FISHERIES FINAL REPORT SERIES | NO. 146

Ecological Background to the Assessment of Shore-Based Recreational Fishing on Ocean Beaches and Rocky Headlands in Sanctuary Zones in Mainland NSW Marine Parks

Jordan, A & Creese, R

Published by the NSW Department of Primary Industries

Ecological Background to the Assessment of Shore-Based Recreational Fishing on Ocean Beaches and Rocky Headlands in Sanctuary Zones in Mainland NSW Marine Parks NSW DPI – Fisheries Final Report Series No. 146

First published September 2015

ISSN 2204-8669*

More information

A Jordan and R Creese, Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay, NSW 2315, Australia

www.dpi.nsw.gov.au

Cover image: NSW Department of Primary Industries

*Before July 2004, this report series was published by NSW Fisheries as the 'NSW Fisheries Final Report Series' with ISSN 1440-3544. Then, following the formation of the NSW Department of Primary Industries it was published as the 'NSW Department of Primary Industries – Fisheries Final Report Series' with ISSN 1449-9967. It was then published by Industry & Investment NSW as the 'Industry & Investment NSW – Fisheries Final Report Series' with ISSN 1837-2112. It is now published as the 'NSW Trade and Investment – Fisheries Final Report Series' with ISSN 2204-8669.

Contents

List of tables

List of figures

Acknowledgments

Thanks to the various staff in the Department of Primary Industries who assisted in the collation and presentation of the information presented in this report. In particular, Karen Astles for collating information on recreational fishing and its ecological effects, and providing details on resilience. Thanks to the marine park and compliance staff for providing valuable knowledge and assisting with the assessment of site characteristics and activities conducted in the marine park zones. Maps were produced with the assistance of Joe Neilson and Trudy Walford.

Thanks to NSW Department of Environment and Heritage staff, particularly Michelle Linklater, Tim Ingleton and Peter Davies, who provided spatial data on the distribution of nearshore habitats. This study was funded by the New South Wales Department of Primary Industries.

Non-technical summary

Ecological background to the assessment of shore-based recreational fishing on ocean beaches and rocky headlands in sanctuary zones in mainland NSW Marine Parks

Principal investigators: Alan Jordan and Bob Creese

Address: NSW Department of Primary Industries
Port Stephens Fisheries Institute
Locked Bag 1
Nelson Bay, NSW 2230
Tel: 02 4982 1232. Fax: 02 4982 1107

Objectives

To provide background ecological information to inform the assessment of risk on the effects of recreational shore-based line fishing on open ocean beaches and rocky headlands in NSW sanctuary zones. To also describe aspects of shore-based recreational fishing in NSW, its relevant ecological effects, and outline the approach used for assessing risk from this activity.

Key words

Recreational shore-based line fishing, ocean beaches, headlands, marine parks, sanctuary zone

Summary

An amnesty to allow recreational shore-based line fishing in certain NSW marine park sanctuary zones on mainland open ocean beaches and headlands was introduced by the NSW Government in March 2013. This report provides background ecological information on these habitats within NSW marine parks to inform the ecological risk assessment on the effects of shore-based recreational fishing, including spearfishing, on open ocean beaches and rocky headlands in NSW sanctuary zones. It also describes aspects of shore-based recreational fishing in NSW and its relevant ecological effects. The specific biophysical assets, key ecological features and broad social uses of each sanctuary zone included in the amnesty are also provided. The ecological assets assessed include intertidal and subtidal ocean soft-sediments (beaches) and rocky reefs (headlands), fish assemblages, and threatened fish and shorebird species associated with these habitats. The assessment methodology used to estimate the risk to these ecological assets is then outlined.

Firstly, beaches vary in type, length, habitat configuration, exposure and sediment composition, and are dynamic environments due to their exposure. Different beach types and environments within beach systems support characteristic faunal assemblages, which are determined to a large extent by the size of particles making up the sediment and the amount of detached algal material commonly found drifting in the surf zone. The composition of fishes on beaches changes along the NSW coast, with variety of fish species such as Australian salmon, sea mullet, sand whiting, yellowfin bream, tailor and several flathead and stingray species being common. An increasing number of tropical and subtropical species occurring along the north coast. Two threatened shark species (the grey nurse shark and white shark) occasionally move through the shallow waters along ocean beaches. Sandy beaches are also key foraging and roosting sites for shorebirds, including threatened species such as the little tern, pied oystercatcher and beach stone-curlew.

Intertidal and subtidal rocky reefs are common on the ocean coast of NSW, and their distribution and structure can vary greatly, depending on the dominant rock type, exposure and complexity. There are often distinct patterns of marine invertebrates, rockpool fishes and algae within intertidal rocky reef habitats, although there are local variations that are thought to be

determined by such things as exposure, wave action, patchiness in recruitment, and the history of disturbances. Rocky shores are also key habitats for threatened shorebirds, particularly the pied and sooty oyster catcher and osprey.

Shallow subtidal rocky reefs contain habitats known as fringe, turf, kelp, urchin barrens, ascidian and sponge, but there is considerable local variations in their extent. They also contain a diverse assemblage of fish and invertebrate species, which range from small cryptic residents through to transient species that move between reef systems. Abundant fish species include snapper, red morwong, yellowfin bream, luderick, rock blackfish (drummer), wobbegongs, 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 (for example, their distribution, habitat use, movement, and age and growth). The composition of fishes on shallow reefs changes along the NSW coast, with an increasing number of tropical and subtropical species occurring along the north coast. In addition, several threatened fish species are encountered on, or in waters adjacent to, rocky reefs along the NSW coast, including grey nurse shark, white shark and black rockcod.

The characteristics of the shore-based recreational catch along the NSW coast is described from statewide surveys conducted in the period 1999-2000. These surveys found that around 58% of inshore recreational catches are taken from ocean beaches and 42% from rocky headlands. The largest proportion of catch from ocean beaches was taken on the mid north coast and the Hunter regions, whilst the largest proportion of catch from rocky headlands was taken on the north coast and Hunter took. The proportion of catch from rocky headlands far exceeded the catch from ocean beaches from Sydney southward within NSW. The catch from shore-based fishing was dominated by bream (28%), tailor (24%) and whiting (10%), as well as small amounts of luderick and flathead. The specific component activities of shore-based recreational fishing are described, and are characterised as fishing effort (intensity), biomass removal (harvesting and discarding), physical damage (bait collecting, lost gear, trampling and pollutants, fish cleaning), and disturbance (threatened species, lost fishing gear).

The biophysical characteristics of the intertidal and nearshore subtidal habitats and key ecological features within the twenty five marine park sanctuary zones included in the amnesty are described. This includes detailed maps of seabed habitats for each zone, and a description of the zones ecological characteristics where available. The key social uses of each sanctuary zone are also presented, including their use as a scientific reference site. Overall, the habitat characteristics of the sanctuary zones vary from being exclusively ocean beach or rocky reef through to a complex mosaic of sand and reef habitats. This results in many zones containing several habitat types that reflect the local geomorphology. The extent of each habitat also varies between marine parks. For example, relative to the other marine parks the ocean beaches in Batemans Marine Park are generally small and have significant areas of adjacent rocky reef. In contrast, many sanctuary zones in other marine parks are dominated by rocky shore adjacent to subtidal sand habitats. The spatial distribution of the habitats are provided as a key input into the assessment of risk associated with recreational shore-based line fishing on each habitat type.

Finally, the risk analysis process is described, which involves several stages – risk identification, analysis and evaluation, following the establishment of the risk context. The risk analysis stage involves the estimation of the magnitude of potential consequences and the likelihood that those consequences will occur against the higher level objectives. The approach used to assess the ecological risks associated with shore-based recreational fishing in marine park sanctuary zones uses a qualitative risk assessment based on the ISO 31000 (2009) risk management system and the ISO HB 89-2012 guidelines on risk assessment techniques.

Introduction

Marine park zoning and the amnesty on recreational line fishing

NSW marine parks aim to conserve marine biodiversity, maintain ecological processes and provide for sustainable uses of the marine environment. The six marine parks in NSW cover 345,000 hectares, or around 34% of NSW coastal waters distributed across three of the five marine bioregions (Figure 1.1). These bioregions in NSW are, from north to south, Tweed-Moreton (overlapping with Queensland), Manning Shelf, Hawkesbury Shelf, Batemans Shelf and Twofold Shelf (overlapping with Victoria). Bioregional assessments that detail the ecological data used to inform the placement of these marine parks can be found in Breen et al. (2004, 2005) and Avery (2001).

They are currently managed under the *Marine Estate Management Act 2014*, with the principle management arrangement being zoning plans that outline what activities can be undertaken in different areas of the marine park. The four types of zones are sanctuary, habitat protection, general use and special purpose.

The Marine Estate Management (Management Rules) Regulation 1999 defines the objects of the sanctuary zone as:

(a) to provide the highest level of protection for biological diversity, habitat, ecological processes, natural features and cultural features (both Aboriginal and non-Aboriginal) in the zone, and

(b) where consistent with the above, to provide opportunities for the following activities:

- (i) recreational, educational and other activities that do not involve harming any animal or plant or cause any damage to or interference with natural or cultural features or any habitat,
- (ii) scientific research.

The goal was to establish a comprehensive, adequate and representative system of marine protected areas that includes a full range of marine biodiversity at ecosystem, habitat and species levels (NSW MPA 2001). Recreational fishing is not permitted in sanctuary zones, but is allowed in general use and habitat protection zones and in many special purpose zones, which are areas designated to manage specific activities such as aquaculture and maritime facilities or which have special cultural features (Table 1.1).

This report focuses exclusively on the sanctuary zones that occur on ocean beaches and ocean rocky headlands in mainland NSW marine parks. This is in response to the amnesty on shore-based recreational line fishing in these sanctuary zones announced in March 2013. The one exception where the amnesty does not apply is adjacent to a section of Burrewarra Point within the Burrewarra Point sanctuary zone in Batemans Marine Park. The amnesty does not apply to sanctuary zones located within estuaries or in embayments, such as inside Jervis Bay. Restrictions remain in marine park sanctuary zones around islands that cannot be reached by land. The amnesty also does not apply to Lord Howe Island Marine Park or to the 12 aquatic reserves in NSW. The extent and distribution of sanctuary zones are described as they are currently defined within the Marine Estate Management (Management Rules) Regulation 1999 (i.e. prior to the amnesty on shore-based recreational fishing in ocean beach and rocky headland sanctuary zones being declared).

Figure 1.1. NSW coastline showing bioregions and location of mainland marine parks.

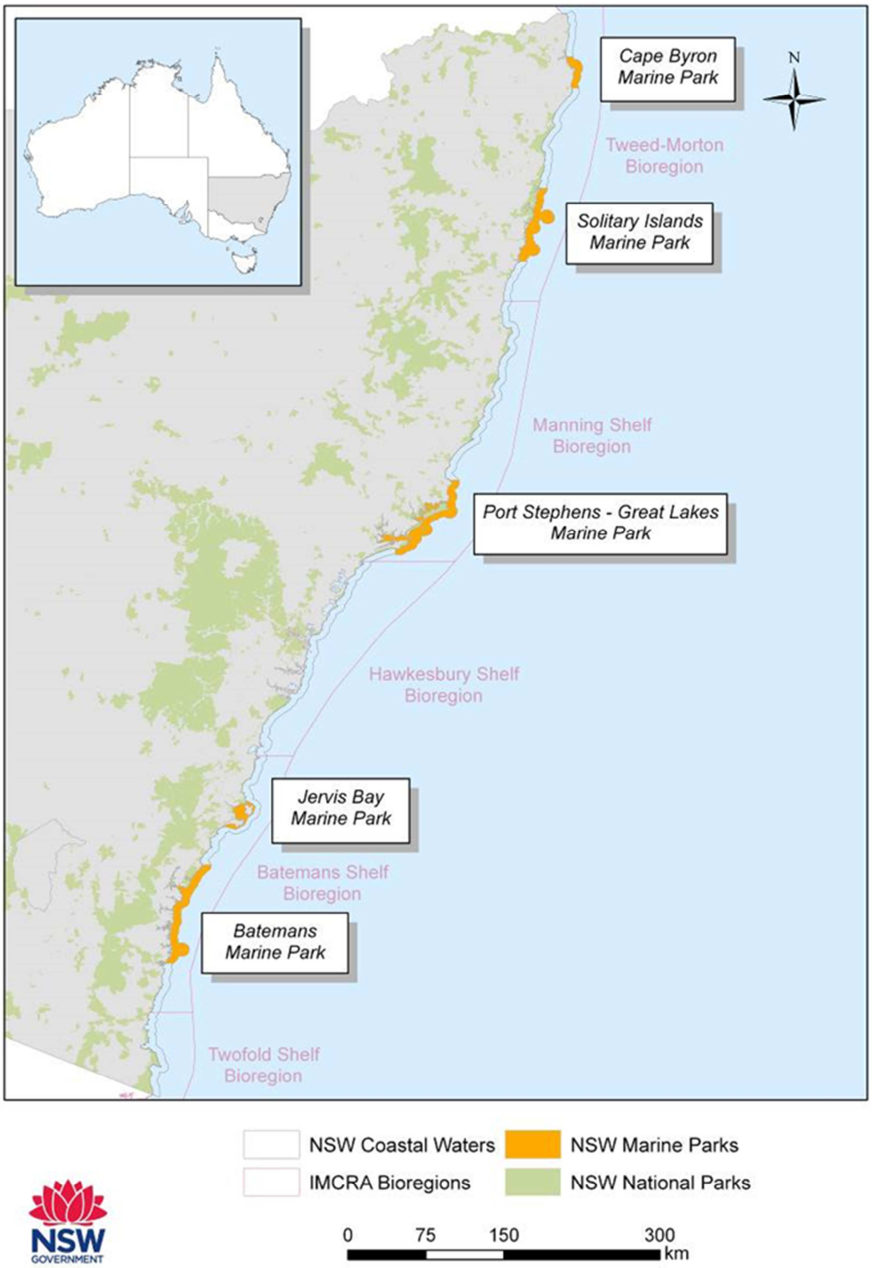


Table 1.1. Marine park zones showing where shore-based recreational fishing is permitted.
☑- permitted, ☒- not permitted, blank – not applicable.

Marine Park	General Use	Habitat Protection	Restricted habitat protection	Sanctuary	Special Purpose
Cape Byron	✔	✔		X	
Solitary Islands	✔	✔		X	
Port Stephens -Great Lakes	✔	✔		X	
Jervis Bay	✔	✔		X	
Batemans	✔	✔	X	X	X

Marine park features

Coastline

Excluding estuaries, ocean sanctuary zones occupy approximately 5% of the length of the NSW mainland coastline, at a total of around 87 kilometres. This means that, following declaration of the amnesty, over 95% of the NSW coastline remained open to shore-based recreational fishing. In practical terms, however, not all of this coastline is suitable for shore-based recreational fishing due to either lack of access, safety issues or other management restrictions. The ocean coastlines within the five NSW mainland marine parks have between approximately 12% and 23% within sanctuary zones, ranging from 11.0 to 34.5 kilometres in total length within a marine park (Figure 1.2). The minimum percentage of ocean coastline open to shore-based recreational fishing within the marine parks is 78% within Cape Byron Marine Park, and the maximum percentage is within Solitary Islands Marine Park at 88% (Figure 1.3). More detailed descriptions of the mainland marine parks and their ocean sanctuary zones are presented in Chapter 5.

Figure 1.2. Zoning arrangements in Cape Byron and Solitary Islands Marine Parks. Red areas indicate sanctuary zones that contain a shoreline section that is included in the amnesty.

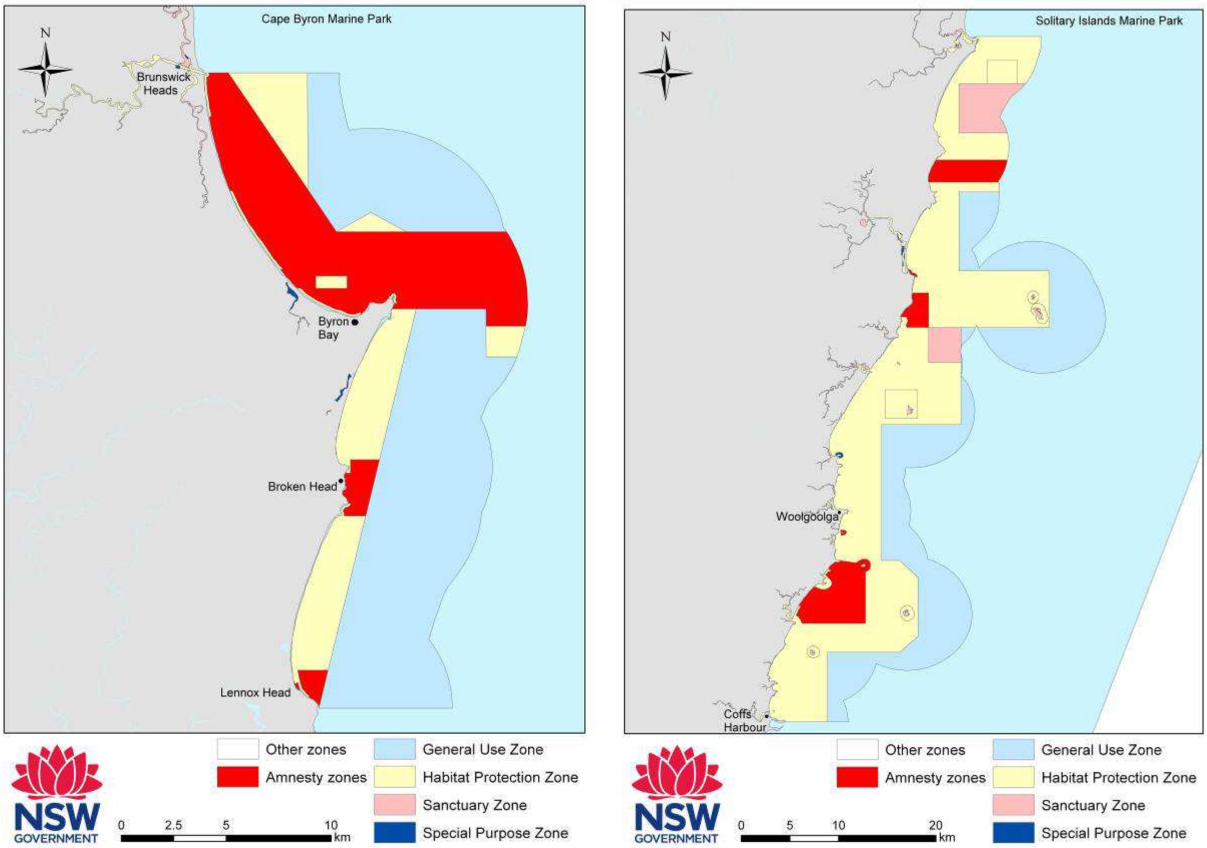
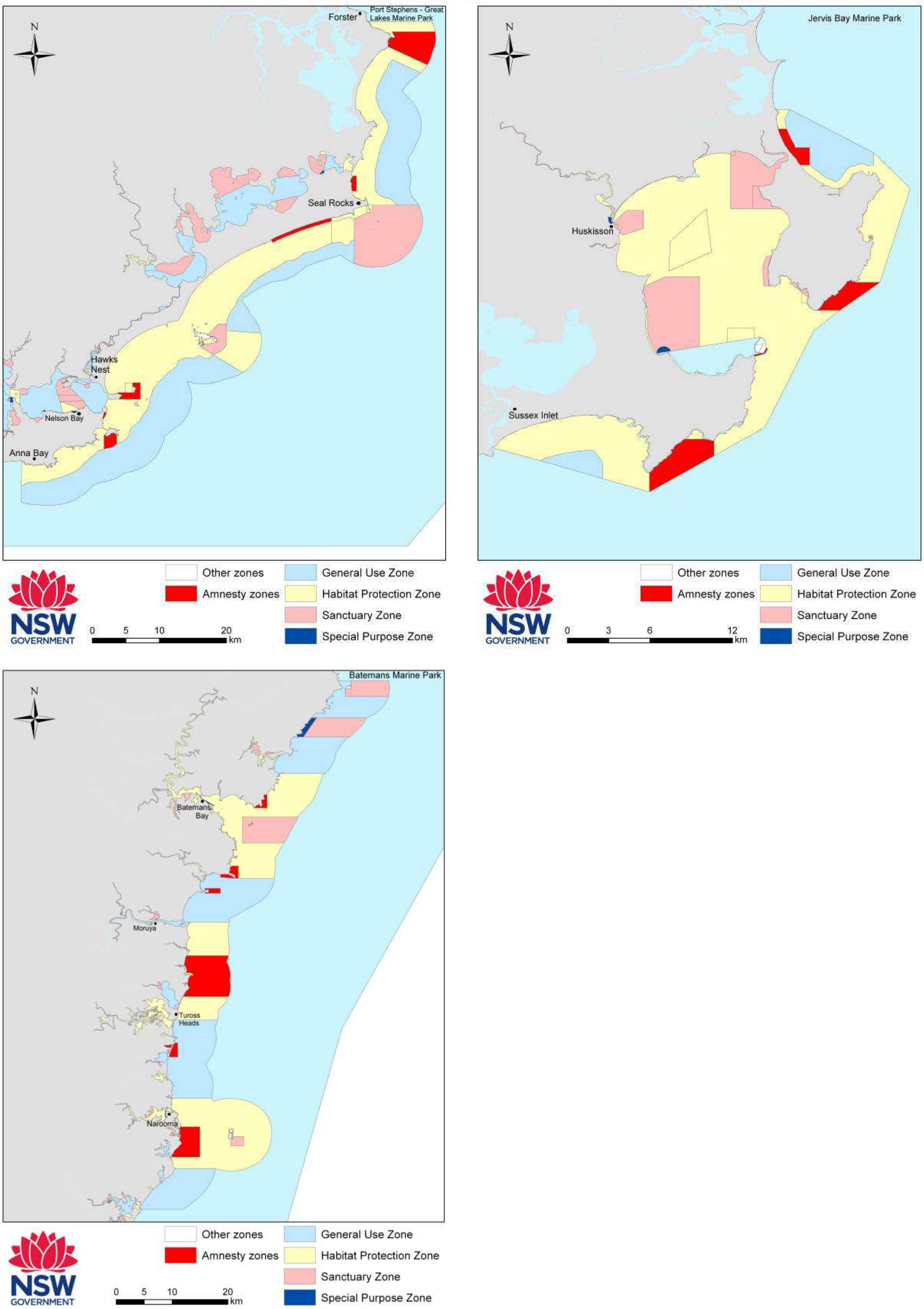


Figure 1.2 continued. Zoning arrangements in Port Stephens-Great Lakes, Jervis Bay and Batemans Marine Parks. Red areas indicate sanctuary zones that contain a shoreline section that is included in the amnesty.



Ocean beaches

Across all mainland marine parks there are 210 defined ocean beaches, of which 50 contain a sanctuary zone (Table 1.2). However, not all sanctuary zones that contain beach habitat have beaches for their entire length, hence these figures represent the proportion of beaches containing a sanctuary zone in all or part of them. The length of ocean beaches vary widely along the coast within marine parks, the largest being Mungo Beach in Port Stephens-Great Lakes Marine Park, and Tyagarah Beach in Cape Byron Marine Park at around 17 and 14 kilometres, respectively. In contrast, many beaches are less than 100 metres long, particularly in the Batemans Marine Park. The smallest percentage of ocean beaches within a marine park containing a sanctuary zone is approximately 13% (Jervis Bay), and the largest is 35% (Cape Byron) (Table 1.2). Overall, the total percentage of beaches in marine parks open to shore-based recreational fishing is approximately 76%. Not all of these ocean beaches may be suitable for shore-based recreational fishing, but marine park zoning is not restricting access to them.

Table 1.2. Number and percentage of ocean beaches within marine parks that contain (in part or whole) a sanctuary zone

Marine Park	Total number of beaches in marine park	Number of beaches in marine park in SZ	% of beaches with a SZ	% of beaches without a SZ
Cape Byron	17	6	35	65
Solitary Islands	40	7	18	82
Port Stephens	57	12	18	82
Jervis Bay	8	1	13	87
Batemans Bay	88	30	30	70
Total	210	56		

Headlands

Along most of the coast there are prominent rocky reef outcrops adjacent to most headlands, although there are also a number of significant reef systems that occur immediately offshore of ocean beaches in all regions. There are also many areas where intertidal and subtidal rocky reef occurs that is not associated with a distinct headland feature. Hence, across all mainland marine parks it is not possible to define the number or extent of ocean headlands. Similar to beaches, not all sanctuary zones that contain headland areas have rocky reef for their entire length. The number and length of ocean rocky reef habitat vary widely along the coast within marine parks reflecting the patterns of coastal bedrock geology and resistance to weathering.

The highest proportion of nearshore rocky reef relative to sanctuary zones occurs in the Batemans Marine Park and the smallest being in Cape Byron Marine Park. Overall, the total length of rocky reef habitat in marine parks open to shore-based recreational fishing is also greatest in Batemans Marine Park. Not all of these rocky nearshore areas may be suitable for shore-based recreational fishing, but marine park zoning is not restricting access to them.

Scope of ecological background to the risk assessment

The declaration of the amnesty was accompanied by a commitment to undertake an ecological risk assessment of shore-based line fishing in the affected sanctuary zones. Given that less than 5% of the NSW ocean coastline is within sanctuary zones, the assessment would be done on small and fragmented sections of the marine estate. In addition, the risk posed by shore-based recreational fishing to ocean sanctuary zones could only be assessed on a small but highly variable proportion of each individual sanctuary zone, i.e. not the whole sanctuary zone. This very narrow spatial context means that risk levels cannot be derived with a high degree of certainty.

This assessment was to be done exclusively on shore-based recreational fishing in ocean beach and rocky headland sanctuary zones, which includes line fishing and spearfishing methods. This activity was to be assessed in isolation from other human activities that can occur on ocean beaches and rocky headlands in, or adjacent to, the sanctuary zones, and irrespective of recreational fishing that might occur in adjacent zones from shore and/or boat. This narrow focus further increases the uncertainty around the assessment. Any activity on its own along a small portion of a coastline may appear to have little effect on habitats and fish assemblages but, in combination with other human pressures, it may still have negative consequences (e.g. Crain et al. 2009, Lewin et al. 2006).

This report provides background information on the key ecological assets of nearshore open ocean habitats in NSW (chapter 2), aspects of shore-based recreational fishing and relevant ecological effects (chapters 3-4), and an outline of the specific ecological assets, key ecological features and broad social uses of each sanctuary zone included in the amnesty (chapter 5). Lastly, the assessment methodology used to estimate the risk to the ecological assets is outlined (chapter 6). The assessment was done with guidance from the Marine Estate Expert Knowledge Panel using the principles developed by the Marine Estate Management Authority Principles paper (MEMA 2013).

Ecological assets of nearshore ocean environments in the NSW Marine estate

Introduction

The assessment relating to the amnesty on shore-based recreational fishing on ocean beaches and headland covers three key ecosystem components – marine habitats, assemblages of marine fish and listed threatened species of fish and birds that are associated with these habitats. Marine habitats are assessed as nearshore soft-sediments and rocky reefs containing both intertidal and subtidal sections.

The first level that seabed habitats are mapped throughout the NSW ocean environments are rocky reefs and soft-sediments. These two habitats can be accurately mapped using airborne and/or acoustic remote sensing methods as their boundaries are generally optically or acoustically distinct and can be discriminated at a fine spatial scale. The distribution, extent and structure of a number of seabed habitats at several hierarchical levels within NSW State Coastal waters were compiled for a series of bioregional assessment reports using existing broadscale bathymetric and marine sediment datasets, and seabed habitat data defined from previous single-beam and swath acoustic surveys and aerial photography. Shallow nearshore reefs (generally <15 metres depth) were digitised from aerial photographs, while intertidal rocky shores and beach habitats were derived from the intertidal zone present in the NSW cadastral layer, attributed with shore features referenced from NSW 1:25,000 topographic maps (see Breen et al. 2004, 2005). Subtidal habitats in depths generally >15 metres have been extensively mapped more recently using high resolution swath acoustics that provide geo-referenced bathymetry and acoustic backscatter that indicates harness and roughness of the seabed (see Jordan et al. 2010). In addition, underwater video surveys have allowed a description of the visually dominant sessile biota in order to broadly describe the distribution and composition of the dominant macrobiota. While the mapped classes are based on abiotic features, the most distinct separation of biotic assemblages occurs between rocky reef and soft-sediment habitats (Williams and Bax 2001). Hence, maps of shallow rocky reef and soft-sediment habitats used in the ecological risk assessment provide a surrogate for biological diversity in these habitats.

Ecological assets

Nearshore ocean soft-sediment habitats

The inner region of the continental shelf of NSW is characterised by a zone shoreward from ~60 metres water depth that contains a complex mosaic of soft-sediment and rocky reef habitats. This region contains both nearshore sands (generally found between 0-30 metres depth and shows a decreasing grain size with increasing water depth), and inner shelf gravels (patchily distributed between 20-60 metres depth). Ocean beaches contain both intertidal and subtidal components, and in NSW are exclusively wave-dominated beach types, which tend to be either moderately sloping (intermediate) or steeply-sloping (reflective), depending on their exposure to waves and swell. This strongly influences the type of sediments and presence of bars and rips, with sandbars, spits and beaches also changing in size and shape depending on wind and water flow (Short 1993). There are more than 700 beaches along the coast NSW coast varying in beach type, length, habitat configuration, exposure and sediment composition (Short and Woodroffe 2009). For example, many ocean beaches are interspersed with intertidal reef and contain subtidal rocky reef immediately offshore which reduces the exposure to swell and movement of sediment.

Different beach types and environments within beach systems support characteristic biotic assemblages, determined to a large extent by the size of particles making up the sediment. A higher diversity of intertidal species has been found on beaches with finer sands, while those with coarse sands tend to have fewer species (Hacking 1998, Brown and McLachlan 1990). The fauna of the lower beach may extend their distribution into and beyond the surf zone, into depths where the seabed is more stable (Schlacher et al. 2008). Detached macrophytic algal material, commonly found drifting in the surf-zone following heavy seas also supports characteristic assemblages of organisms different to those found on plants of nearby reefs.

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 includes: *Pseudolana elegans* (isopod), *Urohaustoriius gunni* (amphipod), *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) as they are often collected for bait by recreational anglers. There is also a diverse range of smaller species that live within the sediment, including algae and crustaceans that are an important part of the food chain in this habitat.

The shallow subtidal areas of sandy beaches are important spawning, nursery and feeding areas for a variety of fish species such as eastern Australian salmon *(Arripis trutta)*, sea mullet *(Mugil cephalus)*, sand whiting *(Sillago ciliata)*, yellowfin bream *(Acanthopagrus australis)*, tailor *(Pomatomus saltatrix)* and several flathead and stingray species. The composition of fishes on beaches varies along the NSW coast, with an increasing number of tropical and subtropical species occurring along the north coast. 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. 2013). Further information on species common in ocean beach habitats is detailed in Rowling et al. (2010) and references within. A summary of the key life-history characteristics of a number of the targeted species is presented in Appendix 1. Two threatened shark species (the grey nurse shark *Carcharias taurus* and white shark *Carcharodon carcharias)* occasionally move through the shallow waters along ocean beaches (see section 2.4).

Sandy beaches are also key foraging and roosting sites for a variety of shorebirds and seabirds, including threatened species such as the little tern, pied oystercatcher, and beach stone-curlew and those listed under international agreements such as the whimbrel and red-necked stint. Beaches are also important for nesting turtles, with records of both green *(Chelonia mydas)* and loggerhead turtles *(Caretta caretta)* nesting on some northern NSW beaches.

Nearshore ocean rocky reef habitats

The broad distribution of intertidal and subtidal rocky reefs on the ocean coast of NSW reflects the patterns of bedrock geology and resistance to weathering. Along most of the coast there are prominent rocky reef outcrops adjacent to most headlands, although there are also a number of significant reef systems that occur immediately offshore of ocean beaches in all regions (Jordan et al. 2010). While shallow subtidal reef habitats can be described by their dominant benthic biota, they have not been mapped at that level, although recent video mapping of subtidal reefs indicates it is possible over limited areas (Masens 2008). This reflects the fact that benthic communities can be highly variable at a range of spatial scales and often occur as a mosaic of habitats.

The geomorphic structure of rocky intertidal shores can vary greatly, depending on the dominant rock type (e.g. platform, cobble, boulder), exposure (e.g. protected, exposed) and slope (steep, inclined, flat) (Banks and Skilleter 2002). Rockpools and crevices and shallow gulches are also important areas as they generally retain seawater during low tide. 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.

There are often distinct patterns of marine invertebrates, rockpool fishes and algae within this habitat, although considerable temporal and spatial variations are common. These local variations in the distribution of organisms are thought to be determined by levels of exposure, wave action, complex biological interactions (competition, predation etc), patchiness in recruitment and the history of disturbances at individual sites (Underwood and Chapman 1995, Otway 1999). So, while there are general patterns of zonation of rocky shore plants and animals, there is a large amount of local variations, with many species occurring over different parts on the intertidal reef rather than in distinct and consistent zones. Rocky shores are also an important habitat for a range of birds, some of which are resident while others are migratory and appear annually.

While a considerable amount of research on the ecology of ocean intertidal reefs has occurred along the Sydney and adjacent coasts (e.g. Ponder et al. 2002 and references within, Gladstone et al. 2007), such habitats in northern and southern NSW have received far less attention (see Otway 1999). The rocky shores within the Solitary Islands region have been surveyed (Smith and Simpson 1990, 1991a, 1993, Smith and James 1999), and several small-scale projects have been conducted in the Byron Bay region (e.g. Bent 1990, Smith 1991, Smith and James 2003).

Shallow nearshore rocky reefs have been mapped along the NSW coast, although limited spatial information is available on the distribution of their dominant sessile biota. However, the habitat is known to contain the following broad habitats based on their dominant macrobiota, although there is considerable fine scale spatial variation in their extent:

- Fringe habitat – occurs just below low tide level to around a depth of 3 metres and contains a diverse range of algae, generally dominated by the brown algae *Phyllospora comosa* in the south and *Ecklonia radiata* in the north of the state. The habitat also includes turfing algae, several species of red and brown algae, and smaller amounts of coralline algae (Underwood et al. 1991). However, the algal species composition of the fringe habitat can vary, with some shallow reefs dominated by the *Dictyopteris muelleri*, with other macroalgae including Ulva, *Sargassum* and *Padina* also important components of the benthic cover (Bucher and Hartley 2004).
- Turf habitat – dominated by turfing coralline and filamentous algal species such as *Corallina* spp. and *Zonaria* spp., but often containing smaller amounts of other larger species such as *Sargassum.*
- *Phyllospora* habitat – dominated by the brown alga *Phyllospora comosa* and is mostly restricted to a narrow band adjacent to the intertidal zone (Underwood et al. 1991). A range of filamentous, turfing and crustose coralline algae are often present beneath the canopy, with the habitat present in waters south of around Port Stephens.
- *Ecklonia* habitat – this usually occurs at depths of more than 2 metres, and is characterised by a canopy of the brown macroalgae *Ecklonia radiata*, although some reefs contain other brown algal species (Kennelly 1995, Underwood et al. 1991). An understory consists of coralline algae and a diverse range of foliose algae. There are also sponges, ascidians and other sessile invertebrates, but these are not generally dominant.
- Barrens habitat – usually occurs at depths greater than 2 metres, and is devoid of macroalgae, with surfaces often covered with encrusting coralline algae and small numbers of sessile invertebrates. There is a strong correlation between the types and amount of algal cover and the abundance of the long-spine urchin *Centrostephanus rodgersii*, and the overall abundance of urchins at barrens sites strongly influences the assemblage of algal species found there. Such barrens have been estimated to cover around 50% of shallow rocky reefs along the central and southern NSW coast (Andrew and O'Neill 2000).

- *Pyura* habitat – this habitat is dominated by the large solitary ascidians *Pyura gibbosa* and *P. stolinifera,* with a small amount of filamentous and turfing algae.
- Sponge habitat – sponge-dominated assemblages often replace macroalgae as the dominant sessile assemblage in the deeper sections of shallow reefs. This is particularly evident in areas where walls, overhangs and caves provide suitable habitat, or as part of the understorey beneath the macroalgae. The distribution, ecology and taxonomic knowledge of sponges in NSW waters have been reviewed by Davis et al. (2010).

There are also small areas of habitat dominated by the large brown alga *Durvillaea potatum* that occurs in a narrow band in the immediate subtidal zone on the far south coast of NSW (Andrew and O'Neill 2000).

