	1	1
Mollymook Creek	4	5	5
Millards Creek	2	4	3
Burrill Lake	1	3	2
Tabourie Lake	3	3	3
Termeil Lake	2	2	2
Meroo Lake	2	1	2
Willinga Lake	4	3	4
Durras Lake	3	3	3
Durras Creek	5	2	4
Clyde River	1	1	1
Saltwater Creek Rosedale	3	3	3
Tomaga River	2	1	1
Candlagan Creek	2	3	2
Moruya River	1	1	1
Congo Creek	2	3	3
Meringo Creek	5	4	5
Kellys Lake	3	2	2
Coila Lake	2	2	2
Tuross River	3	3	3
Lake Brunderee	2	1	1

Estuary	Turbidity[a]	Chlorophyll[b]	Overall[c]
Lake Tarourga	1	3	2
Lake Brou	2	2	2
Lake Mummuga	2	1	2
Kianga Lake	3	2	3
Wagonga Inlet	1	2	2
Little Lake Narooma	2	1	2
Bullengella Lake	5	2	4
Nangudga Lake	3	3	3
Corunna Lake	3	3	3
Tilba Tilba Lake	4	5	5
Little Lake Wallaga	1	2	2
Wallaga Lake	1	3	2
Bermagui River	1	2	1
Baragoot Lake	3	3	3
Cuttagee Lake	1	1	1
Murrah River	2	2	2
Bunga Lagoon	1	1	1
Wapengo Lagoon	3	3	3
Middle Lagoon	3	3	3
Nelson Lagoon	2	1	1
Bega River	2	2	2
Wallagoot Lake	1	2	2
Merimbula Lake	2	1	2
Pambula River	1	1	1
Nullica River	1	1	1
Towamba River	1	1	1
Saltwater Creek Eden	3	2	2
Woodburn Creek	2	2	2
Wonboyn River	4	3	3
Merrica River	1	1	1
Nadgee River	2	3	2
Nadgee Lake	2	1	2

a Turbidity is a measure of water quality and surrogate for seagrass sustainability.
b Chlorophyll concentrations are a consequence of nutrient enrichment.
c Overall score is the mean of turbidity and chlorophyll scores.
Source: Data are from the New South Wales Office of Environment & Heritage monitoring, evaluation and reporting program

Water pollution

Water pollution from urban run-off can have negative impacts on the health of marine wildlife from increased susceptibility to disease or from the accumulation of contaminants in the tissue of wildlife through the food chain over long periods of time. Heavy metals, POCs and other toxins have been identified as possible threats to pinniped and marine turtle health, though NSW data is limited (Brodie et al. 2014, Shaughnessy 2009). In particular, the toxic components of oil may penetrate the skin and carapace of hatchlings and adult marine turtles, affecting respiration, salt gland function, and blood chemistry (Department of the Environment and Energy 2017) Long-term exposure may compromise health and increase vulnerability to other environmental stressors. Heavy metals and POCs have been found in marine turtles in Australia, and are capable of transferring to offspring, reducing hatchling health (Department of the Environment and Energy 2017). Losada et al. (2009) present evidence for the biomagnification of anthropogenic PBDEs through the marine food web in Sydney Harbour. While the study is concerned with marine invertebrates and fish species of various trophic levels, it is suggestive of the potential accumulation of PBDEs in higher order, apex level marine mammals and birds.

Seabirds and shorebirds, particularly long-lived species and those that feed near industrialised areas, are also exposed to the toxic effects of chlorinated hydrocarbons, metals, petroleum products, and chemicals associated with plastics, via inhalation or ingestion, external contact, or biomagnification (Burger and Gochfeld 2002). These pollutants have been variously implicated in mass mortalities, physical and behavioural abnormalities, reproductive failure, and subsequent declines in seabird populations (Burger and Gochfeld 2002). See 6.2.1 for further details on the threat of run-off to wildlife health.

Sediment contamination

Toxicants enter receiving waters from atmospheric deposition and stormwater. Urban stormwater can contain polycyclic aromatic hydrocarbons (PAHs, from car and truck exhausts), metals from road run-off, smelters, and chemical industries. The highest threat from diffuse sources of toxicants occurs around ports, and major population and industrial centres. There are also legacy effects of accumulation of toxicants in sediments (*e.g.* Sydney Harbour, Port Kembla, Lake Macquarie, Lake Illawarra and Hunter River).

Past studies have shown that extensive areas of Sydney Harbour estuary have sediments containing high concentrations of a wide range of contaminants, i.e. heavy metals (Birch 1996, Birch and Taylor 1999, Birch 2000, Irvine and Birch 1998), organochlorine pesticides (Birch and Taylor 2000), polycyclic aromatic hydrocarbons (McCready et al. 2000) polychlorinated dibenzodioxins (dioxins) and dibenzofurans (furans) and other halogenated hydrocarbons (Roach et al. 2009, Thompson et al. 2009). In the past, these contaminants would have had a mixed origin, from diffuse and industrial/point sources, but recent inputs are primarily from diffuse sources.

Further details on toxicants and sediment contamination from urban stormwater discharge are presented in the Hawkesbury bioregion background environmental report (MEMA 2016).

Pathogens

Pathogens have strong implications for people engaging in water based activities such as swimming, sailing, surfing and boating. They are also important for oyster growing. The main driver of microbial pollution to estuarine and coastal waters is urban and rural run-off after rain (Beachwatch 2016).

The microbial water quality of beaches and other swimming locations in NSW is monitored under OEH's Beachwatch Programs. The latest assessments (2014–2015)[43] show that:

- On the **north coast**, swimming suitability was good at 75% (n = 4) of estuary swimming sites and none (n=3) of the lagoon sites in Ballina Shire, none (n=1) of the estuarine beach sites in Richmond Valley Council, and just under 50% of the lake/lagoon swimming sites (n = 13) in Lake Macquarie City Council.
- In the **central region**, swimming conditions were good at the one estuarine beach site, none of the four lake or lagoon sites in Wyong Shire, and none of the 10 estuary and lake sites in Gosford City Council. Around Sydney, about 75% (43/57) of estuary or lake sites were graded as good. Only one estuary site was assessed in Illawarra and Shellharbour Councils, and it was rated as good.
- On the **south coast**, 100% of samples from estuary swimming sites in Eurobodalla and Bega Valley Shires were good (n=1 and n=3, respectively).

Antibiotic resistant and potentially pathogenic bacteria – as well as antimicrobial agents – may be released into the environment via urban run-off and sewage effluent. Resistant bacteria have been isolated from marine mammals in South Carolina and Florida (Bossart 2011, Greig et al. 2007, Schaefer et al. 2009). There is likely a positive correlation between urban development and degraded water quality, and the presence of antibiotic resistant *E. coli* strains in the intestinal systems of inshore Atlantic bottlenose dolphins in these areas (Greig et al. 2007). This has been identified as a potential threat to the health of marine wildlife, as the establishment of antibiotic resistant pathogens in dolphin populations as well as other marine mammals may act as reservoirs for the dissemination of disease-causing bacteria and their resistance genes further in the marine environment (Greig et al. 2007, Schaefer et al. 2009).

[43] http://www.environment.nsw.gov.au/beach/ar1415/index.htm

Groundwater pollution

There is a growing understanding that some intermittent estuaries may be strongly dependant on groundwater, and therefore very susceptible to groundwater pollution. At present, OEH research is showing increasing evidence of a strong groundwater presence for intermittent lagoons, but not much data on the extent of contamination.

Poorly maintained landfill sites and undocumented legacy sites of toxin use or dumping can present the risk of groundwater contamination by toxics.

Marine debris (including microplastics)

Approximately three-quarters of litter along the Australian coast is plastic, most of which originates from local sources (CSIRO 2014). Most litter is found near urban centres, and is concentrated around stormwater drains (Duckett and Repaci 2015). A study of 120 sites across 1000 km of coastline found that estuaries and embayments are consistently the most littered (Smith and Edgar 2014). Embayments are characteristically littered by plastic bags and other plastic pieces (mobile litter), whereas estuaries are littered by relatively more fishing line. Subtidal coastal sites are littered by more glass and metal pieces (longer-lasting litter). A long-term study near Coffs Harbour showed plastics account for 91% of debris (Smith and Markic 2013).

Microplastics are potentially carried by urban stormwater, particularly if it contains sewage overflows, however, data on this topic is limited. Saltmarsh habitats, particularly those near urban centres, are commonly degraded by marine debris.

In 2003, marine debris was recognised as a key threatening process for marine vertebrates under the *EPBC Act*. It is considered one of six major processes threatening biodiversity in Australia (Kingsford et al. 2009). Over 250 marine species are believed to be impacted by plastic ingestion (Laist 1997). A technical report considering the impacts of marine debris on biodiversity revealed that over 80% of reported incidents between organisms and marine debris was associated with plastic, with 11% of all reported encounters involving microplastics (GEF 2012). Globally, rates of debris ingestion among cetaceans have been found to reach as high as 31% of a population, affecting approximately 56% of species, and accounting for up to 22% of mortalities among stranded animals (Baulch and Perry 2014). Rates of plastic ingestion by seabirds is predicted to reach 99% of all species by 2050 in the absence of effective waste management policy, based on a spatial risk analysis conducted by Wilcox et al. (2015). The same study found that the region of greatest expected impact is the southern boundary of the Indian, Pacific, and Atlantic Oceans, specifically between Australia and New Zealand. Similarly, a risk analysis based on spatial modelling of sea turtle exposure to marine plastics and the consequence of exposure, identified the east coast of Australia among regions of the highest risk to sea turtle populations (Schuyler et al. 2015). Globally, it was estimated that up to 52% of sea turtles may have ingested plastic marine debris (Schuyler et al. 2015).

Marine debris, including plastics, may physically affect marine mammals, turtles, and seabirds and shorebirds, including entanglement, resulting in restricted mobility, starvation, infection, amputation, drowning, suffocation, or strangulation, and blockage, laceration, or perforation of the digestive tract following ingestion, resulting in starvation or increases in buoyancy (Laist 1997, Burger and Gochfeld 2002, Baulch and Perry 2014, Werner et al. 2016, Department of the Environment and Energy 2017). Entanglement in marine debris has been identified as a threat to Australian sea lion and sea turtle populations (Shaughnessy 2009, Brodie et al. 2014). Necropsies of threatened marine species by Taronga Zoo show ingestion of and entanglement by marine debris in NSW.

Though less studied than physical impacts, the release of toxic chemical additives, such as plasticisers and flame retardants, applied during manufacture and desorption of persistent organic pollutants that have accumulated on the hydrophobic surface of plastic debris from the surrounding water may have deleterious physiological implications, biomagnifying and disrupting biological systems (Baulch and Perry 2014, Werner et al. 2016). Microplastics are liable to concentrate hydrophobic persistent organic pollutants (POPs), which have a greater affinity for the hydrophobic surface of plastic compared to seawater. Due to their large surface area to volume ratio, microplastics can become heavily contaminated – up to six orders of magnitude greater than ambient seawater – with waterborne POPs. The exposure to compounds that have adhered to microplastics, as well as entanglement and ingestion of non-degradable debris, have been identified as a major threat to be addressed in the Australian Government's Recovery Plan for Marine Turtles in Australia (Department of the Environment and Energy 2017). In addition to direct physical and physiological impacts to marine wildlife, microplastics have been found to impede algal photosynthesis, and to be toxic to fish and invertebrates, potentially disrupting trophic systems supporting seabird and shorebird populations (Sutherland et al. 2012). Further, micro- and nanoplastics can be ingested by low trophic fauna due to their small size, enabling the trophic transfer of associated toxins (Wright et al. 2013).

Sedimentation

Here we refer to substantial accumulation of coarse sediments that changes water depth. Turbidity from suspended solids is addressed under water pollution (above). There is little evidence of sedimentation from urban run-off, though there may be some specific localised examples. Sedimentation is most likely to occur during subdivision and construction of green field sites, and from unsealed roads.

Suspended sediment can also carry pollutants such as adsorbed pesticides, nutrients, heavy metals and organic matter. Sediments from highly urbanised catchments are also associated with elevated concentrations of potential toxicants such as heavy metals, pesticides, and PAH (see *Section 6.2.2 Point discharges*). There is no evidence of contamination of sediments away from highly urbanised or industrialised catchments.

The impacts of sedimentation on wildlife health and described in *6.2.1 Land use intensification Agricultural diffuse source run-off.*

Foreshore development

The foreshore occurs where the land meets the water, and is more specifically defined as the part of the shore up to the highest astronomical tide. In reality, many foreshore developments extend into both the terrestrial and subtidal environments. Foreshore development in urban areas can affect the environmental values of the waterway (Dafforn et al. 2015). These activities include:

- shoreline hardening by building of breakwalls, wharves, jetties, marinas, and boat ramps (Figure 50)
- increased recreational access by vehicles and people
- land reclamation.

Such activities are mostly permanent and functionally irreversible. Therefore, they have long-term consequences. Foreshore development can act through multiple stressors, which can be similar for different forms of development.

Sea-level rise resulting from climate change is considered a major threat to urban areas. The primary response is likely to be increased construction of seawalls and other hard structures, which will exacerbate the current issues.

The extent of foreshore development has not been consistently assessed, but in general, it is very high in the larger estuaries, or those with high commercial use. These include Port Jackson, Hunter River, Botany Bay, and Port Kembla. It is moderate in the other large estuaries, such as Port Hacking, Lake Illawarra, Tuggerah Lakes, Brisbane Water and Lake Macquarie. The smaller estuaries have the least amount of foreshore development.

Figure 50. Example of foreshore development in an estuary.

Current Management - Foreshore Development

State Environmental Planning Policy (Infrastructure) 2007 streamlines a range of (mostly public) developments without consent, provided there is adequate consultation with relevant agencies and an environmental impact assessment under Part 5 of the *EP&A Act*. This includes much foreshore development, such as: ports, wharves and marinas, airports, water supply, stormwater and sewerage infrastructure, dredging, beach nourishment, riparian corridor and bank management, bank stabilisation, foreshore access, and flood mitigation works. Coastal protection works are also managed under this SEPP but are proposed to be moved to the Coastal Management SEPP.

Fisheries Management Act 1994 regulates any works on public water land that involved dredging and or reclamation may harm marine vegetation. Regulates for the free fish passage in all waters.

Other State Environmental Planning Policies (SEPPs), Regional Environmental Plans may regulate foreshore development in specified precincts, such as the Sydney Harbour foreshore and waterways, Hawkesbury-Nepean River, Georges River, Sydney Growth Centres, Three Ports, State Significant Precincts (e.g. Sydney Opera House, Luna Park, North Head, Barangaroo, Sydney Olympic Park, Sandon Point, the Bays). Other SEPPs regulate activities that involve foreshore development or occur on the foreshore, such as SEPP 62 (Sustainable Aquaculture).

Protection of the Environment Operations Act 1997 controls water pollution and regulates scheduled activities including marinas and boat repair facilities, sewage treatment, dredging and other land or water based extractive activities.

National Parks and Wildlife Act 1974 and related regulations is the key legal instrument which drives/governs all NPWS management activities in NSW. The objects of the Act include the conservation of nature including habitat, ecosystems and ecosystem processes, biological diversity, landforms of significance and landscapes and natural features of significance include wilderness and wild rivers. It also aims to foster public appreciation, understanding and enjoyment of nature and culture heritage and their conservation.

Crown Lands Act 1989 requires prior approval from the Crown for the occupation and carrying out of activities on Crown land. This includes coastal waters within the limits of the State, and a significant amount of developed and undeveloped land around coasts and estuaries.

DoI Lands & Forestry also has the following relevant policies that fall under the *Crown Lands Act* 1989:

- Domestic waterfront facilities policy 2014
- Coastal Crown Land Policy 1991
- Crown lands Policy for marinas and waterfront commercial tenures 1991.

SEPP (Exempt and Complying Development Codes) 2008 provides complying development standards for some types of foreshore development. It also regulates where development consent is needed in foreshore areas and environmentally sensitive areas (such as coastal lakes, wetlands, riverfront areas, acid sulfate soils, and coastal hazard areas).

Local Environmental Plans identify land use zones (including foreshore and waterway zones) with zone objectives, and permissible and prohibited development types. Development controls apply to each zone, which guide local government decision-making on development applications.

Coastal Zone Management Plans, Estuary Management Plans and Local Land Services Local Strategic Plans and **Regional Strategies** and statutory plans that identify priority actions along foreshores and waterways, which aim to address the environmental, social and economic needs of local communities. They may involve foreshore development such as bank stabilisation, coastal protection works such as seawalls, navigational dredging works, flood mitigation works, land reclamation, environmental rehabilitation, stormwater management or channel naturalisation.

NSW Government Guidelines such the **NSW Coastal Policy (1997)** and the **Coastal Design Guidelines for NSW (2003),** which inform environmentally sensitive planning and urban form in coastal settlements.

Standalone policies and site based plans of management of local governments or public authorities such as DPI Fisheries, Sydney Water, OEH, Property NSW, other foreshore public landowners and private land managers such as ports and airports. Further, Plans of Management are prepared under the *Crown Lands Act 1989* by the Department of Industry – Lands & Forestry and NSW Crown Holiday Parks Trust.

There are also relevant industry guidelines such as Australian Standards for shipbuilding and maritime structures, recommendations for fish friendly and environmentally friendly seawalls, and other marine infrastructure such as fish friendly marinas.

There is considerable reform in relation to coastal management in NSW, including:

- A new ***Biodiversity Conservation Act 2016*** (commencing in 2017), with a new system of clearing thresholds, permits and licenses to manage vegetation clearing. The reforms will include changes to local development consent including a new Biodiversity Assessment Method and offset schemes. As part of this process it will also require integration with other planning instruments that regulate vegetation clearing, such as the **draft *State Environmental Planning Policy (Coastal Management) 2016***.
- ***Coastal Management Act 2016*** (commencing in 2017) - establishes an integrated framework for managing development in the coastal zone, including urban development, coastal protection works, works or activities within coastal wetlands, beaches, headlands, coastal lakes and lagoons, estuarine and coastal waters. **The Coastal Management Manual** will impose mandatory requirements for the preparation of Coastal Management Programs under the Act, with additional step-by-step guidance.

Potential impacts of foreshore development

Water pollution

Foreshore development, particularly in conjunction with hard surfaces and structured drainage, can result in:

- discharge of increased loads of nutrients and suspended solids from run-off and stormwater (diffuse source water pollution)
- larger volumes of run-off, often with increased velocities
- reduced infiltration of rainwater into soils.

Harty and Cheng (2003) note that losses of saltmarshes in Brisbane Water were caused by the encroachment of mangroves, which was driven by land clearing in adjacent catchments, and increased sediment and nutrient inputs via run-off. They also observed areas around the estuary where the landward encroachment of saltmarshes was prevented by artificial modification of the shoreline.

Physical disturbance

Physical disturbances from foreshore development can be direct, such as from the clearing of saltmarsh and mangrove habitats, or indirect, such as shading of seagrass from jetty and pontoon infrastructure.

Changes to foreshores and floodplains can disrupt carbon flow and connectivity (Heatherington and Bishop 2012), and reduce or remove habitat. Intertidal habitats can be lost or significantly altered by foreshore developments involving shoreline hardening, reclamation, localised dredging and increased private and public access.

In the case of shoreline hardening, horizontal soft sediments or natural reef platforms in both the intertidal and subtidal zones are often replaced by vertical, featureless seawalls. This can completely change the available habitats and significantly reduce biodiversity. Such habitat modification, as well as the provisioning of artificial habitat in the form of wharves and pontoons, can assist the spread of non-indigenous species, and fundamentally change and fragment native communities of invertebrates, algae, or fish.

Direct damage to foreshore habitats such as saltmarsh and mangrove has been highlighted as a major threat (Carr 2012, Laegdsgaard et al. 2009).

Replacement or modification of mudflats, vegetation, wetlands, and rocky shore by foreshore development results in the permanent loss or degradation of habitats (Kingsford et al. 2009, Sutherland et al. 2012). In particular, land clearing is considered the most significant threat to species in Australia since European settlement, and is therefore listed as a key threatening process requiring management under the *EPBC Act 1999*. Land clearing and land use intensification affect both migratory and resident marine species by reducing available nesting, foraging, or roosting habitats, and subsequently reducing the health and breeding success of threatened species, including shorebirds and seabirds, turtles, and marine mammals (Department of the Environment 2015, Department of the Environment and Energy 2017, Hawkins et al. 2017). The stability and quality of habitats may also be indirectly degraded by development of near shore areas, through changes in estuarine or coastal hydrogeomorphology, including wave dynamics, river flows, beach deposition, and habitat complexity.

The supply of sediment to coastlines is increasingly disrupted by hydrological modifications in part associated with land reclamation, and urbanization (Defeo et al. 2009). Subsequently, many coastlines and their habitats are experiencing accelerating rates of erosion and retreat (Defeo et al. 2009). Armouring structures, such as intertidal seawalls, designed to protect beaches from this effect may further alter hydrodynamic systems, sand transport, and the erosion-accretion dynamics of beaches, resulting in unplanned environmental impacts on adjacent shorelines and drowned beaches seawards of the structure (Defeo et al. 2009). Subsequently, marine wildlife may be impacted both by reductions in suitable habitat and declining intertidal prey resources (Defeo et al. 2009).

As many marine species have high site fidelity, habitat loss and degradation have significant impacts. Ports and marinas, aquaculture facilities, swamp reclamation, jetties, and armoured beaches can limit marine turtle foraging grounds leading to the displacement of a population, and subsequently reducing stock fitness and reproductive output (Department of the Environment and Energy 2017). For some shorebird species, reductions in nesting, feeding, or roosting sites can increase energy costs as a consequence of increased travel between habitats and competition for remaining space and resources. Foreshore development and estuary stabilisation is listed as a key threat to the recovery of the endangered little terns in NSW, causing habitat destruction both directly, and through the disruption of natural processes, such as estuarine flow and sand deposition, that create new nesting sites (NSW National Parks and Wildlife Service 2003). Additionally, loss of estuarine habitats such as mangroves, saltmarshes, seagrass beds, and intertidal mudflats, as well as changes to estuarine morphology and hydrology, adversely affect estuarine productivity and hence food resources available to the little tern and other shorebirds (NSW National Parks and Wildlife Service 2003).

Along the coast of NSW, direct habitat loss and hydrological change in estuaries leading to the degradation of nesting areas and foraging areas is also a key threat to the critically endangered hooded plover, and endangered pied oystercatcher (Department of Environment, Climate Change and Water 2010, Lane and Harris 2013). Urban and industrial development of the northern coast of NSW, and associated increases in human populations is considered a key threat to the critically endangered beach stone-curlew (Department of Environment, Climate Change & Water 2010). The loss of available wintering, stop-over, and breeding habitats is particularly significant for migratory shorebirds in Australia and the East Asian-Australasian Flyway, disrupting migration routes and compromising their ability to acquire sufficient energy reserves for their migration (Department of the Environment 2015). It is estimated that since European settlement, 50% or more of Australia's wetlands, particularly southern estuaries and coastal wetlands, have been converted to other uses or altered to support urban, industrial, or agricultural development (Lee et al. 2006, Department of the Environment 2015).

Changed habitat structure and reduced food availability associated with foreshore development may also impact the behaviour, life-history processes, and population health of marine mammals (Hawkins et al. 2017). Like shorebirds and turtles, marine mammal populations with high site fidelity or resident populations that occupy localised and highly developed areas, are most vulnerable to the effects of coastal development. Coastal development and associated habitat loss, degradation and auditory or visual disturbance may result in the disruption of critical behaviours and subsequently energy budgets and breeding success, decreased prey availability and competition for resources, and temporary or permanent abandonment of core habitats (Hawkins et al. 2017).

Coastal infrastructure and development may exacerbate or be exacerbated by other environmental stressors, such as water pollution and marine debris associated with run-off, increases in predation and disturbance associated with recreation and vessel traffic, the introduction of pests and diseases, and climate change. Foreshore habitat that has been destabilised or eroded due to extensive coastal development and associated land clearing and alteration of natural flow and deposition regimes may be more vulnerable to the impacts of more extreme weather events and rising sea-levels associated with climate change (Jones et al. 2007, Defeo et al. 2009).

Exposure of Australian marine wildlife to debris, including plastics, and toxic pollutants is more likely to occur near heavily urbanised or industrialised coastlines (Lavery et al. 2008, Leite et al. 2014). Cumulative, interactive, or multi-pathway impacts may have population-level consequences, such as degradation of habitat suitability, lower reproductive success, decreased health, and increased vulnerability to other environmental stressors, resulting in the decline of populations or their stalled recovery over time (Hawkins et al. 2017, Department of the Environment and Energy 2017). Whilst the impact of foreshore development in the central region of NSW is largely historical, monitoring and management actions are still required to mitigate associated cumulative and ongoing impacts.

Wildlife disturbance

Artificial hardening of foreshores affects the types of species that can colonise these areas. Differences also exist between natural hard habitats and artificial hard surfaces, with the latter often colonised by more introduced species than natural habitats (Bulleri and Chapman 2010). Differences also exist between natural hard habitats and artificial hard surfaces, with the latter often colonised by more introduced species than natural habitats (Bulleri and Chapman 2010). Many native species have been reported to be less abundant in artificial foreshore habitats than in adjacent natural areas (Goodsell 2009). As such artificial shores within estuaries provide a good indication of the spatial distribution of some of the ecological threats to foreshore habitats and potentially seagrasses (Astles et al. 2010).

Foreshore development often increases access to estuarine areas, leading to increased wildlife disturbance. Wildlife disturbance from increased human presence is described in 6.1.9.

Marine debris

Foreshore development brings people in close proximity to the coastal environment, and increases the likelihood of litter and other debris entering waterways. See previous section on Marine debris under urban stormwater: potential impacts for more information.

Pests and diseases

As noted above, artificial surfaces can facilitate the attachment and expansion of introduced species.

Changes to tidal flow patterns

Tidal restriction and changes to flow patterns are a significant threat to saltmarsh and mangroves (Carr 2012, Laegdsgaard et al. 2009) (see Section *6.2.3. Changes to flow can also disrupt carbon flow and connectivity* (Heatherington and Bishop 2012) and remove habitat.

Beach nourishment and grooming

Beach grooming is the practice of mechanically scraping the surface of beaches to remove natural and artificial objects, primarily for aesthetic purposes. It is very common on estuarine beaches in Sydney Harbour, Botany Bay, Pittwater, Tuggerah Lakes, and Lake Macquarie, but rare on estuarine beaches outside the central region. The exception is in the Port Stephens estuary, with Jimmys Beach and Shoal Bay being the most active areas.

Beach nourishment is the placement of sand on a beach. In NSW, it mainly occurs at sites where erosion is threatening infrastructure.

Beach nourishment and grooming can improve amenity and increase social value, but can harm natural systems. Sea level rise and other changes to wave climate can result in changes in the structure and location of ocean and estuarine beaches. If the location of beaches is fixed or defined by infrastructure or development, nourishment programs are increasingly likely to be used to mitigate erosion (Peterson and Bishop 2005).

Potential impacts of beach nourishment and grooming

Physical disturbance

Beach nourishment has the potential to smother shallow reefs and affect other habitats through processes such as changes to slope and grain size. In turn, this can reduce densities of invertebrates, with potential flow-on effects for shorebirds, surf fishes and crabs (Peterson and Bishop 2005). Despite nourishment being common, few examples of well-designed monitoring are available to assess efficacy or biological impact (Cooke et al. 2012).

Grooming disturbs the sediment structure, destroys the entrances to burrows and removes all macro-organic detritus from the beach (James 2000, Noriega 2007). Beaches are generally poorly supplied by organic material, and many beach ecosystems rely on the supply and in-situ decomposition of organic material, such as wrack (decomposing marine plant material e.g. seaweed, seagrass). Despite this, there is little published material on the effects of cleaning, with the exception of a single study on ghost crabs (Stelling-Wood et al. 2016). They found some small, inconsistent effects of beach grooming on the abundance of ghost crab burrows.

Though one of the goals of beach nourishment is to restore eroded beach habitat, there is evidence of short- to medium-term negative impacts occurring on several beach ecosystem components, at population, community, and ecosystem levels (Defeo et al. 2009). These occur at the 'borrow site' (where sediment is taken from), 'target site', and adjacent beaches indirectly impacted through longshore and Aeolian sediment transport (Speybroeck et al. 2006). During nourishment, nesting and foraging resident and migratory shorebirds can be disturbed, and ground nests damaged (Speybroeck et al. 2006). However, it has been suggested that changes in beach sediment such as the introduction of stones, pebbles, or shells may create favourable nesting conditions (Speybroeck et al. 2006).

In addition to physical disturbance, shorebirds and waders may also be indirectly affected by upward trophic impacts from poorly designed beach nourishment, as sand compaction, burial, and changes in geomorphology or sediment characteristics can reduce intertidal prey availability for up to 6 months, post-nourishment (Peterson et al. 2006, Speybroeck et al. 2006). Peterson et al. (2006) found that declines in macroinvertebrate populations directly attributable to beach filling using coarser sediments than the natural sand resulted in a 70 – 90% temporary decline of beach use by shorebirds in North Carolina. Direct mortality of organisms when buried, or the indirect reduction of prey availability for shorebirds, may result in the temporary or permanent emigration of marine wildlife from habitats where nourishment has occurred (Defeo et al. 2009). Conversely, beach grooming may disturb resident wildlife and cause direct damage to eggs and hatchlings of nesting turtles and shorebirds, such that many groomed beaches no longer support breeding populations (Defeo et al. 2009).

By removing wrack from the beach, dependent macroinvertebrate populations may decline, resulting in reduced prey availability to shorebirds (Defeo et al. 2009). There is little evidence available on long-term or cumulative ecological effects of beach nourishment and grooming, though reviews from both Australia and the USA note that the degree and speed of ecological recovery depends on physical beach habitat characteristics and the nourishment strategy applied, particularly if the replacement sediments fail to match the original (Defeo et al. 2009, Jones et al. 2007, Speybroeck et al. 2006). A 2012 study found that, in Australia, little monitoring of the biological impact of beach nourishment occurs (Cooke et al. 2012).

Clearing riparian and adjacent habitat, including wetland drainage

In their natural, undisturbed condition, estuaries are fringed by native vegetation, and generally associated with a variety of connected wetlands, depending on the estuary type. Open tide and wave-dominated estuaries have relatively large, tidally inundated mangroves and saltmarsh in lower to mid reaches, with freshwater-dominated floodplain forests, swamp and lagoons further upstream. Intermittent lagoons are usually associated with extensive saltmarsh and floodplain forests, which are only inundated as the lagoons fill with freshwater to their highest levels prior to opening. The remaining flood-inundated saltmarshes around intermittent lagoons are now recognised as important habitat for the vulnerable shrub species *Wilsonia backhousei* (OEH unpubl data).

Rural, urban and industrial development in estuarine areas has damaged mangrove, seagrass, saltmarsh and coastal lagoon communities through land clearance, agriculture, dredging, reclamation, drainage and waterfront development. In upper estuarine zones, development has removed vegetation from river banks, wetlands, and floodplains; increased sediment, nutrient and pollutant loads into streams; and removed organic matter and snags (large woody debris) from rivers (Figure 51).

Many estuarine species rely on adjacent wetlands for food or shelter, or to complete their life cycle. Floodplains and wetlands in freshwater and estuarine areas provide essential nursery habitat for large amounts of fish and invertebrate species, many of which are commercially and recreationally significant.

The plants growing on the water's edge, banks of rivers and creeks and along the edges of wetlands are referred to as riparian vegetation. This can include trees, shrubs, grasses and vines in a complex structure of groundcovers, understorey, and canopy. Riparian vegetation is important for habitat connectivity (Heatherington and Bishop 2012), bank stabilisation and reinforcement, temperature regulation of the adjacent waterway, organic matter input from overhanging vegetation (leaves, branches, fallen timber, insects), and filtration of sediments and nutrients in run-off waters. It is threatened by direct removal during agricultural activities such as cropping right to the water’s edge or by allowing livestock to graze within the riparian zone and access waterways. Loss of riparian vegetation can result in bank erosion which has implications for sedimentation and receiving-water turbidity, reducing habitat for fish and other aquatic species, and increasing temperature and light levels in nearshore environments.

Figure 51. Example of wetland drainage.

Riparian vegetation degradation along NSW watercourses has been listed as a key threatening process in the FMA because of its negative effects on many threatened species, populations and ecological communities.

The level of loss of habitat in the catchments of estuaries is greatest in cleared catchments (Table 29). The **central region** has the greatest proportion of catchments with >50% cleared (63% of catchments), and only 17% of catchments with less than 25% clearing. The **northern region** has next highest degree of clearing, while the **southern region** has a low level of clearing, with 61% of catchments having less than 25% clearing and 36% having less than 10% cleared. While clearing of habitat on Crown lands is regulated, substantial clearing of adjacent habitat still occurs on private lands, especially in rural areas.

Table 29. Percentage of estuary catchments in catchment clearing classes in New South Wales.

Per cent catchment cleared	North	Central	South
>75	7	28	9
50–75	27	35	10
25–50	35	20	19
10–25	15	12	25
<10	16	5	36

Potential impacts of clearing riparian and adjacent habitat

Wetland drainage and coastal floodplain loss

The development of rural settlements and agriculture on many of Australia's coastal floodplains involved the construction of an extensive network of drains. These were used to reduce the impacts of major floods, convert swampy land into agricultural land, and remove stormwater from agricultural land (Johnston et al. 2003). Natural channels and tidal creeks were straightened and converted to drains, while elsewhere new drains were excavated. Floodplain drainage systems allowed agriculture to diversify, improved production, increased land access and reduced health risks for both stock and humans (Johnston et al. 2003).

Floodgates are top-hinged structures that open seaward on the ebb tide, and shut against a culvert on a flooding tide. They were installed for flood mitigation and are a predominant form of tidal restriction in coastal wetlands of south-eastern Australia (Boys et al. 2012).

Floodgates play a significant role in preventing saline tidal water from inundating low-lying agricultural land, and preventing river rises from backflooding urban and rural areas. However, they have many direct and indirect impacts on water quality and the environment, (Johnston et al. 2003, Walsh and Copeland 2004, Boys and Pease 2016), including:

- fragmentation and loss of fish habitat
- wetland loss and reduced birdlife
- nutrient accumulation
- reduced numbers of juvenile fish and disrupted prawn migration (specifically, Kroon (2005)) (see section below on water pollution)
- reduced fish passage and recruitment of juvenile fish behind floodgates
- increased incidence of redspot disease in fish and other sublethal effects on fish and oysters
- increased fish kills from acid or deoxygenation (see section below on water pollution)
- increased export of acid and toxic metals from acid sulfate soils
- enhanced blackwater impacts and rapid transport to the estuary
- increased acid discharge as a result of drain pumping in high-permeability acid sulfate soils
- increased monosulfidic black ooze (MBO) formation in drains and transport to estuary
- more fires in back-swamps leading to loss of organic topsoil and scalding.

In coastal NSW, 603 floodgates have been identified as barriers to fish passage. Of these, 54 have been remediated, thereby opening 123 km of waterway to fish passage and improving approximately 1,694 ha of key habitat. A substantial amount of estuarine wetlands in northern NSW , approximately 62,000 ha equating to a loss of approximately 72% of prime fish habitat, has been impacted by drainage of the coastal floodplain, mostly associated with flood mitigation works between the mid-1950s and early 1970s (Rogers et al. 2016).

This widespread impact on prime fish habitat and a reduction in estuary health is no more starkly apparent than in the NSW prawn and scale fish fisheries. For example, School Prawn and Eastern King Prawn catches in NSW are considered fully exploited or overfished respectively at only 75% of the catch rates that were maintained historically during the 1970s and 1980s. Some rivers now only support recreational catches (e.g. Shoalhaven River). Some of this decline could be attributed to fisheries management changes introduced to ensure long-term sustainability (Creighton 2013). However broad and consistent trends for most species in wild fisheries indicate other underlying factors, specifically limitations to recruitment due to reductions in water quality and loss of habitat, for example Taylor et al. (2017) highlighted Eastern King Prawns require good connectivity between marsh habitat in the lower estuary with oceanic water. Much of the water quality decline, especially pH, heavy metals and anoxic or low dissolved oxygen conditions is due to the draining of floodplain wetlands (Creighton 2013).

Significant reductions in priority wetland habitats in eastern Australia have also been attributed to water extraction (e.g. coastal Lake Denison/Jack Smith Lake and the Coorong (1982 – 2006; Nebel et al. 2008). Concurrently, resident and migratory shorebird populations have declined by 81% and 73%, respectively (Nebel et al. 2008). Wetland drainage for agriculture and flood control has been identified as a key threatening process to estuarine habitats in the Clarence Lowlands bioregion of NSW, reducing water availability, exposing acid sulfate soils, affecting the regeneration of wetland vegetation, and limiting or isolating habitat for native fauna (Department of Environment and Climate Change NSW 2008). Many of the estuarine environments in this region provide important nesting, foraging, and roosting habitat for a number of threatened and migratory shorebirds and seabirds, including the white-bellied sea-eagle, greater- and lesser sand-plovers, sooty- and pied oystercatchers, and little tern, among others (Department of Environment and Climate Change NSW 2008).

Wildlife disturbance

Wildlife disturbance occurs via habitat loss and pollution, as detailed below.

Physical damage

The conversion of mangroves for development and agricultural purposes has been identified as an ongoing threat to migratory shorebird populations, as they provide foraging and sheltering habitat during stop-overs (Sutherland et al. 2012). Removal of mangroves may also detrimentally impact the food quantity and quality available to shorebirds such as the little tern, and other species, including juvenile and adult green turtles (NSW National Parks and Wildlife Service 2003, Lee et al. 2006, Brodie et al. 2014, Department of the Environment and Energy 2017). Additionally, vegetation clearing in estuarine environments may expose wildlife in these areas to other stressors, by increasing accessibility to humans, vehicles, domesticated animals, and pests. See section 6.2.1 for further details.

Pests and disease

A major cause of degradation is the introduction of introduced species. In some areas, the only riparian vegetation present is made up of introduced species, such as willow, camphor laurel, privet, lantana and a host of other weed species.

Non-native plants are a poor substitute for native plants because:

- Introduced vegetation reduces the diversity of native invertebrate communities (e.g. insects), which are important food sources for fish.

Native fish are adapted to the continuous leaf fall provided by native plants however many introduced trees drop all of their leaves in autumn, thus altering the timing and quality of organic debris entering the waterway. Some introduced species, such as willows, have a tendency to grow out into the bed of the waterway, grossly affecting channel integrity and structure. The willows tight root systems form obstructions and can divert water into banks, causing erosion. Water pollution

Wetland habitats provide a biological filter for run-off. Intact riparian and catchment habitat protect soils from erosion, and therefore reduce inputs of sediments and nutrients to waterways. They also act as filters, slowing overland flow to reduce sediment loads. The high levels of clearing and habitat loss detailed above lead to large amounts of nutrient and sediment in waterways, as shown in Figure 45 and Figure 48.

Sedimentation

The removal of sediment-binding vegetation has severe consequences for estuaries and the coastal zone. On the east coast of Australia increased soil erosion and sediment delivery following extensive land clearing in the contributing catchments, associated with European settlement, is highlighted as a key driver of the decline of numerous nearshore habitats including seagrass meadows and in-shore coral reef (Coates-Marnane et al. 2016). Recent studies in Moreton Bay, QLD have indicated that the sediment environment of the Bay has undergone a dramatic change with muddy sediments now covering an estimated area of over 860 km^2, more than double the area found in 1970. Mud is now the dominant sediment type (Lockington et al. 2017). Further, modern turbidity regimes in the study area are the result of the compounded effect of both a historical increase in fine sediment supply and a rapid decline in the effective storage capacity of the basin (Coates-Marnane et al. 2016).

Acid run-off

The main source of this diffuse source pollutant is acid sulfate soils. In their natural state, these soils are submerged. However, the artificial draining of floodplains and wetlands results in permanently saturated soils becoming exposed to the atmosphere. As a result, they become oxidised and produce sulfuric acid. The acid in turn mobilises iron, aluminium and other metals present in the soil, which leach into ground water and adjacent drains. Exported iron can oxidise again in waters that are considerable distances away from the source, producing iron oxyhydroxide or hydroxide flocs (iron floc) that coat benthic communities and stream banks.

The majority of coastal catchments (~76%) have a high probability of occurrence of acid sulfate soils within the immediate vicinity of estuarine waters (Figure 52). The impacts of acid sulfate soils have been observed many times in NSW estuarine waters (e.g. Hyne and Wilson 1997, Corfield 2000, Dove and Sammut 2007a; b, Amaral et al. 2011, Amaral et al. 2012, Nath et al. 2013).

The acid produced by oxidation of iron sulfides affects both soil and water, and can severely damage the environment. Short-term effects include fish kills and disease, mass death of microscopic organisms, increased light penetration due to water clarity, loss of acid-sensitive crustaceans and destruction of fish eggs. Long-term effects include loss of fish habitat, persistent iron coatings, alterations to waterplant communities, invasion by acid-tolerant waterplants, reduced spawning success due to stress, chemical migration barriers, reduced food resources, growth abnormalities, damaged and undeveloped eggs, reduced recruitment, reduced growth rates, higher water temperatures due to increased light penetration and increased predation.

Fish kills affect many ages of fish, and the loss of larvae and juveniles can be a regular occurrence. Some 70% of commercial fish species spend part of their life cycles in estuaries. The impacts of acidic water therefore raise major concerns for the future of commercial and recreational fishing industries (see: Samut et al. (1995), Callinan et al. (1993), and Samut and Lines-Kelly (1996) for further acidification impacts on fish including mortality and disease).

Early life history stages of estuarine fish are considerably affected by acidified water from acid sulfate soil leachate. For example, significant mortality of embryos and yolk-sac larvae of Australian Bass has been observed if they are exposed to acid-sulfate soil leachate that results in a pH in the receiving estuarine water below 5.5, or when pH is below 6.8 and aluminium is present at a total concentration of 800ug/L (Hyne and Wilson 1997).

Juveniles of three commercial fish species and one commercial prawn species have been shown to avoid acidified water, indicating that the acidic component of acid sulphate run-off alone has the potential to affect migration of these species in the field (Kroon 2005).

Oysters (Dove and Sammut 2007a; b, NSW DPI 2007c) and other bivalve molluscs (Bamber 1990) can be severely impacted from direct exposure to ASS outflows including increased mortality, reduced growth, shell gaping and dissolution, suppressed feeding activity and soft tissue damage.

Blackwater

Hypoxic blackwater is characterised by high levels of dissolved organic carbon in the water column. The metabolism of the carbon depletes dissolved oxygen, which can kill fish and crustaceans (Whitworth et al. 2012). Blackwater has occurred numerous times in river estuaries, such as the Richmond, Macleay and Hunter.

The development of floodplain drainage infrastructure has increased the chances of blackwater production and accelerated delivery to estuaries. Before flood mitigation attempts, post-flood deoxygenation processes would have occurred mainly on the fringes of the backswamps, where the plants less tolerant to inundation would have been located. The blackwater produced would then have been diluted by those existing reserves of water in the deeper parts of the wetland.

The drainage of wetlands has increased the prevalence and abundance of flood-intolerant pasture species. The inundation of these species and subsequent accelerated decomposition following large, summer floods strips the water of oxygen (Eyre et al. 2006, Walsh et al. 2004, Whitworth et al. 2012, Wong et al. 2010). The extensive drainage networks increase the volume of acidified and deoxygenated water and the speed at which they travel from floodplains to streams (Johnston et al. 2003). Mass fish kills and poor water quality are dramatic and well documented effects of floodgate and drain management of floodplains particularly in northern NSW, following intensive rain and high flush events (Heath and Winberg 2010). In these northern estuaries, key sources of low oxygen to the system were all areas that were formerly important fish habitats. All these wetlands have been extensively drained and floodgated (Walsh et al. 2004).

Fish are not the only species affected by an anoxic acidic flood event, mobile organisms, if access is available, leave the affected area whereas sessile species die (Nielson and Jernakoff 1996) resulting in marked declines in the biomass of benthic invertebrates (Nixon 1998). For example, research on the Clarence River, New South Wales just after the 2013 anoxic acidic flood event showed that there were no benthos – polychaetes, bivalves or whatever – alive in the sediments from Grafton, just below the tidal limit through to the ocean (Ryder and Mika 2013). This profound loss of organisms prolongs the impact of the event, defaunted areas tend to be recolonised by a less diverse range of opportunistic species tolerant of low oxygen conditions or those better at first exploiting open species left after all the original animals have died or migrated (e.g. small polychaete worms, nematodes, and clams) (Nielson and Jerkanoff 1996). Further, these significant changes to the functional diversity of macrofauna communities are likely to have an effect on nutrient cycling within the benthic sediments (Banks 2011).

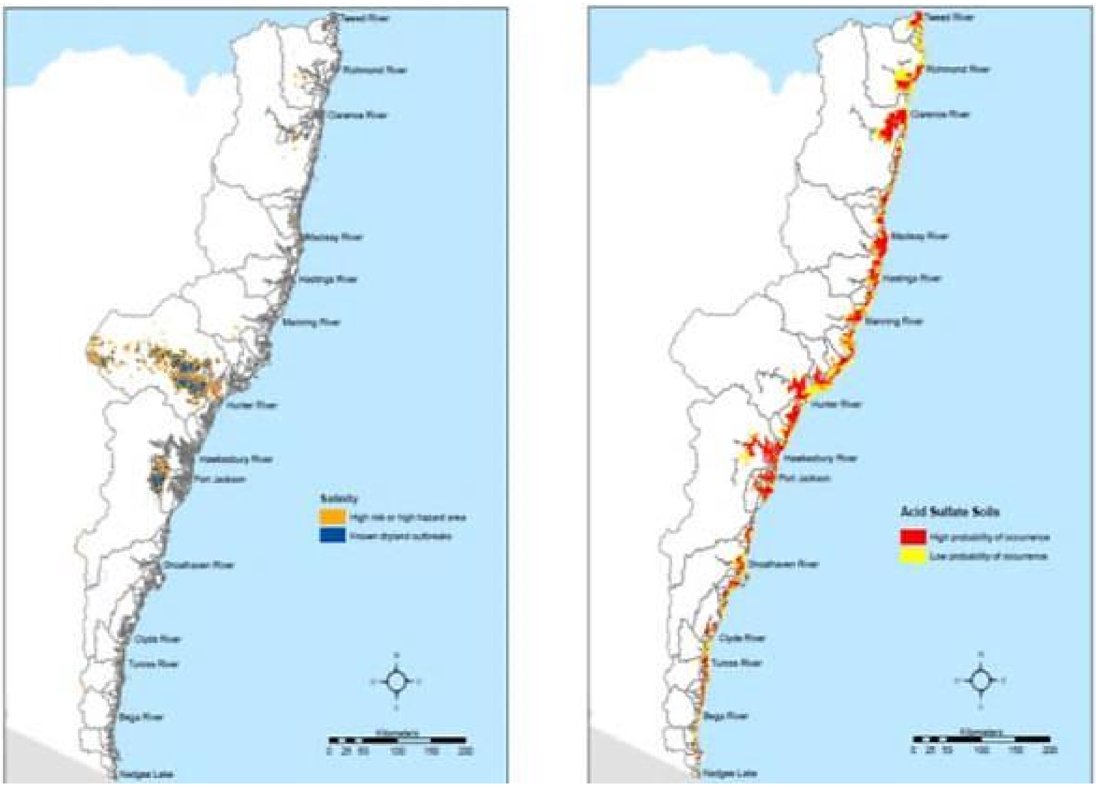


Figure 52. Potential acid sulfate soils risk areas in New South Wales.

Stock grazing of riparian and marine vegetation

Stock grazing on riverbanks removes vegetation, increases nutrients and compacts and disturbs soil, making plant germination and survival difficult and increasing bank erosion and water turbidity.

The *FMA* and FMA Regulations set out provisions to protect marine vegetation (such as saltmarshes, mangroves) from harm on public water land below the astronomical high-tide mark or the foreshore of such land. A permit is required to harm marine vegetation in these areas. Under the Fisheries Management (General) Regulation 2010 it is illegal for livestock of any type to graze and trample marine vegetation (including saltmarsh and mangroves) on public water land (e.g. Crown land or local government land). This does not apply to private land. Coastal saltmarsh is also listed as an endangered ecological community under Part 3, Schedule 1 of the TSCA 1995 (NSW).

Saltmarsh and mangroves provide habitat and shelter for fish, especially juveniles and smaller fish species. Where saltmarsh and mangroves occur on private foreshore land, they are often used as pasture and a natural source of salt-lick for livestock.

Potential impacts of stock grazing on riparian and marine vegetation

Grazing has significant impacts on saltmarsh and mangrove plant communities as a result of physical disturbance. It can change the distribution of some saltmarsh species, as they may be more palatable and grazed more heavily than others. In areas where grazing and trampling are high, saltmarsh plants are unable to regenerate or re-establish. Hoofed animals disrupt the dense vegetation and root system, often destroying delicate succulent chenopods, such as *Sarcocornia* spp. and *Suaeda* spp., and allowing tidal water to pool. Such pools form habitat for biting insects, such as mosquitoes and midges, or other plant species (e.g. *Triglochin striata*), which are more tolerant of waterlogging and lower salinity (Zedler et al. 1995).

Trampling also introduces gaps in which weeds can establish (Bridgewater 1982), affecting the dynamics of saltmarsh communities. Saltmarsh plants cannot compete with pasture species, and therefore their expansion is limited by competition (Genders 1996) in these altered environments. Ongoing trampling of saltmarsh by stock and feral animals also disrupts saltmarsh by creating gaps in dense areas of vegetation, killing plants, especially succulent species, and preventing them from regenerating or re-establishing. Stock trampling can destroy plant root systems and compact the soil, severely impacting on the habitat value of saltmarsh areas.

Agricultural diffuse source run-off

Agricultural activities can range from broadscale, low-intensity grazing to high-intensity market gardening, horticulture, and feed lotting. The level of agricultural activity in the catchments of estuaries is greatest on the north and south coasts, where the majority of catchment clearing is for agriculture (Figure 43). Nutrient exports from rural catchments on the north coast tend to be greater than south coast.

The degree of impact from agriculture is mostly proportional to the level of intensity. This includes ground disturbance, ground cover, addition of fertilisers and pest control chemicals, and production of liquid effluents. Agricultural clearing also removes natural vegetation, particularly along freshwater drainage lines.

Diffuse source run-off from agricultural lands enters the marine estate directly or via freshwater creeks and rivers. This source of water pollution is a key stressor on the quality of estuarine waters in NSW. In some areas, diffuse source pollution from agricultural lands can be the largest source of pollution to an estuary[44].

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[44] www.environment.nsw.gov.au/water/dswpoll.htm

Potential impacts of agricultural diffuse source run-off

Water pollution: nutrients

The large rivers deliver the greatest loads of nutrients to NSW estuaries (Figure 43). This is more a function of their size rather than a high generation rate, with the exception of some river valleys in northern NSW, which have intensive cropping close to riverbanks.

A summary of the concentrations of diffuse pollutants in run-off from different agricultural land use types is available in Fletcher et al. (2004). This work was undertaken more than 10 years ago for the Stormwater Trust Program[45], and is still widely used to estimate diffuse pollutant loads for new developments in NSW. There are only a few contemporary measurements of pollutant concentrations or loads from land use activities in NSW (e.g. Haine et al. 2011). These measurements show that concentrations or loads are relatively greater than previously reported in Fletcher et al. (2004), indicating that some land use activities have intensified.

Excessive nutrients entering estuaries can also lead to the overabundance of algae that can smother and kill underlying vegetation in estuaries over time. Due to the diffuse nature of the inputs the impacts can occur over a wide range of habitats in estuaries, including saltmarsh, beaches and mudflats, shallow soft sediments, mangroves and seagrass.

The introduction of pollutants into the marine environment via agricultural run-off can detrimentally impact marine wildlife. Turtles, for instance, are particularly vulnerable to sustained environmental stress caused by anthropogenic pollution, given their long life spans, benthic feeding habits, and near shore proximity (Lutcavage et al. 1997, Aguirre and Lutz 2004). Deteriorating turtle health and disease prevalence has been associated with water quality degradation due to agricultural run-off and its associated contaminants (Aguirre and Lutz 2004, Arthur et al. 2006, dos Santos et al. 2010, Van Houtan et al. 2010, Brodie et al. 2014).

These contaminants, including metals, organochlorine pesticides, elevated nutrients, sediment, and algal toxins – have been identified as a possible threat to the health of green turtles in the estuarine environments of Queensland (Brodie et al. 2014). Among green turtle populations in Queensland there is an increasing prevalence of fibropapillomatosis, a herpesvirus-associated disease which causes cutaneous tumours on external and internal soft tissue, including the underside of flippers and tail, eyes, and internal organs (Brodie et al. 2014). Tumours may obstruct movement, respiration, vision, and food consumption, impeding turtle survival. In addition to immunosuppressive factors, fibropapillomatosis occurrence has been associated with changes in algal community composition – specifically, a decline in diversity – resulting from agricultural run-off and subsequent influxes of nutrients to the marine environment.

Outbreaks of the disease among green turtle populations in Hawaii have been found to be clustered in areas of high anthropogenic impact, where widespread invasive algal blooms and high nitrogen-footprints occur (Van Houtan et al. 2010). In eutrophic conditions, algal species out-compete seagrass and subsequently become the dominant component of the diet of green turtles. In addition to restricting nutrient uptake by turtles, algal blooms sequester anthropogenic nitrogen as the amino acid arginine, which is known to promote and regulate herpesviruses and tumour development (Van Houtan et al. 2010). As such, the consumption of algal blooms associated with run-off and increased nutrient loads has been proposed as a factor in the increased incidence of fibropapillomatosis among marine turtles in Brazil (dos Santos et al. 2010, dos Santos et al. 2011). However, data regarding the impact of agricultural run-off, eutrophication, and algal blooms on the health of marine turtles in NSW are limited.

Nutrient pollution in marine environments associated with agricultural run-off may result in the rapid growth of harmful microalgae, otherwise limited by the availability of nitrates and phosphates (Ajani et al. 2001, Heisler et al. 2008). These harmful algal blooms can cause hypoxia in the marine environment, or produce potent neurotoxins. In Australia, and globally, the frequency, intensity, and distribution of harmful algal blooms in both estuarine and coastal environments have increased (Ajani et al. 2001, Fire and Van Dolah 2012, Hallegraeff 1992, Heisler et al. 2008).

[45] www.environment.nsw.gov.au/stormwater/usp/

In NSW, whilst the occurrence of toxic or potentially toxic algal blooms in estuarine and coastal environments has been recorded (Ajani et al. 2001), there are limited examples of the impacts of such blooms and their toxic metabolites on higher order marine wildlife in the state, with data predominantly concerning effects on marine fish, invertebrates, and humans. Nevertheless, in recent decades, research has correlated marine mammal morbidity and mortality with the occurrence of harmful algal blooms, with exposure to algal toxins occurring through food-web transfer or respiration (Bossart 2011, Fire and Van Dolah 2012). For instance, in the USA, brevetoxins and saxitoxins produced by dinoflagellates such as *Karenia brevis* – blooms of which are known as ‘red tides’ - and domoic acid produced by certain diatoms have been found to accumulate in fish, invertebrates and seagrass, resulting in the death of wildlife at higher trophic levels, including humpback whales, bottlenose dolphins, sea lions, and Florida manatees (Geraci et al. 1989, Flewelling et al. 2005, Fire and Van Dolah 2012). Seabirds and shorebirds are also affected by the harmful algal blooms and their toxins. Domoic acid has been associated with mass mortalities of cormorants, pelicans, and ducks, while the spread of algal coverage by eutrophication in intertidal areas may restrict foraging habitat (Fire and Van Dolah 2012, Sutherland et al. 2012). Further, lyngbyatoxin, has been implicated as a co-factor in the promotion of fibropapollomatosis in green turtle populations in Moreton Bay, Queensland (Arthur et al. 2006, Arthur et al. 2008).

See also information on trends in condition provided for stormwater pollution in Section 6.2.1.

Water pollution: sediments

Sediments in run-off contribute to sedimentation and turbidity in estuarine waters. This has implications for a wide variety of plants and animals in these waters. Fine sediment discharge in the Great Barrier Reef has been identified as one of the greatest water quality risks to the reef, reducing the light available to seagrass ecosystems and inshore coral reefs (State of QLD 2013). Turbidity leading to a reduction in light levels within the water column is widely recognised as a primary cause of seagrass loss in Australia (Carruthers et al. 2002, Waycott et al. 2005) and overseas (Green and Short 2003, Shepherd et al. 1989).

Estimates of sediment exports are available for all coastal catchments in NSW (Figure 48). Recent monitoring of water clarity (turbidity) across the state shows that 85% of estuaries sampled between 2007 and 2014 have very good to fair water clarity. Those with poor to very poor water clarity are typically rivers with large upland catchments.

Sediments and nutrients from agricultural catchments can be exported directly to marine waters from coastal catchments during high rainfall and floods (e.g. Eyre 2000, Eyre and Ferguson 2006). It is likely that the greatest exports will be adjacent to the larger river systems that have modified catchments. Harty and Cheng (2003) note that losses of saltmarshes in Brisbane Water were caused by the encroachment of mangroves, which was driven by land clearing in adjacent catchments, and increased sediment and nutrient inputs via run-off.

Upper and middle reaches of estuaries are particularly susceptible to turbidity, because suspended sediments in freshwater flocculate and fall out when they mix with saline water. These sediments are easily resuspended by waves or currents, and can contribute to chronic turbidity.

Increased sedimentation and associated substrate disturbance can also affect wildlife. Land run-off has been identified as a cause of habitat degradation and a threat to Australian sea lions, which are principally benthic feeders (Shaughnessy 2009). Further, changes in sediment flow to intertidal regions and wetlands has been identified as a future threat to migratory shorebird populations globally (Sutherland et al. 2012). Large sediment influxes from heavy rain or flooding events into the marine environment may result in the loss of seagrass habitat due to light limitation, resulting in starvation, and decreases in turtle health and breeding conditions (Department of the Environment and Energy 2017).

Water pollution: toxicants

Work in the Great Barrier Reef lagoon has identified the risk of pesticides to freshwater and some inshore and coastal habitats and indicated potentially harmful concentrations of agricultural chemicals in the offshore waters (GBR Reef Plan 2013). These chemicals are mostly associated with sugarcane farming. There are no data on chemicals in run-off from NSW catchments, but there are substantial areas of cane farming in northern NSW.

Over the past 20 years, artificial chemicals and substances such as pesticides are suspected of causing about 8% of fish kills in NSW. For further details see:

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/634570/Fish-Kills-FAQ-August-2011.pdf.

However, fish kills are not the only result of exposure to toxic substances. Fish populations can display the effects of exposure through reduced viability of sperm, eggs and larvae; increased incidence of abnormalities; and reduced life expectancy. Pesticides can also cause skeletal defects and reduce fish growth when eggs are exposed to certain levels. Herbicides entering estuarine waters can reduce growth of seagrass, saltmarsh, mangroves, and micro and macroalgae (McMahon et al. 2005).

There is little NSW data on aqueous concentrations of agricultural chemicals. A pilot study of sediments offshore of the Clarence River immediately after a flood did not detect any agricultural chemicals (OEH unpubl data), but detection limits were relatively high. Sampling of sediments offshore of the Hunter River also did not detect any agricultural chemicals in sediments.

Toxic contaminants introduced into estuarine habitats through agricultural run-off may adversely impact marine wildlife via trophic interactions. Herbicides, for instance, reducing marine flora may result in habitat degradation and a reduction in food availability. Additionally, persistent contaminants resistant to natural breakdown or metabolism may accumulate in the tissue of wildlife over an individual's lifetime and at higher trophic levels. The inshore waters of NSW provide habitat for Indo-Pacific bottlenose dolphin populations. These dolphins may be particularly vulnerable to the bioaccumulation of such toxins, given their high site fidelity, long life span, high trophic level, and – like other cetaceans and marine mammals – large fat repositories within which anthropogenic contaminants may be stored (Bossart 2011).

Bioaccumulation of persistent organohalogen compounds (POCs) in the fat stores of cetaceans has been variously linked to infectious disease susceptibility, immunosuppression, reproductive impairment, endocrine disruption, and neoplasia, disrupting multiple biological systems when mobilised (Bossart 2011). These compounds may include 'legacy' chemicals such as organochlorine pesticides (e.g. dichlorodiphenyltrichloroethane, DDT), which are no longer used but residues of which persist in agricultural soils. DDT and hexachlorobenzene, a banned fungicide, has been identified among other POCs in Indo-Pacific humpback and Australian snubfin dolphins from the Mackay-Whitsundays and Fitzroy River catchments, likely a result of run-off from agriculture and associated land modification in the region (Cagnazzi et al. 2013). DDT and other POCs were also found to be present in the blubber of bottlenose dolphins, dugongs, and the adipose tissue of a green turtle in Northeast Queensland (Vetter et al. 2001).

Run-off in the Upstart Bay catchment area, which mobilised contaminants such as pesticides and metals from an agricultural area of high sugarcane production after a period of heavy rainfall, was implicated in the localised mass stranding of 102 large green turtles in 2012. Mercury, present in some fungicides, and cadmium, from superphosphate fertilisers, were present in tissue samples collected from the stranded turtles at higher concentrations than found in other green turtle populations globally (Brodie et al. 2014). Prompted by this mass stranding event, the World Wildlife Fund (WWF) initiated a study into the effects of increased pollutant load associated with agricultural run-off on the survivorship of green turtles in the Great Barrier Reef. While further investigation is in progress, initial findings indicate that elevated levels of copper, antimony, and manganese in turtles sampled from Upstart Bay relative to a control population, are correlated with clinical markers of inflammatory response and liver dysfunction (WWF 2016). Trace element exposure may therefore be affecting sea turtle health directly or indirectly. Preliminary comparisons of forage between Upstart Bay and a control site indicate enriched copper concentrations in the former, suggesting that contaminants may be trophically transferred (WWF 2016). Further, elevated dioxin concentrations were also identified in blood sampled from turtles in the region at levels that are associated with increased risks for chronic biochemical and immunological effects (WWF 2016).

Seabirds and shorebirds, particularly long-lived species, are also exposed to the accumulation and toxic effects of chlorinated hydrocarbons and metals, via inhalation, external contact, or biomagnification (Burger and Gochfeld 2002). Organochlorine insecticides and dioxins can accumulate and persist at high concentrations in predatory seabirds, particularly those that feed near industrialised or agricultural areas (Burger and Gochfeld 2002). Effects on egg-shell formation, the nervous system, development, and behaviour and subsequent declines in seabird populations are well documented, the most well-known example being DDT-induced egg-shell thinning in brown and white pelicans, northern gannets, double-crested cormorants, petrels, and other seabirds (Burger and Gochfeld 2002).

Water pollution: salts

Salt is only an issue for tidal freshwater reaches in riverine and drowned river valley estuaries, and includes the salinisation of underlying groundwater. It is not specifically identified here as a key stressor that affects the environmental assets of the NSW marine estate. The main determinants of soil salinity and dryland salinity are geology, landscape, soil, land use and climate. Salinity problems are greatest in drier environments, where rates of evaporation are usually very high. Threats also arise from the use of poor-quality irrigation water with high levels of salt. While salinity is a significant problem in inland catchments, salinity outbreaks have already occurred in freshwater reaches of several coastal catchments, and salinity is a potential hazard in fresh waters. These include the large barrier rivers or drowned valleys: Tweed, Brunswick, Richmond, Clarence, Nambucca, Manning, Hunter, Hawkesbury, Parramatta, Georges, Shoalhaven, Moruya and Tuross rivers.

Groundwater pollution

There is a growing understanding that some intermittent estuaries may be strongly dependent on groundwater, and therefore very susceptible to groundwater pollution. At present, little agriculture is undertaken in the catchments of potentially susceptible estuaries within the marine estate.

Deliberate introduction of animals and plants

The introduction of animals and plants into areas outside of their natural range can be either inadvertent or deliberate. The effects of species with self-sustaining populations from either method can be devastating to local ecological communities. The deliberate introduction of plants and animals are those introduced to improve conditions for some human activity, e.g. improve prospects for agricultural prosperity (domesticated animals and plants), hunting or fishing (e.g. foxes), forestry, to improve aesthetics (pets and garden plants), land management initiatives (e.g. bitou bush used for sand dune stabilization). Animals and plants introduced inadvertently to NSW are discussed elsewhere in the report and referred to as pests and diseases.

Since 1788, approximately 3000 introduced plant species have established self-sustaining populations in Australia; more than 1,750 of these have been recorded in NSW (EPA 2015). More than 650 species of land based animals have been introduced to Australia, with 73 establishing wild populations. Australian waters host more than 200 species of introduced marine organisms, however not all are considered invasive (generating a negative impact on the local ecosystem and species) (EPA 2015).

Deliberately introduced species impacting the NSW estuarine and coastal marine environments include: bitou bush (*Chrysanthemoides monilifera ssp. rotundata*), foxes (*Vulpes vulpes*), feral cats, introduced rats, and wild dogs. These species are now classified as widespread in NSW.

Bitou bush is currently listed as a weed of national significance, a key threatening process, and a NSW noxious weed. It has infested an estimated 80% of the NSW coastline, and has become the dominant species along 36% of the state’s coastline (DEC 2006b). Bitou bush is highly competitive, smothering native plant communities and destroying the natural habitat and food sources for native animals (DEC 2006b).

The European red fox has been implicated in the decline and extinction of a vast array of native species, has been identified as a primary threat to approximately 40 native species, and was declared a key threatening process in 1998 (DEC 2006b). Foxes have been identified as a key threat to protected shorebirds within the NSW marine estate.

Current management

Once established, invasive species are difficult to manage effectively and remain a significant threat to biodiversity (EPA 2015). Many invasive species are listed as key threatening processes in NSW legislation, with pest animal and plant species identified as a threat to over 70% of all threatened species (Coutts-Smith et al. 2007). It is difficult from a management perspective to differentiate between those invasive species deliberately or inadvertently introduced.

As deliberately introduced plants and animals affecting the NSW marine estate environmental assets are widespread, total eradication of these species is not feasible. Instead, control measures involve determining priorities for control of these species, then focusing resources in areas where the benefits of control will be the greatest (EPA 2015). The highest priority environmental assets for protection from invasive species are threatened and protected species listed under the *TSC Act* (EPA 2015).

Pest management relevant to the NSW marine estate include: threat abatement plans (TAPs) such as those for the fox (NSW OEH 2011) and bitou bush (DEC 2006a); biodiversity priorities for widespread weeds; regional pest strategies and other management plans; and the NSW Threatened Species Priorities Action Statement. All TAPS incorporate a monitoring program to measure their effectiveness and the response of the main threatened species affected (EPA 2012).

Key legislation related to invasive species management is the *Noxious Weeds Act 1993*, *Rural Land Protection Act 1998, TSC Act, FM Act, Game* and *Feral Animal Control Act 2002*, and *Quarantine Act 1908* (EPA 2012). NSW DPI is the lead agency in the NSW Invasive Species Plan (draft 2015-2022), with OEH as a key partner in its implementation. The NSW Invasive Species Plan has four goals: (1) prevent the establishment of new invasive species; (2) eliminate or prevent the spread of new invasive species; (3) reduce the impacts of widespread invasive species; and, (4) ensure NSW has the ability and commitment to manage invasive species and protect environmental assets. Actions to control new and emerging weeds are also a priority under the *Biosecurity Act 2015*.

Fox control is the primary management action to protect threatened shorebirds at priority sites in NSW. The risk from the impacts of widespread pests on native species and ecological communities remains high irrespective of current management as control methods are often imperfect and expensive. Land use changes can further reduce the cost-effectiveness of control programs and ongoing funding is required (i.e. widespread pests are not eradicated, rather impacts are minimised through targeted ongoing control).

Potential impacts of the deliberate introduction of animals and plants

Invasive pests with self-sustaining populations are a key threat to biodiversity in NSW (EPA 2015). While there are many stressors associated with invasive pests, the key stressors from deliberately introduced species in NSW include:

- Predation and consumption;
- Wildlife disturbance;
- Competition; and
- Habitat disturbance (modification and degradation) caused by either physical disturbance or by an imbalance in the natural biota; and disease transmission.

Wildlife disturbance and predation

Vertebrate pests are widespread in NSW and are a significant threat to the survival of native fauna at state and regional scales. Foxes are a primary threat to the survival of beach-nesting shorebirds, including four endangered species in all coastal regions of NSW. Foxes were the primary cause of regional declines and extinction of a suite of ground-nesting birds in open habitats, which are have similar ecological requirements to shorebirds in NSW (NSW National Parks and Wildlife Service 2001). Within NSW, egg, and chick loss due to fox predation at shorebird nesting sites is high (NPWS unpublished data) and localised extinctions of little penguin colonies have occurred on the mainland primarily because of fox predation (Priddel et al. 2008). The NSW Threat Abatement Plan: Predation by the Red Fox (2001) includes a literature review of the impact of foxes on native fauna including ground-nesting birds.

The NPWS little penguin mortality database included 28 mortalities from fox predation on the Manly colony in the 2015-16 financial year and 42 reports from other land based predators in the last 20 years. Unpublished NPWS data collected under the Fox Threat Abatement Plan (Fox TAP) and Saving our Species (SoS) programs show that from all known endangered little tern nesting sites in NSW over the last 15 years, fledging rates were 36% higher at mainland sites with fox control than mainland sites without fox control and 8% of eggs and chicks observed at mainland sites with fox control were lost to fox predation compared to 18% at mainland sites without fox control. However, a large proportion of eggs and chicks observed were lost to unknown causes (31% across all sites and years) making the level of impact uncertain. Overall, the data showed that the sum of breeding pairs across all sites in NSW declined at approximately 3% per year between 2001 and 2015. Thus, while management appears to have increased fledging rates and decreased mortality due to foxes, it has not been sufficient to counter long-term declines in the breeding population of little terns in NSW. The fledging rates that might be required to achieve recovery are unknown. Analysis of data for other threatened beach-nesting shorebirds in NSW are in progress.

Widespread weeds such as bitou bush, glory lily, and *Juncus acutus* are significant threats to coastal ecosystems such as coastal saltmarsh and threatened flora therein such as *Chamaesysce psammogeton*, *Sophora tomentosa* and *Senecio spathulatus*. In addition to widespread weeds, species that are new and emerging in NSW also pose a significant risk to estuarine ecosystems. For example, Bitou bush impacts biodiversity and ecosystems through competition for light, nutrients, and water, as well as through changes to soil chemistry (allelopathy), fire regimes, decomposition rates (Lindsay and French 2004) and bird species richness and abundance (French and Zubovic 1997). The NSW Threat Abatement Plan for Invasion of Native Plant Communities by *Chrysanthemoides monilifera* (bitou bush and boneseed) (2006) includes a literature review of specific coastal plant species and ecological communities that are at risk from bitou bush invasion, many of which are threatened.

6.2.2 POINT DISCHARGES

A point source is a single, identifiable source of pollution, such as a pipe or an outlet that discharges effluent from any premises. In this report, stormwater drains are not included as point sources. Industrial, sewage and thermal wastes are commonly discharged to rivers and the sea in this way. Point sources are differentiated from non-point (or diffuse) sources, which are those where the pollutants originate from a large area and have no specific source.

Industrial discharges

Industrial discharges to the marine estate include those from coal-fired power stations, desalination plants and heavy industry. Sewage-treatment plants, sewage overflows, effluent and septic run-off are treated as point discharges for the purpose of this assessment. The majority of industrial discharges occur in the central region, with sewage discharges accounting for the large majority of discharges outside of Greater Sydney. Where sewage contains trade wastes (e.g. in Sydney, Newcastle, Wollongong) significant loads of contaminants can be discharged in addition to the nutrient, carbon and pathogen loads from sewage (Figure 53, Figure 54).

Relative to diffuse source inputs, point source waste discharges contribute a minor proportion of non-toxicant pollutants to the marine estate. The NSW Monitoring Evaluation and Reporting Strategy 2010–2015 (Roper et al. 2011) showed that the amount of nutrients entering estuaries from diffuse sources is up to two orders of magnitude greater than from sewage-treatment plants. In NSW, the majority of old estuary outfalls have been diverted to ocean outfalls, reuse schemes, or a combination of both. The most recent data on the location and volume of discharges to estuary waters is from 1999 (MHL 1999), and shows that the north coast has most estuary outfalls, while the Hawkesbury Shelf has greatest load per estuary (Table 30).

Many pollutants will persist for many years, or will not degrade at all, in the case of metals. The burial of older sediments by fresh particulate matter may decrease the threat from some contaminated sediments, unless dredging or other disturbance occurs (Hedge et al. 2009). Considerable industrial activity still exists in other parts of the NSW coast, most notably Botany Bay and Port Kembla. Although aquatic ecology has improved due to better environmental regulation over the last few decades, threats remain in these locations (He and Morrison 2001).

A detailed description of contamination from industrial discharges within estuaries of the central region is presented in MEMA (2016) and (Hedge et al. 2014) and references within. This includes Sydney Harbour which has a long history of contamination associated with disposal from industrial discharges.

Table 30. Distribution and load of sewage discharges to New South Wales estuaries.

Region	Number of estuaries	Total nitrogen load (tonnes/year)	Average load (tonnes/year)
Northern	13	123	9.5
Central	2	60	30
Southern	2	13	6.5

Source: MHL 1999

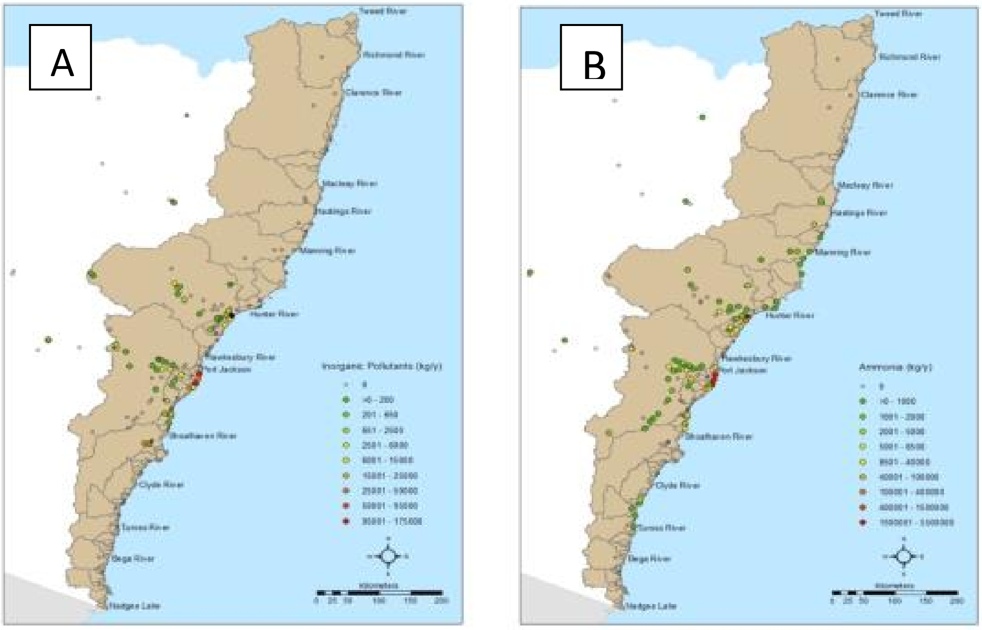

Figure 53. National Pollution Inventory reported loads of inorganic pollutants (A) and ammonia (B) discharged to water in 2012–2013, including mining, industrial and urban discharges. *Source: OEH*

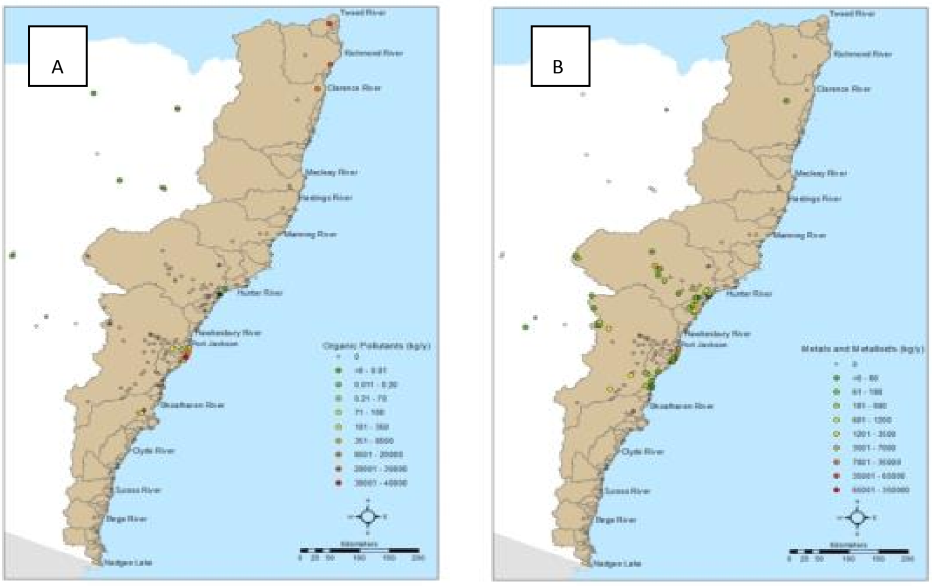

Figure 54. National Pollution Inventory reported loads of organic pollutants (A) and metals and metalloids (B) discharged to water in 2012–2013, including mining, industrial and urban discharges. *Source: OEH*

Current management

In NSW, point source waste discharges are regulated by all three levels of government: federal, state and local. The NSW EPA is the primary regulator of significant point sources. Smaller discharges, such as many rural sewage systems, are regulated by local government.

The EPA uses environment protection licences to control activities that could affect the environment. It regulates:

- air, water and noise pollution
- waste and resource recovery
- contaminated land
- chemicals and hazardous materials
- pesticides

The EPA also monitors emissions and compliance, conducts audits and investigates reports of pollution. If necessary, EPA can impose fines, require stricter operating conditions, impose pollution reduction programs and order people to clean up pollution.

Regulation of point source discharges has dramatically reduced the inputs of contaminants directly into waterways. Most industrial effluents are now discharged to sewers via trade waste agreements. Some large, industrial centres (e.g. Hunter/Kooragang and Port Kembla) still discharge pollutants to waterways under environment protection licences.

Potential impacts of industrial discharges

Water and sediment pollution: toxicant discharges

Toxicants are chemical contaminants that may harm living organisms at the concentrations often found in the environment. The ANZECC/ARMCANZ Guidelines for Fresh and Marine Water Quality list potential toxicants under the following broad groups:

- metals and metalloids
- non-metallic inorganics
- organic alcohols
- chlorinated alkanes and chlorinated alkenes
- anilines
- aromatic hydrocarbons (e.g. PAHs, PCBs and dioxins)
- phenols and xylenols
- organic sulfur compounds
- phthalates
- miscellaneous industrial chemicals
- organochlorine pesticides (e.g. DDT) and organophosphorus pesticides (e.g. chlorpyrifos)
- carbamates (e.g. carbaryl) and other miscellaneous pesticides
- pyrethroids
- herbicides and fungicides.

Common toxicants from industrial discharges include metals and metalloids, petrochemicals, garden pesticides and fertilisers. Historically, industrial activities resulted in elevated metal and organic chemical concentrations in the water column and sediments in many estuaries, principally in the central region (e.g. Port Jackson, Port Kembla, Lake Macquarie, Lake Illawarra and the Hunter River (Hayes et al. 1998, Hedge et al. 2009, Jennings et al. 1996, Lottermoser 1998, Matthai and Birch 2000, Spooner et al. 2003). Elevated metal and organic chemical concentrations in sediments have been linked to significant risk to aquatic organisms (Gall et al. 2012, Hunt et al. 2010, Johnston and Roberts 2009). Fewer studies have been reported for other NSW locations. Bivalve surveys in NSW (Scanes and Roach 1999) have shown that measurable concentrations of organochlorine compounds, PAH and PCB, and significantly elevated levels of trace metals only occurred in a small number of industrialised estuaries along the NSW coast.

While much of the industrial pollution contamination is historical it should be noted that many pollutants will persist for many years (or will not degrade at all, in the case of metals). Further details on water and sediment pollution from industrial discharges within estuaries of the central region is presented in MEMA (2016) and (Hedge et al. 2014) and references within.

Thermal discharges

Thermal pollution is a well-recognised issue for estuarine waters along the NSW Illawarra and central coasts, which receive cooling discharge from coal-fired power stations (Ingleton and McMinn 2012, Robinson 1987). Lake Illawarra and Lake Macquarie receive cooling discharge from coal and gas-fired power stations.

Other smaller power stations, fuelled by sugarcane waste, have been constructed on north coast rivers (e.g. Tweed and Richmond), but discharge there is small. Thermal pollution only occurs from a few sites in Sydney Harbour estuary, where industries and facilities use water for cooling, including air-conditioner condensers. Unless there is a significant shift from coal and gas-fired power stations as a means of energy production, thermal pollution along the Illawarra and central coasts is not likely to reduce.

Potential impacts of thermal discharges

Physical disturbance

Losses of seagrass (*Z. capricorni*) have been documented around the warm water effluent from power stations in Lake Macquarie and Lake Illawarra. In most cases the *Z. capricorni* appears to have been replaced by species of *Halophila* which are more tolerant to warm water and which are home to a different assemblage of fauna (Robinson 1987). Tuggerah Lakes used to have thermal discharges but Munmorah power station was decommissioned in 2012. Thermal effluent from the power station resulted in a loss of seagrass within a 2 km region around the outlet pipe (Batley et al. 1990). There is expected to be large amounts of plankton and larval animals entrained in cooling waters, but the consequences are poorly understood. This is particularly the case where plants are situated in key areas for reproduction (e.g. Australian bass breed in brackish waters near the Tweed and Richmond plants), but the impacts are localised.

Sewage effluent and septic run-off

Sewage is a water-carried waste, in solution or suspension, which is intended to be removed from a community. Sewage discharges remain one of the last major industrial inputs to the marine estate. Where sewage contains trade wastes (e.g. Sydney, Newcastle, Wollongong), significant loads of contaminants can be discharged in addition to the nutrient, carbon and pathogen loads from sewage. The NSW Monitoring Evaluation and Reporting Strategy 2010–2015 (Roper et al. 2011) shows that the amount of nutrients entering estuaries from diffuse sources is up to two orders of magnitude greater than from sewage-treatment plants.

Several sewage-treatment plants discharge directly into estuaries within the central region (primarily the Hawkesbury–Nepean River and Hunter River). Together with diffuse inputs of nutrients, sewage-treatment plant discharges contribute to nutrient loading to these systems.

Recreational water quality on beaches in several estuaries is monitored through the ongoing Beachwatch program[46].

Potential impacts of effluent and septic run-off

Water pollution: nutrients

Nutrients are carried in septic run-off in many estuaries throughout NSW that contain adjacent septic systems. Few studies of impacts of sewage on estuaries were found, though Gay (2002) demonstrated significant impacts in the Brunswick River. In the past, sewage discharge to intermittent and wave-dominated lakes resulted in very poor water quality (e.g. Lake Macquarie, Belongil Lagoon, Lake Conjola), but all of these have been removed in the past decade or two. Estuary condition sampling (Figure 49,

[46] http://www.environment.nsw.gov.au/beachapp/default.aspx

Table 28) provides some indication where nutrient pollution is greatest, and suggests that there are ongoing issues with sewage loads to estuaries in places such as the Hawkesbury River.

Water pollution: pathogens

Once in a water body, pathogens can infect humans through contaminated fish and shellfish, skin contact or ingestion of water. Beachwatch recorded a significant reduction in ocean water pathogen load after sewage outfalls were moved offshore (Beachwatch 2016). Beachwatch now identify stormwater run-off, which may include sewage overflows, as the major risk factor for pathogens at some estuarine beaches.

Aspects of the marine environment that relate specifically to human health, such as pathogens that indicate suitability of water for human recreation, particularly swimming, are discussed in the context of social and economic threat and risk assessment in BMT WBM (2017).

Pathogens released into the environment via urban run-off and sewage effluent have negative impacts on marine wildlife population health. For example, the occurrence of toxoplasmosis in marine mammal populations has been linked to domestic cat waste that has entered the marine environment through sewerage. The impact of pathogens on marine wildlife is described in 6.2.1.

Water pollution: toxicants

Bioaccumulation of contaminants was identified as a major problem around Sydney's sewage outfalls in the 1980s and 1990s, but there was no evidence of this after the move to deep water outfalls. Other studies have not shown any appreciable bioaccumulation near the other outfalls in Newcastle, Wollongong or the smaller plants.

Water pollution: microplastics

Microplastics are small plastic particles generally smaller than 5 mm. They can come from a variety of sources, including cosmetics, clothing and industrial processes. They are currently classified as:

- primary microplastics, which are manufactured and are a direct result of human material and product use, and include
- air-blasting media (microplastic scrubbers blasted at machinery, engines and boat hulls to remove rust)
- microbeads used in cosmetics, shampoos and facial-cleansers
- secondary microplastics, which are microscopic plastic fragments derived from the breakdown of larger plastic debris and from washing clothes in washing machines.

A significant source of microplastics to the marine environment is from sewage contaminated with fibres from washing clothes. This is because many textiles contain >170% more synthetic fibres than natural fibres (e.g. cotton, wool, silk).

Recent work has shown the presence of microplastics in various parts of Sydney Harbour, including areas not majorly affected by sewerage outfall (E. Johnston UNSW 2016 pers. comm.). However, not enough studies have been done to understand any trend in the degree of microplastics pollution in NSW waters. Restriction of some sources (e.g. microbeads in facial scrubs) might reduce some pollution, although many other sources, such as fragmentation of macroplastic or fibres from textiles, are likely to continue.

6.2.3 HYDROLOGIC MODIFICATIONS

Entrance-training structures

Entrance-training structures, such as breakwaters and river training walls, are primarily built in systems that experience significant shoaling of the estuarine entrance, such as wave-dominated riverine estuaries, coastal lakes, and coastal lagoons. Such are generally not built in drowned river valley estuaries, due to the deep nature of their entrances. The infrastructure that defines the coastal river entrances plays a pivotal role in the safe navigation of marine vessels, including commercial fishing fleets and recreational boaters (Figure 55). Breakwaters and river training walls are also a popular destination for fishing, walking, and site seeing.

Training walls and breakwalls are generally designed to provide an immoveable footprint (shape), as well as reducing the flow width to create deeper channels without dredging. The design compromises between maintaining a navigable channel under normal tidal response, and maintaining the ability to pass larger catchment floods without increasing flood damage. These structures generally increase tidal prism (volume of water exchanged on a tide) and flows. Water velocities may increase, but this depends on the relation between geometry, flow, and tide levels.

The number of estuaries with training walls varies between the three coastal regions, with 35% of estuaries in the **northern region**, 18% in the **central region**, and only 10% in the **southern region**. Most of these are single or double breakwalls on the larger estuaries, built when coastal freighters were a major transport method, and often when coastal commercial fishing vessels were greater in number and of a larger size.

Many of the larger estuaries also have hard bank protection built to stabilise river banks or navigation channel locations. An important example of this is the Macleay River, in which large amounts of rock protection were placed to stabilise the new entrance and the downstream river channels immediately after the 1893 breakout just north of South West Rocks.

(a) 

(b) 

Figure 55. Estuary entrance before and after the development of training structures at Brunswick Heads; (a) 1936, (b) 2016. (a) Source: State Library of NSW.

Artificial entrance opening regimes

Artificial entrances are opened to reduce flood risk to low-lying properties in systems that experience periodic entrance closure. Generally, the entrance is opened mechanically once water levels within the estuary reach a nominated threshold. Channel scouring occurs rapidly, depending on the head potential between the estuary and the ocean. Once an entrance channel is established, the lagoon becomes tidal and salinity can rise significantly. Without further intervention, the entrance generally closes during the following weeks to months as sand from the nearshore zone is brought in by waves.

In the north coast, entrance opening occurs in 17of 57 estuaries (30%). The primary reason is to stop inundation of low-lying assets, but some are illegally opened by local communities for reasons such as perceptions of improved water quality and to create surfing breaks. Navigation dredging also occurs in Hastings and Myall Rivers and Wallis Lake.

On the central coast, channel dredging occurs in four major ports (Hunter, Port Jackson, Botany Bay and Port Kembla). Sediments from port dredging, which are often mildly contaminated, are dumped at sea in designated spoil grounds. Entrance opening has been recorded for 13 out of 39 estuaries (33%), for similar reasons to the north coast.

In the south coast, entrance opening occurs in 28 out of 91 estuaries (30%). Table 31 rates the relative importance of different hydrologic modifications to NSW estuary types.

Table 31. Importance of key activities in the estuarine systems of New South Wales.

Modification	Estuary type			
	Riverine estuary	Drowned river valley	Coastal lake	Coastal lagoon
Entrance training	High	Not applicable	High	Low
Shoreline infrastructure	High	High	High	Low
Artificial entrance opening	Not applicable	Not applicable	Low	High

Potential impacts of hydrologic modifications

Flooding and freshwater flows

Many modification works are designed specifically to reduce flooding intensity or frequency. During smaller discharge, high-frequency floods, flows are usually contained within the riverbanks and any levees throughout the upper and middle-estuary reaches. This has often allowed floodplains to be used for agriculture. A consequence is that the rapid death and decomposition of non-native vegetation results in the return of deoxygenated waters to rivers and estuaries as floods recede (Eyre et al. 2006, OEH unpubl. data).

Overall, channelisation increases flood energy. Over time, this causes channel cut-offs during floods, thereby shortening channel length, increasing the bed slope, and thus further increasing the flood energy. As a result, discharge-eroded sediments can travel further into the coastal zone. Artificially opening intermittent estuaries affects the abundance and diversity of microscopic animals (meiofauna) (Dye and Barros 2005), macroscopic animals (macrobenthos) (Gladstone et al. 2006) and fish (Griffiths 1999, Jones and West 2005).

Tidal behaviour

Entrance-training works and dredging of the lower estuary regions are likely to have increased the potential tidal prism. This leads to more frequent inundation of intertidal habitats, such as saltmarsh and shorebird nesting habitat.

Sedimentation

The widespread alteration of tidal behaviour and freshwater flows, combined with increased sediment supply due to catchment disturbances, can alter sedimentation and erosion patterns throughout the estuary. The construction of training walls also allows beach sand into the estuary, and expands the flood-tide delta (e.g. Lake Illawarra).

Physical disturbance

Widespread areas of shallow subtidal and intertidal habitats and saltmarsh are lost by reclamation and shoreline hardening, increased tidal prisms and the exclusion of tidal influence by floodgates and levees.

Modification of hydrological regimes – including the artificial opening of estuaries or estuary entrance modification – is recognised as a major cause of the loss of biological diversity, ecological function, and subsequently shorebird diversity in affected areas (Kingsford et al. 2009). Estuary mouths have been identified as high priority roosting habitats under threat for a number of threatened and migratory shorebird species in NSW (Department of Environment, Climate Change and Water 2010, Lane and Harris 2013). Alterations to hydrological regimes and associated impacts are identified as a key threatening process affecting both resident and migratory shorebirds in Australia (Department of the Environment 2015). These impacts are further described in *6.1.12 Modified freshwater flows.*

Estuary entrances are artificially modified to manage flood risk, water quality, recreational amenity, and fishery productivity (Gladstone et al. 2006). Mechanical opening and construction of training walls cause physical disturbance to the habitat of shorebirds and their prey, changing topography, increasing the tidal prism; changing water flows, velocity, and quality; and modifying natural processes of sedimentation and erosion. Alteration of hydrology via modification of estuary entrances may lead to the inundation of intertidal zones, causing the permanent loss of shorebird foraging and nesting habitats, and flooding of nests resulting in direct mortalities of chicks and eggs (NSW National Parks and Wildlife Service 2003). Subsequently, the breeding success of endangered species such as the little tern - which nests close to the water in estuaries or on coastal beaches near the mouth of estuaries – may be negatively affected (NSW National Parks and Wildlife Service 2003). Further, the installation of training walls at openings allows sand from beaches to enter estuaries, expanding the flood-tide delta and reducing shorebird habitat. For instance, construction of a northern break wall and dredging of the entrance channel to Lake Illawarra resulted in disturbance of a little tern nesting area. Though creation of replacement habitat using dredge spoil was initially successful, predation of eggs by silver gulls decimated the colony (Harris and Dunn 2010). At Brou Lake and Wallagoot Lake, the nests of little terns are threatened by flooding from king tides when the entrances are open, or by risking lake levels when closed (NSW National Parks and Wildlife Service 2003).

Tidal entrances control sediment flux into and out of the estuary, erosion-deposition regimes within the estuary, and flow velocity (Mirfenderesk and Tomlinson 2009). As such, modification of entrances may incidentally alter the morphology, water quality, and ecology of the estuary impacting the quality of shorebird habitat. For example, stabilisation of the tidal inlet of the Nerang River on the south east coast of Queensland through dredging and training wall construction had impacts of habitat quality by changing the tidal regimes, increasing the tidal prism, shifting sediment, changing salinity, and turbidity (Mirfenderesk and Tomlinson 2009). Intertidal nesting and foraging habitats may also be permanently lost through processes of reclamation and shoreline hardening, which further increase tidal prisms or exclude tidal influence through floodgates and levees. The historical closure of the former Yarrahapinni Broadwater on the Macleay River – an area that once provided important food sources and habitat for estuarine-dependent fauna – through the construction of tide gates and a levee to prevent inundation of grazing land, was widely considered as having disastrous ecological effects, restricting flushing and allowing pollutants from connected acidic swamps to degrade water quality in lower Macleay channels, and resulting in declines of mangrove wetlands and supratidal saltmarsh (Tulau 2011).

Further, modification of estuary entrances affects the abundance, diversity, and subsequently availability of prey species by altering tidal patterns and salinity. Griffiths (1999) found that after Werri and Shellharbour Lagoons, NSW, were opened to the sea, abundances of marine-spawning fish species increased, though it was noted that the upward cascading trophic effects on avifauna required further study. Subsequent research has shown that changes in community structure and the recruitment of marine species associated with artificially opening estuaries is dependent upon resident community characteristics and modification strategy. For instance, the artificial opening of Lake Conjola, NSW, caused increases in tidal currents, fluctuations in water levels, and higher salinities, resulting in significant damage to seagrass beds and a concurrent decrease in fish recruitment to the site (Jones and West 2005). The construction of rock walls in conjunction with dredging at the entrance of the Tweed River in NSW has led to major changes in estuarine processes, constricting width, increasing channel depths and flows at the mouth, and altering tidal ranges and flushing throughout the estuary (Tulau 1999). Catches from the river have reportedly declined, while aerial photography has recorded a reduction in estuarine habitats in the region (Tulau 1999).

Pests and diseases

The large amount of artifical structures in NSW estuaries is likely to facilitate greater invasion and dispersal of introduced and pest species.

6.3 CLIMATE CHANGE

6.3.1 CLIMATE CHANGE COMPONENTS

The key components of climate change that are considered in this report in the context of potential impacts on the environmental assets in the NSW marine estate are:

- Altered ocean currents and nutrients
- Climate and sea temperature rise
- Ocean acidification
- Altered storm and cyclone activity (including flooding, storm surge and inundation)
- Sea-level rise.

This does not include an assessment of these components on some aspects of the marine estate, such as impacts on geomorphic features and coastal infrastructure. These are only considered when they affect aspects of the biological diversity associated with these features. Indirect effects due to species range shifts or loss are also considered.

Overall, the impacts of climate change on the biophysical environment of NSW, and limitations associated with predictions, have been assessed at a regional level (DECCW 2010b). By 2050, the climate in the Sydney and central coast region is virtually certain to be hotter, with mean daily maximum and minimum temperatures increasing by an estimated 1.5–3 ^{o}C. Rainfall is likely to increase in all seasons except winter; increased evaporation is likely in spring and summer; the impact of the El Niño-Southern Oscillation is likely to become more extreme; and the sea level is virtually certain to keep rising. South-east Australia is considered a global hot spot for ocean warming, occurring at around four times the global average, due to increased strength and southward penetration of the East Australian current (EAC) (Hobday et al. 2006, Ridgway 2007, Poloczanska et al. 2012).

The impacts associated with the climate change components will result from a number of specific identified stressors that are also derived from other activities, including physical disturbance, wildlife disturbance and water pollution. Some are derived specifically from the identified changes, such as increased ocean acidity and sea temperature. The impacts were analysed in two reviews commissioned by the Australian Greenhouse Office (Hobday et al. 2006, Hobday and Matear 2005). Different coastal impact models have also been developed to assess projected changes to wave climate and examine impacts such as inundation and erosion (BMT WBM 2010; 2011). The redistribution of species under climate change, either via direct or indirect pathways, will have significant implications for the marine estate and its sustainable management (Pecl et al. 2017).

A detailed description of the key components of marine climate change, and an assessment of the impacts on a range of environmental assets in Australia is presented in Poloczanska et al. (2012) and chapters within.

This section details aspects relating to current management arrangements that aim to minimise the effects of climate change on local communities, and the impacts associated with the identified components as they relate to environmental assets in estuaries in NSW. Impacts of climate change on environmental assets on the open coast and continental shelf is presented in section 8.3.

Current management

Overall, limiting climate change will require substantial, sustained reductions of greenhouse gas emissions worldwide (IPCC 2013). Climate change is a key threat to marine environments in NSW, and climate change adaptation strategies have become a core component of natural resource management (DECCW 2009).

The NSW Government has committed to minimise the effects of climate change on local communities. Climate change adaptation programs that are aimed at building the resilience of the state's natural environment, economy and communities by:

- managing water resources
- protecting ecosystems and natural resources
- preparing for the impacts of climate change[47]
- helping communities adapt (including assessing the vulnerability of regional communities[48]).

The NSW Government has established the NSW Adaptation Research Hub[49] to research the best adaptation responses for NSW under the management initiative of coasts, biodiversity, and communities. A joint government and university program to downscale global climate-change prediction models for the NSW coast is contributing to this research.

Potential impacts of climate change in NSW regions

The long-term impacts of climate change will occur at a global scale, and will interact with local-scale stressors to effect the NSW marine environment. Significant effects have already, and are predicted to continue to occur across south-east Australia (Cetina-Heredia et al. 2015, Coleman et al. 2017, Hobday et al. 2006, Provost et al. 2017, Wernberg et al. 2011, Verges et al. 2014, Verges et al. 2016), including changes to:

- marine species distribution and abundance
- phenology or timing of life cycle events
- physiology, morphology and behaviour (e.g. rates of metabolism, reproduction, development)
- movement of propagules/organisms and subsequent change to genetic patterns
- biological communities via species interactions.

Climate change may also facilitate the spread, establishment and virulence of pathogens and exotic species (Campbell et al. 2011, Harvell et al. 2002, Wernberg et al. 2011).

Because estuaries are transition zones, linking land, freshwater and marine ecosystems, they are likely to be affected by interacting climatic and hydrologic variables. Unfortunately, predictions of climate change are complex, particularly in estuaries due to the dynamic nature of estuarine systems overlaid with other anthropogenic stressors. Changes to dissolved carbon dioxide concentrations, temperature, precipitation and sea level will likely affect estuary circulation, levels of salinity, suspended sediments, dissolved oxygen and biogeochemistry (Gillanders et al. 2011).

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[47] http://www.climatechange.environment.nsw.gov.au/Impacts-of-climate-change

[48] http://www.climatechange.environment.nsw.gov.au/Adapting-to-climate-change/Regional-vulnerability-and-assessment

[49] http://www.climatechange.environment.nsw.gov.au/Adapting-to-climate-change/Adaptation-Research-Hub

Species that have a wide tolerance to multiple environmental variables (e.g. estuarine residents and marine migrants) are likely to survive and tolerate changing estuarine conditions, while early life history stages (i.e. eggs and larvae) are most likely to be affected. There is little evidence that species will adapt to changing conditions (Naglekerken and Connell 2015). Marine mammals, birds, and reptiles are predicted to be impacted both directly and indirectly by climate change. Predicted changes may adversely affect the distribution, phenology, demography, survival, breeding success, diet, and migration patterns of species. As many of these species are apex predators, the threat of climate change is predicted to be compounded by changes in marine ecosystem dynamics including through changes in prey distribution, abundance, and primary productivity (Baxter 2016, Chambers et al. 2011). The specific impacts of climate change are poorly understood, and few broadscale, coordinated baseline data or ongoing monitoring programs are available to assess potential changes in natural settings (Hobday et al. 2006, Poloczanska et al. 2012, Wernberg et al. 2011) which remains a critical knowledge gap requiring attention if impacts are to be adequately detected, understood and mitigated.

Assessing the potential impacts of climate change in NSW

To help communities to understand and adapt to climate change, a statewide assessment of potential climate change impacts has been undertaken (DECCW 2010b). The assessment has provided projections of climate change and identified the impacts of these changes on settlements, land and ecosystems of NSW. Different parts of NSW will experience different changes in climate, and will require different responses to these changes. However, considerable uncertainty remains about the regional impacts and implications of climate change, and much finer-scale information is needed to understand the severity and extent of future impacts.

Work aimed at identifying climate-change related threats to the marine environment has been more limited than that relating to terrestrial ecosystems. Most work has focused on coastal erosion, inundation and sea level rise. Significant direct and indirect threats to marine biodiversity are also likely to stem from changes to ocean currents, temperature and chemistry, storm events and changes in freshwater input (Department of Climate Change 2009).

Shifts in the range and distribution of species (Cetina-Heredia et al. 2015, Garcia Molinos et al. 2015, Pecl et al. 2011, Robinson et al. 2015), the composition and interactions within aquatic communities and the structure, dynamics and connectivity of communities are also predicted (Coleman et al. 2017, Provost et al. 2017, Verges et al. 2014).

The key components and stressors associated with climate change are discussed in more detail below.

Altered ocean currents and nutrients

Changes in the East Australian Current and movement of water to surface from deep in the ocean (upwelling) may affect ecosystems in NSW estuaries, with organisms that spend part of their lives on the open coast most likely to be affected. In particular, connectivity between estuarine and marine environments may be altered by climate change (Gillanders et al. 2011). The connectivity between tropical and temperate regions will increase through the strengthening of the EAC, and this will result in a greater diversity of subtropical and tropical species entering estuaries, particularly the northern and central regions. Estuarine circulation may also change, due to alterations in water temperature, salinity and flow, but long-term impacts have not been studied for Australian estuaries (Gillanders et al. 2011). The changes in ocean currents are also likely to influence the amount and frequency of nutrient inputs into estuaries from the open coast, but the relative contribution may not influence overall levels.

There are not expected to be significant and measurable changes within estuaries due to altered ocean currents and nutrients over the next 20 years. The key habitats and associated biota likely to be affected in the longer term in the estuaries include planktonic assemblages due to changes in connectivity (Coleman et al. 2017).

Ocean currents and nutrients can have wide-ranging effects on seabirds and shorebirds. Changes to ocean currents, upwelling, rainfall, stratification, and turbidity are expected to influence nutrient concentrations, which may have consequences for prey availability and detection of predators (Chambers et al. 2011). Changes in ocean currents and sea surface temperatures during El Nino events have been associated with delayed breeding and reduced fecundity in wedge-tailed shearwaters and sooty terns and changes in nutrient concentrations including chlorophyll concentrations have been linked to delayed breeding in sooty terns and common noddies (Chambers et al. 2011). Changes in the rainfall and run-off in estuaries can increase nutrient concentrations causing algal blooms and decreased trophic stability leading to negative health impacts on birds (Chambers et al. 2011). Productive areas adjacent to the EAC are important foraging areas for many species and the strengthening of the EAC may influence productivity in these areas (Chambers et al. 2011). However, due to the complexity of climate-driven interactions the true impact of altered ocean currents and nutrient inputs on these species is largely unknown.

Ocean currents also influence turtle movements, juvenile dispersal, and the availability of prey. Warm currents can also provide a thermal refuge for turtles (Poloczanska et al. 2009). As the EAC strengthens and turtles move further south and experience stark temperature differences outside the EAC, increased turtle mortalities from thermal shock are likely to be observed (Poloczanska et al. 2009). Though there is limited information on how upwelling and altered winds may impact marine mammals as a result of changing nutrient levels and associated productivity, we know that upwelling zones are important feeding areas for cetaceans and pinnipeds and potential changes in their locations may alter the distribution of marine mammal populations (Schumann et al. 2013). Though the strengthening of the EAC is likely to alter water conditions and subsequent prey availability, the scale at which this will affect marine mammals is not known (Schumann et al. 2013).

Climate and sea temperature rise

Australia's temperate coast is predicted to continue warming, increasing by 1–3 ^{o}C over the next century, and extreme thermal events will increase. Rising temperatures may influence the distribution and abundance of fishes and other organisms in estuaries by changing recruitment and reproductive processes. The extent of impacts will depend on whether species are at the extremes of their distribution and temperature tolerance (i.e. northern or southern boundary of geographic range) (Gillanders et al. 2011). Key habitats and associated biota likely to be affected in the longer term include saltmarsh, (Santilan et al. 2014), mangroves (Duke et al. 2017), seagrass (Hyndes et al. 2016), beaches and mudflats (Jones et al. 2007) and shallow rocky reefs (Wernberg et al. 2011) due to the broader changes in several ecological functions and processes (Poloczanska et al. 2012). An assessment of the impacts on key harvested fish species are presented in Pecl et al. (2011).

Predictive studies also show that the change in the movement of water masses (the EAC) per se, rather than associated larval survival due to variation in water temperature, may have the greatest impact on future species distributions in NSW (Cetina-Heredia et al. 2015).

Marine mammals are affected by both increasing air and water temperatures (Schumann et al. 2013) and may adapt to temperature increases through physiological and behavioural adaptations. Physiological adaptations may include changes in blubber thickness and blood flow to extremities to reduce body temperature. Where physiological adaptations are not adequate, marine mammals may change their seasonal distributions to occupy cooler waters to help thermoregulation (Schumann et al. 2013). Shifts in the distributions of cetaceans have been observed internationally, with both cold- and warm-water-associated species shifting their distributions to inhabit water within their thermal tolerance. However, factors such as prey availability, competition, and habitat availability may impede shifts, resulting in declines of some species (Schumann et al. 2013). For endangered southern-right whales, due to their wide-ranging temperature requirements their distributions may expand resulting in a longer migration and increased energy requirements (Schumann et al. 2013).

A key threat to marine mammals from climate change is from changes to the availability of prey (Schumann et al. 2013) such as plankton, crustaceans, and fish. Long-term declines in the availability of important prey species outside NSW such as krill have already been observed (Schumann et al. 2013). Lower availability of krill in warm temperatures has been associated with lower calving rates of southern-right whales and is predicted to limit the birth rates of blue whales (Schumann et al. 2013). Migratory species such as southern-right and humpback whales whose migrations, breeding, and feeding patterns are dependent on seasonal use of breeding habitat and foraging areas will be vulnerable if climate change results in a separation of these requirements (Schumann et al. 2013).

Temperature is known to alter the survival and breeding success of pinnipeds through affecting the availability of their prey (Schumann et al. 2013). Though pinnipeds can behaviourally adapt to changes in prey distributions, declines in fitness and survivorship may occur if species must move outside of their preferred thermal tolerance (Schumann et al. 2013). Declines in breeding success and pup fitness have been observed in Antarctic fur seals during periods of warming, with a 10% decline in pupping with each 1°C increase in temperature (Schumann et al. 2013). As pinnipeds also undertake life-history behaviours on land, increasing air temperatures will affect their ability to undertake activities such as breeding, resting, and nursing young on land, as they will need to enter the water more frequently to thermoregulate (Schumann et al. 2013). Increased air temperatures have also been associated with a higher incidence of disease in pinnipeds (Schumann et al. 2013).

Temperatures also influence seasonal foraging patterns of turtles and increased temperatures are predicted to change the distribution of turtles including expansion to higher latitudes in NSW. Changes in food availability associated with high temperatures in foraging sites have been linked to reductions in females nesting (Poloczanska et al. 2009).

Increased sea surface temperature is associated with changes breeding success, breeding seasons, and survival of shorebirds and seabirds globally (Chambers et al. 2011). This can occur through a range of direct and indirect effects, including changes to food availability through changing trophic dynamics (including zooplankton, primary productivity, fish abundance and distribution), temperatures exceeding thermal tolerance, and subsequent changes to wind, rainfall, and storms increasing mortalities and reducing fitness (Baxter 2016). In Queensland, seabirds have been observed to reduce provisioning rates in high sea surface temperature conditions resulting in poor chick growth (Chambers et al. 2011). Several species of seabirds (e.g. sooty terns, bridles terns, lesser noddies) in south-western Australia have been laying eggs progressively later in the season since 1980, correlated with increased sea surface temperature (Chambers et al. 2011).

The proximity of foraging and nesting habitat is important for the fitness of seabirds and some species may be at risk where increased temperature changes the distributions or seasonal availability of prey resulting in longer foraging trips (Chambers et al. 2011). Increased air temperatures are also likely to impact roosting and nesting shorebirds and seabirds. Heat stress and mortality can occur in seabirds such as little penguins when air or burrow temperatures exceed 35°C (Chambers et al. 2011). Heat-associated loss of dune vegetation has also resulted in loss of nesting habitat of seabirds (e.g. black noddies) (Chambers et al. 2011). In NSW, air temperatures exceeding 42°C have been linked to losses to the viability of shorebird eggs (NPWS unpublished data).

Ocean acidification

Increases in atmospheric carbon dioxide concentrations are anticipated to acidify oceans and cause fundamental changes in ocean chemistry. They can also lead to metabolic disruptions through hypercapnia (excessive concentrations of carbon dioxide). Species diversity and abundance will generally decrease with acidification, shifting novel communities of non-calcifying organisms. Calcifying, sessile animals are the most vulnerable to ocean acidification (Parker et al. 2013, Ross et al. 2011). A particularly vulnerable group is marine molluscs (e.g. oysters, abalone, whelks), most evident in their pelagic calcifying larval stages (Parker et al. 2010, Scanes et al. 2014a).

Acidification acts in concert with temperature to reduce fertilisation success in Sydney rock oysters, resulting in smaller size, longer time to development and increased abnormality of larval stages, which are predicted to be most vulnerable (Parker et al. 2010). However, other studies reveal little influence of acidification and temperature on some processes (e.g. fertilisation) in a wide range of marine invertebrates (Byrne et al. 2010). Difficulties with calcification can also reduce the energy allocation to important processes, such as reproduction. The effects of temperature and acidification on marine invertebrates is dependent on life-history stage and the amount of change expected (Byrne et al. 2010, Byrne and Przeslawski 2013).

Elevated carbon dioxide may affect marine organisms through changes to metabolic physiology, calcification rates of hard structures (e.g. shells, external skeletons) and flow-on effects through changes to food webs (Provost et al. 2017). Estuaries in NSW may be more susceptible to reduced pH, because they are shallower, less saline and have lower alkalinity than marine waters; however, few studies have focused on potential effects to estuarine organisms (Gillanders et al. 2011).

Acidification also increases primary production and consumption by herbivores, as well as increasing energy required by carnivores when they hunt; this changes trophic structures and simplifies communities (Nagelkerken and Connell 2015). Little evidence has been found for adaptation to decreased pH (Nagelkerken and Connell 2015). Due to the regional scale changes in pH that are expected to occur, calcifying organisms across are a wide range of estuarine habitats are likely to be impacted in the longer term.

The primary impact of ocean acidification on marine mega-fauna is from reduction in prey availability (Schumann et al. 2013). For species that directly feed on calcifying organisms such as baleen whales, ocean acidification may deplete the amount of food available leading to fitness and population declines (Schumann et al. 2013). As many marine mammals are top order predators, reductions in all trophic levels will ultimately impact their prey availability and therefore declines in prey species that feed on calcifying organisms such as fish will also impact marine mammals such as dolphins and seals (Schumann et al. 2013). Marine turtles and birds may also be affected by ocean acidification from reductions in calcifying prey species such as molluscs and from decreased productivity from losses of coral reefs (Chambers et al. 2011, Poloczanska et al. 2009).

Altered storm and cyclone activity

Rainfall is a key determinant of climate-driven changes to nutrients, sediments and freshwater inputs (e.g. Andersen et al. 2006, Fan and Shibata 2015, Hancock 2012, Hinsby et al. 2012, Howarth et al. 2006, Jeppesen et al. 2009, Jeppesen et al. 2011, Kaushal et al. 2008, Van Liew et al. 2012). Typically, inputs are projected to increase when the amount and intensity of rainfall increase but not necessarily in direct proportion. For example, small changes to rainfall may translate to greater changes in freshwater inputs (Chiew and McMahon 2002, Newton 2009). The overall extent of change will partly depend on land use (Bossa et al. 2014, Fan and Shibata 2015, Tu 2009, Wu et al. 2013).

Urbanisation has the potential to amplify climate-driven exports of nitrate due to the increased hydrologic connectivity of impervious surfaces (Kaushal et al. 2008). Similarly, conversion of forest to agricultural land may promote greater nutrient and sediment exports under various climate scenarios, due to reductions in groundcover and soil water holding capacity (Bates et al. 1997).There are some good local examples of proactive management that seek to change the design of stormwater infrastructure to accommodate climate-driven changes to nutrient, sediment and freshwater inputs (http://www.wsud.org/adopting-wsud/background/climate-change). The ongoing release of NARCliM products will also assist in identifying management strategies that build resilience or allow waterways to adapt in a way that move them to a new, but healthy ecological state.

The reviews showed that in NSW the predicted changes in the abovementioned variables will alter ocean currents, due to increased frequency of El Niño-Southern Oscillation (ENSO) events; an increase in extreme storm surges; and a decreasing flow of fresh water to estuaries, with a shift in nutrient supply to the nearshore coastal waters. These alterations will be manifest in:

- significant estuarine and nearshore habitat change
- change in trophic (food chain) relationships

- shifts in the distribution and recruitment patterns of aquatic plants and animals, including commercially and recreationally harvested fish and invertebrates (Pecl et al. 2012, Cetina-Heredia et al. 2015).

Physical disturbance

The main events in NSW estuaries that results in physical disturbance are associated with east coast lows (intense low pressure systems). These will lead to:

- greater erosion
- periods of decreased salinity in estuaries
- increased nutrient and sediment inputs to estuaries
- increased erosion of stream banks
- greater loads of plastics and other marine debris.

Developments in the region that are near current high-tide levels will be susceptible to more frequent storm, tidal and ocean inundation. As sea levels rise, stormwater drainage is likely to become less effective, and will therefore affect urban areas near estuaries. Habitats currently susceptible to the combined effects of marine and catchment flooding will be further affected by sea-level rise; the scale of impacts will vary dependant on the vulnerability of each location. This will affect all estuary types along the NSW coast.

Ongoing water level, wave climate and rainfall time series data is being collected by Manly Hydraulics Laboratory, and the Port Hacking oceanographic station is being maintained under collaboration and contract with IMOS (Integrated Marine Observing System) (see Ajani et al. 2001, Lee et al. 2001; 2007, Thompson et al. 2009).

The NSW Climate Impact Profile 2010 will soon be superseded by the outputs of the NSW and Australian Capital Territory (ACT) Regional Climate Modelling (NARCliM) project[50]. This project provides more detailed climate projections to help local government, businesses and communities minimise the impacts of climate change.

Rainfall projections from NARCliM generally show an increase in summer and autumn rainfall, and decrease in spring and winter rainfall in the near future (2030) for most of the NSW coast (OEH 2015). Mean annual rainfall is projected to increase slightly (up to 3%) in the mid to northern parts of the coast, and decrease slightly (up to 3%) in the most southern parts by 2030.

Rainfall erosivity, which considers the intensity of rainfall, can be used to indicate the risk of soil erosion under future land use and climate change (Meusburger et al. 2012). Preliminary projections from NARCliM indicate that annual rainfall erosivity will increase by up to 20% in the Hunter, central coast and Sydney Metropolitan area (Yang, unpublished data). In these areas, there is likely to be a high risk of sheet and hillslope erosion, and increased delivery of sediment to adjacent waterways. Increases in erosivity and run-off will result in greater loads of nutrients and sediments to estuaries waters, which will cause excessive algal growth and turbidity, and in the longer term impact on a wide range of estuarine habitats, particularly saltmarsh, seagrass and subtidal rocky reefs (see relevant chapters in Poloczanska et al. (2012)).

Overall, the risk of impact of nutrients, sediments and freshwater inputs on the NSW marine estate is potentially high in areas where there is a coincident increase in rainfall, high erosivity and planned future urban expansion or intensification. The Hawkesbury–Nepean and the Hunter River catchments are likely to be at highest risk.

[50] http://www.ccrc.unsw.edu.au/sites/default/files/NARCliM/index.html

Storm and cyclone activity including flooding and storm surge are known to have significant impacts on marine mammals (Schumann et al. 2013). Flooding can alter conditions such as salinity, pH, turbidity, and DO and can have negative effects on species by reducing prey availability and causing osmotic disruption (Schumann et al. 2013). Indo-Pacific bottlenose dolphins in NSW have both died or abandoned estuarine habitats where flooding has altered water conditions (Schumann et al. 2013). Flooding can degrade water quality and increase the incidence of disease (Schumann et al. 2013). Toxoplasmosis is increasingly infecting cetaceans and high flooding in Queensland has led to greater infections in Indo-Pacific humpback dolphins (Schumann et al. 2013). Extreme events are known to increase strandings and misadventure, particularly of pinniped pups and cetacean calves (Schumann et al. 2013).

Estuarine species are more vulnerable to stranding during extreme events as they are unable to shelter in deeper water (Schumann et al. 2013). Species that calve in the calm waters of coastal bays and estuaries such as southern-right whales are also likely to be negatively affected by increases in extreme events that will alter the sea state (Schumann et al. 2013). Pinniped pup mortalities are known to increase during extreme events including of hauled-out pups that are washed from the shore into rough sea conditions (Schumann et al. 2013).

Juvenile turtles that forage in shallow estuaries will be vulnerable to increased severe weather events if they cannot shelter in deeper water (Poloczanska et al. 2009). Cyclone activity in Queensland has led to large-scale strandings and mortalities of green turtles (Poloczanska, Limpus, and Hays 2010). Where increased storms remove seagrass habitat or reduce seagrass from increased turbidity and poor water quality, foraging turtles will also be affected (Poloczanska et al. 2009). Changes in water quality after storms are also expected to negatively affect turtles in estuaries by increasing algal blooms and harmful run-off leading to poor health and increased disease (Poloczanska et al. 2009).

Altered storm and cyclone activity including flooding, storm surge, and inundation from extreme events can have catastrophic impacts on seabirds and shorebirds (Chambers et al. 2011). On land, inundation and extreme weather cause destruction of nests, breeding colonies, and increased mortalities (Chambers et al. 2011). On water, extreme weather can cause mortalities through injury, hypothermia, and poor foraging conditions (Chambers et al. 2011). Poor foraging conditions from extreme events also have compounding effects on fledgling rates during breeding seasons (Chambers et al. 2011). In particular, east coast lows and associated coastal erosion in NSW, which are predicted to increase, are already having detrimental impacts on shorebird breeding sites. In NSW, several critically endangered hooded plovers were lost to an east coast low event in June 2016, this included direct mortalities and loss of foraging and roosting habitat with animals moving to parkland and paddocks to forage (NPWS unpublished data). Additional chick mortalities were observed after flood events in Tuross Lake and Nelsons Lagoon, significant depletion of sand was observed in southern NSW during 2015 and 2016 at all known shorebird breeding sites, and an endangered little tern nesting site was impacted by a storm event in Bonville Creek Sand Spit (NPWS unpublished data).

In northern NSW, shorebirds including their nest habitat, nests, eggs, and chicks are typically impacted 4-6 times per year from storm events and inundation (e.g. increased swells, high tide events, flooding, hail). In 2017 in northern NSW, endangered little tern eggs and nests were lost during a severe hail storm, and a critically endangered beach stone-curlew nest and an endangered pied oystercatcher nest were lost to storm surge inundation (NPWS unpublished data). Due to the significant losses already occurring to threatened shorebird species, increased storm events with climate change are likely to have serious consequences for shorebirds in NSW.

Sea-level rise

Sea-level rise has been modelled, and other potential coastal and estuarine issues associated with climate change assessed for NSW (McInnes et al. 2009), resulting in a NSW-specific allowance for local sea-level rise attributable to local oceanographic processes, in addition to the Intergovernmental Panel on Climate Change (IPCC) global average (see DECCW 2010b). The NSW allowance was incorporated in the sea-level rise benchmarks adopted in the NSW Government’s Sea Level Rise Policy Statement (DECCW 2010b). More recent research has examined the nature of sea-level rise trends and the processes that contribute to sea level anomalies (MHL 2011).