Overall, the species composition of algal assemblages is determined primarily by depth, exposure to swell, latitude, distance offshore and patterns of recruitment and grazing, and therefore varies within and between reefs. Further details on the presence of these shallow rocky reef habitats along the NSW coast are described in Chapter 6.

Nearshore subtidal rocky reefs also contain a diverse assemblage of fish and invertebrate species that range from small cryptic residents through to transient species that move between reef systems. Abundant fish species include snapper *(Pagrus auratus),* red morwong *(Cheilodactylus fuscus)*, yellowfin bream *(Acanthopagrus australis)*, bullseyes *(Pempheris compressus)*, luderick *(Girella triscupidata)*, rock blackfish *(Girella elevata),* wobbegongs *(Orectobolus ornatus)*, eastern blue groper *(Achoerodus viridis)*, and many species of wrasse and leatherjackets. Many pelagic migratory species also regularly occur on shallow reefs, including yellowtail kingfish *(Seriola lalandi)*, silver trevally *(Pseudocaranx georgianus)* and yellowtail scad *(Trachurus novaezelandiae)*. The composition of fishes on shallow reefs varies along the NSW coast, with an increasing number of tropical and subtropical species occurring along the north coast.

The habitat use and life history characteristics of key harvested coastal fishes in south-east Australia has recently been reviewed, and provides the most current summary from primary and grey literature (Curley et al. 2013). Reviewed species include luderick *(Girella tricuspidata),* eastern rock blackfish *(Girella elevata)*, yellowfin bream *(Acanthopagrus australis)*, tarwhine *(Rhabdosargus sarba)*, snapper *(Pagrus auratus)*, red morwong *(Cheilodactylus fuscus)* and eastern blue grouper (Achoerodus viridis). Further information on species common in shallow rocky reef habitats is detailed in Rowling et al. (2010) and references within. A summary of the key life-history characteristics of a number of the targeted species is presented in Appendix 1. In addition, several threatened fish species are encountered on, or in waters adjacent to, rocky reefs along the NSW coast (see section 2.4).

Ecological processes

Ecological processes affect the distribution and abundance of animals and plants (including algae), and include components such as recruitment, grazing (herbivory and filtering), predation, competition, growth, reproduction, decomposition and movement (Creese and Kingsford 1998). At larger ecosystem scales these processes can also be considered as ecosystem functions and/or services. Ecosystem functions are processes that play a vital or disproportionate role in functions that are necessary to maintain an ecosystem (e.g. nutrient cycling), while ecosystem services are processes that sustain and fulfil human life (Tallis and Kareiva 2005). Ecosystem functions and services have been categorised as provisioning (e.g. food and bait), regulating (prevention of erosion, flood control), supporting (nutrient cycling) and cultural (recreational and spiritual value). These functions and services can involve single or multiple processes and are often required to operate in conjunction with physical and chemical process (e.g. nitrogen cycling). Ocean beaches and rocky reefs provide a wide range of ecosystem functions and services (Connell 2007, Dittman 2007, Underwood and Chapman 2007), and these can differ considerably due to functional differences in the structure of benthic habitats, and patterns of human use.

Nearshore ocean soft-sediment habitats

Primary productivity is generally small on beaches because of the unstable nature of the sediment and substantial water-movement and wave-action which do not allow algae to grow and remain in place (Short and Jones 1995, Schlacher et al. 2008, Schlacher and Hartwig 2012). Microscopic algae do, however, live on and in the intertidal and subtidal sand on beaches and do contribute to primary production – providing food for some of the meiofauna (e.g. nematodes and copepods; Schlacher and Hartwig 2012) and macrofauna (e.g. crabs: Schlacher and Hartwig 2012). Phytoplankton are ubiquitous in the water close to shore and contribute to the productivity of the habitat, providing food for filter-feeders and deposit-feeders when they are washed ashore (Short and Jones 1995, Schlacher et al. 2008).

Due to the low primary productivity of beaches, the beach ecosystem is generally driven by the delivery of resources from the sea or land. These resources arrive in the form of particulate detritus, dissolved organic matter, carrion, stranded algae, or terrestrial plants arriving via run-off or as flotsam (Short and Jones 1995, Schlacher et al. 2008). The delivery of these concentrated nutrients is naturally sporadic, although the input of low concentrations of nutrients from the ocean is relatively consistent (Short and Jones 1995). The sporadic nutrient arrivals appear to be important in maintaining the diversity and abundance of a range of opportunistic invertebrates and fishes on and around beaches. The frequency and magnitudes of the input of carrion and macroalgae are highly important and play a critical role in regulating the biodiversity of these systems. The rapid break-down of the carrion and stranded macrophytes is one of the major ecosystem services occurring on beaches.

Scavengers are a major trophic group on beaches and play a substantial role in the break-down of organic material. Without the ecological processes carried out by the invertebrates on beaches the decomposition would take longer. These scavengers themselves become prey for other invertebrates, fishes and birds; and are used for bait by recreational anglers. Deposit feeders also contribute to the removal or cycling of organic material on beaches by indiscriminately ingesting sediment or selectively eating organic particles from sediments. Deposit feeders are, however, generally not common on ocean beaches (Short and Jones 1995).

Filter-feeders such as pipis are the major group of macroinvertebrates on beaches. They filter large volumes of seawater and remove particulate material, bacteria and phytoplankton, and are prey for fishes and crabs, and provide food and bait for people. Predation and recruitment are likely important ecological processes structuring the marine biodiversity on NSW ocean beaches. Predation by fishes, crabs and macroscopic invertebrates and humans can influence fluctuations in these assemblages. It is well-known that species such as pipis can have recruitment pulses or “good recruitment” years the abundances of species can become quite high and highly noticeable; while in bad years the abundances of species can wane greatly.

Predators are common on intertidal and shallow subtidal portions of beaches. Invertebrate predators such as polychaete worms and crabs can be abundant and highly active. They themselves can become prey for a range of fish (e.g. flathead, stingrays and stingarees) and bird predators (e.g. pied oyster catchers) who will also feed on filter-feeding bivalves and other infaunal invertebrates (Schlacher et al. 2008). Many fish such as sea mullet and sand whiting are prey for carnivorous fishes such as tailor, salmon, mulloway and sharks. These fish are also prey for birds foraging in these areas such as penguins and sea eagles.

Nearshore ocean rocky reef habitats

Primary productivity on shallow temperate rocky reefs and the overlying water is relatively high as macroalgal biomass on both intertidal and subtidal areas can be substantial, and provides the basis for a substantial food chain in these, and adjacent habitats (Steinberg and Kendrick 1999). Additionally, both phytoplankton and microalgae growing on most hard surfaces on the reefs are also important energy sources on rocky reefs. Nutrients necessary to enable the growth of micro- and macroalgae come into the reefs from the ocean – often from nutrient-rich water driven up from deep off the continental shelf by oceanographic processes such as upwelling (Suthers and Waite 2007) – or from terrestrial sources via creeks and rivers (Gillanders 2007). The generally clear water over the oceanic reefs means that sunlight can reach algae to depths of over 30 m which enables algae to grow rapidly (Steinberg and Kendrick 1999).

Macroalgae themselves provide habitat and shelter for invertebrates and fishes (Steinberg and Kendrick 1999). These animals range from microscopic species, such as copepods and amphipods, that inhabit the dense algal turfs and the extensive surfaces of kelp fronds, and the diverse assemblages of sponges, bryozoans and ascidians that inhabit the kelp holdfast, up to lobsters and kelp fish that inhabit the kelp forests for shelter, protection and food. Many of these species are not found on rocky reefs if macroalgae are not present and abundant.

The algae support a diverse and abundant range of grazers and detritivores (i.e. scavengers) (Steinberg and Kendrick 1999). Grazers such as urchins and limpets are well known to affect the distribution and abundance of algae on rocky reefs (Underwood and Chapman 2007). Subtidally, the black sea urchin *Centrostephanus rodgersi* is primarily responsible for 'barrens' areas which are generally devoid of macroalgae (Andrew and Constable 1999). Herbivorous fishes play a substantial role on intertidal and subtidal reefs. Their effects are not as pronounced as that of urchins (Steinberg and Kendrick 1999), and affect smaller patches of reef or target specific species of favoured algal food across entire reefs (e.g. luderick grazing on Ulva spp. Jones 1999a). These fishes are often highly abundant on reefs and make up a substantial portion of the fish biomass (Jones 1999a), with species such as luderick and rock blackfish being targeted specifically by recreational fishers at some locations.

Filter-feeders are diverse and, in some cases, the dominant organisms on rocky shores and reefs (Underwood and Kingsford 1991, Butler 1995, Keough 1999). These organisms filter large volumes of water and remove particulate material, bacteria and phytoplankton (Butler 1995, Gili and Coma 1998). They capture carbon and nitrogen from the surrounding water and provide food for people and bait for recreational anglers. Predation on filter-feeders can play an important role in structuring communities on rocky reefs (e.g. Underwood and Chapman 1999). Extraction by humans is also considered to be important and may have substantial effects (Underwood 1993, Underwood and Chapman 2007).

Predators are common on rocky shores and subtidal reefs, and are considered important in driving these systems (Duffy and Hay 2001). Invertebrate predators such as predatory whelks, starfish, crabs, lobsters and octopus can be abundant and highly active on rocky reefs (Underwood and Chapman 1995, Underwood and Chapman 2007). They themselves can become prey of octopus, fishes (e.g. wrasse, bream, snapper) and birds (e.g. sooty oyster catchers). Fish form a diverse array of predators on rocky reefs. There are fishes that feed on plankton (e.g. seahorses, mado, yellowtail scad) (Glasby and Kingsford 1999), small invertebrates such as amphipods and prawns (e.g. leatherjackets, morwong, bream) (Hutchins 1999, Lowry and Cappo 1999), sessile and sedentary invertebrates such as barnacles, gastropods and urchins (e.g. wrasses, Port Jackson sharks) (Henry and Gillanders 1999, Jones 1999b, Lincoln-Smith 1999, Lowry and Cappo 1999), and on other fishes (e.g. tailor, kingfish, snapper, wobbegong). Molluscan predators such octopus, cuttlefish and squid are also important predators on rocky reefs. Numerous bird predators, such as cormorants, penguins and sea eagles, commonly forage over rocky reefs for fishes. Human predation has also been documented to affect the ecology of these systems (Keough et al. 1993, Keough and Quinn 2000, Lowry and Suthers 2004, Barrett et al. 2007, Barrett et al. 2008, Stuart-Smith et al. 2008, Barrett et al. 2009) and concerns have long been raised about their impacts (Kingsford et al. 1991, Underwood 1993).

Impacts on ecological processes can have flow-on effects to multiple species and, in some case, ecosystems. 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 1999, Willis et al. 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 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). In Tasmania the removal of lobsters from subtidal reefs reduced the resilience of these ecosystems to invasion from the mainland urchin *Centrostephanus rodgersii* which has the potential to create widespread barrens instead of the previous kelp coverage on these reefs (Ling 2009). These studies indicate how impacts on target species may have indirect effects on other species which can then lead to ecosystem level changes (Babcock et al. 1999, Shears and Babcock 2002)

Threatened species

Threatened fish, including shark species in NSW are listed under the *Fisheries Management Act 1994,* while threatened marine mammals and reptiles are listed under the *Threatened Species Conservation Act 1995*. Several threatened fish and shark species may occur within nearshore ocean beach and reef habitats, including grey nurse shark *(Carcharias taurus)* (critically endangered), white shark *(Carcharodon carcharias)* and black rockcod *(Epinephelus daemelli)*.

Several threatened marine mammals and reptiles may be found in NSW coastal waters at differing times of the year, often passing through on migrations along the east coast. Many species are endemic to the subtropical east coast of Australia, or more broadly to the east coast or southern parts of Australia. The humpback whale *(Megaptera novaeangliae)* is the most commonly encountered of the seven whale or dolphin species listed as threatened under NSW and Commonwealth legislation.

All turtles are listed under State or Commonwealth legislation as threatened, and a national recovery plan for all species of sea turtles has been finalised. A number of threatened shoreline and seabird species commonly occur along the coast, such as the pied and sooty oystercatchers, osprey, beach stone-curlew and the little tern, which nest immediately above the high water mark. Seabirds are protected and managed under the *National Parks and Wildlife Act 1974* and the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999.* Migratory bird species that fly seasonally to breeding and reach feeding grounds pass through the marine parks and are present for only short periods each year. Some species, such as the little tern, wedge-tailed shearwater, whimbrel, eastern curlew and the red-necked stint may reside in the marine parks for part of the year to breed or feed. Of particular importance are the endangered little tern, the fleshy-footed shearwater (listed as vulnerable), and the wedge-tailed shearwater which has major nesting sites on islands in the marine park. Birds migrating between Australia and Japan, and Australia and China are protected under international agreements, the Japan–Australia Migratory Birds Agreement (JAMBA) and the China–Australia Migratory Birds Agreement (CAMBA). Under these agreements the NSW Government has a commitment to maintain populations of migratory waders and their habitats.

Grey nurse shark (*Carcharias taurus*)

Grey nurse sharks display high site fidelity and congregate at a number of sites along the inshore coastal waters of NSW and southern Queensland that are subject to significant recreational and commercial activity (NSW DPI 2001, 2013). These sites have rocky reef with gravel or sand filled gutters, overhangs or caves and are termed aggregation sites (NSW DPI

2013). Through a series of surveys along the entire NSW coast, 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, with seven of these key sites are already given high levels of protection through the inclusion into new and existing marine park sanctuary zones (NSW DPI 2002, 2012).

While these recognised critical habitats within marine parks are offshore and are not included in the beach and headland amnesty, grey nurse sharks participate in migration and frequently undertake excursions to adjacent reef habitats, aggregating in shallow gutters off the edge of rocky headlands in surrounding areas (Otway and Parker 2000, Otway et al. 2003, Otway and Ellis 2011). Individuals are susceptible to accidental hooking in these aggregation and movement between sites (NSW DPI 2011). The sanctuary zone at Burrewarra Point was excluded from the amnesty because of the known presence of grey nurse sharks at this site.

The length and extent of these movements vary depending on age, sexual maturity and stage in reproductive cycle (NSW DPI 2013). Pregnant females are known to migrate north to southern Queensland after mating in spring where they spend about 6 months at aggregation sites away from sexually mature males. The pregnant females migrate south to NSW waters and give birth in winter and early spring at various sites (NSW DPI 2013). These individuals then enter a one year resting period. With females producing on average, one live pup or less per year due to unusual instar-uterine cannibalism, this is potentially the lowest reproductive rate of any shark. As a result of this low fecundity (maximum 2 young biennially) and onset sexual maturity (6–8 years), there is a low potential for the population size to recover from decline and makes this species 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 as result of commercial fishing, recreational spear and game fishing, and shark control activities such as beach meshing (NSW Fisheries 2002). Hook and line fishing has been identified as the major threat to the species survival and largest source of this species mortality; causing approximately 12 known mortalities per annum (NSW DPI 2011). In response to this species' decline, grey nurse sharks were protected from fishing in NSW in 1984, with a 'critically endangered' status implemented since 2008 under the *Fisheries Management Act 1994* (NSW DPI 2013).

Black rockcod *(Epinephelus daemelii)*

Black rockcod, also known as black cod or saddled rock cod, is a large reef fish endemic to warm temperate and subtropical southwest Pacific waters of Australia to New Zealand and the Kermadec Islands (Choat et al. 2011, NSW DPI 2011, Harasti 2013). In Australia, this 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). Blackrock cod juveniles inhabit intertidal rock pools then move to deeper coastal waters as they mature (<50 metres), occupying caves, gutters and beneath bommies on rocky reefs (NSW DPI 2007, Harasti et al. 2013, Harasti and Malcolm 2013). Individuals are territorial and display high site fidelity, often residing in the same caves for the entirety of their lives (NSW DPI 2007). Black rockcod are slow growing protogynous hermaphrodites, first developing as sexually mature females then changing to males at around 100-110 centimetres and approximately 30 years old in New Zealand studies (NSW DPI 2007, Francis 2012, Harasti et al. 2013, Harasti and Malcolm 2013). In Australia, individuals have been recorded up to 1.5 metres total length and 81 kilograms, 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 based of little aging data of 65 years or greater (Hutchins and Swainston 1986, Harasti et al. 2013).

Black rockcod were once widespread along the NSW coast, although were heavily targeted by spearfishers during the 1950s through to the late 1970s (Harasti et al. 2013, Harasti and

Malcolm 2013). The removal of large 'trophy' fish by these fishers resulted in a reduction in males in various areas, unbalancing the sex ratio of local populations and ultimately impacting reproductive success (Harasti et al. 2013). These concentrated spearfishing efforts as well as overharvesting from line and net fishing captures, led to the extensive decline of their abundance. These fishing threats in conjunction with black rockcod's naturally vulnerable life history characteristics means any recovery of abundance and size structure is expected to be gradual (NSW DPI 2007, 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 *NSW Fisheries Management Act 1994* (NSW DPI 2007, 2011). While this species is protected from all fishing activities in state waters, accidental capture and hooking injuries still poses a threat to the population (NSW DPI 2007).

White shark *(Carcharodon carcharias)*

Great white sharks, also commonly known as white pointers or 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). This species is highly mobile, being capable of travelling large distances in a relatively short time but can remain in the same area for weeks or even months (NSW DPI 2005, Bruce et al. 2006).This distribution includes the coastal waters of NSW, with electronic tagging studies identifying one of the two important nursery areas for juvenile white sharks in eastern Australia in the Port Stephens region (Bruce and Bradford 2008, 2011, Bruce et al. 2013). 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 metres) in particular are known to occur close to shore which makes them vulnerable to by-catch in commercial and recreational fisheries, and by spending significant time in the surf zone, increases the risk of encounter with beach users (Weng et al. 2007, Lowe et al. 2012, 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 metres). Females give birth to relatively few live pups (between 4 and 10) that are fully developed and independent at birth, and measure between 120- 150 centimetres 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 environments, and their decline can have can have fundamental structural impacts on ecosystems through numerous top–down processes. In Australian waters, this species' numbers have been depleted over the last few decades as a result of the implementation of beach safety (shark) meshing nets on coastal beaches, by-catch in a range of commercial and occasionally recreational fisheries and prior to protection they were heavily targeted by gamefishers (NSW DPI 2005). Their natural rarity, low natural mortality, low reproductive rate and other life history characteristics make their populations highly vulnerable to the impacts of fishing. As a result of this decline and very low potential for population recovery, white sharks are now listed as a vulnerable species in NSW.

Shorebirds

Shorebirds are a fundamental component of coastal ecosystems, comprising of a large proportion of visible vertebrate fauna within estuarine, ocean beach and rocky shore environments (DECCW 2010). These coastline predators utilise a wide variety of coastal and inshore habitats for roosting and foraging activities. Preferred roosting locations are generally above the high water mark and frequently include structures like saltmarsh, sandy ocean beaches, sand bars and spits, mangroves, rock walls, rock platforms and oyster racks (DECCW 2010). These sites allow access to water, 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 2010). 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 2010).

Threats to shorebirds and their habitats are increasing as the human population increases along the coast (DECCW 2010). Shorebirds are highly susceptible to a range of human stressors including human disturbance from increased beach users, 4WD vehicles, entanglement in marine debris, habitat loss, coastal development and increased pollution which disturb essential roosting and foraging areas (OEH 2012). Shorebirds are also influenced by numerous recognised Key Threatening Processes including alteration to natural flow regimes, anthropogenic climate change, predation by the European Red Fox and other introduced species (OEH 2012).

A summary of the key life-history characteristics of a number of the shorebird species is presented in Appendix 2.

Shore-based recreational fishing in NSW marine waters

Introduction

Recreational fishing is a popular activity in Australia, with an estimated 3.36 million Australian residents aged 5 years or older having fished at least once in the 12 months prior to May 2000 (Henry and Lyle 2003). New South Wales (NSW) had the largest number of recreational fishers (estimated to be around 999,000 in the 2001 survey), and it is likely that has increased substantially since 2001. Within NSW, Sydney had the largest number of people who fished (482,739; 48.3% of the NSW total) but this represented only 13.1% of Sydney's population at the time of the survey (Table 3.1). The south and mid north coasts had the least number of people who fished (49,264; 4.9% of the NSW total), but this represented 30% of the resident population of these regions. This means that fewer residents of Sydney participate in fishing and that a substantial proportion of people who fish reside outside of Sydney.

Five main categories of recreational fishing methods were classified in the survey: line fishing, fishing with pots or traps, fishing with nets, diving and other collection methods (including harvesting by hand) (Henry and Lyle 2003). Line-fishing, diving and 'other' were the primary methods conducted from shore and used to inform the ecological risk assessment. Diving (using spears or underwater hand collection) contributed around 1% of the overall recreational fishing effort for NSW (Table 3.2). Spearfishing was the primary activity used in diving methods (75% of dive events) and snorkel diving (hand collection) accounted for the remainder (25%). Other collection methods, especially the use of pumps, rakes or spades were particularly important in NSW, largely concerned with the collection of bait species (including yabbies/nippers), accounting for 3% of events and 1% of hours fished.

The average duration by event, based on fishing method, in NSW was on average 3.5 hours per fishing trip for line fishing events, using bait. Spearfishing events averaged 2.5 hours per event. Alternative harvesting methods averaged 1.7 hours in duration per event across alternative methods. Being largely concerned with the collection of bait, such events were, on average, of short duration.

The variation in effort by number of events and hours of fishing for different fishing gear clearly reflects operational issues and highlights the need to consider effort by fishing method, rather than simply the total time fished on a given day. Ultimately the patterns of gear usage are influenced by a combination of regulations and availability of target species (i.e. opportunity).

Shore-based fishing attracted a greater level of activity (4,502,291 events or 58.7% of total) than fishing from boats (3,120,093 events or 40.7% of total) in NSW (Table 3.3). Within NSW 65% of fishing events and 64% of fisher hours occurred on ocean beaches and 31% of fishing events and 34% of fisher hours occurred on rocky headlands. Mid north coast and Hunter regions had the largest proportion of fishing events and fisher hours of NSW on ocean beaches whereas the south coast had the largest proportion of events and fisher hours on rocky headlands in NSW (Figure 3.1). These regional differences reflect, in part, the fact that northern NSW has a larger proportion of accessible beaches and the south coast has a larger proportion of rocky headlands.

Table 3.1 Estimated percentage of persons and proportion of the resident population aged 5 or older who fished recreationally in the 12 months prior to May 2000 in NSW

		Number of Recreational fishers	
Region	**Participation rate, % of regional population**	**% of Australia**	**% of NSW**
Richmond Tweed	26	1.5	5.0
Mid North Coast	29.9	2.2	7.5
Hunter	25.2	3.9	13.2
Sydney	13.1	14.4	48.3
Illawarra	20.9	2.2	7.4
South Eastern	30.1	1.5	4.9
Total NSW	17.1	29.7	

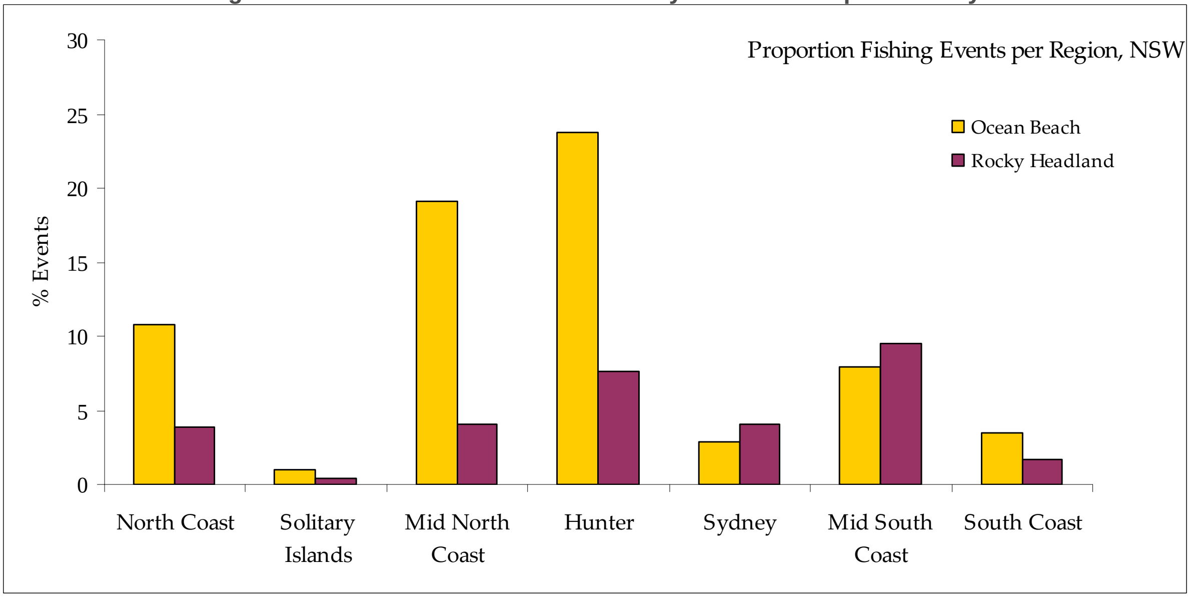
Table 3.2. Annual fishing effort in events and hours by fishing method in NSW for recreational fishers aged 5 or older who fished recreationally in the 12 months prior to May 2000 in NSW

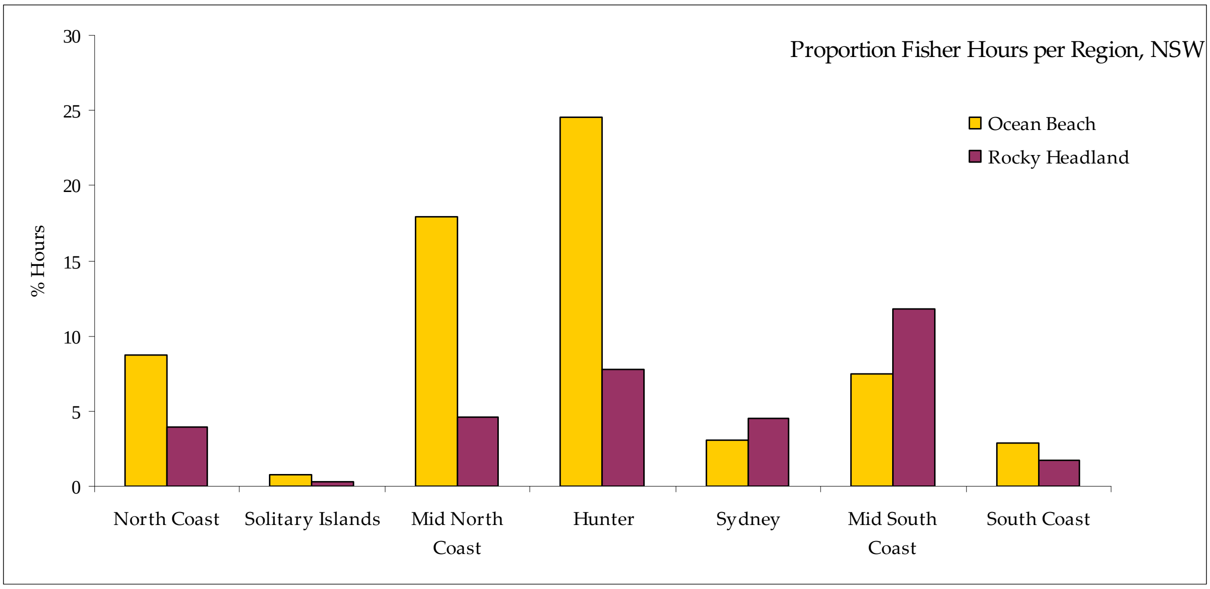
Effort	Method	% NSW National	% NSW All methods
Events	Line:	35.2	90.2
	Pots & traps:	17.5	3.9
	Nets:	13.4	1.1
	Diving:	29.3	1.0
	Other:	31.6	3.8
	All methods	33.1	100.0
Fisher Hours	Line:	35.6	85.2
	Pots & traps:	13.7	12.3
	Nets:	16.9	0.8
	Diving:	31.1	0.6
	Other:	33.2	1.1

Table 3.3 Recreational fishing effort by fishing platform in NSW recreational fishers aged 5 or older who fished recreationally in the 12 months prior to May 2000 in NSW

Platform		NSW	Total (Aust)	% NSW National	% NSW All
Boat	No. events	3,120,093	9,827,807	31.7	40.7
	% total	40.7	42.4		
Shore	No. events	4,502,291	13,294,769	33.9	58.7
	% total	58.7	57.3		
Both	No. events	48,499	81,729	59.3	0.6
	% total	0.6	0.4		
Total Events		7,670,883	23,204,305	33.1	33.1

Figure 3.1. Percentage of fishing events (fishing trips) and fisher hours by region and habitat type in NSW recreational fishers aged 5 or older who fished recreationally in 12 months prior to May 2000.





Fishing frequency

Nationally, recreational fishers fished for an average of 6.13 days per fisher between May 2000 and April 2001, and was similar in NSW. Western Australian residents averaged the highest levels of fishing activity (6.94 days per fisher) and the Australian Capital Territory (4.61 days per fisher) the least. Averages, however, fail to recognise the fact that the distribution of fishing effort (and catch) amongst recreational fishers is usually highly skewed. That is, a large number of fishers usually do relatively little fishing. At the other extreme; relatively few fishers are very active and contribute disproportionately to the overall effort (and catch). Nationally, about two thirds of all fishers (i.e. 2.2 million persons) fished for 5 or less days over the 12 month survey period, while just 3% of all fishers (about 101,000 persons) fished for more than 25 days. At the lower end of the effort scale, about 60% of all fishers (i.e. about 2.26 million persons) accounted for less than 20% of the total effort (about 4.1 million fisher days). By contrast, at the top of the activity scale, just 15% of fishers were responsible for about half of the overall fishing effort, with the upper 3% (who each fished for greater than 25 days) also contributing about 20% of the national fishing effort. This clearly highlights the potential for a relatively small proportion of the recreational fisher population to exert a substantial impact in terms of effort (and also catch), suggesting that minor shifts in the dynamics of participation (based on activity levels) at the upper end of the fishery will have significant implications on effort (and catch) levels.

Catch by recreational fishing

Around fifty eight percent (58%) of inshore recreational catches are taken from ocean beaches and 42% from rocky headlands (Table 3.4). Within NSW the largest proportion of catch from ocean beaches was taken on the mid north coast and the Hunter regions, whilst the largest proportion of catch from rocky headlands was taken on the north coast and Hunter took (Figure 3.2). The proportion of catch from rocky headlands far exceeded the catch from ocean beaches from Sydney southward within NSW.

Figure 3.2 Proportion of finfish catch by region and shore type for NSW recreational fishers aged 5 or older who fished recreationally in the 12 months prior to May 2000 in NSW.

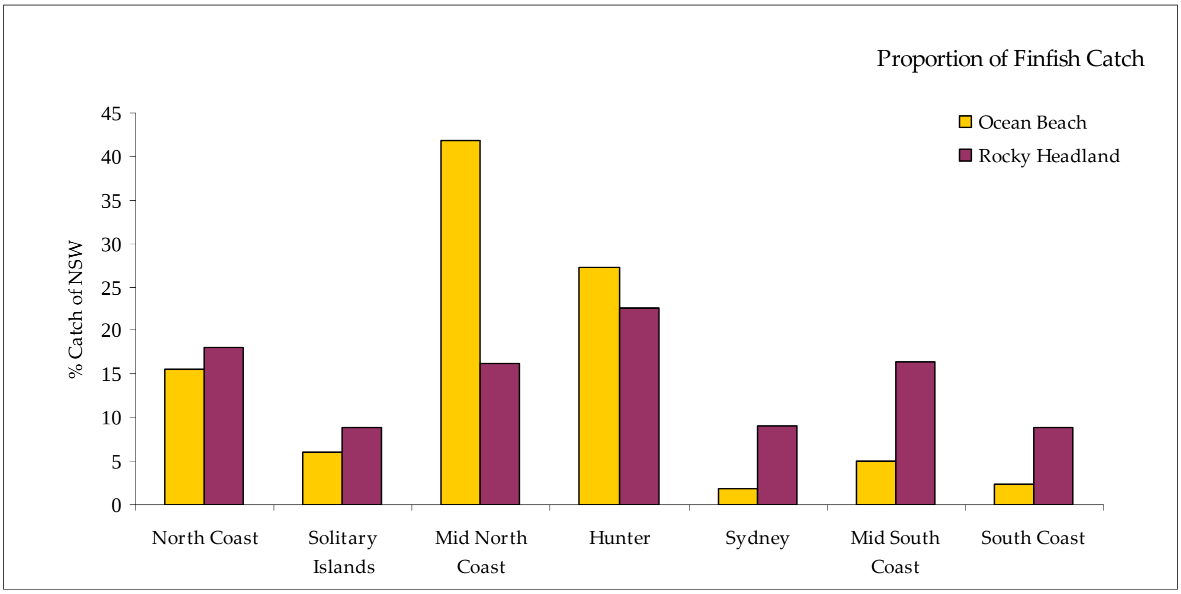
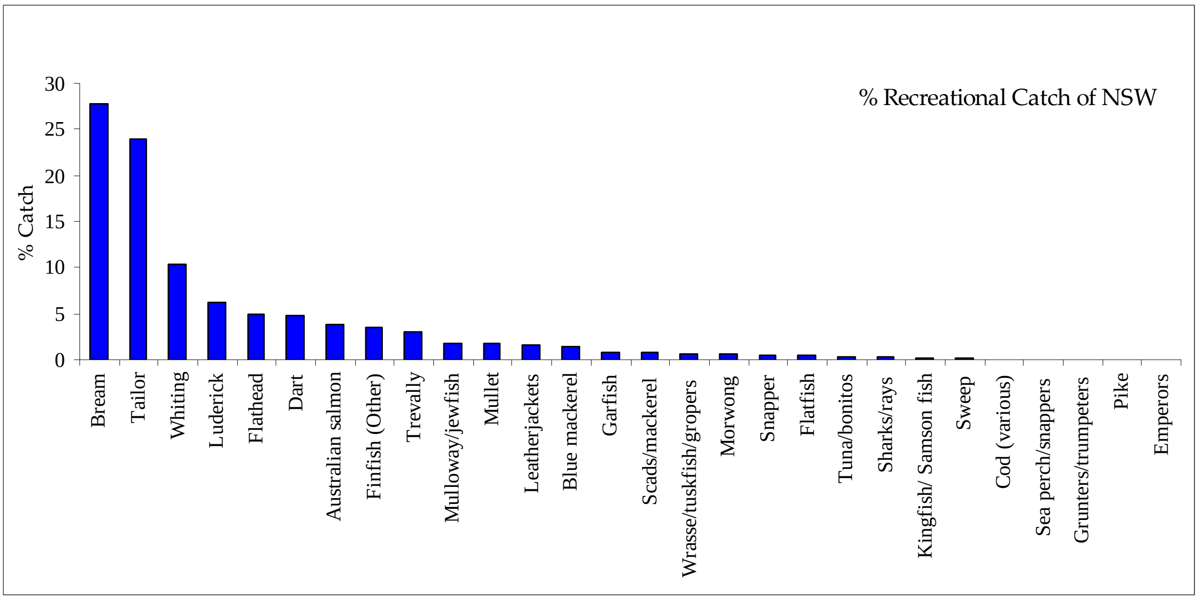


Table 3.4 Percentage of finfish catch by region and shore type for NSW recreational fishers aged 5 or older who fished recreationally in the 12 months prior to May 2000 in NSW

Region	Shore Type	Percentage of catch
North Coast	Ocean Beach	15.5
	Rocky Headland	18.0
Solitary Islands	Ocean Beach	6.0
	Rocky Headland	8.9
Mid North Coast	Ocean Beach	41.9
	Rocky Headland	16.3
Hunter	Ocean Beach	27.3
	Rocky Headland	22.6
Sydney	Ocean Beach	1.9
	Rocky Headland	9.0
Mid South Coast	Ocean Beach	5.1
	Rocky Headland	16.4
South Coast	Ocean Beach	2.3
	Rocky Headland	8.9
Total	Ocean Beach	58.1
	Rocky Headland	41.9

Based on the available data, bream and tailor represented the highest proportion of the harvest in NSW for shore-based fishing at 27.8% and 23.9%, respectively (Henry and Lyle 2003) (Figure 3.3). Whiting was the next highest at 10.1%, followed by luderick, flathead and dart. This catch composition differs from that of boat-based fishers where the ten most commonly harvested taxa (the Sydney region), by number, were eastern blue-spotted flathead, ocean leatherjacket, snapper, silver trevally, southern calamari, blue mackerel, silver sweep, yellowtail, grey morwong and southern maori wrasse (Steffe and Murphy 2011).