The rate of sea-level rise since the mid 19th century has been larger than the mean rate during the previous two thousand years. Between 1901 and 2010, global mean sea level rose by 0.19 m. Global mean sea level will continue to rise, and is very likely to exceed rates observed during 1971 to 2010, due to increased ocean warming and increased loss of mass from glaciers and ice sheets. Sea level in the Sydney region is expected to rise 0.4 m and 0.9 m above the 1990 mean sea level by 2050 and 2100, respectively (DECCW 2010b). Flood frequency, height and extent are also likely to increase in the lower portions of coastal floodplains.

Sea level rise and storms are virtually certain to increase coastal inundation and erosion. This will cause the erodible coastline to recede: typically by 20–40 m by 2050, and 45–90 m by 2100, with shoreline retreat likely to be higher in estuaries. Where beaches are backed by seawalls, there is likely to be a reduction in beach habitat (DECCW 2010b). Saline waters may move into new areas of the coastal plain, inundating areas with acid sulfate soils and causing a decline in soil structure (e.g. tidal foreshores of the upper Parramatta River).

Saltmarsh, mangroves and some seagrasses are likely to be displaced, but mangroves should re-establish in other areas currently occupied by saltmarsh. Infrastructure and development are virtually certain to impede re-establishment of estuarine habitats in the urbanised or developed estuaries within NSW. Sea-level rise is a considerable threat to mangroves and saltmarshes where these habitats cannot retreat inland, due to a lack of available habitat (Ross and Adam 2013). As sea levels rise, the distribution of saltmarsh will be constrained by topography and structures such as seawalls, roads and buildings. In many places saltmarsh will be left with nowhere to migrate to, resulting in its loss from some coastal sites. The impacts on saltmarsh is expected to occur over the next 20 years, with overall impacts inceasing though time. The magnitude of overall wetland loss is uncertain reflecting limited information on the hydrodynamic and bio-geomorphic conditions in estuaries (Rodrı´guez et al. 2017). Further details are available in Rogers et al. (2012) and Roger et al. (2013) who examined the vulnerability and adaptive capacity of wetlands to cope with sea-level rise, based on the results of long-term monitoring of saltmarsh accretion. A review of responses of saltmarsh and mangroves to climate change stressors is also presented in McKee et al. (2012).

In the upper reaches of the Hunter River, much of the adjacent land is used for farming or agriculture. As such, there will be little scope for wetlands to retreat as sea levels rise, unless landward disturbances (e.g. grazing, flood mitigation infrastructure such as levies, hard surfaces) are removed or moved upslope. The function of much of this infrastructure and the land uses it facilitates will also be compromised. For example, floodgate drainage capacity is controlled by downstream tidal levels, particularly low tides. When these rise, the efficiency of the system is reduced, and floodwaters will take longer to drain.

Sea-level rise will result in beaches moving slowly inland, but the impacts on rocky shores are likely to be larger. Shifts in the range and distribution of species, the composition and interactions within rocky shore communities and the structure and dynamics of communities are expected to occur, and increasing through time. Because a rise in sea level will change the proportions of habitat orientation, a change to associated marine communities are likely (Vaselli et al. 2008). There is considerable uncertainty about the effect of sea-level rise on intermittent estuaries. However, it is anticipated that the water level will rise within the estuary, due to increases in berm height.

Estuarine food webs and some fishes are likely to be adversely affected, due to changes in species composition of estuarine invertebrates (DECCW 2010b). Loss of intertidal habitat is also expected to exacerbate the decline of migratory shorebird populations that use these areas for foraging and nesting (Jones et al. 2007). This includes internationally significant areas, such as Stockton, Homebush Bay and Towra Point (DECCW 2010a). Little penguin nesting areas are also likely to be impacted, for example, within North Harbour of Port Jackson which may be threatened by increasing sea levels, particularly during storms (Dann and Chambers 2013).

The increasing use of artificial structures (seawalls, breakwalls, etc.) to protect valuable coastal infrastructure in estuaries and along shorelines from climatic changes (sea level rise and storms) will have impacts themselves. The diversity and composition of marine biota are influenced by these structures and the materials they are made of (e.g. see review by Firth et al. (2016)) and their orientation (Vaselli et al. 2008). Artificial structures can facilitate invasive species (Glasby et al. 2007) which may increase the risk of invasion in the future with the proliferation of new structures. Moreover, the properties of some materials used to construct artificial structures will change chemically (e.g. concrete) with ocean acidification and temperature increases and this will have flow on effects to associated biota.

Sea level rise may impact marine mammals that breed and rest in coastal bays and estuaries such as humpback and southern right whales by limiting their preferred nearshore habitat (Schumann et al. 2013). Sea level rise may also impact pinnipeds by limiting suitable haul-out and breeding sites, particularly where current sites are on low-elevation islands or border cliffs (Schumann et al. 2013). If sea level rise impacts seagrass beds and infauna in estuaries, turtles are also likely to be negatively affected (Poloczanska et al. 2009). Shorebirds and seabirds that nest in low-lying areas are most at-risk to sea level rise. Birds that nest and forage on coastal beaches, mangroves, mudflats, and low-lying islands may be negatively affected by sea level rise due to inundation of their preferred habitat (Chambers et al. 2011). This is of particular concern where development impedes natural accretion of coastal habitats (Chambers et al. 2011). As inundation and increased extreme weather events are already threatening shorebird habitat and causing mortalities, any increase in sea level is likely to exacerbate these threats.

7. OPEN COAST AND CONTINENTAL SHELF

The continental shelf represents the section of seabed outside estuaries, which generally gradually increases in depth before reaching the shelf break (~200 m water depth). After this point, depth rapidly increases on the continental slope. This report focuses on the component of the continental shelf that is within the NSW coastal waters boundary and extends for 3 nm (the limit of state jurisdiction) offshore from either the mainland coast or the eastern coast of islands (e.g. Montague Island).

In general, the continental shelf of NSW is characterised by an inner-shelf zone (shoreward from ~60 m water depth) and an outer zone (>~60 m depth). The inner-shelf zone contains considerable amounts of rocky reefs that are either outcropping or close to the surface, while the outer zone is the surface of a thick sediment wedge (Boyd et al. 2004). The shelf contains a complex arrangement of both rocky reef and unconsolidated (mostly sand) habitats, the broad distribution of which reflects the inner shelf's patterns of bedrock geology, geological history and coastal inputs (Boyd et al. 2004, Jordan et al. 2010, Roberts and Boyd 2004).

The key feature of the shelf within NSW coastal waters is the regional and local variation in the slope of the seabed of the inner-shelf regions. This results in considerable regional differences in the extent of shallow (0–20 m) and deep (>20 m) seabed habitats. The slope's variation is further influenced by the longitudinal position of the NSW coastal waters boundary, which ranges from 5.6 to 18.4 km off the coast depending on the presence of offshore islands, such as Montague Island and North Solitary Island.

Overall, the inner shelf is steeper along much of the coast south of Newcastle than regions further north, except in some areas where large reef systems are present, such as in the southern part of Shoalhaven Bight. The majority of the inner continental shelf in the northern region is shallower than 60 m, reflecting its overall shallower slope in that region (Figure 56). In the southern region, much of the inner continental shelf contains depths greater than 60 m, with depths as great as 130 m in NSW coastal waters offshore from Montague Island (Figure 56). Steep depth gradients are prominent offshore from much of the Sydney coast and Jervis Bay, where the 60-m depth contour is located less than 1 km from shore.

Prominent rocky reef outcrops are found seaward of most headlands along the NSW coast, although significant rocky reef systems are also located in shelf areas that are not continuous to shore, or are continuous to shore on offshore islands. The ocean beaches are strongly influenced by wave exposure, resulting in fine-scale structuring of sand bars, troughs and gutters, and rip channels that are frequently changing (Short 2003). In addition to sand on beaches there are several distinct offshore sand bodies along the shelf (Boyd et al. 2004, Gordon et al. 1978).

7.1 COASTAL WATERS

The coastal waters within NSW is the habitat of the water column that exists vertically between the seafloor to the water surface, and horizontally between mean high water on the coastline and 3 nm seaward. The coastal water column contains different pelagic habitats, which are structured by a dynamic combination of depth, salinity, temperature, density, oceanic and inshore currents, and atmospheric conditions (e.g. wind). Surface layers are strongly influenced by atmospheric forces, while deeper water layers have more constant temperature and salinity, and increasing density. These deeper layers are strongly influenced by oceanic currents such as the EAC (Suthers et al. 2011).

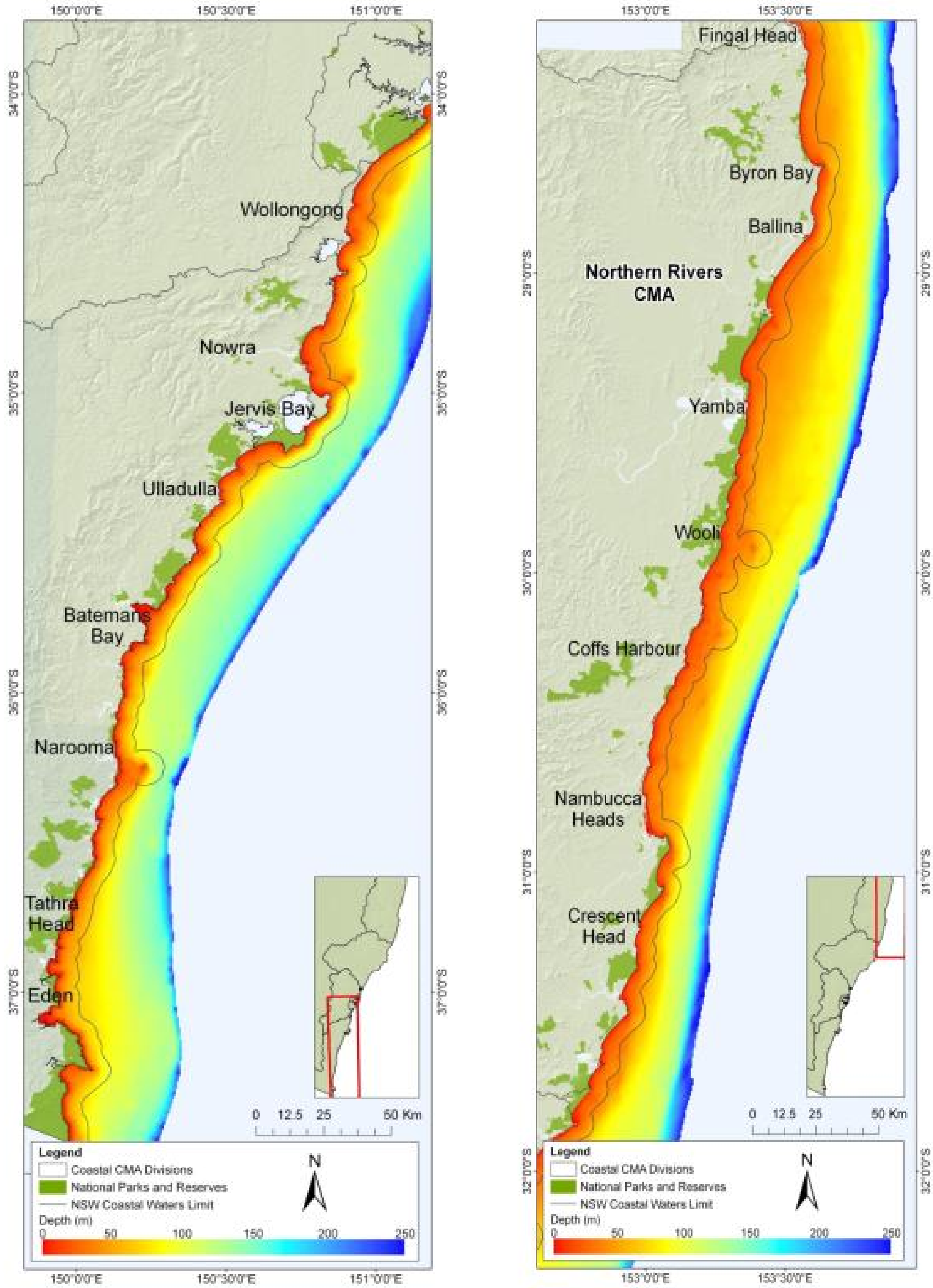


Figure 56. Interpolated, broadscale, bathymetry distribution along the northern and southern continental shelf regions of New South Wales.

The EAC, which brings warm water from the tropics, flows southward along the edge of the NSW shelf and dominates the area's oceanography. Its water is low in nutrients and salinity, and has a deep blue colour that is evidence of its low productivity levels. The EAC is variable between seasons and years. However, on average, it flows as a more consistent southward stream in the northern waters, then separates between Smokey Cape and Stockton Bight to head east along the Tasman Front towards Lord Howe Island, and then to New Zealand. Below the separation zone, large, warm- core, anticlockwise eddies pinch off and form an extension of the EAC to the south, reaching as far as the east coast of Tasmania.

While the EAC itself only occasionally washes over the shelf into NSW waters, it indirectly influences shelf waters in several ways. For instance, it interacts with the shelf slope to bring cold, deeper, nutrient-rich water from the slope on to the shelf. These intrusions occur periodically anywhere along the coast, but there are some well-known spots. Just south of Ballina and of Laurieton, for example, the alignment of the coast is conducive to upwelled waters that frequently reach the surface during northerly winds. Cold, core eddies shed from the shoreward side of the EAC can also lead to significant upwelling. The shelf within the southern region is less influenced by the EAC than are regions further north, but the current is still evident on the shelf at times, particularly during summer and autumn.

Four different mechanisms drive upwelling events along the NSW coast (Roughan and Middleton 2002). Three of these involve the EAC, while the other is a nearshore process. Regional and global-scale oceanic and atmospheric processes significantly influence nutrient dynamics, affecting the capacity of coastal waters to maintain nutrient, organic and inorganic processes.

While all rivers and bays with open entrances discharge into coastal waters, discharge volumes and sediment loads vary significantly. The major rivers discharging into NSW coastal waters are the Richmond, Clarence, Hunter and Hawkesbury. The discharges increase significantly during and following heavy rains year-round. Further details are provided in the OEH marine waters monitoring, evaluation, and reporting technical report[51].

7.2 COASTAL HABITATS

7.2.1 BEACHES

Ocean beaches contain both intertidal and shallow subtidal components. In NSW, beaches are exclusively wave-dominated, which tend to be either moderately sloping (intermediate) or steeply sloping (reflective), depending on their exposure to waves and swell. Wave and swell exposure strongly influences the type of sediments and presence of bars and rips. Sandbars, spits and beaches also change in size and shape depending on wind and water flow.

The NSW coast has more than 700 beaches, which vary in type, length, habitat configuration, exposure and sediment composition. For example, many ocean beaches are interspersed with intertidal reef, and contain subtidal rocky reef immediately offshore that reduces swell exposure and sediment movement. Although they are dynamic environments, the maximum tidal range of approximately 2 m generally results in a small intertidal zone.

The exposure of beaches to swells varies considerably. This is due to the complex shape of the coastline and the oblique action of predominant southerly swells hitting the coast, which sets up a northward sweep around the headlands and along the beaches. The northward sweep is responsible for the net northward longshore transport of sediment along the coastline.

The key ecosystem services provided by beaches relevant to this review (adapted from Defeo et al. 2009) include:

- water filtration and purification
- sediment storage and transport
- nutrient mineralisation and recycling
- breakdown of organic materials and pollutants

[51] http://www.environment.nsw.gov.au/soc/socTechReports.htm

- nursery areas for juvenile fishes
- nesting sites for turtles and shorebirds, and rookeries for pinnipeds
- prey resources for birds and terrestrial wildlife
- bait and food organisms
- functional links between terrestrial and marine environments in the coastal zone.

The **northern region** of the NSW marine estate is characterised by relatively long, wave-dominated beaches that mostly run north–south (Figure 57). A large proportion of beaches are >10 km long, and are broken up by smaller rocky headlands. The larger rocky headland features at Lennox Head, Evans Head, Woody Head, Nambucca Heads, South West Rocks, Port Macquarie, Forster, Seal Rocks, and Port Stephens to Stockton Beach result in many smaller beaches that generally contain adjacent areas of subtidal rocky reef. The extent of the adjacent rocky reef is large in some locations, such as the coastal section immediately north of Nambucca Heads.

Figure 57. Ocean beach in the northern region of New South Wales

Around 90 beaches are present in the **central region**, varying in type, length, habitat configuration, exposure and sediment composition. The many long sandy beaches include Narrabeen, Terrigal and Belmont, and numerous smaller beaches include Tamarama, Bilgola and Wattamolla. The **southern region** has more small beaches than the central region, reflecting the rocky shoreline that dominates most of the southern region. Large beaches in this region are found at Geroa, Shoalhaven, Bherwerre, Moruya North Dalmeny and Bermagui.

Associated biota

Primary productivity is generally small on beaches, because the unstable nature of the sediment, and substantial water movement and wave action prevent the growth of algae (Schlacher and Hartwig 2013, Schlacher et al. 2008b). Instead, the ecosystem is generally driven by the delivery of particulate detritus, dissolved organic matter, carrion, stranded algae or terrestrial plants arriving via run-off or as flotsam (Jones and Short 1995, Schlacher et al. 2008b). The delivery of these concentrated nutrients is naturally sporadic, although the input of low concentrations of nutrients from the ocean is relatively consistent.

Microscopic algae can add to primary production and provide food for some of the meiofauna (e.g. nematodes, copepods, and macrofauna, such as crabs) (Schlacher and Hartwig 2013). Phytoplankton also contribute to productivity, providing food for filter feeders such as pipis, and deposit feeders such as worms and snails (Jones and Short 1995, Schlacher et al. 2008b).

Different beach types and environments within beach systems support characteristic faunal assemblages, determined to a large extent by sediment particle size. Beaches with fine sands have a higher diversity of intertidal species, while beaches with coarse sands tend to have fewer species. The fauna of the lower beach may extend their distribution into and beyond the surf zone, into depths where the seabed is more stable. Detached macrophytic algal material, commonly found drifting in the surf zone following heavy seas, also supports characteristic assemblages of organisms different from those on plants of nearby reefs.

Attached plants are generally absent, because of the mobile nature of sand and the lack of protection from wave energy. However, a diverse range of invertebrate species can occur below the sand surface, the most obvious being the macrofauna, which is dominated by crustaceans, polychaetes and molluscs (Jones and Short 1995). Typical invertebrate macrofauna associated with NSW beaches include *Pseudolana elegans* (isopod), *Urohaustoriius gunni* (amphipod), and *Scolelepis normalis,* and *Nepthys australiensis* (polychaetes) (Hacking 1998). Two of the more familiar species on sandy beaches are the pipi *(Donax deltoides)* and beach worms (Family: Onuphidae). Recreational anglers often collect these species for bait. Many smaller species live within the sediment, including algae and crustaceans, which are an important part of the food chain in this habitat.

Scavengers, such as ghost crabs, are a major trophic group on beaches. They break down organic material, form prey for other invertebrates, fishes and birds, and are also collected by recreational anglers for use as bait. Deposit feeders also remove and cycle organic material by indiscriminately ingesting sediment, or selectively eating organic particles from sediments; however, they are not generally common on ocean beaches (Jones and Short 1995). Filter feeders are the major group of macroinvertebrates on beaches.

Predation and recruitment are likely important ecological processes that structure the marine biodiversity on ocean beaches. Predation by fishes, crabs, macroscopic invertebrates and humans can influence fluctuations in these assemblages.

Sandy beaches are key foraging and roosting sites for shorebirds and seabirds. This includes threatened species, such as the little tern, pied oystercatcher and beach stone-curlew. Beaches are also important for nesting turtles, with records of both green turtles (*Chelonia mydas*) and loggerhead turtles (*Caretta caretta*) nesting on northern NSW beaches.

The habitat use and life-history characteristics of several species associated with beach habitats has recently been reviewed, and provides the most current summary from primary and grey literature (Curley et al. 2013b). Further information on species common in ocean beach habitats is detailed in Rowling et al. (2010) and references within.

7.2.2 SHALLOW SOFT SEDIMENTS

Shallow soft-sediment habitats are extensive throughout NSW marine waters, and are likely to be the dominant habitat in most sections of the coast. In general, they are dominated by sandy sediments, but they also commonly contain pebbles, cobbles and boulders. Soft sediments have been mapped into a shallow habitat class (0–25 m), consistent with rocky reef classes. As yet, there is little ecological basis for these specific classes: but this classification broadly reflects the main classes of sediments.

Soft sediments are the dominant shallow-water habitat on the open coast of the **northern region,** due to the relatively small amount of shallow rocky reef. This reflects both the regional geology and sediment supply along this section of the coast. Inner-shelf sediments have been examined in detail across the northern region. In the Byron Bay area, Gordon et al. (1979) and Bickers (2004) investigated marine sediments. They found surficial sediments containing quartzose sand with variable amounts of shell and gravelly sand around reefs, but little mud. Sand covers the inner nearshore zone to a depth of 5–10 m, and forms an inner-shelf sand body to depths of 11–22 m.

The **central region** contains a much higher proportion of rock-dominated shoreline that extends into shallow depths, resulting in a lower proportion of shallow soft sediments. The **southern region** also contains a large amount of rocky shoreline, and smaller beaches as a result. However, soft sediments are still the dominant shallow-water habitat on the open coast of this region.

The majority of shallow soft-sediment habitats have been mapped on the open coast of NSW, at least out to approximately the 15 m depth contour, particularly in the central region and within most marine parks (Jordan et al. 2010).

Associated biota

Many of the animals within the shallow soft-sediment habitat occur as infauna (animals living within the sediment), generally dominated by amphipods, bivalves and polychaete worms. Overall, gradients in sediment type, in combination with depth, can considerably change macrofaunal composition. Studies on soft-sediment infauna suggest that shallow, nearshore communities are highly dynamic, reflecting their high-energy wave environment. The fine-scale structuring of soft-sediment habitats is influenced primarily by sand ripples and waves, and variations in particle size and shell content (Ku 2007). This is likely to result in small-scale variations in faunal composition, because habitat structure is often strongly related to macrofaunal diversity in soft-sediment habitats.

Soft-sediment habitats on the inner continental shelf also commonly contain larger, sessile macrofauna (e.g. sponges, ascidians, bryozoans, seawhips) that increase the diversity and complexity of the habitat. These are particularly prevalent in areas of higher current flows adjacent to offshore islands and pinnacles, but are less common in shallow areas due to the extent of disturbance from waves and swell.

The composition of fishes in shallow soft-sediment habitats changes along the coast, with more tropical and subtropical species occurring in the northern region. The dominant fish species include ambassids, atherinids, eastern Australian salmon, yellowfin bream, flatheads, leatherjackets, girrellids, sea mullets, tailor, sand whiting and stingrays. Both adults and juveniles are caught in these habitats, indicating that the shallow, subtidal areas off beaches serve more than just a nursery function; they are also important spawning and feeding areas. Two threatened shark species (the grey nurse shark, *Carcharias taurus,* and white shark, *Carcharodon carcharias)* occasionally move through the shallow waters adjacent to ocean beaches.

The habitat use and life history characteristics of several species associated with shallow soft-sediment habitats has recently been reviewed, and provides the most current summary from primary and grey literature (Curley et al. 2013b). Further information on species common in ocean beach habitats is detailed in Stewart et al. (2015) and references within.

7.2.3 DEEP SOFT SEDIMENTS

Deep soft-sediment habitats are extensive throughout NSW marine waters, and are likely to be a dominant habitat along most sections of the coast. In general, they are dominated by sandy sediments, but also commonly contain pebbles, cobbles and boulders. Overall, the sediments on the shelf of the **northern region** are mostly dominated by inner-shelf sand, mid-shelf muddy sand and outer-shelf carbonate sand, although there are localised variations to this broad pattern (Roberts and Boyd 2004, Boyd et al. 2004). The wide distribution of coarse sediment throughout the inner continental shelf reflects the small input of finer coastal sediments, strong tidal currents and oceanic swells (Boyd et al. 2004). The most significant sediment variations on the inner shelf are patchy, finer sediments offshore from the Yamba and Wooli regions, and coarser sand offshore from Tweed Heads, areas south of Yamba, and throughout the Solitary Islands region.

Offshore from the Clarence River, different types and size range of sediments are found on the inner shelf, identified as nearshore sand and inner-shelf sand (Walsh and Roy 1983). Overall, grain size in the nearshore sands becomes finer as distance offshore increase. Fine-grained, muddy sands blanket the area off the mouth, and extend south of the Clarence River, with a belt of coarser inner-shelf sands seaward of the nearshore sands and muddy sediments. There is also evidence of a mound of sand around 8 km long and up to 5 km wide located ~4 km seaward of the Iluka Bluff to Woody Head coastline (Jordan et al. 2010), defined as an inner-shelf sand body. Previous interpretations of the area (Walsh and Roy 1983) suggest that sediment may be actively supplied to this sand body.

There is significant fine-scale structuring of unconsolidated habitats on the inner and mid-shelf, influenced primarily by sand ripples and waves, and variations in particle size and shell content (Bickers 2004, Ku 2007). Some areas contain varying amounts of boulders, cobbles and pebbles, particularly adjacent to areas of rocky reef. A detailed examination of sediments around a large, inner-shelf reef complex north-east of Coffs Harbour found distinct areas of gravel, coarse sand and fine sand, but no overall relationship between grain size and proximity to the nearest reef edge (Ku 2007). The majority of the areas with coarse or gravel-like sediment contain large ripples (>60 cm) and those with fine sand contain small ripples (<60 cm). Many areas also have sharp transitions between fine and gravel-like substrates, with coarse sediments generally occurring in depressions up to 1 m deeper than surrounding fine sediments.

More broadly, fine-scale variations in sediment type and seabed morphology are evident in all areas mapped. Much of the sediment within the reef complexes contains a high proportion of boulders, cobbles and pebbles, and variability in sediment size at a range of spatial scales is a key feature of most areas of deep soft-sediment habitat.

A large proportion of deep, soft-sediment habitats have been mapped on the open coast of NSW, particularly in the central region and within most marine parks (Jordan et al. 2010).

Associated biota

As many as 241 species of infauna have been identified from soft-sediment habitats in the Solitary Islands area, excluding potentially diverse groups, such as polychaete worms and isopods (Smith and Rowland 1999). Approximately 85% of the species identified in soft-sediment samples were not previously been listed for the Solitary Islands region, and species diversity and composition increased from shallow sites (20 m) to intermediate sites (50 m) (Smith and Rowland 1999).

The variations in sediment type, in combination with depth, are likely to cause considerable differences in macrofaunal composition (Edgar et al. 1999, Beaman et al. 2005). Differences in species composition are found between samples taken from coarser-grained gravel-like substrates, sand and mud areas. Most of the animals within these habitats occur as infauna, although the habitat also commonly contains larger sessile macrofauna (e.g. sponges, ascidians, bryozoans, seawhips) that increase the diversity and complexity of the habitat (Bax and Williams 2001, Bickers 2004, Beaman et al. 2005). These are particularly prevalent in areas of higher current flows adjacent to offshore islands and pinnacles. The abundance and diversity of sessile macrofauna often decreases with depth, with deep unconsolidated habitats containing a few octocorals (soft corals or sea fans) and ascidians (Bax and Williams 2001, Beaman et al. 2005).

While there is currently little information regarding the distribution and diversity of soft-sediment assemblages in the regions, it is likely that the considerable structural complexity in this habitat (Jordan et al. 2010) influences the patterns of faunal assemblages.

The habitat use and life history characteristics of several species associated with deep soft-sediment habitats has recently been reviewed, and provides the most current summary from primary and grey literature (Curley et al. 2013b). Further information on species common in ocean beach habitats is detailed in Stewart et al. (2015) and references within.

7.2.4 HEADLANDS AND ROCKY SHORES

Rocky shores represent those areas of the coast where the local geomorphology has resulted in intertidal areas dominated by rock. They are common along both exposed and sheltered coastlines of NSW, and occur adjacent to the majority of rocky headlands. Due to regional differences in geology, rocky shores are more common in the central and southern regions than in the north. The extent and structure vary greatly, depending on the dominant rock type (e.g. platform, cobble, boulder), exposure (e.g. protected, exposed), and slope (e.g. steep, inclined, flat) (Figure 58).

Figure 58. Rocky shore on the open coast of New South Wales. *Source NSW DPI*

Associated biota

Weathering produces cracks, crevices and pools in rocks. These are important habitats for a diversity of organisms. Rockpools, crevices and shallow gulches generally retain seawater during low tide. Distinct patterns of marine invertebrates, rockpool fishes and algae are often found within this habitat, although considerable temporal and spatial variations are common.

Local variations are thought to be determined by levels of exposure, wave action, complex biological interactions (e.g. competition, predation), patchiness in recruitment and the history of disturbances at individual sites, with many species occurring over different parts on the intertidal reef rather than in distinct and consistent zones (Underwood and Chapman 1995, Otway 1999). There is evidence that an increase in the structural complexity of the rocky shore increases the number of microhabitats, which may increase the diversity of species within an area (Smith and James 1999, Smith 2005).

Previous studies have identified a range of areas within rock platforms (Underwood and Chapman 1995, Smith and James 1999, Otway 1999 and references within), including:

- a high-shore area dominated by littorinid snails
- wave-exposed, mid-shore areas occupied by barnacles and limpets
- sheltered, mid-shore areas dominated by barnacles and grazing snails, such as *Nerita atramentosa, Bembicium nanum* and *Austrocochlea constricta*
- low-shore areas dominated by the encrusting tube worm *Galeolaria caespitosa*
- a low-shore algal community with a range of animals, including solitary ascidians (*Pyura stolonifera*) and macroalgal grazing chitons.

While some organisms occupy a range of habitats, many are restricted to certain areas within the rocky shore, such as rock pools and crevices. Some of the most diverse and abundant animals are gastropods (e.g. whelks), chitons and bivalves (e.g. oysters, mussels) (Smith and James 1999, Smith 2005). Crustacean species are also common, particularly barnacles and crabs, along with conspicuous echinoderms (e.g. sea urchins, starfish) and anemones. A range of fish species are also commonly found in rock pools (Harasti et al. 2013), including juvenile black cod (Harasti et al. 2014).

A diverse and conspicuous range of plant species often grow on rocky shores. These are generally defined as encrusting, foliose or canopy-forming species. Some of the more obvious species are Neptune's necklace (*Hormosira banksia)*, several green algae (*Ulva* spp. and *Ulva* spp.) and assemblages of red algae. Coastal rocky shores are also important roosting and feeding habitats for many birds, including threatened bird species such as the sooty oyster catcher, and species that use the shore for feeding or shelter during high tide. Rocky shores on islands may provide an important refuge from disturbance and feral predators.

The ecology of ocean intertidal reefs has been researched along the Sydney and adjacent coasts (see Underwood and Chapman 1995; 2000, Underwood 2000). Studies in the northern part of the central region assessed rocky shores by morphology (e.g. rock platform, crevices, rock pools, boulders and cobbles) and tidal height (Gladstone 2005, Gladstone et al. 2007, Gladstone and Sebastian 2009).

Similar habitats in northern and southern NSW have received far less attention (Underwood et al. 1991). However, studies have indicated spatial differences in relative diversity of coastal rocky shores in the northern region when standardised for area (Smith and Simpson 1991a, b, Smith and James 1999). This was influenced by the presence of the murex shell (*Pterotyphis angasi*), bubble shell (*Hydatina physis)*, flower stromb (*Strombus mutabilis)*, nudibranch (or spanish dancer, *Hexabranchus sanguineus*) and the giant clam (*Tridacna maxima)*.

7.2.5 SHALLOW ROCKY REEFS

The distribution of shallow subtidal rocky reefs (i.e. those in depths <25 m) has been mapped along the entire open coast of NSW. Prominent, rocky reef outcrops are adjacent to most headlands along much of the coast, although significant shallow-reef systems are also found immediately offshore from ocean beaches in all regions. Overall, some distinct regional differences are seen in the extent and distribution of shallow rocky reefs along the NSW coast.

The **northern region** is generally characterised by small, isolated shallow reefs, mostly associated with rocky headlands (Figure 59). The main exceptions with substantial areas of shallow reef are Woody Head, Shelley Beach Head, Brooms Head, Woolgoolga area, Nambucca Heads, Black Head, and between Port Stephens and Stockton Beach. Shallow reef also occurs adjacent to most of the offshore islands in the north coast region, including Cook Island, Julian Rocks, North West Rock, Groper Islet, South West Solitary Island, North West Solitary Island, Split Solitary Island, Broughton Island, Cabbage Tree Island and Little Island. The full extent of the shallow reef has not been mapped in all areas, with nearshore sections likely to extend further offshore in most places.

The **central region** contains extensive areas of shallow-reef system, particularly adjacent to the Sydney coast: mostly offshore, continuous around headlands and separated by sandy beaches (Figure 60). Much of the reef extends offshore into deeper water, continuous with deep reef habitats. The seabed is characterised by large blocks of reef separated by irregular corridors of soft sediment, often surrounded by smaller patches of reef on the outer edges.

The southern part of the central region from Sydney to Stanwell Park is composed of Triassic sandstones, which form the coastline and characteristic high cliffs. Given the consistent geology of this area and the Sydney coast, and that the majority of the coastline contains nearshore reef, extensive areas of reef on the shelf are likely.

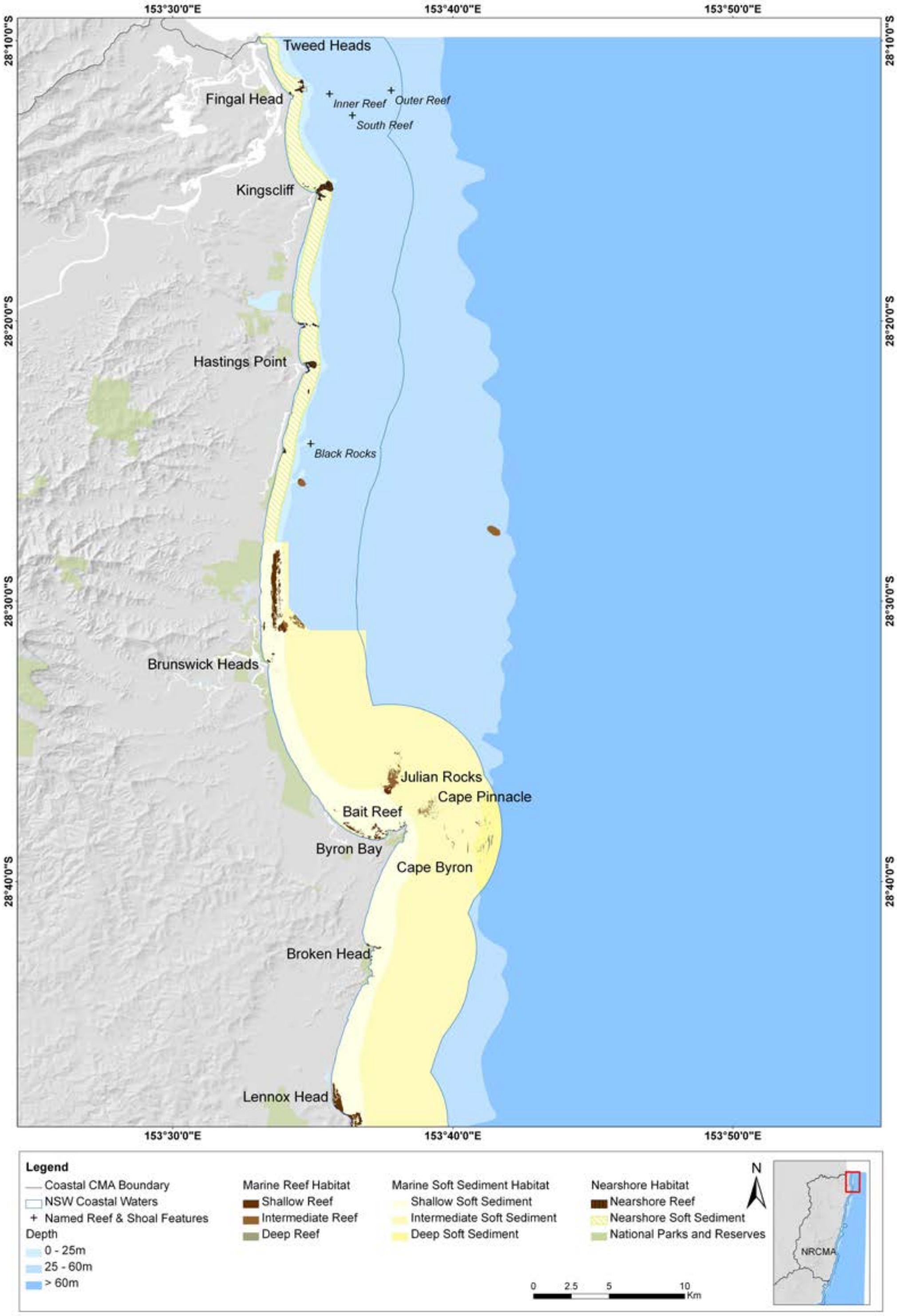


Figure 59. Map of seabed habitats showing extent of shallow rocky reefs in a portion of the northern region of New South Wales. *Source NSW OEH.*

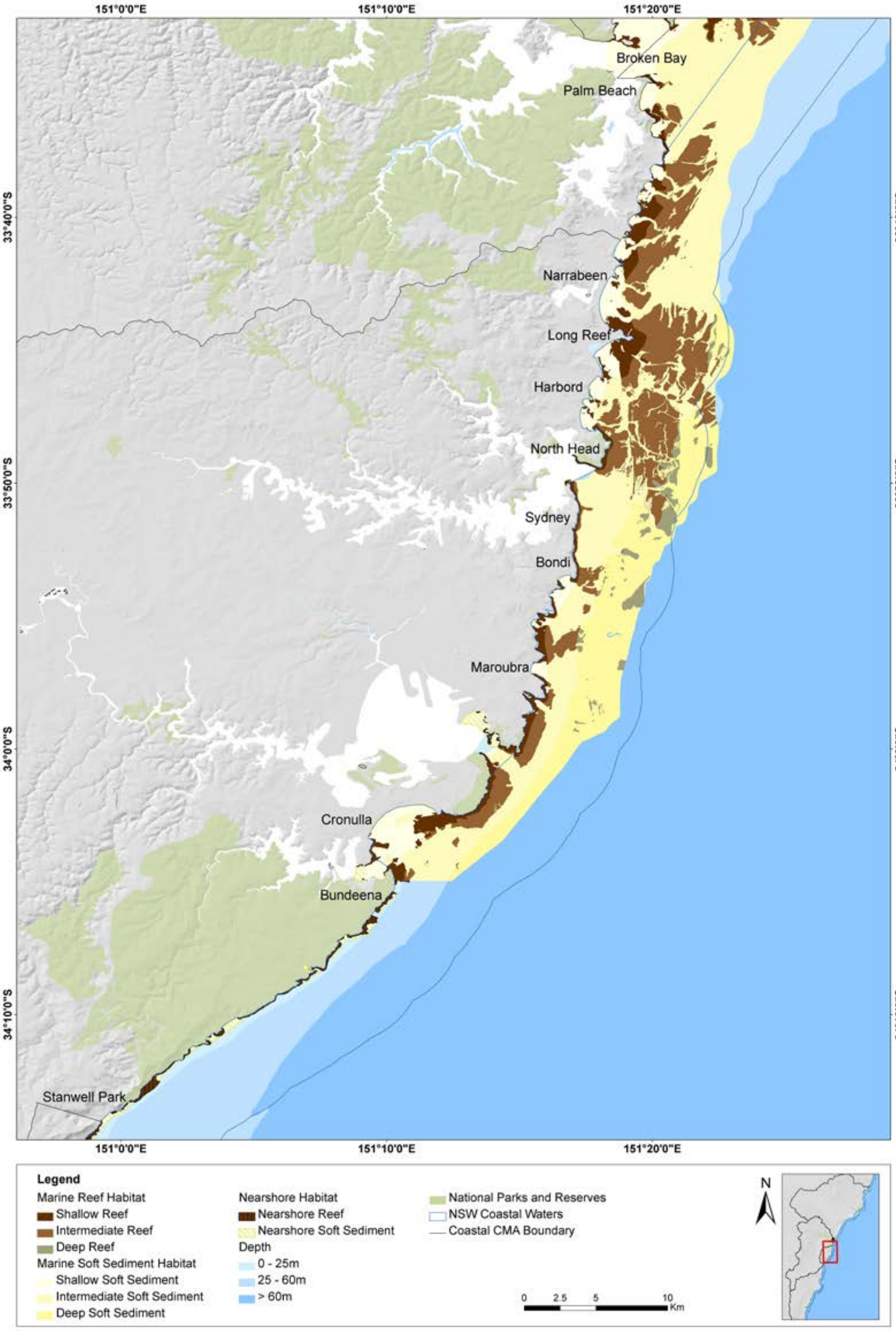


Figure 60. Map of seabed habitats showing extent of shallow rocky reefs in a portion of the central region of New South Wales. *Source NSW OEH.*

A large proportion of the **southern region** contains shallow nearshore reef, particularly adjacent to the headlands and areas with continuous rocky coastline (Figure 61). Prominent reef systems are found offshore from Brush Island, Tollgate Island and Montague Island. Several distinct areas of these reefs are characterised by moderate slopes and rapid increases in depth associated with near-vertical walls. There is also evidence of large areas of intermediate and deep reef at considerable distances offshore, particularly offshore of the Tollgate Islands. Their structure varies considerably as the reefs directly north and south of the Tollgate Islands drop considerably faster to the surrounding seabed than those to the east. The reefs in this region generally also contain a matrix of sand gutters of varying extent, which mostly contain well-sorted sand and gravel. The small amount of swath acoustic coverage along this section of coast indicates that intermediate reef is present on the inner shelf, although its extent is unknown.

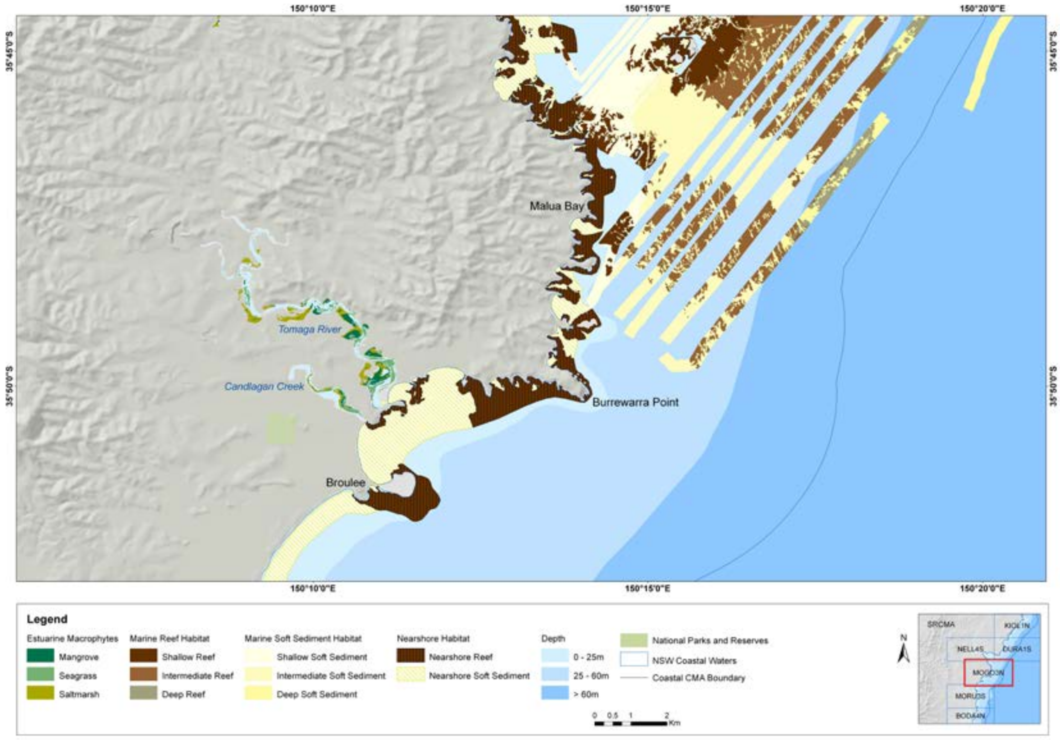


Figure 61. Map of seabed habitats showing extent of shallow rocky reefs in a portion of the southern region of New South Wales. *Source NSW OEH.*

An extensive nearshore reef system also occurs along the shoreline of this region. Near Narooma, however, the coast has much higher proportion of sand-dominated beaches, which are interspersed with nearshore reef: primarily adjacent to the prominent headlands, such as Broulee and the Moruya Heads region. While these large headland reefs appear to extend further offshore, many of the smaller reefs (e.g. off Tuross Head and north of Narooma) only extend around 100 m from the shore. South of Narooma, patchy nearshore reef is adjacent to the rocky shorelines, but not as consistently as the fringing subtidal reef that occurs adjacent to intertidal reef. Much of the reef is either not continuous to shore, or becomes greater in extent with increasing distance from shore.

The majority of shallow-reef habitats have been mapped on the open coast of NSW, at least out to approximately the 15 m depth contour, with adjacent reefs mapping in many areas, particularly in the central region and within most marine parks (Jordan et al. 2010).

Associated biota

While shallow subtidal reef habitats can be described by their dominant benthic biota, there is only limited information about the distribution of the animals and plants that dominate the rocky reef habitat at the local level. This reflects the high variability of benthic communities at different; they often occur as a mosaic of habitats. Overall, shallow rocky reefs contain a diverse assemblage of plant, fish and invertebrate species. These range from small, sessile or cryptic residents through to transient species that move between reef systems. Subtidal rocky reefs provide attachment space for a wide range of sessile species (algae and invertebrates) which in turn create further habitats for numerous species of fish. Rocky reefs are made up of habitats such as fringe, turf, macroalgal beds, urchin-grazed barren areas and, in deeper water, ascidian or sponge gardens (Edgar 1997, Kennelly 1995a). Large brown algae (e.g. *Ecklonia radiata*, *Sargassum* spp., *Cystosiera* spp) are common in the lower reaches of many wave-dominated estuaries.

Macroalgae are the dominant habitat-forming biota in these areas, a major primary producer of coastal regions and the basis of many food webs. Overall, the species composition of algal assemblages is determined primarily by depth, exposure to swell, latitude, distance offshore and patterns of recruitment and grazing; it therefore varies within and between reefs. The species richness of many groups can be high. For example, up to 588 species of macroalgae have been identified within the northern NSW region (Rule et al. 2007).

Macroalgae also provide habitat and shelter for invertebrates and fishes (Steinberg and Kendrick 1999). Microscopic species, such as copepods and amphipods, inhabit the dense algal turfs and the extensive surfaces of kelp fronds. A diverse assemblage of sponges, bryozoans and ascidians inhabit the kelp holdfast, while lobsters and kelp fish inhabit the kelp forests for shelter, protection and food. Many of these species are not found on rocky reefs that do not contain abundant macroalgae.

In the **northern region**, the pattern of habitats is generally different on shallow reefs around the offshore islands (Figure 62). Some of these have been mapped at a fine scale, including at Split Solitary, South Solitary Island, North Solitary Island, South West Solitary and North West Solitary Island (Smith and Edgar 1999). These islands are fringed by different reef habitats, including those dominated by coral, kelp, boulders, gravel, algae and urchin barrens (Smith and Edgar 1999). Despite fine-scale differences in the distribution of the main habitat types, such as kelp and coral, most habitats are generally present around each island. Overall, corals tend to be a dominant component on reefs more than about 1.5 km from the coast and less than 25 m deep, with hard coral cover on mid-shelf reefs reasonably high at a mean of 37% (Malcolm unpubl. data).

Figure 62. Coral habitat on shallow reefs in the northern region of New South Wales. *Source NSW DPI.*

These patterns are most likely due to variability in natural processes such as growth, recruitment, competition and predation. There are also strong cross-shelf differences in fishes associated with shallow reefs in the Solitary Islands region (Malcolm et al. 2010; 2011). Three distinct assemblages occur on the shallow reefs defined as inshore (1.5 km), mid-shelf (1.5–6 km) and offshore (>6 km), with the cross-shelf pattern persistent over the scale of years.

Shallow rocky reefs in both the **central** and **southern regions** are dominated by macroalgae and associated biota, often with an understory of turf and sessile invertebrates. Urchin barrens (Figure 63) are a dominant habitat type on shallow reefs in the central region, with an estimated cover of around 50% (Andrew and O'Neill 2000). Many reefs in the central region contain large, barren areas; those adjacent to Point Stephens extend from close to the shoreline down to around 30 m deep. These constitute a distinct habitat dominated by encrusting coralline algae and higher numbers of planktivorous fish (Curley et al. 2002).

Figure 63. Urchin barren. *Source NSW DPI.*

Abundant fish species in NSW rocky reefs include snapper, red morwong, yellowfin bream, luderick, rock blackfish (drummer), wobbegongs, bullseyes, eastern blue groper, and many species of wrasse and leatherjackets. Many pelagic migratory species also regularly occur on shallow reefs, including yellowtail kingfish, silver trevally and yellowtail scad. These fishes vary considerably in their ecology and life-history characteristics (e.g. distribution, habitat use, movement, age, growth). Several threatened fish species, such as the grey nurse shark, white shark and black rockcod, are also found on or near rocky reefs along the NSW coast.

The composition of fishes on shallow reefs varies along the coast, with an increasing number of tropical and subtropical species occurring in the **northern region**. Fish assemblages within the region are also very diverse, with a dominance of temperate species, and an influx of tropical species over the warmer months. From around December to May, water temperatures in the region are more strongly influenced by the EAC, which transports a variety of juvenile and adult tropical species into the region. Water temperatures during this period are normally 21–24 °C, allowing tropical vagrants to settle and establish in areas outside their normal range. This mix of tropical and temperate species increases diversity, albeit temporarily, over summer and autumn (Malcolm et al. 2010).

The invertebrate fauna of the continental shelf of northern NSW is comprised of a mix of warm-temperate, subtropical and cool-temperate fauna. Several lists of invertebrate have been published from NSW, but they are all from the Sydney region (Ponder et al. 2002). No comprehensive list of northern NSW fauna is currently available for any invertebrate group, with a few exceptions. Phipps and Tarrant (1988) produced a checklist of marine molluscs, echinoderms and corals from the Solitary Islands Marine Park, and various authors have examined coral communities (e.g. Veron et al. 1974, Veron and Done 1979, Harriott et al. 1994, Harriott et al. 1999). A comprehensive review of specific marine taxonomic groups in the northern region is presented in Rule et al. (2010).

Smith and Simpson (1993) recorded more than 400 verified invertebrate species from a study of *Ecklonia radiata* holdfast assemblages. More than 50% of the recorded species are molluscs, with crustaceans, polychaetes and echinoderms being the next most diverse groups. The remaining taxa are each represented by fewer than 50 species, with brachiopods, echiurans, nemerteans, platyhelminths, sipunculids and urochordates represented by fewer than 10 species. More sampling effort is needed for most invertebrate taxa to allow even a basic estimation of the biodiversity of the region.

7.2.6 DEEP ROCKY REEFS

Deep rocky reefs (i.e. those in depths >25 m) are a common habitat in NSW coastal waters, with many areas mapped at high resolution over the past decade. For the purpose of this assessment, rocky reefs in depths >25 m are classed as 'deep', which is a combination of both 'intermediate' and 'deep' categories presented in related seabed mapping reports, particularly Jordan et al. (2010). The broad distribution of the habitat reflects the patterns of bedrock geology, showing considerable variability in geomorphic structure (e.g. boulders, gutters, walls, pinnacles) and patchiness extent.

Deep rocky reefs are generally continuous with shallow reefs adjacent to rocky headlands or offshore islands. Their extent has only been fully mapped in some regions, often within existing marine parks and within much of the central region. This limits the capacity to evaluate the actual extent of the habitat. However, there are indications that the extent of deep reef varies regionally, with more reef in the southern region than in the north.

The **northern region** has extensive areas of deep, rocky reef, which have been mapped in areas offshore from Tweed Heads, Cape Byron, Yamba, Port Macquarie, Seal Rocks and Port Stephens, and throughout the Solitary Islands area. A number of known reef and shoal areas are yet to be mapped, including those offshore of Old Bar, Lake Macquarie and Tuggerah Lakes. North of Newcastle, rocky reef areas include nearshore reefs that extend several kilometres offshore into intermediate depths (e.g. Black Head); discrete, intermediate-depth reefs (e.g. The Pinnacles); and island-associated reefs that extend into intermediate depths (e.g. Broughton Island).

The extensive reef systems adjacent to the Sydney coast indicate there is a mostly continuous reef on the inner and midshelf regions, particularly south of Sydney Harbour. Some large reef systems extend up to ~7 km offshore, continuous with headlands and separated by sandy beaches (Figure 60). The majority of the reef occurs in intermediate depths, which often start within several hundred metres from shore, indicating steeply sloping nearshore reefs. The seabed is characterised by large blocks of reef separated by irregular corridors of soft sediment, surrounded by smaller patches of reef on the outer edges in many places.

Reef habitat is less extensive south of Sydney Harbour, with most restricted to within around 1.4 km from shore. The seabed is dominated by intermediate reef, which is at its greatest extent off North Head and Long Reef. Reflecting the steeper overall slope of the inner shelf off Sydney Harbour, deep reef is present only ~1.5–3 km offshore: much closer than similar depths in most other regions. The lack of high-resolution swath bathymetry for the reefs in the Sydney region precludes an assessment of the reef structure, although it is likely to be patchier and more complex than represented.

There are extensive areas of deep rocky reef throughout both the **central** and **southern regions**, although significant areas of the continental shelf in these depths remain unmapped. Large areas of deep rocky reef habitat have been mapped on the open coast of NSW, particularly in the central region and within most marine parks (Jordan et al. 2010).

Associated biota

A gradual transition in dominant habitat-forming biota generally occurs at a depth of around 25–30 m. Here, kelp (and coral in the north) often decrease in abundance, becoming sparse within a mosaic of algae and sponge-dominated assemblages. The habitat often contains a range of sessile invertebrate species, including sponges, ascidians, octocorals, soft corals, anemones and bryozoans (Bickers 2004, Edgar 1997, Fitzpatrick 2003, Mau et al. 1998). Erect, vase, elongate, tubular, and branching sponges are common, while black corals (*Antipathes* sp.), sea pens, sea whips and branching soft corals are sparsely distributed. Over 50 species of sponge were identified on a small number of deep reefs off Sydney, with the number of sponge species increasing with depth, particularly for the erect or massive species (Roberts and Davis 1996). The cover of encrusting sponges decreased with depth and small-scale spatial variation in sponge distribution and abundance was a feature of the habitat. In general, sessile invertebrate abundance and diversity is lowest in sections of deep reef consisting of cobble and boulders, with the more continuous, higher-profile reef supporting greater diversity.

Deep rocky reefs also contain a wide diversity of less conspicuous marine animals including nudibranchs, many types of molluscs (e.g. cowries), bryozoans, feather-duster worms, basket-stars, seawhips and seastars, anemones, crabs, shrimps, and octopus (Edgar 1997). Rocky reefs also contain a diverse assemblage of fish species that range from small cryptic residents through to transient species that move between reef systems. Marine turtles are known to frequent these rocky reefs where they seek protection and food.

The variability in reef complexity is likely to influence the diversity of biota within the region (Harman et al. 2003). The high diversity in sponge growth forms indicates a high species diversity (Bell and Barnes 2001), although large plasticity in growth forms occurs for some species (Ponder et al. 2002).

The composition of fishes, pelagic migratory species and threatened fish species on deep rocky reefs have some similarity to those found on shallow reefs, but a number of species are specifically associated with the deeper reef habitats. The most abundant cryptic species are the bullseyes *Pempheris compressa* and *P. affinis* and the white ear *Parma microlepis*, while there are a number of cryptic species that tend to live in crevices and holes within the reef (e.g. anglerfish, moray eel).

Deep subtidal habitats are potentially an important zone for direct interaction between estuary and marine fauna, with a range of consequences for intertidal habitat use and nursery ground functioning. The interface between marine areas and the shallow water estuary may be richer and more complex than previously recognised (Bradley et al. 2017).

7.2.7 FISH ASSEMBLAGES

Fishes in coastal and continental shelf areas of NSW are highly diverse, often habitat specific, with large variations in the extent of movement either seasonally or all year round. The NSW coastline gradually changes from tropical in the north to cool temperate in the south hosting a broad range of habitat for fishes including rock pools, soft sediments and rocky reefs that extend to around 100 m within State coastal waters. The composition of fishes on shallow reefs varies along the coast, with an increasing number of tropical and subtropical species occurring in the **northern region**. Tropical vagrants often get washed down the east Australian Current to southern reefs over the summer and autumn periods, but as the water temperature drops over winter many of this fishes don't survive (Malcolm et al. 2010). The majority of fishes that inhabit the NSW coastline have a pelagic larval stage creating connectivity between habitats across the coastline.

A search of Atlas of Living Australia (www.fish.ala.org.au) found records for 1123 species, representing 215 families, from the NSW coastline to a depth of 100 m. At least 242 of these species are considered endemic to south eastern Australia.

It is the rocky reefs of NSW that provide habitat for the greatest diversity fishes. Abundant fish species in NSW rocky reefs include snapper (*Chrysophrys auratus*), blue morwong (*Nemadactylus douglasii*), yellowfin bream (*Acanthopagrus australis*), luderick (*Girella tricuspidata*), rock blackfish (drummer; *Girella elevata*), bigscale bullseye (*Pempheris multiradiata*), mado sweep (*Atypichthys strigatus*), eastern blue groper (*Achoerodus viridis*), and many species of wrasse (Labridae) and leatherjackets (Monacanthidae) (Malcolm et al. 2007). Many pelagic species also regularly occur on shallow reefs, including yellowtail kingfish (*Seriola lalandi*), silver trevally (*Pseodocaranx georgianus*) and yellowtail scad (*Trachurus novaezelandiae*). The fishes of NSW vary considerably in their ecology and life-history characteristics (e.g. distribution, habitat use, movement, age, growth) (see review in Curley et al. 2013).

Many species sharks and rays inhabit the NSW coastline. These species are the apex predators that are at the top of the food chain and are important for sustaining a healthy marine ecosystem. The most abundant species are the Port Jackson shark (*Heterodontus portusjacksoni*), wobbegongs (Orectolobidae) and whalers (*Carcharhinus spp.*). The grey nurse shark (*Carcharias taurus*), scalloped hammerhead shark (*Sphyrna lewini*), great hammerhead shark (*Sphyrne mokarran*) and white shark (*Carcharodon carcharias*), which are all listed as either endangered or vulnerable, migrate along the NSW coastline. The tiger shark (*Galeocerda cuvier*) and bull shark (*Carcharhinus leucas*) also migrate along the NSW coastline. The smooth ray (*Dasyatis brevicaudata*), southern eagle ray (*Myliobatis australia*), and eastern fiddler ray (*Trygonorrhina fasciata*) are commonly the mostly commonly encountered species of ray.

Many of these species also occur at times on soft-sediment habitats which is the dominant habitat type on the open coast of NSW (Jordan et al. 2010). In addition, a large number of fish species occur almost exclusively on this habitat. A comparison of fish assemblages across a depth gradient of 30 m to 100 m, found both spatial and temporal variability in the demersal fish assemblage in coastal waters off Sydney (Gray and Otway 1994). A total of 75 species were caught and identified during this study. The fish assemblage at 30 m was dominated by urolophid and rhinobatid rays, and by eastern smooth boxfish (*Anoplocapros inermis*), eye gurnard (*Lepidotrigla argus*) and long spine flathead (*Platycephalus longispinis*). At 60 m depth the fish assemblage also included tiger flathead (*Platycephalus richardsoni*) and southern school whiting (*Sillago bassensis*).

At 100 m depth the fish assemblage was dominated by longspine snipefish (*Macroramphosus scolopax*), eye gurnard (*Lepidotrigla argus*), roundsnout gurnard (*Lepidotrigla* mulhalli), threespine cardinalfish (*Apogonops anomalus*), tiger flathead (*Platycephalus richardsoni*), John dory (*Zeus faber*), blacktip cuccumberfish (*Chlorophthalmus nigripinnis*), southern school whiting (*Sillago bassensis*) and nannygai (*Centroberyx affinis*) (Gray and Otway 1994). There is evidence that the local scale distribution of sediments of varying composition also influences the structure of the soft sediment fish assemblages (Shultz et al. 2014).

The high species diversity of fishes along the NSW coast makes the coastline popular with recreational divers. As well as, high numbers and diversity of good quality table fish also makes the NSW coastline highly popular with recreational fishers (see West et al. 2015). Many species of fish are harvested or caught as bycatch on the open coast as part of a number of commercial fisheries (principally ocean trap and line, ocean trawl and ocean haul) (see Stewart et al. 2015). Specific details of these fisheries and their catch composition are presented in sections 8.1.2 and 6.1.3, respectively. There are regional variations in catch compositions that reflect both local conditions and target species.

For the purpose of this assessment, fish assembages also includes invertebrates that are harvested or landed as bycatch (see Stewart et al. 2015). The key groups and species include:

- Molluscs - blacklip abalone (*Haliotis rubra*), cockles (Family: Arcoida and Veneroida), Loligo squid (Uroteuthis species), octopus (*Octopus* spp.), pipi (*Donax deltoides*), Southern calamari (*Sepioteuthis australis*), turban shells (*Turbo torquatus*, *Turbo imperialis*, *Turbo undulatus*)
- Crustaceans - brown tiger prawn (*Penaeus esculentus*), school prawn (*Metapenaeus macleayi*), bugs (*Ibacus* spp.), Eastern king prawn (*Melicertus plebejus*), Eastern rock lobster (*Jasus verreauxi*), spanner crab (*Ranina ranina*)
- Echinoderms - purple sea urchin (*Centrostephanus rodgersii*), red sea urchin (*Heliocidaris tuberculata*)

7.2.8 PLANKTONIC ASSEMBLAGES

Planktonic organisms live in the water column, and includes plants (phytoplankton), animals (zooplankton) and microbes (bacteria and protists) and range in size from < 0.05 microbes to jellyfish exceeding 1 m in diameter. Phytoplankton converts sunlight into energy through photosynthesis and produces oxygen, and those on the shelf are dominated by diatoms, which typically bloom along the coast during spring. As the waters of NSW shelf are often low in nutrients, higher concentrations of nutrients and higher abundance of phytoplankton are tightly associated with nutrient uplift caused by oceanographic features such as fronts, eddies and coastal. The abundance of zooplankton (Dela-Cruz et al. 2008) and other secondary producers, such as salps (Everett et al. 2011) are also related to oceanographic features, nutrient concentrations and phytoplankton abundances. Many marine organisms have a planktonic larval stage (e.g. corals, fishes, lobsters, urchins) which is important for dispersal and population connectivity. Plankton is the basis of most marine food chains, being important food for many invertebrates, fishes and some species of whales.

7.3 MARINE THREATENED AND PROTECTED SPECIES

This section details threatened and protected species found in coastal habitats. Such species include fish and sharks, marine reptiles, marine mammals, and birds.

7.3.1 THREATENED AND PROTECTED FISH AND SHARKS

Threatened fish in NSW, including shark species, are listed under the *FMA*. Several threatened fish and shark species may occur in continental shelf waters, including the critically endangered grey nurse shark (*Carcharias taurus*) (Figure 64), black rockcod (*Epinephelus daemelli*) (Figure 65), and white shark (*Carcharodon carcharias*).

Grey nurse shark

Grey nurse sharks migrate and frequently undertake excursions to adjacent reef habitats, aggregating in shallow gutters off the edge of rocky headlands in surrounding areas (Otway et al. 2003, Otway and Ellis 2011, Otway and Parker 2000). The length and extent of the larger-scale movements vary depending on age, sexual maturity, and stage in reproductive cycle (NSW DPI 2013). Grey nurse sharks also display high site fidelity, congregating at sites of significant recreational and commercial activity along the inshore coastal waters of NSW and southern Queensland (NSW DPI 2001 2013). These aggregation sites have rocky reef with gravel or sand-filled gutters, overhangs or caves (NSW DPI 2013).

Pregnant females migrate north to southern Queensland after mating in spring, where they spend about six months at aggregation sites away from sexually mature males. Afterwards, they migrate south to NSW waters to give birth in winter and early spring (NSW DPI 2013), and then rest for one year. Females produce one live pup or fewer per year on average, due to unusual cannibalism within the uterus, potentially the lowest reproductive rate of any shark. As a result of this low fecundity (maximum two young biennially) and onset sexual maturity (6–8 years), the population has a low potential to recover from decline. This species is therefore extremely vulnerable to human-induced pressures (Otway et al. 2004, NSW DPI 2013).

Grey nurse shark abundance in NSW waters has declined significantly in recent decades, due to commercial fishing, recreational spear and game fishing, and shark control activities such as beach meshing (NSW Fisheries 2002a). Hook-and-line fishing is the major threat to survival and the largest source of mortality, causing around 12 known deaths each year (NSW DPI 2011). In response to the decline, grey nurse sharks were protected from fishing in NSW in 1984, with a critically endangered status implemented since 2008 under the *FMA* (NSW DPI 2013).

Thirteen key aggregation sites for grey nurse sharks have been identified in state waters (NSW DPI 2002). These critical habitat sites have specialised regulations for fishing. Seven sites have already been given high levels of protection through inclusion in new and existing marine park sanctuary zones (NSW DPI 2002, 2012).

Figure 64. Grey nurse shark, critically endangered under the *Fisheries Management Act 1994. Source NSW DPI.*

Black rockcod

The black rockcod is also known as black cod or saddled rockcod. This large reef fish is endemic to the warm-temperate and subtropical southwest Pacific waters of Australia, New Zealand, and the Kermadec Islands (Choat et al. 2006, NSW DPI 2011, Francis et al. 2015) (Figure 65). In Australia, the species has been recorded from southern Queensland to east Victoria and offshore islands of Lord Howe Island, Norfolk Island and Elizabeth and Middleton Reefs (Kuiter 1993, Harasti et al. 2013).

Juvenile black rockcod live in intertidal rock pools. They move to deeper coastal waters (<50 m deep) as they mature, occupying caves, gutters and beneath bommies on rocky reefs (NSW DPI 2007b, Francis et al. 2015, Harasti and Malcolm 2013, Harasti et al. 2014). Individuals are territorial and display high site fidelity, often residing in the same caves for their whole lives (NSW DPI 2007b).

Black rockcod are slow-growing protogynous hermaphrodites. In New Zealand studies, the fish first develop as sexually mature females, then change to males at around 100–110 cm and around 30 years old (NSW DPI 2007b, Francis 2012, Francis et al. 2015, Harasti and Malcolm 2013). In Australia, individuals have been recorded up to 1.5 m total length and 81 kg, although most individuals are substantially smaller (NSW DPI 2011, Harasti and Malcolm 2013). Like all large serranids, black rockcod are long-lived, with a life expectancy of 65 years or greater, based on a small amount of ageing data (Hutchins and Swainston 1986, Francis et al. 2015).

Figure 65. Black rockcod, also known as black cod or saddled rockcod. *Source NSW DPI.*

Black rockcod were once widespread along the NSW coast, although they were heavily targeted by spearfishers during the 1950s through to the late 1970s (Francis et al. 2015, Harasti and Malcolm 2013). The removal of large 'trophy' fish by spearfishers reduced the number of male fish in various areas, unbalancing the sex ratio of local populations and ultimately reducing reproductive success (Francis et al. 2015). These concentrated spearfishing efforts, as well as overharvesting from line and net-fishing captures, led to the extensive decline of this species. While this species is protected from all fishing activities in state waters, accidental capture and hooking injuries still pose a threat to the population (NSW DPI 2007b).

In conjunction with black rockcod's naturally vulnerable life-history characteristics, these fishing threats mean that any recovery of abundance and size structure is expected to be gradual (NSW DPI 2007b, Harasti and Malcolm 2013). In response to this species' decline, black rockcod were previously declared as a protected species in NSW waters and are now listed as a vulnerable species under the *FMA* (NSW DPI 2007b 2011).

White shark

White sharks, also commonly known as white pointers or great white sharks, are found throughout the world in temperate and subtropical oceans, with a preference for cooler waters (NSW DPI 2005, Weng et al. 2007). Its distribution includes the coastal waters of NSW, with electronic tagging studies identifying the Port Stephens region as one of the two important nursery areas for juvenile white sharks in eastern Australia (Bruce and Bradford 2008; 2011, Bruce et al. 2013).

The species is highly mobile, and can travel large distances in a relatively short time. It can also remain in the same area for weeks or even months (NSW DPI 2005, Bruce et al. 2006). White sharks inhabit a wide range of habitats, from offshore pelagic to coastal inshore waters surrounding rocky reefs and islands, often near seal colonies (NSW DPI 2005, Weng et al. 2007). Juvenile white sharks (<3 m) often occur close to shore, which makes them vulnerable to bycatch in commercial and recreational fisheries; by spending significant time in the surf zone it also increases their risk of encountering people (Weng et al. 2007, Bruce and Bradford 2008; 2012, Bruce et al. 2013).

White sharks are long-lived and late-maturing species, reaching sexual maturity at approximately 10 years of age (4.5–5.5 m long). Females give birth to relatively few (4–10) live pups that are fully developed and independent at birth, and measure between 120–150 cm in length (NSW DPI 2005). It is unlikely that females reproduce every year.

As apex predators, great white sharks play an important role in marine ecosystems. Their decline may affect ecosystem structure through many top-down processes. In Australian waters this species' numbers have been reduced over the last few decades due to beach safety (shark) meshing nets on coastal beaches and bycatch in a range of commercial and occasionally recreational fisheries. Before they were protected, white sharks were also heavily targeted by gamefishers (NSW DPI 2005). Their low abundance, natural mortality and reproductive rate, and other life-history characteristics, make their populations highly vulnerable to the impacts of activities that increase their mortality. As a result of the decline and very low potential for population recovery, white sharks are listed as a vulnerable species in NSW.

7.3.2 THREATENED AND PROTECTED MARINE MAMMALS, REPTILES AND BIRDS

Forty-two species of marine mammals are recorded in NSW waters; none are endemic to the region, and are likely to be encountered within all national and international waters (Bryden et al. 1998, Smith 2001). The marine mammals belong to three separate mammalian orders and comprise 34 cetacean (whales and dolphins) species, seven pinnipeds (seals and sea lions) and one sirenian (dugong) (Table 32). Many of these species occur principally in coastal waters, but are detailed in the estuarine section where relevant.

Eight species of cetacean (five baleen whales and three toothed whales) are currently listed on the schedules of the *TSCA*. Marine mammal species are generally widely distributed and some are migratory. Four cetacean species are listed as threatened in NSW: the southern right whale (*Eubalaena australis*) and blue whale (*Balaenoptera musculus*), which are listed as endangered, and the sperm whale (*Physeter macrocephalus*) and humpback whale (*Megaptera novaeangliae*), which are listed as vulnerable (Department of the Environment 2015). The southern right whale, blue whale and humpback whale are listed as nationally threatened (Department of the Environment 2015). The abundance of *E. australis* in NSW waters is estimated to be around 17 individuals, with a south-east coast population estimate of around 257 individuals.

It is possible that the re-establishment of calving grounds in NSW may conflict with current usage of the sites. Around 70% of the historically used calving grounds are currently associated with some form of infrastructure, including Twofold Bay (the only known historic calving ground in NSW), now the site of major industrial and shipping activity (Pirzl 2008). *Arctocephalus pusillus* and long-nosed (formerly New Zealand) fur seal *A. forsteri* are the most commonly occurring pinniped species throughout NSW (Shaughnessy 1985), though they are concentrated in southern NSW waters.

Table 32. Marine mammal species recorded in New South Wales waters.

Species	Common name	Conservation status[a]		
		NSW	EPBC	IUCN
Order Cetacea[b]				
Balaenoptera acutorostrata	Minke whale	P	P	LC
Balaenoptera edeni	Bryde's whale	P	P	D
Balaenoptera musculus	Blue whale	E	E	E
Delphinus delphis	Common dolphin	P	P	LC
Eubalaena australis	Southern right whale	V	E	LC
Feresa attenuate	Pygmy killer whale	P	P	D
Globicephala macrorhynchus	Short-finned pilot whale	P	P	LC
Globicephala melas	Long-finned pilot whale	P	P	LC
Grampus griseus	Risso's dolphin	P	P	D
Kogia breviceps	Pygmy sperm whale	P	P	LC
Kogia simus	Dwarf sperm whale	P	P	–
Lagenodelphis hosei	Fraser's dolphin	P	P	D
Megaptera novaeangliae	Humpback whale	V	P	V
Mesoplodon grayi	Gray's beaked whale	P	P	D
Mesoplodon layardii	Strap-toothed beaked whale	P	P	D
Orcinus orca	Killer whale	P	P	LC
Peponocephala electra	Melon-headed whale	P	P	LC
Physeter macrocephalus	Sperm whale	V	P	V
Pseudorca crassidens	False killer whale	P	P	LC
Stenella attenuate	Pantropical spotted dolphin	P	P	LC
Stenella coeruleoalba	Striped dolphin	P	P	LC
Stenella longirostris	Spinner dolphin	P	P	LC
Steno bredanensis	Rough-toothed dolphin	P	P	D
Tursiops truncates	Bottlenose dolphin	P	P	D
Tursiops adunctus	Indo-pacific bottlenose dolphin	P	–	–
Order Sirenia				
Dugong dugon	Dugong	E	P	V
Order Pinnipedia				
Arctocephalus pusillus	Australian fur seal	V	P	–
Arctocephalus forsteri	Long-nosed fur seal	LC	P	LC
Arctocephalus tropicalus	Subantarctic fur seal	P	V	–
Hydrurga leptonyx	Leopard seal	P	P	LC
Neophoca cinerea	Australian sea lion	P	V	E
Lobodon carcinophagus	Crab-eater seal	P	P	LC
Mirounga leonina	Southern elephant seal	P	P	LC

a Conservation status is listed under New South Wales (NSW), Commonwealth (*Environment Protection and Biodiversity Conservation Act 1999*; EPBC) and International Union for Conservation of Nature (IUCN) schedules. D = data deficient; E = endangered; LC = least concern; P = protected, V = vulnerable; '–' means a species is not listed under the schedule (adapted from Ganassin and Gibbs 2005b).
b Some of the whale species occur outside the 3 nm limit.

Marine reptiles

Seventeen species of marine reptiles have been recorded in open coastal waters of NSW. The main species are detailed in Table 33, and are dominated by turtles. Specific details on the diversity and distribution of marine reptiles, including turtles and sea snakes, are presented in Section 5.8.

Table 33. Marine reptiles recorded within New South Wales waters.

Family and species	Common name	Conservation status[a]		
		NSW	EPBC	IUCN
Cheloniidae				
Caretta caretta	Loggerhead turtle	E	E	E
Chelonia mydas	Green turtle	V	V	E
Eretmochelys imbricata	Hawksbill turtle	P	V	C
Natator depressus	Flatback turtle	P	V	D
Dermochelyidae				
Dermochelys coriacea	Leatherback turtle	V	V	C
Hydrophiidae				
Aipysurus duboisii	Reef shallows seasnake	P	P	–
Hydrophis elegans	Elegant seasnake	P	P	–
Pelamis platurus	Yellow-bellied sea snake	P	P	–

a Conservation status is listed under New South Wales (NSW), Commonwealth (*Environment Protection and Biodiversity Conservation Act 1999*; EPBC) and International Union for Conservation of Nature (IUCN) schedules. C = critically endangered; D = data deficient; E = endangered; P = protected, V = vulnerable; '–' means a species is not listed under the schedule (adapted from Ganassin and Gibbs 2005b).

Shorebirds

Shorebirds are a fundamental component of coastal ecosystems, comprising a large proportion of visible vertebrate fauna within estuarine, ocean beach and rocky-shore environments (DECCW 2010a). These coastline predators use a wide variety of coastal and inshore habitats for roosting and foraging. Preferred roosting locations are generally above the high-water mark, and frequently include structures such as saltmarsh, sandy ocean beaches, sand bars and spits, mangroves, rock walls, rock platforms and oyster racks (DECCW 2010a). These sites allow access to water, an open field of view, and close proximity to foraging areas. Common foraging habitats are intertidal flats, beaches, rocky headlands and along the fringes of freshwater wetlands (DECCW 2010a). The birds' uses of these areas are influenced by the tidal cycle, with foraging occurring at low tide regardless of whether it is day or night (McNeil et al. 1992, DECCW 2010a). Further details are provided in Section 5.8 Estuarine threatened and protected species.

Surveys of birds using rocky shores on the open coast within the central region show considerable site differences in the number of individuals, diversity and importance for specific species (Gladstone 2005, Gladstone et al. 2007). For example, Norah Head is an important high-tide roost for gulls and terns, and a significant low-tide foraging area for migratory shorebirds. Threats to shorebirds and their habitats are growing as the human population increases along the coast (DECCW 2010a). Shorebirds are susceptible to a range of human stressors that disturb essential roosting and foraging areas (OEH 2012), including:

- greater human presence on beaches
- 4WD vehicles
- entanglement in marine debris
- habitat loss

- coastal development
- increased pollution.

Shorebirds are also influenced by many recognised key threatening processes, including alteration to natural flow regimes, climate change, and predation by introduced species such as the European red fox (OEH 2012). Further details on life history characteristics of key shorebird species are presented in Appendix 4.

Seabirds

Seabirds breed on offshore islands along the NSW coast. For example, Cabbage Tree and Boondelbah islands support the only confirmed breeding site for the vulnerable Gould's petrel in Australia; the Broughton Island group, along with Cabbage Tree and Boondelbah islands, supports half the NSW breeding population of wedge-tailed shearwaters. Further details are provided in Section 5.8.

Little penguins

The little penguin (*Eudyptula minor*) is the smallest species of penguin, reaching approximately 30 cm in height and 1 kg in weight (OEH 2014). They reach maturity at approximately three years and have an average lifespan of seven years. Once they begin breeding, 75% will stay with the same partner for life. Male penguins return to their colony to nest and attract mates between June and August, though the breeding season is variable. Breeding pairs take turns incubating the eggs for the 35-day incubation period. After chicks have hatched, the pair alternate between hunting and caring for young for eight to nine weeks until the young have fledged.

Little penguins are diurnal: feeding in the ocean during the day and returning to the colony at night (OEH 2014). They feed predominantly on pelagic fish, cephalopods and crustaceans (BirdLife International 2012). At night, they nest in burrows in sand dune vegetation, rocks, sea caves, headlands, and occasionally under buildings (OEH 2014). Little penguins occur in temperate marine waters in southern Australia and New Zealand (Priddel et al. 2008, BirdLife International 2012).

They are the only penguin species to breed on mainland Australia (OEH 2014). Colonies are generally restricted to offshore islands, and approximately 25,000 pairs nest on islands off the NSW coast, with large colonies on Montague Island, Tollgate Island and Brush Island. The only breeding colony on mainland NSW is located in Manly, Sydney Harbour (Priddel et al. 2008). Nesting records indicate that the furthest north that *E. eudyptula* nest is the Solitary Islands.

Threats to little penguins include:

- predation by foxes, domestic cats and dogs
- loss and degradation of nesting habitat
- collisions with vehicles on roads and in the water
- vandalism (Priddel et al. 2008)
- pollution and run-off (OEH 2014)
- oil spills (Giese et al. 2000)
- decline in food sources
- restriction of access to nest sites (NSW Scientific Committee 2000)
- potential predation from the growing long-nosed fur seal population along the NSW coast (G. Ross, pers. obs.).

Threats are amplified during breeding season, because dependent young are typically unable to survive if one parent dies (OEH 2014). Mainland colonies are more vulnerable to threats. The number and size of mainland colonies is in decline across Australia (Priddel et al. 2008). A second NSW population from southern NSW (around Twofold Bay and Eden) is now extinct. The population of more than 500 breeding pairs was decimated by dog attacks in the 1940s and 1990s.

8. COASTAL WATERS USES AND ACTIVITIES

Activities that threaten the environmental assets on the coast and open waters of the NSW marine estate can be broadly characterised according based on the same two primary divisions (marine resource-use impacts and land based impacts) presented in the Estuarine activities and uses section (see also Table 2).

While many of the resource-use activities are specific to coastal waters, many of the same land based impacts occur, including the overall discharge of estuarine waters into continental shelf waters. Climate change is considered as a separate threat category because the human activities that are responsible, although primarily derived from land based activities, occur on a global rather than a regional scale.

8.1 RESOURCE-USE ACTIVITIES

Coastal resource-use activities cover shipping, boating, fishing and aquaculture; recreation and tourism; and effects from dredging, mining, changes to freshwater flows and service infrastructure.

8.1.1 SHIPPING

This section includes impacts from both large and small commercial shipping vessels.

Large commercial vessels (e.g. trade ships, cruise ships)

For the purposes of this report, large commercial vessels include all international and domestic vessels carrying cargo or passengers transiting though the NSW marine estate. This includes coal ships, container ships, oil tankers, cruise ships and naval vessels (Figure 66). Thousands of these large commercial vessels transit through the NSW marine estate every year.

Shipping relating to large commercial vessels in the coastal and open waters occurs primarily outside state coastal waters, with the major shipping lane of the east coast of Australia being located between 10–15 nm offshore and running parallel to the coast. This shipping lane is the most active in Australia, with as many as 350 vessels in excess of 300 tonnes operating in the shipping lane at any one time.

Most of this traffic originates from, or is travelling to, one of the major east Australian ports; Brisbane, Newcastle or Sydney. Hence, most of the activity in state coastal waters occurs in the central region. In the financial year 2015-2016, approximately 6,013 trading vessels and cruise ships visited NSW ports, with 5,926 (98.5%) in the central region, 18 (0.4%) in the north and 69 (1.1%) in the south (Port Authority of New South Wales, Annual Report 2015-16).

https://www.parliament.nsw.gov.au/la/papers/DBAssets/tabledpaper/webAttachments/69937/Attachment%20H%20-%20Port%20Authority%20of%20NSW%202015-16%20Annual%20Report.pdf

Figure 66. Large commercial vessel common on the open coast of New South Wales.

Small commercial vessels (ferries, charter boats, fishing vessels)

Domestic small commercial vessels include:

- passenger vessels (carrying more than 12 passengers)
- trading vessels (e.g. tugs, barges, dredgers and other vessels carrying no more than 12 passengers)
- fishing vessels and hire-and-drive vessels (e.g. cruisers, houseboats and powered dinghies) used for commercial, governmental or research activity in Australian territorial waters (exclusive economic zone) including of the NSW marine estate.

These vessels are termed 'domestic' because their place of departure and the first place of arrival are within Australia. They do not undertake international voyages, even though they may travel outside Australian territorial limits. There are a total of 1591 small commercial (non-fishing) vessels registered by ports, with 72% in the Central region, 9% in the North and 19% in the South (RMS Maritime Industry & Environment).

Commercial fishing vessels operate out of most NSW estuaries to access marine waters for commercial fishing activities. These include prawn and ocean trawlers, ocean trap and line-fishing vessels, lobster vessels and those targeting abalone and sea urchins (Figure 67). They vary significantly in size and area of operation. Nature based tourism charters operate out of most NSW ports to undertake whale and dolphin watching, fishing charters, scuba diving and snorkelling.

Figure 67. Small commercial vessels common in coastal waters

Government agencies operate domestic commercial vessels for compliance, surveillance and research purposes, including the NSW Water Police, RMS, Fisheries NSW, OEH and the Ports Authority of NSW. Research and other non-government organisations also operate domestic commercial vessels to undertake research, education and environmental awareness activities within the marine estate. There are also a large number of volunteer rescue boats (e.g. surf life saving, marine rescue). An estimated 8,748 registered commercial vessels operate in the NSW marine estate.

DPI Crown Lands Division operates 25 coastal harbours along the NSW coast, which currently berth 588 commercial vessels. Of these, 276 are commercial fishing trawlers and 312 are charter vessels (DPI Crown Lands 2014).

Potential impacts of shipping

Physical disturbance

Ships primarily anchor off three main ports: Sydney Harbour/Port Botany, Port Kembla and the Port of Newcastle. Historically, large vessels have anchored in NSW waters within the 3 nm boundary. More recently, NSW Transport has recommended to vessel masters that they anchor beyond the 3-nm boundary, although this is not a legislative requirement.

The tracking of vessels, which is publically available on the AMSA website[52], suggests that anchoring is occurring within NSW waters – and that some vessels may be anchoring over high-profile rocky reef (OEH unpublished data). With individual chain links weighing up to 200 kg and the long length of chain being deployed (5–10 times the water depth), the scale of impacts from anchor scour may be considerable. Threats could include physical damage to the substratum and its associated fauna (predominantly sponges, ascidians and bryozoans), which will likely have slow rates of recovery.

There have been no comprehensive studies on the impacts of ship anchoring on marine habitats and biodiversity in NSW, or in Australia generally. However, international studies have found that anchoring can degrade marine habitats, in particular rocky reefs, with resultant losses in fish life and macroinvertebrates. Anchoring can also stir up sediments, smothering nearby microhabitats and reducing opportunities for photosynthesis by marine macroalgae.

Ships can also damage rocky reefs, beaches and other habitats if they run aground or sink. For example, during a severe storm in June 2007, a 40,042 tonne bulk carrier, *Pasha Bulker*, grounded on Nobby's Beach at Newcastle. The ship was carried onto rock ledges on the beach during the storm and its hull was breached, but no oil pollution occurred at the time of the grounding. The *Pasha Bulker* was successfully refloated after three attempts, with a very minor leak of lube oil detected and cleaned up. Inspections by divers showed that the reef where the vessel grounded was extensively damaged, biota was removed and rocks broken. There was evidence of contamination by antifouling paints, but since TBT was not used on the ship, no remediation was attempted.

[52] https://www.amsa.gov.au/

The impacts of commercial vessels on marine fauna from vessel strike are outlined in section 6.1.1.

Wildlife disturbance

The risks to marine wildlife are increased in areas where the density of shipping traffic is correspondingly high. Several marine species use sound as their primary sensory input for social communication, foraging and other vital processes. Background noise may affect marine mammals and reptiles by masking normal sounds and vocalisations, or causing hearing deficit. The impact of increased undersea noise levels on wildlife is a relatively new area of research, but it is reasonable to assume that at least some acoustic sources may act as stressors for marine wildlife.

In October 2008, the 58th session of the IMO MEPC approved the inclusion of a new item on 'noise from commercial shipping and its adverse impacts on marine life'. The basis for the new item was a proposal by the United States to develop non-mandatory technical guidelines to minimise incidental noise from commercial shipping operations in the marine environment, thereby reducing potential adverse impacts on marine life.

Draft guidelines were approved by MEPC 66 in April 2014. The importance of this issue and the need for further research were also noted. AMSA will oversee the implementation of these guidelines in Australian waters. There is currently a knowledge gap about the impact of underwater noise in the NSW marine estate.

The growing demand for tourism has led to a greater number of large cruise ships and commercial vessels using newly developed anchorages (such as Twofold Bay) in the southern part of the state. There were 30 visits to the Port of Eden during 2015-16 by the Royal Australian Navy. This was followed by 22 cargo ships, and 8 cruise ships to the Port of Eden during 2015–16.

This poses an increased risk to large, slow-moving cetaceans and marine turtles, such as the endangered southern right whale (*E. australis*) and the leatherback turtle. Until recently, right whales in Australian waters were considered as one population. However, recent work suggests that south-east Australian right whales may be demographically separate from those in south-west Australia (Department of Sustainability, Environment, Water, Population and Communities 2011). For the south-east population, which numbers in the low hundreds, increased shipping raises the level of risk from acoustic disturbance and vessel strike.

Further details on wildlife disturbance from commercial vessels are described in section 6.1.1.

Water pollution

Details of water pollution from large and small commercial vessels are presented in section 6.1.1. The impacts are considered to be lower on the open coast than in estuaries, due to the reduced level of shipping activity in open waters. However, the impact from large vessels is expected to be greatest in the **central region**, where vessel activity is at its highest, and at similar levels in all regions for small commercial vessels. Small vessel water pollution would be expected to affect water quality, beaches and rocky shores.

Marine debris

Details of water pollution from large and small commercial vessels are presented in section 6.1.1. Overall, the impact from marine debris is expected to be low on the open coast, and be principally in the **central region** where vessel activity is at its highest.

8.1.2 COMMERCIAL FISHING

Six share-managed fisheries (Ocean Trap and Line, Ocean Trawl, Ocean Hauling, Rock Lobster, Southern Fish Trawl and Abalone) and two restricted fisheries (Sea Urchin and Turban Shell, and) operate in coastal and continental shelf waters (Table 34). Because fishery activities and the controls on them generally occur at a statewide level, rather than bioregional or local, the descriptions below are largely generic in nature. Aspects specific to the regions are highlighted where appropriate. As most of the effort in the Estuarine General Fishery occurs in estuarine waters, and only hand gathering is permitted along some coastal beaches, the details of this fishery are presented along with the other estuarine fisheries in Section 6.1.2.

Under the Offshore Constitutional Settlement, management of commercial fisheries in offshore waters (between 3 nm and 80 nm) falls under state responsibility, with the exception of ocean trawl fishing south of Barrenjoey Headland, and purse seining outside 3 nm. However, the context of this assessment is restricted to commercial fishing activities that occur within state coastal waters. It does not include activity and potential impacts that occur in Commonwealth waters, but notes the shared stock management for some species and jurisdictional arrangements.

Relevant current legal instruments include:

- *Fisheries Management Act 1994*
- Fisheries Management (General) Regulation 2010
- Fisheries Management (Supporting Plan) Regulation 2006
- Fisheries Management (Share Management Plan) Regulation 2006
- Commonwealth *Environment and Biodiversity Conservation Act 1999*
- *Marine Estate Management Act 2014*
- Marine Estate Management Regulation 2009
- Marine Estate Management (Management Rules) Regulation 1999.

Commonwealth export approval under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*). Since 2001, the Department of the Environment and Energy has been undertaking export approval assessments of the major Australian commercial fisheries under the *EPBC Act*.

The assessments test the sustainability of each fishery against a set of guidelines (including consideration of the impacts of fisheries on marine species protected under Part 13 of the *EPBC Act*) and result in a decision to either: (i) refuse to allow export, (ii) allow export with controls or conditions (called 'Wildlife Trade Operations' - WTOs), or (iii) allow export without control or conditions (‘Exempt’). The approvals are issued for varying periods, with a maximum export approval time frame of five years for fisheries that were assessed to meet all of the guidelines.

Of the eight NSW fisheries that have been assessed none were refused export, five were allowed export with conditions (as WTOs) and three were exempt from export control (i.e. assessed to meet all of the guidelines).

As detailed in Section 6.1.2, commercial fishing catch and effort data (and recreational estimates) are used to monitor the condition of fish stocks, with commercial fisheries on the open coast catching a large range of species. Fish species or species groups are assigned an exploitation status according to an assessment process. This includes the amount of knowledge held on the species, any long or short-term estimates, changes to harvest and changes to relative harvest effort. Over time, the level and proportion of species subject to detailed assessment continues to increase (Stewart et al. 2015).

In this current assessment process, stock exploitation categories (e.g. overfished, fully fished) contribute to the assessment of overall risk. Details of the exploitation status definitions are provided in Appendix 2. A selection of these species were also assessed in 2016 according to the Status of Australian Fish Stocks (SAFS) framework, and those determinations can be found on the SAFS website (http://fish.gov.au/). Further details are provided in Section 6.1.2.

Table 34. Commercial fisheries operating in New South Wales open coastal and continental shelf waters.

Fishery	Gear types used	Occurrence	Comments
Ocean Trap and Line	Multiple gear types (details in text)	Coastal and offshore waters along entire coastline	Multiple species
Ocean Trawl[a]	Fish and prawn trawling using otter trawl and Danish seine nets	Mostly coastal and offshore waters north of Barrenjoey	Multiple species
Ocean Hauling	Multiple net types (details in text)	Mostly beach hauling and restricted to coastal waters, both north and south of Barrenjoey	Includes some activity in lower parts of estuaries
Rock Lobster	Lobster traps and hand collecting	Coastal and offshore waters along entire coastline	Targets eastern rock lobster
Abalone	Hand collecting	Mostly in coastal waters of the southern region	Targets abalone
Sea Urchin and Turban Shell	Hand collecting	Mostly in coastal waters of the southern region	Targets several sea urchin and turban shell species
Estuary General	Multiple gear types	Limited hand gathering along some ocean beaches	Most of the estuary general catch occurs in estuarine waters
Southern Fish Trawl[a]	Fish trawling using Otter trawl and Danish seine nets	Coastal waters south of Barrenjoey	Multiple species

a Fisheries are combined in the assessment

Ocean Trap and Line fishery

The Ocean Trap and Line (OTL) fishery is a multi-method, multi-species fishery targeting demersal and pelagic fish in continental shelf and slope waters along the entire NSW coast. A wide range of finfish species are taken in the fishery, while spanner crabs are also harvested from Tweed Heads to approximately Hat Head on the mid-north coast of NSW. Tuna and tuna-like species are also taken, but are primarily managed by the Australian Government and generally taken in Commonwealth waters.

The fishery uses a variety of methods, most commonly involving traps or lines with hooks (Figure 68). The methods used in the fishery, and the key species taken by each method, are:

- demersal fish trap (snapper, silver trevally, rubberlip morwong, and leatherjackets)
- setlines or trotlines (snapper and sharks)
- driftlines (spotted and Spanish mackerel, yellowtail kingfish, and sharks)
- hand-held line (mulloway, yellowtail kingfish, and bonito)
- trolling or leadlining (yellowtail kingfish, mackerel, and tuna)

There are three distinct line-fishing endorsements (NSW DPI 2006):

- ‘line west’ (waters west of the 183 m depth contour)
- ‘line east’ (waters east of the 183 m depth contour to the 4000 m depth contour) (primarily Commonwealth waters)
- ‘school and gummy shark’ (a specific endorsement for taking these species is restricted to waters south of the Moruya River mouth).

Handlining generally accounts for approximately half (51.6%) of the OTL line-fishing effort in fisher days, while the remaining effort results from trolling (17.5%), droplining (12.8%), setlining (7.0%) and trotlining (5.3%) (I&I NSW 2009). There are specific restrictions in the operation of the OTL fishery, including those within sanctuary zones and some habitat-protection zones in NSW marine parks (Figure 69).

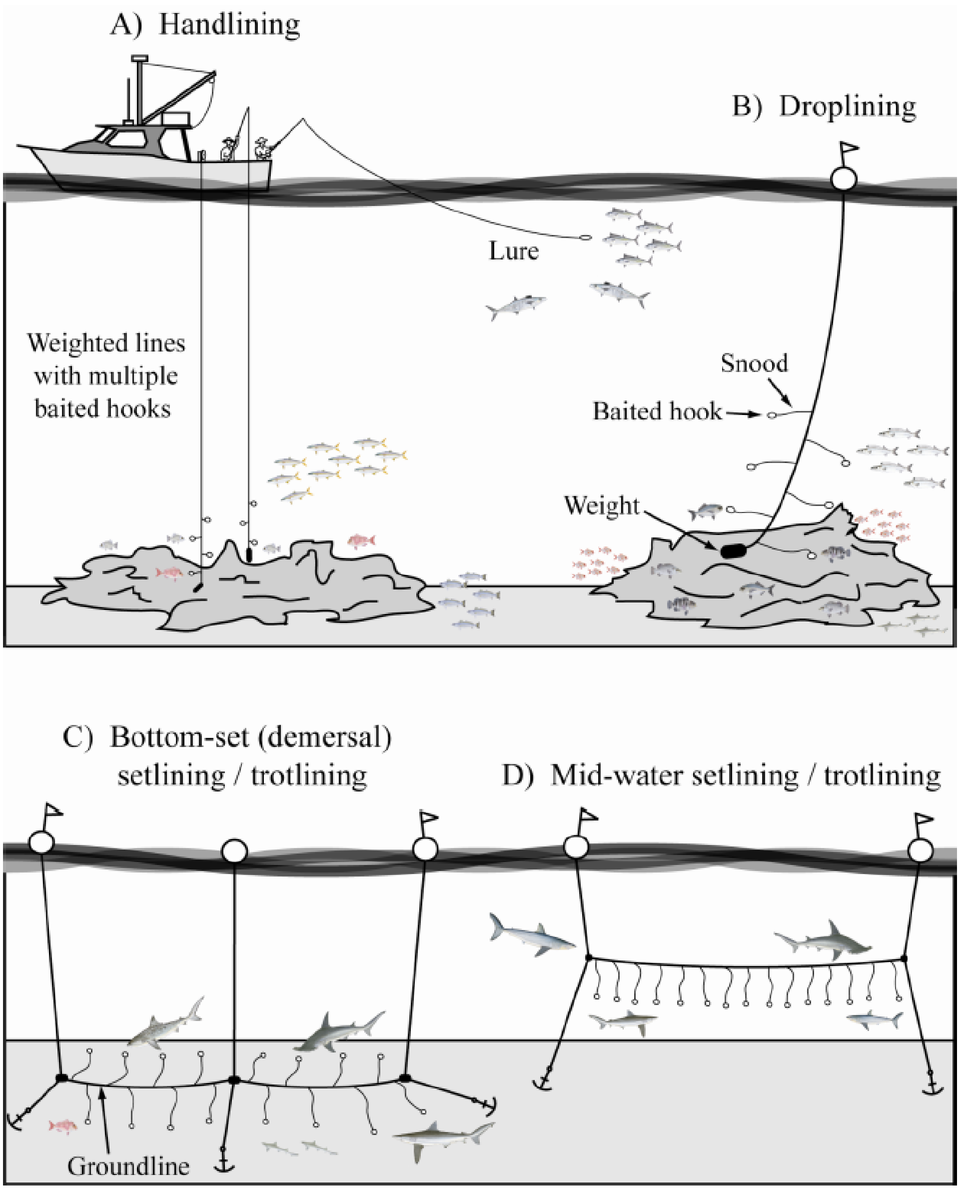


Figure 68. Ocean trap-and-line methods (from Macbeth and Gray 2015).

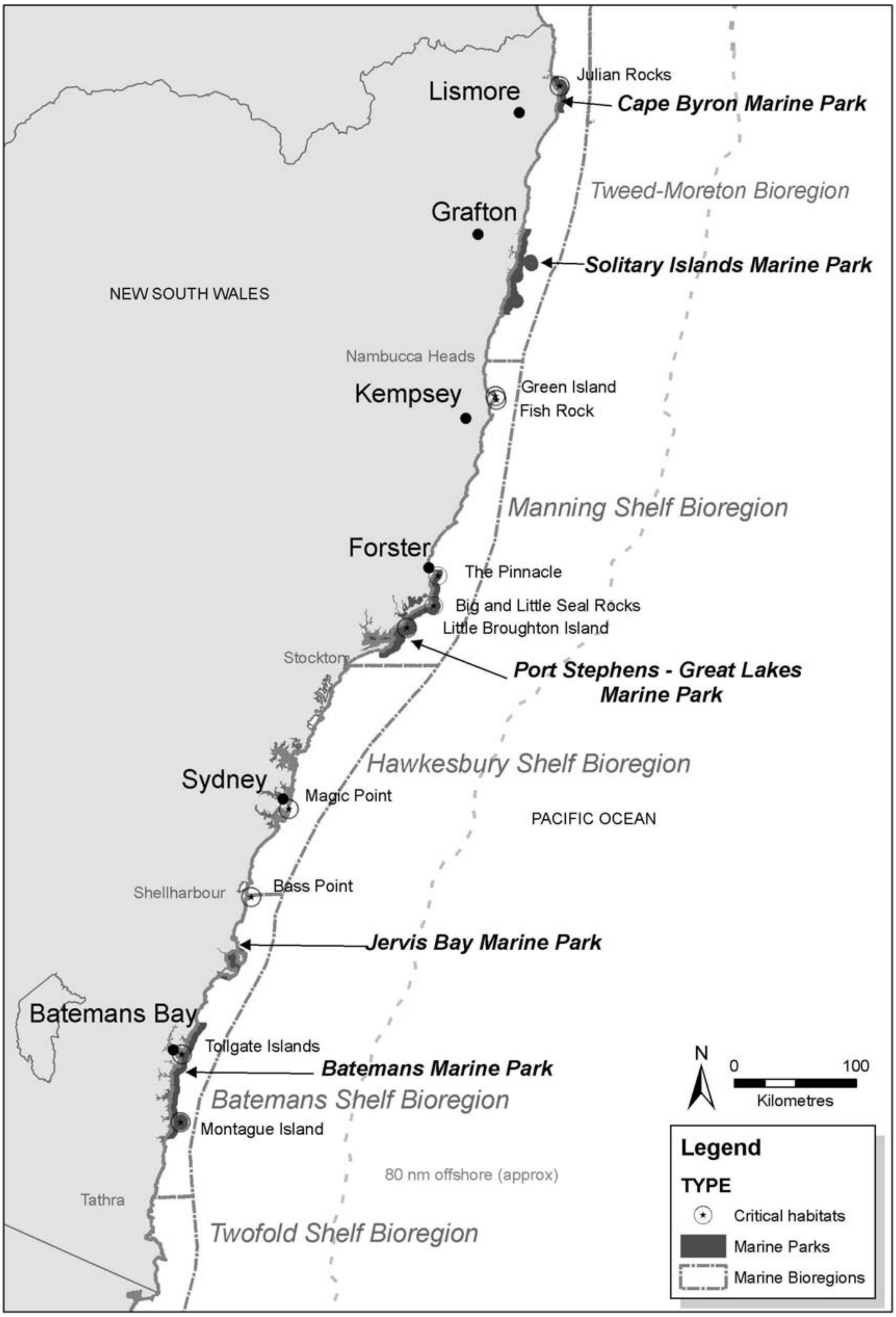


Figure 69. Distribution of marine parks along the New South Wales coast.

Several of the methods in the fishery are restricted to Commonwealth waters; therefore, this associated catch is not considered here. The fishery in general operates all year, apart from seasonal closures for spanner crab, which prohibit the taking of females (21 October to 20 January) and males (21 November to 20 December).

The overall catch from the fishery within the state coastal waters in the latest reported year (2013–2014) was 1,483 tonnes (Figure 70). The catch of six of the main species declined between 2009–2010 and 2013–2014 by about 100 tonnes, although snapper increased between 2012–2013 and 2013–2014. Spanner crabs were the only major species to show a steady increase since 2010–2011 of about 64 tonnes, although the northern zone (from which the majority of harvest occurs) has moved to a quota regime in 2015. The combined catch of other species has remained steady between 2009–2010 and 2013–2014 of about 450 tonnes. This reflects a limited period in the fishery. Trends in landings are not a specific indicator of abundance, and changes in catch per unit effort (CPUE) and other economic indicators are important factors. Further details of long-term trends and CPUE for the key species are presented in Stewart et al. (2015).

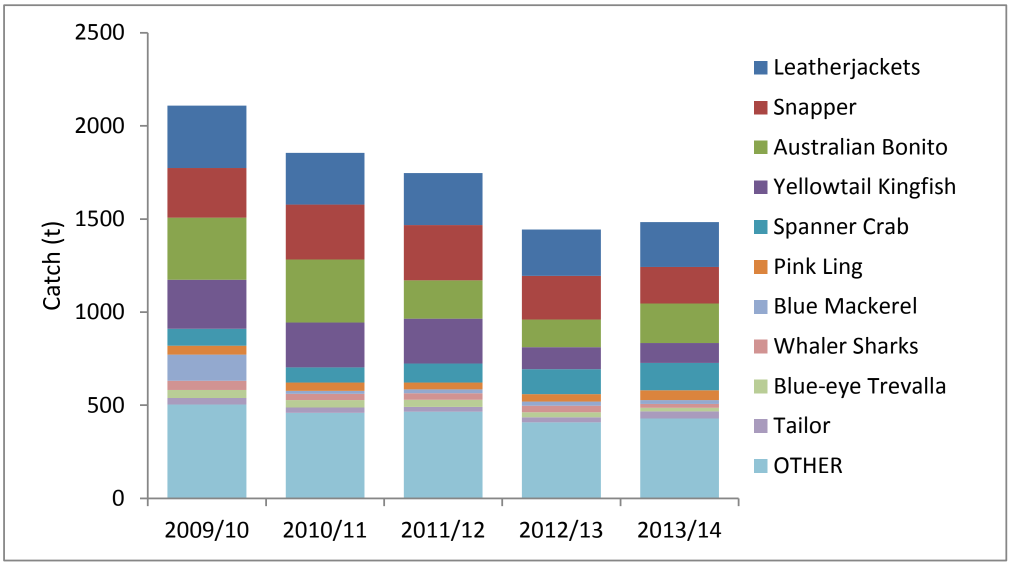


Figure 70. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the Ocean Trap and Line fishery in New South Wales coastal waters; catch is reported by the top 10 species, with the remainder classified as 'other'. *Source: DPI Fisheries catch records database extract 26 November 2015.*

The proportion of the OTL fishery catch taken in NSW coastal waters within 3 nm is largest in the **northern region** and least in the **southern region**, at approximately 40% and 10%, respectively (Figure 71). Catch composition varies substantially between the three regions, with the northern region dominated by snapper, Australian bonito and spanner crabs, and the southern by yellowtail kingfish and Australian bonito (Figure 72).

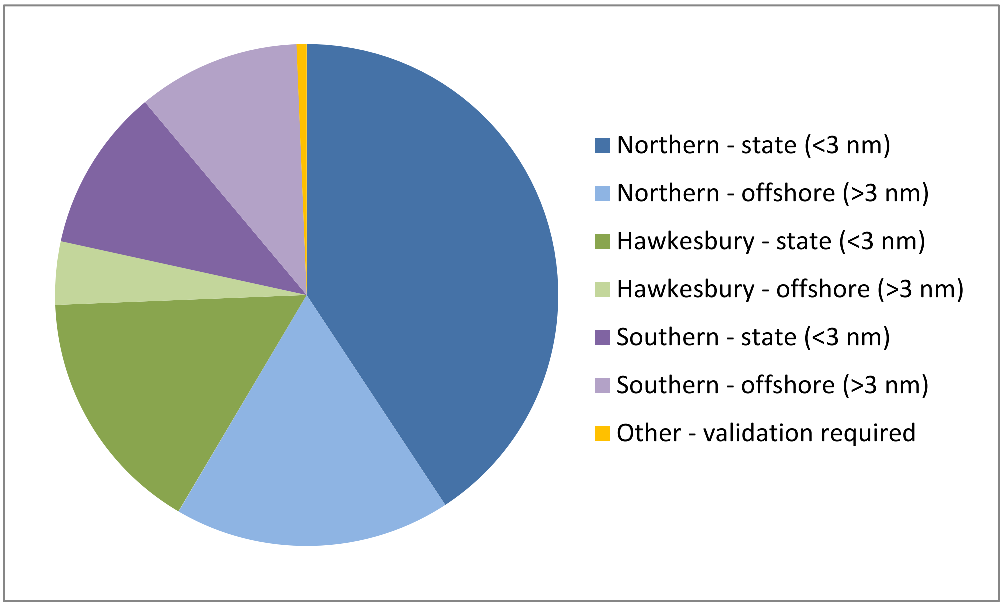


Figure 71. Proportion of catch in the NSW Ocean Trap and Line fishery in each coastal region across New South Wales for 2013–2014. *Source: DPI Fisheries catch records database extract 26 November 2015.*

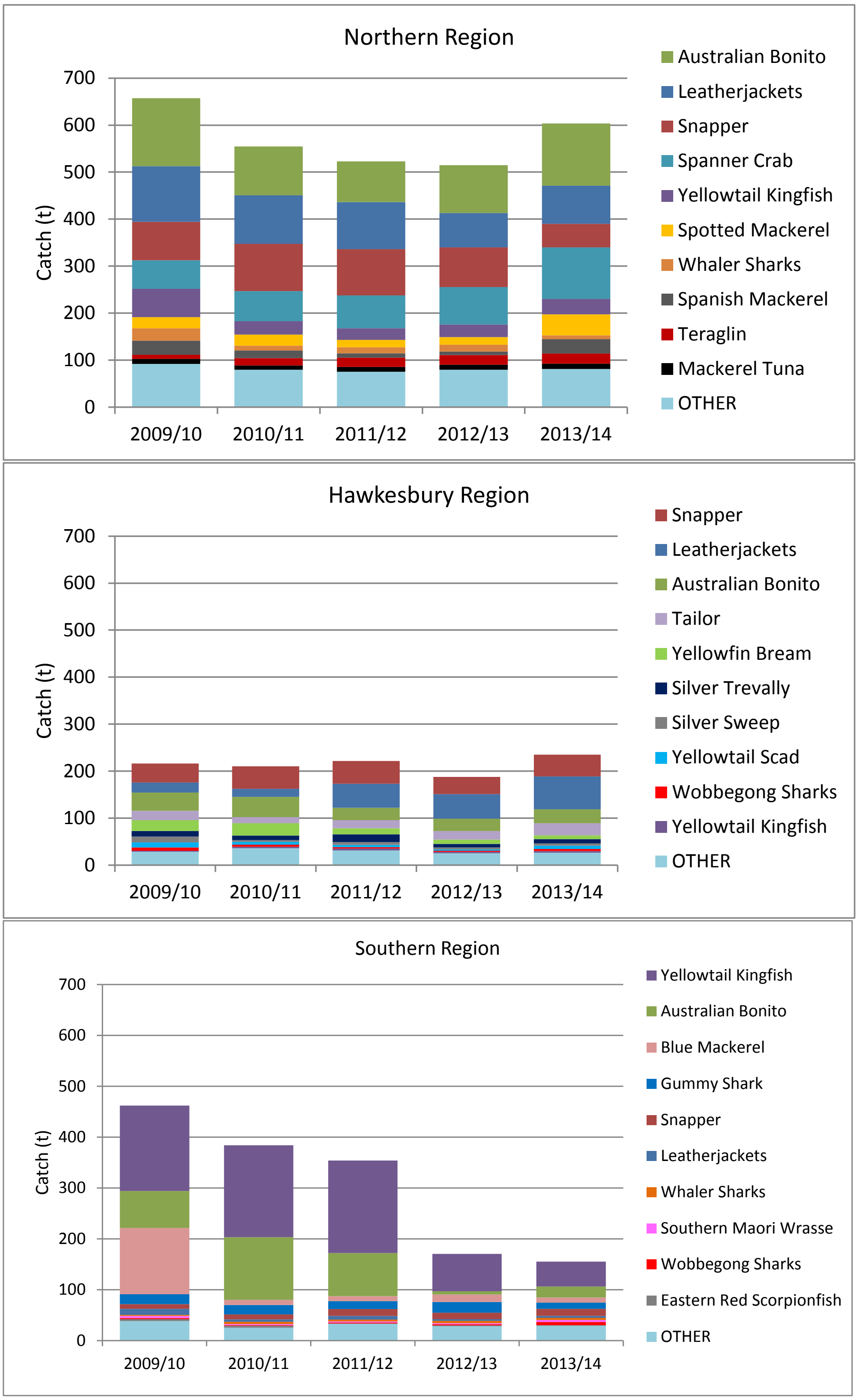


Figure 72. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the New South Wales Ocean Trap and Line fishery inside 3 nm for top 10 species in each coastal region. *Source: DPI Fisheries catch records database extract 26 November 2015.*

Over the past 15 years, catch composition for the whole OTL fishery reported across the entire NSW fishing jurisdiction has varied considerably. Overall, catch levels have decreased and effort has decreased by 4%. Further details of long-term trends and CPUE for the key species are presented in Stewart et al. (2015).

Collectively, the methods in this fishery were assessed in the EIS conducted in 2005–2006 as having a low to moderately low direct risk to marine habitats (NSW DPI 2006). However, the EIS indicated that a more accurate evaluation of risks would require information on the spatial distribution, composition and vulnerability of the various habitats, and the frequency, duration, extent and direct effects of the various fishing methods on the habitats (NSW DPI 2006). In contrast, several other risk components were identified as having a high risk, particularly in relation to ecological processes and some primary, secondary and bycatch species.

The OTL EIS concluded that a high level of uncertainty existed about the components of the fishery activity that resulted in ecological risk, due to the lack of information about the potential impacts.

A key component of the OTL fishery relates to the use of

Current management arrangements

DPI manages the Ocean Trap and Line Fishery (OTLF) in accordance with the *Fisheries Management (Ocean Trap and Line Share Management Plan) Regulation 2006*, the OTL Fishery Management Strategy as well as the *Fisheries Management Act 1994* and subordinate legislation.

Management actions in the OTL Fishery Management Strategy (FMS) to address its impact on species assemblages, species diversity, ecological processes and marine habitats include requirements to:

- define and map trap and line-fishing grounds in NSW
- collect information on the number of fish traps lost during fishing operations
- implement fish escape panels in fish traps.

Below is a summary of the key management arrangements addressed in the OTL FMS (details can be found on the DPI website[53]):

- capping the amount of fishing gear able to be used throughout the fishery
- trip limits for specified shark species
- further measures to reduce the impact of the fishery on threatened species, including the endangered grey nurse shark
- compulsory use of escape panels in fish traps to reduce the number of small fish brought to the surface
- developing a code of practice for the fishery
- improving reporting of fishing activity and monitoring
- reducing fishing effort using the restructuring tools provided by share management or other means
- ongoing performance monitoring and review of the fishery.

A number of management actions have been implemented to address the impact of the OTLF on species assemblages, species diversity, ecological processes and marine habitats.

Gear used in the OTLF is highly regulated, the FM Act and OTL SMP prescribe current limits and/or restrictions on fishing gear used in the OTLF including:

- A maximum of 30 traps may be used at any one time;
- A maximum use of 10 setlines with no more than six hooks attached to any set line within 3 nautical miles;
- A maximum use at any one time of 1200 hooks applies to any line fishing method outside 3 nautical miles;

[53] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/224480/OTL-FMS.pdf

- A maximum use of 30 drift lines at any one time with no more than one hook or no more than five hooks if a gang of hooks attached to the drift line;
- Mandatory use of circle hooks on all set lines;
- Prohibition on the use of bottom set lines with wire trace line in waters within 3 nautical miles of NSW coastal baselines;
- Implementation of fish escape panels in fish traps;
- A prohibition on the use of automatic baiting machines in the OTLF; and
- Implementation gear restrictions that apply in or near critical habitat of Grey Nurse Shark;
- A restriction on the maximum number of spanner crab nets that may be used at any one time, and the surface area of a spanner crab net not to exceed 1.6 m^2.

Commercial catch limits are implemented via fishing closures under the Act, those applicable to the OTLF include:

- A commercial weekly and total catch limit applying to shark species harvested in the OTLF.
- A commercial daily catch limit of six Wobbegong Sharks across all Fisheries
- A catch quota system for the spanner crab northern zone sector of the OTLF was implemented on 1 July 2015.
- A range of commercial trip limits apply to commercially important species taken predominantly in Commonwealth managed fisheries, including Orange Roughy, Oreodory, Pink Ling, Mirror Dory, Blue-eye Trevalla, Blue Grenadier, Royal Red Prawn, Redfish, Warehou, Morwong, Ocean Perch and Flathead. The trip limits apply to particular gear types and waters.

A recovery program and associated management arrangements for mulloway, covering all stakeholder groups, were implemented in 2013 to rebuild the population to a sustainable level in NSW. The current management arrangements include:

- A reduction to the recreational bag limit from five (with only 2 over 70 cm) to two;
- An increase to the minimum legal length from 45 cm to 70 cm;
- A by-catch allowance of 10 fish between 45 and 70 cm for mulloway incidentally caught in estuarine meshing nets; and
- A 500 kg possession limit per ocean hauling endorsement holder.

Minimum shareholdings were previously implemented in 2006 for the line fishing eastern and western zones, demersal fish trap and school and gummy shark sectors of the OTLF. The implementation of minimum shareholdings has had an impact in reducing the number of operators over time.

Management actions to address threatened species interactions include:

a) mandatory reporting of threatened and/or protected species interactions for all commercial fisheries, including distribution of a waterproof threatened and protected species identification brochure; and

b) scientific observer work.

DPI continues to implement measures to mitigate the impact of OTLF fishing on Grey nurse Sharks including, but not limited to:

- mandatory use of circle hooks for all unattended line fishing methods (non- offset circle hooks in waters < 92 m),
- prohibiting wire trace on bottom setlines in all waters within 3 nautical miles of the coast, and within buffer zones of all Grey Nurse Shark critical habitats and key aggregation sites,
- mandatory reporting of threatened species interactions,
- fishing closures for the OTLF around critical habitat and key aggregation sites,
- a weekly catch limit of 500 kg applies to a combination of shark species to limit targeted shark fishing, and
- a Priorities Action Statement has been developed for Grey Nurse Sharks.

Interactions between the OTLF and threatened and/or protected species have been observed during two observer programs undertaken in the OTLF Fishery as part of DPI's scientific observer program.

Bycatch is managed in the demersal fish trap sector of the OTLF via the mandatory inclusion of escape panels in fish traps. Escape panels are designed to reduce the number of small fish brought to the surface thereby allowing for them to be released from traps unharmed. Information on the number of fish traps lost during fishing operations is also collected by DPI.

Other management initiatives that been implemented to reduce risks from the fishery to species of concern include:

- ongoing reporting of environmental performance of all commercial fisheries under Commonwealth law (*EPBC Act*) for approval and maintenance of Wildlife Trade Operation status for export purposes
- a desktop study titled 'Broad-scale interactions between fishing and mammals, reptiles and birds in NSW marine waters' by Ganassin and Gibbs (2005)
- implementing threatened, endangered and protected species reporting
- disseminating information on handling and releasing turtles if caught
- spatial or temporal closures to commercial fishing, including -all waters within aquatic reserves and marine parks
- telecommunication cable closures off Sydney
- recreational fishing havens
- other waters closed to some or all commercial fishing methods
- prohibiting the possession of, harm to or trade in threatened, endangered and protected species
- implementing 2011 Mulloway Recovery Plan requirements (minimum size increase)
- implementing trip limits for shark species
- producing a shark and ray identification guide (2008)
- finalising a Code of Practice (2011)
- implementing wobbegong shark temporary size limit and ongoing trip limits
- implementing a northern zone spanner crab quota system (2015).

In relation to the spanner crab component of the OTLF, fishing mortality in New South Wales in the northern region is controlled through an interim Total Commercial Access Level (ITCAL). This ITCAL was based on current shareholdings that were effective from July 2015, with a total allowable catch for the fishery commencing in July 2017. Given the small proportion of total landings taken in New South Wales, it is unlikely that fishing of this part of the stock is having a detrimental effect on the entire east coast stock (McGilvray and Johnson, 2016). Fishing pressure from the recreational sector is negligible.

Potential impacts of the Ocean Trap and Line fishery

Reductions in abundance of species and trophic levels

This stressor relates specifically to the harvest of fish assemblages from the OTL fishery. Overall, the main direct impact of the OTL fishery on primary, key secondary and other retained species is the potential for biological overfishing, which substantially decreases exploitable mature biomass and spawning biomass of stocks.

The stock status of exploited marine species assessed using available data from 2013–2014 is presented in Appendix 3. Further details are provided in the Status of Fisheries Resources in NSW 2013–2014 report[54] (Stewart et al. 2015).

[54] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/598436/INT16-61462-Attachment-C-Status-of-Fisheries-Resources-in-NSW-2013-14-Full-Report-406-pages-updated.pdf

In the northern region, Australian bonito, leatherjackets, yellowtail kingfish and snapper make a significant component of the catch, with the majority of the catch in this region coming from state coastal waters rather than Commonwealth. Spanner crabs make up the majority of the commercial catch across NSW, and are caught by specifically endorsed fishers using spanner crab nets, also known as dillies.

Overall, approximately 40% of recent statewide landings taken are from the northern region, and are dominated by two growth-overfished (snapper, yellowtail kingfish), four fully fished (Australian bonito, spotted mackerel, Spanish mackerel, spanner crab), and four undefined species (leatherjackets, whaler sharks, teraglin, mackerel tuna) in the top 10 landed species, including those species defined as either moderate (M) or higher risk in the OTL EIS (NSW DPI 2006a).In addition, mulloway is a key secondary species in the OTL fishery (overfished).