Figure 3.3 Percentage of finfish catch by species for NSW recreational fishers aged 5 or older who fished recreationally in the 12 months prior to May 2000 in NSW.



Release rates

Recreational fishers release or discard fish for a variety of reasons, these include fisheries regulation (size limits, bag limits or closed seasons), poor eating quality, damage (due to capture, including predation), catch and release fishing and/or for ethical reasons. The influence of these factors will vary between individual fishers and species, but information on the released component of the catch has relevance as a measure of fishing success (i.e. whether any fish were caught or not), the need for and effectiveness of catch regulations (size and bag limits) and potential issues relating to post-release survival.

Species for which release rates were in the high category included finfish such as sharks/rays, pink snapper, bream, cod and wrasse/tuskfish/gropers. It is likely that many of the sharks/rays and wrasse were released because of perceived poor eating qualities, while size-related factors (primarily occurrence of undersized individuals) were likely to have been important for the remaining species. A wide variety of fish occupied the medium rate of release category, including species such as sea perches/snappers, emperors, mulloway/jewfish, flathead, trevally, tailor, mackerels, whiting, Australian salmon, and luderick.

Ecological effects of shore-based recreational fishing

Introduction

There are many human activities that can interact with the marine animals and plants on ocean beaches and rocky headlands. However, this report is only about shore-based recreational fishing, and hence the overview that follows discusses what is known about this activity in isolation from other human activities that can occur on ocean beaches and rocky headlands. The consequence of this narrow focus is that ecological effects of other human activities on the marine ecosystem are not examined and the interactions of these with recreational fishing are not explored. In a different context, such as reviews of marine park zoning arrangements, it will be important to consider more fully the relative impacts from recreational fishing on marine biodiversity.

There have been few studies on the ecological effects of marine shore-based recreational fishing globally and none in NSW, except for a few specific effects on some targeted species (e.g. effects of catch and release). McPhee et al. (2002) and Ford and Gilmour (2013) review much of the scientific literature and the issues associated with recreational fishing in temperate south-eastern Australia. These reviews provide much of the background to the assessment of ecological risk from shore-based recreational fishing.

Recreational fishing is becoming increasingly popular both nationally and internationally (Henry and Lyle 2003, Cooke and Cowx 2004, Rowling et al. 2010, Ford and Gilmour 2013). Its contribution to the total landings of many marine species is also increasing in relation to the commercial fisheries and for some species it is the major fishery (Henry and Lyle 2003, Coleman et al. 2004, Cooke and Cowx 2004, Rowling et al. 2010).

Despite high participation in recreational fishing, there are very few assessments specifically of the effects of recreational fishing, let alone specifically offshore-based fishing (Ford and Gilmour 2013). Most assessments of fishing tend to focus on commercial fishing; or they include all forms of fishing and do not separate the effects of the commercial and recreational sectors. Often data on the landings of fish species are used to infer the importance of various fishing approaches (e.g. Cooke and Cowx 2004, Coleman et al. 2004). This approach does not, however, allow conclusions to be derived about the ecological impacts associated with recreational fishing as the ratio of recreational to commercial landings does not indicate impacts (Arlinghaus and Cooke 2005).

Another approach has been to use spatial comparisons of fish populations and the wider ecosystem across areas that differ in fishing effort either as snap-shots or time series analyses to provide an indication of the effects of fishing, usually over small to medium spatial-scales (100 metres to tens of kilometres; Babcock et al. 1999, Keough and Quinn 2000, Shears and Babcock 2002, Willis et al. 2003a, Willis et al. 2003b, Barrett et al. 2007, Stuart-Smith et al. 2008, Barrett et al. 2009). Few of these studies separate recreational and commercial fishing or shore- or boat-based fishing (Stuart-Smith et al. 2008). This kind of approach has potential for species that are relatively site attached (at least at some time of their lives) or move over areas of tens of kilometres (e.g. within the scale that the fishing effort varies). Marine park zones and recreational fishing havens in NSW currently provide some of the clearest potential to assess the ecological sustainability of recreational fishing and allow comparisons with commercial fishing effects for these species.

Specifically in relation to spearfishing in NSW, while known to be a popular recreational activity there is little information on its distribution and levels of effort, and no published studies on the potential impacts on local fish populations. It is likely that overall effort is patchy but highest closest to population centres, including those popular as tourist destinations along the coast. However, the skill level of spearfishers strongly influences the distribution of effort, with experienced fishers targeting more remote and exposed areas over greater depth ranges

(Kingsford et al. 1991, Lincoln Smith et al. 1989). While the catch composition of spearfishers is often dominated by species that are relatively sedentary and associated with rocky reefs, such as leatherjackets and morwongs (Kingsford et al. 1991), they composition is much broader for more experienced fishers.

A number of studies have shown that spearfishing can significantly impact local densities, size, and depth distributions of targeted species (Godoy et al. 2010, Jouvenel and Pollard 2001). A recent study on the Sydney coast provided correlative evidence that in a small MPA that allows line fishing but excludes spearfishing that very small partial-take MPAs may be effective for a number of species (Curley et al. 2013) as differences were reflected in the consistently higher densities of legal-sized yellowfin bream and red morwong within the MPA than at fished control locations over the two year sampling period. These effects occurred in both a relatively sedentary (red morwong), and more mobile species (yellowfin bream).

Stressors from shore-based recreational fishing

Shore-based recreational fishing is not a single activity but is made up of a number of smaller activities, such as accessing the particular fishing spot, possibly collecting bait, catching fish, and then either releasing those fish back into the water or retaining them. These component activities are the stressors of shore-based recreational fishing. A stressor is an activity that, when it reaches a threshold level, causes an impact, directly or indirectly, on a habitat or species group (Petraitis and Hoffman 2010). All human activities produce stressors, however, seven stressors were characterised for the assessment shore-based recreational fishing (Table 4.1).

Landed catch (harvesting)

Unlike commercial fisheries, recreational fishing is not subject to annual reporting of landed catches. The last reported survey of recreational fishing occurred in 2000/2001 (Henry and Lyle 2003), with a new survey currently underway that will be completed in late 2014. All estimates of current recreational catches in NSW are based on the results presented in Henry and Lyle (2003) (Table 4.2). It should be noted that the estimates for recreational catches are for all areas (estuarine and coastal), fishing methods, and platforms (boat-based or shore-based). These are provided as background information as it is not possible to attribute relative impact on fish species across the state.

As data in Henry and Lyle (2003) are not available at the spatial scales of individual sanctuary zones, survey data on levels of shore-based line fishers within a proportion of sanctuary zones were collected over approximately a 4-6 weeks period in March-April 2013 following the introduction of the amnesty. This information was used to provide an indication of the patterns of use.

Table 4.1 Summary of the stressors from marine shore-based recreational fishing and examples of their possible consequences for the three components of marine biodiversity used in this risk assessment.

Stressor	Fish	Habitats	Threatened & protected species
1.Harvesting	- decreased abundance - truncated age classes - changes to life history characteristics - behavioural changes (flight response)		- accidental capture - hooking or spear damage
2. Discarding (catch & release)	- lethal and sub-lethal effects - increased stress levels - reduced ability to avoid predators - increased scavenging (from bait and injured discarded fish)	- aesthetic value (dead or injured fish)	- accidental death - predation on shore-bird nests from increased abundance of predatory birds attracted by discards - scale damage leading to infection - physiological stress from handling
3. Bait collection & use	- reduced abundance - potential introduction of disease and increased nutrients from non-fish or foreign bait sources	- physical alteration of habitats - changes to biophysical processes	- reduction in foraging area available to shore-birds
4. Lost fishing gear	- ingestion of sinkers, lures, hooks - entanglement	- physical damage from entanglement around biogenic habitats, e.g. corals & sponges	- entanglement - ingestion of sinkers, lures & baited hooks
5. Disturbance - physical damage, litter, fish cleaning		- damage and/or removal of sessile and algae intertidal biota from trampling - aesthetic value (litter)	- predation on shore-bird nests from higher abundance of predatory birds attracted by fish cleaning
6. Harvesting of ecosystem function components	- altered assemblage structure due to potential trophic cascade (more prey species if larger predators are lower in abundance)	- altered benthic habitat structure from reduction of grazers	- depletion of food sources
7. Non-compliance with fishing rules	- removal of undersized fish leading to depletion of reproducing adults	- damage to intertidal and subtidal habitats	- entanglement - ingestion of sinkers, lures & baited hooks - disturbance to ecological processes (e.g. nesting, foraging)

The effect that recreational harvest might have on these species would be expected to vary among species, and 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 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. The recreational proportion of the total catch of four of the six species studied by Stewart (2011) - mulloway, silver trevally, snapper and tarwhine, is 50% or greater (Table 4.2). 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 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).

Table 4.2 Summary of total landed catch from all commercial fisheries and estimated landings from recreational fishing for 2007/08 for key recreational fish species of ocean shore-based fishing in NSW. Data source: Rowling et al. (2010).

Common name	Scientific name	Commercial landings (t)	Estimated recreational landings (t)
Australian salmon	*Arripis trutta*	1500	150 - 210
Crimson banded wrasse	*Notolabrus gymnogenis*	0.1	20
Eastern blue groper	*Achoerodus viridis*	0	20 - 50
Eastern sea garfish	*Hyporhamphus australis*	40	10
Luderick	*Girella tricuspidata*	320	270 - 550
Mulloway	*Argyrosomus japonicus*	40	100 - 500
Red Morwong	*Cheilodactylus fuscus*	3	10
Sand whiting	*Sillago ciliata*	110	230 - 460
Silver trevally	*Pseudocaranx georgianus*	133	100 - 210
Snapper	*Pagrus auratus*	250	180 - 250
Tailor	*Pomatomus saltatrix*	50	150 - 350
Tarwhine	*Rhabdosargus sarba*	30	130 - 210
Yellowfin bream	*Acanthopagrus australis*	220	820 - 1070
Pipi	*Donax deltoides*	10	20 - 50
Beachworms	Onuphidae	10	10

One ecological effect of harvesting is that it can lead to serial depletion of populations. Sedentary species, such as beachworms, pipis, and species with high site fidelity (Fergus et al. 2013) are most susceptible to this type of an effect. Some sedentary reef species, for example, may be impacted by spear fishing which can effectively target one or a few species at specific locations (e.g. Lowry and Suthers 1998). 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.

Catch and release (discarding)

Recreational fishers do not always catch the species and size of fish that they aim to target and do not always retain all of the target species that they catch (based on the 2001 National Recreational Fishing Survey (Henry and Lyle 2003)). Broadhurst et al. (2005) estimated 30-50% of fish species were released or discarded by recreational fishers in Australia. The effects on released fish can be lethal or sub-lethal, and contribute to unaccounted mortality and possible ecological impacts on the fish communities and populations of species. The mortality rate of fish that have been released varies widely among species, types of fishing gear used, location of hooking, how it is released and its exposure to handling stresses (confinement, scale damage, physical contact). There have been several studies done in NSW on the effects of catch and release on key species of recreational fishers (Table 4.3).

Table 4.3 Summary of mortality rates from catch and release studies of common recreational fish species in NSW

Species	Release type	Hook location	Mortality rate	References
Yellowfin bream (juvenile)	Immediate, cut line	Ingested	16%	Broadhurst et al. 1999
Yellowfin bream (adult)	Delayed		8%	Broadhurst et al. 2005
	Immediate		28%	Broadhurst et al. 2005
	Immediate	Ingested	24%	Broadhurst et al. 2005
Sand whiting (adult)			8%	Butcher et al. 2006
Eastern sea garfish		Ingested	49%	Butcher et al. 2010
Luderick	Delayed		<1%	Butcher et al. 2011
Mulloway (adult)			35%	McGrath et al. 2011
Mulloway (juvenile)		mouth	0%	Broadhurst & Barker, 2000
Snapper (adult)			25-33%	McGrath et al. 2011 Broadhurst et al. 2005
Snapper (juvenile)			8%	Broadhurst et al. 2011
Trevally	Delayed		37%	Broadhurst et al. 2005
	Immediate		2%	Broadhurst et al. 2005

There is also the potential for longer-term (not immediate) effects of catch and release of recreational fishing species which may influence their mortality rates over periods of days to weeks. These sub-lethal effects may include elevated stress levels and scale loss which may lead to infection and disease. Again, sub-lethal effects vary species - yellowfin bream (Butcher et al. 2010) and yellowtail kingfish (Butcher et al. 2011) apparently suffer few sub-lethal effects whereas trevally (Broadhurst et al. 2005) had low initial mortalities (<2%) but this increased over time. Species like trevally may have a delayed stress response which could make them more susceptible to predation because of impaired behaviour as a result of capture stress. Raby et al. (2013) have recently suggested that post-release predation is an under-studied but potentially important source of unaccounted mortality from recreational fishing.

Lethal and sub-lethal 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 (48%) the retained gear was recreational in origin. Most adult sharks can survive external hooking of this type, but 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). Encounters between shore-based recreational fishers and threatened shark species leading to accidental hooking can be spatially and temporally concentrated. For example, Port Stephens has been identified as one of three important Australian nursery areas for white sharks during October to January and these juvenile sharks are known to use ocean beach sanctuary zones in this area (Bruce and Bradford 2012, Bruce et al. 2013).

Because the magnitude of sub-lethal 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.

Bait collection and use

Recreational fishing use a large variety of natural baits that can be harvested from the shore including crabs, algae, ascidians, limpets, beachworms and pipis (Kingsford et al. 1990; Fairweather 1991). Ecological effects of bait harvesting will depend on the method of harvest, intensity, substrate type and species targeted. In intertidal soft sediments, such as sandflats or beaches, digging for bait can alter the biophysical properties of sediments which can reduce its suitability for other infaunal species. There is little quantitative information about the bait harvester activities of shore-based recreational in NSW. Murray-Jones and Steffe (2000) studied the harvesting of pipis on Stockton Beach in NSW and found that 80% of the annual catch was taken by commercial fishers, 18% by recreational food harvesters and <2% taken by recreational fishers. In this study, recreational fishing on its own contributed very little to the overall harvesting of pipis one particular beach. It is problematical to extrapolate from this one study to other places or times, but the assumption has been made that harvesting of pipis for bait on the beaches under consideration is at very low levels.

Bait harvesting may potentially also have indirect effects on marine biota, such as disturbance to shore-bird foraging and depletion of their food source, but there are no data for this at the scale of this assessment in NSW. Because the extent of this stressor is unknown, it remains a source of risk.

Lost fishing gear

Shore-based recreational fishing in NSW occurs on highly dynamic and complex inshore marine ecosystems. One consequence of this is that fishing equipment can frequently be lost due to the rough conditions (e.g. waves washing away gear) and/or snagging gear on reefs. The most frequent types of gear lost while fishing are sinkers, hooks, lures and fishing line (example in Table 4.4). A study Smith et al. (2008) found fishing related litter to be the most prevalent form of litter on the coastline between Yamba and South West Rocks in northern NSW. The ecological effects of lost recreational fishing gear from shore-based fishers include entanglement of shorebirds (Ferris and Ferris 2004) and marine reptiles by fishing line leading to injury or death, ingestion of sinkers and lures by shore-birds mistaken for prey or from foraging, entanglement around subtidal or intertidal biotic habitats, such as sponges or algae leading to damage or severance of structures. For example, at Black Rock on the north coast of NSW (Smith et al. 2008) found over 50% of the fishing related litter was found entangled around coral causing damage. Monofilament fishing line can persist for long periods of time in the marine environment and has been found to be a major source of mortality in other parts of the world (Yoshikawa and Asoh 2004). There have been too few studies done to quantify the magnitude, extent or frequency of lost shore-based recreational fishing gear in NSW coastal waters or document the consequences of it. This stressor, therefore, remains an underdetermined source of risk to the sustainability of marine biodiversity.

Table 4.4 Summary of recreational fishing items recovered from intertidal areas in three coastal sanctuary zones within the Cape Byron Marine Park during March/April 2013 (i.e. during the amnesty). Data source: Collected during human use surveys, Cape Byron marine park ranger.

Location	Sinkers	Hooks	Lures	Line (m)
The Pass	1	1		34.1
Brays Hole	5			61.1
Bream Hole	8	9	4	119.8
Total	14	10	4	215.1#

Note: # This length of line was collected over a stretch of approximately 300 m of rocky headland and equates to 0.71 cm of fishing line per m of rocky shore.

Disturbance, physical damage, litter and fish cleaning

Disturbance refers to the artificial interruption of normal biological and/or ecological activities of an individual animal. A disturbance may lead to an impact on an animal and/or its population if the disturbance is of a sufficient magnitude, duration and/or frequency. Disturbance to intertidal animals (e.g. shore-birds, crabs) by shore-based recreational fishing can occur through access to a fishing site, static presence in an area and mobile presence within and between fishing sites. Access to many fishing sites requires walking through foreshore habitats in which shore-birds roost or nest (DEC 2008) and walking along a beach or rocky headland where animals forage (Meager et al. 2012, DEC 2008). Static presence, such as standing on a shore fishing, is of longer duration than mobile activities and can therefore have greater effects (Maguire 2008). For example, threatened shore-birds that forage on ocean beaches and rocky headlands can have their feeding times substantially reduced due to the static presence of people engaging in recreational activities such as fishing or sun bathing (Thomas et al. 2003). Static presence can also result in extended periods of separation of adult birds from their young (Weston and Elgar 2005).

Physical damage from trampling on rocky shores can reduce the cover of canopy forming algae (Keough and Quinn 1998). Litter and discarded fish frames from fishing cleaning on ocean shores can attract predatory birds and fish species (Maguire 2008). If fish cleaning is done in close proximity to nesting shore-bird sites predatory birds can then be attracted to prey on their chicks and eggs.

Studies that quantify the magnitude, extent and frequency of disturbance by shore-based recreational fishing in NSW coastal waters are too few to draw specific conclusions of its consequences. Recreational fishers are not the only group of human visitors which might cause this sort of stress, and in many cases they might be a minority group. Never-the-less, this stressor remains an under-determined source of risk to the sustainability of marine biodiversity.

Changing ecosystem processes

Whilst there are many studies globally that have documented the ecosystem effects of fishing, these have usually focused on large scale commercial fishing effects. However, with the increasing realisation of the magnitude of recreational fishing globally and nationally, the ecosystem effects of shore-based recreational fishing is greatly needed. In Australia, there have been very few such studies (e.g. McPhee et al. 2002, Ford and Gilmour 2013, Frisch et al. 2012). Degradation in the structure and/or function of the marine ecosystems occurs when a habitat, species or community is rendered unable to function within its natural range (Mortelliti et al. 2010). Habitats function within their natural range when they provide an array of environments for species and/or microhabitats that might reasonably be expected to occur in a habitat (e.g. Caley et al. 2001). Species and communities function within their natural range when they are able to undertake all their biological and ecological processes throughout their life cycle. Therefore, degradation of a habitat, species or community encompasses a range of effects that could result in either the partial or complete loss of such functions.

For habitats these effects include fragmentation, reduction in size, changes in density, inter and intra-patch connectivity, complexity (e.g. physical structure, sediment structure, composition, shape), heterogeneity, symbiotic relationships, nutrient cycling, carbon cycling, facilitation, flushing and dilution. For species and communities these effects include changes to abundance, distribution, composition, age structure, reproductive output, dispersal, recruitment, genetics, trophic dynamics, productivity, symbiotic relationships, nutrient and carbon cycling.

Because there are no studies in NSW that have investigated the ecosystem effects of shore-based recreational fishing it remains a possible source of risk to marine ecosystems in NSW.

Non-compliance with fishing rules

Illegal fishing has all the same effects of licensed recreational fishing but can add pressure on marine biodiversity by ignoring limits on fish protection. For example, Steffe and Murphy (2011) found that retained catches of recreational fishers in the greater Sydney region contained substantial proportions of under-sized fish. Smallwood and Beckley (2012) found 2-4% of shore-based recreational fishers fished within sanctuary zones in Ningaloo Marine Park. There have been no published surveys to date of illegal recreational fishing or its effects on marine biodiversity in NSW, but it remains a possible source of additional risk.

Ecological assets and social uses in NSW marine park ocean sanctuary zones

Introduction

A range of ecological assets occur throughout NSW marine parks, although those relevant to the assessment of open coast shore-based recreational line-fishing are ocean soft-sediments and rocky reefs. A brief description of the ecological assets of each marine park is provided, followed by specific details on the intertidal and nearshore subtidal habitats and key ecological features within the sanctuary zones included in the ecological risk assessment. The key social uses of each sanctuary zone are also presented.

Cape Byron Marine Park

The Cape Byron Marine Park is located on the far north coast of NSW in the shires of Byron and Ballina, and was declared in 2002. The marine park extends from Lennox Head in the south to the northern breakwall of the Brunswick River in the north. It covers an area of around 22,000 hectares from the mean high water mark and upper tidal limits of coastal estuaries for three nautical miles to the limit of the NSW State waters (see Figure 1.2).

The marine park contains a diverse range of estuarine and ocean habitats including sandy beaches, rocky shores, subtidal soft-sediments and reefs, and emergent rocks and islands, the largest being Julian Rocks. The Brunswick River is the largest estuary within the marine park at around 220 hectares, and contains large areas of seagrass, saltmarsh and mangroves. There are several smaller creeks that are open only intermittently. Seabed habitats have been mapped throughout the entire marine park, and a description of the extent, distribution and structure of intertidal and subtidal habitats in both estuarine and ocean areas is presented in Marine Parks Authority (2003) and Jordan et al. (2010).

This chapter focuses specifically on those nearshore ocean habitats included in the assessment relating to the amnesty on shore-based recreational fishing: intertidal soft-sediment (beach), subtidal soft-sediment, intertidal reef (rocky shore) and subtidal reef. The total length of open ocean coastline in the marine park is approximately 40.9 kilometres, which consists of 9.4 kilometres of Sanctuary Zone, 31.3 kilometres of Habitat Protection Zone, and 0.2 kilometres of Special Purpose Zone.

Ocean soft-sediments

Extensive areas of intertidal and shallow subtidal soft-sediment habitats occur within the Cape Byron Marine Park. There are several long sweeping sandy beaches, including Tyagarah (including the Brunswick Heads section), Belongil, Main, Clarks, Tallow and Seven Mile Beach, and several smaller beaches including Wategos, Little Wategos, Kings, Brays and Whites Beach. There is considerable variation in the exposure of the beaches to swells, due to the complex shape of the coastline and presence of shallow offshore reefs in some areas. The oblique action of predominant southerly swells hitting the coast also sets up a northward sweep around the headlands and along the beaches, and this is responsible for the net northward longshore transport of sediment along the beaches in the marine park. The shape of the shoreline and the maximum tidal range of approximately 2 metres results in generally a small intertidal zone on the beaches.

Intertidal sandy beach habitats are continuous with, and ecologically linked to, the subtidal soft sediment habitats occurring immediately offshore. There is fine-scale structuring of ocean beaches in the nearshore zone that is strongly influenced by wave exposure, resulting in sand bars, troughs and gutters, and rip channels that are frequently changing (Short 2003). Surficial sediments on the inner-shelf in the Byron Bay area are quartzose sand with variable amounts of shell and gravelly sand around reefs, but little mud (Gordon et al. 1979, Colwell 1982, Bickers 2004). Sand covers the nearshore zone to a depth of 5-10 metres, with an inner-shelf sand body to depths of 11-22 metres. At a fine scale there are also distinct areas of coarse sediment in the troughs of sand waves located seaward of exposed beaches between Lennox Head and Cape Byron (Bickers 2004).

Very little work has been conducted in northern NSW on the ecology of benthic communities inhabiting nearshore soft-sediments (Hacking 2003). A small number of studies have examined macrofaunal assemblages inhabiting soft sediments within the Solitary islands region, but only a single small-scale study examining molluscs inhabiting soft sediments has been conducted within the Cape Byron Marine Park (Adams 2005). Different beach types and environments within beach systems support characteristic assemblages, determined to a large extent by the size of particles making up the sediment. A diverse range of invertebrate species often occur beneath the surface of the sand, the most obvious being the macrofauna which are dominated by crustaceans, polychaetes and molluscs (Jones and Short 1995). Typical invertebrate macro-fauna associated with a range of northern NSW beaches includes isopods, amphipods and polychaetes (Hacking 1998). Two of the more familiar species on sandy beaches in Cape Byron Marine Park are pipis *(Donax deltoides)* and beach worms (Family: Onuphidae) as they are often collected for bait by recreational anglers.

Ocean soft-sediment habitats are important nursery and feeding areas for a variety of fish species, and support a characteristic fish assemblage including sand whiting, dart, yellowfin bream and mullet. The surf zones of exposed sandy beaches are important nursery grounds for some species of fish previously considered to be dependent on estuaries.

Ocean rocky reefs

Overall, intertidal and nearshore ocean rocky reef habitats are limited in extent within the marine park, reflecting the region’s geology and dominance of beaches and subtidal soft-sediment habitats. The majority of nearshore shallow reefs occur adjacent to the rocky headlands, particularly Lennox Head and Cape Byron. There are also a number of small shallow reefs that are not continuous to shore within Byron Bay offshore Main Beach and The Pass. These reefs have been the focus of most studies relating to fish and the macrobenthic assemblages, with several reefs contained no *Ecklonia* and dominated by a cover of *Lobophora* and *Zonaria* (Harriott et al. 1999, Bucher and Hartley 2004, Bickers 2004). Other small reefs in the Cape Byron area contain *Ecklonia*, but generally at only low abundance (Bickers 2004). The geomorphic and biotic structure of intertidal reefs in the region have been described in a number of studies, which have detailed large variations in species richness and composition between locations (Smith 1991, Smith and James 2003). Such variations appear to be influenced by wave exposure, geomorphic diversity and extent of sand inundation.

Sanctuary zone assessments

There are four open coast sanctuary zones included in the amnesty, and these are distributed across the length of the marine park, with some sanctuary zones having several locations where there is a shoreline component to the zone (Table 5.1).

Table 5.1. Characteristics of ocean beach and headland sanctuary zones in Cape Byron Marine Park

Sanctuary Zone	Length of Coast (km)	Number of Beaches	Name
Byron Bay	6.8	2	011 Tyagarah Beach-Belongil Beach
			014 Wategos Beach / The Pass
Broken Head	1.7	4	017 Kings Beach 1
			018 Kings Beach 2
			019 Brays Beach
			020 Whites Beach
Lennox Head	0.7	0	021 Seven Mile / Lennox Head Beach
The Moat/Bream Hole	0.2	Part only	021 Lennox Head Beach adjacent to The Moat/Bream Hole

Byron Bay Sanctuary Zone

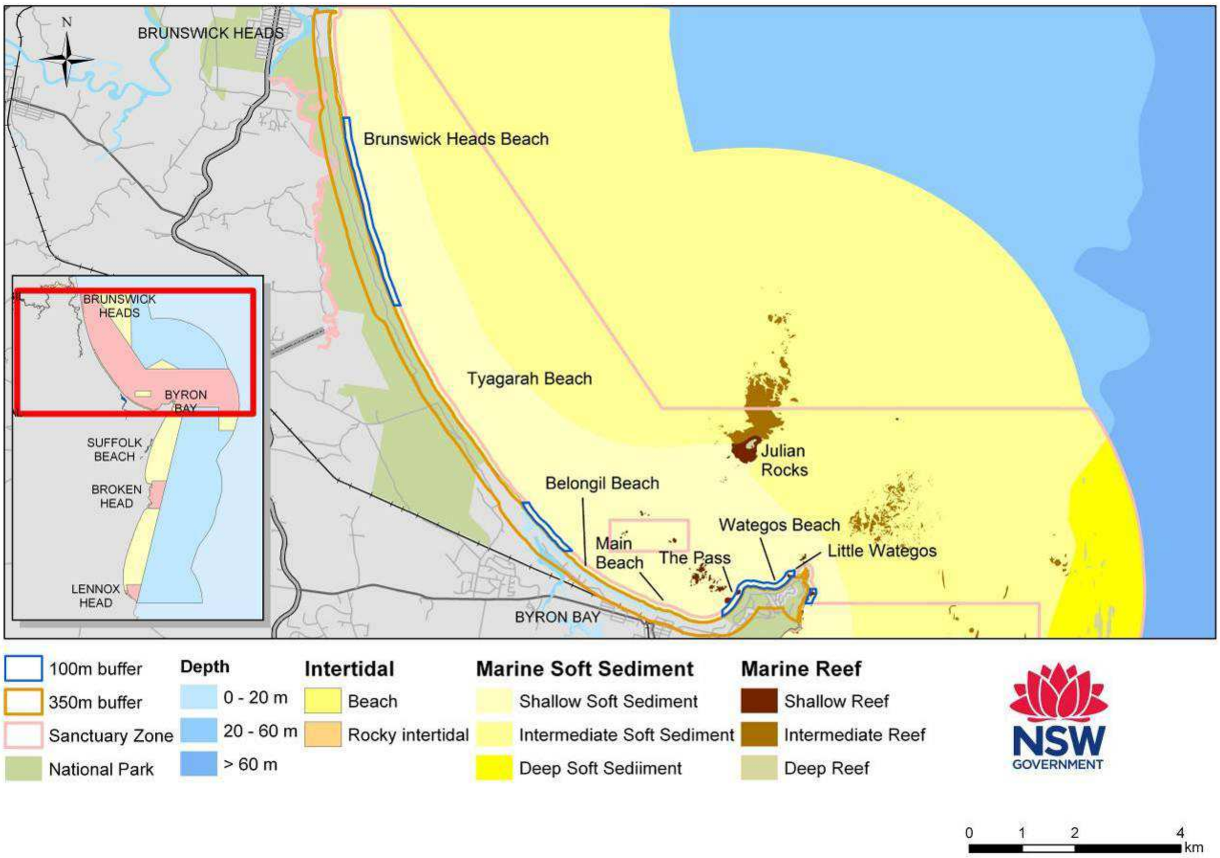
The Byron Bay Sanctuary Zone is a large zone that includes the Byron Bay embayment; approximately 3.6 kilometres of Tyagarah Beach at Brunswick Heads and Byron Bay; offshore waters of Tyagarah Beach; Julian Rocks; Cape Byron; and a transect east of Cape Byron to the outer boundary of the Marine Park (Figure 5.1). The shoreline components of this sanctuary zone consist of four separate sections that have a total coastline length of approximately 6.8 kilometres, including Brunswick Heads Beach, northern Tyagarah Beach, The Pass and Wategos Beach and eastern Cape Byron (Table 5.1).

The intertidal and nearshore subtidal habitats within the Byron Bay Sanctuary Zone are dominated by soft sediment habitats, with only relatively small areas of intertidal and subtidal reef. The sections at Brunswick Heads and northern Tyagarah Beach are exclusively beach and subtidal sand habitats. The section between The Pass and the eastern end of Wategos Beach is also mostly sand habitat, with an area of intertidal reef approximately 450 metres long between the two beaches. This reef only extends as a narrow subtidal strip, with only two additional small areas of subtidal reef present in this location offshore of the Pass and eastern end of Wategos Beach. The small section of sanctuary zone on the eastern side of Cape Byron consists of almost equal proportions of subtidal reef and sand, and is considerably more exposed than locations on the north-western side of the headland, and almost inaccessible due to the topography.

The key ecological features of this shoreline zone are:

- Rocky intertidal areas at The Pass and Wategos Beach have relatively low species richness, but species composition areas similar to that at Broken Head, which were both distinct from of sites in the region (Smith and James 2003).
- The beach area important pipi habitat.
- Turtles, whales, dolphins, rays and sharks frequently observed at The Pass and Wategos Beach.
- Belongil Creek mouth important site for resident and migratory shorebirds, including Pied Oyster Catchers. Frequented by threatened species such as Beach Stone Curlews, Little Terns, Double Banded Plovers, Red Capped Plovers and others.

Figure 5.1. Seabed habitats within the Byron Bay sanctuary zone.



Broken Head Sanctuary Zone

The Broken Head Sanctuary Zone extends between the northern end of Kings Beach and the eastern-most point on the rocky headland at the southern end of Brays Beach (approx 100 metres north of Snapper Rock) (Figure 5.2). It incorporates Cocked Hat Rocks below mean high water mark and the surrounding reef to the eastern boundary. The shoreline components of this sanctuary zone consist of five separate sections that have a total coastline length of approximately 1.7 kilometres, including Kings Beach (which has two separate sections) and Brays Beach, and three sections of rocky shore that are adjacent to these beaches.

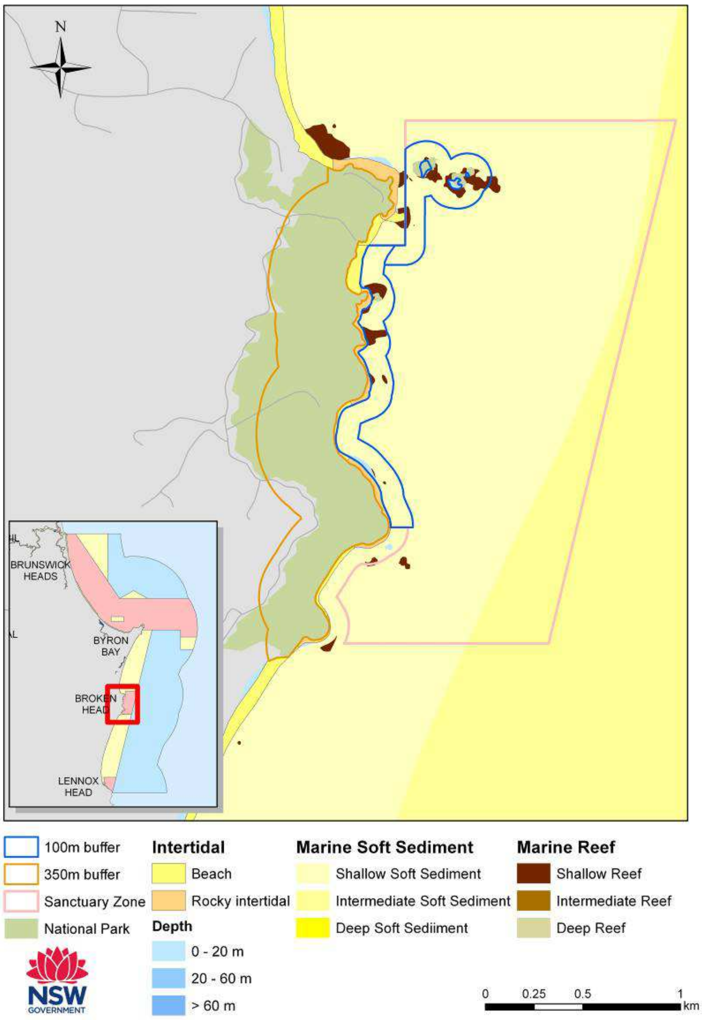
The intertidal habitats within the Broken Head Sanctuary Zone contain sections of beach habitat at Kings Beach and Brays Beach that are both approximately 200 metres long, with a second small section of Kings Beach due south of the main beach. The remaining intertidal area consists of rocky shores that are adjacent to these beaches, the longest being approximately 700 metres long between these two beaches. The headland is composed of metamorphic rock that has a steep profile which restricts the extent of the intertidal platform. This section of rocky shore extends as continuous subtidal reef for approximately 100 metres offshore adjacent to several of the headlands, the rest becoming subtidal sand close to shore.

The key ecological features of this shoreline zone are:

- Rocky intertidal areas have relatively low species richness, but species composition areas similar to that at Cape Byron, which were both distinct from of sites in the region (Smith and James 2003).
- Subtidal reefs include a high geomorphic diversity and dominated by brown algae (Golvers 1995).

- Cocked Hat Rocks important bird roosting site and rock platforms used by Sooty Oyster catchers.

Figure 5.2. Seabed habitats within the Broken Head sanctuary zone



Lennox Head Sanctuary Zone

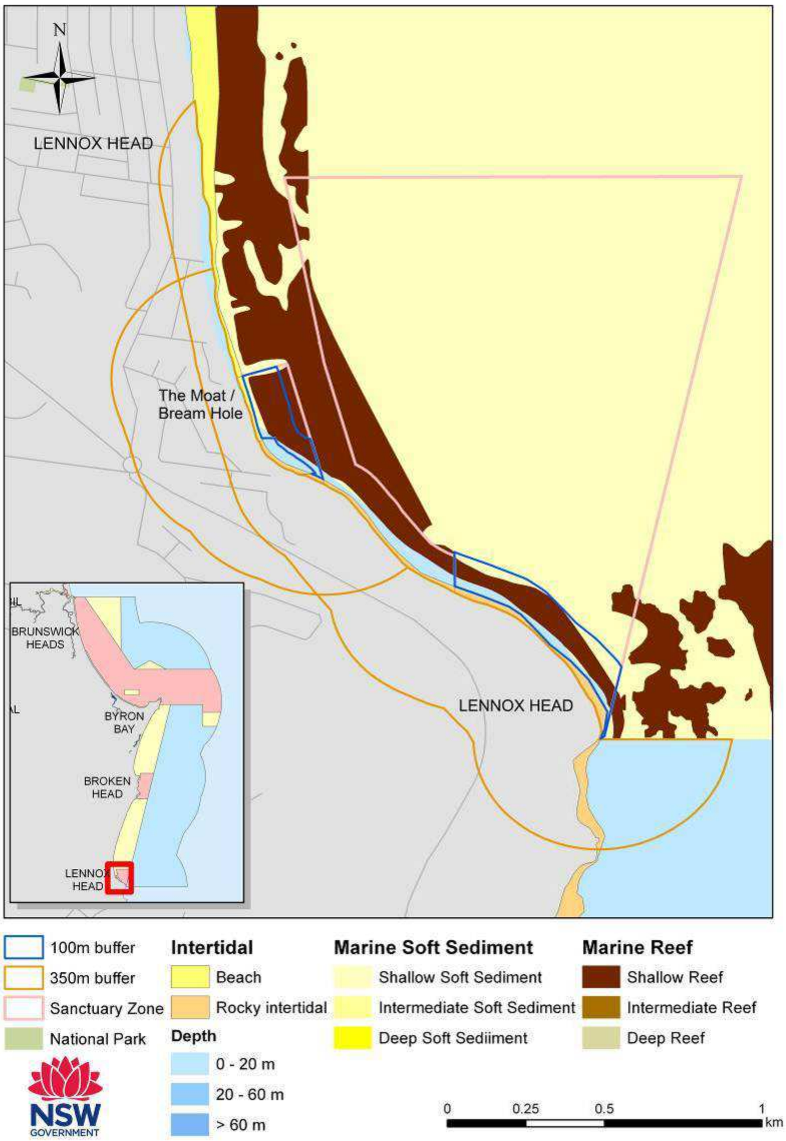
The western margin of this sanctuary zone commences at mean high water mark at the southern boundary of the marine park and continues in a generally north north-easterly direction offshore for approximately 1.8 kilometres. The zone only has a single small section of approximately 0.7 kilometres that is continuous to shore, and included within the amnesty assessment (Figure 5.3).

The intertidal habitats within the sanctuary zone are restricted to intertidal reef that are dominated by basaltic boulders that are relatively free from sand inundation. This intertidal reef extends subtidally for up to 200 metres offshore, and is continuous with reefs either side of the zone.

The key ecological features of this shoreline zone are:

- Intertidal boulder reefs at Lennox Head supports a relatively high species richness compared to other sites in the marine park, and contains several distinct assemblages associated with different tidal heights and geomorphic structure (i.e. boulders, rock pools) (Smith and James 2003).

Figure 5.3. Seabed habitats within the Lennox Head and The Moat sanctuary zones.



The Moat Sanctuary Zone

This sanctuary zone includes the waters of The Moat (also known as Bream Hole) that are bounded by the southern side of the Lennox Head boat channel, the subtidal reef edge and beach adjacent to The Moat, and the boulder foreshore which occurs adjacent to Lennox Head (Figure 5.3). The shoreline components of this sanctuary zone consist of a single section that has a total coastline length of approximately 0.2 kilometres.

The key ecological features of this shoreline zone are:

- Relatively high species diversity due to the presence of a variety of microhabitats such as crevices, holes, ledges, pools and overhangs, and restricted exposure due to the adjacent offshore reef (Smith and James 2003). This feature is considered the only rocky shore of its type in the Tweed-Moreton Bioregion as no other inshore reef provides similar geomorphic structure and water conditions, or supports such a diverse representation of temperate and tropical biota (Marine Parks Authority 2003).
- The southern section has a particularly abundant and diverse assemblages of molluscs, which included turban shells, cone shells, zebra shells, moon shells, tent shells,

periwinkles, cowries and mussels, several nudibranchs and two species of sea hare (Bent 1990).

- Rich in crustaceans including true crabs and hermit crabs, and a large numbers of other echinoderms including brittle stars, starfish, sea urchins, and sea cucumbers (Smith 1991).
- Subtidal waters support mixed algal assemblages and two species of seagrass *(Zostera capricornia* and *Halodule univeris)*, the later species being at the southern limit of its range (Dawes 1995, Smith and James 2003).
- The presence of seagrass outside of estuaries in rare on the NSW coast, with no other known location of *Halodule universis.*

Social uses in sanctuary zones

Human use of the sanctuary zones vary considerably, reflecting differences in access, location to populations centres, traditional uses and tourism activities. Primary uses were identified for each zone (or location where relevant). The marine park is used for a large variety of social and commercial activities apart from recreational fishing. In some cases, shore-based recreational fishing can come into conflict with some other uses, such as fishing close to surfing locations, such as Wategos and The Pass (Table 5.2). For evaluation of social risk the number of activities were grouped into minimal (0-2), low (3-5), moderate (6-8), and high (>8). The use of the sanctuary zone for ongoing monitoring of ecological assets was also identified.

Table 5.2. Social uses (other than by anglers) and scientific study of nearshore sanctuary zones in Cape Byron Marine Park

Sanctuary Zone	Social Use	Scientific study
Byron Bay	***Tyagarah Beach**:* Swimming Walking Surfing	Infrequent use for assessing pipi populations
	***Belongil**:* Swimming Walking Surfing Passive use	Seabird and shorebird observations
	***Wategos Beach**:* Snorkelling Swimming Surfing Kayak Walking Passive use Boating	Dolphin population monitoring
Broken Head	Snorkelling Swimming Surfing Passive use Kayak	None known
Lennox Head	Snorkelling Surfing	None known
The Moat/Bream Hole	Snorkelling Swimming Passive use	The habitats and biota of this site have been extensively studied by a variety of researchers since 1990. The most recent survey is by Owler (2012).

Solitary Islands Marine Park

The Solitary Islands Marine Park (SIMP) was declared in 1998 under the *NSW Marine Parks Act 1997*. Prior to this it was a multiple use marine reserve, initially declared in 1991 under the *NSW Fisheries and Oyster Farms Act 1935.* The marine park covers an area of approximately 71,000 hectares and extends for approximately 75 kilometre from Muttonbird Island in the south to Plover Island in the north, and from the mean high water mark and upper tidal limits of coastal estuaries to the limit of the NSW State waters.

The marine park contains a diverse range of habitats including intertidal and subtidal reefs, soft-sediments, beaches, seagrass beds, mangroves, saltmarsh, and pelagic waters which all support somewhat distinct groups of plants and animals. As the park extends from the high tide mark to at least 70 metres deep and 20 kilometre offshore in some areas, there is considerable diversity in flora and fauna due primarily to the variations in depth, dominant sessile assemblage, oceanographic influences, and the presence of offshore islands. These factors have resulted in a unique environment where tropical, subtropical and temperate marine fauna and flora co-exist, and as a result the region supports a biologically diverse range of marine species.

The open ocean habitats of the marine park contain a complex distribution of both soft-sediment habitats and rocky reef habitats. The soft-sediment habitats are dominated by coarse sediments reflecting the absence of finer coastal sediments, and the influence of strong tidal currents and oceanic swells. There is also fine-scale structuring of unconsolidated habitats in the marine park, influenced primarily by the presence of sand ripples and waves, and variations in particle size and shell content (Ku 2007, Jordan et al. 2010). There are also areas that contain small amounts of boulders, cobbles and pebbles, particularly adjacent to areas of rocky reef.

Surveys of subtidal soft sediment habitats in the marine park identified 241 invertebrate species (Smith and Rowland 1999), which excludes potentially diverse groups such as polychaete worms and isopods. Despite extensive previous collections, approximately 85% of the species identified in the soft-sediment samples had not previously been listed in the marine park region (Smith and Rowland 1999). There were significant differences in species in samples taken from the northern, central and southern sections of the marine park, and differences in species composition between samples of varying sediment size (Smith and Rowland 1999). Fish assemblages of unconsolidated sediments in the marine park are also likely to vary significantly between locations, sites, depths and fine-scale habitats, and a detailed study in progress is currently examining these patterns (Shultz et. al. 2012).

There are large areas of complex rocky reef throughout the marine park, and distinct patterns in the distribution of reef assemblages, with corals tending to be a dominant on reefs more than about 1.5 to 2.5 kilometres from the coast and less than 25 metres depth. Below 25 metres bottom communities are dominated by sponges and a mixed assemblage of invertebrates. These include such groups as stalked ascidians, sea-whips, gorgonians, hydrozoans, and black coral. The inshore reefs (those <1.5 kilometre offshore) are characterised by abundant macroalgae dominated by kelp *Ecklonia radiata,* and various species of *Sargassum* and *Caulerpa* and an understorey of coralline algae and a range of foliose algae. A variety of sponges and other sessile invertebrates can also occur on shallow reefs, and often form a diverse under-storey assemblage.

There is also a strong cross-shelf pattern in reef fish assemblages, with the number of tropical species and overall reef fish diversity increasing offshore, but with higher levels of endemism inshore. The region also supports more than 900 species of mollusc, 150 species of algae, 90 species of coral and over 530 species of reef fish, with about 12% of these fishes endemic to the east coast of Australia. Of these, about 5% are endemic to the subtropical region of the east coast. The reef fish assemblages in the marine park have been compared with those in other marine parks in NSW on reefs 15–30 metres deep, and are significantly different (Malcolm et al.

2007). Fishes range from residents with small home ranges to more-transient species that move between reef systems, as well as migratory fishes with seasonal movements. Some fishes are threatened or protected, some have high conservation value due to their endemism or their ecological role, and some are valued by fishers. Mammals, reptiles and birds are also a distinct part of the fauna, being permanent residents, seasonal visitors, or individuals just passing through.

Seabed habitats have been mapped throughout extensive areas of the marine park, and a description of the extent, distribution and structure of intertidal and subtidal habitats in ocean areas is presented in Marine Parks Authority (2009) and Jordan et al. (2010).

This chapter focuses specifically on those nearshore ocean habitats included in the assessment relating to the amnesty on shore-based recreational fishing: intertidal soft-sediment (beach), subtidal soft-sediment, intertidal reef (rocky shore) and subtidal reef. The total length of open ocean coastline in the marine park is approximately 102 kilometres, which consists of 12.3 kilometres of Sanctuary Zone, 88.7 kilometres of Habitat Protection Zone and 1 kilometre of Special Purpose Zone.

Ocean soft-sediments

The coastline of the marine park includes about 40 ocean sandy beaches ranging from 100 metres to many kilometres long, from Sandon Beach in the North to Park Beach at Coffs Harbour in the south. Sandy beach habitats are naturally dynamic, changing temporally through storm activity and prevalent seasonal patterns. Intertidal sandy beach habitats are continuous with, and ecologically linked to, the soft substratum habitats occurring immediately offshore. The beaches vary in their exposure to waves and swell, which influence the type of sediments present and the presence of bars and rips (Short 1993). Some of the ocean beaches are interspersed with a mosaic of intertidal and subtidal rocky reefs, which reduce their exposure to swell.

A study of sandy beach habitats in the marine park recorded between four and seventeen species of larger invertebrates per sample (Hacking 1997, 1998), with beach type influencing the number of species found. Higher species richness was generally found on beaches with finer sand which were exposed to higher wave energy, such as Moonee Beach. Beaches exposed to lower wave energy and with coarse sands such as Korora Beach tended to have lower species richness. A diverse range of invertebrate species often occur beneath the surface of the sand, the most obvious being the macrofauna which are dominated by crustaceans, polychaetes and molluscs (Jones and Short 1995), particularly the pipi *(Donax deltoides)* and beach worms (Family Onuphidae). Very small animals living in the sand are called meiofauna (animals ranging in size from over 63 microns to 1 millimetre), with over 79 meiofauna taxa recorded from Arrawarra Beach in the marine park alone (Bell 2005).

Sandy beach shallows are important nursery and feeding areas for a variety of fish species. The waters over beaches and intertidal flats also support characteristic fish such as various bait-fishes, flatheads, whiting, and mullet. The surf zones of exposed sandy beaches are important nursery grounds for some species of fish previously considered to be estuary dependent. Sandy beaches are also key feeding and roosting sites for a variety of shorebirds, seabirds, and migratory wading birds. These include threatened species such as the little tern and pied oystercatcher. Beaches are also important for migratory waders listed under international agreements, such as the whimbrel, red-necked stint and common sandpiper, with locations including Moonee Beach, Corindi Beach, Red Rock South Beach, Station Creek Beach and Wooli Beach (Smith 1991, NPWS unpubl. data).

Ocean rocky reefs

Intertidal rocky shores throughout the marine park occur mostly adjacent and below rocky headlands, and occasionally along stretches of beach, and range from broad low slope platforms, to outcrops, to narrow steep sloping headland points and bluffs. Adjacent to most of these rocky shores are sub-tidal reefs that vary considerably in extent (Jordan et al. 2010). Consistent with most shallow inshore reefs in NSW, reefs in the marine park are characterised by abundant macroalgae (Millar 1990, 1998), dominated by the kelp *Ecklonia radiata*, and various species of *Sargassum* and *Caulerpa* (Smith and Simpson 1991b, Harriott et al. 1994, Mau et al. 1998). They generally contain an understorey of algae dominated by coralline algae and a diverse range of foliose algae, including species of *Zonaria, Rhodymenia* and Ulva (Kennelly 1995, Edgar 1997). There are also *sponges* and sessile invertebrates (invertebrates that attach themselves to the bottom of the sea) on shallow reefs, and these can form diverse under-storey assemblages. Barnacles and solitary ascidians (sea squirts), such as the pyurids *Herdmania momus* and cunjevoi *Pyura stolonifera*, can also be dominant on shallow exposed reefs, as can areas of bare rock with microalgal communities. Corals do occur on these reefs but primarily as a small component of the understorey assemblage. The species composition of algal assemblages varies within and between reefs, although generally the cover of larger macroalgae decreases with distance offshore (Harriott et al. 1994, Malcolm et al. 2010a).

Sanctuary zone assessments

There are five open coast sanctuary zones included in the amnesty and these are distributed across the length of the marine park, with some sanctuary zones having several locations where there is a shoreline component to the zone (Table 5.3).

Table 5.3. Characteristics of ocean beach and headland sanctuary zones in the Solitary Islands Marine Park

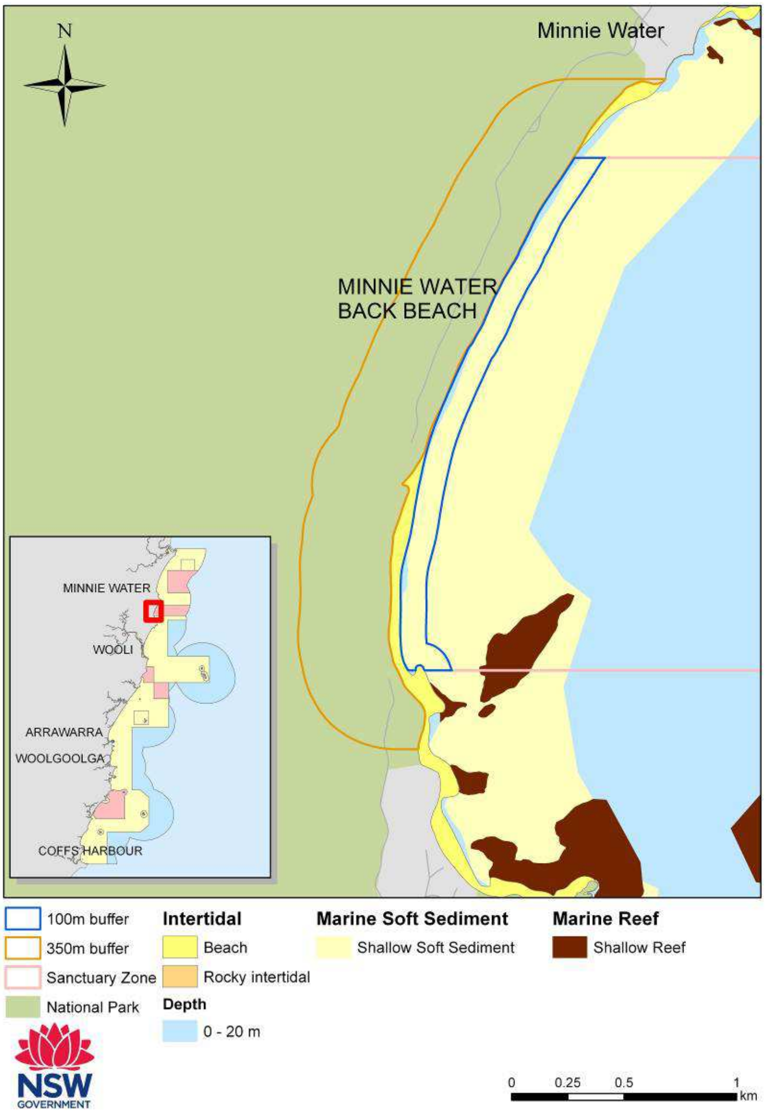
Sanctuary Zones	Length of Coast (km)	Number of Beaches	Beach number and name
Northern Section – southern area	2.4	1	068 Minnie Water Back Beach
Jones Beach and Jones Point	1.3	1	074 Jones Beach and Jones Point
Central Section – northern box	3.0	3	075 Barcoongerie Rocks 1 (part of) 076 Barcoongerie Rocks 2 077 Freshwater Beach
Flat Top Point	1.3	0	Flat Top Point
Southern Section	4.3	2	094 Diggers Point to Bare Bluff 097 Moonee Beach

Northern Section – southern area Sanctuary Zone

This sanctuary zone extends along Minnie Water Back Beach from approximately 500 metres south of the northern tip of the beach for about 2.4 kilometres south, then seaward to the outer boundary of the marine park (Figure 5.4). The entire zone is adjacent to the Yuragir National Park, and access is limited. The shoreline components of this sanctuary zone consist of the one defined beach, and does not include any intertidal or subtidal rocky reef habitat.

No research has been undertaken in the intertidal and subtidal habitats included in this assessment, although the plants and animals are expected to be similar to those in other exposed beach habitats along the NSW coast, as described in chapter 2. In relation to threatened species, pied oyster catchers inhabit this location and use the beach zone as a feeding and resting area.

Figure 5.4. Seabed habitats within the nearshore component of the Northern Section – southern area Sanctuary Zone



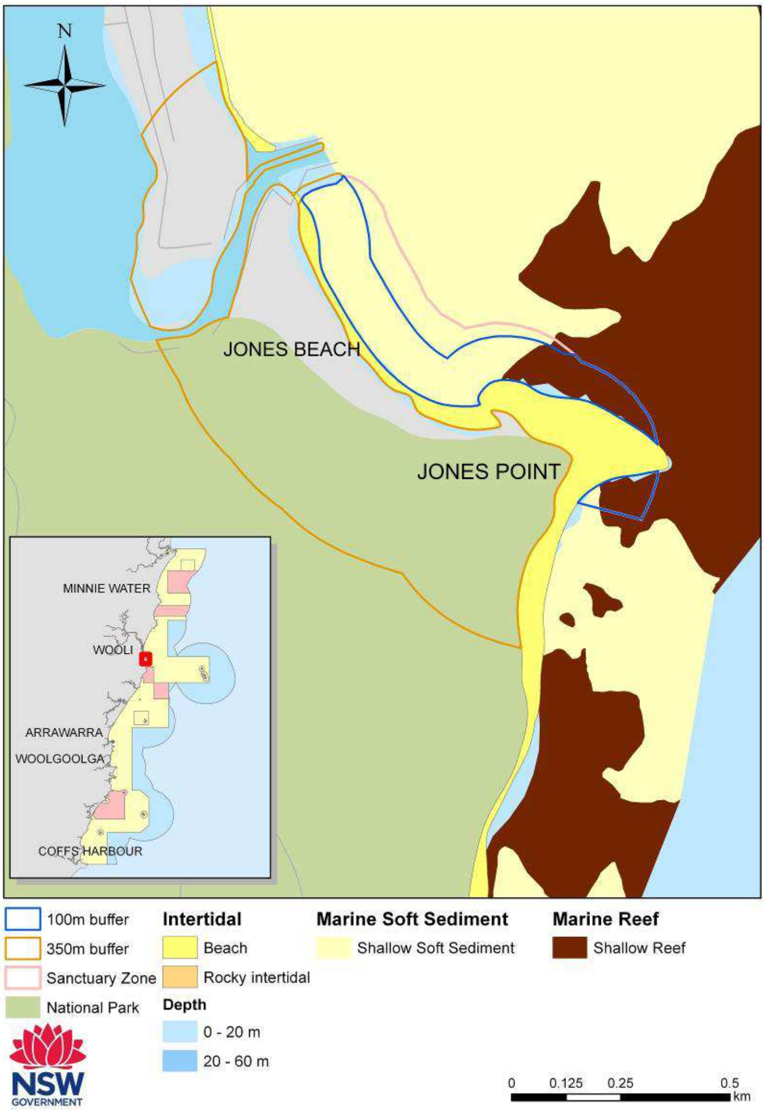
Jones Beach and Jones Point Sanctuary Zone

Jones Beach and Jones Point Sanctuary Zone extends along the shoreline between the southern Wooli Wooli River breakwall south to a point on the southern side of Jones Point and to a distance 200 metres offshore (Figure 5.5). It is a remote location, being on the southern side of the Wooli River. The entire zone is adjacent to the Yuragir National Park and has limited direct access. The shoreline components of this sanctuary zone consist of one defined beach which is approximately 630 metres in length, and an area of intertidal and subtidal reef adjacent to the headland.

The key ecological features of this shoreline zone are:

- Large area of intertidal algae *Homosira* (Coleman et al. 2011).
- Known location for species such as blue groper, yellowfin bream drummer, mangrove jack, estuary cod and moses perch
- The rocky reef area has suitable habitat for sub-adult black cod.
- Sooty oyster catchers occur on the rocky shore section, and pied oyster catchers inhabit the beach areas.

Figure 5.5. Seabed habitats within the Jones Beach and Jones Point Sanctuary Zone

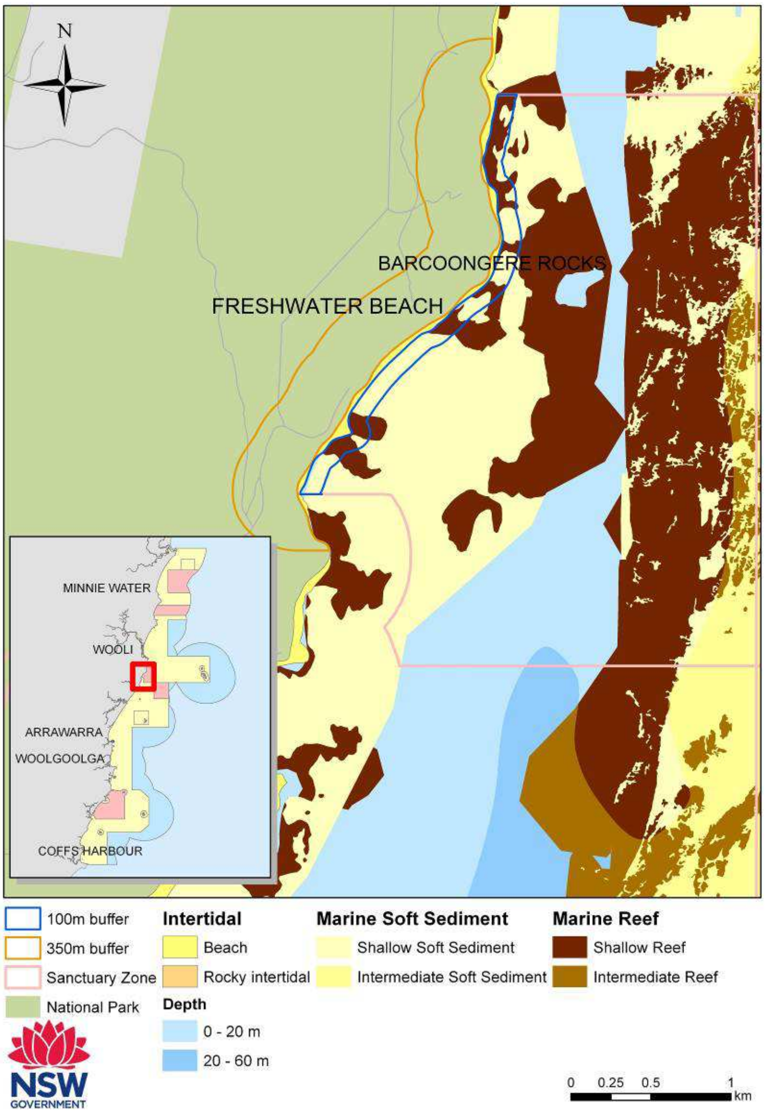


Central Section Sanctuary Zone

The Central Section Sanctuary Zone extends from ~1.5 kilometres south of Jones Point to the southern end of Freshwater Beach. It also extends south to a point in line with the northern end of Pebbly Beach, excluding approximately 1 kilometre of rocky foreshore north of Pebbly Beach out to 500 metres (Figure 5.6). The entire zone is adjacent to the Yuragir National Park and has limited access. The sanctuary zone has a total coastline length of approximately 3.0 kilometres. The shoreline is dominated by intertidal rocky reef in the northern section, and beach habitat in the south. There are numerous patches of subtidal rocky reef distributed immediately adjacent to the shore, particularly in the northern section. Much of this reef is transient due to the movement of sand during storm events. Given the characteristics of the location it is considered to be dominated by rocky reef.

The plants and animals are expected to be similar to those in other exposed beach and rocky reef habitats along the NSW coast, as described in chapter 2. Given the mosaic of rocky reef and sand habitats the range of fish species is likely to be high, with mulloway, blue groper, drummer, mangrove jack, gold spotted sweetlip, estuary cod and moses perch expected to commonly occur. The adjacent rocky reef at Baarcoongerie Rocks has a high relative abundance of eastern rock lobster, blue groper and snapper. Pied oyster catchers inhabit the intertidal beach areas, while the rocky reef area has suitable habitat for sub-adult black cod. White sharks and grey nurse shark are also likely to traverse through the area.

Figure 5.6. Seabed habitats within the Central Section Sanctuary Zone.



Flat Top Point Sanctuary Zone

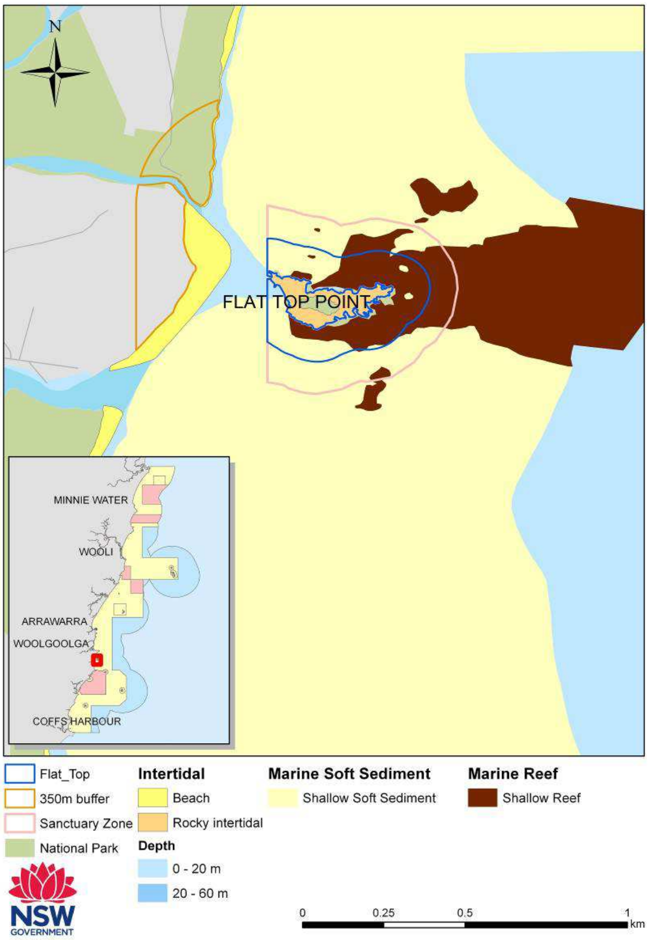
The Flat-Top Point Sanctuary Zone extends from the mean high water mark to 200 metres around the northern, eastern and southern parts of the Point and has a total coastline length of approximately 1.3 kilometres (Figure 5.7). It is a tombolo that is connected to the mainland by a sand-spit, which can be submerged at higher tides or following large storms when the spit is eroded. It is one of two tombolos present in the marine park, providing a unique mosaic habitat of reef and sand against the coast. The majority of the intertidal and subtidal habitats are rocky reef, apart from a small section on the western margin.

The key ecological features of this shoreline zone are:

- Highest relative species-richness of intertidal invertebrates recorded in the Solitary Islands Marine Park (Smith and Simpson 1991a).

- Intertidal habitat includes a rock-platform with raised outcrops providing complex cracks and crevices for crustaceans and molluscs and extensive deep and shallow rock-pools for a diverse assemblage of fishes (Harasti et al. unpubl. data) and invertebrates.
- The most-southern coastal record of giant clam *Tridacna maxima* on the eastern Australian mainland.
- Complex sub-tidal reef habitat with extensive kelp forest *(Eklonia radiata)* and understorey sponge communities.
- Threatened species recorded at this location include black rock-cod *Epinephelus daemelii* and sooty oystercatchers.
- Nursery area and adult habitat for blue groper, a nursery area for red morwong, a nursery and adult habitat for yellowfin bream, and a nursery for tarwhine (Malcolm unpubl. data).
- Sixty-five reef fish species recorded, many are endemic to south-eastern Australia (Malcolm unpubl. data).

Figure 5.7. Seabed habitats within the Flat Top Point Sanctuary Zone



Southern Section Sanctuary Zone

The Southern Section Sanctuary Zone extends from the mean high water mark on Moonee Beach (1.5 kilometres north from the northern side of Moonee Creek to 500 metres south of Look- At-Me-Now Headland), then from Diggers Point along Fiddamans Beach to the most eastern point of Bare Bluff (Figure 5.8). It then joins the South West Solitary (Groper) Island sanctuary zone via a line of sight from Bare Bluff to the northern most tip of South West Solitary

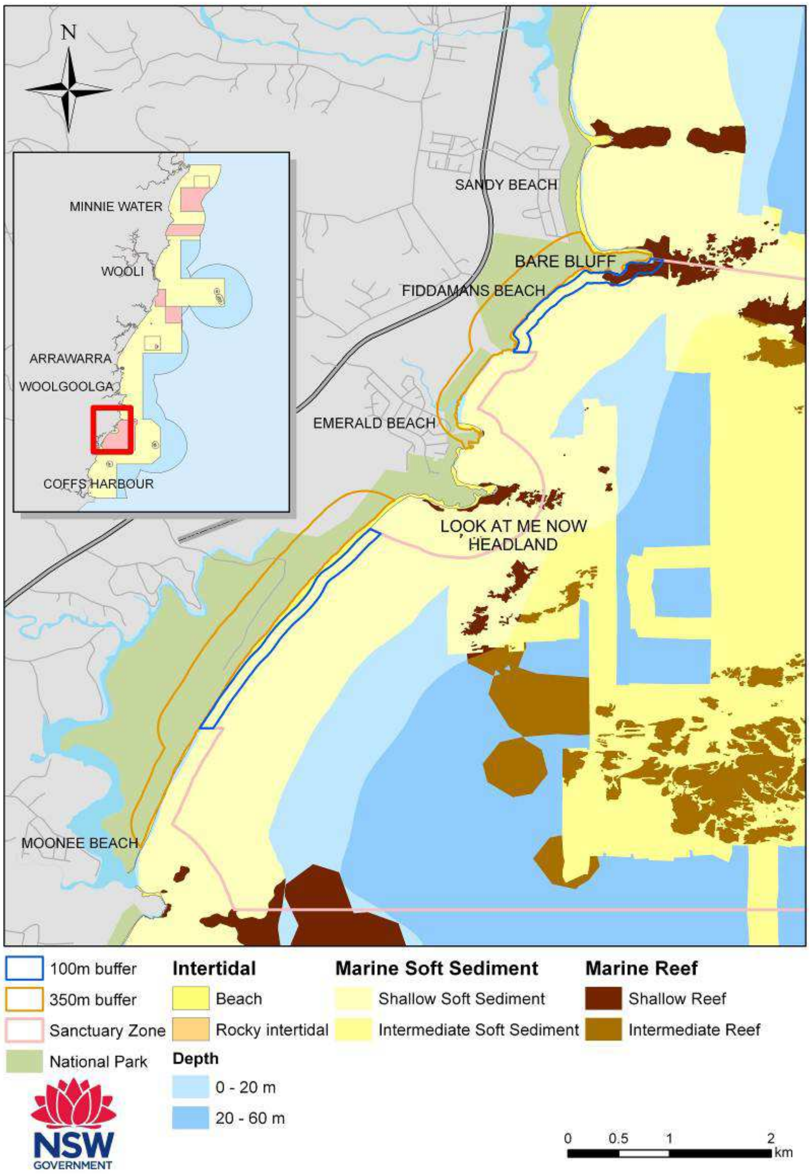
(Groper) Island. The sanctuary zone then extends further south offshore. The entire sanctuary zone is adjacent to the Moonee Beach Nature Reserve. The central part of Moonee Beach, which is sanctuary zone, is remote due to access at the southern end requiring crossing of Moonee Creek, while the northern end can be accessed from Emerald Beach.

The shoreline components of this sanctuary zone consist of two beaches (Back Sandy Beach and Moonee Beach) that extend for approximately 4.3 kilometres. The intertidal and subtidal habitats are dominated by soft-sediments, with a small area of rocky shore and subtidal rocky reef adjacent to Bare Bluff and Diggers Point.

The key ecological features of this shoreline zone are:

- Mulloway hole on the southern side of Bare Bluff
- Moonee Beach had the highest species richness and biomass of macro-invertebrates per metre of beach from eight beaches surveyed in and immediately adjacent to the Marine Park (Hacking 1997, 1998).
- Some of the species utilising shallow waters offshore from this beach from recent survey data include long-spine and blue-spotted flathead, eastern shovelnose ray, fiddler ray and southern eagle ray, which are all south-eastern Australian endemics. The most abundant fish were whiting species.
- Dolphins consistently use this area and it appears to be a maternity family site for a pod of common dolphins. Humpback whale mothers have also been observed using shallow (4 to 6 m) depth in this bay as a temporary nursery area.
- Important lobster habitat
- Moonee Beach and adjacent estuary is an area used by for migratory waders including Bar-tailed Godwit, Whimbrel and Eastern Curlew and resident shorebirds include Pied Oystercatcher and Sooty Oystercatcher (M. Murphy unpubl. data).
- Turtle nesting has also been recorded on this beach.

Figure 5.8. Seabed habitats within the Jones Beach and Jones Point Sanctuary Zone



Social uses in sanctuary zones

Human use of the sanctuary zones vary considerably, reflecting differences in access, location to populations centres, traditional uses and tourism activities. Primary uses were identified for each zone. The marine park is used for a large variety of social and commercial activities apart from recreational fishing. In some cases, shore-based recreational fishing can come into conflict with some other uses, such as fishing close to surfing and/diving locations (Table 5.4). For evaluation of social risk the number of activities were grouped into minimal (0-2), low (3-5), moderate (6-8), and high (>8). The use of the sanctuary zone for ongoing monitoring of ecological assets were also identified.