In the central region, snapper, leatherjackets, Australian bonito and tailor make a significant component of the catch, with approximately 15% of recent statewide landings taken from this region. It is dominated by three growth-overfished (snapper, yellowtail kingfish, silver trevally), five fully fished (Australian bonito, tailor, sweep, yellowfin bream, yellowtail scad) and two undefined species (leatherjackets, wobbegong sharks) in the top 10 landed species, including those species defined as either moderate or higher risk in the OTL EIS (NSW DPI 2006a)

In addition, mulloway is a key secondary species in the OTL fishery (classed as overfished).

While several of the key species in the fishery (snapper, yellowtail kingfish and silver trevally) have been assessed as growth-overfished, they form a small overall proportion of the catch of these species taken in the coastal waters in the central region. This reduces the risk of this activity to these species, which are distributed across a broad region of temperate and subtropical waters of eastern Australia.

In the southern region, the catch is dominated by yellowtail kingfish and Australian bonito, blue mackerel, gummy shark and snapper, with the proportion of recent statewide landings taken from this region ranging from approximately 35% (2009–2010) to 10% (2013–2014). The catch is dominated by two growth-overfished (yellowtail kingfish, snapper), two fully fished (Australian bonito, gummy shark) and five undefined species (leatherjackets, wobbegong sharks, southern maori wrasse, eastern red scorpionfish, whaler sharks) in the top 10 landed species, including those species defined as either moderate or higher risk in the OTL EIS.

Incidental bycatch

Most of the species caught by the OTL fishery are retained for sale. Unwanted species caught in traps are usually alive and are released into the water, while escape panels in fish traps minimise retention of smaller and juvenile fish. Some unwanted fish species caught on setlines, driftlines, or droplines are dead on retrieval and are discarded at sea. Macbeth and Gray (2015) estimated that the overall bycatch ratio (expressed here as the proportion of the total catch (by number) that was subsequently discarded) for each of the three OTLF line-fishing categories examined was 15% for handline, 7% for dropline and 17% for set/trotline.

Anecdotal reports suggest that there is minimal gear loss in the OTL fishery. Fishers indicate that traps have a maximum life of about a year: even less when using escape panels. An Australian underwater video study suggests that there is minimal potential for ghost fishing, because fish can readily swim in and out of the traps (Moran et al. 2003). Overall, lost fishing gear probably poses a low to moderate risk to most ecosystem components, but there is no information upon which to base a more detailed risk assessment. Owing to the considerable uncertainty related to gear loss in the fishery and its potential impact, it was identified as an information gap that needs to be addressed.

Undersize and berried spanner crabs are the most common bycatch of this fishery, and fishers, managers and researchers have developed specific regulations and industry best practice guidelines to minimise post release mortality (Brown et al. 2003). These include gear design and amount, vessel manning requirements and regulated fishing practices, such as the immediate removal and return to the water of unwanted crabs. Spanner crabs are targeted using passive gear (Kennelly et al. 1990).

Incidental catch of species of conservation concern

The OTL EIS found that of 18 threatened species of fish considered, 15 were at low or low–moderate risk from the current operation of the fishery. The remaining three species (grey nurse shark, black cod and white shark) were at high, moderately high and moderate risk, respectively.

As noted earlier, hook-and-line fishing is the major threat to the grey nurse shark's survival and largest source of this species mortality, causing around 12 known deaths per year (NSW DPI 2011). Observations in the OTL fishery reported that five grey nurse sharks were caught during fishing days, and six great white sharks were recorded in the northern region, all hooked via set or trotlines (Macbeth et al. 2009). Notes from observers indicated that all sharks were alive upon release. More recently, Macbeth and Gray (2015) found interactions between handline, dropline and set/trotline fishing gears and threatened and/or protected species during the observed fishing days were rare, with only two grey nurse and four white sharks being hooked during the study.

The NPWS Elements database captures data on wildlife that are entangled in fishing gear. Many entanglements are reported each year in gear types used by the OTL fishery (see Section 6.1.2 for details). Cetaceans are the most commonly reported to entangle in fishing gear. Whales are particularly vulnerable to entanglement in traps in coastal waters during their annual migration. NPWS has recorded 142 fishing gear entanglements with cetaceans from 2007-2016 (average of 14 per year), mostly humpback whales. These entanglements are the largest known anthropogenic threat to cetaceans recorded in the NPWS Elements database. Most entanglements reported are with trap gear (43 recorded). Most trap entanglements are associated with the OTL fishery, though some are also attributed to the lobster fishery and recreational fishing.

Traps are known to entangle whales in NSW when they are not easily detected by the animal, long ropes and dense traps are more likely to cause an entanglement (Ganassin and Gibbs 2005). However, low reporting effort and a lack of information on gear or fishery type associated with entanglements impedes an accurate assessment of the threat of the OTL to marine fauna populations. Whales can also become entangled during fishing operations (e.g. a humpback whale was entangled during an observer study in the OTL (Macbeth and Gray 2016). Many entanglements (36 recorded) also occur with lines and ropes, which have been linked to the OTL fishery and recreational fishing. Due to the difficulty of sighting animals and identifying the type of fishing gear involved, the number of animals entangled each year is likely to be higher than reported.

Seabirds (e.g. pelicans, cormorants, shearwaters, gannets) can be entangled or caught in the OTL including in passive demersal long line fishing methods (Ganassin and Gibbs 2005). For example, a short-tailed shearwater was hooked during on OTL line-fishing trip during an observer study (Macbeth and Gray 2016). Shorebirds and seabirds are most at risk of entanglement or capture from line fishing methods. Sinkers and hooks can also cause mortality in birds if accidently ingested (Ganassin and Gibbs 2005). Long-line fisheries are associated with global declines in some seabird species (e.g. albatross, shearwaters). Species including albatross, giant petrel, shearwater, gannet, and skua have been recorded as captured in long-line fisheries in Australia. Global data suggests capture of 0.4 birds per 1000 hooks are likely to occur (Ganassin and Gibbs 2005).

An estimated 400 turtles are caught in pelagic long-line fisheries in Australia each year, with loggerhead and leatherback turtles the most vulnerable (Ganassin and Gibbs 2005). Turtles commonly entangle in fishing gear in NSW and are frequently entangled in traps, lines, and ropes, though for most entanglements gear type is unknown. Turtles and birds are most vulnerable when gear is set near the surface. Dolphins and seals have been also recorded as captured in long-line fisheries in Australia (Ganassin and Gibbs 2005). Seal entanglements in NSW mostly occur on lines or ropes, though for most reports gear type is not identified. Juvenile seals are also prone to capture in traps.

The risk of the OTL fishery to threatened and protected species of birds, marine mammals and reptiles was assessed as moderate, some of which reflects the uncertainty related to impacts of the fishery, and recognised as an information gap that needs to be addressed. Interactions with protected species are rare.

Physical disturbance

The OTL EIS assessed the impact of the fishery on habitats such as hard and soft substrata and associated biota. Based on limited observations in the literature, the impact of traps on these habitats was considered very small when compared with natural disturbance regimes. Hard and soft substrates and associated biota were reported at low to moderate–low risk from the OTL fishery, although a lack of detailed control or ongoing comparative information was noted. The EIS also notes that there is considerable 'refuge' habitat that is unaffected by the fishery.

Wildlife disturbance

Competition between fishers and wildlife can occur when prey items and foraging grounds overlap with fishers, reducing population health (Ganassin and Gibbs 2005). Marine wildlife including birds, dolphins, and seals have been observed feeding off discards in NSW fisheries using line and trap methods among others and are at greater risk of entanglement or capture when doing so (Ganassin and Gibbs 2005). For example, seals are known to disrupt fishing trap and handline fishing activities causing negative interactions with fishers (Ganassin and Gibbs 2005).

Fishing vessels operating in the OTL fishery regularly travel up and down the NSW coast and between state and Commonwealth waters. They may potentially disturb wildlife at these times in the same way as described in Section 8.1.1, although relative risk is subject to the due to the limited number of commercial entitlements.

Marine debris

Entanglement in, or ingestion of, discarded material (particularly plastic or synthetic) by marine mammals, reptiles and seabirds is a key threat to their survival (Laist 1997, NSW Scientific Committee 2003, Threatened Species Scientific Committee 2003). Floating debris poses the greatest entanglement threat to surface-dependent species that are attracted to it as a food source or shelter. Determining the origin of fishing gear acting as marine debris is difficult, because it can travel long distances. However, debris that may originate from the OTL fishery includes line segments (perhaps with attached hooks), ropes, floats and bait packaging. These items have been found to harm marine vertebrates in other parts of the world (Laist 1997).

While gear loss in the OTL fishery has not been investigated, most studies of debris found on Australian beaches have recorded fishing-related items (Cunningham and Wilson 2003, Haynes 1997, Herfort 1997, Kiessling 2003, Slater 1991, Whiting 1998), indicating its presence in the surrounding ocean (Jones 1994). A study of selected ocean beaches in NSW found 13% of the debris to be fishing related, 60% of which was from commercial origins and the remaining 40% recreational (Herfort 1997). Among the fishing debris recorded on NSW beaches, trap fishing gear dominated central NSW beaches, while recreational fishing gear dominated beaches around urban centres, especially those on the central coast of NSW (Herfort 1997).

Ocean Trawl Fishery

Two types of trawling currently operate in ocean waters under the NSW Ocean Trawl Fishery (OTF): prawn trawling and fish trawling. Both methods employ otter trawl nets, or to a lesser extent, Danish seine nets. Much of the ocean trawl catch on the south-east coast comes from Commonwealth waters and is not considered here. The prawn trawl sector is NSW's most valuable harvest fishery.

The overall catch from the fishery within NSW coastal waters in 2013–2014 was 2,615 tonnes, which has varied little in recent years (Figure 73). This reflects a limited period in the fishery. Trends in landings are not a specific indicator of abundance, and changes in CPUE and other economic indicators are important factors. Further details of long-term trends and CPUE for the key species are presented in Stewart et al. (2015).

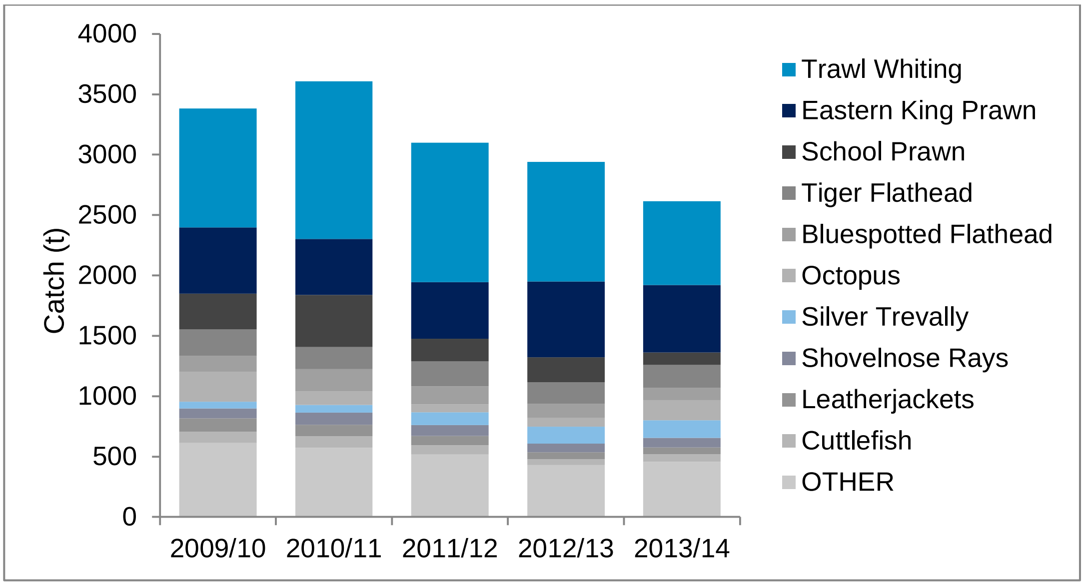


Figure 73. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the Ocean Trawl Fishery in New South Wales coastal waters; catch is reported by the top 10 species, with the remainder classified as 'other'. *Source: DPI Fisheries catch records database extract 26 November 2015.*

Over the past 15 years, overall catch levels for the OTF reported across the entire NSW fishing jurisdiction have decreased, and effort has decreased by 8%. New marine park areas and fishery consolidation are likely to have contributed to this decline. Overall, the catch is dominated by trawl whiting, eastern king prawn, school prawn and tiger flathead, which combined make up around 60% of the catch in most years (Figure 74). Around 80 species are regularly reported, reflecting the multi-species nature of trawl gear and the economic contribution of byproduct species to the fishery.

The proportion of the OTF catch taken in NSW coastal waters within 3 nm is largest in the **northern region** and least in the **southern region**, at approximately 50% and 10%, respectively (Figure 74). Trawl whiting dominates the gross weight of the catch composition in all regions, followed by eastern king prawns in the north, tiger and blue-spotted flathead in the Hawkesbury and silver trevally in the south (Figure 75).

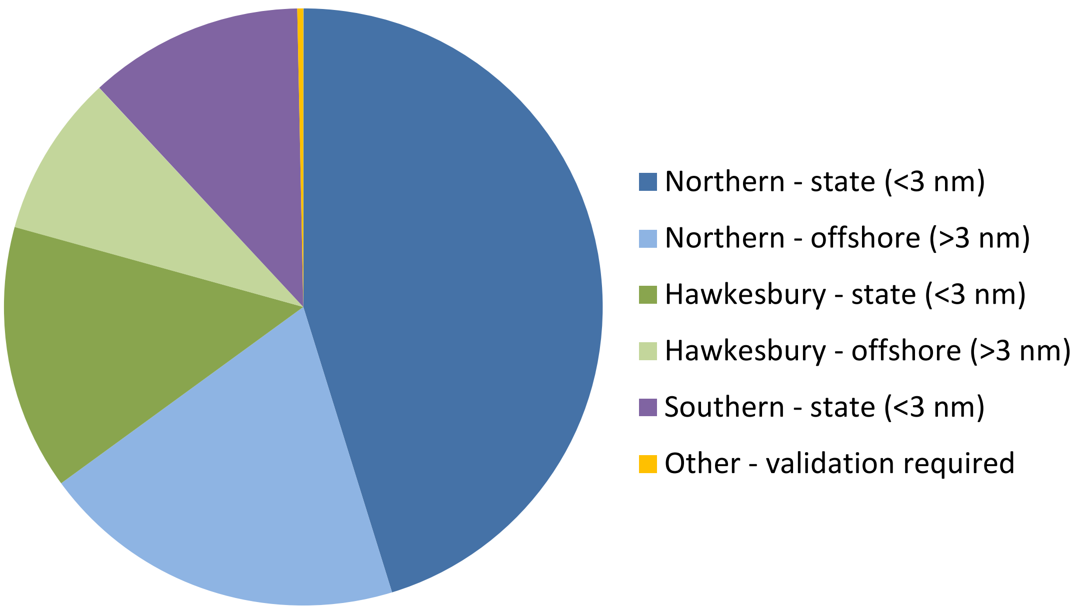


Figure 74. Proportion of catch in the New South Wales Ocean Trawl Fishery in each region for 2013–2014. *Source: DPI Fisheries catch records database extract 26 November 2015.*

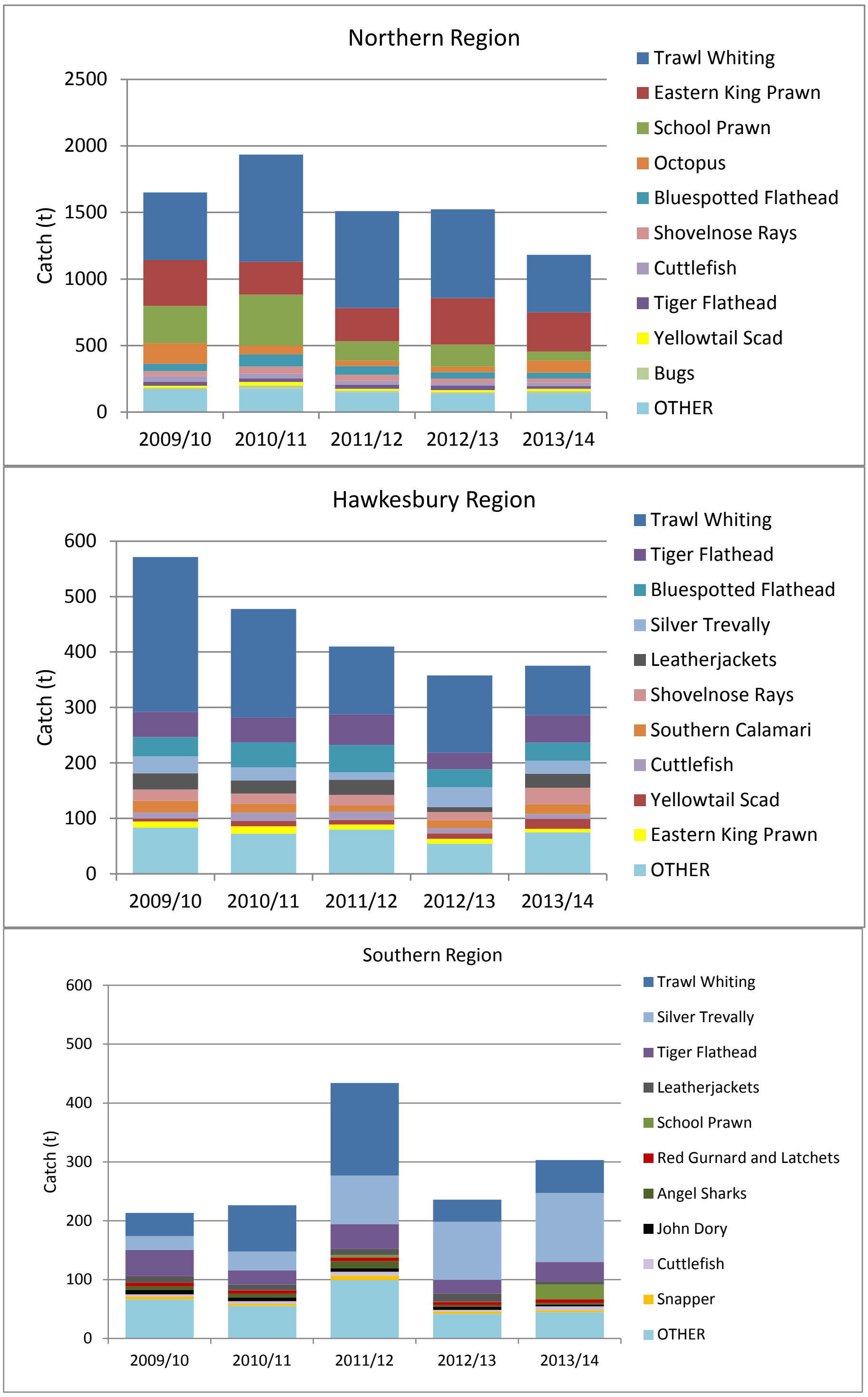


Figure 75. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the New South Wales Ocean Trawl Fishery inshore 3 nm for the top 10 species in each region. *Note: Scale of y-axis on Northern graph is different. Source: DPI Fisheries catch records database extract 26 November 2015.*

Current management arrangements

DPI manages the Ocean Trawl Fishery (OTF) in accordance with the Fisheries Management (Ocean Trawl Share Management Plan) Regulation 2006 the OTF Fishery Management Strategy as well as the *Fisheries Management Act 1994* and subordinate legislation.

The controls on fishing gear and assessment of improved gear configurations used in the OTF have changed significantly since the OTF EIS was prepared, and will continue to do so, with the aims of:

- increasing fishing efficiency

- harvesting species at an optimum size
- further reducing bycatch
- responding to any emerging sustainability issues (e.g. Broadhurst et al. 2006; 2012a).

Gear used in the OTF is highly regulated, designed to catch target species at optimum size and to minimise bycatch, and is constantly under review. Ground gear requirements, mesh sizes and bycatch reduction devices (BRDs) are some of the tools used to minimise bycatch. Given the spatial and temporal variability in bycatch an adaptive closure program is also used to respond to short term bycatch issues.

Bycatch is managed in the prawn trawl sector of the OTF via the mandated inclusion of BRDs. Bycatch is managed in the fish trawl sector of the OTF via restrictions on the configurations of nets (a minimum mesh size of 90 mm is permitted in the cod end of otter trawl nets) and or a combination of net configuration and spatial closures (e.g. fishers using nets to target trawl whiting may reduce the size of the mesh used in the cod end of their nets but are restricted to designated trawl whiting grounds).

The OTF Fishery Management Strategy provides for short term spatial and temporal fishing closures to be implemented in response to flooding events to protect juvenile and displaced fish and prawns from the effects of trawling. This is implemented via a fishing closure made pursuant to section 8 of the *FM Act*.

The OTF operates under specific guidelines developed to manage and minimise bycatch of juvenile mulloway in the OTF, and includes trigger levels for initiating (and lifting) short term fishing closures (made pursuant to section 8 of the *FM Act*) to trawling in response to high levels of juvenile mulloway. The current gear requirements are designed predominately to limit fishing effort (e.g. headrope and sweep length restrictions), and for optimal selectivity (e.g. mesh size and orientation, sweep lengths and bycatch reduction devices).

Given the significant spatial and temporal variability in bycatch, an adaptive closure program is now used in NSW to respond to short-term bycatch issues (e.g. off river entrances following flood events, and to protect juvenile mulloway and prawns). Many such short-term trawl closures have been implemented to address bycatch issues since the introduction of the OTF FMS in 2007. In recent years, an industry-proposed temporary spatial closure has been implemented in ocean waters off Ballina to provide and assess potential increases in economic prawn yields.

Methods to reduce unwanted bycatch were introduced into the prawn trawl fishery in 1999 by means of compulsory bycatch reduction devices. A fishery scientific observer program in NSW examines the highest-risk methods to ensure that resources are allocated effectively, with an observer program for the OTF commencing in 2014.

Different types of bycatch reduction devices are available, but the composite square-mesh panel is used by the majority of fishers. Square-mesh panels and composite square-mesh panels installed on trawl nets enables non-target fish species and undersize target species to escape from the codend of the trawl. These devices effectively remove up to 40% of total unwanted bycatch (Macbeth et al. 2008).

Grid bycatch reduction devices installed as an escape exit for large marine biota also enable non-target species, such as turtles, rays and other fish, to escape the net. In the Clarence River, up to 90% of bycatch and as much as 67% of undersize, commercially important species have been removed from prawn trawls with no subsequent loss to targeted catch (Broadhurst et al. 2004). Additional research has been done on the use of square-mesh codends, in which the mesh is hung on the bar, rather than the diamond; however, these have not been fully implemented yet (e.g. Broadhurst et al. 2010).

Prawn counts apply to the OTF, Estuary Prawn Trawl and Estuary General Fisheries, and were introduced as a requirement of the relevant Fisheries Management Strategies between 2004 and 2005 to minimise the harvesting of prawns at times and in areas where prawns are below optimum size. Prawn counts are implemented via a fishing closure made pursuant to section 8 of the *FM Act*.

Catch limits apply to a range of species taken from NSW waters as part of the OTF (Gemfish, Redfish, Blue and Silver Warehou, Jackass Morwong, Ocean Perch and Flathead spp.). Commercial catch limits are implemented via a fishing closure made pursuant to section 8 of the *FM Act*.

As part of the Commercial Fisheries Business Adjustment Program (BAP) the following species taken in the fish and prawn trawl sectors of the OTF will be quota managed from December 2018: trawl whiting (stout and eastern school), tiger flathead, blue spot flathead, silver trevally, and gemfish.

For the remaining species (including eastern king, school prawns and yellow tail scad) that will not be quota managed, protection will be provided by other BAP management initiatives including increased minimum shareholdings that apply in all OTF sectors by December 2017 and in the case of the ocean prawn trawl sector a cap on the amount of effort that will be implemented by December 2018.

A number of management actions have been implemented to address the impact of the OTF on marine habitats. Closures as part of marine parks, aquatic reserves and fishing closures (under section 8 of the *FM Act*, and the OT SMP) apply, including closure of all reefs and depths greater than 1100 m to all forms of trawling.

Management actions to address threatened species interactions include a) mandatory reporting of threatened species interactions for all commercial fisheries, including distribution of a waterproof threatened and protected species identification brochure; and b) scientific observer work. The FMS's for all the major commercial fisheries (excluding lobster and abalone) required the implementation of a cross-fishery scientific observer program. The program has been implemented based on a framework that identifies the highest priority methods for observation based on a number of measures and to ensure that resources are directed towards the methods that pose the greatest risks.

Fishers in the fish trawl sector of OTF are no longer permitted to use bobbin gear on the ground ropes of fish trawl nets north of Seal Rocks. The purpose of this restriction is to stop fishing on or adjacent to reef substrates. Fishers in the fish trawl sector of OTF operating south of Seal Rocks may use bobbin gear that is no larger than 100 mm. This means that fishers may operate adjacent to lower profile reef substrates. In order to reduce the extent of adverse interactions between gear used in the fish trawl sector of the OTF on softer sediments fishers are permitted to use no more than a single ground chain of greater than 16 mm gauge.

Potential impacts of the Ocean Trawl Fishery

Reductions in abundances of species and trophic levels

This stressor relates specifically to the harvest of fish assemblages (including molluscs and crustaceans) from the OTF. Overall, the stock status of exploited marine species in this fishery assessed using available data from 2013–2014 is presented in Appendix 3. In this latest assessment, both the eastern king prawn and silver trevally continue to be defined as growth-overfished; trawl whiting, school prawn, tiger flathead and blue-spotted flathead are fully fished; and octopus, shovelnose rays, leatherjackets and cuttlefish are undefined.

Further details are provided in the Status of Fisheries Resources in NSW 2013–2014 report[55] (Stewart et al. 2015).

In the northern region, trawl whiting, eastern king prawn and school prawns make up a significant component of the catch taken in coastal waters, with approximately 45% of recent landings taken from this region. The catch is dominated by one growth-overfished (eastern king prawns), five fully fished (school prawn, yellowtail scad, tiger flathead, blue-spotted flathead, bugs), and three undefined species (octopus, shovelnose rays, cuttlefish) in the top 10 landed species, including those species defined as either moderate or higher risk in the OTF EIS.

[55] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/598436/INT16-61462-Attachment-C-Status-of-Fisheries-Resources-in-NSW-2013-14-Full-Report-406-pages-updated.pdf

Given the growth-overfished status of one of the key species, this represents an increased level of risk for this activity in this region. The catch of undefined species, combined with the large percentage of the OTF catch taken in the northern region, further increases the risk.

In the central region, trawl whiting, tiger flathead, blue-spotted flathead and silver trevally make up a significant component of the catch. Approximately 10% of landings are taken from this region, and as the overall level of catch in these regions is considerably smaller than the northern region, the risk associated with this activity is reduced. The catch is dominated by two growth-overfished (silver trevally, eastern king prawns), four fully fished (yellowtail scad, tiger flathead, blue-spotted flathead, bugs) and three undefined species (leatherjackets, shovelnose rays, cuttlefish) in the top 10, including those species defined as either moderate or higher risk in the OTF EIS.

In the southern region, trawl whiting, silver trevally, tiger flathead and leatherjackets make up a significant component of the catch. Approximately 10% of landings are taken from this region, dominated by two growth-overfished (silver trevally, snapper), three fully fished (tiger flathead, john dory, school prawn) and four undefined species (leatherjackets, angel sharks, cuttlefish, red gurnard/latchet) in the top 10, including those species defined as moderate or higher risk in the OTF EIS. These species have a wide distribution across a broad region of temperate waters or eastern Australia.

The OTF EIS assessed the impact of harvesting on the spawning and mature biomass of the main species taken. Five species of finfish were at the highest level of risk, all elasmobranchs (fiddler, angel and saw sharks and greeneye and Endeavour dogfishes). These species have low resilience, low refuge availability, poor selectivity of fishing gear and inadequate stock assessments. As these species are primarily caught in deeper waters on the outer continental shelf (i.e. Commonwealth waters), they are not considered to add to the risk associated with the OTF in NSW waters.

Incidental bycatch

Demersal trawling retains a range of target, byproduct and bycatch species. Bycatch varies significantly at different times in different places, and can include small or undersize primary and byproduct species, and other non-marketable species. Ground gear requirements, mesh sizes and bycatch reduction devices are some of the tools used to minimise bycatch.

There is little information on the quantity, composition, frequency and temporal and spatial variability of discarded, unmarketable commercial species. This is a source of unaccounted mortality, which means the stock status of some of the primary and key secondary species will be inadequate. Therefore, the level and composition of discarded, unmarketable commercial species in the OTF must be investigated. Furthermore, the motives for discarding commercial species should be analysed to determine whether the management strategy itself contributes to excessive discarding (e.g. through legal size limits).

A list of all non-commercial bycatch species recorded from observer surveys on commercial fishing vessels was compiled from the studies of Kennelly et al. (1998) and Liggins (1996). A total of 156 species were caught, containing 37 species of elasmobranchs, 109 species of teleosts, 10 species of crustaceans and one species group of molluscs. The composition of bycatch species of commercial species taken by fish trawlers varied substantially between years and at large and small spatial scales (Liggins 1996). Fifty per cent of the total catch (overall years and ports) was discarded by fish trawlers, and 54% of the discarded catch consisted of non-commercial species. A more recent study quantified the catch composition, including discards in the Sydney inshore whiting fishery (Graham and Wales 2008).

Physical disturbance

Trawling has the potential to have the greatest impact, because it has a direct effect on benthic habitats that contribute to species diversity. It can reduce the number of species in a particular habitat type and change the composition of the species in a habitat. For example, trawling over low-profile reef habitat can reduce the diversity of sessile species by destroying and removing entire assemblages over a relatively short time, particularly if areas are trawled repeatedly in a season or year (e.g. Sainsbury 1988).

Trawlers usually operate over soft-sediment habitats. Trawl tracks in soft sediment made by otter boards, bobbins and ground chains disturb infauna, and damage and expose burrowing invertebrates (e.g. heart urchins) to scavengers (Freese et al. 1999, Hall 1999). Collie et al. (2000) noted that invertebrate assemblages living in naturally stable sediments and biogenic habitats are more adversely affected by trawl damage than those in coarse, more naturally disturbed sediments. They and other authors suggest that the more frequent an area is trawled within a fishing season or year, the more likely it is to be maintained in a permanently altered state (Collie et al. 2000, Kaiser et al. 2000, Rijnsdorp et al. 1998). There is little information on the precise location of trawl grounds in the OTF or how frequently they are trawled. Therefore, it is not possible to determine the potential extent of any impacts from trawl activity on state coastal waters. Assessment of trawl fisheries in Commonwealth waters indicates that impacts on soft sediments are likely to range from minimal for most area of trawl area up to significant localised effects in areas that are trawled very frequently (Pitcher et al. 2015).

An assessment of risk from the OTF concluded that the habitat-forming biota associated with reefs and sediments, and the biota on low-relief reefs, should be assigned a high risk level (Astles et al. 2009). At that time, little information was available about the distribution of continental shelf habitats. This increased the likelihood that ocean trawling in NSW waters could lead to widespread degradation of ecological assets in continental shelf habitats. A broader assessment of risks associated with demersal trawling on the continental shelf and slope of southern Australia identified that risks were low for inner shelf habitats due to a range of susceptibility attributes (Williams et al. 2011). These included the relatively large habitat areas on the inner shelf, low proportional overlap of fishing effort, large areas of relatively dynamic, naturally disturbed sediment plains with little emergent fauna, and a relatively high proportion of hard, high relief rocky outcrop to bottom trawl.

This was influenced by two attributes that assume higher productivity in shallow waters compared to deeper areas reflecting faster regeneration time of fauna; and adaptation of fauna to a greater degree of natural disturbance. Trawl impacts on shallow fauna vary greatly between major taxonomic groups (Kaiser et al. 2006), and may be long-lasting (years to decades) for large structural fauna (e.g. Pitcher et al. 2008). When slow-growing species are lost, their species diversity may stay permanently depleted, because regrowth and recolonisation is extremely low. For example, some sponges may take >100 years to regrow (Leys and Lauzon 1998). In addition, because sessile species (e.g. sponges, gorgonians) often provide habitat for other species (e.g. fish, molluscs, crustaceans), their removal can reduce species diversity for some taxa and change the composition of others (Gray 1997).

The conclusion in Williams et al. (2011) was also reached due partly to the lack of information on the distribution of fishing grounds and fishing effort, and partly to the inability to quantify the magnitude of the effect size of fishery impacts. The growing amount of information on the distribution, extent and structure of seabed habitats and the associated biota on the continental shelf (e.g. Jordan et al. 2010) has greatly improved the understanding of the likely extent of these impacts.

The use of bobbins (restricted in size and to otter fish trawl gear south of Seal Rocks) on trawl gear enables trawlers to fish over low-profile reef, and close to the edges of high-profile reef where foliose and turfing algae, and sessile invertebrates could occur (Bax and Williams 2001). Trawling over habitat that has a low profile (i.e. <1 m), and often patchy mosaic of hard ground (often boulder habitat) that is common in NSW shelf waters is likely to result in impacts on benthic assemblages, but the level of impacts may be localised, and there is uncertainty about recovery times. There are also soft sediment areas on the inner shelf that contain sessile invertebrate assemblages attached to underlying bedrock or biogenic material (Jordan et al. 2010).

Incidental catch of species of conservation concern

Trawling may incidentally catch threatened and protected species when they are associated with a particular habitat that is being trawled, or are feeding on the primary, key secondary or bycatch species either taken by OTF fishers or feeding from the net itself. For example, there is evidence of seals entering nets to feed (Shaughnessy and Davenport 1996).

Turtles, sharks, protected finfish, and seals are most likely to be directly caught in trawl nets while feeding on the finfish species targeted by the OTF, or on benthic fauna or flora on trawl grounds. They may be caught while moving from one area to another. Seals, turtles, and birds (e.g. flesh-footed shearwater, albatross spp.) have been reported as entangled in the OTF in NSW and green turtles and loggerhead turtles are particularly at risk from this interaction (Ganassin and Gibbs 2005, Johnson in prep). When these animals are caught in trawl nets they are likely to die of drowning (Ganassin and Gibbs 2005). During an observer study in NSW, observers recorded three turtles from 590 tows in the north region, two seals from 897 tows near Ulladulla, and 27 seals from 1109 tows near Eden (Ganassin and Gibbs 2005). A recent DPI observer program that surveyed 8% of the OTF over 65 days, recorded one albatross and three seal mortalities (DPI unpublished observer data). In Australia, dolphins and seals have been recorded as captured in trawl fisheries. Seabirds can become entangled in the net or trawl gear, such as the float line or bellylines, when they attempt to scavenge from the net as it is hauled in (Wienecke and Robertson 2002). However, seabird death from OTF methods is likely to be rare: much like that in the neighbouring south-east Trawl Fishery, in which seabird mortality has been observed to be 'virtually non-existent' (Knuckey and Liggins 1999).

The OTF EIS concluded that threatened and protected fish species were at low or moderately low risk from OTF operation. The risk of the OTF impeding the conservation and recovery of threatened marine mammals and reptiles was assessed as low or moderately low, and that for threatened seabirds was moderately low. In May 2012, the great hammerhead shark was listed as a vulnerable species and the scalloped hammerhead shark as an endangered species in NSW. This means both species are now totally protected and can no longer be taken by commercial trawlers.

Wildlife disturbance

Contact but not capture can occur when a threatened or protected species encounters any part of a trawl net while in operation. This can occur accidentally, or deliberately if the animal is raiding the net for food (Broadhurst 1998, Hickman 1999). Marine mammals (e.g. dolphins, seals), reptiles, and birds (e.g. cormorants) have been observed feeding off bait, catch or discards in NSW trawl fisheries and are at greater risk of entanglement, capture, vessel strike, or ingestion of fishing gear when doing so (Ganassin and Gibbs 2005). Seals in particular are known to raid trawl nets, and may tear nets open with their teeth and then become entangled in pieces of net that are torn off. Due to the mobility of turtles and marine mammals, such encounters are difficult to document. Hence, the level of the impact of contact with trawl nets on threatened and protected species is unknown.

Fishing vessels operating in the OTF regularly travel up and down the NSW coast and between state and Commonwealth waters. They may potentially disturb wildlife at these times as described in Section 8.1.1, although risk is reflective of the limited number of commercial entitlements.

Marine debris

When trawl fishing gear is lost at sea, either in part or whole, it has little ability to continue 'fishing'. The heavy netting collapses, and is clearly visible, so fish can avoid it though other wildlife are at risk of entanglement. Fishers in the OTF report that the incidence of lost fishing gear is minimal; they usually try to retrieve any lost gear. In a study recording fishing debris on NSW beaches, prawn trawl debris dominated the northern beaches, while fish trawl debris dominated the southern beaches. This was correlated to the distribution and intensity of trawling along the NSW coast (Herfort 1997). Very little discarded trawl gear was collected from beaches in the central region.

The same impacts from marine debris in the OTL fishery (see the *Marine debris* section) apply to the OTF.

Ocean Hauling Fishery

The Ocean Hauling Fishery (OHF) is a multi-species fishery that operates mainly on the open coast on specific beaches, but also has limited activity in some estuaries. The OHF includes haul netting (Figure 76), garfish netting and purse seining. Boats used in the OHF range from small runabouts and punt-style vessels in the beach based sector, to larger jet boats with motors up to 45 hp. Larger vessels are used in the purse-seine sector, where vessels range in size from 4 to 22 m. The boats used in the rest of the boat based hauling sector of the fishery are often 3-6 m in length.

The effort in this fishery remained relatively steady over the last five years, with effort days in 2013–2014 being approximately the same as those in 2009–2010. Statewide catches in the OHF have decreased over the last five years by 675 tonnes, with the 2013–2014 total annual statewide harvest being 4,143 tonnes (Figure 77).

Overall, the catch is dominated by sea mullet and eastern Australian salmon; these make up around 70% of the catch in most recent years. This has largely been due to the increasing value of pre-spawning sea mullet, which has become one of NSW's most valuable commercial finfish species. The Lobster Fishery also uses several OHF target species, such as sea mullet, eastern Australian salmon and luderick as bait in inshore lobster traps.

Figure 76. Ocean hauling in New South Wales waters. *Source NSW DPI.*

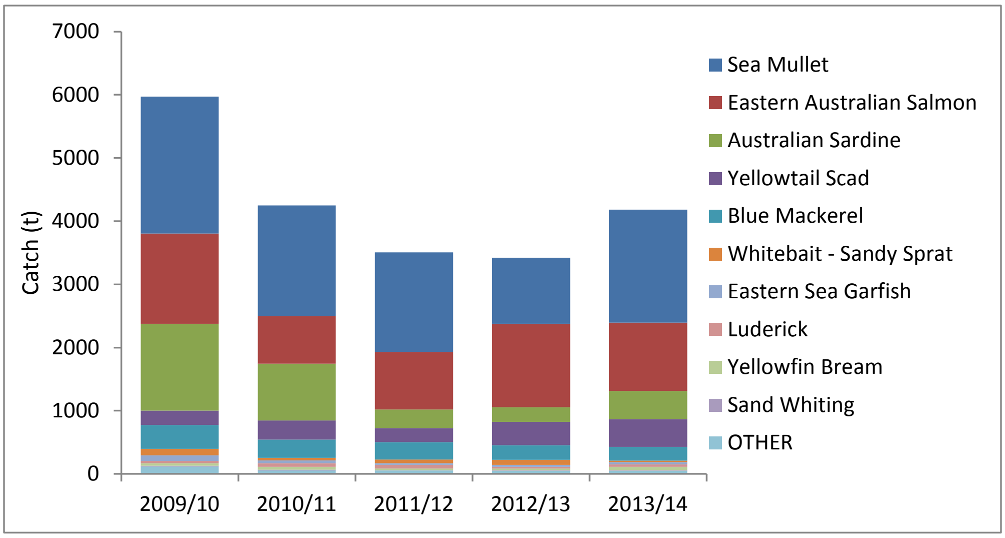


Figure 77. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the ocean haul fishery in New South Wales coastal waters; catch is reported by the top 10 species, with the remainder classified as 'other'. *Source: DPI Fisheries catch records database extract 26 November 2015.*

The proportion of the OHF catch taken in NSW coastal waters within 3 nm is largest in the **northern region** (~45%), least in the **central region** (~15%), and ~25% in the **southern region**, although this varies considerably (Figure 78). Sea mullet dominates the catch composition in the northern and central regions, along with yellowtail scad in the central region. Eastern Australian salmon and yellowtail scad are the dominant species in the catches in the southern region (Figure 79).

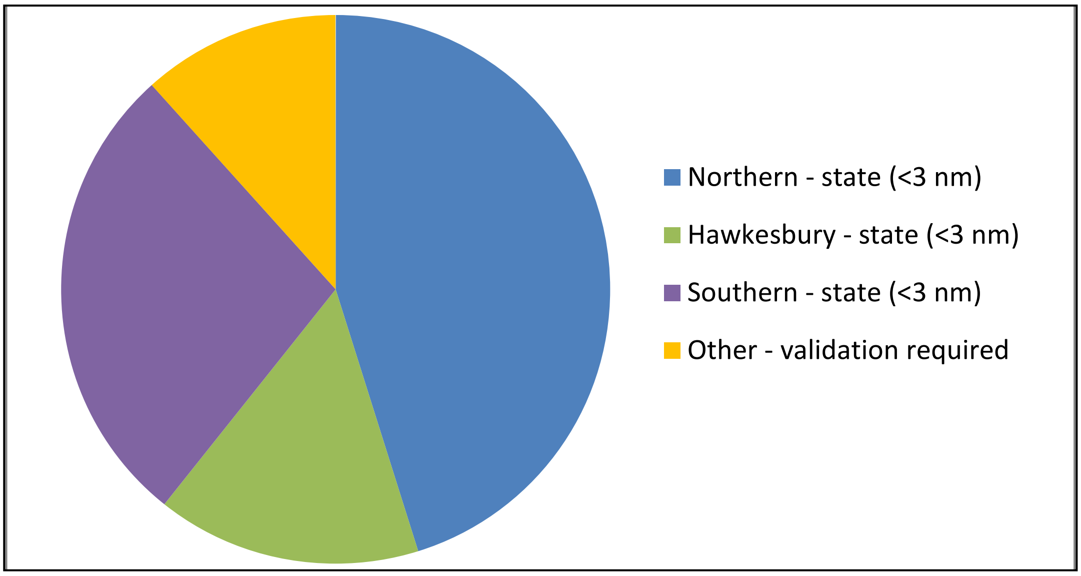


Figure 78. Proportion of catch in the New South Wales ocean haul fishery in each coastal region of New South Wales for 2013–2014. *Source: DPI Fisheries catch records database extract 26 November 2015.*

Current management arrangements

DPI manages the Ocean Hauling Fishery (OHF) in accordance with the Fisheries Management (Ocean Hauling Share Management Plan) Regulation 2006, the OH Fishery Management Strategy as well as the *Fisheries Management Act 1994* and subordinate legislation. The OHF operates under legislative arrangements with limited entry, gear restrictions, and permanent and seasonal restrictions on operational areas. Codes of conduct for the beach haul and purse-seine sectors cover direct and ancillary operations, including

- compliance with environmental legislation
- pollution
- reporting and interactions with non-target species
- speed limits on beaches
- use of agreed access points
- avoiding environmental damage
- local arrangements with relevant local governments.

Restrictions also apply to the OHF prohibiting operating on weekend and public holidays – Nov to February for hauling net (general purpose) and pilchard, anchovy and bait net (hauling), and all year for garfish net (hauling).

A fishing closure currently prohibits the taking of tailor, from any waters, by endorsement holders in the OHF and Estuary General Fishery by all methods other than set lines, hand held lines and drift lines (and a landing net when used in conjunction with those methods). The following exceptions apply:

Endorsement holders in the EG and OH Fisheries are permitted a bycatch trip limit of tailor if:

- taken using a hauling net (general purpose) – a 100 kg (whole weight) bycatch trip limit applies; or
- taken by use of any other net permitted in the EG and OH Fisheries – a 50 kg (whole weight) bycatch trip limit applies.

A fishing closure currently prohibits the taking of Australian salmon north of Barrenjoey Headland by endorsement holders in the EG and OH Fisheries by all methods other than set lines, hand held lines and drift lines (and a landing net when used in conjunction with those methods). The following exceptions apply:

- Endorsement holders in the OH Fishery must not take or be in possession of Australian salmon of more than the following amounts:
  - if taken using a hauling net (general purpose) – no more than 3,000 kg whole weight; or
  - if taken by use of any other net permitted in the OH Fishery – no more than 50 kg whole weight.
- Endorsement holders in the EG Fishery must not take or be in possession of more than 50 kg whole weight of Australian salmon taken using any net.

An annual total catch trigger limit of 224 tonnes (t; north of Barrenjoey Headland) applies (based on a calculation of expected bait needs in commercial trapping operations). If the total catch approaches 224 t, a review of the closure will be undertaken. A minimum legal length of 30 cm (total length) for silver trevally was introduced in 2007.

A recovery program and associated management arrangements for mulloway, covering all stakeholder groups, were implemented in 2013 to rebuild the population to a sustainable level in NSW. The current management arrangements include:

- A reduction to the recreational bag limit from 5 (with only 2 over 70 cm) to 2;
- An increase to the minimum legal length from 45 cm to 70 cm;
- A by-catch allowance of 10 fish between 45 and 70 cm for mulloway incidentally caught in estuarine meshing nets; and
- A 500 kg possession limit per ocean hauling endorsement holder.

Fishers operating in the OHF do so according to the NSW Ocean Hauling Fishery Commercial Fishers Code of Practice for Hauling Activities. The code of practice is aimed at promoting sustainable management practices and minimising conflict with other stakeholders by for example, establishing guidelines for minimum distances that gear may be used near from persons engaged in water activities and guidelines for the handling and return of unwanted catches to the water.

The taking of garfish has been prohibited on weekends in the OHF for many years. This management response was designed to reduce fishing mortality by reducing the total number of available fishing days. Together with other restrictions and increased compliance, eastern sea garfish has recently been assessed as fully fished: an improvement from its previous overfished status.

Several management actions were included in the OHF FMS to address the fishery’s impact on species assemblages, species diversity, ecological processes and marine habitats. Below is a summary of the key management arrangements addressed in the FMS; details can be found on the DPI website[56]:

- setting the area of ocean beaches closed to beach hauling at 17%
- measures to better protect marine habitats
- new programs for better monitoring of fish stocks
- introduction of catch limits for non-target species
- changes to fishing practices to reduce impacts on non-target species.

[56] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/224481/OH-FMS.pdf

Potential impacts of the Ocean Hauling Fishery

Reductions in abundances of species and trophic levels

This stressor relates specifically to the harvest of fish assemblages from the OHF. Overall, the stock status of exploited marine species assessed using available data from 2013–2014 is presented in Appendix 3. Further details are provided in the Status of Fisheries Resources in NSW 2013–2014 report[57] (Stewart et al. 2015).

In the **northern region,** sea mullet, Australian sardine and eastern Australian salmon make up the majority of the catch, with approximately 45% of recent landings taken from this region. The catch is dominated by seven fully fished (sea mullet, eastern sea garfish, eastern Australian salmon, luderick, yellowfin bream, yellowtail scad, whitebait – sandy sprat) and two undefined or uncertain species (frigate mackerel, Australian sardine) in the top 10 landed species, including those species defined as either moderate or higher risk in the OHF EIS (NSW Fisheries 2002c). The catch also contributes a small amount to the harvest of one overfished species (mulloway) in the northern region.

In the central region, sea mullet, Australian sardine and eastern Australian salmon make up the majority of the catch, with around 15% of recent statewide landings taken from this region. This is dominated by eight fully fished (yellowtail scad, sea mullet, eastern Australian salmon, sand whiting, luderick, eastern sea garfish, tailor, eastern sea garfish) and two undefined/uncertain species (silver sweep, goldspot mullet) in the top 10 landed species, including those species defined as either moderate (M) or higher risk in the OHF EIS (NSW Fisheries 2002c).In particular, the purse-seine fishery of silver sweep depleted localised populations in this region.

In the southern region, sea mullet, Australian sardine and eastern Australian salmon make up the majority of the catch, with around 20% of recent statewide landings taken from this region (although this is variable). There are also six fully fished (eastern Australian salmon, yellowtail scad, sea mullet, eastern sea garfish, luderick, sand whiting) and two undefined or uncertain species (silver sweep, Australian sardine) in the top 10 landed species, including those species defined as either moderate or higher risk in the OHF EIS (NSW Fisheries 2002c). The OHF also contributes a small amount to the harvest of one growth-overfished species (silver trevally) in the southern region.

In this latest assessment, eastern sea garfish has been moved from being overfished to fully fished following five consecutive years of improved age compositions in landings, and substantial increases in catch rates since the mid 2000s.

The overall characteristics of the southern region includes the dominance of sea mullet and Australian sardine in all years (generally making up >80% of landings), the recognition that the landings and length distribution of sea mullet using hauling nets on ocean beaches has remained relatively stable through time, lack of evidence that current sardine harvest levels are not sustainable, the absence of overfished species in the dominant landings, and the very small contribution of mulloway to the landings.

[57] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/598436/INT16-61462-Attachment-C-Status-of-Fisheries-Resources-in-NSW-2013-14-Full-Report-406-pages-updated.pdf

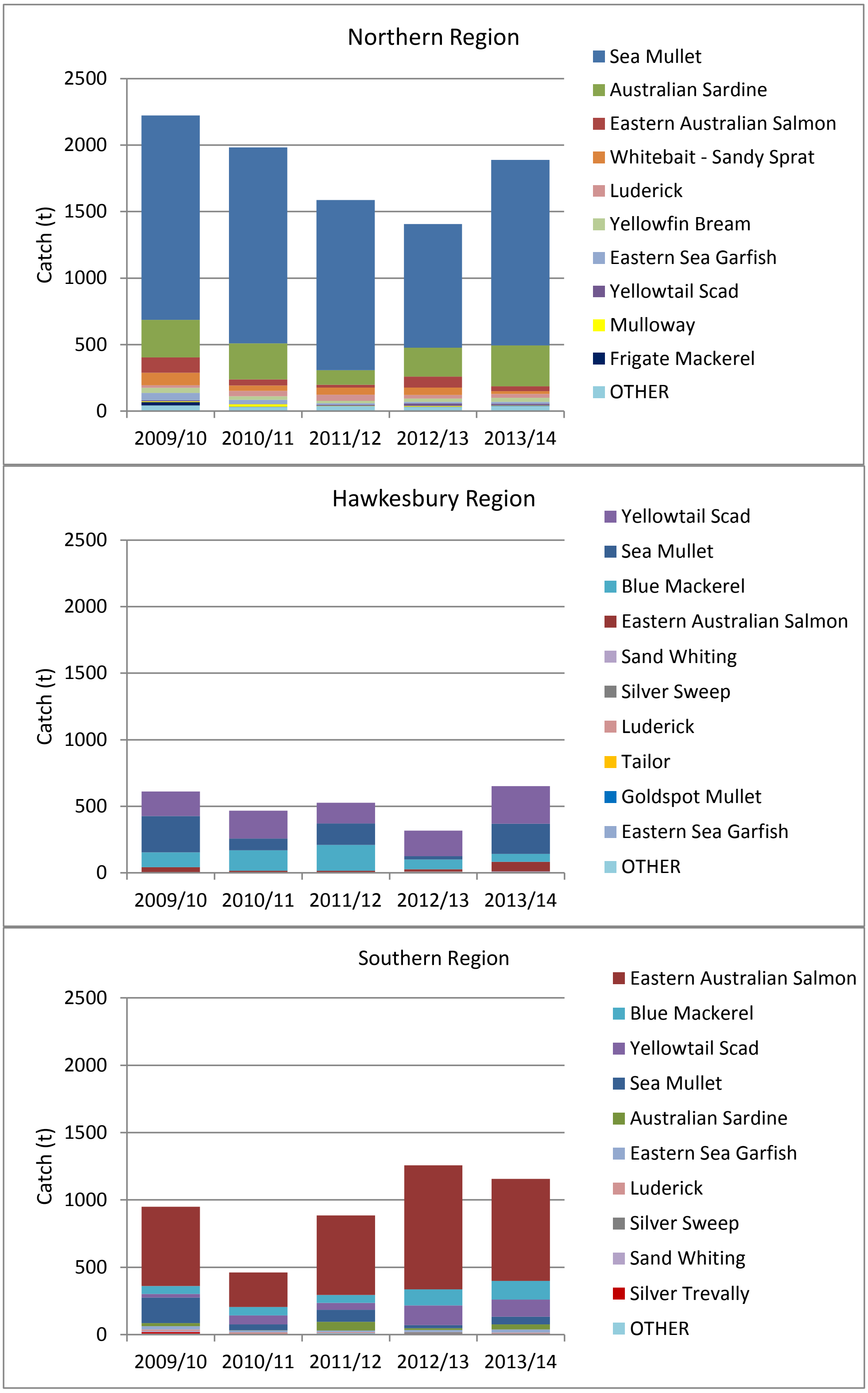


Figure 79. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the New South Wales ocean haul fishery inshore 3 nm for the top 10 species in each region. *Source: DPI Fisheries catch records database extract 26 November 2015.*

Incidental bycatch

The OHF EIS noted that anecdotal evidence and reported landings suggest that the fishery tends to target a single species, with little bycatch. Fishers observe schools before deploying nets, and can determine catch composition reasonably accurately. This was supported by a scientific observer survey of general-purpose hauling nets in the OHF (MRAG Americas 2005), which reported predominant catches of the target species with low levels of bycatch and discards.

Incidental catch of species of conservation concern

Marine mammals, turtles, and birds (e.g. penguins, terns) could be entangled or caught in the OHF including in active net methods (Ganassin and Gibbs 2005). MRAG Americas (2005) did not report any interactions between haul nets and marine mammals, sea turtles or seabirds during OHF operation. Except for some protected fish species, such as sygnathids, and the little penguin, other threatened and protected species are unlikely to be captured by OHF methods. However, in 2012, one cormorant was also captured using a purse seine net in the OHF (Submission to the Department of the Environment to consider the renewal of the Commonwealth Government's export approval for the NSW Ocean Hauling Fishery). Turtles could be at some risk from most OHF methods, principally in the northern and central regions. There is also some risk of interactions with grey nurse sharks and white sharks at some ocean beaches, although this may be seasonal.

Wildlife disturbance

Marine birds, dolphins, and seals have been observed feeding off bait, catch or discards in NSW fisheries using haul methods and are at greater risk of entanglement, capture, or ingestion of fishing gear when doing so (Ganassin and Gibbs 2005). Fishers may set purse-seine nets near foraging dolphins, seals, and whales, which can capture those animals. Marine mammals are occasionally reported to be able to escape purse-seine nets.

Disturbance of shorebird nesting, foraging, and roosting habitat can occur when OHF fishers access sites and fish on or near the shore. Noise and light from beach hauling activities can cause additional disturbance to some species.

Physical damage

The OHF EIS noted that any effects on habitats from this fishery were likely to be associated with beach based hauling methods, since they were the only methods to come into contact with the substratum (NSW Fisheries 2002c). The use of general-purpose haul nets over beds of strapweed (*Posidonia australis*) had already been banned before the species was listed as an endangered population in 2013. Damage to shorebird habitat may occur when fishers access sites or operate near nesting areas.

Marine debris

The OHF only uses mesh nets, and hence results in lower risks than fisheries that use a more diverse range of gear types. The overall risk was considered to be minimal in the EIS for the fishery (NSW Fisheries 2002c).

Lobster Fishery

The Lobster Fishery (LF) is a quota-managed fishery that extends from the Queensland border to the Victorian border and includes all waters under the jurisdiction of NSW. The gross value was around $10 million for a commercial catch of 145 tonnes in 2013–2014, and around $11 million for 150 tonnes in 2014–2015 (NSW DPI 2015).

The LF is the only NSW commercial fishery that is allowed to take rock lobster species, and the only Australian commercial fishery that targets the eastern rock lobster (*Sagmaraisus verreauxi*). Catches of *S. verreauxi* represent 99.9% (by weight) of all rock lobster species in the NSW commercial catch. Other lobster species harvested occasionally include the southern rock lobster (*Jasus edwardsii*) and tropical rock lobster (*Panulirus longipes* and *P. ornatus*). Small quantities of other byproduct species are also retained.

The LF primarily uses traps set in continental shelf waters off the NSW coast. Gear is mainly deployed on rocky reefs, but also on soft sediment on the mid and outer continental shelf. The fishery is characterised by inshore and offshore sectors. Inshore fishers typically use small beehive or rectangular traps in waters up to 10 m deep, and larger rectangular traps in depths to about 50 m. Offshore fishers fishing the mid and outer continental shelf use large rectangular traps (up to 2 m in length). Lobsters may also be hand gathered, but the use of artificial breathing apparatus (e.g. scuba diving) is prohibited.

The inshore component of the fishery uses predominantly small boats of 4-6 m in length. These vessels are usually aluminium runabouts with outboard motors. The offshore fishery is dominated by larger vessels, typically greater than 8 m in length. All boats used in the LF must be licensed fishing boats. Approximately 200 tonne of bait species are used across the entire NSW fishery per year. This largely comprises mullet and luderick taken in other NSW commercial fisheries. Fish frames (e.g. tuna) and meat products (e.g. bones) are sometimes used by offshore lobster fishers.

The most recent annual statewide total catch is 157 tonnes, of which 147 tonnes (90%) was eastern rock lobster (Figure 80).

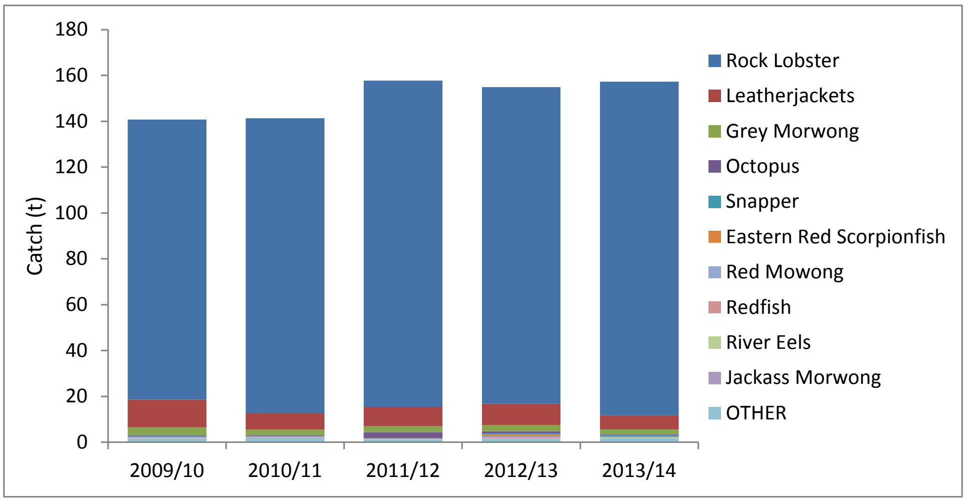


Figure 80. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the Lobster Fishery in New South Wales coastal waters; catch is reported by the top 10 species, with the remainder classified as 'other'. *Source: DPI Fisheries catch records database extract 26 November 2015.*

The proportion of the LF catch taken in NSW coastal waters within 3 nm is largest in the **northern region** and least in the **southern region**: 30% and 20%, respectively (Figure 81). The proportion taken in NSW coastal waters outside 3 nm is also largest in the northern region, and approximately equal in the other two regions, at 13% and 10%, respectively (Figure 81).

Eastern rock lobsters dominate the catch composition in the northern and **central** (Hawkesbury) regions. In the southern region, a greater diversity of species is taken, with leatherjackets making up 20% of the catch (Figure 82).