Table 5.4. Social uses (other than by anglers) and scientific study of nearshore sanctuary zones in the Solitary Islands Marine Park

Sanctuary Zone	Social use	Scientific study
Northern Section – southern area	Beach walking Surfing Swimming	Reef fish monitored using Baited Remote Underwater Video
Jones Beach and Jones Point	Walking	Reference site for eastern rock lobster monitoring proposed. Not yet surveyed.
Central Section – northern box	Walking	Reef fish monitored using Baited Remote Underwater Video
Flat Top Point	Snorkelling Passive use Walking	Shallow reef fish communities using Underwater Visual Census
Southern Section	Snorkelling Walking Surfing Swimming	Reef fish monitored using Baited Remote Underwater Video. Shallow reef fish and benthic communities monitored using Underwater Visual Census. Shallow inshore beach fishes using Baited Remote Underwater Video

Port Stephens-Great Lakes Marine Park

The Port Stephens-Great Lakes Marine Park (PSGLMP) was declared in December 2005, and covers approximately 98,200 hectares of marine and estuarine habitats from Forster in the north to the northern end of Stockton Beach. The marine park extends from the mean high water mark offshore to the three nautical mile limit of NSW waters and includes all of Port Stephens and the Karuah River, the Myall River, Myall and Smiths Lakes and all of their creeks and tributaries to the limit of tidal influence (see Figure 1.2).

The extent of the PSGLMP was identified for its many outstanding ecosystems, habitats and species meeting criteria for comprehensiveness and representativeness; it's high degree of naturalness and catchment protection; recommendations from previous assessments; and the extent to which it complements existing Marine Protected Areas and conservation management strategies (Breen et al. 2004). The special features include the largest area of mangrove and saltmarsh in NSW and the only tide dominated river valley in the bioregion; the largest system of coastal brackish lakes in the State and the only major example of this ecosystem type in the bioregion (Myall Lakes); and the largest intermittent lagoon in the State (Smiths Lake). It also includes Broughton Island, the second largest island in NSW, which provides important habitat for the threatened grey nurse shark and black cod, and Cabbage Tree Island (John Gould Nature Reserve), the primary breeding site for the threatened seabird Gould's petrel.

The marine park contains a diverse range of habitats including intertidal and subtidal reefs, soft sediments, beaches, seagrass beds, mangroves, saltmarsh and open waters which all support distinct groups of plants and animals. As the park extends from the high tide mark to at least 90 metres deep and 6 kilometres offshore in some areas, there is considerable diversity in flora and fauna. Such diversity is due to the variations in depth, various dominant sessile assemblages, oceanographic influences and the presence of offshore islands. These factors have resulted in a unique environment where subtropical and temperate marine fauna and flora co-exist. Seabed habitats have been mapped throughout much of the marine park, and a description of the extent, distribution and structure of habitats in ocean areas is presented in Jordan et al. (2010).

This chapter focuses specifically on those nearshore ocean habitats included in the assessment relating to the amnesty on shore-based recreational fishing: intertidal soft-sediment (beach), subtidal soft-sediment, intertidal reef (rocky shore) and subtidal reef. The total length of open ocean coastline in the marine park is approximately 137 kilometres, which consists of 20.3 kilometres of Sanctuary Zone and 113.7 kilometres of Habitat Protection Zone.

Ocean soft-sediments

Ocean soft-sediment habitats are extensive throughout the continental shelf waters of the marine park, dominated by coarse sediments reflecting the absence of finer coastal sediments, and strong tidal currents and oceanic swells. Some beach habitats are large, such as Mungo Beach and Seven Mile Beach located in the north of the marine park. Some are smaller and located within large rocky headlands such as One Mile Beach and Fingal Bay. There are also small ocean beaches that are interspersed with intertidal and subtidal rocky reef that reduces the exposure to swell. Sand covers the nearshore zone to a depth of 5-10 metres, with an inner-shelf sand body to depths of 11-22 metres. There are also areas that contain small amounts of boulders, cobbles and/or pebbles, particularly adjacent to areas of rocky reef. Intertidal sandy beach habitats are continuous with, and ecologically linked to, the subtidal soft sediment habitats occurring immediately offshore. There is fine-scale structuring of ocean beaches in the nearshore zone that is strongly influenced by wave exposure, resulting in sand bars, troughs and gutters, and rip channels that are frequently changing (Short 2003).

Little work has been conducted in northern NSW on the ecology of benthic communities inhabiting nearshore soft-sediments (Hacking 2003). In general, different beach types and environments within beach systems support characteristic assemblages, determined to a large extent by the size of particles making up the sediment. A diverse range of invertebrate species often occur beneath the surface of the sand, the most obvious being the macrofauna which are dominated by crustaceans, polychaetes and molluscs (Jones and Short 1995). Typical invertebrate macro-fauna associated with a range of northern NSW beaches includes isopods, amphipods polychaetes, pipis *(Donax deltoides)* and beach worms (Family: Onuphidae) (Hacking 1998).

Ocean soft-sediment habitats are important nursery and feeding areas for a variety of fish species, and support characteristic fish assemblages including pilchards, anchovies, whiting and mullet. The surf zones of exposed sandy beaches are important nursery grounds for some species of fish previously considered to be estuary dependent. The ocean beaches in the region are also an important habitat for a range of sharks and marine mammals and reptiles. Firstly, around thirty species of marine mammals have been recorded within the marine park region from records of live animals and strandings, with twenty-four being whales and dolphins, six species of seals and one dugong (Ganassin and Gibbs, 2005a, b). Dolphins are the most common marine mammals sighted in the marine park, with the bottlenose dolphins (genus *Tursiops)* being the most abundant. There is evidence of two separate Indo-Pacific bottlenose dolphin *(Tursiops aduncus)* populations present, one occurring predominantly inside the Port, and another along the open coastal regions adjacent to areas including Broughton Island and Forster (Möller and Beheregaray, 2001; Möller et al. 2007). Several of the world's seven species of marine turtles have been recorded in the region (Ganassin and Gibbs, 2005a, b). Most often seen are the green turtle *(Chelonia mydas)*, loggerhead turtle *(Caretta caretta)* and hawksbill turtle *(Eretmochelys imbricate).*

Several of the ocean beaches in the marine park are important habitats for juvenile white sharks. Juvenile white sharks can be found all year round occurring in the region however spend most of their residency times at Bennett's Beach (Hawks Nest) and Mungo Brush with the key aggregation time from early spring to mid-summer. Sharks can remain resident in the area for weeks to months and spend a considerable amount of their time (36.5%) in near-shore waters including the surf zone of beaches (Bruce et al. 2013).

The ocean coast between Smiths Lake, Myall Lake, Port Stephens and the Hunter River supports the most area of important bird habitat for threatened and other species (Breen et al. 2004). Shorebirds also breed within the area, above high water on coastal shores. While this location lies outside the high tide boundary of this study it is included here as it lies close to the vicinity of this boundary and these birds use the intertidal zone for feeding.

Ocean rocky reefs

Overall, intertidal and nearshore ocean rocky reef habitats are extensive within the marine park, reflecting the regions geology and dominance of rocky headlands in numerous sections of the coast. Areas of such reef occurs adjacent to most rocky headlands within the marine park, particularly Tomaree and Yacaaba headlands, Big Gibber, Sugarloaf Point, Charlotte Head and Cape Hawke. There are several major islands and many smaller islands or rocks within the marine park, all of which contain some amount of subtidal reef, including Boondelbah, Little, Cabbage Tree Islands, Broughton Island, and the Seal Rocks features, including Edith Breaker, Sawtooth Rocks and Big and Little Seal Rocks.

Shallow reefs (those less than 20 metre depth) are characterised by abundant macroalgae, dominated by the kelp *Ecklonia radiata*, and various species of *Sargassum* and *Caulerpa*, with an understorey of coralline algae and foliose algae. Many reefs in the marine park are known to contain large areas of urchin barren which extend from close to the shoreline down to depths of around 30 metres and are most characteristic of boulder habitat. Sponges and other sessile invertebrates can also occur on shallow reefs, but are generally not dominant. Mapping of reef habitats has revealed considerable details of their extent, distribution and structure, and indicated that there are large areas of complex reef at depths of more than 20 metres in both the northern and southern ends of the marine park. At depths greater than 20 metres, the seabed is dominated by sponges and invertebrates including stalked ascidians (sea-squirts), sea-whips, hydrozoans and black coral.

Sanctuary zone assessments

There are six open coast sanctuary zones included in the amnesty and these are distributed across the length of the marine park, with all sanctuary zones having only one location where there is a shoreline component to the zone (Table 5.5).

Table 5.5. Characteristics of ocean beach and headland sanctuary zones in Port Stephens-Great Lakes Marine Park

Sanctuary Zone	Length of Coast (km)	Number of Beaches	Beach Names
The Pinnacle	2.5	2	201 Cape Hawke 1
			202 Cape Hawke 2
Celito South	2.7	5	211 Number Six
			212 Number Five
			213 Number Four
			214 Number Three
			215 Number Two
Fiona	8.3	1	220 Fiona/Submarine
Yacaaba	1.6	0	
Zenith	1.1	4	224 Zenith
			225 Wreck North
			226 Wreck
Fingal Island	4.0	0	

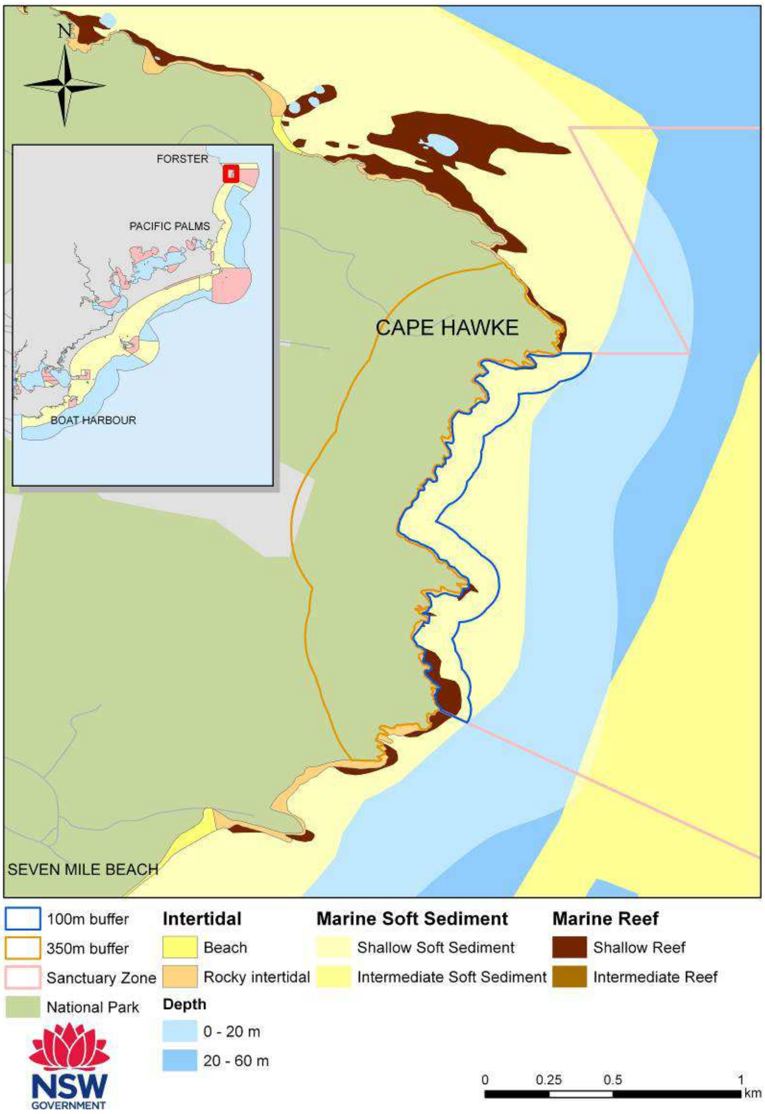
The Pinnacle Sanctuary zone

The Pinnacle Sanctuary Zone extends along the shoreline between the south-eastern tip of Cape Hawke to the point on the rocky headland approximately 800 metres north-east of the northern end of Seven Mile Beach (Figure 5.9). The entire sanctuary zone is adjacent to the prominent headland in the Booti Booti National Park, and while access is limited to a small section of the coast, the zone is adjacent to the township of Forster. The shoreline components of this sanctuary zone consist of two defined beaches, although these are <100 metres long, and only one contains soft-sediments. The sanctuary zone has a total coastline length of approximately 2.5 kilometres (Table 5.5).

The almost continuous rocky shore is characterised by steep topography, hence the intertidal habitats within the Pinnacle Sanctuary Zone are either narrow and boulder wall dominated or do not exist along much of the shoreline. The subtidal habitat adjacent to the rocky shoreline in the northern section are mostly soft-sediment, with small areas of narrow rocky reef present in the south.

No research has been undertaken in the intertidal and subtidal habitats included in this assessment, although the plants and animals are expected to be similar to those in other exposed soft-sediment and nearshore rocky reef habitats along the NSW coast, as described in chapter 2. This zone is within the known published range of movement around the known adjacent for grey nurse shark aggregation sites at Latitude Rock and The Pinnacle (critical habitat) aggregation sites for grey nurse sharks (Otway and Parker 2000). The zone has suitable habitat for sub-adult black cod, with defined ‘hot spot’ sites at the adjacent Latitude Rock and Pinnacle (Harasti and Malcolm 2013).

Figure 5.9 Nearshore seabed habitats within the Pinnacle Sanctuary Zone



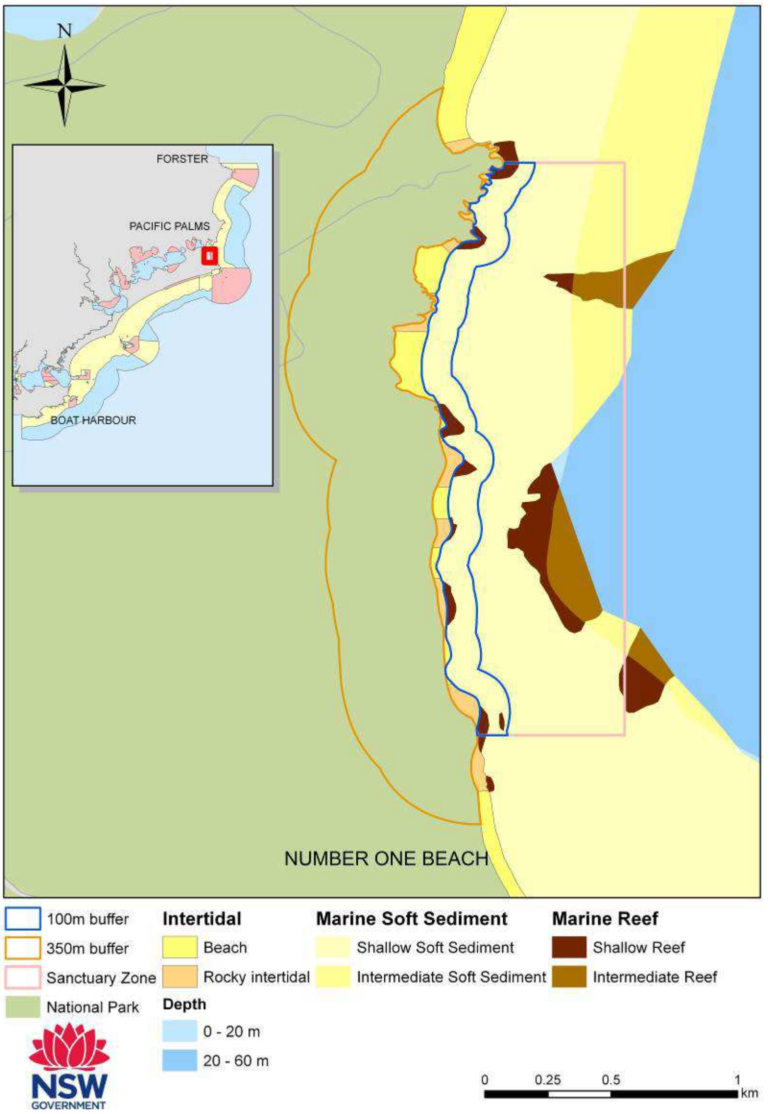
Celito South Sanctuary zone

The Celito South Sanctuary Zone extends along the shoreline between the rocky headland immediately south of Smiths Lake to the northern end of Number One Beach (Figure 5.10). The entire sanctuary zone is adjacent to the small headlands in the northern end of the Myall Lakes National Park, and access is limited. The shoreline components of this sanctuary zone consist of five defined beaches, although all of these are <150 metres long. The sanctuary zone has a total coastline length of approximately 2.7 kilometres (Table 5.5).

The intertidal habitats are characterised by the small beaches separated by narrow headlands that have steep topography resulting in very small tidal zones along much of the shoreline. The subtidal habitat is dominated by soft-sediments, with only small areas of rocky reefs adjacent some of the headlands.

No research has been undertaken in the intertidal and subtidal habitats included in this assessment, although the plants and animals are expected to be similar to those in other exposed soft-sediment and nearshore rocky reef habitats along the NSW coast, as described in chapter 2.

Figure 5.10. Seabed habitats within the Celito South Sanctuary Zone

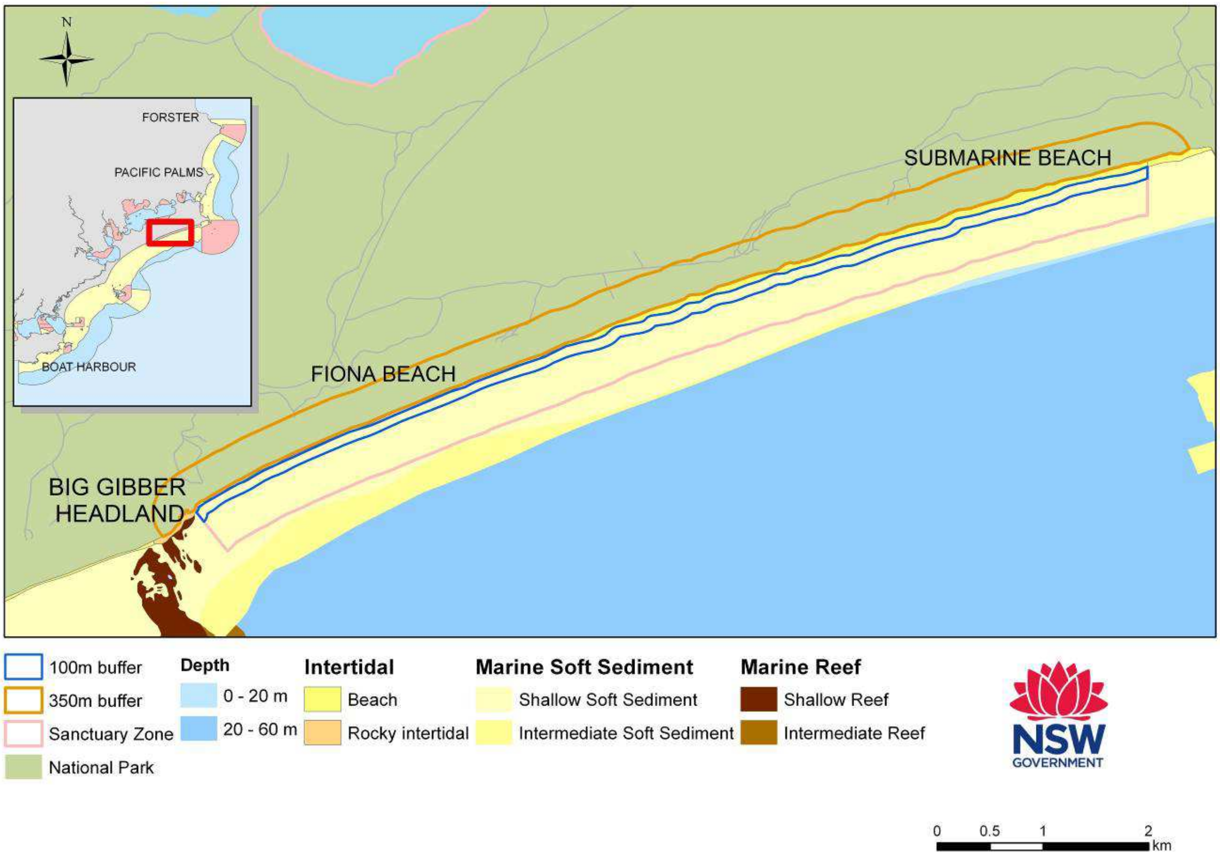


Fiona Sanctuary zone

The Fiona Sanctuary Zone extends along the shoreline between the northern end of Submarine Beach and the rocky headland at the southern end of Fiona Beach, known as Big Gibber Headland (Figure 5.11). The entire zone is adjacent to central section of the Myall Lakes National Park, and access is limited to a small section of the coast. The shoreline components of this sanctuary zone consist of the two defined beaches which have a combined length approximately 8.3 kilometres (Table 5.5). The subtidal habitat consists exclusively of soft-sediments, dominated by sand of varying particle size.

No research has been undertaken in the intertidal and subtidal habitats included in this assessment, although the plants and animals are expected to be similar to those in other exposed soft-sediment habitats along the NSW coast, as described in chapter 2. However, data indicates that beach habitat is used by pied and sooty oyster catches and little terns. It is also a location known for the presence of juvenile white sharks close to shore.

Figure 5.11. Seabed habitats within the Fiona Beach Sanctuary Zone

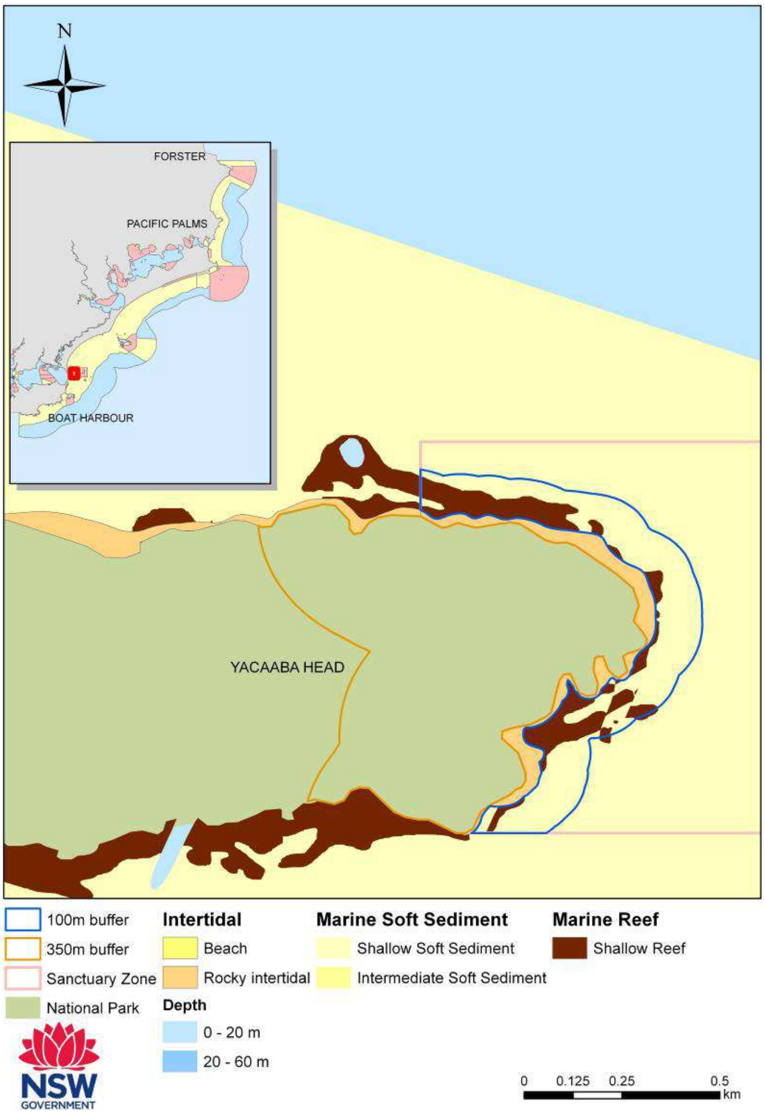


Yacaaba Sanctuary zone

The Yacaaba Sanctuary Zone extends along the shoreline between the northern and southern side of Yacaaba Headfor a distance of approximately 1.6 kilometres (Figure 5.12). The entire sanctuary zone is adjacent to a southern section of the Myall Lakes National Park, and access is limited. The shoreline consists exclusively of rocky shore, which is characterised by steep topography resulting in a tidal zone that is either narrow or absent along much of the shoreline. The subtidal habitat adjacent to the rocky shore is mostly continuous, but narrow and patchy around the headland.

No research has been undertaken in the intertidal and subtidal habitats included in this assessment, although the plants and animals are expected to be similar to those in other exposed soft-sediment and nearshore rocky reef habitats along the NSW coast, as described in chapter 2.

Figure 5.12. Seabed habitats within the nearshore component of the Yacaaba Sanctuary Zone



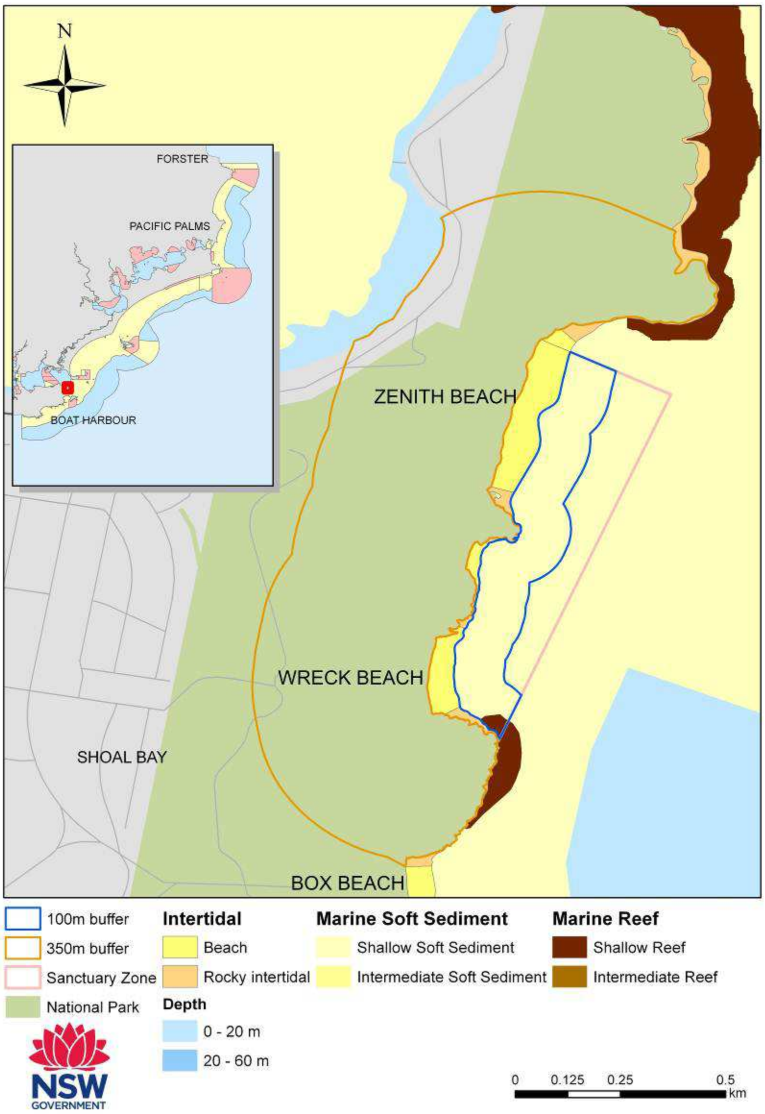
Zenith Sanctuary zone

The Zenith Sanctuary Zone extends along the shoreline between the northern end of Zenith Beach and the southern end of Wreck Beach (Figure 5.13). The entire sanctuary zone is adjacent to a section of the Tomaree National Park and easy access is limited to a small section of the coast in the north. The shoreline components of this sanctuary zone consist of three defined beaches that vary considerably in length, the largest being Zenith Beach at approximately 350 metres. The sanctuary zone has a total coastline length of approximately 1.1 kilometre (Table 5.5).

The intertidal habitats are characterised by sand dominated beaches separated by headlands that have moderately steep topography resulting in small tidal zones along much of the shoreline. The subtidal habitat is dominated by soft-sediments, with only a small area of rocky reef adjacent some of the headland in the most southern section of the sanctuary zone.

No research has been undertaken in the intertidal and subtidal habitats included in this assessment, although the plants and animals are expected to be similar to those in other exposed soft-sediment habitats along the NSW coast, as described in chapter 2. This includes a range of fish species that are known to commonly occur on ocean beach habitats such as sand whiting, tailor, salmon, and yellowfin bream.

Figure 5.13. Seabed habitats within the Zenith Beach Sanctuary Zone



Fingal Island Sanctuary zone

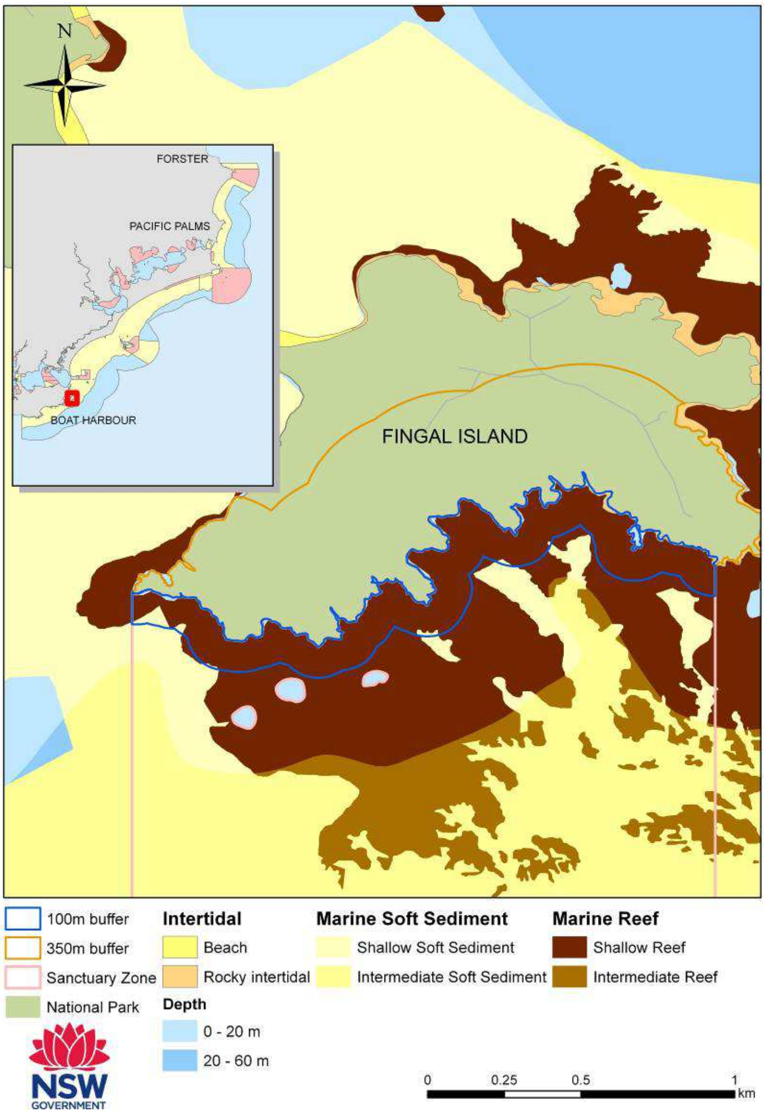
The Fingal Island Sanctuary Zone extends along the shoreline on the southern side of Fingal Island for a distance of approximately 4.0 kilometres (Figure 5.14, Table 5.5). The entire sanctuary zone is adjacent to a section of the Tomaree National Park, and access is limited. The shoreline consists exclusively of rocky shore, which is characterised by moderate topography resulting in a narrow tidal zone along much of the shoreline. The subtidal habitat adjacent to the rocky shore is continuous around the headland.

The key ecological features of this shoreline zone are:

- Rocky intertidal areas have relatively low species richness and abundance compared to offshore sites
- Shallow reef habitat that contains a range of kelp, ascidian and sponge dominated benthic assemblages

- Rock platforms used by sooty oyster catchers

Figure 5.14. Seabed habitats within the nearshore component of the Fingal Island Sanctuary Zone



Social uses in sanctuary zones

Human use of the sanctuary zones vary considerably, reflecting differences in access, location to populations centres, traditional uses and tourism activities. Primary uses were identified for each zone. The marine park is used for a large variety of social and commercial activities apart from recreational fishing. In some cases, shore-based recreational fishing can come into conflict with some other uses, such as fishing close to surfing and/diving locations (Table 5.6). For evaluation of social risk the number of activities were grouped into minimal (0-2), low (3-5), moderate (6-8), and high (>8). The use of the sanctuary zone for ongoing monitoring of ecological assets were also identified

Table 5.6. Social uses (other than by anglers) and scientific study of nearshore sanctuary zones in Port Stephens-Great Lakes Marine Park

Sanctuary Zone	Social Use	Scientific study
The Pinnacle	Snorkel Kayaking	None known
Celito South	Snorkel Kayaking	None known
Fiona Beach	Swimming Surfing Walking Passive beach use	None known
Yacaaba	Snorkel Diving Boating Kayaking	None known
Zenith	Swimming Surfing Walking Passive beach use Snorkel Boating Kayaking	None known
Fingal Island	Boating Kayaking	Reef fish monitored using Baited Remote Underwater Video and Underwater Visual Census

Jervis Bay Marine Park

The Jervis Bay Marine Park was declared in 1998 and its first zoning plan commenced in October 2002. The marine park covers an area of approximately 220 square kilometres and encompasses Jervis Bay and the coast from Kinghorn Point (north of the bay) to the northern headland of Sussex Inlet (in the south). The boundary of the marine park extends from the high tide mark to 1.5 kilometres offshore and contains the tidal waters of the estuaries within these boundaries (see Figure 1.2).

Jervis Bay Marine Park is visually stunning both below and above the water due to its geology and oceanography. It is relatively natural, undeveloped coastline that is generally unpolluted, clean environment with a unique mix of ecosystems and habitats (e.g. subtidal rocky reefs, seagrass beds, mangroves, saltmarsh, intertidal and subtidal soft-sediments, intertidal rocky shores and pelagic waters). In addition, the proximity of the Jervis Bay to the oceanic shelf mean that the oceanic conditions play an important role in the ecology of the area. The interaction of temperate and subtropical currents and other oceanographic processes, in combination with the complex array of habitats, support a rich diversity of animal and plant life.

Reef habitats are extensive, and recent swath mapping has been very informative on their extent, distribution and structural complexity (NSW MPA 2010). Previously unmapped areas of reef have been identified, and some areas that were mapped approximately have now been mapped accurately in high-resolution (NSW MPA 2010). This includes large areas of complex reef in Crookhaven Bight adjacent to Beecroft and Bherwerre peninsulas.

Shallow reefs (those less than 20 metres deep) are characterised by abundant macroalgae, dominated by the kelp *Ecklonia radiata*, and various species of *Sargassum* and *Cystophora*, with an understorey of coralline algae and foliose algae. Sponges and other sessile invertebrates can also occur on shallow reefs, but are not generally dominant.

The region also supports more than 230 species of algae and hundreds of species of invertebrates (predominantly molluscs, crustaceans, polychaetes, echinoderms, and sponges). Over 210 species of reef fish have been recorded in the marine park, some of which are threatened or protected. Some of these are endemic or have an important ecological role. Some are also valued by fishers, and, as is generally the case for reef fish in a localised area, many species are uncommon. Mammals, reptiles and birds are permanent residents, seasonal visitors, and individuals just passing through. Some are threatened species that benefit from the resources in and condition of the marine park.

This chapter focuses specifically on those nearshore ocean habitats included in the assessment relating to the amnesty on shore-based recreational fishing: intertidal soft-sediment (beach), subtidal soft-sediment, intertidal reef (rocky shore) and subtidal reef. The total length of open ocean coastline in the marine park is approximately 62 kilometres, which consists of 11.0 kilometres of Sanctuary Zone and 50.8 kilometres of Habitat Protection Zone, with much of the marine park located within Jervis Bay.

Ocean soft-sediments

The coastline of the marine park includes ocean beaches that are generally backed by dune systems and large coastal barriers (e.g. Warrain beach and Bherwerre beach). The small town of Currarong sits at the southern end of one of the major beaches and the Wreck Bay Aboriginal Community sits above Summer Cloud Bay beach. All of the ocean beaches within the marine park lie adjacent to the Jervis Bay National Park, Department of Defence Beecroft Weapons Range and Booderee National Park.

Ocean rocky reefs

Intertidal rocky shores throughout the Jervis Bay Marine Park are generally associated with the large headlands provided by Beecroft and Bherwerre Peninsulas. In many locations, these are almost vertical rock and are very exposed to oceanic swell. There are also a few small intertidal reefs that intersperse small embayments (e.g. Wreck Bay and Caves Beach) and some of the long beaches in the area (e.g. Kinghorn Point). The majority of reefs around Jervis Bay are rugged, high complexity reefs made of sandstone and are generally associated with the Beecroft and Bherwerre Peninsulas. Some of the reefs to the north are, however, made of siltsone which tends to form gently sloping, low profile reefs.

Sanctuary zone assessments

There are four open coast sanctuary zones included in the amnesty and assessed as part of this report. These are distributed across the length of the marine park, with all sanctuary zones having only one location where there is a shoreline component to the zone (Table 5.6).

Table 5.6. Characteristics of ocean beach and headland sanctuary zones in Jervis Bay Marine Park

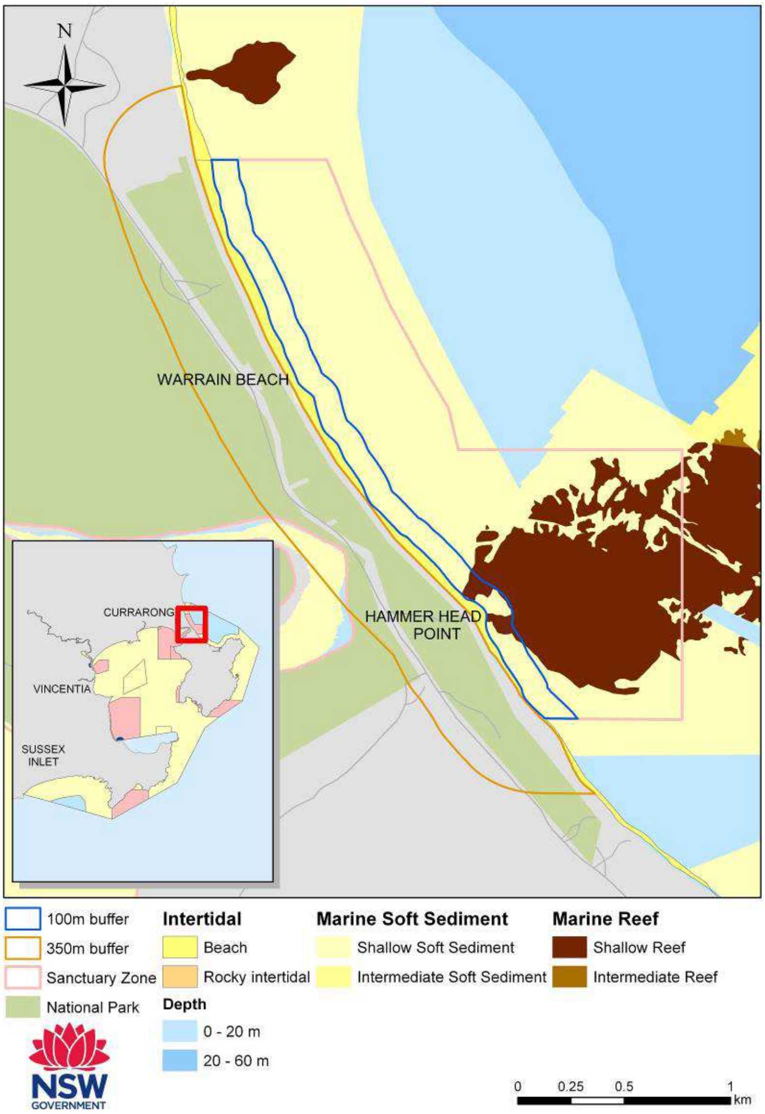
Zone	Length of Coast (km)	Number of Beaches	Name
Hammer Head	3.0	1	405 Currarong
Point Perpendicular/Crocodile Head	3.7	0	
Bowen Island	0.1	0	
St Georges Head/Steamers Head	4.3	0	

Hammer Head Sanctuary Zone

The Hammer Head Sanctuary Zone extends along the mid-section of the Warrain Beach in the southern section of Crookhaven Bight for a distance of approximately 3.0 kilometres (Figure 5.15). The zone is dominated by a north easterly facing sandy beach that is general coarse grained and iron rich giving its yellow colouration (Thom 1987). A small section of subtidal reef is present in the southern section of the zone that gradually slopes down to approximately 10 metres within 150 metres of the shore (NSW MPA 2010). The entire shoreline component of the zone is adjacent to the Jervis Bay National Park.

The key ecological features of this shoreline zone have not been examined, but the soft-sediments would be expected to contain assemblages of plants and animals consistent with other exposed beaches, including a molluscs, worms and a range of other small and medium-sized invertebrates (e.g. amphipods and crabs) (see chapter 2). The associated fish species are expected to be similar to other beach sites, for example flathead, mulloway, yellow fin bream, salmon, stingrays and sharks. It is likely that grey nurse sharks traverse along this beach as part of their coastal movement. Bird species includes pied oyster catchers, cormorants and sooty oyster catchers and other species are likely to forage over the intertidal shore at low tide.

Figure 5.15. Seabed habitats within the nearshore component of the Hammer Head Sanctuary Zone



Point Perpendicular/Crocodile Head Sanctuary Zone

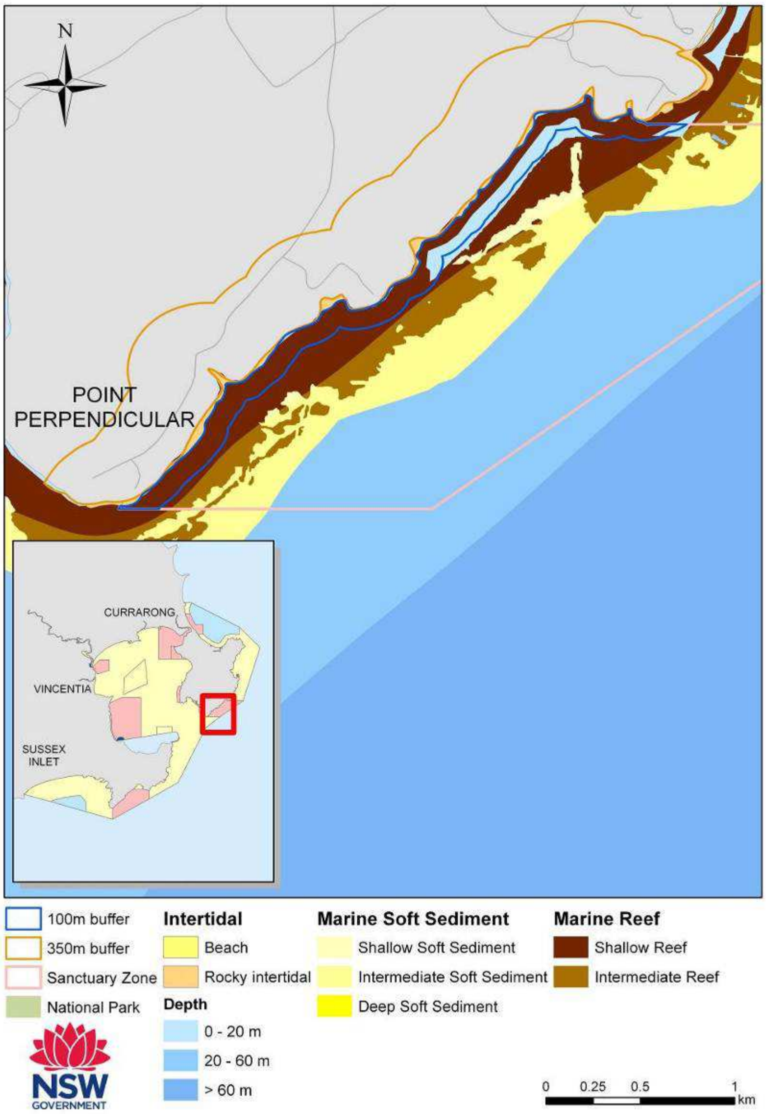
Point Perpendicular/Crocodile Head Sanctuary Zone extends along the eastern side of Beecroft Peninsula from near the tip of Point Perpendicular north for a distance of approximately 3.7 kilometres (Figure 5.16, Table 5.6). There is restricted and limited access to this location as it is adjacent to the Dept. of Defence weapons range. The shore is generally made up of sheer vertical cliffs, and hence access to the shoreline is very limited. The extensive subtidal rocky reef is highly complex as it consists of vertical cliffs, large boulders and overhangs and descends rapidly to 40 metres depth within a few hundred metres of the shore (NSW MPA 2010). There are no beaches within this Sanctuary Zone.

The key ecological features of this shoreline zone are:

- Subtidal rocky reefs contain a range of kelp, turfing and foliose algae, and large areas of encrusting coralline algae. Associated with these cliff faces, cracks and crevices and the macroalgae would be a diverse range of invertebrate grazers (e.g. limpets), filter-feeders (e.g. barnacles, cunjevoi, sponges) and small and large mobile invertebrates (e.g. amphipods, crabs, slipper lobsters, lobsters, octopus).

- Pelagic fish species such as snapper, yellowtail kingfish, yellowtail scad and slimy mackerel common.
- Important location for large predators such as common dolphins and sharks, including grey nurse sharks
- A range of birds such as penguins, Australasian gannets and shearwaters also inhabit and feed in this area.

Figure 5.16. Seabed habitats within the nearshore component of the Point Perpendicular/Crocodile Head Sanctuary Zone



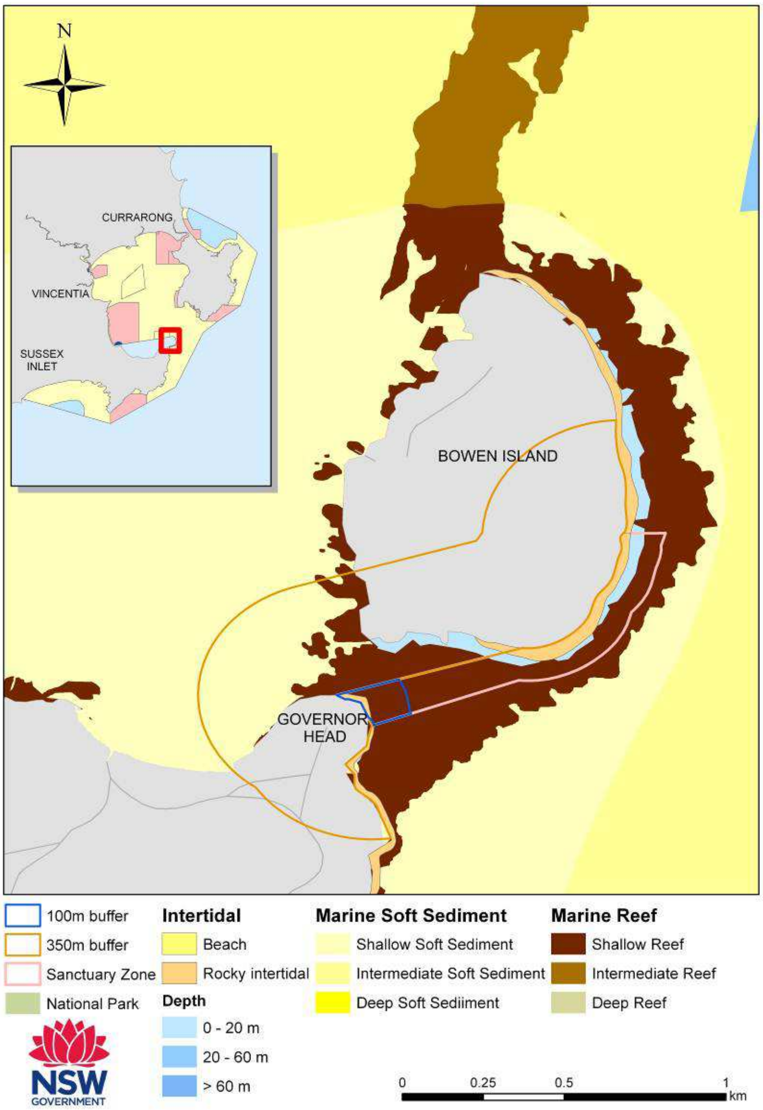
Bowen Island Sanctuary Zone

Bowen Island Sanctuary Zone is on the south-eastern side of Bowen Island at the southern headland at the entrance to Jervis Bay (Figure 5.17). The shoreline component of the zone only extends for approximately 100 metres on the northern end of Governor Head. There is limited access to the zone as the adjacent Booderee National Park restrict access to formed walking trails. The shoreline consists entirely of intertidal rocky reef, which extends into continuous subtidal rocky reef that surrounds the eastern section of the island. There are no beaches within this Sanctuary Zone.

The key ecological features of this shoreline zone are:

- Subtidal rocky reefs contain a range of kelp, turfing and foliose algae, and large areas of encrusting coralline algae.
- Pelagic fish species such as yellowtail kingfish, yellowtail scad and slimy mackerel common.
- Important location for large predators such as common dolphins, seals and sharks, including grey nurse sharks.
- Sooty oyster catchers occur on the rocky shore that dominates this zone.
- A range of birds such as penguins, Australasian gannets and shearwaters also inhabit and feed in this area.

Figure 5.17. Seabed habitats within the Bowen Island Sanctuary Zone



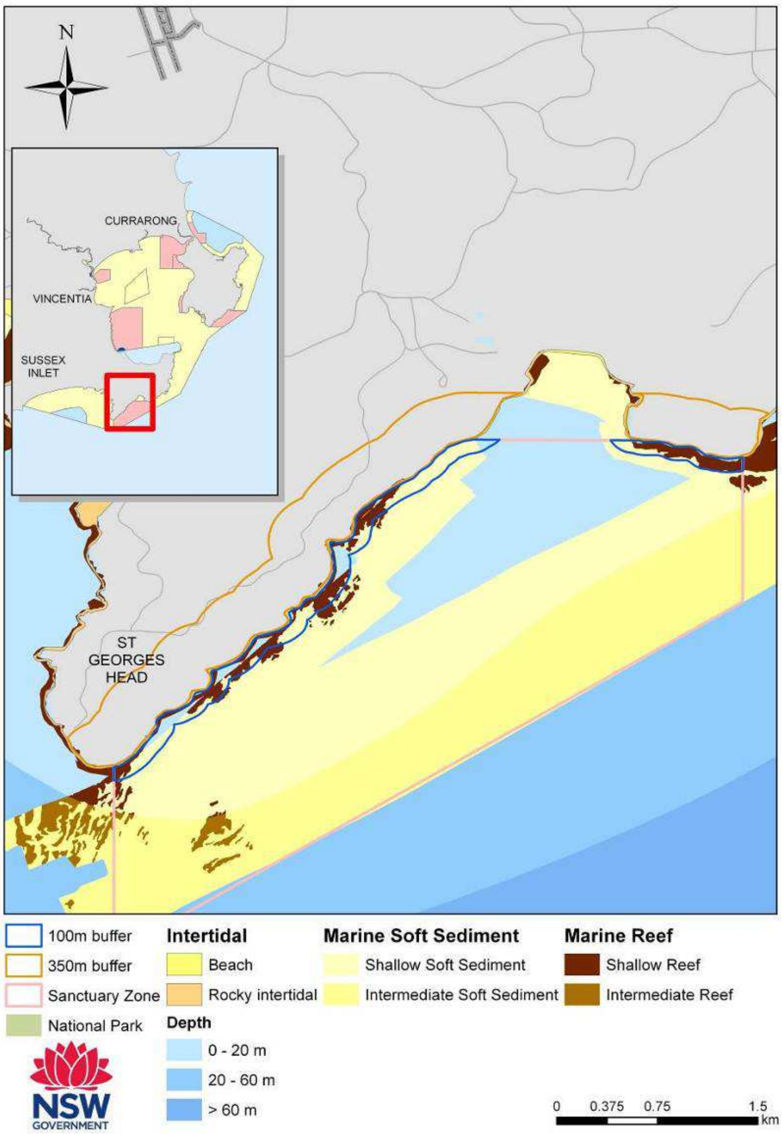
St Georges/Steamers Head Sanctuary Zone

St Georges/Steamers Head Sanctuary Zone extends along the eastern side of Bherwerre Peninsula from near the tip of St Georges Head north for a distance of approximately 4.3 kilometres (Figure 5.18, Table 5.6). There is limited access to the zone as the adjacent Booderee National Park restrict access to a limited number of walking trails. The shore is generally made up of sheer cliffs, and hence the intertidal rocky reef is small. The subtidal rocky reef is continuous along the shore, but narrow in most places and only extending into large areas of reef in a few locations along the zone. There are no beaches within this Sanctuary Zone.

The key ecological features of this shoreline zone are:

- Subtidal rocky reefs contain a range of kelp, turfing and foliose algae, and large areas of encrusting coralline algae.
- Pelagic fish species such as snapper, yellowtail kingfish, yellowtail scad and slimy mackerel common.
- Important location for large predators such as dolphins and sharks, including white sharks.
- A range of birds such as Australasian gannets and shearwaters also inhabit and feed in this area.
- Steamer's Head itself is a large seal haul-out location with between 50 – 120 seals during the year (Burleigh et al. 2008).

Figure 5.18. Seabed habitats within the St Georges/Steamer Head Sanctuary Zone



Social uses in sanctuary zones

Human use of the sanctuary zones vary considerably, reflecting differences in access, location to populations centres, traditional uses and tourism activities. Primary uses were identified for each zone. The marine park is used for a large variety of social and commercial activities apart from recreational fishing. In some cases, shore-based recreational fishing can come into conflict with some other uses, such as fishing close to surfing and/diving locations (Table 5.7). For evaluation of social risk the number of activities were grouped into minimal (0-2), low (3-5), moderate (6-8), and high (>8). The use of the sanctuary zone for ongoing monitoring of ecological assets were also identified.

Table 5.7. Social uses (other than by anglers) and scientific study of nearshore sanctuary zones in Jervis Bay Marine Park

Zone	Social Use	Scientific study
Hammer Head	Beach driving Surfing Swimming Walking	None known
Point Perpendicular/Crocodile Head	Scuba diving	Underwater Visual Census and Baited Remote Underwater Video surveys
Bowen Island	Snorkelling Scuba diving	None, but scientific research occurs in the contiguous sanctuary zone in the Commonwealth Booderee National Park
St Georges Head/Steamers Head	Scuba diving	None known

Batemans Marine Park

The Batemans Marine Park (BMP) was declared in 2007 and covers an approximately 85,000 hectares of marine and estuarine habitats and extends from near Bawley Point in the north to the southern side of Wallaga Lake ocean entrance. The marine park includes all embayments, estuaries, rivers, creeks and lakes (excluding Nargal Lake) to the limit of tidal influence, and from the high water mark to three nautical miles offshore, including Montague Island (see Figure 1.2).

The extent of the Batemans Marine Park was identified for its many outstanding ecosystems, habitats and species meeting criteria for comprehensiveness and representativeness; it's high degree of naturalness and catchment protection; recommendations from previous assessments; and the extent to which it complements existing Marine Protected Areas and conservation management strategies (Breen et al. 2004).

An outstanding feature of the marine park are the numerous offshore islands such as the Tollgate Islands and Montague Island, that provide breeding areas for many seabird species while the surrounding reef habitats support populations of the endangered grey nurse shark, pelagic fish, seals and penguins. A number of coastal lakes and lagoons including Durras, Brunderee, Tarourga and Brou Lake are highly significant as they remain in relatively natural condition. The Clyde River, Batemans Bay, Moruya River, Tuross River and Wagonga Inlet also support significant estuarine habitats including seagrass, mangrove and saltmarsh.

Batemans Marine Park encompasses an area with diverse habitats including intertidal and subtidal rocky reefs, soft sediments, sandy beaches, seagrass beds, mangroves, saltmarsh and open waters which all support distinct groups of plants and animals. Rocky reef habitats are particularly diverse, with large areas of complex reef at depths from the shoreline to the offshore extent of the marine park. Many of the shallow reefs are dominated by a canopy-cover of large brown seaweeds such as kelp *(Ecklonia radiata)* and crayweed *(Phyllospora comosa)*. In contrast, some shallow reefs are completely devoid of kelp and other seaweeds and are known as 'barrens'. These habitats are facilitated by the grazing pressure by dense populations of sea urchins and a variety of herbivorous fish. The biological communities of deeper reefs are dominated by a diverse range of sponges, sea whips, gorgonian sea fans as well as a high diversity of fish.

The many offshore islands of BMP are important to a range of resident and migratory species. Montague Island is significant as it is a haul-out site for Australian and New Zealand fur seals and supports one of the largest colonies of little penguin on the east coast of Australia. The islands also provide important breeding habitat for a range of seabirds including gannets, the threatened sooty oystercatcher and shearwaters. Underwater, some of the islands have unique sub-tidal habitats including gutters and caves that are critical to the east coast population of the endangered Grey Nurse Shark.

Seabed habitats have been mapped throughout extensive areas of the marine park, and a description of the extent, distribution and structure of intertidal and subtidal habitats in ocean areas is presented in Jordan et al. (2010). This chapter focuses specifically on those nearshore ocean habitats included in the assessment of the amnesty on shore-based recreational fishing, which includes intertidal soft-sediment (beach), subtidal soft-sediment, intertidal reef (rocky shore) and subtidal reef. The total length of open ocean coastline in the marine park is approximately 162 kilometres, which consists of 34.5 kilometres of Sanctuary Zone, 121.3 kilometres of Habitat Protection and General Use Zones and 6.6 kilometre of Special Purpose Zone.

Ocean soft-sediments

The coastline of the marine park includes many ocean beaches that are typically backed by low to steep vegetated coastal cliffs or dune systems. These range from small embayed beaches dominated by rocky headlands at either end, such as those in the Murramarang-Durras and Narooma regions, to large coastal barriers such as that occurring between Moruya and Broulee. Some beaches are interspersed with intertidal and subtidal rocky reef that reduces their exposure to swell and many feature an estuary mouth at either the southern or northern extremity. Relative to the other marine parks the ocean beaches in Batemans Marine Park are generally small and have significant areas of adjacent rocky reef.

Ocean rocky reefs

Intertidal rocky shores throughout the Batemans Marine Park occur mostly adjacent and below rocky headlands, and occasionally along stretches of beach. They vary greatly in extent, structure and exposure - in some areas the rock strata show significant deformation such as folding (i.e. anticlines and synclines) due to geological processes of compression and uplift over time. Seven rock platforms within the marine park have been identified as being significant in terms of their unique physical characteristics, natural condition and associated biota. These include Murramarrang Point, O'Hara Head, Snapper Point, Point Upright, Wasp Head, Flat Rock Island, Broulee Point and Broulee Island (Short 1995). In addition the intertidal rocky shores at Tuross Head, Dalmeny Head and Wagonga Head display a wide range of habitat types with concomitant high species diversity. As many as 134 species have been recorded from Wagonga Head (Otway 1999).

Sanctuary zone assessments

There are six open coast sanctuary zones included in the amnesty, and these are distributed across the length of the marine park, with some sanctuary zones having several locations where there is a shoreline component to the zone (Table 5.8).

North Head Sanctuary Zone

The North Head Sanctuary Zone extends along the shoreline between the northern end of the headland of Oakey Beach to Three Island Point in the south, and to a maximum distance of approximately 1 kilometre offshore (Figure 5.19). The entire sanctuary zone is adjacent to the Murramarang National Park, and easy access is limited to a small section of the coast. The shoreline components of this sanctuary zone consist of three defined beaches, with one of these dominated by pebbles. The sanctuary zone has a total coastline length of approximately 4.8 kilometres (Table 5.8).

The only intertidal and subtidal soft-sediment habitats occur adjacent to Oakey Beach in the north and North Head Beach in the south. Both of these beaches are only around 300 metres long and are bordered by extensive rocky reefs. The remaining area contains continuous rocky shore adjacent to a large area of continuous subtidal rocky reef. Much of the rocky shore adjacent to the headlands contains a wide expanse of intertidal habitat.

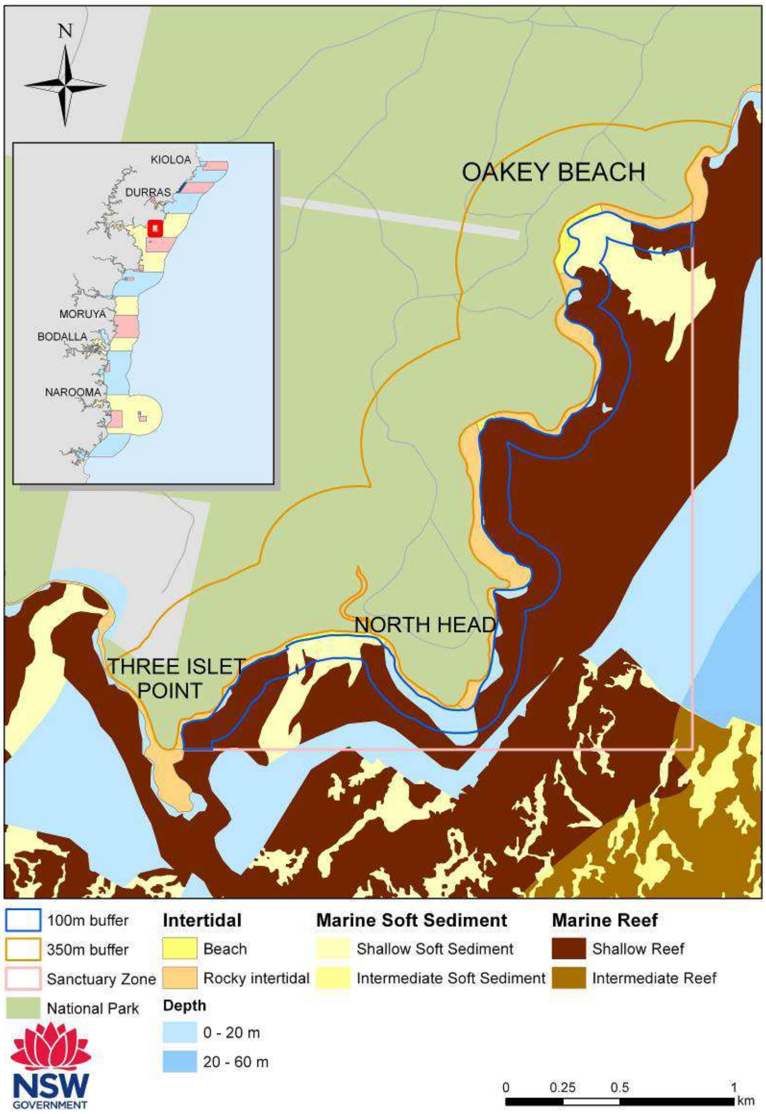
The key ecological features of this shoreline zone are:

- Subtidal rocky reefs contain a range of kelp, coralline turfing and foliose algae, and large areas of encrusting coralline algae.
- Grey nurse are likely to occur at this location due to the vicinity of grey nurse shark aggregation sites. There is also the presence of suitable black cod habitat close to shore. Pied oyster catchers are likely to occur at this location.

Table 5.8. Characteristics of ocean beach and headland sanctuary zones in Batemans Marine Park

Sanctuary Zone	Length of Coast (km)	Number of Beaches	Beach number -name
North Head	4.8	3	520 Oaky
			521 Honeysuckle
			522 North Head
Burrewarra (North Section)	4.7	5	548 Jimmies Island
			549 Nuns
			550 Black
			551 Guerilla Bay North
			552 Guerilla Bay
Burrewarra (South Section)	2.8	4	553 Burrewarra Point 1
			554 Burrewarra Point 2
			555 Burrewarra Point 3
			556 Burrewarra Point 4
Broulee Island	2.1	1	560 Broulee
Mullimburra	7.9	10	568 Congo
			569 Congo Point South
			570 Congo Point South 2
			571 Meringo
			574 Mullimburra Point South 1
			575 Mullimburra Point South 2
			576 Mullimburra Point South 3
			577 Kellys
			578 Bingie Bingie Point
			579 Bingie
Brou Beach	3.0	1	590A Brou
Bullengella Lake - Corunna Lake	5.8	6	603 Bullengulla
			605 Barunga Point
			606 Bogola
			607 Fullers North
			608 Fullers South
			609 Loader

Figure 5.19. Seabed habitats within the North Head Sanctuary Zone



Burrewarra Sanctuary Zone(North Section)

The Burrewarra Sanctuary Zone (north section) extends between the northern end of the headland adjacent to Rosedale to the southern end of Guerilla Bay beach (Figure 5.20). The section contains five defined beaches, although all of these are small, several being <100 metres long. This northern section of the sanctuary zone has a coastline length of approximately 4.7 kilometres (Table 5.8), is easily accessed from a number of locations, and is adjacent to a number of major townships adjacent to Batemans Bay.

Intertidal and subtidal soft sediment habitat is restricted to the small beaches and areas immediately adjacent. The rest of the area in this section of the sanctuary zone contains rocky shore or subtidal rocky reef that is mostly continuous.

The key ecological features of these shoreline zone areas are:

- Subtidal rocky reefs contain a range of kelp, coralline turfing and foliose algae, and large areas of encrusting coralline algae.
- Grey nurse are known to occur at this location. There is also the presence of suitable black cod habitat close to shore.

Burrewarra Point Sanctuary Zone (South Section)

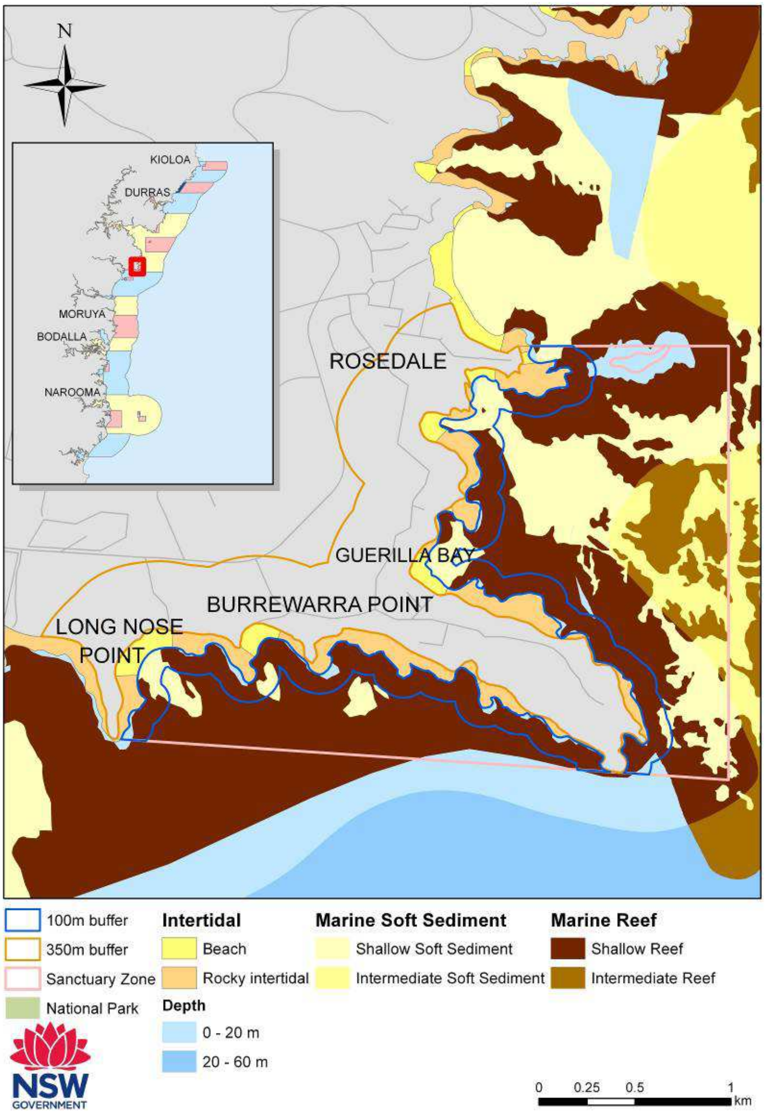
The Burrewarra Sanctuary Zone (south section) extends from 700 metres on the southern shore of Burrewarra Point to Long Nose Point (Figure 5.20). The section contains four defined beaches, although all of these are small, several being <150 metres long, and are dominated by pebbles and cobbles. This southern section of the sanctuary zone has a coastline length of approximately 2.8 kilometres (Table 5.8).

Intertidal and subtidal soft sediment habitat is restricted to several small areas north of Long Nose Point. The rest of the area in this section of the sanctuary zone contains rocky shore or subtidal rocky reef that is mostly continuous and extends a considerable distance offshore.

The key ecological features of these shoreline zone areas are:

- Subtidal rocky reefs contain a range of kelp, coralline turfing and foliose algae, and large areas of encrusting coralline algae.
- Grey nurse are known to occur at this location. There is also the presence of suitable black cod habitat close to shore.

Figure 5.20 Seabed habitats within the Burrewarra Sanctuary Zone



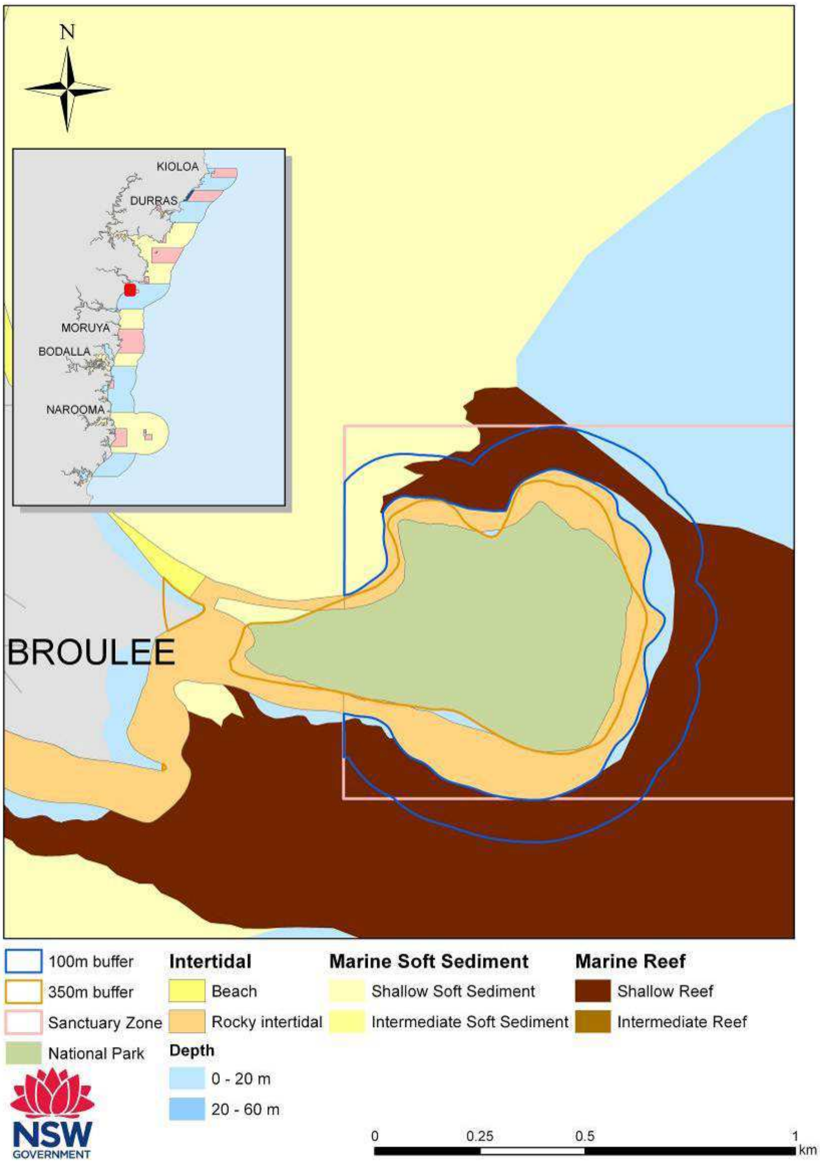
Broulee Island Sanctuary Zone

The Broulee Island Sanctuary Zone extends around the majority of the island to a line several hundred metres east of the mainland coast (Figure 5.21). The sanctuary zone has a coastline length of approximately 2.1 kilometres. Intertidal and subtidal soft sediment habitat is restricted to a small area on the northern side of the island and extends for <200 metres. The rest of the sanctuary zone contains rocky shore or subtidal rocky reef that is mostly continuous around the island. The intertidal reefs are particularly extensive around the island, and contains large tide pools and extensive areas of boulders.

The key ecological features of these shoreline zone areas are:

- Subtidal rocky reefs contain a range of kelp, coralline turfing and foliose algae, and large areas of encrusting coralline algae.
- Rocky shore is an important part of this zone.