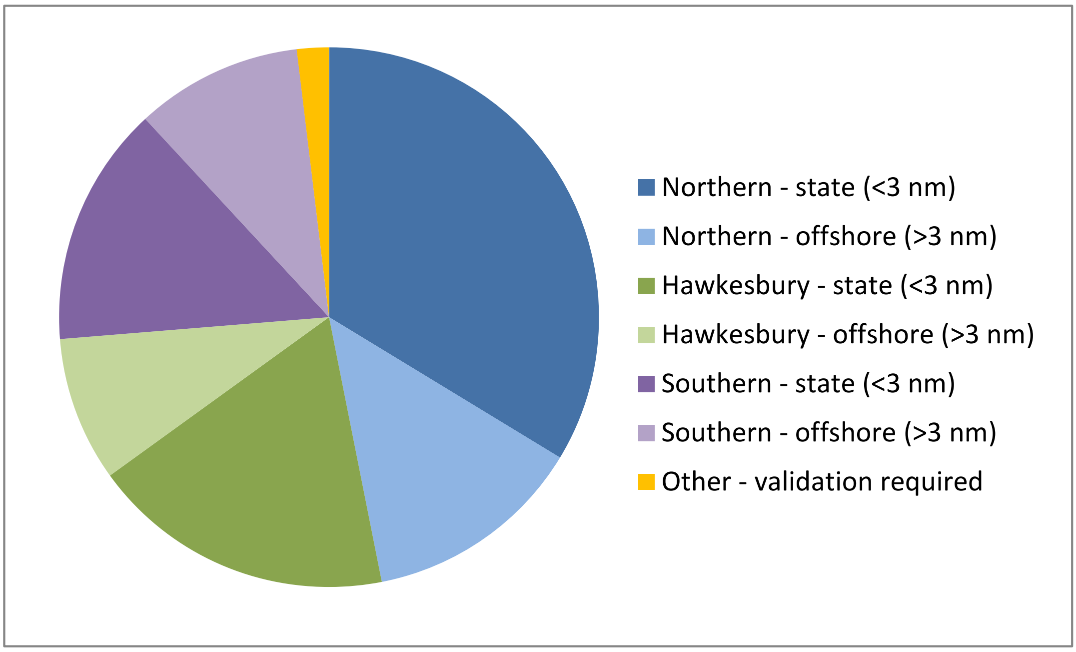
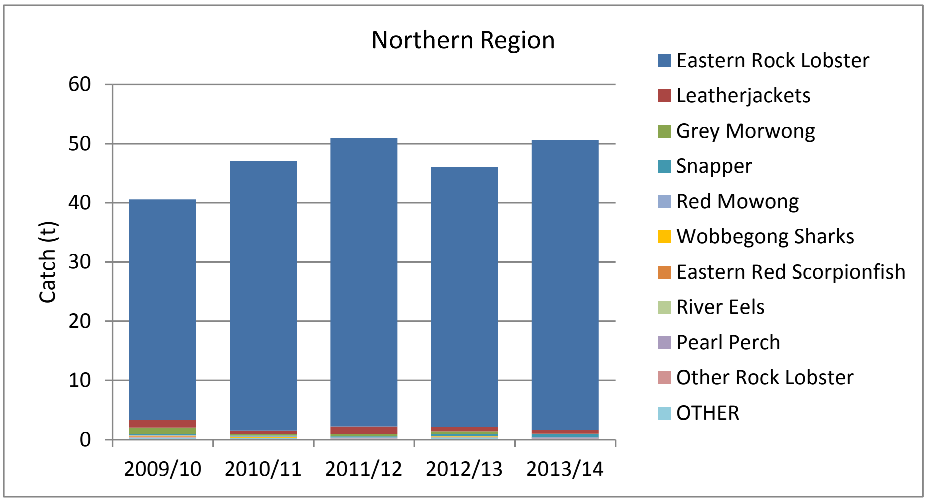
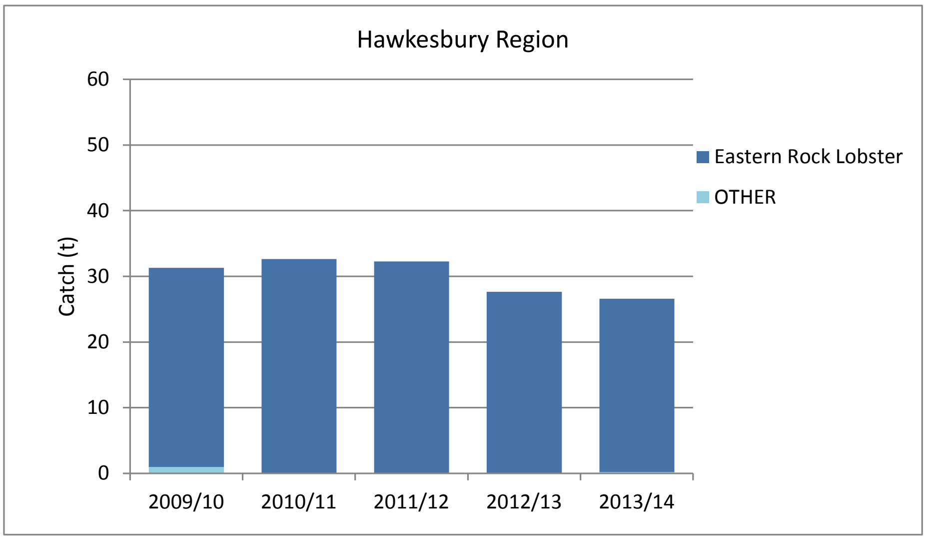


Figure 81. Proportion of catch in the New South Wales Lobster Fishery in each region for 2013–2014. *Source: DPI Fisheries catch records database extract 26 November 2015.*





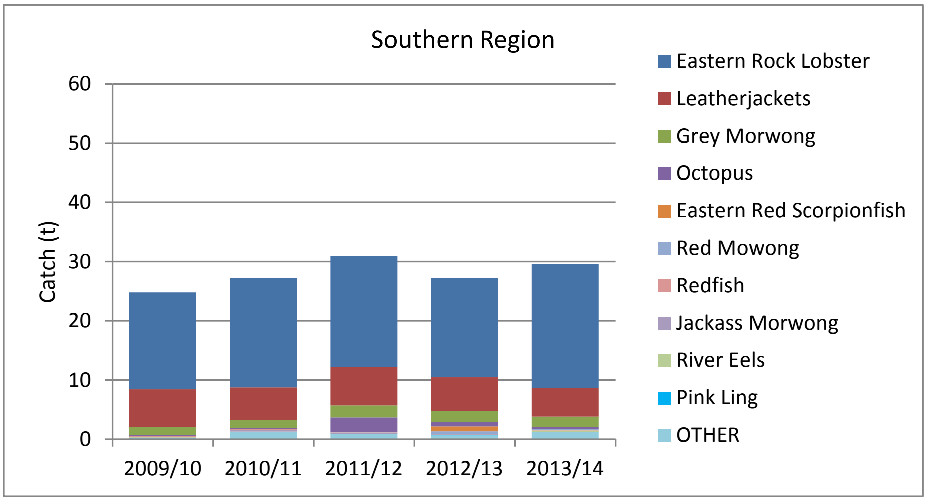


Figure 82. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the New South Wales Lobster Fishery inshore 3 nm for the top 10 species in each coastal region. *Source: DPI Fisheries catch records database extract 26 November 2015.*

Current management arrangements

Management arrangements for this fishery are primarily specified in the Fisheries Management (Lobster Share Management Plan) Regulation 2000 (LSMP). Fishery objectives and management responses are detailed in the LSMP and the NSW Lobster FMS. The fishery's performance is monitored against its objectives on a yearly basis to set the total allowable commercial catch (TACC) for each fishing period.

In February 2008, lobster fishers also developed a voluntary code of practice, which is reviewed every two years in consultation with the Lobster Industry Working Group. The code outlines broad principles and accountabilities for the sustainable management of their fishery including ways to minimise bycatch and interactions with threatened and protected species, and to reduce social and environmental impacts in general. The code was last reviewed in May 2014[58].

The commercial harvest of eastern rock lobster is subject to a TACC set annually by the statutory and independent Total Allowable Commercial Catch Setting and Review Committee established under the *FMA*. The TACC is allocated among all shareholders in the LF. Individual quotas are allocated by weight, in proportion to shareholding on an annual basis. There are a small number of spatial restrictions on the LF.

Potential impacts of the Lobster Fishery

Reductions in abundance of species and trophic level

This stressor relates specifically to the harvest of fish assemblages from the lobster fishery. Overall, in 2004, the LF EIS assessed the harvesting of the target species of lobster as an intermediate risk (NSW DPI 2004). The fishery is classified as fully fished, and there were concerns regarding the decline in spawning stock and small-sized lobsters in the previous 3-4 years. The EIS noted that there was no imminent risk of recruitment failure, but there was a significant risk if measures were not implemented to rebuild and closely monitor the spawning stock of the target species (NSW DPI 2004).

Overall, the stock status of exploited marine species assessed using available data from 2013–2014 is presented in Appendix 3. Further details are provided in the Status of Fisheries Resources in NSW 2013–2014 report[59] (Stewart et al. 2015).

The major management initiatives implemented in the mid 1990s were share management and a TACC (quota), individually numbered management tags and introduction of maximum legal length. Since a subsequent decrease in the maximum legal size in 2004 and decrease in the TACC to 102 tonnes in 2004–2005, the spawning stock has rebuilt. As a result, the TACC increased to 160 tonnes in the 2015–2016 fishing period (NSW Government 2015).

All commercially caught lobsters must be tagged to ensure compliance with quota restrictions, and distinguish lobsters caught legally from those taken by recreational fishers or illegally in the marketplace. This aims to deter black marketing of lobster. Lobsters caught in NSW waters cannot be sold unless they are tagged, and the tag cannot be removed without being broken.

The catch often includes lobsters above and below the maximum and minimum legal lengths, and berried (egg-carrying) females of legal size. The LF EIS (NSW DPI 2004) reports that just over 53% of the target species caught is discarded (data from 1999–2000 to 2001–2002). Discard rates were similar during the 2008–2010 survey. The discarding of undersized lobsters may adversely affect their survival and growth; however, the risk associated with this is unknown. Capture in traps and subsequent discarding can have direct effects through:

- physical damage to the lobsters via contact with the traps
- injury or stress through handling
- injury and stress through exposure before return to the water
- increased predation before a discarded lobster returns to its home ground.

[58] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/228770/Lobster-Code-of-Practice.pdf

[59] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/598436/INT16-61462-Attachment-C-Status-of-Fisheries-Resources-in-NSW-2013-14-Full-Report-406-pages-updated.pdf

The EIS also notes that the handling of berried females and oversized lobsters could affect their fecundity. However, there is no evidence of a significant problem, and this aspect was not considered a research priority in the lobster FMS. An informal risk assessment assigned a low level of risk to the discarding of rock lobsters within the EIS (NSW DPI 2004). This conclusion has been reinforced by the documented recovery of the lobster population, despite the observed rates of capture and subsequent return to the water of lobsters that are berried, sublegal or greater than legal maximum size.

Incidental bycatch

The quantity of bycatch species caught in the LF is very small, and hence there is no need for bycatch reduction measures, such as escape panels in traps. Hermit crabs comprised about 80% of the total weight of discards during the 2000–2002 survey, and about 90% during the 2008–2010 survey. The former survey noted that 83% of the hermit crab catch was returned to the water, but this had risen to 99% in the 2008–2010 observer survey. Other species caught as bycatch include snapper, grey morwong, red morwong, octopus, and leatherjackets. For the majority of fish, less than 1 tonne of each species is discarded annually.

Two species of wobbegong sharks, the spotted wobbegong (*Orectolobus maculatus*) and the banded wobbegong (*Orectolobus ornatus*), are known bycatch from the LF. Wobbegongs in general are the most commercially fished shark species in NSW waters, with total commercial fishery landings declining steadily from about 120 tonnes in 1990–1991 to 68 tonnes in 2002–2003. These species have low fecundity and high longevity, and the decline in stocks caused concern. The risk to wobbegongs from the fishery was assessed as high for these reasons (NSW DPI 2004). Subsequent restrictions on the taking of wobbegong sharks were applied across the LF, OTLF and OTF. Confidence in the population status of wobbegong has recently increased, to the extent that size limits have been removed, but trip limits remain in place. Less than 100 kg/yr have been reported as being taken in the LF in 2012–2013 and 2013–2014 (NSW DPI 2015).

Loss of fishing gear was assessed in the lobster EIS to have a low risk for target and bycatch species, a negligible risk for threatened and protected species, and a low risk to other habitats and biodiversity.

Incidental catch of species of conservation concern

The only protected finfish species likely to be affected by the LF is the eastern blue groper (*Achoerodus viridis*), which is protected from commercial fishing. The EIS assessed the risk from the LF to be low, given this species' resilience, limited interaction with the fishery, and perceived increase in numbers throughout most of its range.

The NPWS Elements database captures data on wildlife that are entangled in fishing gear. Many entanglements are reported each year in gear types used by the LF fishery (see 6.1.2 Commercial fishing for details). Cetaceans are the most commonly reported to entangle in fishing gear. Whales are particularly vulnerable to entanglement in traps in coastal waters during their annual migration and entanglements in trap lines and floats occur regularly and are increasing. NPWS has recorded 142 fishing gear entanglements with cetaceans from 2007-2016 (average of 14 per year), mostly humpback whales. These entanglements are the largest known anthropogenic threat to cetaceans recorded in the NPWS Elements database. Most entanglements reported are with trap gear (43 recorded). Most trap entanglements are associated with the OTL fishery, though some are also attributed to the lobster fishery and recreational fishing. Traps are known to entangle whales in NSW when they are not easily detected by the animal, long ropes and dense traps are more likely to cause an entanglement (Ganassin and Gibbs 2005). Many entanglements (36 recorded) also occur with lines and ropes, which have been linked to the LF, OTL, and recreational fishing. Due to the difficulty of sighting animals and identifying the type of fishing gear involved, the number of animals entangled each year is likely to be higher than reported. Seal entanglements in NSW mostly occur on lines or ropes, though for most reports gear type is not identified. Juvenile seals are also prone to capture in traps.

The LF EIS found that rope entanglements pose a low risk to threatened species and biodiversity, because of the infrequent interactions reported between these types of fauna and lobster fishing gear. There had only been one report of an entanglement of a humpback whale in the rope attached to a lobster pot during fishing in the five years before the completion of the EIS. This whale was released unharmed. As at January 2015, there had been no reports of interactions with threatened and protected species in the LF since mandatory reporting commenced in 2009. However, there are no mitigation measures to protect species from entanglement in inshore traps and these reports do not account for entanglements in lost gear.

Wildlife disturbance

Competition between fishers and wildlife can occur when prey items and foraging grounds overlap with fishing, reducing population health (DPI 2005). Marine mammals, reptiles, and birds have been observed feeding off the bait, catch or discards from trap fisheries in NSW and are at greater risk of entanglement, capture, vessel strike, or ingestion of fishing gear when doing so (Ganassin and Gibbs 2005). Seals can take fish from traps and lobster fishers in NSW report catch losses as a result (Ganassin and Gibbs 2005). Immature seals are reported to get trapped within traps when attracted to fish or baits (Ganassin and Gibbs 2005).

Marine debris

Marine debris from fishing vessels may include plastics, paper and fishing gear. Overall, the LF EIS assessed these risks as low or negligible from the operations of the fishery.

The Lobster Code of Practice notes that fishers should responsibly dispose of litter or derelict fishing gear, and conduct fishing activities and maintenance of fishing boats and vehicles in a manner that minimises waste, emissions and water pollution.

Physical damage

The LF EIS assessed the impact of the fishery on habitats including hard and soft substrata and associated biota. Based on limited observations in the literature, the magnitude of the impacts of traps on these habitats was considered as very small compared with natural disturbance regimes. Hard and soft substrates were reported at low risk from the LF, while their associated biota was at moderate–low risk. The EIS also notes that considerable amounts of refuge habitat are unaffected by the fishery.

Abalone Fishery

Blacklip abalone (*Haliotis rubra*) are the only commercially harvested abalone species in the NSW Abalone Fishery (AF). Abalone are commercially harvested from shallow rocky reefs by divers who operate from trailer boats with a deckhand, typically using surface-supplied air to operate in waters <30 m deep (Figure 83). Most commercial abalone fishing takes place on the south coast of NSW, primarily from Narooma to the Victorian border.

Abalone harvesting is limited through a total allowable catch (TAC, with the commercial catch controlled through a quota-management system and share-managed fishery arrangements. A TACC is set each year by the statutory and independent Total Allowable Catch Setting and Review Committee. In 2016, the TACC has been set as 130 tonnes (Figure 84). The TACC is proportionally allocated to shareholders on the basis of their shareholding in the fishery. In addition to the TACC, a legal minimum length (LML) applies to abalone harvesting. The LML was increased from 115 to 117 mm in July 2008, and applies to all commercial and recreational harvest sectors. An additional, larger LML applies to the commercial fisheries that operate at small spatial scales within the southern areas of the AF.

Figure 83. Abalone fishing in New South Wales waters. *Source NSW DPI.*

The commercial harvest of abalone of has gradually been increasing over the last five years, and in 2013–2014 the maximum TAC of 130 tonnes was landed (Figure 59). Effort in the fishery has also increased during this time by 18%. The industry is still recovering from the significant effects of an outbreak of the *Perkinsus* sp. parasite in abalone populations, which reduced some populations from Jervis Bay and Port Stephens by >90% (Liggins and Upston 2010). There is currently a conditional commercial fishing closure for Region 1, which is the whole of the waters north of the middle of Wreck Bay Beach, Jervis Bay, to protect against the spread of *Perkinsus sp.*

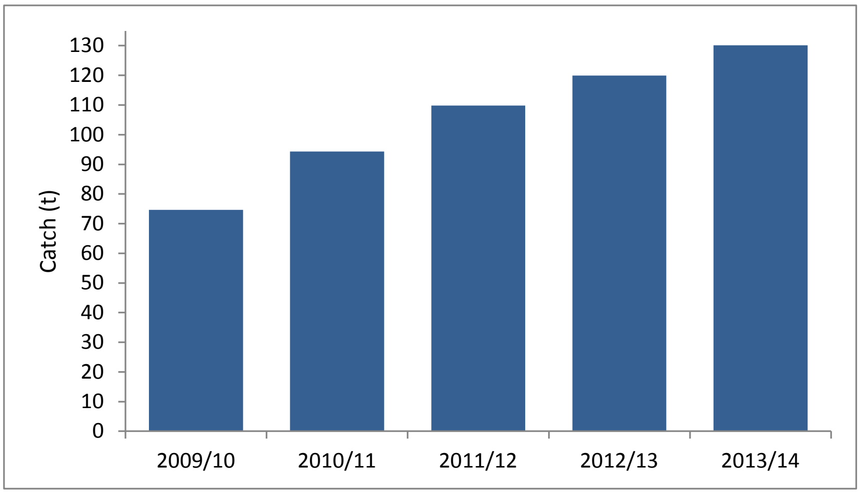


Figure 84. Catch (tonne) by financial year between 2009/10 and 2013/14 of blacklip abalone in New South Wales waters; no regional data breakdown is available, as catch is taken almost entirely in the southern region.

Current management arrangements

The NSW Total Allowable Catch Setting and Review Committee (the Committee) is established by Division 4 (S26-34) of the *Fisheries Management Act* 1994. The Committee is required to determine the Total Allowable Commercial Catch (TACC) for the commercial sector of the abalone fishery

The Committee is not subject to control or direction of the Minister but in reaching its decision is required to have regards to:

- all relevant scientific, industry, community, social and economic factors
- the need to ensure that the abalone resources are exploited in a manner that will conserve stocks in the long term
- the impact on other species and the environment and
- the precautionary principle as set out in Section 30(2) C of the Act.

The Committee must consider the full extent of abalone exploitation to meet its statutory obligations. Total removals of abalone stock are made up of:

- the quota allocated to commercial fishers
- the total legal catch by recreational and Aboriginal (indigenous?) fishers and
- Catches of commercial, recreational and Aboriginal fishers not sanctioned by the Regulations controlling the fishery and not recorded in catch statistics (illegal catches).

The legal and illegal components of the non-commercial fishery currently are estimated as a single figure based on historical evidence, compliance information, and judgements from the department and Industry.

Catch per unit effort (CPUE) data is used to provide a general indication of overall trends in availability of abalone to the Fishery. This information is derived from abalone catch and effort data. Despite continued concerns regarding the accuracy of CPUE to reflect changes in abundance, it is used as a measure of the Fishery's performance and increasing levels of CPUE are considered positive, and indicative of an increasing level of legal size stock.

The CPUE for the 2015 fishing period was 48.18 kg/hr and 49.26 kg/hr for the 2016 fishing period (as at 31 August 2016). This follows an increasing trend over the last ten years.

NSW is implementing finer-scale management of the commercial Abalone Fishery with voluntary catch caps for areas and two LMLs (117 mm for most of the fishery; 123 mm from Wonboyn south).

Fisheries NSW is developing an interim harvest strategy for the AF to inform future management, TACC setting, stakeholder input and research planning. The NSW abalone stock is currently classified as 'transitional-recovering' in the Status of Key Australian Fish Stocks Report 2014, and 'uncertain' under the NSW resource assessment process. A formal harvest strategy (with agreed performance indicators and an appropriate monitoring and assessment program) is central to improving the management of the Abalone Fishery.

Potential impacts of the Abalone Fishery

Reductions in abundance of species and trophic level

The major stressor that is relevant to the AF in NSW is the reduction in abundance of lower-order trophic levels. The AF EIS found that harvesting abalone above the LML was a potential high risk to the abundance of mature stock at local geographical scales and a moderate risk at general scales. It also found there was a moderate risk to the distribution of abalone at all scales and the size structure and non-retained (discarded) abalone at local scales (The Ecology Lab Pty Ltd 2005). However, the EIS also noted that the impact of illegal catch of abalone at much smaller sizes than the LML had a greater risk to local populations of abalone than the risk posed from legal commercial harvesting.

Overall, the stock status of exploited marine species assessed using available data from 2013–2014 is presented in Appendix 3. Further details are provided in the Status of Fisheries Resources in NSW 2013–2014 report[60] (Stewart et al. 2015).

Limited dispersal of abalone larvae away from their parents, in addition to other biological processes such as predation, means that there is slow recovery of depleted populations at local scales. The combined effects of illegal fishing, a geographical shift in fishing effort due to the effects of *Perkinsus* and the potential for increased discarding might increase the risk to remaining harvested populations of abalone.

Sea Urchin and Turban Shell Fishery

The commercial harvest of sea urchins and turban shells (SUTS) is managed as one fishery in NSW. The two primary species of sea urchin targeted by the SUTS fishery are the purple sea urchin (*Centrostephanus rodgersii*) and red sea urchin (*Heliocidaris tuberculata*), although commercial catches of the green sea urchin (*H. erythrogramma*) have averaged <105 kg/yr for the last decade (Figure 85). Two species of turban shell provide the majority of the commercial harvest in NSW: the Sydney turban shell (*Turbo torquatus*) and the military turban shell (*T. militaris*). A third species, the green turban shell (*T. undulata*), is less commonly taken (Figure 86).

Commercial fishers commonly dive for SUTS using surface-supplied compressed air (hookah). Sea urchins are removed using a hook, while turban shells are taken by hand. There is no bycatch. Fishing for sea urchins is generally constrained to seasonal periods where their roe is well developed. Turban shells are harvested year-round for their fleshy foot.

SUTS may be taken commercially in all NSW waters except those specified as prohibited in the Fisheries Management (General) Regulation 2010. Several areas have been closed to the commercial SUTS fishery since 1994, to provide reference sites for stock assessment purposes and to act as refuge. A minimum legal length of shell has been set for the Sydney turban and military turban shell. A TAC for the red sea urchin of 60 tonnes per year has been in effect since 2002.

Figure 85. Sea urchin species commonly taken in New South Wales; left to right, *Centrostephanus rodgersii, Heliocidaris erythrogramma* and *Heliocidaris tuberculata. Source NSW DPI*

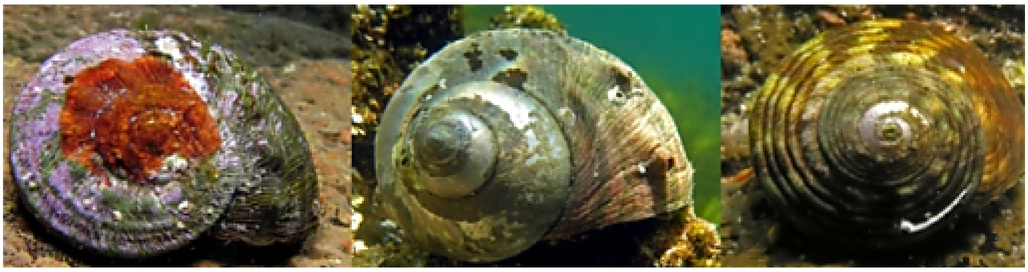


Figure 86. Turban shell species commonly taken in New South Wales; left to right, *Turbo torquatus, Turbo militaris* and *Turbo undulates. Source NSW DPI.*

[60] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/598436/INT16-61462-Attachment-C-Status-of-Fisheries-Resources-in-NSW-2013-14-Full-Report-406-pages-updated.pdf

Statewide total commercial catches for the SUTS fishery have remained steady for the last three years at approximately 84 tonnes, a 26% increase since 2009–2010 (Figure 87). The level of catch from other sectors (e.g. recreational fishery) is unknown. The dominant species taken in the commercial SUTS fishery is the purple sea urchin, making up 89% of the catch in 2013–2014, with the remainder consisting of red sea urchins and turban shells (Figure 87).

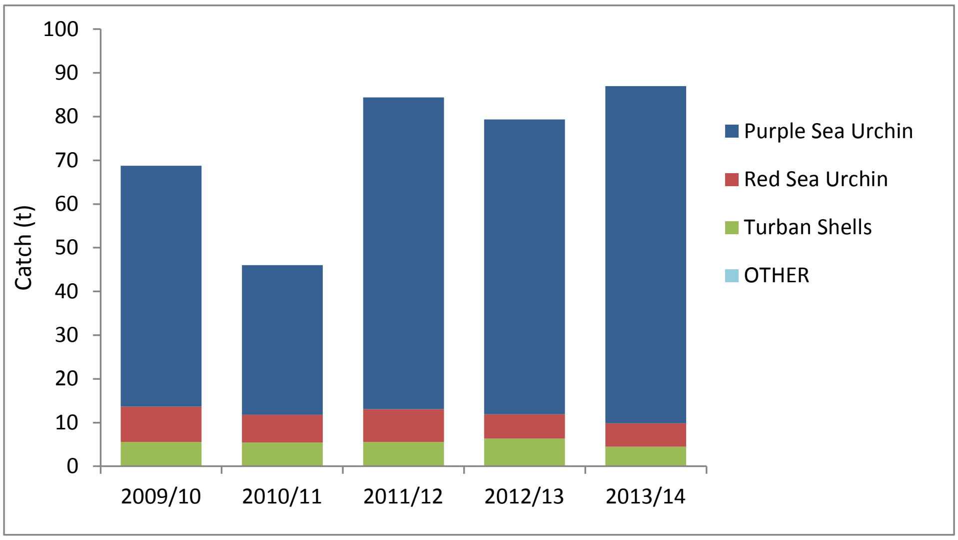


Figure 87. Catch (tonnes) by financial year between 2009/10 and 2013/14 of purple sea urchin, red sea urchin and all turban shells in New South Wales waters. *Source: DPI Fisheries catch records database extract 26 November 2015.*

The proportion of the SUTS fishery catch taken in NSW coastal waters inside 3 nm is largest in the **southern region** (87%) and approximately equal in the other two regions (Figure 88). Purple sea urchins dominate the catch composition in all regions, with red sea urchins making up a small percentage.

The status of the purple sea urchin resource in 2013–2014 was determined as moderately fished, as a result of the low exploitation rate of the total estimated biomass. The status for the red and green sea urchin resources was determined as uncertain, due to a lack of understanding of population sizes and general biology. In the case of the red sea urchin, this was also due to past anecdotal evidence of serial depletion and no ongoing fishery independent biomass estimates, or the recovery of areas following the implementation of TACC arrangements in 2002. The status of turban shells was determined as undefined, with catches commonly not reported to species.

Current Management Arrangements

The fishery is managed under the NSW *Fisheries Management Act 1994* and the NSW Fisheries Management (General) Regulation 2010. The fishery is managed by the NSW Department of Primary Industries.

Input controls

- Limited access – limited to fishing business owners eligible for an endorsement or their nominated fisher.
- Closures (details below).

Output controls

- Total Allowable Commercial Catch (TACC) for red sea urchins of 60 tonnes. The TACC is divided equally between all entitlement holders, and is divided between 5 management regions according to biomass in each region.
- Size limits for Sydney and military turban shells - minimum size of 75 milometres.
- Recreational fishers are subject to bag limits of 10 urchins, and bag and size limits for molluscs.

Fishers are required to make daily reports of catch, effort, and geographic location where catch is taken, and any threatened species interactions. The fishery is subject to a range of spatial closures. These include a network of marine protected areas (under the NSW *Marine Parks Act 1979*), aquatic reserves and intertidal protected areas (under the NSW *Fisheries Management Act 1994*), and fishery specific closures.

The fishery is divided into five fishing regions, which are divided into sub-regions. A number of these sub-regions have been closed to the fishery since 1994 to provide reference points for stock assessment and refugia. New fishing closures were introduced in 2002 to areas previously subjected to intensive fishing and some new areas opened.

Harvest of red sea urchins is prohibited in Region 5 of the fishery (from Montague Island south to the Victorian border), as the TACC for this region has been set at zero.

Potential impacts of the Sea Urchin and Turban Shell Fishery

The major stressor that is relevant to the SUTS fishery is reductions in abundances of species lower- order trophic level. Fishing activity is targeted hand collection, and is unlikely to cause disturbance or impact on non-target species.

Urchins are a keystone ecosystem species. However, no indications are evident or of concern from analysis of commercial catch data trends for the major harvested species (the purple urchin). Past anecdotal evidence of localised depletion of red urchins resulted in the assessment and implementation of the TACC for this species in 2002. While no recent fishery independent biomass surveys are available, the commercial harvest is largely market limited, a low proportion of the TACC has been taken each year, and no regional catch caps have been exceeded. The harvest of turban shells is a small proportion of the total harvest and is largely market limited.

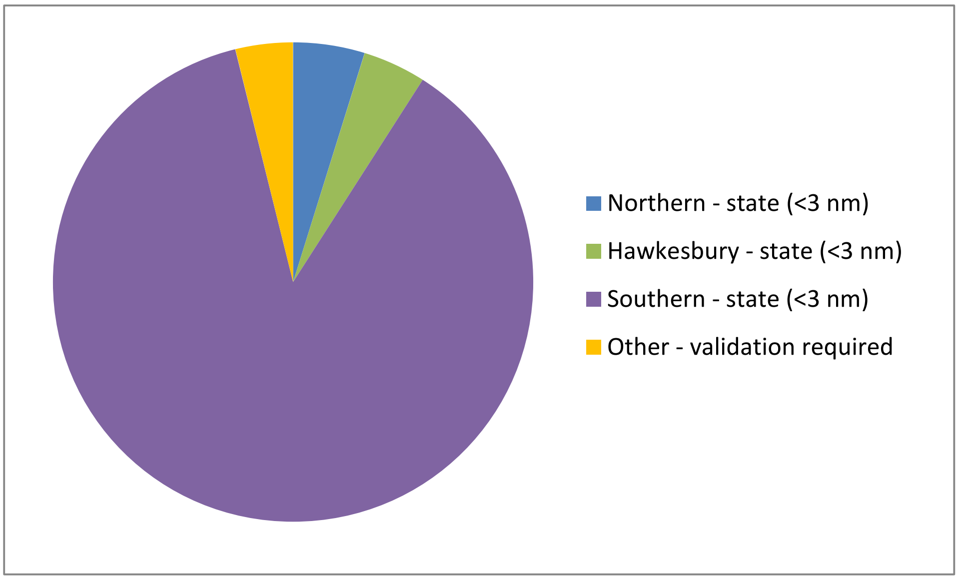


Figure 88. Proportion of catch in the New South Wales Sea Urchins and Turban Shells Fishery in each region in 2013–2014. *Source: DPI Fisheries catch records database extract 26 November 2015.*

Figure 89. Catch (tonnes) by financial year between 2009/10 and 2013/14 in the New South Wales sea urchins and turban shells fishery for the top 10 species in each region. *Source: DPI Fisheries catch records database extract 26 November 2015.*

CHARTER FISHING

Charter fishing activities provide opportunities for recreational anglers to undertake estuarine or marine fishing and for adventure tourism for visitors to the NSW marine estate. Well-equipped boats and localised fishing expertise helps recreational anglers to fish successfully across a range of fishing types and species, and to access areas not normally available to them. Operators derive a profit from the use of fishery resources by hiring out their knowledge and equipment to recreational fishers.

Charter boat operators providing fishing trips for anglers in NSW need a licence issued by NSW DPI to operate their business. The licensing scheme, which came into effect in 2000, avoids an uncontrolled rise in charter fishing boat pressure on fish stocks.

The NSW marine and estuarine recreational charter fishing boat fleet has many different sized vessels that target a great variety of fish species. Although they can theoretically move from port to port in response to seasonal and tourist demand, most operators are port based and do not move their operations. The ocean charter boat sector is subdivided into three subcomponents:

- **nearshore bottom fishing and sportfishing**
- **gamefishing**
- **deep-sea-bottom fishing.**

Only the first subcategory is wholly contained within the 3 nm limit of state waters, with gamefishing and deep-sea-bottom fishing mostly occurring further offshore. Charter fishing business information and historical catch records indicate that most of these businesses operate from a single port.

Charter fishing activities are heavily affected by fishing tourist demand, as well as weather and sea conditions on a day-to-day basis. Weekend periods are much more popular than weekday periods. Charter activities are also highly seasonal with more activity during the summer fishing season.

Charter boat operators are required to complete a log book to calculate catch rates for the fishery. They must record:

- catch
- species composition
- number taken
- effort
- total number of charter trips
- duration of individual trips
- amount of time spent fishing for different species.

From the database returns from the 131 vessels that submitted log books in 2012, a total of 44,547 people took charter trips in NSW. Nearshore angling was by far the most active component, accounting for 89% of all charter trips (Dominion Consulting 2014).

Potential impacts of charter fishing

Reductions in abundance of species and trophic levels

NSW DPI records indicate that 198 charter fishing boats were authorised to operate in NSW waters (as of October 2015). These boats are constrained by a wide suite of bag and size limits and gear restrictions, which significantly reduce the overall catch capacity. The capped nature of the charter fishery also limits its ability to expand. The total charter catch would be included in the total catch estimated by a recent statewide telephone and diary based survey of recreational activity in NSW **(**West et al. 2015).

Incidental bycatch

DPI Fisheries commissioned a study, which commenced in December 2014, to implement an independent observer program for the recreational fishing charter boat sector. Once the study is complete, a better assessment of potential impacts will be possible.

The study aims to independently verify:

- log book data on the species targeted by the sector
- incidental bycatch caught
- levels of mortality

And to collect:

- otoliths for age analysis on the species targeted
- other relevant information to help resource assessment and management.

Incidental catch of species of conservation concern

There is no specific information available on the level of interactions with threatened and protected fish, marine mammal, reptile or bird species resulting from charter fishing. Shorebirds and seabirds are most at risk of entanglement or capture from line fishing methods. The literature suggests a capture rate of 0.36 birds per 100 fisher hours (Ferris and Ferris 2004). Species are prone to entanglement or accidental capture when their diet, habitat, or diurnal feeding patterns overlap with fishing/fish stocks, or where fishing gear is difficult to detect or escape from (Ganassin and Gibbs 2005). Mortalities occur when the animal cannot surface to breathe, is strangled, or sustains injury (Ganassin and Gibbs 2005). Marine wildlife including birds, dolphins, and seals have been observed feeding off discards in NSW fisheries using line and trap methods among others and are at greater risk of entanglement, capture, vessel strike, or ingestion of fishing gear when doing so (Ganassin and Gibbs 2005). Sinkers and hooks can also cause mortality in birds if accidently ingested (Ganassin and Gibbs 2005). Competition can occur between fishers and wildlife when prey items and foraging grounds overlap with fishing, reducing population health (Ganassin and Gibbs 2005).

Marine debris

There is no specific information available on the level of marine debris resulting from charter fishing activities.

8.1.3 RECREATIONAL FISHING

Recreational fishing is a popular activity throughout NSW. This activity is broadly defined as the capture of aquatic fauna by anglers without a commercial licence, for either personal use or catch and release (Crowder et al. 2008). Recreationally caught fish cannot be sold. Methods used include traditional hook-and-line angling, trapping, jigging, netting, spearfishing, and hand collecting, mostly of which can be either shore- or boat based (Crowder et al. 2008). Overall catch is limited by a suite of bag and size limits and gear restrictions and a wide range of regional fishing closures [61].

Recreational fishing in coastal and marine waters occur in a range of environments that range from rocky shores, beaches, offshore areas on the continental shelf, with an increasing effort of fishing on artificial reefs (Keller et al. 2016). There are a number of specialist components of the fishery that target specific species with hook and line, such as black marlin and tuna, many through structured game fish tournaments (Ghosn et al. 2015).

The diversity of fishing methods and areas fished results in a wide range of harvested species, and the details of these are presented in the following sections for landings from coastal and marine waters. Analysis of the catch specific to estuarine waters in presented in section 6.1.4.

In terms of effort, a recent telephone and diary based survey of recreational activity in NSW revealed a declining trend in fishing effort (West et al. 2015). Between the last two survey periods, 2000–2001 and 2013–2014, recreational fishing effort (fisher days) in NSW and ACT waters declined by 37%. This was partly linked to the decreased number of fishers, but also due to a lower average number of days fished annually per fisher.

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[61] For more information, see http://www.dpi.nsw.gov.au/fisheries/recreational

Between 2013 and 2014, coastal recreational fishing effort (fisher days) and harvest (kept) respectively accounted for 29% and 30% of recreational fishing activity across NSW. During this period, the total effort expended by anglers on the coast was 750,315 fisher days, and the total number of fish harvested was 1,960,566. Of the total recreational effort expended within the coastal waters of NSW, 93% occurred within inshore waters and 7% occurred within offshore waters (Figure 90). Similarly, 91% of the total harvest (kept) in coastal waters came from inshore waters and the remainder came from offshore waters.

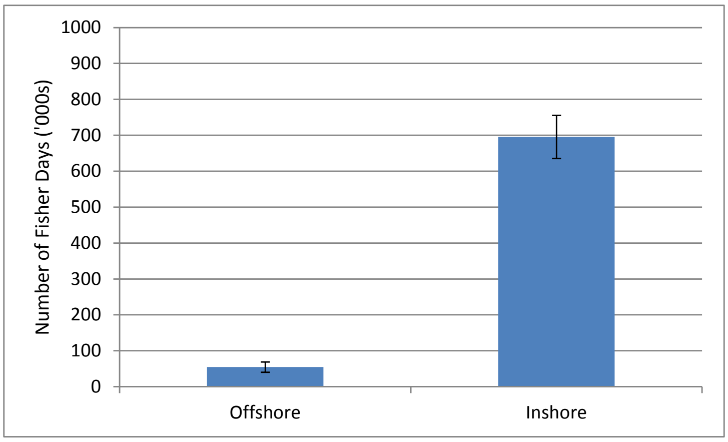
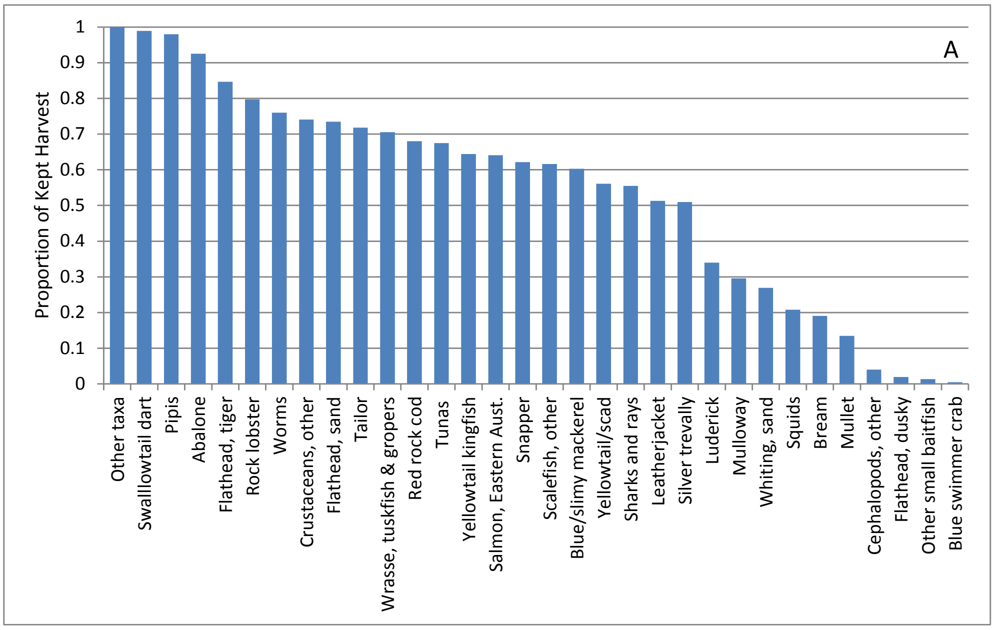


Figure 90. Proportion of recreational fishing effort (fisher days) in NSW waters during 2013–2014 by New South Wales and Australian Capital Territory residents aged five years and older. *Source NSW DPI.*

Within coastal waters, 14 species were harvested only from inshore waters (Figure 91). Four species (swallowtail dart, pipis, abalone and tiger flathead) had inshore harvests of >80% of the state recreational catch. Of the 17 species harvested in all three water bodies (estuarine, inshore and offshore), 51% of the kept catch was taken in inshore waters and 8% in offshore waters (Figure 92, Table 35).



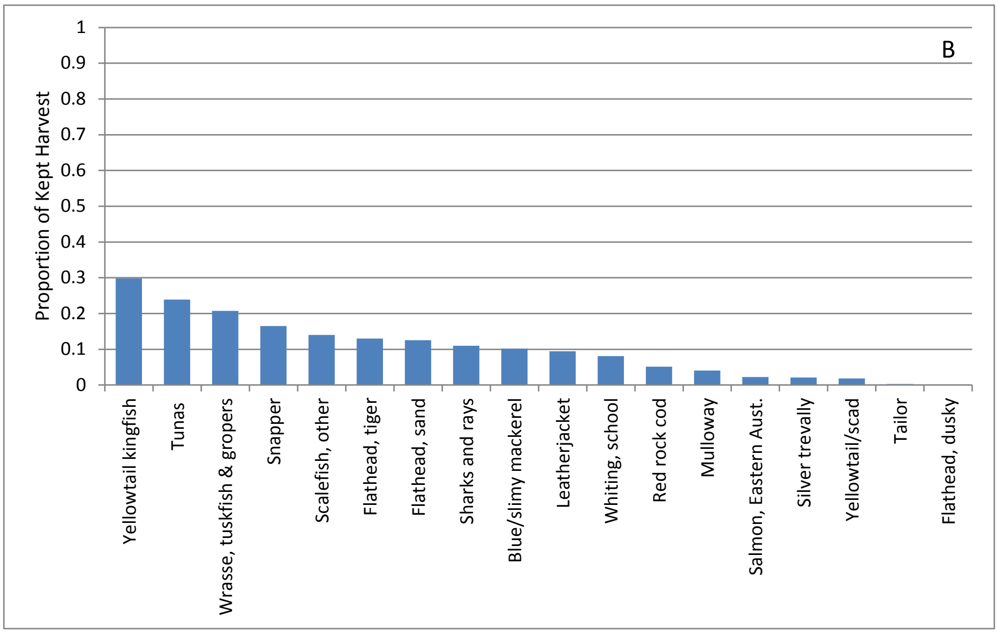


Figure 91. Proportion of kept recreational harvest of species taken in (A) inshore waters and (B) offshore waters of New South Wales during 2013–2014, by New South Wales and Australian Capital Territory residents aged five years and older. *Source NSW DPI.*

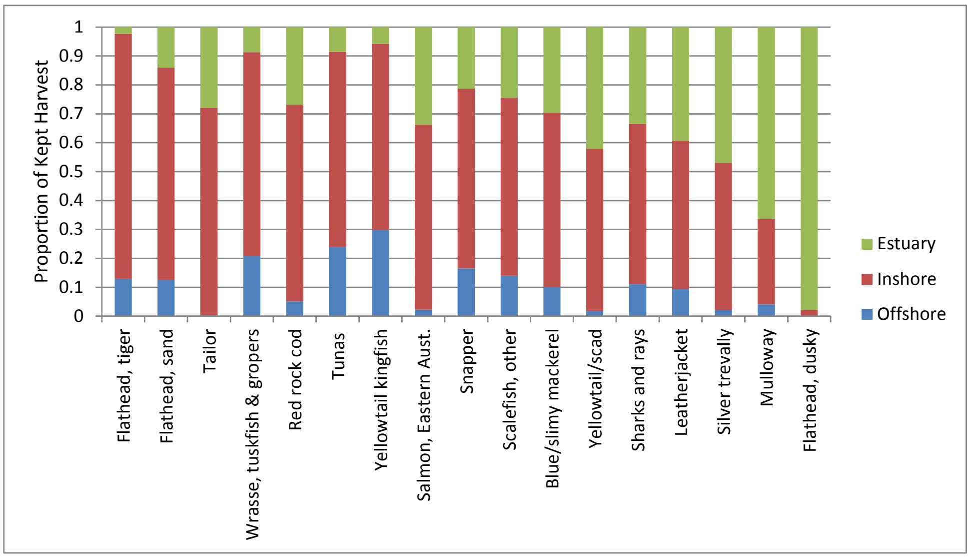


Figure 92. Proportion of kept recreational harvest of species taken in all three water bodies of New South Wales during 2013–2014, by New South Wales and Australian Capital Territory residents aged five years and older. *Source NSW DPI.*

Table 35. Proportion of fish harvested recreationally by New South Wales and Australian Capital Territory residents aged five years and older, within NSW coastal waters between June 2013 and May 2014.

Inshore				
Species or group[a]	**Total harvest (kept)**	**Standard error[b]**	**Proportion of statewide harvest**	**NSW stock status[c]**
Other taxa	***1,013***	***1,002***	1.00	NA
Swallowtail dart	***42,793***	***18,866***	0.99	Undefined
Pipis	*85,958*	*31,221*	0.98	Uncertain
Abalone	***17,040***	***10,525***	0.92	–
Flathead, tiger	***33,365***	***13,956***	0.85	Fully fished
Rock lobster	***18,508***	***11,128***	0.80	Fully fished
Worms	*199,307*	*69,587*	0.76	Undefined
Crustaceans, other	***6,448***	***6,178***	0.74	–
Flathead, sand	323,710	77,228	0.73	Not determined
Tailor	136,141	37,223	0.72	Fully fished
Wrasse, tuskfish and gropers	***13,615***	***6,205***	0.71	–
Offshore				
Yellowtail kingfish	***10,467***	***5,362***	0.30	Growth-overfished
Tunas	***11,066***	***5,651***	0.24	Fully fished (yellowfin tuna)
Wrasse, tuskfish and gropers	***4,008***	***2,263***	0.21	–
Snapper	***30,674***	***9,289***	0.17	Growth-overfished
Scalefish, other	***38,774***	***8,769***	0.14	–
Flathead, tiger	***5,125***	***4,239***	0.13	Fully fished
Flathead, sand	***55,338***	***25,210***	0.13	Not determined
Sharks and rays	***582***	***340***	0.11	Undefined
Blue or slimy mackerel	***12,727***	***4,651***	0.10	Moderately fished

a Species groups shown are those that were among the most commonly harvested groups within the state by number. **b** Values in bold indicate relative standard error >40%; values in italics indicate fewer than 30 households recorded catches of the species. **c** Current exploitation status for each species group is based mainly on the assessment of NSW commercial data; NA = not applicable.

In inshore coastal waters, the **northern region** had the largest total harvested recreational catch (141,3771; 43%) followed by the **southern region** (104,1077; 32%) then the **central region** (807,962; 25%) (Figure 94). Total recreational harvest in offshore waters was substantially smaller than inshore, being largest in the **southern region** (164,154; 40%) followed by the **northern region** (151,710; 37%) then the **central region** (97,284; 23%) (Figure 94).

In the **northern region**, the largest inshore harvests were sand flathead (176,132 individuals), bream (155,393), tailor (148,489) and worms (134,483) (Figure 96). Four species groups (swallowtail dart, mulloway, pipis and other scalefish taxa) had >90% of their inshore harvest taken in the northern region.

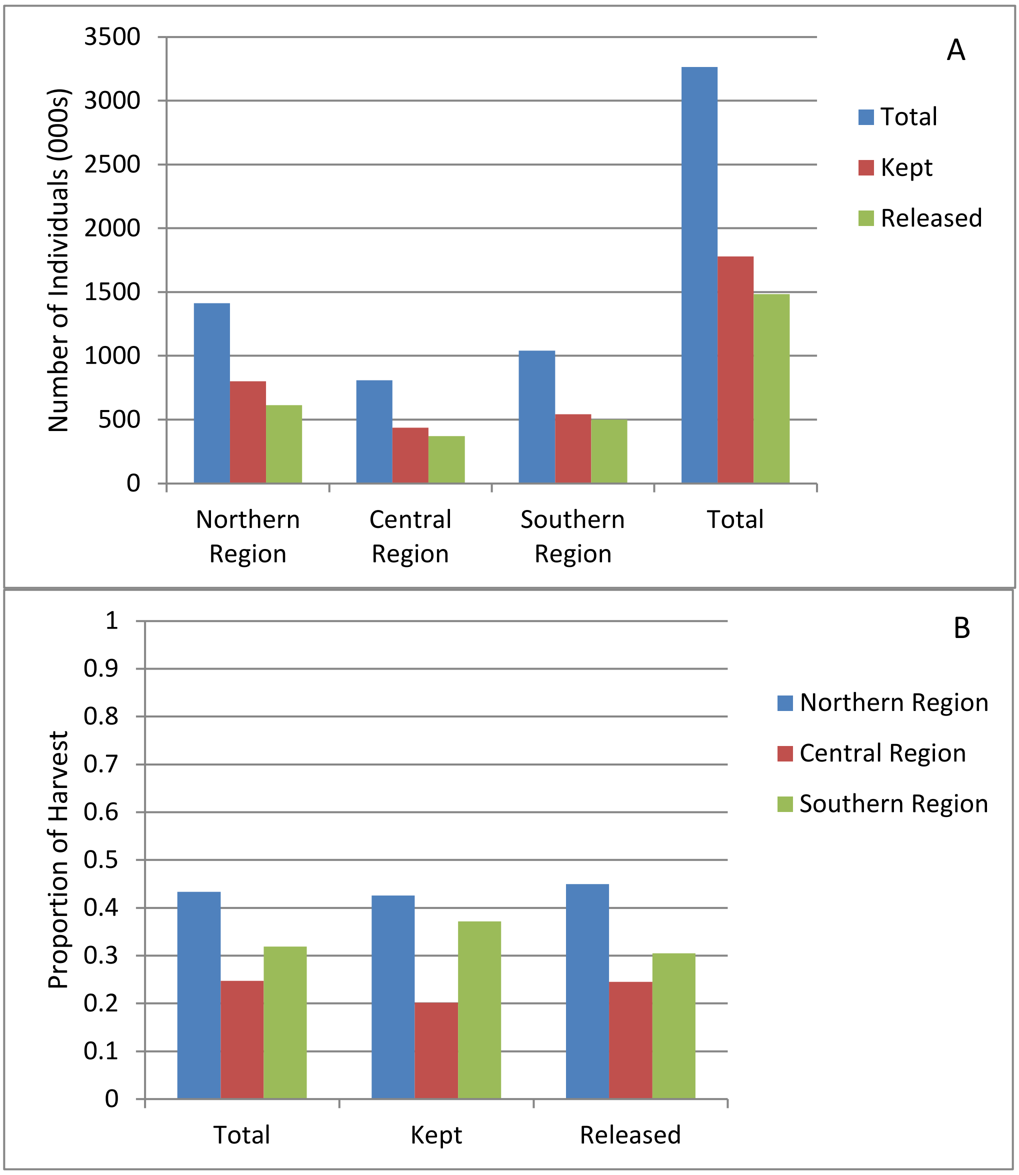
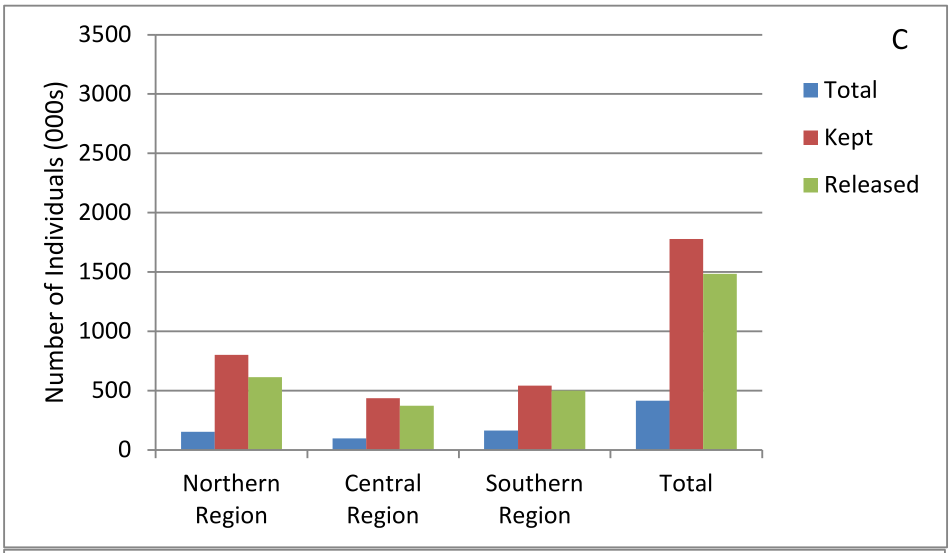


Figure 93. Harvested recreational catch and proportion taken within each region for inshore waters (A, B) and offshore waters (C, D) of New South Wales during 2013–2014. *Source NSW DPI.*



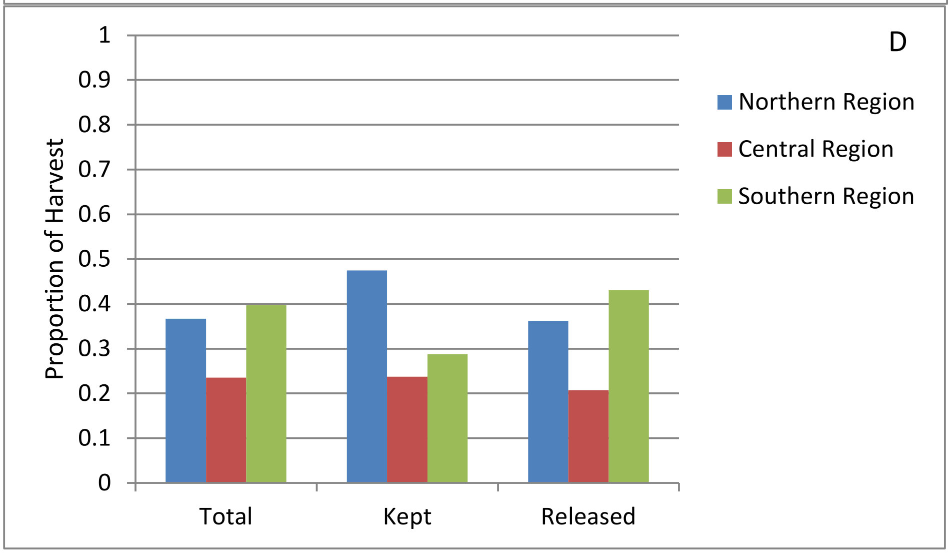


Figure 94. (Continued)

In the **central region**, the largest inshore harvests were sand flathead (205,959 individuals), salt or freshwater scalefish (166,749), luderick (60,147) and bream (57,034). Four species groups (luderick, rock lobster, other cephalopods, and abalone) had >50% of their inshore harvest taken in the central region (Figure 96).

In the **southern region**, the largest inshore harvests were sand flathead (283,959), salt or freshwater scale fish (92,899), snapper (73,427), worms (61,723) and Australian salmon (61,751). Five species groups (school whiting, other crustaceans, squid, tiger flathead and tunas) had >70% of their inshore harvest taken from the southern region (Figure 96).

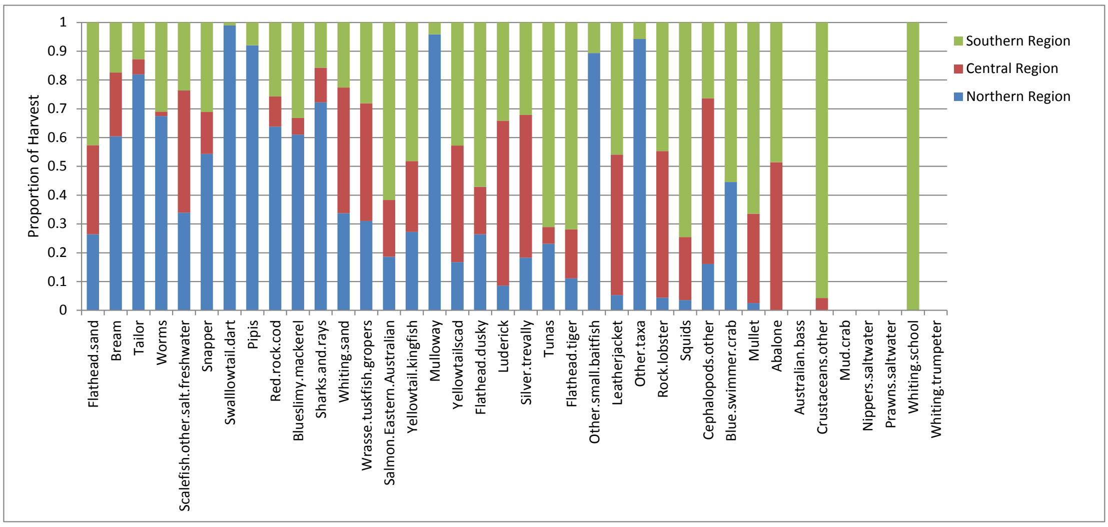


Figure 95. Proportion of total recreational harvest taken across all regions of New South Wales inshore coastal waters during 2013–2014. *Source NSW DPI.*

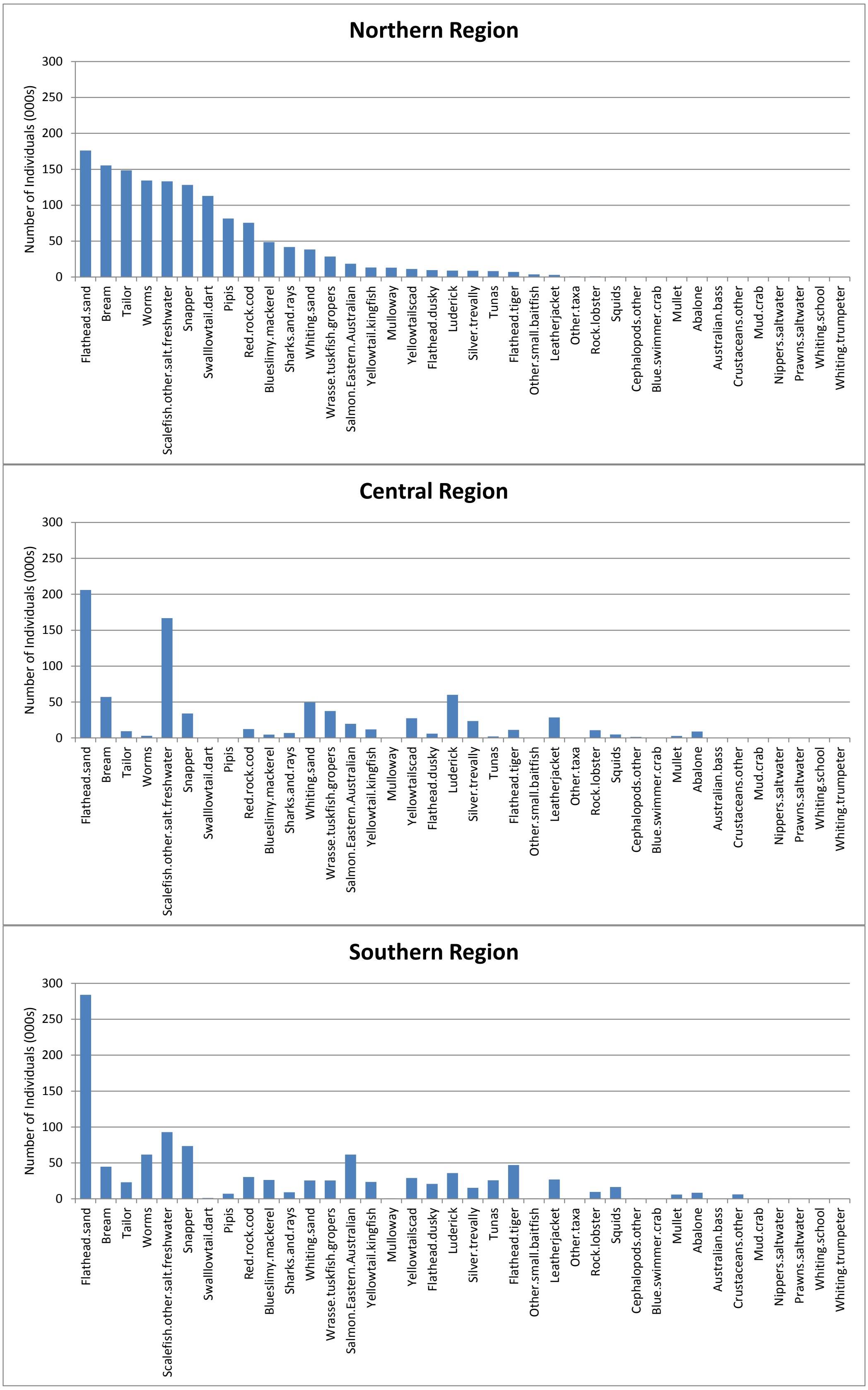
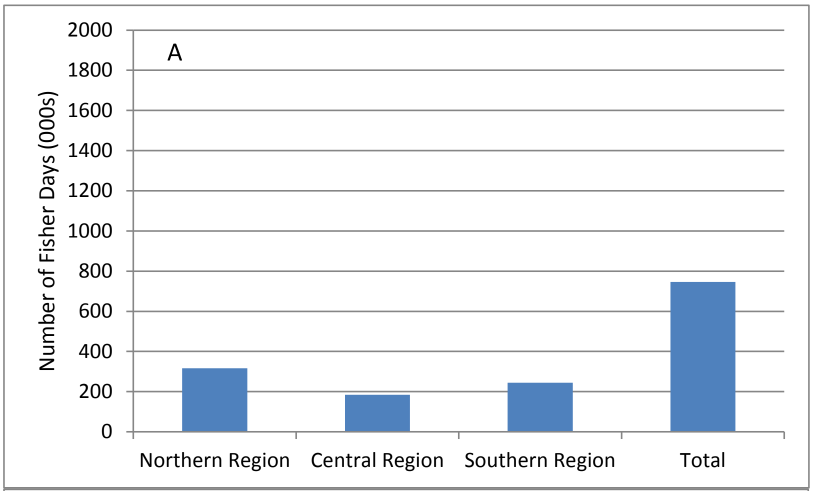


Figure 96. Total recreational harvest of each species group taken in each region in inshore waters of New South Wales during 2013–2014. *Source NSW DPI.*

Total coastal recreational fishing effort (inshore and offshore) was largest in the northern region (316,930 fisher days, 42%) followed by the southern region (244,279, 33%) and then the central region (185,057, 25%) (Figure 97). The greatest proportion of recreational fishing effort in coastal waters occurred in inshore waters. The northern region had the largest proportion of recreational effort in inshore waters (299,128, 43%) followed by southern and then central regions (Figure 98).



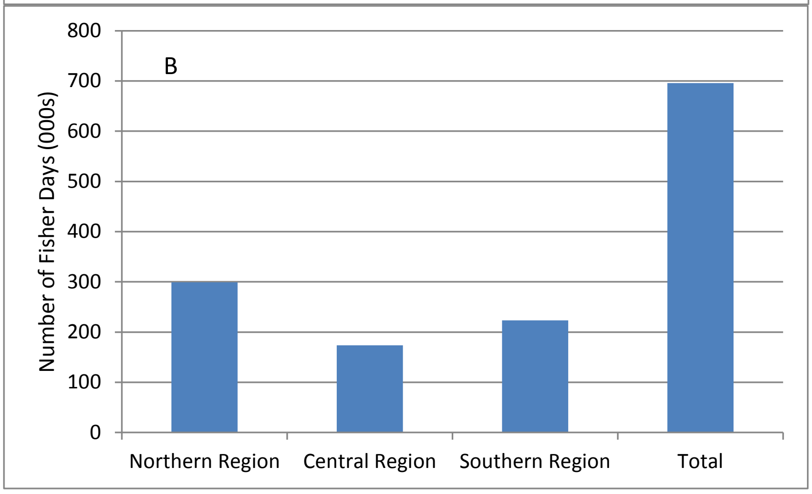


Figure 97. Total recreational fishing effort in ocean waters (A) and inshore waters (B) of New South Wales during 2013–2014. *Source NSW DPI.*

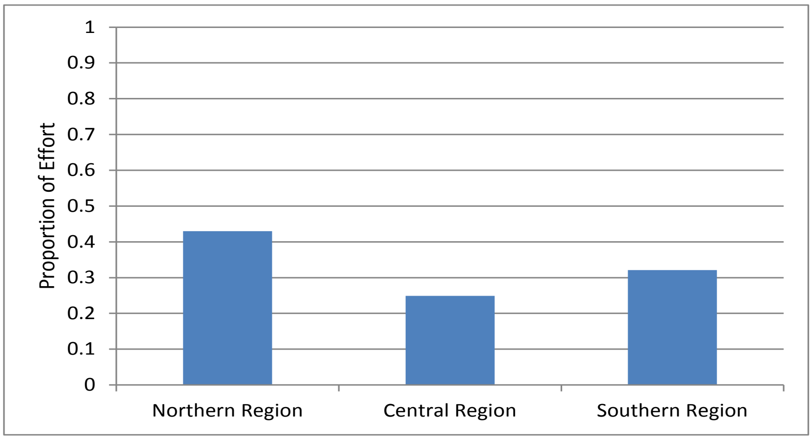


Figure 98. Proportion of recreational fishing effort in inshore waters in each region of New South Wales during 2013–2014. *Source NSW DPI.*

Although coastal recreational fishing occurs throughout the state, surveys of coastal marine trailer boats between Norah Head and Shellharbour from 2007 to 2009 provide the most recent, comprehensive and site-specific information (Steffe and Murphy 2011). The surveys collected information on coastal recreational effort and harvest from the areas adjacent to Norah Head, Terrigal, the Hawkesbury River system, Long Reef, the Port Hacking system, Bellambi, Port Kembla, Shellharbour, Sydney Harbour and Botany Bay. The greatest levels of coastal effort were in the area adjacent to the Hawkesbury River, and the greatest levels of harvest in the area adjacent to Port Hacking (Table 36).

Table 36. Summary of average site-specific results from coastal marine trailer boat surveys of recreational anglers conducted between 2007 and 2009.

Area	Average annual boat based harvest (numbers)	Average annual boat based effort (number of angling trips)	Dominant species in boat based harvest
Norah Head	10,824	51,575	Eastern blue-spotted flathead, silver trevally, grey morwong, ocean leatherjacket, snapper
Terrigal	10,298	15,416	Eastern blue-spotted flathead, yellowtail, grey morwong, ocean leatherjacket, snapper
Hawkesbury	45,243	1,376,805	Ocean leatherjacket, eastern blue-spotted flathead, snapper, silver trevally, silver sweep
Long Reef	8,252	5,822	Silver trevally, snapper, eastern blue-spotted flathead, blue mackerel, yellowtail
Sydney Harbour	Not assessed	882,039	Not assessed
Botany Bay	Not assessed	540,419	Not assessed
Port Hacking	85,963	1,096,258	Ocean leatherjacket, eastern blue-spotted flathead, southern calamari, blue mackerel, silver sweep
Bellambi	28,619	29,615	Snapper, ocean leatherjacket, eastern blue-spotted flathead, silver sweep, blue mackerel
Port Kembla	33,550	55,679	Eastern blue-spotted flathead, snapper, yellowtail, ocean leatherjacket, blue mackerel
Shellharbour	32,942	26,331	Eastern blue-spotted flathead, ocean leatherjacket, blue mackerel, snapper, yellowtail

Source: Steffe and Murphy (2011)

Current management

Recreational fishing in NSW is managed under the *FMA* and its associated regulations. NSW DPI is responsible for the administration of the *FMA*. For specific details about management of recreational fishing see section 6.1.4 on recreational fishing in estuaries.

Potential impacts of recreational fishing

Reductions in abundances of species and trophic levels

Recreational fishing can directly affect aquatic populations by altering the abundance and size structure of targeted species (Denny and Babcock 2004, Westera et al. 2003) or by changing food webs where particular trophic levels are the primary target (Crowder et al. 2008). Depending on the species, the effect of recreational harvest could include reduced abundance, loss of genetic diversity, reduced reproductive success, and truncation of age and size structure, which can affect life-history traits such as growth rates and size at maturity (Stuart-Smith et al. 2008).

Stewart (2011) found that six species commonly targeted by both recreational and commercial species had their age compositions truncated, meaning that there were more younger fish in the populations being harvested. The recreational proportion of the total catch of four of the six species (mulloway, silver trevally, snapper and tarwhine) studied by Stewart (2011) is 50% or greater. For these four species, therefore, recreational fishing may be contributing to the depletion of larger, older fish from populations across NSW. In extreme scenarios, truncated age-class structure may make populations more susceptible to collapse as a result of poor recruitment of juveniles over several years. This reduces the resilience of populations to environmental change (Beamish et al. 2006).

Spatial effects in the abundance and size distribution of fish species targeted by both recreational and commercial fishers have been documented along the coast of Tasmania. Stuart-Smith et al. (2008) found fish communities tended to decrease with distance from the nearest boat ramp, with lower numbers of large fish and greater numbers of smaller fish at sites closest to access points. Despite the possibility of local depletions of recreationally targeted species in frequently visited sites close to large urban centres, there are no documented cases of serial depletions by recreational fishing in NSW.

Studies in the central region and other sites across temperate NSW have shown that marine protected areas (MPAs) often have higher abundances and larger sizes of lower-order predators (e.g. snapper, drummer, red morwong) than fished locations (Coleman et al. 2013, Curley et al. 2013a, Gladstone 2001, Kelaher et al. 2014, McKinley 2011, Malcolm et al. 2015). Rigorous assessments of MPA effects have been conducted at Bouddi Marine Extension and in Gordons Bay (part of Bronte–Coogee Aquatic Reserve) (Curley et al. 2013a, Gladstone 2001). Fish species richness, total fish density and density of blue groper, luderick, and red morwong were greater in Bouddi Marine Extension than in nearby unprotected areas 28 years after declaration. Luderick and red morwong were also larger within the Bouddi Marine Extension. The limpet *Cellana tramoserica*, which is subject to harvesting, was significantly larger in Bouddi relative to unprotected areas (Alexander and Gladstone 2013).

Impacts on ecological processes can have flow-on effects to multiple species and, in some case, the overall habitat structure. For example, after closure to fishing, snapper and lobster abundances and kelp cover increased in the Leigh Marine Reserve in New Zealand, while the abundance of urchins decreased (Babcock et al. 1999, Willis and Anderson 2003). It was believed that greater predation by lobster and snapper had reduced the abundance of urchins which in turn led to increases in the growth and coverage of reefs by kelp (Babcock et al. 1999, Shears and Babcock 2002). With more kelp the abundances of lobster increased and as they also feed on juvenile urchins, the urchin abundances were further reduced and increased the area that was available for kelp to establish (Babcock et al. 1999, Shears and Babcock 2002). The large extent of urchin barrens on shallow reefs along the NSW coast indicate that such processes are likely to be occurring here, but no specific studies have been conducted to demonstrate the trophic links.

Some sedentary reef species, for example, may be affected by spear fishing, which can effectively target one or a few species at specific locations (e.g. Lowry and Suthers 1998).

Incidental bycatch

Individuals of many species are caught and released by fishers (West et al. 2015). High rates of discard may represent a significant risk to sustainability of stocks if associated mortality is high, because current assessments and management regulations assume that discard mortality is negligible (Stewart 2008). However, this assumption is supported by research into the survival of line-caught fish released by recreational fishers for many key species in NSW. These include:

- Australian bass (94–100%; Hall et al. 2009a; b, Roach et al. 2011)
- yellowfin bream (72–92%; Broadhurst et al. 2005; 2007, Butcher et al. 2007; 2010a, McGrath et al. 2011, Reynolds et al. 2009)
- eastern sea garfish (46%; Butcher et al. 2010b)
- dusky flathead (91–97; Butcher et al. 2008)
- luderick (99%; Butcher et al. 2011)
- mulloway (>70%; Broadhurst and Barker 2000, Butcher et al. 2007, McGrath et al. 2011)
- sand mullet (96%; Broadhurst et al. 2011)
- sand whiting (97%; Broadhurst et al. 2005, Butcher et al. 2006)
- silver trevally (63–98%; Broadhurst et al. 2005)
- snapper (67–92%; Broadhurst et al. 2005; 2012b, Butcher et al. 2012a)
- tailor (92%; Broadhurst et al. 2012c)
- yellowtail kingfish (85%; Roberts et al. 2011).

The fate of discarded trapped crustaceans has also been examined, with survival estimates for:

- blue swimmer crabs (99%; Uhlmann et al. 2009, Leland et al. 2013a, Broadhurst et al. 2014)
- mud crabs (100%; Butcher et al. 2012b)
- eastern rock lobster (>97%; Leland et al. 2013b).

Line fishing has been reported to entangle and hook coastal, estuarine and land based birds. Ferris and Ferris (2002) reported that active recreational fishing from attended handlines and unattended set lines was the primary cause of this interaction. Within estuaries, they reported that this interaction was most likely to occur at jetties, wharves, pontoons, boat ramps, fish cleaning tables and narrow watercourses. Given the level of shore and boat based recreational fishing activity that occurs on the open coast, there is likely to be continued interaction between fishing line methods and these species.

Incidental catch of species of conservation concern

Grey nurse sharks are the key threatened and protected fish and shark species that are occasionally caught by recreational anglers. While direct mortality can occur, lethal and sublethal effects can also occur from releasing accidently caught threatened species (McLoughlin and Eliason 2008). For example, Bansemer and Bennett (2010) found 29% of females and 52% of males of grey nurse sharks with retained fishing gear hanging from the mouth or gills in surveys along the east coast of Australia. In almost half of these sharks, the retained gear was recreational in origin.

Most adult sharks can survive external hooking of this type. However, ingested hooks that lodge in internal organs can have long-term effects. For example, Otway and Burke (2004) found 75% of the sharks on which they did necropsies showed no external signs of hooking. Another autopsy on a grey nurse shark suggested that the likely cause of death was peritonitis arising from perforation of the stomach by small recreational hooks (DEH 2002). Several new closures are now in place to protect grey nurse sharks, including listed critical habitat and key aggregation sites with strict fishing rules. There is also greater promotion on the use of circle hooks to promote the mouth hooking of fish and improve released fish survival rates.

Encounters between shore based recreational fishers and threatened shark species leading to accidental hooking can be spatially and temporally concentrated. For example, Port Stephens is one of three important Australian nursery areas for white sharks during October to January, and juveniles use ocean beach sanctuary zones in this area (Bruce and Bradford 2012, Bruce et al. 2013). There is anecdotal evidence historically that white sharks were targeted by fishers on the beaches north of Newcastle. However, since this evidence came to light, closures were put in place to prevent fishers from targeting sharks from those beaches.

Because the magnitude of sublethal effects from catch and release are unknown, this stressor remains a potentially significant source of risk for the sustainability of recreationally fished and threatened species in NSW.

Marine mammals, reptiles and birds can be entangled or caught in recreational fishing gear including in traps and active line fishing methods so (Ganassin and Gibbs 2005) and all have been reported as entangled in recreational fishing gear in NSW. The NPWS Elements database captures data on wildlife that are entangled in fishing gear. Many entanglements are reported each year in gear types used in recreational fishing (see 6.1.2 Commercial fishing **Error! Reference source not found.** for details). Due to the difficulty of sighting injured animals and identifying the type of fishing gear involved, the number of animals entangled each year is likely to be higher than reported. The risk to particular species from recreational fishing methods are described in *6.1.4 Recreational fishing Incidental catch of species of conservation concern*.

Wildlife disturbance

Disturbance at intertidal feeding grounds and high-tide roosts is one of the five major threats to the conservation of shorebirds in NSW (Smith 1991). Disturbance of shorebird nesting, foraging, and roosting habitat can occur when recreational fishers access sites or fish near foraging sites. Many species of threatened and protected shorebirds are affected by shore and boat-fishing activity and are influenced by the number of people, their proximity to birds, and the type and duration of activity (e.g. little terns, pied oyster catchers, sooty oyster catchers, hooded plovers, beach stone curlews) (Thomas et al. 2003).

Given the known presence of roosting and foraging areas for many threatened and protected bird species, it is likely that some disturbance occurs from the level of shore and boat based recreational activity on the open coast (including recreational fishing). However, in comparison to other shore based activities, such as walking and dog-walking, the degree of disturbance caused by recreational fishers is likely to be relatively low. Seals and dolphins in some locations may also be affected by physical disturbance, such as boat noise and discarding of bycatch and offal.

The threat of wildlife disturbance from recreational fishing is further described in Section 6.1.4.

Marine debris

Limited quantitative data exists on marine debris derived from recreational fishing in NSW, although these impacts have been reported by stakeholders. A study of selected ocean beaches in NSW found 13% of the debris to be fishing related, 40% of which was derived from recreational fishing activities (Hertford 1997). Recreational fishing debris was dominant on beaches around urban centres, especially the central coast (Hertford 1997). To address the waste fishing line issue, a statewide Tangler bin program now provides bins for waste fishing line at key fishing locations.

A survey of subtidal reefs (Smith and Edgar 2014) found that most sites had relatively low levels of marine debris with some exceptions. Plastic items were the most abundant (33% of the total), and mostly comprised of fishing monofilament (82% of plastic items and 27% of the total debris) which primarily originated from recreational fishing activities. At two locations within estuaries (Nambucca and within a fishing permitted zone in Port Stephens Marine Park), marine debris densities were comparable to the most polluted parts of the world. Most of this litter was attributed by the authors to recreational fishing (Smith and Edgar 2014).

Marine debris arising from recreational fishing (e.g. discarded fishing gear, bait bags, general litter) can affect wildlife in coastal waters in the same ways as described for estuarine waters in Section 6.1.4. A study of ingested plastics in Eastern Australian waters found that birds were mostly impacted by hard and soft plastic fragments, but birds of the Suliformes order were most susceptible to ingestion of fishing line (Roman et al. 2016).

Given the known presence in the state of many of the threatened and protected bird, mammal and reptile species, and the level of shore and boat based recreational fishing activity that occurs on the open coast, there is likely to be some level of interaction between fishing-derived debris and these species. For example, NPWS has recorded 10 fishing gear injuries with the little penguin colony at Manly since 1995 including ingestion of or entanglement in fishing line, hooks, and nets.

Physical disturbance

Physical disturbance from recreational fishing includes trampling of foreshore habitats, and operation and anchoring of boats. Physical damage from trampling on rocky shores can reduce the cover of canopy forming algae (Keough et al. 1993), although studies that quantify the magnitude, extent and frequency of disturbance by shore based recreational activities are limited. The issue of trampling impacts are also discussed further in Section 8.1.8.

Spearfishing

Spearfishers comprise a small fraction of fishers relative to recreational anglers in NSW. A recent telephone and diary based survey estimated that spearfishing accounted for 0.67% (8,240 fishers) of total statewide participation of statewide recreational fishing activity between June 2013 and May 2014 (West et al. 2015) (Figure 99). Across NSW, spearfishing in the central region accounted for 2.5% of total recreational fishing effort (4,529 fisher days), with the northern and southern regions accounting for <0.5% recreational fishing effort. A general description of spearfishing can be found in Section 6.1.4 under Spearfishing.

Spearfishers target a wide variety of species, particularly red morwong, luderick, rock blackfish, yellowfin bream, various leatherjackets and dusky flathead. More experienced spearfishers tend to target a select range of prized species, most of which are pelagic rather than 'reef-attached'. These include yellowtail kingfish, mulloway (jewfish), tuna species, snapper, Spanish mackerel and spotted mackerel. Inexperienced spearfishers, often using hand spears, tend to target various reef fish species (e.g. aplodactylids, monacanthids, and cheilodactylids) (Curley et al. 2013a). With a paucity of data on the potential impacts of recreational spearfishing on fish populations (Young et al. 2014), scientists are increasingly reliant upon anecdotal evidence (Gledhill et al. 2013).

Competition spearfishing has been predominantly boat based for many years. In recent years, a few boat based spearfishers have accessed offshore locations to target species such as dolphin fish and various tunas. Gledhill et al. (2013) reviewed 335 historical competition datasets from 50 sites in NSW dated from 1961 to 2011. The data sets were made available voluntarily by spearfishers, and represented more than 13,000 diver days, with 98,000 individual fish caught weighing around 108,000 kg. Approximately 150 different species were represented in the overall catch. The data sets extend from near Coffs Harbour south to near Eden.

The most commonly represented species in these data sets appeared in more than 90% of competitions, with nearly 25 species appearing in more than 50% of competitions. Gledhill et al. (2013) noted the number of species being caught increased greatly from the 1970s to the 1980s and has remained relatively stable until the present. The authors noted that the data provides no indication that the spearfishing experience has declined. Competition locality through the sampling period has undergone a minor shift southwards. Gledhill et al. (2013) noted that in the absence of any climate-induced, southwards range extensions (leading to increased tropicalisation of the catch), the southern shift in competitions would likely create a temperate signal in the dataset.

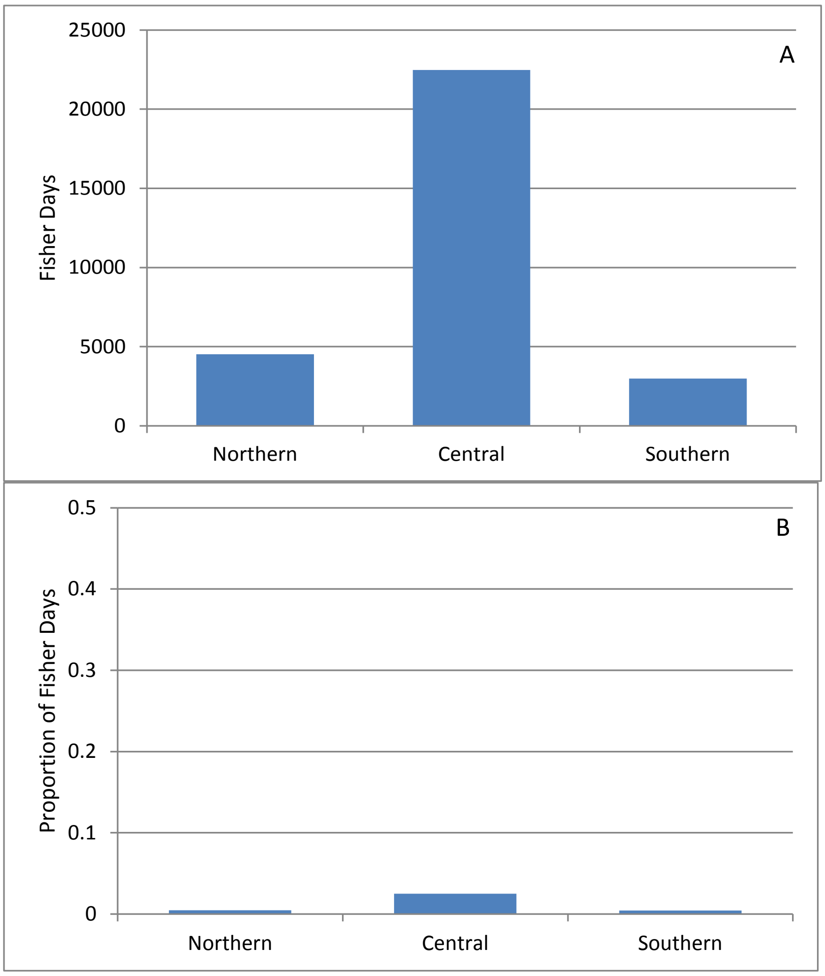


Figure 99. Recreational spearfishing effort across New South Wales regions during 2013–2014; A) number of fisher days, B) spearfishing proportion of total recreational fishing effort.

The specific spatial distribution of spearfishing activity has not been well studied in NSW. However, it is known to occur on rocky reefs around headlands and islands, the beach side of river entrance-training walls, and in open waters. Open water sites include offshore fish attraction devices, which are deployed along the NSW coast by Fisheries NSW between September and June (Recreational Fisheries Management 2011). Studies in the Sydney area show that the activity of spearfishers is patchy, but can be intense – particularly in shallow, sheltered areas (Kingsford et al. 1991, Lincoln Smith et al. 1989).

The largest proportion of the spearfishing harvest was taken in the **central region** (65%, 49,511 individuals) followed by the **southern region** (28%, 21,435) and least in the **northern region** (7%, 5448). Luderick and bream were taken by spearfishers in all three regions, but yellowtail kingfish were only taken in the northern region; squid, tailor and dusky flathead were only taken in the central region; and snapper, abalone and rock lobster were only taken in the southern region (Figure 100, Figure 101). The catch composition of spearfishers around Sydney is often dominated by reef-attached species that are relatively sedentary or docile in nature (e.g. rock cale, leatherjackets, morwongs, sparids, girellids) (Kingsford et al. 1991, Lincoln Smith et al. 1989).

Spearfishing can alter the behavioural responses of targeted species. For example, fishing pressure was found to be positively associated with a higher flight initiation distance of fishes in families that were primarily targeted by spear guns in Papua New Guinea (Feary et al. 2011, Januchowski-Hartley et al. 2011). There are no data on this potential impact in NSW.

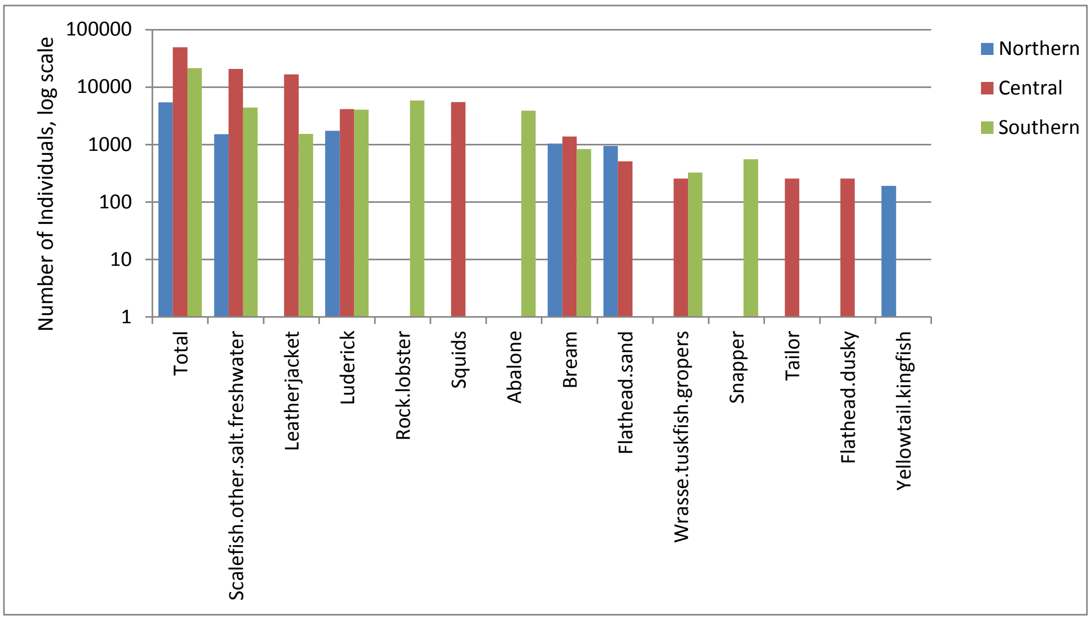


Figure 100. Number of individuals taken by spearfishes in each region of New South Wales for each targeted species group during 2013–2014.

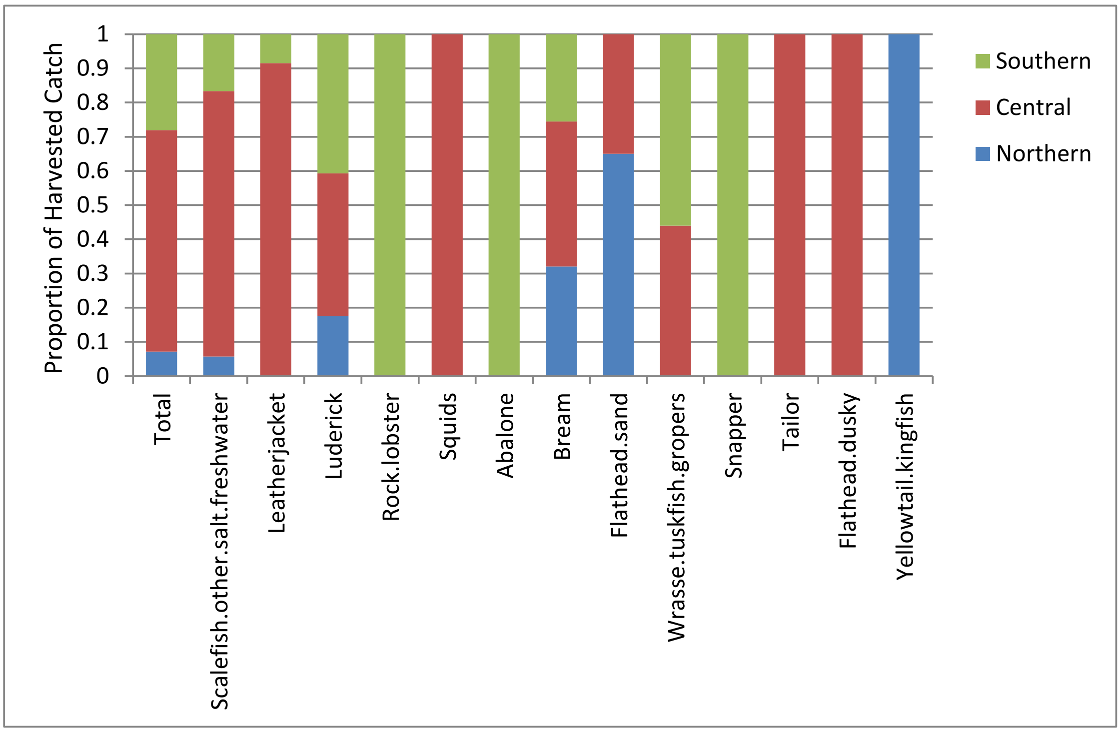


Figure 101. Proportion of harvest of each species group taken by spearfishes in each region of New South Wales during 2013–2014.

Current management

Spearfishers are subject to the same recreational fishing regulations as anglers (see Current management of recreational fishing earlier in Section 8.1.3 Recreational fishing).

Additional prohibitions include:

- use of scuba or hookah apparatus
- use of light with a spear or speargun
- use of power heads or other explosive devices

- spearing of blue, brown or red groper (can be taken by line) or any other protected or threatened fish species listed under NSW or Commonwealth legislation
- spearing on ocean beaches (other than the last 20 m at each end of the beach).

The Australian Underwater Federation is a volunteer organisation that self-regulates the growing sport, along with 'Spear Safe', a national management initiative to provide information and raise awareness on the risks associated with the sport[62]. The federation has a spearfishing code of conduct that promotes sustainable and safe spearfishing[63].

Potential impacts of spearfishing

Reductions in abundances of species and trophic levels

Global research indicates that spearfishing can significantly affect local densities, size, and depth distributions of targeted species (Godoy et al. 2010, Harmelin et al. 1995, Jouvenel and Pollard 2001). There is little data on the current impact of spearfishing across NSW; however, given that the current level of activity only represents 0.67% of total recreational fishing effort, the impact of spearfishing in coastal NSW waters is expected to be low. Historically, spearfishing is thought to have contributed to the decline in numbers of grey nurse sharks, blue groper and black rock cod in NSW (see Section 7.3) (Young et al. 2014).

Some insight into potential impacts has also been gained through spatial comparisons of MPAs versus spearfished areas (Curley et al. 2013). Densities of legal-sized red morwong (*Cheilodactylus fuscus*) were 4.6 times greater in shallow water (<3.5 m) and 2.4 times greater in deeper water (4–12 m) within a 0.1 km^2 MPA closed to spearfishing for 12.5 years, than at fished locations. In the same study, densities of legal-sized, yellowfin bream (*Acanthopagrus australis)* were 2.3 times greater on shallow but not deeper areas of reef within the MPA.

Previous studies found that red morwong is a dominant part of the spearfishing catch (Schmeissing 1999), and is rarely taken by anglers (Lincoln Smith et al. 1989). The species is relatively easy to locate and spear due to its small home range, homing behaviour over distances up to 900 m, diver-neutral and docile behaviour, and tendency to aggregate in relatively shallow water (Lincoln Smith et al. 1989, Lockett and Suthers 1998, Lowry 2003). In combination with its restricted geographical distribution and resultant sensitivity to climate change, these traits have led to its classification as vulnerable (Syms 2011). Similar effects have been demonstrated for red morwong in other NSW MPAs (Coleman et al. 2013). Rapid recolonisation (within 2–4 months) by adult fish has been demonstrated after experimental removal of >70% of adult red morwong from aggregations (Lowry and Suthers 2004). Despite this, recolonisation is likely to be influenced by density of adjacent populations and connectivity of reef habitat.

In some competitions and locations, spearfishing clubs now actively dissuade their members from targeting sedentary species, such as red morwong, and they are no longer targeted during spearfishing competitions The prohibition of spearfishing using scuba gear also provides a depth refuge from spearfishing for some species (Lindfield et al. 2014). Spearfishers also require relatively clear water to be able fish effectively, which further limits spearfishing effort.

Incidental bycatch

Given spearfishers are able to see and identify their catch before unloading their spear, bycatch from spearfishing is expected to be low. Some bycatch can occur when fish are speared but are discarded because they are undersized or have been misidentified. Death can also occur when fish are wounded but escape. While there are no quantitative data on levels of discards by spearfishers in NSW, a study on the Great Barrier Reef found spearfishing produced far less bycatch than line fishers (discards consist of 1% of their catch) (Frisch et al. 2008). There is one record of a marine turtle being taken at Cronulla NSW by spearfishers (G. Ross pers. obs.)

[62] http://auf.com.au/sports/spearfishing/

[63] http://auf.com.au/wp-content/uploads/2012/08/Spearfishing-Code-of-Conduct.pdf

Incidental catch of species of conservation concern

Incidental spearing of threatened and protected species (e.g. grey nurse sharks, blue groper and black rock cod by non-compliant and inexperienced fishers has been occasionally observed along the coast of NSW. Usually, these events receive significant media attention. The overall number of instances is expected to be low, given the extensive advisory campaign around threatened and protected species. See Section *7.3 Marine threatened and protected species.*

Marine debris

The primary source of marine debris associated with spearfishing is similar to that for general recreational and tourism (see Section 8.1.8). Loss of spearfishing equipment contributing to marine debris is minor.

Spearfishers can use boats to access dive sites, and can therefore contribute to boat-derived marine debris (see see Section 8.1.8).

Hand gathering

Hand gathering of invertebrates and algae for food and bait occurs in intertidal and subtidal habitats in all regions (Gladstone and Sebastian 2009, Kingsford et al. 1991, Underwood 1993). Harvested organisms from open coastal habitats include algae (e.g. *Ulva, Enteromorpha*), crustaceans (e.g. lobster, crabs), molluscs (e.g. pipis, limpets, abalone, turbo, periwinkles, whelks, octopus), annelids (e.g. polychaetes, beach worms), echinoderms (e.g. sea urchins) and ascidians (e.g. cunjevoi). Hand gathering for direct consumption tends to be more prevalent among culturally and linguistically diverse communities (Underwood 1993).

There are few studies on the distribution and levels of effort of hand collecting within the region. A late 1980s study estimated that mean densities of up to 23 people per km were harvesting from rocky shores in the Sydney region, with people often clumped together at scales of 50–100 m (Kingsford et al. 1991). At a statewide scale, the distribution of recreational harvesting on rocky shores was not related to proximity to large cities, probably reflecting the willingness of harvesters to travel to preferred locations (Kingsford et al. 1991). More recently, collecting of intertidal organisms represented 65% of all activities that could potentially affect rocky shores at four surveyed sites in the Hawkesbury region (Gladstone and Sebastian 2009). Despite limited quantitative data, concerns of extensive harvesting of intertidal organisms around Sydney led to the implementation of 14 intertidal protected areas (IPAs) by NSW Fisheries in July 1993. Recent interviews with local governments found that harvesting of intertidal organisms continues to be perceived as a key threat to the Hawkesbury region marine estate (NSW DPI 2015, unpublished).

Current management

Hand gathering is managed through the NSW saltwater recreational fishing regulations. As mentioned above and described for estuaries in Section 6.1.4 Recreational fishing, IPAs are temporary fishing closures, renewable every five years, in which the collection of seashore animals is prohibited from the mean high-water mark to 10 m seaward from the mean low water mark.

In 2002, six IPAs were replaced with aquatic reserves. These areas were selected based on length, biodiversity, geographic spread, educational values, research and community consultation. Nine IPAs remain in place: Bungan Head, Mona Vale Headland, Dee Why Headland, Shelly Beach Headland, Sydney Harbour, Bondi, Long Bay, Inscription Point and Cabbage Tree Point. There is also no harvest allowed in all marine park sanctuary zones.

Recreational harvesting of abalone in NSW is currently minimal (bag limit of two per person), particularly within the central region, where collection is only permitted on weekends and adjacent NSW public holidays. These restrictions were implemented as a result of population declines due to the parasite *Perkinsus olseni*.

Potential impacts of hand gathering

Reductions in abundances of species and trophic level

Hand gathering can reduce harvested populations and indirectly affect the structure of associated assemblages (Thompson et al. 2002). Comparisons of aquatic reserves previously designated as IPAs (e.g. Narrabeen, Boat Harbour, Bronte–Coogee, Cabbage Tree Bay, Barrenjoey) to unprotected areas showed no effects for harvested intertidal organisms. This was proposed to be due to lack of compliance within IPAs (Underwood and Chapman 2000). Populations of the limpet *Cellana tramoserica,* which is subject to harvesting, were significantly larger in Bouddi Marine Extension than in unprotected areas (Alexander and Gladstone 2013).

One ecological effect of harvesting is serial depletion of populations. Sedentary species, such as beachworms, pipis, and species with high site fidelity are the most susceptible to this.

There are some concerns about the impact of harvest of beachworms populations. This includes localised depletions and declining levels of total catch, coupled with exploitation of broader areas to support harvest. Recent unpublished studies also indicate age structures of these populations place them at a much high vulnerability to direct (harvest) and indirect (environmental) population pressures.

A study by Fisheries NSW began in early 2016 to identify key locations that support the harvest of important bait species throughout NSW. The study will investigate biological parameters (e.g. population size and structure) at a broad scale, and examine environmental and fishery-related factors affecting the productivity of key populations. Fisheries NSW expects that the study will reduce the uncertainties associated with the level of impact from this stressor on beachworms.

Wildlife disturbance

Disturbance at intertidal feeding grounds and high-tide roosts is one of the five major threats to the conservation of shorebirds in NSW (Smith 1991). Disturbance of shorebird nesting, foraging, and roosting habitat can occur when recreational fishers access sites or fishing in foraging sites. Many species of threatened and protected shorebirds are affected by hand gathering on beaches and are influenced by the number of people, their proximity to birds, and the type and duration of activity (Thomas et al. 2003). As for spearfishing, disturbance of roosting or nesting seabirds and shorebirds by hand gathering and by accessing the rocky shoreline from land can disrupt nesting, increase risk of nest predation by other species, cause trampling or force migratory species into increased vigilance behaviour (Blumstein et al. 2003). The prey items of foraging shorebirds are directly targeted in hand gathering fisheries, which can limit access to food by displacement and competition (e.g. beach stone curlews). The impact on shorebird species from bait collection has been identified as a high priority for research (Department of Environment, Climate Change and Water NSW 2010). This is particularly the case on nesting beaches in northern NSW, where it is possible that the collection of pipis reduces availability of prey species of pied oystercatcher.

Several studies have examined the issue of wildlife disturbance from human activity on rocky shores in the central region (Gladstone 2005; 2006, Gladstone and Sebastian 2009).

The number of recreational fishers is lower than human disturbance from other recreational activities and their overall impact may be lower. However, recreational fishers can have an impact when they access remote sites adjacent to shorebird habitat or where they gather directly on foraging grounds, displacing the animals.

Physical disturbance

Physical disturbance from hand gathering includes trampling of foreshore habitats. These stressors are discussed further in Section *8.1.8 Recreation and tourism.*

8.1.4 CULTURAL FISHING

Line fishing, spearfishing, hand gathering, traditional fishing methods

As described in Section *6.1.5 Cultural fishing,* there is considered to be only a very low level of this activity in NSW currently, and the risks posed by it are likely to be minimal across the regions.

8.1.5 CHARTER ACTIVITIES

Whale and dolphin watching

The key areas for cetacean watching in coastal and open waters in NSW are Sydney, Byron Bay, Port Stephens, Jervis Bay, Eden and Merimbula (O'Connor et al. 2009). Charters in NSW are primarily directed towards Indo-Pacific bottlenose dolphins, which occur year-round, and humpback whales during their annual migration. Southern right whales are less common, but also targeted on their annual migration (O'Connor et al. 2009). Expansion of the whale watching industry may subject migratory populations to continual rates of disturbance as they move along the east coast of Australia (Smith 2001). Cetacean-watching tours opportunistically target other wildlife and any of the 36 cetacean species present in NSW may be viewed, as well as seals, seabirds, turtles, and other marine fauna species.

Though whales and dolphins are the main focus of marine wildlife tourism in NSW, seals are also a source of ecotourism. Seals can be viewed when hauled-out or in the water, and tourists can observe seals from land or vessels, or by swimming with them. Haul-out sites on mainland NSW are uncommon and difficult to access from land, so seal watching is primarily opportunistic.

Current management

Whales and dolphins are protected in NSW waters under the *NPW Act* and in Commonwealth waters under the *EPBC Act.* For a detailed description of the current management of these activities, see Section *6.1.6 Charter activities***.** In marine parks, including Montague Island, tourism operators are licensed and managed using a best-practice code of conduct for commercial tourism operators.

Potential impacts of whale and dolphin watching

The key stressors derived from whale and dolphin-watching activities are physical disturbance and wildlife disturbance. For a detailed description, see section *6.1.6 Charter activities.*

8.1.6 AQUACULTURE

Finfish farming

Aquaculture activity on the open coast of NSW is restricted to finfish farming. In 1999, the first marine finfish aquaculture in sea pens was established in NSW on a 30 ha site off Port Stephens in the northern region. In 2013, Fisheries NSW received a state significant infrastructure application for a 20-ha marine aquaculture research lease, offshore adjacent to the existing lease of Port Stephens. An EIS, draft environmental management plan, visual amenity study and a submissions report accompanied the Fisheries application.

The EIS identified 27 risks associated with the proposal to conduct finfish aquaculture in sea pens. Twenty-three issues were identified as representing a low to negligible risk. No issues were identified as representing a high or extreme risk, but four were classified as moderate. These related to impacts on water quality and sedimentation, chemical use, pests and diseases and impacts on wildlife (migratory whales and sharks). These issues and required mitigation measures are summarised in the environmental management plan that must be implemented as a requirement under project approval, issued via the *Environmental Planning and Assessment Act 1979*[64].

At present, Fisheries NSW is negotiating with a commercial partner to operate the lease for its five-year experimental life.

8.1.7 RESEARCH AND EDUCATION

Sampling of flora and fauna on the open coast and continental shelf is conducted for a wide range of research and educational activities within all regions, includes from both intertidal and subtidal habitats. See Section 6.1.8 *Research and education* for further detail.

64 https://majorprojects.affinitylive.com/public/65529e4f654ff352026382c7b8ad0719/SSI%20Approval_%20Marine%20Aquaculture%20Research%20Lease.pdf

Current management arrangements

Assessments are made of all proposed research and educational sampling that requires specific harvesting of flora and fauna. A scientific collection permit is required for individuals who intend to collect fish or marine vegetation for scientific research. This permit can be issued under Section 37 of the *FMA* to allow the taking or possession of fish or marine vegetation that would otherwise be unlawful. As part of issuing permits, NSW DPI has a statutory responsibility under Section 111 of the *EP&A Act* to assess the environmental impacts of activities authorised by permit. To assess these impacts, NSW DPI requires the applicant to consider the potential impacts of their proposed research.

In assessing permit applications, special attention must be given when the research involves a listed threatened species or techniques that might affect listed threatened species, or is being done in a listed endangered ecological community. The assessment also considers whether the proposed action is:

- likely to harm critical habitat
- consistent with the objectives or actions of a recovery plan or threat abatement plan
- likely to result in the operation of, or increase the impact of, a key threatening process.

Matters of national environmental significance are also considered under the *EP&A Act* if the proposed activity is likely to have an impact upon any 'Matter of National Environmental Significance' under the *EPBC Act*.

Animal care and ethics committees assess and report issues relating to animal care and ethics, including fish, cephalopods and vertebrates. This is conducted under the *NSW Animal Research Act 1985,* which aims to protect animal welfare by ensuring their use in research is always humane, considerate, responsible and justified. The Animal Research Regulation 2010 and the Australian Code for the Care and Use of Animals for Scientific Purposes (8th Edition, 2013) are used when conducting animal research or supplying animals for research.

Any organisation that uses or supplies vertebrate animals for research or teaching in NSW is affected by the *NSW Animal Research Act 1985*. The Act applies to all individuals, groups, institutions, organisations, schools and companies that use animals. Under the *Animal Research Act,* organisations that conduct research with vertebrates must either become an accredited research establishment or obtain an animal research licence. This Act is administered by the Animal Welfare Unit of NSW DPI. In addition, all research must be covered by a current Animal Research Authority. These are issued by approved animal care and ethics committees, which in turn are administered by the Animal Welfare Unit and the Animal Research Review Panel of NSW DPI.

8.1.8 RECREATION AND TOURISM

Boating and boating infrastructure

A detailed description of this activity, current management and potential threats is presented Section 6.1.9. There is little information available of the extent of the activity in coastal and open waters compared with estuarine waters.

Potential threats from boating and boating infrastructure

Water pollution

There are large numbers of marinas, sailing clubs, jetties, and pontoons in NSW, although almost all are located in estuaries. Much of the copper and TBT contamination is likely to be the result of the large numbers of recreational boats in small areas of estuaries, but there are little impacts on the open coast. For more information, refer to this heading under Section 6.1.9.

Physical disturbance

The wash from recreational vessels can erode the banks of estuaries and coastal lakes and change the composition of soft-sediment invertebrates in non-vegetated and vegetated areas (Bishop 2004). It is also possible that boat wash can lead to increased turbidity by resuspending sediments. Boating infrastructure such as jetties and pontoons can impact seagrasses by reducing light levels. Jetties typically reduce the density of seagrasses that are directly below them. For more information, refer to this heading under Section 6.1.9.

Boating can also cause injury and mortalities in marine fauna from vessel strike. Further information on the threat of vessel strike is outlined in Section 6.1.9.

Pests and diseases

The large numbers of marinas, sailing clubs, jetties and pontoons in NSW are likely to facilitate greater invasion and dispersal of introduced and pest species. For more information, refer to this heading under Section 6.1.9.

Wildlife disturbance

As described in Section 6.1.9, noise from boating can affect the health and behaviour of marine and terrestrial wildlife (e.g. reduce fitness to feed, breed, migrate, nest and rest). For more information, refer to this heading under Section 6.1.9.

Marine debris

Boating can contribute to general marine debris. For more information, refer to this heading under Section 6.1.9.

Snorkelling and diving

Snorkelling and diving within coastal waters is mostly restricted to shallow rocky reef habitats across the regions. There is little information on the level of activity as much of it occurs as a private recreational activity rather than through commercial operations. For more information, refer to this heading under Section 6.1.9.

Current management

In the past few decades development of diving codes of conduct and increased recognition of scuba diver impacts may have reduced impacts. Scuba divers have become more aware of their own potential to cause an impact, and increased environmental awareness changes behaviour. Community groups throughout NSW involved with scuba diving (e.g. Solitary Islands Underwater Research Group) have formed an umbrella group called Underwater Volunteers NSW[65] and have developed codes of conduct for low-impact diving and for underwater photographers, including within MPAs and with protected species. The motivation for many divers involved in these community groups is the desire to contribute to environmental conservation and to increase personal knowledge and skills (Hammerton et al. 2012). Since a study by Roberts (1993) at Julian Rocks estimated 100,000 incidents linked to the physical damage of corals and sessile life forms, the dive industry has adopted recommendations by to reduce impacts (Bucher et al. 2007).

Potential impacts of diving and snorkelling

Snorkelling and diving are generally passive and are unlikely to have any impact on marine biodiversity or habitats. However, scuba divers can potentially damage delicate benthic communities if they approach too closely. They can also interfere with marine wildlife. A code of conduct for diving with grey nurse sharks[66] applies in all NSW waters, including grey nurse shark critical habitat and aggregation sites. Diving with grey nurse sharks is a popular pastime at several sites in all regions.

Further details are provided in the Hawkesbury bioregion environmental background report (MEMA 2016).

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[65] http://uvnsw.net.au/

[66] http://www.environment.gov.au/node/18423

Physical damage

The recommendations adopted by the dive industry mentioned above (Bucher et al. 2007) include:

- dive briefs that emphasise diver buoyancy
- training dives on sandy flats
- regular dive trails to help reduce the area of impact.

Bucher et al. (2007) also notes individual diver impact may have decreased since 1993, with anecdotal evidence suggesting little change in benthic coverage in the decade between studies.

Wildlife interactions and behavioural changes

Further specific details are provided in the Hawkesbury bioregion environmental background report (MEMA 2016).

Swimming, surfing, walking and other passive use including dog walking

These activities are generally passive and are unlikely to have any impact on marine biodiversity or habitats. However, activities such as walking and dog walking can disturb and harm wildlife as described in Section 6.1.9.

Four-wheel driving

Four wheel driving occurs in several specific locations along the NSW coast, and occurs primarily on intertidal habitats that are often associated with adjacent recreational four wheel drive tracks that occur on both private and public lands. There are only a couple of beach driving locations in central region (including the norther end of Bate Bay, Cronulla and Blacksmiths Beach), and no beach driving is allowed in the southern region. Four wheel driving occurs in many more specific locations in the northern region.

Potential impacts of four-wheel driving

Physical disturbance

Four-wheel drives can physically damage beaches and affect abundance and diversity of organisms living on and with the sand. A study of four-wheel driving on beaches showed significant changes to beach–dune morphology, with smaller dunes set further back from the shoreline and a significant decrease in elevation of dune crests (Houser et al. 2013). Schlacher et al. (2008a) quantified the extent of physical damage to beaches. They reported ~2–8 tyre tracks per metre of beach face, with up to 90% of the beach covered in tyre tracks. Tyre ruts reach up to 28 cm deep (mean depth: ~6 cm), with the deepest rutting occurring between the foredunes and the drift line. The study estimated that vehicles disrupted up to 9.4% of the available faunal habitat matrix (top 30 cm of the sand) in a single day. Similar scales of physical impacts for New Zealand beaches and inferred considerable ecological impacts have been reported (Stephenson 1999).

Fairweather and Ramsdale (2008) reported higher compaction of sediments on beaches with four-wheel drive vehicles. The vehicles significantly affected macrofauna associated with wrack, reducing macrofaunal abundance and species richness. These effects were greatest in the high-shore soft-sand area, where rutting of sand by tyres is most obvious and wrack also tends to accumulate.

Wildlife disturbance

Ghost crabs can be crushed in large numbers by vehicles. Crabs in burrows less than 30 cm deep (50% of individuals) are killed by repeated vehicle traffic and a large number are crushed by night traffic (Schlacher et al. 2007). Sand compaction and de-watering by beach traffic reduces the abundance and diversity of other fauna on beaches (Schlacher et al. 2008b).

Recent work near Lake Macquarie has shown a significant change in ghost crab burrows and activity, as well as vegetation cover and diversity due to four-wheel drive use in foredune environments (B Cooke, Macquarie University unpubl data).

Impacts on shorebirds in coastal environments are similar to those in estuaries (see section 6.1.9 Recreation and tourism Four-wheel driving). Physical disturbance, loss of nests and eggs, and compaction of beach substrates are among the recorded impacts on shorebirds by four-wheel driving activity (Greenslade and Greenslade 1977, Kingford 1990). Four-wheel driving on coastal beaches has been identified as a threat to the recovery of endangered little tern populations in NSW (NSW National Parks and Wildlife Service 2003). Four-wheel driving on coastal beaches may also affect nesting marine turtles (Sargent et al. 2012). Vehicular intrusion into beach nesting sites may result in crushed nests, eggs, and hatchlings (Sargent et al. 2012, Department of the Environment and Energy 2017). Physical modification of nesting sites may also be problematic. On some beaches, four-wheel driving may reduce the emergence success of turtle hatchlings, by compacting sand over nests, eroding dunes, reducing suitable nesting habitat, and creating deep and long-lasting tyre ruts that impede movement towards the sea (Sargent et al. 2012, Department of the Environment and Energy 2017). A study on the effect of vehicle ruts on the beach dispersal of green turtle hatchlings found that progress towards the sea was slowed by ruts as shallow as 5 cm, and largely prohibited by a single 15 cm rut, resulting in increased exposure to predation, dehydration, and increased energy expenditure (van de Merwe et al. 2012). In NSW, both loggerhead and green turtles are known to nest as far south as Sydney.

Additional details are provided in the Hawkesbury bioregion environmental background report (MEMA 2016).

Shark control measures

Shark meshing only occurs within the central region. The Shark Meshing (Bather Protection) Program (SMP) currently uses specially designed, bottom-set meshing nets off 51 beaches between Newcastle and Wollongong. The program runs from 1 September to 30 April each year. Specific details are presented in the Hawkesbury Shelf environmental background report (MEMA 2016), including impacts on environmental assets and current management arrangements.

Adiitional shark meshing was trialled in the northern region in November 2016 for a pilot study, followed by consistent deployments of nets between 8 December 2016 and 30 May 2017. The species that were the target of the meshing trial were white, tiger and bull sharks. Shark meshing was conducted at Seven Mile Beach off Lennox Head; Lighthouse, Shelly and Sharpes beaches off Ballina; and Main Beach at Evans Head. The nets used followed the broad specifications of those used in the SMP (Green et al. 2009).

The five nets caught a total of 275 animals during the almost six months trail period; including three white sharks, three tiger sharks and three bull sharks. The remaining 266 animals comprised at least 18 species. This included a number of threatened, protected and endangered species, including greynurse shark, loggerhead turtles, green turtles (*Chelonia mydas*), great hammerhead (*Sphyrna mokarran*), and Indo-Pacific bottlenose dolphins (*Tursiops aduncus*). The relative abundances of these different species in nets varied substantially among beaches and across time. The total immediate survival of netted animals was 47% (i.e. 128 of the 275 netted animals survived). The pooled survival among all target sharks was 44% (two white, one tiger and two bull sharks died), but varied between 0% and 76% for other relatively abundant species (i.e. where >10 were caught). Further specific details are presented in NSW DPI (2017).

8.1.9 DREDGING

Dredging is principally limited to estuarine waters, although it occurs at times in coastal and open waters at a local scale. For more detail, see Section 6.1.10.

Current management

Details are provided in the Hawkesbury bioregion environmental background report (MEMA 2016) and Section 6.1.10 of this report.

Potential impacts of dredging

Details as they relate to potential impacts in coastal and open waters are provided in the Hawkesbury Shelf bioregion environmental background report (MEMA 2016). Also, for more information, see Section 6.1.10 in this report.

8.1.10 MINING

Extractive industries considered in this section are limited to potential offshore mining activities in the marine waters of the central region. There is virtually no mining or exploration activity occurring in the continental shelf portion of the NSW marine estate at present. However, two extractive activities have potential to develop in the central region: offshore sand extraction to provide sands for building and beach nourishment, and oil and gas production.

The potential for offshore sand mining in the region is indicated by a shelf sand body in the region from South Head to Bondi and Maroubra south, and a more significant shelf sand body in water depths of 30–70 m around 0.5–2.5 km off the coast between Jibbon Point to around Wattamolla Beach (NSW DPI 2007a). The most significant areas for oil or gas production on the shelf in the region are located outside NSW coastal waters.

Current management

An embargo is in place on marine mineral extractions within NSW waters. However, 2011 saw a major submission on mining marine aggregates to the NSW Planning System Review process (Brown and Associates 2011). This indicates that there is still active interest in aggregate mining off the NSW coast. The submission notes that current orders reserving areas of NSW's coastal waters from exploration and mining would need to be lifted before exploration licences could be issued.

Mining of sand for beach nourishment was considered by AECOM (2010). They noted that there is currently a prohibition on offshore minerals extraction, due to the effect of the *Offshore Minerals Act 1999 (NSW)*. Mining would require an amendment to Schedule 2 of the *Offshore Minerals Act 1999,* and the introduction of companion regulations to enable a mining licence to be issued over an area of sand within NSW waters to 3 nm limit.

An offshore oil and gas exploration licence (PEP 11) has been granted for seafloor between Port Stephens and Wollongong, including within NSW waters. However, only one test drill has apparently been made so far, which was 110 km offshore.

Potential impacts of mining

Water pollution

Sand extraction - there is very little risk of chemical contaminants or other pollutants if clean offshore sands are dredged up and transported to onshore facilities. Potential impacts of oil and gas drilling include spills and waste materials such as drilling mud and associated turbidity.

Physical disturbance

Brown and Associates (2011) cite data from WBM Oceanics 1996 that indicate significant turbidity close to operations by trailing suction dredges (20–600 mg/L suspended solids), which 'quickly' reduce to background levels. They note that the sand fraction of plume settles within 30 minutes, but that the fine fraction remains suspended for several hours. In contrast, literature cited in Cardno (2009) indicated suspended sediment concentrations from barge discharge water of 9000 mg/L at discharge point, declining to 9 mg/L 1.5 km behind the barge. This proposal included a subsurface (–15 m) discharge of excess water, which would reduce impacts on plankton and seabird foraging.

Such a plume of suspended material could have implications for primary production, smothering nearby benthic reef assemblages and mobile fauna: particularly if operations were continuous. This would be exacerbated if operations occurred in waters greater than 60 m depth, where there is an increased percentage of fine clay in sediments (OEH unpubl. data).

Cardno (2009) in AECOM (2010) summarise the assessment of ecological impacts performed for the 1993 Metromix sand extraction proposal. They concluded that impacts on benthic invertebrates would be significant, but highly localised and short term, persisting until recolonisation occurred. Experimental manipulations showed that recolonisation would occur within 2–3 months, though this rate may changes as the area of undisturbed seabed (which acts as a source of recruits) becomes smaller. They claimed that longer-term or wider scale impacts are not expected:

> 'Mobile species, such as fish and prawns, and large bivalves may be able to avoid the dredger extraction head by swimming away or burrowing, respectively. Some of the organisms extracted would be released back into the sea with the excess dredging water, however, not all would survive, because of the change in water pressure, abrasion against the sand, impact with the screens, deposition into unsuitable habitat or consumption by predators such as fish. Other organisms would be relocated to the nourishment zone with the sand. The removal of organisms would change the structure of benthic assemblages and affect their ability to recover from natural disturbances, resulting in a net loss of benthic productivity.' (AECOM 2010).

For further details on physical disturbance, see also Section 6.1.10.

Sedimentation

The types of mining activities considered here would not lead to the deposition of sediments in the offshore marine environment.

Wildlife disturbance

The movement of vessels associated with either sand extraction or oil and gas exploration would create the same pressures and potential impacts as discussed for shipping activities in Section 8.1.1.

Seismic surveys are an infrequent source of sound in NSW estuarine and coastal waters, but may be used during oil or gas exploration. Seismic testing equipment has been implicated in adverse impacts on marine mammals, marine turtles, fish and elasmobranchs. Both marine mammals and marine turtles avoid sound generated during seismic surveys.