Figure 5.21 Seabed habitats within the Broulee Island Sanctuary Zone



Mullimburra Sanctuary Zone

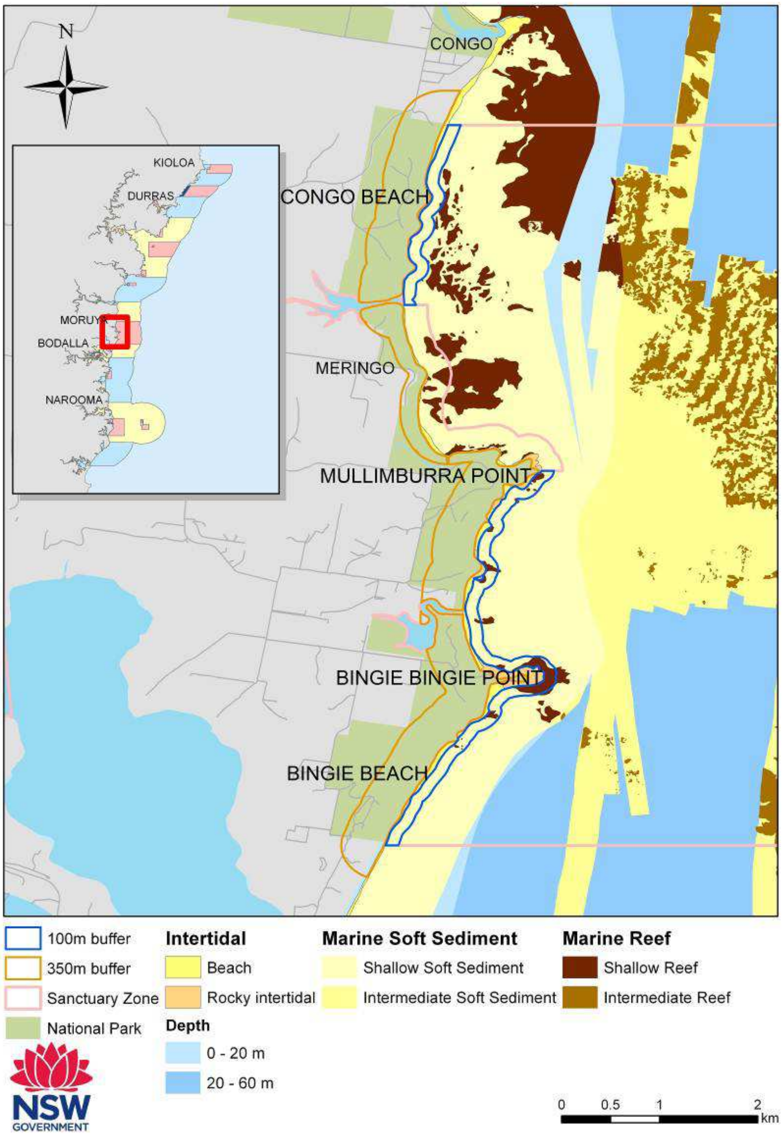
The Mullimburra Sanctuary Zone contains two areas of shoreline to the north and south of the Meringo region. The northern area extends from approximately 2 kilometres south of Congo Point to the mouth of Meringo Lake (Figure 5.22). The shoreline consist of four defined beaches, the longest being the southern end of Congo Beach at approximately 650 metres. This section is dominated by intertidal and subtidal soft-sediment habitat, although around 500 metres of rocky shore exists between the beaches. This intertidal reef is adjacent to soft-sediment habitat.

The southern area extends from the southern end of Mullimburra Point to approximately mid way along Bingie Beach (Figure 5.22). The shoreline consist of six defined beaches, the longest being the section of Bingie Beach at 1.0 kilometres, apart from the small sections of intertidal and subtidal reef adjacent to the four most prominent headlands. This is most extensive around Bingie Point, with several hundred metres of the rocky shore extending into subtidal reef that is continuous around the headland. The entire sanctuary zone is adjacent to the Eurobodalla National Park, and access is available limited to several sections of the coast. The sanctuary zone has a total coastline length of approximately 7.9 kilometres.

The key ecological features of these shoreline zone areas are:

- Ocean beach habitat inshore of patchy subtidal shallow rocky reef in the northern section
- Subtidal rocky reef adjacent to the headlands that contain a range of kelp, coralline turfing and foliose algae, and large areas of encrusting coralline algae

Figure 5.22 Seabed habitats within the nearshore component of the Mullimburra Sanctuary Zone



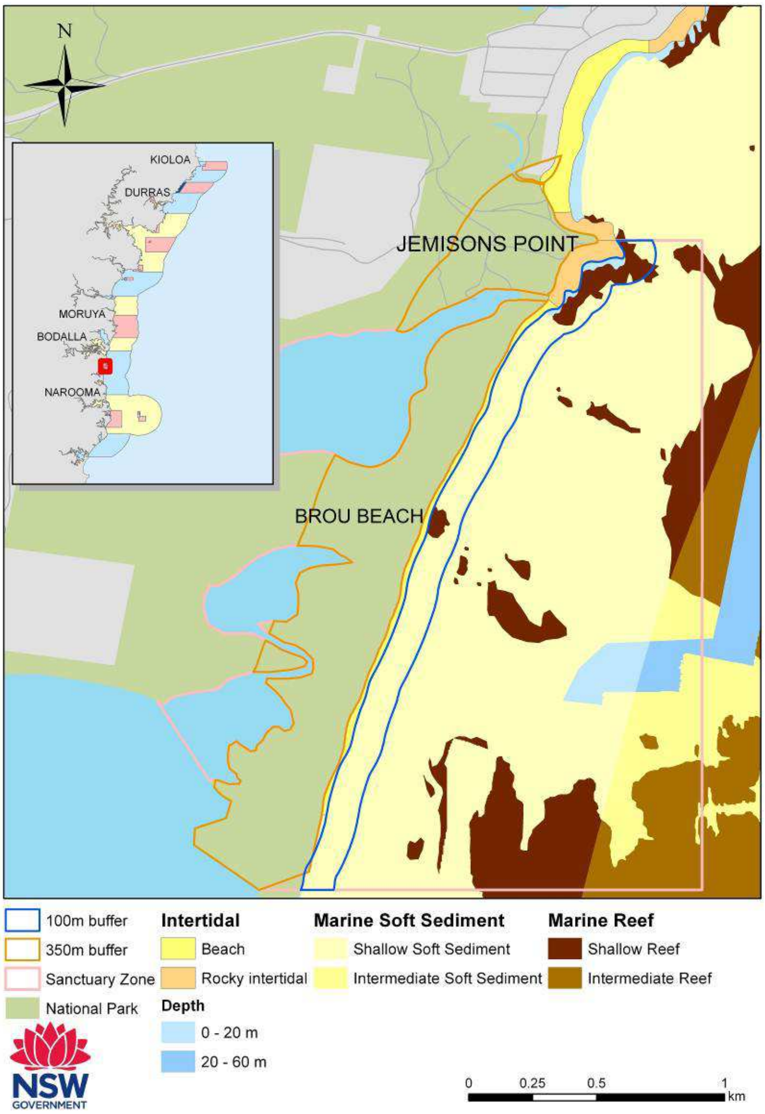
Brou Beach Sanctuary Zone

The Brou Beach Sanctuary Zone extends along the long section of shoreline from Jemisons Point to the mouth of Brou Lake (Figure 5.23). The shoreline consists of one defined beach that is approximately 2.5 kilometres long, and a section of rocky shore adjacent to the headland in the north. A small area of subtidal reef is present adjacent to the rocky shore, with the rest of the subtidal habitat being sand. The sanctuary zone has a coastline length of approximately 3.0 kilometres. The entire sanctuary zone is adjacent to the Eurobodalla National Park, and access is available limited to several sections of the coast.

The key ecological features of these shoreline zone areas are:

- Ocean beach habitat inshore of patchy shallow and intermediate depth rocky reef
- Subtidal rocky reefs adjacent to the headland that contains a range of kelp, coralline turfing and foliose algae, and large areas of encrusting coralline algae.

Figure 5.23 Seabed habitats within the Brou Beach Sanctuary Zone



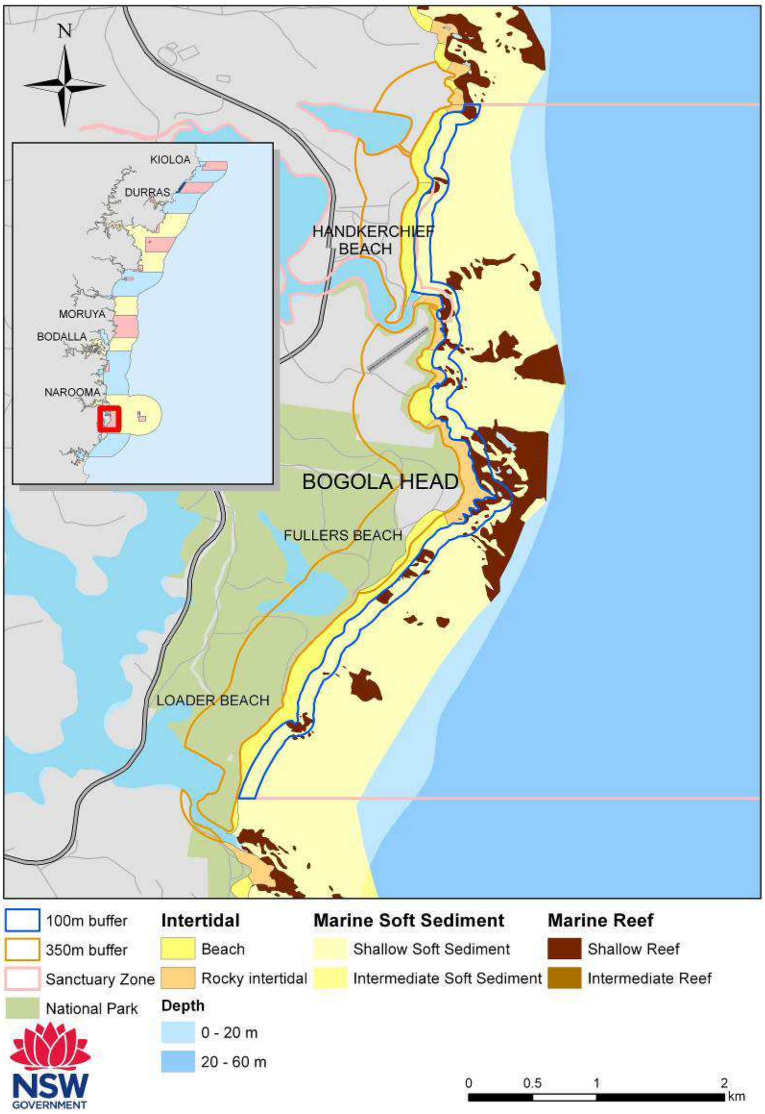
Bullengella Lake - Corunna Lake Sanctuary Zone

The Bullengella Lake-Corunna Lake Sanctuary Zone extends along a long continuous section of coast from just south of Glass House Rocks in the north to Loader Beach in the south (Figure 5.24). The shoreline consists of six defined beaches, the longest being in the southern end of the zone at around 1.0 kilometres. Overall, the sanctuary zone is dominated by intertidal and subtidal soft-sediment habitat, although around 900 metres of rocky shore exists adjacent to Bogola Head. This intertidal reef is adjacent to an area of patchy subtidal rocky reef habitat. The sanctuary zone has a coastline length of approximately 5.8 kilometres. Most of the southern section of the sanctuary zone is adjacent to the Eurobodalla National Park, and access is available limited to several sections of the coast.

The key ecological features of these shoreline zone areas are:

- Subtidal rocky reefs contain a range of kelp, coralline turfing and foliose algae, and large areas of encrusting coralline algae.
- Ocean beach habitat inshore of area of patchy shallow rocky reef

Figure 5.24 Seabed habitats within the Bullengella Lake - Corunna Lake Sanctuary Zone



Social use in sanctuary zones

Human use of the sanctuary zones vary considerably, reflecting differences in access, location to populations centres, traditional uses and tourism activities. Primary uses were identified for each zone. The marine park is used for a large variety of social and commercial activities apart from recreational fishing. In some cases, shore-based recreational fishing can come into conflict with some other uses, such as fishing close to surfing and/diving locations (Table 5.9). For evaluation of social risk the number of activities were grouped into minimal (0-2), low (3-5), moderate (6-8), and high (>8). The use of the sanctuary zone for ongoing monitoring of ecological assets were also identified.

Table 5.9. Social uses (other than by anglers) and scientific study of nearshore sanctuary zones in Batemans Marine Park

Zone	Social use	Scientific reference use
North Head	Scuba diving Snorkelling Swimming Walking	Shallow reef fish and habitat monitoring using underwater visual census
Burrewarra (North Section)	Scuba diving Snorkelling Swimming Walking	Reef fish monitored using Baited Remote Underwater Video. Shallow reef fish and habitat monitoring using Underwater Visual Census
Burrewarra Point (South Section)	Scuba diving Snorkelling Swimming	Reef fish monitored using Baited Remote Underwater Video
Broulee Island	Rock platform walking Indigenous usage Surfing Snorkelling Scuba Diving	Shallow reef fish and habitat monitoring using Underwater Visual Census
Mullimburra	Swimming Surfing Beach walking Snorkelling	None known
Brou Beach	Beach walking Swimming	None known
Bullengella Lake - Corunna Lake Sanctuary Zone	Beach walking Swimming Surfing	None known

Ecological risk assessment method

Estimation of risk to the marine ecological assets

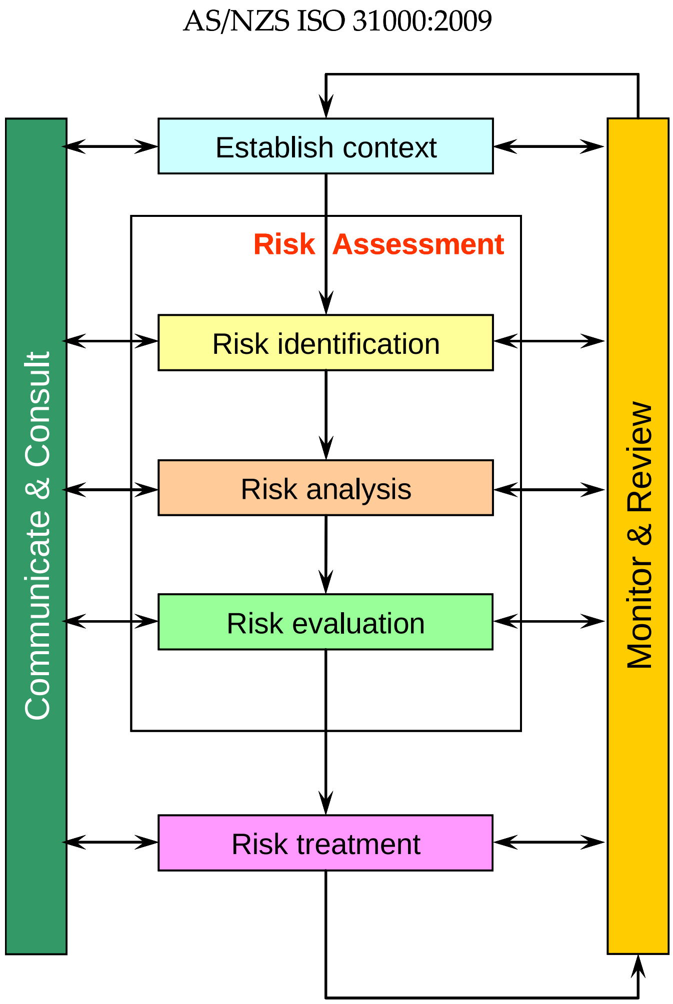
The assessment methodology adopted by the Marine Estate Expert Knowledge Panel (MEMA 2013) uses the international standard definition of risk; which is “the impact of uncertainty on achieving objectives” (ISO, 31000; 2009). The risk analysis process involves several stages – risk identification, analysis and evaluation (Figure 6.1). This process follows the establishment of the risk context, which defines the undesirable outcome that occurs as a result of some activity that will have an impact on the objectives.

Risk identification categorises the ecological assets or values to be assessed and generates a list of the sources of potential risks. The sources of risk are the range of human activities that can directly and/or indirectly exert pressure on marine ecological assets such as foreshore development, pollution and resource use. For this assessment only one human activity, shore-based recreational fishing is being assessed. The ecological assets consist of the marine habitats that support sessile and fish assemblages, and threatened species that occur in these habitats.

The risk analysis stage forms the main part of the risk assessment, and involves the estimation of the magnitude of potential consequences and the likelihood that those consequences will occur against the higher level objectives outlined in legislation. The approach used to assess the ecological risks associated with shore-based recreational fishing in marine park sanctuary zones uses a qualitative risk assessment based on the ISO 31000 (2009) risk management system and the ISO HB 89-2012 guidelines on risk assessment techniques. These methods were first adapted for use in fisheries management by Fletcher et al. (2002) as reported in Fletcher (2005), but have been further refined over the past decade for use in developing fisheries situations (Fletcher, 2010; Fletcher et al., 2012; FAO, 2012).

The consequence and likelihood matrix method (MEMA 2013) combines the scores from the ratings of consequence (levels of impact) and the likelihood (levels of probability) that a specific consequence will occur to generate a risk score and risk rating (see section 6.3). Essentially, the higher the probability that a ‘worse’ consequence may actually occur, the greater is the level of risk.

Figure 6.1. Outline of risk analysis and management process applied to assess the ecological risk to marine assets in this assessment.



Risk identification

Marine ecological assets

Marine seabed habitats have been mapped extensively along the NSW coast (Jordan et al 2010). The extent, distribution and structure of these habitats were identified and examined in the assessment, specifically areas of subtidal and intertidal vegetated or unvegetated hard or soft substrata. The direct impacts on these habitats as a result of shore-based recreational fishing are assessed, while the secondary impacts related to such things as changes in food web structure were not considered. Three threatened fish species may occur within nearshore ocean beach and reef habitats and were included in the assessment: grey nurse shark *(Carcharias taurus*), white shark *(Carcharodon carcharias*) and black cod *(Epinephelus daemelli)*. A number of threatened shoreline-associated bird species that commonly occur along the coast, such as the pied and sooty oystercatchers, osprey, beach stone-curlew and the little tern, were also included in the assessment. Details of the characteristics of these habitats and species are presented in chapter 2. Table 6.1 lists the marine ecological assets considered in this report. Specific details of the key captured fish species considered are presented in Appendix 1.

Table 6.1. The marine ecological assets assessed in this project.

Group	Substratum	Sub-group 1	Sub-group 2
Intertidal	Soft-sediment	Unvegetated	Beaches
	Rocky shore		Algae & invertebrate sessile
Subtidal	Soft-sediment	Unvegetated	Invertebrate sessile
	Rocky reef		Algae & invertebrate sessile
Water column			Captured fishes
Intertidal		Threatened species	Listed shorebirds
Subtidal		Threatened species	Black cod
			Grey nurse shark
			White shark

Human pressures on marine ecological assets

The key pressures, stressors and the potential impacts of shore-based recreational fishing were considered as part of the assessment of ecological risk. Shore-based recreational fishing on ocean beaches and headlands is the pressure, and the stressors are the factors of an activity that can potentially result in a change in some aspect of a marine habitat, species or community. Recreational fishing has more than one stressor (see chapter 4). These were aggregated into a number of main impact categories and stressors each affecting different aspects of fish assemblages and the habitats they depend on. For some stressor measures it was possible to obtain quantitative information, but for others it may only be qualitative, such as presence or absence, or surrogates (e.g. the number of public access points within 50 metres of a rocky shore habitat).

The key impacts and stressors were characterised as: fishing effort (intensity), biomass removal (harvesting and discarding), physical damage (bait collecting, lost gear, trampling and pollutants, fish cleaning), and disturbance (threatened species, lost fishing gear). The extent and rate to which an ecological asset returns to its former state is determined to a large extent by the type and magnitude of the impact, and the spatial and temporal scales of the impact and recovery (Glasby and Underwood 1996, Underwood 1989).

The recreational fishing survey data from the period around 2000 (Henry and Lyle 2003) were used to provide general background information on the levels of catch and effort at several spatial scales to assist in the evaluation of recreational fishing activity. This was available for NSW by regions and shore type. Although this survey was done over 15 years ago it is currently the only consistent data set currently reported across the State on recreational fishing trends. Details of the recreational fishing data from Henry and Lyle (2003) are presented in Chapter 3.

This assessment could only focus on a single human activity (shore-based recreational fishing) in two specific marine habitats (open coast ocean beach and rocky headland sanctuary zones), and therefore it was not be possible to assess the effects of interactions with other human activities and stressors such as aquatic recreation or commercial fishing. Consequently, the risk levels could potentially be under estimated and the issues needing to be addressed to reduce the risks may be incomplete. Therefore, extreme care should be taken to not take the results from this assessment out of context.

Key characteristics of coastal fish species and assemblages

Much of the information on the life history characteristics and habitat use of key harvested coastal fishes in south-east Australia has recently been reviewed, and provides the most current summary from primary and grey literature (Curley et al. 2013). Reviewed species include luderick *(Girella tricuspidata)*, eastern rock blackfish *(Girella elevata),* yellowfin bream *(Acanthopagrus australis),* tarwhine *(Rhabdosargus sarba)*, snapper *(Pagrus auratus)*, red morwong *(Cheilodactylus fuscus)* and eastern blue grouper *(Achoerodus viridis)*. Further information was obtained from Rowling et al. (2010) and references therein.

A summary of the key life-history characteristics of a number of the harvested species is presented in Appendix 1. A number of these life history characteristics and habitat use determine the resilience property of a species, which are those attributes that enable it to return to its variability in abundance and distribution and/or function prior to the natural disturbance. The key resilience properties of a number of key species harvested by shore-based recreational fishers were considered as part of the assessment of ecological risk. The extent and rate to which a populations returns to its former state is governed to a large extent by the inherent characteristics of the species (Glasby and Underwood 1996, Underwood 1989).

Key characteristics of soft-sediment and rocky reef habitats

Areas of marine habitats and shore-based infrastructure (e.g. walking tracks) were calculated from existing spatial data, available aerial imagery, marine habitat maps (Jordan et al. 2010), estuarine habitat maps (Creese et al. 2009) and other publically available spatial layers from agencies such as the NSW Office of Environment and Heritage and Department of Lands. Areal data within ocean beach and rocky headland sanctuary zones were calculated using two buffers – 100 metres from the shoreline seaward and 350 metres from the shoreline landward to capture intertidal and land-based stress measures.

A number of key resilience characteristics of soft-sediment and rocky reef habitats were identified and considered as part of the assessment of ecological risk from shore-based recreational fishing. These characteristics determine the resilience property of a species, which are those attributes that enable it to return to its variability in abundance and distribution and/or function prior to the natural disturbance. The key resilience properties of the habitats in this assessment (Table 6.1) include: habitat extent and distribution, type of adjacent habitats, and relative size of whole sanctuary zone. Details of these characteristics and key ecological features for each sanctuary zone assessed in presented in chapter 5.

Risk analysis

The risk analysis stage involves the estimation of the magnitude of potential consequences and the likelihood of specific consequences occurring. These scores are combined to generate a risk level. First, the Marine Estate Expert Knowledge Panel developed consequence tables with five qualitative criteria ranging from insignificant to catastrophic (Appendix tables 3.1, 3.2). These were developed to cover the ecological assets being examined: habitats and fish assemblages, and threatened species (fish and shorebirds) (Tables 6.1). The consequence of shore-based recreational line fishing was assessed against specific objectives defined for each ecological asset.

Second, a likelihood table was developed with five levels ranging from rare to almost certain (Appendix table 3.3). These levels were based on qualitative categories, with indicative ranges identified. The likelihood of the ‘hazardous’ event (i.e. the consequence) actually occurring was estimated, not the likelihood of the activity occurring. The relative levels of impact and likelihood were determined given the current management controls that are already in place. A five by five risk matrix based on the consequence and likelihood levels was developed for the risk calculation (MEMA 2013: Appendix table 3.4). These risk values have been separated into four risk ranking categories from ‘minimal’ to ‘high’ risk (Appendix table 3.5).

For each ecological asset at the defined level of soft-sediment and rocky reef habitats and individual threatened species, the consequence of shore-based recreational fishing in each sanctuary zone was estimated. The likelihood of the consequence occurring within a five year time-frame was then assigned to one of a number of levels. This process was conducted for each marine park through specific workshops attended by a range of departmental staff with extensive local knowledge, including scientists, managers, compliance officers and marine park rangers. Staff were provided the background information outlined in this report on ecological assets, pressures and stressors, including the habitat maps and key ecological features presented in chapter 5.

It is important to recognise that the risk levels could be under-estimated because the potential negative consequences of shore-based recreational fishing may only be manifested at larger spatial scales, greater than the small portion of a sanctuary zone being assessed on any one ocean beach or rocky headland. Scaling up to larger spatial scales from individual beaches or rocky headlands may further dilute any potential negative effects detected at the smaller scale.

A further reason why risk levels could be under-estimated is that shore-based recreational fishing is being assessed in isolation from other human activities that can occur on ocean beaches and rocky headlands adjacent to the sanctuary zones, and in isolation from recreational fishing from shore and/or boat occurring in adjacent zones. While shore-based recreational fishing (or any other single activity) along a small portion of the coastline may be assessed, on its own, to have little effect on habitats and fish assemblages, in combination with other human pressures it may lead to substantial negative consequences which will go undetected in this qualitative risk assessment focused on shore-based recreational fishing.

The outcomes of the individual workshops and specific details on the key factors determining the defined levels of both consequence and likelihood for each ecological assets were presented to the Marine Estate Expert Knowledge Panel, and incorporated with other social and economic risks in their overall Ocean Beaches and Headland Assessment Report.

References

Adams, D. (2005). A preliminary survey of mollusc communities found within non-vegetated sediments of the Cape Byron Marine Park. Southern Cross University.

Andrew, N. L. and Constable A. (1999). Sea urchins. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales Press, Sydney. pp 126-135.

Andrew N.L. and O'Neill A.L. (2000). Large-scale patterns in habitat structure on subtidal rocky reefs in New South Wales. Marine and Freshwater Research 51, 255–263.

Arlinghaus, R. and Cooke S. J. (2005). Global impact of recreational fisheries. Science 307: 1561-1562.

Avery, R.P. (2001). Byron Bay Area Assessment, Tweed-Moreton Bioregion, Northern NSW: A Review of the current marine biodiversity data sets and an introduction to systematic Marine Protected Area Planning in NSW. A NSW National Parks Wildlife Service Report to the NSW Marine Parks Authority.

Babcock, R.C., Kelly, S., Shears, N.T., Walker, J.W., Willis, T.J. (1999). Changes in community structure in temperate marine reserves. Marine Ecology Progress Series 189, 125-134.

Banks, S.A. and Skilleter, G.A. (2002). Mapping intertidal habitats and an evaluation of their conservation status in Queensland, Australia. Ocean & Coastal Management 48, 485–509.

Bansemer, C.S. and Bennett M.B. (2010). Retained fishing gear and associated injuries in east Australian grey nurse sharks *(Carcharias taurus)*: implications for population recovery. Marine and Freshwater Research 61, 97-103.

Barrett, N.E., Edgar, G.J., Buxton, C.D. and Haddon, M. (2007). Changes in fish assemblages following 10 years of protection in Tasmanian marine protected areas. Journal of Experimental Marine Biology and Ecology 345, 141-157.

Barrett, N. S., Edgar, G. J., Polacheck, A. S., Lynch, T. and Clements, F. (2008). Ecosystem monitoring of subtidal reefs in the Jervis Bay Marine Park 1996-2007. Tasmanian Aquaculture and Fisheries Institute, internal report #54.

Barrett, N. S., Buxton, C.D. and Edgar, G.J. (2009). Changes in invertebrate and macroalgal populations in Tasmanian marine reserves in the decade following protection. Journal of Experimental Marine Biology and Ecology 370, 104-119.

Beamish, R. J., McFarlane, G.A. and Benson, A.(2006). Longevity overfishing. Progress in Oceanography 68, 289-302.

Bell, T.A. (2005). The impact of four wheel drive vehicles on, and the natural variation of, sandy beach meiofauna. M.Sc. Thesis. University of New England, Armidale, Australia.

Bent, S. (1990). A survey and assessment of the marine habitat and species assemblages at Lennox Head Reef, Northern New South Wales. Integrated Project, University of New England.

Bickers, A. (2004). Cape Byron habitat mapping. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, Report #37.

Bishop, M.J., Peterson, C.H., Summerson, H.C., Lenihan, H.S. and Grabowski, J.H. (2006). Deposition and long-shore transport of dredge spoils to nourish beaches: impacts on benthic infauna of an ebb-tidal delta. Journal of Coastal Research 22, 530–546.

Breen, D.A., Avery, R.P. and Otway, N.M. (2004). Broad-scale biodiversity assessment of the Manning Shelf Marine Bioregion. NSW Marine Parks Authority, 137pp.

Breen D.A., Avery R.P. and Otway N.M. (2005). Broadscale biodiversity assessment of the Batemans Shelf and Twofold Shelf Marine Bioregions. NSW Marine Parks Authority, 149pp.

Broadhurst, M. K., Gray, C. A., Reid, D. D., Wooden, M. E., Young, D. J., Haddy, J. A. and Damiano, C. (2005). Mortality of key fish species released by recreational anglers in an Australian estuary. Journal of Experimental Marine Biology and Ecology 321, 171-179.

Brown, A.C. and McLachlan, A. (1990). Ecology of sandy shores. Elsevier, Amsterdam. 328pp.

Bruce B.D. and Bradford R.W. (2012). Spatial dynamics and habitat preferences of juvenile white sharks in eastern Australia. In: Domeier M (ed) Global perspectives on the biology and life history of the Great White Shark. CRC Press, Boca Raton, 225–253.

Bruce, B. D., Stevens, J. D., & Malcolm, H. (2006). Movements and swimming behaviour of white sharks *(Carcharodon carcharias)* in Australian waters. Marine Biology 150, 161-172.

Bruce, B.D., Bradford,R.W., Hughes, B., Carraro, R., Gallen, C., Harasti, D. and Gladstone,W. (2013). Acoustic tracking and aerial surveys of juevenile white sharks in the Hunter-Central Rivers Catchment Authority Region. Final Report Projects, 50pp.

Bucher D.J. and Hartley, S. (2004). Surveys of subtidal rocky reefs within and adjacent to the Cape Byron Marine Park, New South Wales. Report prepared for NSW Marine Parks Authority, 19pp.

Burleigh, A., Lynch, T., Rogers, T., Lunney, D., Munn, A. and Meikle, W. (2008). Best practice techniques for monitoring the fur seal haul-out site at Steamers Head, NSW, Australia. in A. M. a. W. M. Daniel Lunney, editor. Too close for comfort: contentious issues in human-wildlife encounters.

Butcher, P. A., Broadhurst, M. K., Orchard, B. A. and Ellis, M. T. (2010). Using biotelemetry to assess the mortality and behaviour of yellowfin bream *(Acanthopagrus australis)* released with ingested hooks. ICES Journal of Marine Science: Journal du Conseil 67, 1175-1184.

Butler, A. (1995). Subtidal rocky reefs. In Underwood A.J. and Chapman M.G. (eds.), Coastal Marine Ecology of Temperate Australia, pp 106–120.

Caley, M.J., Buckley, K.A. and Jones, G.P. (2001). Separating ecological effects of habitat fragmentation, degradation and loss on coral commensals. Ecology 82, 3435-3448.

Cappo, M., Alongi, D.M., Williams, D. and Duke, N. (1998). A review and synthesis of Australian Fisheries Habitat Research: Major threats, issues and gaps in knowledge in marine and coastal fisheries habitats - a prospectus of opportunities for the FRDC "Ecosystem Protection Program" (Volume 2 Scoping Review). Australian Institute of Marine Science, Queensland.

Choat, J. H., Van Herwerden, L., Robbins, W. D., Hobbs, J. P., and Ayling, A. M. (2006). A report on the ecological surveys undertaken at Middleton and Elizabeth Reefs, February 2006. Report by James Cook University to the Department of the Environment and Heritage, 51pp.

Coleman, F. C., Figueira, W. F., Ueland, J. S. and Crowder, L. B. (2004). The impact of United States recreational fisheries on marine fish populations. Science 305, 1958-1960.

Coleman, M.A., Chambers, J., Knott, N.A., Malcolm, H.A., Harasti, D., Jordan, A. and Kelaher, B.P. (2011). Connectivity within and among a network of temperate Marine Reserves. PloS one 6, e20168.

Colwell, J.B. (1982). Sedimentology of surface sediments of the NSW shelf (Sonne Cruise SO-015). Geologische Jahrbuch Reihe D 56, 111–124.

Commonwealth of Australia (2006). A Guide to the Integrated Marine and Coastal Regionalisation of Australia Version 4.0. Department of the Environment and Heritage, Canberra, Australia.

Cooke, S. J. and Cowx, I. G. (2004). The role of recreational fishing in global fish crises. BioScience 54, 857-859.

Crain, C.M., Kroeker, K. and Halpern, B.S.(2008). Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters 11, 1304-1315.

Crain, C. M., Halpern, B. S., Beck, M. W., & Kappel, C. V. (2009). Understanding and managing human threats to the coastal marine environment. Annals of the New York Academy of Sciences, 1162(1), 39-62.

Creese, R. G., and Kingsford, M. J. (1998). Organisms of reef and soft substrata intertidal environments: Studying Temperate Marine Environments. A handbook for ecologists. Canterbury University Press, Christchurch. pp 167-193.

Creese, R., Glasby, T., West, G. and Gallen, C. (2009). Mapping the habitats of NSW estuaries. Fisheries Final Report 113, 95 pp.

Curley, B.G., Jordan, A.J., Figueira, W.F. and Valenzuela, V.C. (2013). A review of the biology and ecology of key fishes targeted by coastal fisheries in south-east Australia: identifying critical knowledge gaps required to improve spatial management. Reviews in Fish Biology and Fisheries 23, 1–24.

Curley B.G., Glasby T.M., Curley A.J., Creese R.G. and Kingsford M.J. (2013). Enhanced numbers of two temperate reef fishes in a small, partial-take marine protected area related to spearfisher exclusion. Biological Conservation 167, 435–445.

Darling, E. S. and Côté, I. M. (2008). Quantifying the evidence for ecological synergies. Ecology Letters 11, 1278-1286.

Davis, A., Broad, A., Roberts, D. and Jordan, A. (2010) Review of sponges in NSW coastal waters: ecology, diversity and distribution. DECCW NSW Occasional Report Series.

Dawes, M. (1995) Baseline survey of seagrass patches and their associated substrata and marine benthic communities at Lennox Head Reef, Northern New South Wales. Honours Thesis, Southern Cross University, Lismore.

Department of Environment, Climate Change and Water NSW (2010). Shorebirds of Northern New South Wales, based on a report prepared by D. Rohweder and funded by the Northern Rivers Catchment Management Authority, Department of Environment, Climate Change and Water NSW, Sydney.

Dittman, S. (2007). Soft sediments. In Marine Ecology, S.D. Connell and B.M. Gillanders (eds). Melbourne, Australia, Oxford University Press, pp 428-456.

Duffy, J.E. and. Hay M.E (2001). The ecology and evolution of marine consumer-prey interactions. In Marine community ecology, M. D. Bertness, S. D. Gaines and M. E. Hay. Sunderland (eds). Massachusetts, Sinauer Associates, Inc., pp 131-158.

Edgar, G.J. (1997). Australian marine life; the plants and animals of temperate waters, Reed Books, Victoria, Australia.

Fairweather, P.G. (1991). A conceptual framework for ecological studies of coastal resources: an example of a tunicate collected for bait on Australian seashores. Ocean and Shoreline Management 15, 125-142.

FAO (2012) A guide to implementing an Ecosystem Approach (EAF) for fisheries in Africa. EAF Nansen Project (in press)

FAO (2012) EAF Net EAF Toolbox Fact Sheets. www.fao.org/fishery/eaf-net

Ferguson, A.M., Harvey, E.S., Taylor, M.D. and Knott, N.A. (2013). A herbivore knows its patch: Luderick, *Girella tricuspidata*, exhibit strong site fidelity on shallow subtidal reefs in a temperate marine park. PloS one 8.

Ferris, L. and Ferris, R. (2002). The impact of recreational fishing on estuarine birdlife in central and north coast districts of New South Wales. Australian Seabird Rescue Inc., Ballina.

Fletcher, W.J. (2005) The application of qualitative risk assessment methodology to prioritise issues for fisheries management. ICES Journal of Marine Science 62:1576-1587.