McCauley et.al. (2000) tested the effects of air gun seismic arrays on green and loggerhead turtles exposed to air gun shots. The behavioural responses showed that each species had elicited an avoidance response at a received level of 166 dB, and showed avoidance behaviour at 175 dB. This suggests that behavioural changes may occur at a range of 2 km and avoidance at 1 km from a seismic vessel using an air gun array in 100–120 m depth of water.

Marine turtles are largely found in shallow water, and McCauley et.al. (2000) speculated that sound would not carry as far in shallower water, but noted that this also depends on the sound-transmitting characteristics of the substrate. Turtles that rest on the substrate (a common behaviour) are likely to be able to detect the vibration, but the implications of this are not clear and further work is needed.

8.1.11 MODIFIED FRESHWATER FLOWS

Further specific details of modified freshwater flows are provided Section flows of this report, although the specific stressors and level of impact are expected to be minimal. Further specific details are provided in the Hawkesbury Shelf environmental report (MEMA 2016).

8.1.12 SERVICE INFRASTRUCTURE

This activity includes the laying of infrastructure pipelines and cables on the seafloor, or into the seabed via trenching and boring techniques. A considerable amount of service infrastructure occurs on continental shelf waters in the central region, reflecting the level of urban development adjacent to the marine estate. This includes the significant infrastructure of submarine communications cables, which carry the bulk of international voice and data traffic.

Further details are provided in Section 6.1.13 of this report and the Hawkesbury Shelf environmental report (MEMA 2016), although the specific stressors and level of impact are expected to be minimal in the northern and southern regions.

8.2 LAND USE IMPACTS

8.2.1 LAND USE INTENSIFICATION

All of the coastal catchments in the regions have some level of intensive land use activity and development. The most developed catchments (i.e. where >80% of land is developed) are predominantly urbanised.

Further specific details of land use intensification are provided in Section intensification of this report and the Hawkesbury marine bioregion environmental report (MEMA 2016). The assessment in this section relates to the potential impacts of these activities in coastal and open waters.

Urban stormwater discharge

Urbanised areas have large areas of hard surfaces that significantly reduce infiltration of rainfall, increasing both volume and velocity of run-off. Stormwater run-off in urban areas has traditionally been managed by rapid direction into hard reticulation systems (gutters, pipes, canals), which offer little or no potential for reduction of volume, velocity, or pollutant loads.

Localised impacts of stormwater run-off can occur in coastal habitats where reduced salinity and input loads of nutrients and sediments can disrupt ecological processes. Large volumes of run-off can scour and redeposit sediment, smothering habitats and resuspending sediments which increases turbidity.

Potential impacts of urban stormwater discharge

Water pollution

Dissolved nutrients exported to coastal seas by rivers are generally taken up rapidly by phytoplankton. This may elevate phytoplankton levels for limited periods in certain locations during floods. There is no evidence that any harmful algal blooms in NSW are associated with land based nutrients (Pritchard et al. 2001). Due to the higher frequency of upwelling relative to floods from NSW catchments, Pritchard et al. (2001) concluded that the majority of phytoplankton production on the NSW shelf is driven by uplift of nutrient-rich slope water on to the shelf. Turbidity from urban run-off may be transported to coastal waters, but the influence would be small and localised away from the large urban centres in the Hawkesbury Shelf region.

Though less concentrated in coastal environments, marine pollution impacts on coastal marine wildlife in a similar manner to those in estuaries (see Section 6.2.1 Land use intensification). Using humpback whales and bottlenose dolphins as sample species, the International Whaling Commission (IWC) produced a large body of evidence that Polychlorinated Biphenyls (PCBs) can impact immunity, thyroid health, skeletal integrity and reproductive hormones. IWC is now researching impacts of polycyclic aromatic hydrocarbons (PAH) and microplastics on cetaceans and this will be available via a web based tool for risk assessment.

Pathogens

The presence of pathogens has strong implications for the use of waters by humans for swimming, sailing, surfing and a range of other passive recreational activities. It is also important for oyster growing. The main driver of microbial pollution to coastal waters is urban run-off after rain (Beachwatch 2016).

The microbial water quality of beaches and other swimming locations in NSW is monitored under OEH's Beachwatch Programs. The latest assessments (2014–2015)[67] show that:

- On the **north coast**, 100% of monitored ocean beaches (n=6) were graded as good-very good.
- In the **central region**, 43/46 (93%) of Hunter/central coast ocean beach sites were graded as good or very good; the poor sites were all adjacent to estuarine lagoons. In Sydney, 37/38 (97%) ocean beach sites were graded good or very good, with the single poor

[67] http://www.environment.nsw.gov.au/resources/beach/ar1415/FB1-summary-how-to-read.pdf

grading being near a sewage outfall. In the Illawarra, 15/15 were graded good or very good.

- On the **south coast**, 100% (n = 34) of beach sites were graded good or very good.

Groundwater pollution

There are no known examples of influences of contaminated groundwaters on coastal environments.

Marine debris (including Microplastics)

See information under Marine debris in Section *6.2.1 Land use intensification Microplastics* are potentially carried by urban stormwater, particularly if it contains sewage overflows. There are, however, few data on this topic.

Sediment contamination

Sediments from highly urbanised catchments are associated with elevated concentrations of potential toxicants such as heavy metals, pesticides and PAHs. These effects occur near discharge points in low-energy environments. Impacts in coastal waters would be very small.

Foreshore development

As described in Section 6.2.1 Land use intensification many foreshore developments extend into both the terrestrial and subtidal environments, and can affect environmental values in many ways (Dafforn et al. 2015).

Potential impacts of foreshore development

Physical disturbance

Intertidal habitats can be lost or significantly altered in form by foreshore developments involving shoreline hardening, reclamation, localised dredging and increased private and public access. In the case of shoreline hardening, horizontal soft sediments or natural reef platforms in both the intertidal and subtidal zones are often replaced by vertical, featureless seawalls. This can lead to a complete change in the available habitats and can significantly reduce biodiversity. Historic foreshore development in the coastal areas has primarily led to a loss of dunes, dune vegetation, interdune swamps and associated ecological communities.

All changes to land use on foreshores and floodplains decrease the naturalness of foreshores, disrupting connectivity (Heatherington and Bishop 2012) and removing habitat. They also result in the discharge of increased loads of nutrients and suspended solids from run-off and stormwater (diffuse source water pollution); larger volumes of run-off, often with increased velocities; and reduced infiltration of rainwater into soils.

Impacts of habitat loss or degradation affecting marine wildlife in estuarine environments also affect wildlife in coastal areas (see *6.2.1 Land use intensification Foreshore development*). In addition, habitat modification has been listed as a significant threat in the Australian Government’s 10 year recovery plan for marine turtles (Department of the Environment and Energy 2017). Foreshore development near the nesting beaches of turtles can result in direct mortality where nests are destroyed, or reduction in the availability or quality of suitable nesting habitat, causing displacement or behavioural modification of individuals and populations (Department of the Environment and Energy 2017). For instance, swamp reclamation behind dunes may affect the moisture content of sand and subsequently the success of egg incubation (Ackerman 1997).

Land clearing associated with foreshore development may reduce shade provided by vegetation, resulting in increases in sand temperature and subsequently affecting the sex-ratio and mortality of turtle hatchlings (Kamel and Mrosovsky 2006). Armoured beaches and resulting changes in sediment flow may result in the loss of dry sand, eliminating turtle nesting habitats (Defeo et al. 2009). As marine turtles utilise light as an orientation cue, artificial light from coastal development can impede nesting by females, and disrupt hatchling orientation, expending energy reserves necessary to reach pelagic feeding areas and exposing them to predation, dehydration, and entrapment (Department of the Environment and Energy 2017, Truscott et al. 2017). As such, artificial lighting can contribute to the long-term decline of the reproductive output of a nesting area, reducing habitat value (Department of the Environment and Energy 2017).

Wildlife disturbance

Artificial hardening of foreshores removes habitats: often low-profile intertidal habitats, such as intertidal flats or saltmarsh, but also dune vegetation and inter-dune swamps. This fundamentally affects the types of species (e.g. birds) that use or can colonise these areas.

Foreshore development also leads to increased human populations accessing shores. People and dogs on beaches are the main threatening activity to threatened shore birds such as little terns and hooded plovers, but also other shore based wildlife.

Marine debris

Foreshore development brings people in close proximity to the foreshore and increases the likelihood of litter and other debris entering waterways.

Pests and diseases

Artificial surfaces can facilitate the attachment and expansion of introduced species. Bitou bush (boneseed) was widely planted to stabilise dunes affected by mining and other foreshore activities. It now infests 80% of the NSW coast (900 km, and up to 10 km inland), with only the far south coast relatively free of bitou. For 36% of the coast it is the dominant vegetation, resulting in the loss of natural dune vegetation and ecological values[68].

Changes to tidal flow patterns

See Section 8.2.3 Hydrologic modifications for further details.

Beach nourishment and grooming

As described in Section 6.2.1 *Land use intensification*, this practice can improve amenity and increase social value, but can harm natural systems.

Beach erosion hot spots, which have been identified by OEH in conjunction with local governments, are primarily on the northern region and central region (Table 37). These are where five or more houses or a public road are located in a current (or immediate) coastal hazard area. There are other locations along the coastline where either a smaller number of houses, or only residential land (i.e. no houses) are in a coastal hazard area[69].

Table 37. Identified beach erosion hotspots in New South Wales.

Region	Local government area	Location
North		
	Byron Shire Council	Belongil Beach
	Ballina Shire Council	Lennox Head
	Clarence Valley Council	Brooms Head
	Clarence Valley Council	Wooli
	Port Macquarie-Hastings Council	Lake Cathie
	Greater Taree City Council	Old Bar Beach
	Great Lakes Council	Winda Woppa – Jimmys Beach
Central		

[68] http://www.environment.nsw.gov.au/pestsweeds/BitouBushFactsheet.htm

[69] http://www.environment.nsw.gov.au/coasts/coasthotspots.htm

Region	Local government area	Location
	Wyong Shire Council	The Entrance North
	Wyong Shire Council	Noraville
	Wyong Shire Council	Norah Head
	Gosford City Council	Wamberal/Terrigal
	Pittwater Council	Bilgola
	Pittwater Council	Mona Vale
	Warringah Council	Collaroy/Narrabeen
South		
	Eurobodalla Shire Council	Batemans Bay

Physical disturbance

Impacts on resident and migratory shorebirds in coastal areas are similar to those in estuarine environments (see 6.2.1 for further details). The ability and survivorship of nesting turtles can be detrimentally affected by the addition or removal of sand for coastal protection. Beach compaction with excess sand during incubation periods may decrease nesting success, whilst changes in beach elevation may prevent turtles from reaching nesting areas or inhibit dispersal of hatchlings to the sea (Grain et al. 1995). Changes in beach characteristics associated with nourishment processes, such as beach compaction, alterations in the hydric and thermal environment and nutrient levels, and increases in contaminants, may decrease survivorship or affect development (e.g. sex) of hatchlings (Ackerman 1997, Grain et al. 1995, Hawkes et al. 2007).

Beach hardening due to nourishment may also impact processes of nest excavation and structure, and emergence of hatchlings from the nest (Ackerman 1997). Exposure of beaches to erosion through beach grooming may result in the reduction of suitable nesting habitat, and grooming may also result in nest destruction. In NSW, two species of turtle (green and loggerhead), are reliably known to nest on beaches from the Queensland-NSW border to as far south as Sydney. A 2012 study found that, in Australia, beach nourishment projects were small but frequent, occurring between 2001 and 2011 on only 130 beaches, with little monitoring of their biological impact (Cooke et al. 2012).

Clearing riparian and adjacent habitat including wetland drainage

Details of clearing riparian and adjacent habitat including wetland drainage are provided in Section 6.2.1 of this report, although the specific stressors and level of impact are expected to be minimal. Further details are provided in the Hawkesbury bioregion environmental background report (MEMA 2016).

Potential impacts of clearing riparian and adjacent habitat

Wildlife disturbance

Wildlife disturbance is via habitat loss and pollution, as detailed below.

Physical damage

In the **central region**, habitat adjacent to popular ocean beaches (e.g. Bondi, Manly) has been completely removed and replaced with carparks, walkways and retaining walls. This is also an infrequent occurrence in the **northern region** (e.g. Forster). Whilst these developments have largely ‘legacy’ impacts, monitoring and management actions are still required to mitigate the cumulative impacts of historical clearing.

Land clearing is considered the most significant threat to species in Australia since European Settlement, and is therefore listed as a key threatening process requiring management under the *EPBC Act 1999*. Further, destruction or fragmentation of habitat, riparian zone degradation, and increased vulnerability to invasive species has led native vegetation clearing to be listed as a key threatening process under the *TSC Act 1999*. Although there is some evidence that the removal of vegetation – particularly invasive and highly competitive species – from coastal dunes enables restoration of sand mobility and native plant communities (Konlechner et al. 2015), indiscriminate removal of dune vegetation may result in the permanent loss or degradation of habitat. This includes nesting and roosting habitat, affecting both migratory and resident marine wildlife, particularly those species with high site fidelity.

Vegetation clearing can destabilise dune systems, accelerating erosion and altering beach morphology, potentially resulting in the loss of dry sand and the subsequent degradation of marine turtle or seabird nesting sites, causing displacement or behavioural modification among individuals and populations (Defeo et al. 2009, Department of the Environment and Energy 2017). While the regular clearing of encroaching vegetation has been identified as a means of preparing and protecting suitable breeding sites for the endangered little tern, increased erosion and associated modification of sand deposition may reduce available nesting sites (NSW National Parks and Wildlife Service 2003). Additionally, the presence of vegetation at the perimeter of nesting sites offers necessary shelter for chicks once they leave the nest (NSW National Parks and Wildlife Service 2003).

The loss of available wintering, stop-over, and breeding habitats is particularly significant for migratory shorebirds in Australia, limiting breeding success and compromising their ability to acquire sufficient energy reserves for their migration (Department of the Environment 2015). Removal of dune vegetation in proximity to nesting sites of marine turtles may not only result in the direct loss of nests, but also reductions of habitat quality. Loss of shading due to vegetation clearing can increase sand and nest incubation temperatures, leading to a greater female-biased sex ratio among hatchlings with significant implications for demographic stability, as observed among hawksbill sea turtles in Guadeloupe (Kamel and Mrosovsky 2006, Kamel 2013, Department of the Environment and Energy 2017). This effect may exacerbate already increased sand temperatures due to climate change (Kamel and Mrosovsky 2006, Kamel 2013). Vegetation has also been identified as important in the stability of green turtle nests during their construction (Chen et al. 2007). Vehicles and humans present onsite to clear dune vegetation may also cause physical damage to nesting habitats.

Clearing of vegetation on dunes may also allow other environmental stressors and their impacts to occur, by increasing the accessibility of beaches to humans, off-road vehicles, domestic animals, and pests. Removal of beach vegetation and associated destabilisation of dune systems may also render coastal habitats more vulnerable to the damaging effects of rising sea-levels, storm surges, and extreme weather events (Defeo et al. 2009, Jones et al. 2007).

Agricultural diffuse source run-off

Agricultural activities are described in Section 6.2.1 of this report.

Potential impacts of agricultural diffuse source run-off

Water pollution: nutrients

There is very little information on low-flow exports from rivers to coastal waters, nor the impacts. Work on flood plumes in coastal waters has shown some stimulation of algal growth following floods.

Direct measurements of nutrient export and their effect on marine waters are yet to be determined in NSW, but aerial photography and satellite imagery show distinct sediment-laden plumes immediately after floods. The OEH is currently examining the positive and negative effects of these plumes on coastal ecosystems. Existing research demonstrates clear dependencies (via stable isotopes) of commercially important marine species on land based sources of carbon (Connelly et al. 2009), along with strong correlations between prawn catches and riverine outflows and discharges (DPI 2014). Negative effects are more likely associated with toxicants, litter and microplastics that are carried within the plumes (see Water pollution: microplastics in Section *6.2.2 Point discharges*).

Impacts on marine wildlife in coastal environments, particularly in relation to algal blooms are described in section 6.2.1.

Water pollution: sediments

Sediments in run-off contribute to sedimentation and turbidity in coastal waters. Hossain and Eyre (2002) estimated that up to 99% of the suspended sediment input to the Richmond River estuary came from the catchment, and that 90% of this was transported in less than 5% of the year, during floods. The export of suspended sediments from estuary to coastal waters was dependent on the size of the flood; 47% was exported in a minor flood, but 88% was exported during a moderate flood. Intermittent estuaries can retain all exports when they are closed, but large floods that open entrances allow the export of the majority of inputs.

For more information, refer to Section 6.2.1.

Water pollution: toxicants

See Section 6.2.1 for further details.

Water pollution: salts

There are no data to assess this threat in the coastal regions.

Groundwater pollution

There are no data to assess this threat in NSW, but it is presumed by OEH to be minimal due to small relative volumes.

Deliberate introduction of animals and plants

Detail on the impact of pests and weeds on coastal and estuarine ecosystems and their management are described in section 6.2.1.

Competition and habitat disturbance

Widespread weeds such as bitou bush, glory lily, and *Juncus acutus* are significant threats to coastal ecosystems such as fore dunes, hind dunes, and threatened flora therein such as *Chamaesysce psammogeton*, *Sophora tomentosa* and *Senecio spathulatus*. In addition to widespread weeds, species that are new and emerging in NSW also pose a significant risk to estuarine and coastal ecosystems. For example, sea spurge (*Euphorbia paralias*) and *Asystasia gangetica*, which grow in coastal sands and have the potential to spread widely and alter fore and hind dune ecosystems (NSW Department of Primary Industries, Parks, Water and Environment Tasmania, n.d.).

8.2.2 POINT DISCHARGES

As detailed in Section 6.2.2, a point source is a single, identifiable source of pollution, such as a pipe or an outlet that discharges effluent from any premises.

Industrial discharges

The primary non-sewage industrial discharge to coastal waters is the saline discharge from the Sydney desalinisation plant. There are also significant discharges to Port Kembla, which, whilst enclosed, is directly connected to coastal waters.

Potential impacts of industrial discharges

Water pollution: hypersaline discharge

Hypersaline effluent is produced from the process of converting seawater to fresh water (desalination) by reverse osmosis. Hypersaline effluent is only discharged directly to shelf waters from the desalinisation plant at Kurnell in the Hawkesbury central region. It has been extensively monitored under EPA licences and the measurable impacts have been minor and localised.

Sewage effluent and septic run-off

Sewage is a water-carried waste, in solution or suspension, which is intended to be removed from a community. Virtually all of the sewage from NSW coastal towns is discharged to coastal waters. Sewage is primarily organic waste (which consists of nutrients and carbon) but also includes various human pathogens and large amounts of fresh water. If industrial trade waste is discharged to sewer, then the sewage can also include a wide range of industrial chemicals. This is primarily an issue in the central region.

Ocean outfalls

In NSW, the majority of treated sewage is discharged directly to the ocean. Most ocean outfalls discharge relatively small volumes of secondary treated sewage, but three Sydney outfalls discharge large quantities of primary treated sewage. There are more ocean outfalls in the central region and the south coast than north coast (Figure 102).

Potential impacts of effluent and septic run-off

Water pollution: nutrients

Outfalls are an obvious source of nutrients to coastal regions, but few impacts have been observed in adjacent waters. For example, Roberts and Scanes (1999) demonstrated very little effect of discharge from small treatment plants on algae and benthic invertebrates of shallow rocky reefs of the NSW central coast. Krogh (2000) documented each ocean outfall on the NSW coast and compiled all information available at the time, including documented effects on surrounding ecosystems. Overall, the study found that effects were relatively minor and limited to the immediate surroundings of the outfall. In all cases, limits for effluent quality and volume were set and monitored through licences.

Recreational water quality on beaches, including in marine parks, is monitored through the ongoing Beachwatch program[70]. Beachwatch concludes the main driver of microbial pollution to coastal waters is urban run-off after rain (Beachwatch 2016). Results of the Beachwatch program are summarised in the section on urban stormwater discharge.

Water pollution: *toxicants*

If toxicants are present in coastal waters, they will have similar consequences to toxicants in stormwater. Sampling of the large deepwater outfall off Sydney did not show any measurable impacts of toxicants, nor has the monitoring around smaller coastal outfalls on the north and south coast.

The potential impacts of point discharges on wildlife have been poorly studied in NSW. Manning et al. (2008) found levels of levels of polychlorinated dibenzo-p-dioxins and furans (PCDD/PCDFs) to be high enough to reduce the breeding success of white-bellied sea-eagles (*Haliaeetus leucogaster*) at Homebush Bay.

Testing by the National Dioxins program (Corell and Muller 2004) found that PCDD/PCDFs and PCBs contribute equally to the toxic load in birds and terrestrial mammals, while for marine mammals, PCBs contribute >90% of the toxic load in dolphins and seals, and >80% in whales. Based on a very small dataset and limited toxicity information, a potential risk is indicated for dolphins living near urban or industrial estuaries.

These dolphins had higher toxic equivalents in their bodies than mammals living in the open ocean, and the levels were within the threshold range of toxicity reference values found to cause toxic effects in laboratory and semi-field studies with species found overseas. The risks to dolphins in other regions and dwelling in the open ocean are not known, though open-ocean species were found to have low levels of dioxins in their bodies (Gatehouse 2004).

Water pollution: microplastics

See Section 6.2.2 for further details.

[70] http://www.environment.nsw.gov.au/beachapp/default.aspx

Figure 102. Approximate locations of ocean sewage outfalls on the New South Wales coast.

Impacts of the Boulder Bay outfall, near the southern limits of the Port Stephens-Great Lakes Marine Park, showed minor and localised effects of discharge on some fish species on shallow rocky reefs (Roberts et al. 1998, Smith and Suthers 1999). The disappearance from the Sydney region within the last half century of the cray-weed (*Phyllospora comosa*) has been suggested to be related to poor water quality in the region due primarily sewage discharges (Coleman et al. 2008).

More general threats of eutrophication (nutrient enrichment leading to algal blooms) were investigated in the late 1990s. Studies found that natural upwelling processes, not sewage effluent or river discharges, were associated with major visible blooms (Pritchard et al. 2001).

Water pollution: pathogens

Pathogens can infect humans through contaminated fish and shellfish, skin contact or ingestion of water.

8.2.3 HYDROLOGIC MODIFICATIONS

Entrance training is primarily carried out on systems that experience significant shoaling of the estuarine entrance (e.g. wave-dominated riverine estuaries, coastal lakes and coastal lagoons). More detail is provided in Section 6.2.3.

Potential impacts of hydrologic modifications

Physical effects

Training walls can prevent natural longshore movement of sand, resulting in widening of beaches at the downflow (usually southern) wall and erosion at the northern wall. This can have implications for beach and dune ecology as it changes the natural dynamics and processes, but at a local scale.

Wildlife disturbance

The impacts of estuary entrance modification on wildlife in coastal environments are similar to in estuaries (see section 6.2.3 for detail).

Natural processes of sand transport to and from beaches and dunes may be modified by artificial entrance modification, particularly by the installation of training walls which can cause a widening of beaches at the southern wall and erosion at the northern wall. Subsequent changes in beach morphology can impact resident communities, and restrict or degrade shorebird nesting and roosting habitat and impede breeding success, particularly those that nest in low dunes including little terns and hooded plovers (NSW National Parks and Wildlife Service 2003, Harris and Dunn 2010).

8.3 CLIMATE CHANGE

The impacts of climate change on the NSW marine estate on the environmental assets of estuaries have been described in detail in Section 6.3 of this report. A broader overview of the key components of climate change in relation to the marine environment is presented in Section

The key stressors associated with climate change and their influence on the environmental assets of the open coast and continental shelf are discussed below.

8.3.1 ALTERED OCEAN CURRENTS AND NUTRIENTS

Continued global ocean warming will penetrate from the surface to the deep ocean and affect ocean circulation. Globally, there has been an observed increase in intensity of western boundary currents on continental east coasts (Cai et al. 2005), and a shift in isotherms that mark species thermal distribution limits (sen Gupta et al. 2015). These are largely associated with increasing wind stress curl spinning up the subtropical gyres in each ocean basin. Such effects have already been observed within south-east Australia, with the increased strength and southward penetration of the EAC (Ridgway 2007) and an increasing latitude of the EAC separation point (Cetina-Heredia et al. 2014). These trends are expected to increase and in the longer term impact on a number of coastal habitats, particularly shallow rocky reefs and planktonic assemblages (see relevant chapters in Poloczanska et al. (2012)).

The above changes, combined with increasing sea temperature, are considered responsible for the southward range extension of many species (Verges et al. 2014), including tropical fish and urchins (Booth et al. 2007, Figueira and Booth 2010, Ling et al. 2008). They are set to have further impacts on marine species in the future (Coleman et al. 2011, Cetina-Heredia et al. 2015, Coleman et al. 2017, Provost et al. 2017).

Analysis of long-term monitoring data offshore at Port Hacking reveals that EAC water has occurred at the 10 m reference site more often over the past 60 years. Over the same period, in addition to rising temperatures, silicate has declined while nitrate has increased (Thompson et al. 2009). This may be associated with the increasing EAC component of low-silicate tropical water, or also with decreasing export of silicate from coastal rivers. Such changes in nutrient ratios could shift phytoplankton composition and affect animals that eat plankton (e.g. fish larvae).

This increased EAC influence may first be evident and affect biodiversity within the Solitary Islands region by reducing representation of temperate biota, with corals and other tropical fauna likely to increase in abundance on coastal reefs (Verges et al. 2014; 2016). Despite a predicted increase in coral habitat in this area, warm EAC waters resulted in coral bleaching in this region in 2016 (Hughes et al. 2017). However, the EAC also influences inshore processes such as upwelling of cold water (Roughan and Middleton 2002; 2004), so there is some possibility that a stronger EAC could also result at times for colder water to be present inshore which may facilitate the persistence and act as refuges for colder water species (Lourenco et al. 2016).

The impact of altered ocean currents and nutrients on marine mammals, reptiles, and birds are described in 6.3.1 Climate change components Altered ocean currents and nutrients.

8.3.2 CLIMATE AND SEA TEMPERATURE RISE

Australia's temperate coast is predicted to continue warming, increasing by 1–3 ^{o}C over the next century, and extreme thermal events (e.g. marine heat waves) will increase (Hobday et al. 2016). There is growing information on the response of marine organisms to climate change within the region given recent anomalous events on both the east and west coasts (Wernberg et al. 2016, Verges et al. 2016, Hughes et al. 2017). distribution and temperature tolerance reflecting their northern or southern boundary of geographic range (Gillanders et al. 2011). For example, the current warming trajectories predict that several tropical fish species that appear seasonally along the coast will survive during winter as far south as Sydney by 2080, facilitating their possible expansion into NSW waters (Figueira and Booth 2010). There is increasing evidence of successful turtle nesting on the NSW north and central coasts. Early development of the purple sea urchin is retarded at sea temperatures predicted under climate change scenarios (Byrne et al. 2010). In contrast, cooler water species such as kelp and other seaweeds have (Wernberg et al. 2016) and are likely to continue to shift poleward as physiological limits are exceeded and trophic structures change.

Key habitats and associated biota likely to be affected in the longer term include beaches and shallow rocky reefs. Temperature increases (either gradual or extreme) will affect habitat formers, particularly seaweeds, along open coasts (Verges et al. 2016, Wernberg et al. 2016. Research on habitat-forming seaweeds common in the central region has shown that increased temperature can induce disease in seaweeds (Campbell et al. 2011) and experimental research demonstrates a change in seaweed microbiomes and induction of disease under future climatic scenarios (Qui et al. in review) . Further, studies on impacts of increased temperature on one of the most abundant habitat formers in the central region (*Ecklonia radiata*) show that genetic diversity within populations may be key for population resilience, and thus for entire ecosystem vulnerability (Wernberg et al. in review). Heat waves in Western Australia have caused extensive loss of kelp beds and associated species (Wernberg et al. 2012; 2016) and kelp has also declined in NSW (Verges et al. 2016).

Poleward contraction of kelp and other macroalgal habitats is a likely outcome of increased water temperatures or extreme thermal events (Smale and Wernberg 2013, Wernberg et al. 2016, Verges et al. 2017), and a reduction in kelp habitat and associated change in community composition and ecosystem function is expected, particularly in the northern NSW region, partly as a result of increased temperature (Verges et al. 2016, Provost et al. 2017. At present there are no published records of latitudinal shifts in the distribution of kelp in northern NSW due directly to climate change (although they are likely to have already occurred), although non-climate stresses (e.g. increased grazing, reduced water quality) are likely to already have had a considerable effect on kelp abundance and will result in considerable interactions that drive local variations in climate change induced responses (Coleman et al. 2008). Overall, there is clear evidence for impacts of climate change on marine macroalgae and temperate rocky reef organisms in Australia (see Wernberg et al. 2011, Wernberg et al. 2016, Verges et al. 2016).

With expected increased EAC influence in the northern NSW region, there is also potential for an increase in the prevalence of coral disease (Dalton and Smith 2006), and coral bleaching, which has been recorded in the Solitary Islands region (Dalton 2003, Edgar et al. 2003). In 2016, there was significant bleaching of coral at Solitary Islands and as far south as Sydney Harbour[71].

In general, the risk from climate and sea temperature rise to many of the coastal environmental assets will increase through time and impact on a number of coastal habitats, particularly shallow rocky reefs, beaches and many threatened and protected bird species (see relevant chapters in Poloczanska et al. (2012)).

In addition to the impacts outlined in section 6.3.1, temperature rise will also impact turtle nests on coastal beaches. Marine turtles are particularly vulnerable to climate change as the sex of hatchlings is determined by nest temperature and increasing temperatures (above ~29^{o}C during the 2nd third of incubation) are leading to a female bias in several nest sites around the world (Poloczanska et al. 2009). Increases in heat waves can also lead to more failed nests. As NSW is at the southern end of the nesting distribution for loggerhead and green turtles, it is an important climate change refuge for lower-temperature nest habitat that can produce males (Poloczanska et al. 2009). The ability of NSW to provide refuge habitat for nesting turtles will be dependent on the careful management of other threats to nesting habitat in the region, including foreshore development, light pollution, disturbance, predation, and inundation.

8.3.3 OCEAN ACIDIFICATION

There is growing information on the potential level of impacts of acidification on many species on the open coast, although much of this information comes from laboratory experiments. Species diversity and abundance will generally decrease, shifting to communities of non-calcifying organisms. Acidification also increases primary production and consumption by herbivores, as well as increasing energy required by carnivores when they hunt. These result in changes to trophic structures and an overall simplification of communities, with little evidence for adaptation to lower pH (Nagelkerken and Connell 2015). For example, under acidified conditions, kelp production is predicted to decrease (Britton et al. 2016), kelp competitors (turfing algae) are predicted to do better, but increased consumption may negate this effect (e.g. Ghedini et al. 2015). Field studies at naturally acidified sites indicate that indirect effects may play a greater role in determining calcifying species abundance than direct physiological effects (Connell et al. 2017).

Elevated carbon dioxide may affect marine organisms through changes to metabolic physiology, calcification rates of hard structures (e.g. shells, external skeletons) and flow-on effects through changes to food webs. Calcifying, sessile animals are the most vulnerable to ocean acidification (Parker et al. 2013, Ross et al. 2011), although indirect effects via species interactions may negate some impacts (Connell et al. 2017). A particularly vulnerable group is marine molluscs (e.g. oysters, abalone, whelks), most evident in their pelagic calcifying larval stages (Parker et al. 2010, Scanes et al. 2014a). Studies show that fertilisation may not be impacted (Byrne et al. 2010) but development may. Overall, a lower pH will likely impact on planktonic assemblages but empirical data is rare (Poloczanska et al. 2016).

Predicted changes in ocean acidification could further impact sandy beaches by reducing calcification rates in marine organisms (Feely et al. 2004), including several ocean beach crustaceans and molluscs (Hall-Spencer et al. 2008). Due to the regional scale changes in pH that are expected to occur, calcifying organisms across are a wide range of coastal habitats are likely to be impacted in the longer term.

The impact of altered ocean currents and nutrients on marine mammals, reptiles, and birds are described in section 6.3.1.

[71] http://www.abc.net.au/news/2016-04-19/coral-bleaching-found-in-sydney-harbour,-rising-sea-temperatures/7336826

8.3.4 ALTERED STORM AND CYCLONE ACTIVITY

A predicted increase in storm activity and associated changes in rainfall, storm surge and associated flooding along the east coast of Australia is expected to result in measurable impacts across a number of coastal habitats. This will occur though a range of stressors, many of which will interact, resulting in cumulative impacts.

On the NSW coast, many of the impacts will result from physical disturbance associated with east coast lows (intense low pressure systems). These will lead to:

- greater erosion, particularly on beaches
- increased nutrient and sediment inputs to coastal waters
- greater loads of plastics and other marine debris
- Greater and more frequent physical disturbance to the benthos

Developments in the region that are near current high-tide levels will be susceptible to more frequent storm, tidal, and ocean inundation. Communities currently susceptible to the combined effects of marine and catchment flooding will be further affected by sea-level rise; the scale of impacts will vary dependant on the vulnerability of each location. Details on rainfall projections are presented in section 6.3.

In addition to the impacts outlined in *6.3.1 Climate change components Altered storm and cyclone activity*, changing weather patterns will also impact turtle nests on coastal beaches through inundation and destruction of green and loggerhead turtle nests (Poloczanska et al. 2009). High rainfall can also make nest sites too moist to lay eggs and obscure the environmental conditions that signal females to nest (Poloczanska et al. 2009).

8.3.5 SEA-LEVEL RISE

Details about sea level rise predictions are presented in section 6.3. In general, sea level in the Sydney region is expected to rise 0.4 m and 0.9 m above the 1990 mean sea level by 2050 and 2100, respectively (DECCW 2010b). Sea level rise in combination with increased storms will increase coastal inundation and erosion. This will cause the erodible coastline to recede: typically 20–40 m by 2050, and 45–90 m by 2100. Shoreline retreat is very likely to occur on ocean beaches, and where beaches are backed by seawalls there is likely to be narrowing and loss of these areas (DECCW 2010b), and associated biota. While there is still uncertainty about the exact magnitude of physical changes resulting from global climate change (IPCC 2007), ecological responses (e.g. assemblage composition, range and distribution, species interactions) on ocean beaches are expected to occur (Brown and McLachlan 2002). In combination with more frequent and severe storms (IPCC 2007), sea level rise is likely to result in loss of habitat and displacement of species, particularly shorebirds. Rising sea level will have some impacts on rocky shore biota through changes in the availability of vertical and horizontal intertidal habitat, and change in composition of assemblages (Vaselli et al. 2008).

In addition to the impacts outlined in Section 6.3.1, sea level rise will also impact turtle nests on coastal beaches through inundation and destruction of nests and loss of nesting habitat (Poloczanska et al. 2009). Nest sites may be buffered from sea level rise where they can accrete naturally, but where beach movement is impeded by coastal development or topography, loss of nesting habitat is expected (Poloczanska et al. 2009).

9. ABBREVIATIONS

Abbreviation	Description
ACT	Australian Capital Territory
AF	Abalone Fishery
AMSA	Australian Maritime Safety Authority
ARA	appropriate regulatory authority
AWQG	Australian Water Quality Guideline
CPUE	Catch per unit effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DPI	NSW Department of Primary Industries
DSWP	diffuse source water pollution
EAC	east Australian current
EGF	Estuary General Fishery
EIS	environmental impact statement
ENSO	El Niño-Southern Oscillation
EP&A	*Environmental Planning and Assessment Act 1979*
EPA	Environment Protection Authority
EPBC	*Environment Protection and Biodiversity Conservation Act 1999*
EPTF	Estuary Prawn Trawl Fishery
FMA	*Fisheries Management Act 1994*
FMS	fishery management strategy
GPS	global positioning system
IMO	International Maritime Organization
IMOS	Integrated Marine Observing System
IPA	intertidal protected areas
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LF	Lobster Fishery
LML	legal minimum length
LSMP	Lobster Share Management Plan
MARPOL	International Convention for the Prevention of Pollution from Ships
MBT	monobutyltin
MEM	marine estate management
MEPC	Marine Environment Protection Committee
MPA	marine protected areas
NOAA	National Oceanic and Atmospheric Administration
NARCliM	NSW and ACT Regional Climate Modelling
NPI	National Pollution Inventory
NPWS	National Parks and Wildlife Service
NSW	New South Wales
OEH	NSW Office of Environment & Heritage
OHF	Ocean Hauling Fishery
OISAS	Oyster Industry Sustainable Aquaculture Strategy
OTF	Ocean Trawl Fishery
OTL	Ocean Trap and Line
PAH	polyaromatic hydrocarbons
PCB	polychlorinated biphenyl
POAA	Priority Oyster Aquaculture Areas
POMS	Pacific oyster mortality syndrome
RAC	Resource Assessment Class
RMS	Roads and Maritime Services
SUTS	sea urchin and turban shell
TAC	total allowable catch
TACC	total allowable commercial catch
TBT	tributyltin
TSCA	*Threatened Species Conservation Act 1995*
WQIP	water quality improvement plans

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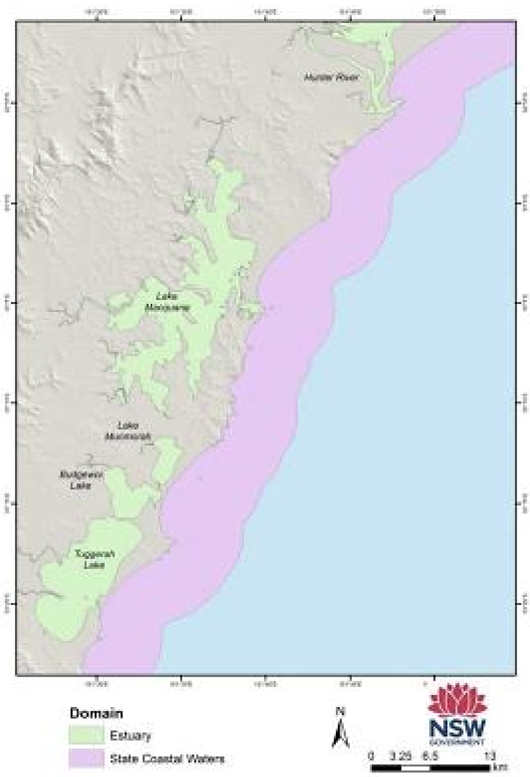
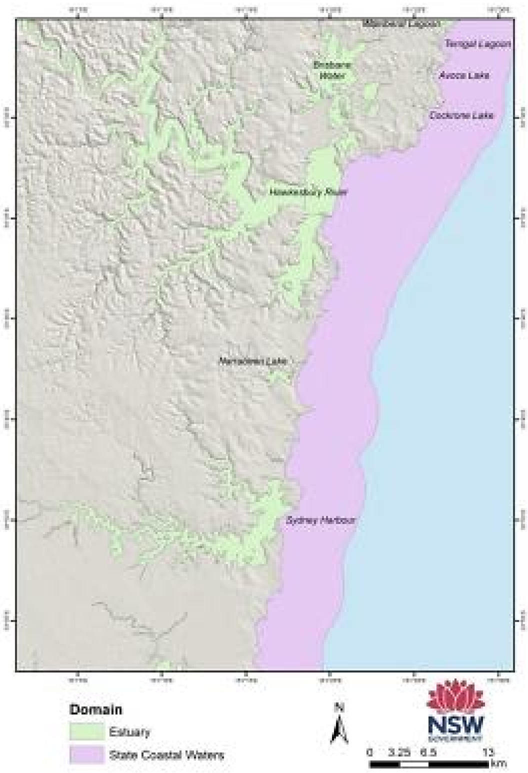
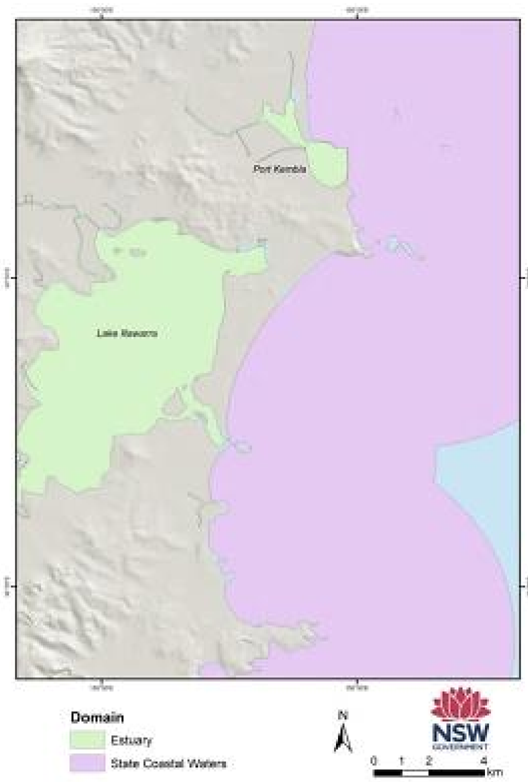
APPENDIX 1 - THE CENTRAL REGION (HAWKESBURY BIOREGION)

Showing the major estuaries and extent of coastal waters running from north (top right) to south (bottom left)






Botany Bay
Port Hacking
Domain
Estuary
State Coastal Waters
N
NSW
GOVERNMENT
0 1 2 4
km


Port Kembla
Lake Illawarra
Domain
Estuary
State Coastal Waters
N
NSW
GOVERNMENT
0 1 2 4
km

APPENDIX 2 - EXPLOITATION STATUS

The NSW Department of Primary Industries has developed the following scheme to classify the exploitation status of key species. At an annual Resource Assessment Workshop departmental scientists review the information available on all key species and determine an exploitation status for each species (or group of closely related species). Additional information on the framework utilised is available in the report: Scandol, J.P., 2004. A framework for the assessment of harvested fish resources in NSW. 96 pages. NSW Department of Primary Industries – Fisheries Resource Assessment Series No. 15 ISSN 1449-9940.

CATEGORY	CHARACTERISTIC
OVERFISHED	• Recruitment is being significantly suppressed as a result of a small spawning biomass (as determined by a population model or measured stock-recruitment relationship) • Fishing mortality rates are significantly greater than natural mortality rates • Estimates of spawning biomass are less than 20-30% of the estimated unfished spawning stock • The 'Spawning Potential Ratio' is less than 20-40% (depending on life history characteristics) • Catch rates are less than 30% of the initial catch rates • Length and age distributions unstable (excessively affected by recruitment, too few age or size classes in the exploitable population given a species' life history) • Trends in length/age compositions are evident which indicate increasing (and/or excessive) fishing mortality
GROWTH OVERFISHED	• Yield per recruit would increase if length at first capture was increased or fishing mortality decreased • A population model has determined that sustainable yield would increase if fishing mortality was decreased or size at first capture were increased
FULLY FISHED	• Fishing mortality is approximately the same as natural mortality • Estimates of the spawning biomass are greater than 30% of the estimated unfished spawning biomass • Catch rates have been steady for 5-10 years and/or catch rates are greater than 30% of initial catch rates • Length and age distributions are stable • Species are fished throughout their entire geographic range
MODERATELY FISHED	• Fishing mortality is less than half of natural mortality • Estimates of the biomass are greater than 70% of the estimated unfished biomass • Catch rates are greater than 70% of initial catch rates • Species are fished in most of their geographic range but non-fishing areas are known to exist • Markets may limit catch and effort
UNCERTAIN	• A significant amount of evidence has been collected and considered, but there are inconsistent or contradictory signals in the data that preclude determination of exploitation status
UNDEFINED	• Commercial catch data are available but no reasonable attempt has been made to determine exploitation status • Recreational species - some data are available but no reasonable attempt has been made to determine exploitation status

APPENDIX 3 – EXPLOITATION STATUS AND RESOURCE ASSESSMENT CLASS (RAC)

Exploitation status and Resource Assessment Class (RAC) for all species listed in the DPI Fisheries Resource Assessment System for 2011/12 to 2013/14. The exploitation status relates to those defined in appendix 2, and the Resource Assessment Class (RAC) indicates the level of assessment performed. A RAC shaded green denotes that the level of understanding about this species is at or above the target level, and those shaded red are below the target level. N/A denotes that the species was not assessed in that year.

Species	Stock Status					
	2011-12		2012-13		2013-14	
	RAC	Exploitation Status	RAC	Exploitation Status	RAC	Exploitation Status
Angel Sharks (*Squatina* spp.)	Five	Undefined	Five	Undefined	Three	Fully Fished
Australian Anchovy (*Engraulis australis*)	Four	Undefined	Four	Undefined	Four	Undefined
Australian Bonito (*Sarda australis*)	Two	Fully Fished	Two	Fully Fished	Two	Fully Fished
Australian Sardine (*Sardinops sagax*)	Three	Uncertain	Three	Uncertain	Three	Uncertain
Banded Morwong (*Cheilodactylus spectabilis*)	Four	Undefined	Four	Undefined	Four	Undefined
Banded Rockcod (*Epinephelus ergastularius*)	Three	Undefined	Three	Undefined	Three	Undefined
Bass Groper (*Polyprion americanus*)	Four	Undefined	Four	Undefined	Four	Undefined
Beachworms (Onuphidae)	Five	Undefined	Five	Undefined	Five	Undefined
Bigeyes (Priacanthidae)	Four	Undefined	Four	Undefined	Four	Undefined
Blacklip Abalone (*Haliotis rubra*)	Three	Uncertain	Three	Uncertain	Three	Uncertain
Blue Mackerel (*Scomber australasicus*)	Three	Moderately Fished	Three	Moderately Fished	Three	Moderately Fished
Blue Shark (*Prionace glauca*)	Four	Uncertain	Four	Uncertain	Four	Undefined
Blue Swimmer Crab (*Portunus armatus*)	Four	Uncertain	Four	Uncertain	Four	Uncertain
Blue-eye Trevalla (Centrolophidae)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Bluespotted Flathead (*Platycephalus caeruleopunctatus*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Boarfish (Pentacerotidae)	Four	Undefined	Four	Undefined	Four	Undefined
Brown Tiger Prawn (*Penaeus esculentus*)	Four	Undefined	Four	Undefined	Four	Undefined
Bugs (*Ibacus* spp.)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Catfish (Siluriformes)	Five	Undefined	Five	Undefined	Five	Undefined
Cobia (*Rachycentron canadum*)	Four	Undefined	Four	Undefined	Four	Undefined
Cockles (Arcoida and Veneroida)	Five	Undefined	Five	Undefined	Five	Undefined
Common Jack Mackerel (*Trachurus declivis*)	Four	Uncertain	Four	Uncertain	Three	Moderately Fished
Common Silverbiddy (*Gerres subfasciatus*)	Four	Uncertain	Four	Uncertain	Four	Uncertain

Appendix 3 continued

Species	Stock Status					
	2011-12		2012-13		2013-14	
	RAC	Exploitation Status	RAC	Exploitation Status	RAC	Exploitation Status
Crimsonband Wrasse (*Notolabrus gymnogenis*)	Three	Uncertain	Three	Uncertain	Three	Uncertain
Cunjevoi (*Pyura stolonifera*)	Four	Undefined	Four	Undefined	Four	Undefined
Cuttlefish (*Sepia* spp.)	Five	Undefined	Five	Undefined	Five	Undefined
Dart (*Trachinotus* spp.)	Four	Undefined	Four	Undefined	Four	Undefined
Diamondfish (*Monodactylus argenteus*)	Four	Undefined	Four	Undefined	Four	Undefined
Dogfish (Squaliformes)	Five	Overfished	Five	Overfished	Five	Overfished
Dusky Flathead (*Platycephalus fuscus*)	Three	Fully Fished	Three	Uncertain	Three	Uncertain
Eastern Australian Salmon (*Arripis trutta*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Eastern Blue Groper (*Achoerodus viridis*)	Four	Undefined	Four	Undefined	Four	Undefined
Eastern King Prawn (*Melicertus plebejus*)	One	Growth Overfished	One	Growth Overfished	One	Growth Overfished
Eastern Pigfish (*Bodianus unimaculatus*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Eastern Red Scorpionfish (*Scorpaena cardinalis*)	Two	Fully Fished	Two	Fully Fished	Three	Undefined
Eastern Rock Lobster (*Jasus verreauxi*)	One	Fully Fished	One	Fully Fished	One	Fully Fished
Eastern School Whiting (*Sillago flindersi*)	One	Fully Fished	One	Fully Fished	One	Fully Fished
Eastern Sea Garfish (*Hyporhamphus australis*)	Two	Overfished	Two	Overfished	Two	Fully Fished
Estuary Perch (*Macquaria colonorum*)	Three	Undefined	Three	Undefined	Three	Undefined
Flounders (Paralichthyidae and Pleuronectidae)	Four	Undefined	Five	Undefined	Five	Undefined
Frigate Mackerel (*Auxis thazard*)	Four	Undefined	Four	Undefined	Four	Undefined
Gemfish (*Rexea solandri*)	One	Overfished	One	Overfished	One	Overfished
Ghost Nipper (*Trypaea australiensis*)	Four	Undefined	Four	Undefined	Four	Undefined
Ghostsharks (Chimaeriformes)	Four	Undefined	Four	Undefined	Four	Undefined
Giant Mud Crab (*Scylla serrata*)	Three	Uncertain	Three	Uncertain	Three	Uncertain
Goatfish (Mullidae)	Four	Undefined	Four	Undefined	Four	Undefined
Goldspot Mullet (*Liza argentea*)	Three	Uncertain	Three	Uncertain	Three	Uncertain

Appendix 3 continued

Species	Stock Status					
	2011-12		2012-13		2013-14	
	RAC	Exploitation Status	RAC	Exploitation Status	RAC	Exploitation Status
Gould's (Arrow) squid (*Nototodarus gouldi*)	Five	Undefined	Five	Undefined	Three	Fully Fished
Greentail Prawn (*Metapenaeus bennettae*)	Four	Undefined	Four	Undefined	Four	Undefined
Grey Morwong (*Nemadactylus douglasii*)	Two	Overfished	Two	Overfished	Two	Overfished
Gummy Shark (*Mustelus antarcticus*)	One	Fully Fished	One	Fully Fished	One	Fully Fished
Hairtail (*Trichiurus lepturus*)	Four	Undefined	Four	Undefined	Four	Undefined
Hammerhead Sharks (*Sphyrna* spp.)	Five	Undefined	Five	Undefined	Five	Undefined
Hapuku (*Polyprion oxygeneios*)	Four	Undefined	Four	Undefined	Four	Undefined
Jackass Morwong (*Nemadactylus macropterus*)	One	Fully Fished	One	Fully Fished	One	Fully Fished
John Dory (*Zeus faber*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Leatherjackets-other (Monacanthidae)	Five	Undefined	Five	Undefined	Five	Undefined
Loligo Squid (*Uroteuthis* species)	Three	Undefined	Five	Undefined	Five	Undefined
Longtail Tuna (*Thunnus tonggol*)	Four	Undefined	Four	Undefined	Four	Undefined
Luderick (*Girella tricuspidata*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Mackerel Tuna (*Euthynnus affinis*)	Four	Undefined	Four	Undefined	Four	Undefined
Mahi Mahi (*Coryphaena hippurus*)	Four	Undefined	Four	Undefined	Four	Undefined
Mako Sharks (*Isurus* spp.)	Four	Undefined	Four	Undefined	Four	Undefined
Mangrove Jack (*Lutjanus argentimaculatus*)	Four	Undefined	Four	Undefined	Four	Undefined
Mantis Shrimps (Stomatopoda)	Four	Undefined	Five	Undefined	Five	Undefined
Mirror Dory (*Zenopsis nebulosus*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Mulloway (*Argyrosomus japonicus*)	Three	Overfished	Three	Overfished	Two	Overfished
Ocean Jackets (*Nelusetta ayraudi*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Ocean Perch (Sebastidae)	Three	Uncertain	Three	Fully Fished	Three	Fully Fished
Octopus (*Octopus* spp.)	Five	Undefined	Five	Undefined	Five	Undefined
Pearl Perch (*Glaucosoma scapulare*)	Two	Uncertain	Three	Uncertain	Three	Uncertain
Pink Ling (*Genypterus blacodes*)	N/A	N/A	One	Uncertain	One	Uncertain
Pipi (*Donax deltoides*)	Three	Uncertain	Three	Uncertain	Three	Uncertain

Appendix 3 continued

Species	Stock Status					
	2011-12		2012-13		2013-14	
	RAC	Exploitation Status	RAC	Exploitation Status	RAC	Exploitation Status
Red Gurnard and Latchets (Triglidae)	Four	Undefined	Four	Undefined	Four	Undefined
Red Morwong (*Cheilodactylus fuscus*)	Four	Undefined	Four	Undefined	Four	Undefined
Redfish (*Centroberyx affinis*)	Three	Growth Overfished	Three	Growth Overfished	Three	Growth Overfished
River Eels (*Anguilla* spp.)	Five	Undefined	Five	Undefined	Five	Undefined
River Garfish (*Hyporhamphus regularis ardelio*)	Three	Uncertain	Three	Uncertain	Three	Uncertain
Rock Blackfish (*Girella elevata*)	Five	Undefined	Five	Undefined	Five	Undefined
Royal Red Prawn (*Haliporoides sibogae*)	Three	Moderately Fished	Three	Moderately Fished	Three	Moderately Fished
Sand Mullet (*Myxus elongatus*)	Three	Undefined	Three	Undefined	Three	Undefined
Sand Whiting (*Sillago ciliata*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Sawsharks (*Pristiophorus* spp.)	Five	Undefined	Five	Undefined	Five	Undefined
School Prawn (*Metapenaeus macleayi*)	One	Fully Fished	Three	Fully Fished	Three	Fully Fished
School Shark (*Galeorhinus galeus*)	One	Overfished	One	Overfished	One	Overfished
Sea Mullet (*Mugil cephalus*)	Two	Fully Fished	Two	Fully Fished	Two	Fully Fished
Green Sea Urchin (*Heliocidaris erythrogramma*)	Five	Undefined	Three	Undefined	Three	Uncertain
Purple Sea Urchin (*Centrostephanus rodgersii*)	Five	Undefined	Three	Undefined	Three	Moderately Fished
Red Sea Urchin (*Heliocidaris tuberculata*)	Five	Undefined	Three	Undefined	Three	Uncertain
Shovelnose Rays (Rajiformes)	Five	Undefined	Five	Undefined	Five	Undefined
Silver Sweep (*Scorpis lineolatus*)	Three	Uncertain	Three	Uncertain	Three	Uncertain
Silver Trevally (*Pseudocaranx georgianus*)	Three	Growth Overfished	Three	Growth Overfished	Three	Growth Overfished
Snapper (*Pagrus auratus*)	Two	Growth Overfished	Two	Growth Overfished	Two	Growth Overfished
Soles (Soleidae and Cynoglossidae)	Four	Undefined	Four	Undefined	Four	Undefined
Southern Calamari (*Sepioteuthis australis*)	Four	Undefined	Four	Undefined	Three	Fully Fished
Southern Maori Wrasse (*Ophthalmolepis lineolatus*)	Two	Moderately Fished	Four	Undefined	Four	Undefined
Spanish Mackerel (*Scomberomorus commerson*)	One	Fully Fished	One	Fully Fished	One	Fully Fished

Appendix 3 continued

Species	Stock Status					
	2011-12		2012-13		2013-14	
	RAC	Exploitation Status	RAC	Exploitation Status	RAC	Exploitation Status
Spanner Crab (*Ranina ranina*)	Two	Fully Fished	Two	Fully Fished	Two	Fully Fished
Spotted Mackerel (*Scomberomorus munroi*)	One	Fully Fished	One	Fully Fished	One	Fully Fished
Stout Whiting (*Sillago robusta*)	Two	Fully Fished	Two	Fully Fished	Two	Fully Fished
Striped Grunters (Terapontidae)	Four	Undefined	Four	Undefined	Four	Undefined
Striped Marlin (*Tetrapturus audax*)	Two	Uncertain	Two	Uncertain	One	Fully Fished
Tailor (*Pomatomus saltatrix*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Tarwhine (*Rhabdosargus sarba*)	Three	Uncertain	Three	Uncertain	Three	Uncertain
Teraglin (*Atractoscion aequidens*)	Three	Uncertain	Three	Uncertain	Three	Uncertain
Tiger Flathead (*Neoplatycephalus richardsoni*)	One	Fully Fished	One	Fully Fished	One	Fully Fished
Tiger Shark (*Galeocerdo cuvier*)	Four	Undefined	Four	Undefined	Four	Undefined
Tilefish (*Branchiostegus* spp.)	Three	Undefined	Three	Undefined	Three	Undefined
Trumpeter Whiting (*Sillago maculata*)	Three	Undefined	Three	Undefined	Three	Uncertain
Turban Shells (*Turbo torquatus, Turbo imperialis, Turbo undulatus*)	Five	Undefined	Five	Undefined	Five	Undefined
Whaler Sharks (*Carcharhinus* spp.)	Five	Undefined	Five	Undefined	Five	Undefined
Whitebait - Sandy Sprat (*Hyperlophus vittatus*)	Three	Undefined	Three	Undefined	Three	Undefined
Wobbegong Sharks (*Orectolobus* spp.)	Three	Undefined	Three	Undefined	Three	Undefined
Yellowfin Bream (*Acanthopagrus australis*)	Three	Fully Fished	Three	Fully Fished	Three	Fully Fished
Yellowfin Tuna (*Thunnus albacares*)	One	Fully Fished	One	Fully Fished	One	Fully Fished
Yellowtail Kingfish (*Seriola lalandi*)	Two	Growth Overfished	Three	Growth Overfished	Three	Growth Overfished
Yellowtail Scad (*Trachurus novaezelandiae*)	Two	Fully Fished	Two	Fully Fished	Two	Fully Fished

APPENDIX 4 – CONSERVATION STATUS AND KEY THREATS TO SHOREBIRD SPECIES

Common name	Scientific name	Conservation status (NSW TSC Act 1995)	Habitat	Key threatening process (KTP)
Beach stone-curlew	*Esacus magnirostris*	Critically endangered	Rocky reef, beaches and estuaries	Human disturbance, coastal development, predation by the European Red Fox, *Vulpes vulpes* (KTP) and predation, habitat destruction, competition and disease transmission by Feral Pigs, *Sus scrofa* (KTP)
Little tern	*Sterna alibfrons*	Endangered	Sandy beaches and near estuary mouths or adjacent to coastal lakes	Human disturbance, predation by the European Red Fox, *Vulpes vulpes* (KTP) and other introduced species, coastal development, alteration to the natural flow regimes (KTP)
Hooded plover	*Thinornis rubricollis*	Critically endangered	Sandy beaches and rocky shore	Habitat loss, human disturbance, pollution, predation by the European Red Fox *Vulpes vulpes* (KTP), alteration to the natural flow regimes (KTP)
Pied oystercatcher	*Haematopus longisrostris*	Endangered	Ocean beaches and intertidal flats of inlets and bays	Human disturbance, predation by the European Red Fox, *Vulpes vulpes* (KTP) and other introduced species, coastal development, decline of key food source (pipi), alteration to the natural flow regimes (KTP)
Broad billed sandpiper	*Limicola galcinellus*	Vulnerable	Estuarine sandflats, ocean beaches and bays	Coastal development, alteration to the natural flow regimes (KTP)
Black-tailed godwit	*Limosa limisa*	Vulnerable	Sheltered bays and estuaries	Alteration to the natural flow regimes (KTP), habitat loss
Great knot	*Calidris tenuirostris*	Vulnerable	Sheltered coastal and estuarine habitats	Habitat loss, human disturbance, predation by introduced species
Greater sand plover	*Charadrius leschenaulti*	Vulnerable	Ocean beaches and occasionally rock platforms	Coastal development, alteration to the natural flow regimes (KTP)
Lesser sand plover	*Charadrius mongolus*	Vulnerable	Ocean beaches, bays, rocky shore, and mangroves	Coastal development, alteration to the natural flow regimes (KTP)
Sooty oystercatcher	*Haematopus fuliginosus*	Vulnerable	Rocky shore and headlands, ocean beaches, and muddy estuaries	Habitat loss, human disturbance, predation by the European Red Fox, *Vulpes vulpes* (KTP) and other introduced species, anthropogenic climate change
Sanderling	*Calidris alba*	Vulnerable	Low beaches, rocky shore, and mudflats	Alteration to the natural flow regimes (KTP), pollution, human disturbance, coastal development
Terek sandpiper	*Xenus cinereus*	Vulnerable	Rocky pools and reef, coastal mudflats, estuaries	Human disturbance, coastal development, alteration to the natural flow regimes (KTP)