Fletcher, W.J. Chesson, J., Fisher M., Sainsbury, K.J., Hundloe, T., Smith, A.D.M. and Whitworth, B. (2002) National ESD Reporting Framework for Australian Fisheries: The 'How To' Guide for Wild Capture Fisheries. FRDC Project 2000/145, Canberra, Australia. 120pp http://www.fisheries-esd.com/a/pdf/HOW_TO_GUIDE_V1_01.pdf

Francis, M.(2012). Coastal fishes of New Zealand. Craig Potton Publishing, Nelson.

Ford, J. and P. Gilmour (2013). The state of recreational fishing in Victoria: a review of ecological sustainability and management options. Melbourne, Victorian National Parks Association.

Frisch, A.J., Cole, A.J., Hobbs, J.P.A., Rizzari, J.R. and Munkres, K.P. (2012). Effects of spearfishing on reef fish populations in a multi-use conservation area. PloS one, 7(12), e51938.

Ganassin, C. and Gibbs, P. (2005a). Broad-scale interactions between fishing and mammals, reptiles and birds in NSW marine waters. Fisheries Final Report # 80. 171 pp.

Ganassin, C. and Gibbs, P. (2005b). Descriptions of the wildlife species that commonly occur in the marine and estuarine waters of NSW. Report prepared for NSW Department of Primary Industries, Cronulla, 88 pp.

Gili, J.M. and Coma, R. (1998). Benthic suspension feeders: their paramount role in littoral marine food webs. Trends in Ecology & Evolution 13, 316-321.

Gillanders, B.M. (2007). Linking terrestrial-freshwater and marine environments: an example from estuarine systems. In Marine Ecology, S. D. Connell and B. M. Gillanders (eds). Melbourne, Australia, Oxford University Press: pp252-278.

Gladstone, W. (2007). Requirements for marine protected areas to conserve the biodiversity of rocky reef fishes. Aquatic Conservation: Marine and Freshwater Ecosystems 17, 71-87.

Glasby, T. and M. Kingsford (1999). Planktivorous fishes. In Under Southern Seas: The ecology of Australia's rocky reefs, N. L. Andrew (ed). University of New South Wales, Sydney., University of New South Wales Press, 210-217.

Glasby, T. M. and Underwood, A. J. (1996). Sampling to differentiate between pulse and press perturbations. Environmental Monitoring and Assessment 42, 241-252.

Godoy, N., Gelcich, S., Vásquez, J.A., Castilla, J.C., (2010). Spearfishing to depletion: evidence from temperate reef fishes in Chile. Ecological Application 20, 1504–1511.

Golvers, A. (1995). A description of the Eastern Overlap Zone and a preliminary survey of benthic fish composition with relation to aspect and substrate on an inshore reef. Integrated Project, Southern Cross University, Lismore.

Gordon, A.D., Lord, D.B. and Nolan, M.W. (1978). Byron Bay–Hastings Point Erosion Study. New South Wales Department of Public Works, Sydney.

Hacking, N. (1997). Sandy beach macrofauna of Eastern Australia: a geographical comparison. University of New England, Armidale.

Hacking, N. (1998). Macrofaunal community structure of beaches in northern New South Wales, Australia. Marine and Freshwater Research, 49, 47-53.

Hacking, N. (2003). A review of the ecology of offshore ocean sediments with particular reference to marine aggregate resources for beach nourishment in New South Wales. Centre for Natural Resources. Department of Infrastructure, Planning and Natural Resources.

Harasti,D. and Malcolm,H. (2013) Distribution, relative abundance, and length of the threatened serranid *Epinphelus daemlii* in New South Wales, Australia. Journal of Fish Biology, 83(2), 378-395.

Harasti, D., Gallen, C., Malcolm, H., Tegart, P. and Hughes, B. (2013). Where are the little ones? Distribution, relative abundance and site fidelity of juvenile black cod *Epinephelus daemelii* in NSW. Journal of Applied Ichthyology, 1–9.

Harriott,V.J., Smith S.D.A. and Harrison, P.L. (1994) Patterns of coral community structure of subtropical reef in the Solitary Islands Marine Reserve, eastern Australia. Marine Ecology Progress Series, 109, 67-76.

Harriott, V.J., Banks, S.A., Mau, R.L., Richardson, D. and Roberts, L.G. (1999). Ecological and conservation significance of the subtidal rocky reef communities of northern New South Wales, Australia. Marine and Freshwater Research, 50,299-306.

Henry, G. and Gillanders B. M. (1999). Snapper and yellowtail kingfish. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales, Sydney., University of New South Wales Press, 158-163.

Henry, G.W. and Lyle, J.M. (2003) National Recreational and Indigenous Fishing Survey. In: Australian Department of Agriculture Fisheries and Forestry (ed), Canberra,ACT.

Hutchins, B. (1999). Leatherjackets. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales, Sydney., University of New South Wales Press, 194-201.

Jones, G. (1999a). Herbivorous fishes. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales, Sydney., University of New South Wales Press: 202-209.

Jones, G. (1999b). The wrasses. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales, Sydney., University of New South Wales Press, 202-209.

Jones, A. R. and Short, A. D. (1995). Sandy beaches. Coastal Marine Ecology of Temperate Australia, eds. A. Underwood & M. Chapman, Institute of Marine Ecology, University of New South Wales Press, Sydney (eds). 136-151.

Jordan, A., Davies, P., Ingleton, T., Foulsham, E., Neilson, J. and Pritchard, T. (2010). Seabed habitat mapping of the continental shelf of NSW. Department of Environment, Climate Change and Water NSW, pp. 206.

Jouvenel J.-Y. and Pollard D.A. (2001). Some effects of marine reserve protection on the population structure of two spearfishing target-fish species, *Dicentrarchus labrax* (Moronidae) and *Sparus aurata* (Sparidae), in shallow inshore waters, along a rocky coast in the northwestern Mediterranean Sea. Aquatic Conservation: Marine and Freshwater Ecosystems, 11, 1–9.

Kennelly, S.J. (1995). Kelp beds. In Underwood AJ and Chapman MG (eds), Coastal marine ecology of temperate Australia,106–120.

Keough, M. J. (1999). Sessile animals. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales, Sydney., University of New South Wales Press, 136-147.

Keough, M. J. and G. P. Quinn (2000). Legislative vs. practical protection of an intertidal shoreline in southeastern Australia. Ecological Applications 10(3), 871-881.

Kingsford M.J. (1998). Reef fishes. In: Kingsford, M.J., Battershill, C. (Eds.), Studying Temperate Marine Environment: A Handbook for Ecologist. Canterbury University Press, Christchurch, New Zealand, pp. 132–165.

Kingsford, M.J., Underwood, A.J. and Kennelly, S.J. (1991). Humans as predators on rocky reefs. Marine Ecology Progress Series 72, 1-14.

Knott, N.A., Aulbury, J.P., Brown T.H. and Johnston E.L. (2009). Contemporary ecological threats from historical pollution sources: impacts of large-scale resuspension of contaminated sediments on sessile invertebrate recruitment, Journal of Applied Ecology, 46, 770-781.

Ku, V. (2007). Sediments around rocky reefs: Solitary Islands, Australia, unpublished Honours thesis, University of Sydney, 106 pp.

Kuiter, R. H., & Kuiter, R. H. (1993). Coastal fishes of south-eastern Australia (p. 437). Honolulu: University of hawaii press.

Lewin., W., Arlinghaus, R. and Mehner, T. (2006). Documented and potential impacts of recreational fishing: insights for management and conservation. Reviews in Fisheries Science, 14(4), 305-367.

Lincoln-Smith, M. (1999). Reef sharks and rays. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales, Sydney., University of New South Wales Press, 202-209.

Lincoln Smith M.P. Bell, J.D. Pollard D.A. Russell B.C. (1989). Catch and effort of competition spearfishermen in south-eastern Australia. Fisher. Res. 8, 45–61.

Ling, S. D. and C. R. Johnson. (2009). Population dynamics of an ecologically important range-extender: kelp beds versus sea urchin barrens. Marine Ecology-Progress Series 374,113-125.

Lowe, C. G., Blasius, M. E., Jarvis, E. T., Mason, T. J., Goodmanlowe, G. D., & O'Sullivan, J. B. (2012). Historic fishery interactions with white sharks in the southern California bight. Global Perspectives on the Biology and Life History of the White Shark, 169.

Lowry, M.B. and Cappo, M. (1999). Morwongs. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales, Sydney., University of New South Wales Press, 172-179.

Lowry, M.B. and Suthers, I.M. (1998). Home range, activity and distribution patterns of a temperate rocky-reef fish, *Cheilodactylus fuscus*. Marine Biology 132,569-578.

Maguire, G. (2008).Beach-nesting birds get a helping hand -Management actions make a difference for Hooded Plovers along the Victorian Coast. Wingspan, 18(3), 24.

Malcolm, H.A., Gladstone, W., Lindfield, S., Wraith, J. and Lynch, T.P. (2007). Spatial and temporal variation in reef fish assemblages of marine parks in New South Wales, Australia: baited video observations. Marine Ecology Progress Series 350, 277-290.

Malcolm, H.A., Jordan, A. and Smith, S.D.A. (2010). Biogeography and cross-shelf patterns of reef fish assemblages in a transition zone. Marine Biodiversity, 40, 181-193.

Masens, O. (2008) Methods of monitoring distribution and heterogeneity of subtidal reef habitats within the Port Stephens-Great Lakes Marine Park using underwater video surveillance with emphasis on urchin barrens. Honours Thesis- School of Environmental Life Sciences. University of Newcastle, 1-112.

Mau, R., Byrnes, T., Wilson, J. and Zann, L. (1998). The distribution of selected continental shelf habitats and biotic communities in the Solitary Islands Marine Park. Unpublished report from the Southern Cross University School of Resource Science and Management for the NSW Marine Parks Authority, 52 pp.

McLoughlin, K. and Eliason, G. (2008). Review of information on cryptic mortality and survivalof sharks and rays released by recreational fishers, Australian Government Bureau of Rural Resources, GPO Box 858, Canberra ACT 2601, Australia, 22pp.

McNeil, R., Drapeau, P. and Goss-Custard, J. D. (1992). The occurrence and adaptive significance of nocturnal habits in waterfowl. Biological Review: 67, 381-419.

McPhee, D. P., Leadbitter, D. and Skilleter, G. A. (2002). Swallowing the bait: is recreational fishing in Australia ecologically sustainable?. Pacific Conservation Biology, 8(1), 40-51.

Meager, J. J., Schlacher, T. A. and Nielsen, T. (2012). Humans alter habitat selection of birds on ocean-exposed sandy beaches. Diversity and Distributions, 18(3), 294-306.

MEMA (2013). Managing the NSW Marine Estate: purpose, underpinning principles and priority setting. NSW Marine Estate Management Authority. 15 pp. (Available at www.marine.nsw.gov.au).

Millar, A.J. (1990). Marine red algae of the Coffs Harbour region. Australian Systematic Botany 3, 293-593.

Millar, A.J. (1998). Marine algae of the northern section of the Solitary Islands Marine Park. Report to the NSW Marine Parks Authority. Royal Botanic Gardens, Sydney.

Möller, L. M., Beheregaray, L. B., Allen, S. J. and Harcourt, R. G. (2006). Association patterns and kinship in female Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) of southeastern Australia. Behavioral Ecology and Sociobiology, 61(1), 109-117.

Möller, L. M., Wiszniewski, J., Allen, S. J., & Beheregaray, L. B. (2007). Habitat type promotes rapid and extremely localised genetic differentiation in dolphins. Marine and Freshwater Research, 58(7), 640-648.

Mortelliti, A.,Amori, G. and Boitani, L. (2010). The role of habitat quality in fragmented landscapes: a conceptual overview and prospectus for future research. Oecologia 163, 535-547.

Murray-Jones, S. and Steffe, A. S. (2000). A comparison between the commercial and recreational fisheries of the surf clam, *Donax deltoides*. Fisheries Research, 44(3), 219-233.

NSW Department of the Environment and Heritage (2002). *Carcharias taurus* (east coast population) — Grey Nurse Shark (east coast population).

NSW Department of Primary Industries (2005). Factsheet Great White Shark*(Carcharodon carcharias)*. Fisheries Ecosystems Unit, Port Stephens Fisheries Institute, 1-4

NSW Department of Primary Industries (2007). Factsheet Black Rockcod *(Epinephelus daemelii)*. Fisheries Ecosystems Unit, Port Stephens Fisheries Institute, 1-2

NSW Department of Primary Industries (2011). Black Cod *(Epinephelus daemlii)* Recovery Plan. Fisheries Ecosystems Unit, Port Stephens Fisheries Institute.

NSW Department of Primary Industries (2011). Discussion paper for Grey Nurse Shark protection, 1-7

NSW Department of Primary Industries (2012). New fishing and diving rules at Grey Nurse Shark aggregation sites. http://www.dpi.nsw.gov.au/fisheries/species-protection/conservation/what-current/critically/grey-nurse-shark/new-fishing-and-diving-rules.

NSW Department of Primary Industries (2013). Factsheet Greynurse Shark *(Carcharias taurus)*. Fisheries Ecosystems Unit, Port Stephens Fisheries Institute, 1-4

NSW Fisheries (2002). Greynurse Shark *(Carcharias taurus)* draft recovery plan. NSW Fisheries Threatened Species Recovery Planning Program, 1-102

NSW MPA (2000) Issues and Options Paper, Solitary Islands Marine Park. Marine Parks Authority, NSW.

NSW MPA (2001a) Developing a representative system of marine protected areas in NSW – an overview, 36 p.

NSW MPA (2001b) Background Resource Document, Solitary Islands Marine Park. Marine Parks Authority, NSW.NSW Department of Primary Industries, (2004). Lobster Fishery Environmental Impact Statement – Public Consultation Document, vols. 1 and 2, Cronulla Fisheries Centre, Sydney.

NSW MPA (2003). Background Resource Working Paper for the Cape Byron Marine Park, Marine Parks Authority, Byron Bay.

NSW MPA (2010a). Seabed habitat mapping in the Solitary Islands Marine Park and Jervis Bay Marine Park. NSW Marine Parks Authority, Hurstville.

NSW MPA (2010b). Solitary Islands and Jervis Bay Marine Parks: Research Project Summaries 2002 - 2009.

Office of Environment and Heritage (2012) Key Threatening Processes (KTP). http://www.environment.nsw.gov.au/threatenedspecies/aboutKTPSinNSW.htm

Otway, N.M. (1999). Identification of candidate sites for declaration as aquatic reserves for the conservation of rocky intertidal communities in the Hawkesbury Shelf and Batemans Shelf Bioregions. NSW Fisheries Final Report Series, No. 28, 88 pp.

Otway, N.M. and Burke, A.L. (2004). Mark-recapture population estimate and movements of Grey Nurse Shark. NSW Fisheries Final Report Series No. 63. NSW Fisheries, 53 pp.

Otway, N.M. and Ellis, M. T. (2011). Pop-up archival satellite tagging of *Carcharias taurus*: movements and depth/temperature-related use of south-eastern Australian waters. Marine and Freshwater Research, 62(6), 607-620.

Otway, N.M. and Parker, P.G. (2000). NSW Fisheries Final Report Series, No. 19, NSW Fisheries, 101 pp.

Otway, N.M., Burke, A.L., Morrison, M.A., Parker, P.C. (2003). Monitoring of NSW critical habitat sites for conservation of Grey Nurse Sharks. In: NSW Fisheries (ed), 1-50.

Parravicini, V.A., Rovere, P., Vassallo, F., Micheli, M., Montefalcone, C., Morri, C., Paoli, G., Albertelli, M. and C. N. Bianchi (2012). Understanding relationships between conflicting human uses and coastal ecosystems status: a geospatial modeling approach. Ecological Indicators, 19, 253-263.

Petraitis, P.S. and Hoffman, C. (2010). Multiple stable states and relationship between thresholds in processes and states. Marine Ecology Progress Series, 413, 189-200.

Ponder, W., Hutching, P. and Chapman, R. (2002). Overview of the conservation of Australian marine invertebrates. Report prepared for Environment Australia, Sydney, 588 pp.

Raby, G. D., Packer, J. R., Danylchuk, A. J. and Cooke, S. J. (2013). The understudied and underappreciated role of predation in the mortality of fish released from fishing gears. Fish and Fisheries.

Rosenberg, A.A. and Restrepo, V.R. (1994). Uncertainty and risk evaluation in stock assessment advice for U.S. marine fisheries. Canadian Journal of Fish Aquatic Science. 51, 2715–2720.

Rowling, K., Hegarty, A. and Ives, M. (2010) Status of fisheries resources in NSW 2008/09, NSW Industry & Investment, Cronulla, 392 pp.

Schlacher, Thomas A. and Hartwig, J. (2012). Bottom-up control in the benthos of ocean-exposed sandy beaches?. Austral Ecology.

Schlacher, T. A., Schoeman, D. S., Dugan, J., Lastra, M., Jones, A., Scapini, F. and McLachlan, A. (2008). Sandy beach ecosystems: key features, sampling issues, management challenges and climate change impacts. Marine Ecology, 29(s1), 70-90.

Schultz, A. L., Malcolm, H. A., Bucher, D. J. and Smith, S. D. (2012). Effects of reef proximity on the structure of fish assemblages of unconsolidated substrata. PloS one, 7(11), e49437.

Shears, N. T. and Babcock, R. C. (2002). Marine reserves demonstrate top-down control of community structure on temperate reefs. Oecologia, 132(1), 131-142.

Shears, N. T. and Ross, P. M. (2010). Toxic cascades: multiple anthropogenic stressors have complex and unanticipated interactive effects on temperate reefs. Ecology letters, 13(9), 1149-1159.

Short, A.D. (1993). Beaches of the New South Wales coast: a guide to their nature, characteristics, surf and safety. Australian Beach Safety and Management Program. The University Printing Service, University of Sydney, Sydney, 358 pp.

Short, A.D. (2003). Australia beach systems – the morphodynamics of wave through tide dominated beach-dune systems. Journal of Coastal Research, 35, 7–20.

Short, A.D. and Woodroffe, C. D. (2009). The coast of Australia. Cambridge University Press.

Short, J.M. (1995). Protection of coastal rock platforms in New South Wales. Report to the Department of Planning and Total Environment Centre.

Smallwood, C. B., Pollock, K. H., Wise, B. S., Hall, N. G. and Gaughan, D. J. (2012). Expanding aerial–roving surveys to include counts of shore-based recreational fishers from remotely operated cameras: benefits, limitations, and cost effectiveness. North American Journal of Fisheries Management, 32(6), 1265-1276.

Smith, P. (1991). The biology and management of waders (suborder Charadrii) in NSW. NSW National Parks and Wildlife Service, Sydney, NSW.

Smith, S.D.A. and James, K.A. (1999). Surveys of rocky shore habitats - Sandon Bluffs and Station Creek Headland, Solitary Islands Marine Park. Report to the NSW Marine Parks Authority. University of New England, Armidale, NSW: 35 pp.

Smith, S. D. A. and James, K. A. (2003). Rapid assessment of rocky shore biodiversity in the Cape Byron Marine Park. Prepared for the NSW Marine Parks Authority.

Smith, S.D.A. and Simpson, R.D. (1991a). Nearshore corals of the Coffs Harbour region, mid north coast, New South Wales. Wetlands (Australia) 11, 1-9.

Smith, S.D.A. and Simpson, R.D. (1991b). Preliminary reconnaissance survey of the marine communities associated with Willis Creek and Flat Top Point. Part 1. Rocky-intertidal biota. Report to the NSW Public Works Department: University of New England, Armidale, NSW: 24 pp.

Smith, S.D.A. and Simpson, R.D. (1991c). Preliminary reconnaissance survey of the marine communities associated with Willis Creek and Flat Top Point. Part 2. Beach fauna and sublittoral communities, Report to the NSW Public Works Department. University of New England, Armidale, NSW.

Smith, S.D.A and Rowland, J.M. (1999). Soft-sediment fauna of the Solitary Islands Marine Park: preliminary results, Armidale, University of New England.

Smith, S.D.A., Rule, M.J., Harrison, M. and Dalton, S.J. (2008) Monitoring the sea change: Preliminary assessment of the conservation value of nearshore reefs, and existing impacts, in a high-growth, coastal region of subtropical eastern Australia. Marine Pollution Bulletin, 56, 525–534.

Standards Australia/Standards New Zealand (2009). Risk management- Principles and guidelines. AS/ANZ ISO 31000. pp. 24.

Steffe, A. S. and Murphy, J. J. (2011). Recreational fishing surveys in the Greater Sydney Region. NSW Department of Primary Industries.

Steinberg, P. D. and G. A. Kendrick (1999). Kelp forests. Under Southern Seas: The ecology of Australia's rocky reefs. N. L. Andrew. University of New South Wales, Sydney., University of New South Wales Press, 60-71.

Stewart, J. (2011). Evidence of age-class truncation in some exploited marine fish populations in New South Wales, Australia. Fisheries Research, 108(1), 209-213.

Stuart-Smith, R.D., Barrett, N.S., Crawford, C.M., Frusher, S.D., Stevenson, D.G. and Edgar, G.J. (2008) Spatial patterns in impacts of fishing on temperate rocky reefs: Are fish abundance and mean size related to proximity to fisher access points? Journal of Experimental Marine Biology and Ecology 365,116-125.

Suter II, G.W., Barnthouse, L.W. and O'Neill, R.V. (1987). Treatment of risk in environmental impact assessment. Environmental Management, 11(3), 295-303.

Suthers, I. M. and A.M. Waite (2007). Coastal oceanography and ecology. Marine ecology. S. D. Connell and B. M. Gillanders. Melbourne, Australia, Oxford University Press, 199-226.

Tallis, H. and Kareiva, P. (2005). Ecosystem services. Current Biology, 15(18), 746-748.

Thom, B.G. (1987). Coastal geomorphology of the Jervis Bay area. Wetlands 6(2),19-21.

Thrush, S. F., Hewitt, J. E., Hickey, C. W. and Kelly, S. (2008). Multiple stressor effects identified from species abundance distributions: interactions between urban contaminants and species habitat relationships. Journal of Experimental Marine Biology and Ecology, 366(1), 160-168.

Underwood, A. J. (1989). The analysis of stress in natural populations. Biological Journal of the Linnean Society, 37, 51-78.

Underwood, A. J. (1993). Exploitation of species on the rocky coast of New South Wales (Australia) and options for its management. Ocean and Coastal Management 20(1), 41-62.

Underwood, A.J. and Atkinson, M.H. (1995). Rocky intertidal and subtidal habitats', in Jervis Bay: A place of cultural, scientific and educational value. Australian Nature Conservation Agency, Canberra, 123–132.

Underwood, A. J. and Chapman M. G. (1995). Rocky shores. Coastal marine ecology of temperate Australia. Sydney, Australia, University of New South Wales Press Ltd, 55-82.

Underwood, A. J. and Chapman M. G (2007). Intertidal temperate rocky shores. Marine ecology. S. D. Connell and B. M. Gillanders. Melbourne, Australia, Oxford University Press, 402-427.

Underwood, A.J., Kingsford, M.J. and Andrew, N.L. (1991). Patterns in shallow subtidal marine assemblages along the coast of New South Wales. Australian Journal of Ecology, 6, 231-49.

Weng, K. C., Boustany, A. M., Pyle, P., Anderson, S. D., Brown, A., & Block, B. A. (2007). Migration and habitat of white sharks *(Carcharodon carcharias)* in the eastern Pacific Ocean. Marine Biology, 152(4), 877-894.

Weston, M.A. and Elgar, M.A. (2005). Disturbance to brood-rearing Hooded Plover *Thinornis rubricollis*: responses and consequences. Bird Conservation International, 15(02), 193-209.

Williams, A and Bax, N.J. (2001). Delineating fish-habitat associations for spatially based management: an example from the south-eastern Australian continental shelf. Marine and Freshwater Research, 52: 513-536.

Willis, T.J. and Anderson, M.J. (2003) Structure of cryptic reef fish assemblages: relationships with habitat characteristics and predator density. Marine Ecology Progress Series 257,209-221

Yoshikawa, T. and Asoh, K. (2004). Entanglement of monofilament fishing lines and coral death. Biological conservation, 117(5), 557-560.

Appendix 1 - A summary of the key life-history characteristics of a number of the targeted species

Character	Measure	Luderick (*Girella tricuspidata*)	Yellowfin bream (*Acanthopagrus australis*)	Tarwhine (*Rhabdosargus sarba*)
Fecundity	Number of eggs or pups produced per breeding event			Females of 180–260 mm estimated to have batch fecundities of about 4,500–12,400 eggs and potential annual fecundities of 204, 300–557
Life history strategy	Pelagic, demersal, live bearing, eggs cases, parental care	Larvae and eggs pelagic	Larvae and eggs pelagic	Larvae and eggs pelagic
Site attachment	Tight, none, Known or unknown	Some fish show site fidelity, other migratory. Schools aggregate on reefs at specific sites	Fish show movement of scales > 1 km. Some undergo large pre-spawning migrations between estuaries. Most remain in estuary or embayment.	
Habitat specificity -Ad	Rocky reef, ocean soft sediment, estuary etc.	Estuaries, rocky reef, around coastal infrastructure, generally more abundant in shallow water.	Estuaries (rocky reef, seagrass, mangrove, bare, structures), coastal rocky reef and adjacent sand. Abundant in <3 m.	Inshore species found on coastal reefs up to 70 m
Habitat specificity -Ad	Rocky reef, ocean soft sediment, estuary etc.	RR <20 m	RR, SS <3 m	RR <20 m
Habitat specificity -Juv	Rocky reef, ocean soft sediment, estuary etc.	Shallow estuarine (seagrass, mangrove), shallow rocky reef	Estuarine seagrass (prefer *Zostera*) and mangrove (settle at ~14 mm FL and above)	Estuaries seagrass, more abundant in *Zostera,* also in adjacent mangroves
Habitat specificity -Juv		E RR, VSS	E VSS	E VSS
Habitat specificity - larvae	Rocky reef, ocean soft sediment, estuary etc.	offshore waters, settle in estuaries	Different vertical distribution in water column, becoming surface orientated at ~10 mm surface swimming inshore from over cont shelf, then settle in estuaries.	offshore waters, settle in estuaries
Exploitation status	Status level from NSW Resource Assessments	fully fished	fully fished	fully fished
Longevity	Short - <10yr, Medium - 10-20 yr, Long - 20-50 yr, Very long <50 yr	Long, up to 25 yrs	Medium, max length ~55 cm. Max age recorded 22+ yrs	Medium, max size of 40cm FL/45cm TL. Max recorded age 16.5 yr
Age/size at maturity	Year or size species is sexually mature	≥ 2 yrs. 220-280 mm FL males, 260-320mm FL females	200-240 mm FL. Most juv become functional males by 2 years, some directly develop to female.	Maturation begins at ~169mm TL or 2 yrs, 50% mature at ~200 mm TL and 100% mature at ~240 mm TL (5 yrs)
Diet specificity - Ad	Food types and food source - benthic, demersal etc.	Omnivore -prefer red and green algae, 12-65% animal composition. Often use intertidal at high tide for feeding	Predominantly carnivorous benthic feeders, generalist. Diet changes according to location and habitat.	carnivorous - molluscs and benthic invertebrates e.g. crustaceans and worms
Diet specificity - Juv		zooplankton until 90-100 mm move to adult		

Appendix 1 - continued

Character	Measure	Snapper (*Pagrus auratus*)	Red morwong (*Cheilodactylus fuscus*)	Eastern rock blackfish (*Girella elevata*)
Fecundity	Number of eggs or pups produced per breeding event	Average female at 45 cm FL produce ~ 3.5 million eggs		Relatively high
Life history strategy	Pelagic, demersal, live bearing, eggs cases, parental care	Larvae and eggs pelagic - serial spawners	Larvae and eggs pelagic - serial spawners	Larvae and eggs pelagic
Site attachment	Tight, none, Known or unknown		Quite territorial with small home ranges. Strong habitat associations in day and disperse over diff habitats at night.	Site attached
Habitat specificity -Ad	Rocky reef, ocean soft sediment, estuary etc.	Rocky reef, mud and sand in shelf waters at depths 5-200m. Study found prefer complex habitat.	Rocky reefs to depths of <30 m, (large fish >150 mm SL prefer boulder habitat, urchin barrens, sponge habitat)	Coastal and estuarine reefs <25 m, adults prefer areas near breaking waves and adjacent to rock platforms in crevices.
Habitat specificity -Ad	Rocky reef, ocean soft sediment, estuary etc.	RR, SS 5->20m	RR <20m	RR <20m
Habitat specificity -Juv	Rocky reef, ocean soft sediment, estuary etc.	Estuaries, inlets, bays over mud, seagrass, shallow coastal reefs, sand adjacent to reef. Prefer complex habitat e.g. barrens, sponges, mussel beds etc.	Rocky reef favouring shallower depths <5 m, fish >150mm SL prefer Eklonia radiata and turf habitats.	Shallow intertidal reefs, intertidal rockpools
Habitat specificity -Juv		E VSS, E RR	RR <5m	RR <20m
Habitat specificity - larvae	Rocky reef, ocean soft sediment, estuary etc.	Subsurface waters on continental shelf, settle in sheltered waters over mud	Larvae hatch at ~3mm and move offshore over continental shelf.	Pelagic, likely coastal waters
Exploitation status	Status level from NSW Resource Assessments	Growth overfished	Undefined	Undefined
Longevity	Short - <10 yr, Medium - 10-20 yr, Long - 20-50 yr, Very long <50 yr	Long, max recorded size 1.3m TL, max recorded age in NSW 40yrs.	Long, max recorded age 40 yrs (42cm), max recorded size 65cm	Long
Age/size at maturity	Year or size species is sexually mature	In NSW 50% matured at approx. 24.8 cm FL (29 cm TL) and 2.5 yrs. Latitudinal differences. Northern fish maturing smaller and earlier.	~3-5 yrs age	6 to 9 yrs. Fastest in northern NSW
Diet specificity - Ad	Food types and food source - benthic, demersal etc.	Generalist predators - invertebrates from soft sediment and rocky reef habitats.	Benthic carnivores - feed primarily at night on echinoderms, bracyurans, molluscs, polychaetes, crustaceans.	Primarily chlophytes and rhodophytes, opportunistic omnivores (e.g. ascidians)
Diet specificity - Juv			Benthic carnivores - feed at day primarily on crustaceans.	Likely as above

Appendix 2- A summary of the key life-history characteristics of a number of the 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)
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)
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)
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 (KTP)
Sanderling	*Calidris alba*	Vulnerable	Low beaches, rocky shore and muddy flats	Alteration to the natural flow regimes (KTP), pollution, human disturbance, coastal development
Terek sandpiper	*Xenus cinereus*	Vulnerable	Rocky pools and reef, coastal mudflats and estuaries	Human disturbance, coastal development, alteration to the natural flow regimes (KTP)

Appendix 3 – Consequence, likelihood and risk levels defined for use in the assessment of recreational shore-based line fishing.

Appendix table 3.1. Objective and consequence table used for habitats and fish assemblages.

Objective: To conserve marine habitats and fish assemblages within marine parks whilst providing for their ecologically sustainable use

Level	Impacts on ecological assets (Habitats and fish assemblages)
Insignificant (1)	No measurable direct impact on the habitat/local abundance of fishes would be possible against background variations compared to that without fishing.
Minor (2)	Barely measurable direct impacts of shore based recreational fishing on local habitat/abundance of fishes compared to total habitat area in zone; hard to identify any measurable effect for the entire habitat area of the region or at whole of stock/trophic levels outside of natural variation.
Moderate (3)	There are clearly measureable impacts on the habitat/local fish populations, but the levels, given the percentage of habitat or population affected would not affect the overall recovery capacity of the habitats/fishes.
Major (4)	The level of impact on habitats and/or local fish populations may be larger than will enable the stated objectives to be met.
Catastrophic (6)*	Too much of the habitat and/or fish populations are being affected, which may endanger long-term survival of these ecological assets, and result in extreme changes to the regional structure of habitats or fish populations.

* Society values avoiding catastrophic impacts, and hence this level has not been identified on a linear scale

Appendix table 3.2. Objective and consequence table used for threatened species (fish and shorebirds)

Objective: To assist in the protection of threatened species (fish and shorebirds)

Level	Impact on threatened species – (fish and shorebirds)
Insignificant (1)	No direct negative interactions by shore-based recreational fishing.
Minor (2)	Some level of interaction may occur but either no clear negative impacts or extremely few mortalities generated at the time scale of years and no measureable effect on local recovery time.
Moderate (3)	Some individuals directly impacted in most years, although no effect on local dynamics or overall stock level and would not significantly affect stock level recovery. At maximum level where public concern would not be triggered.
Major (4)	The impact on threatened species would start to measurably affect local but not stock level recovery. It would be above that accepted by broader community
Catastrophic (6)	The impact is well above the level that may be having significant additional impacts on their already threatened status demonstrably affecting their recovery. There would be general community concern

Appendix table 3.3. Likelihood definitions used to define likelihood levels

Level	Descriptor
Rare (1)	Never reported for this situation, but still plausible (< 5%).
Unlikely (2)	Uncommon, but has been known to occur elsewhere. Expected to occur here only in specific circumstances (5-30%).
Possible (3)	Some clear evidence to suggest this is possible in this situation (30-50%).
Likely (4)	It is expected to occur in this situation (50-90%).
Almost certain (5)	It is almost certain to occur in this situation (>90%).

Appendix table 3.4. Risk matrix used to define risk levels in the assessment

Likelihood		Level of Risk				
Almost certain	5	5	10	15	20	30
Likely	4	4	8	12	16	24
Possible	3	3	6	9	12	18
Unlikely	2	2	4	6	8	12
Rare	1	1	2	3	4	6
		1	2	3	4	6
Consequence level		Insignificant	Minor	Moderate	Major	Catastrophic

Appendix table 3.5. Risk levels and management implications

Risk Level	Risk score	Management implications
Minimal	0 – 6	Expected to meet the stated objectives - monitoring not required.
Low	7 – 10	Expected to meet the stated objectives, but monitoring required at specified intervals.
Moderate	11 - 15	Expected to meet the stated objectives, but regular monitoring and reviews required. Additional management actions/responses might be required.
High	16 or more	Not expected to meet most of the stated objectives without additional management actions/responses

Other titles in this series

No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project no. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales.

No. 4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. 70pp.

No. 5 Kennelly, S.J. and Broadhurst, M.K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). 18pp + appendices.

No. 6 Allan, G.L. and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. 237pp + appendices.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. 54pp + appendices.

No. 8 Heasman, M.P., O'Connor, W.A. and O'Connor, S.J., 1998. Enhancement and farming of scallops in NSW using hatchery produced seedstock. 146pp.

No. 9 Nell, J.A., McMahon, G.A. and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. 25pp.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydney rock and Pacific oysters. Part 1: Sydney rock oysters. 122pp.

No. 11 Watford, F.A. and Williams, R.J., 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to changes in the distribution of seagrass. 51pp.

No. 12 Andrew, N.L., Worthington D.G., Brett, P.A. and Bentley N., 1998. Interactions between the abalone fishery and sea urchins in New South Wales.

No. 13 Jackson, K.L. and Ogburn, D.M., 1999. Review of depuration and its role in shellfish quality assurance. 77pp.

No. 14 Fielder, D.S., Bardsley, W.J. and Allan, G.L., 1999. Enhancement of Mulloway (*Argyrosomus japonicus*) in intermittently opening lagoons. 50pp + appendices.

No. 15 Otway, N.M. and Macbeth, W.G., 1999. The physical effects of hauling on seagrass beds. 86pp.

No. 16 Gibbs, P., McVea, T. and Louden, B., 1999. Utilisation of restored wetlands by fish and invertebrates. 142pp.

No. 17 Ogburn, D. and Ruello, N., 1999. Waterproof labelling and identification systems suitable for shellfish and other seafood and aquaculture products. Whose oyster is that? 50pp.

No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. and Walford, T.R., 2000. Sampling estuarine fish species for stock assessment. Includes appendices by D.J. Ferrell, B.C. Pease, T.R. Walford, G.N.G. Gordon, C.A. Gray and G.W. Liggins. 194pp.

No. 19 Otway, N.M. and Parker, P.C., 2000. The biology, ecology, distribution, abundance and identification of marine protected areas for the conservation of threatened Grey Nurse Sharks in south east Australian waters. 101pp.

No. 20 Allan, G.L. and Rowland, S.J., 2000. Consumer sensory evaluation of silver perch cultured in ponds on meat meal based diets. 21pp + appendices.

No. 21 Kennelly, S.J. and Scandol, J. P., 2000. Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery. 43pp + appendices.

No. 22 Williams, R.J., Watford, F.A. and Balashov, V., 2000. Kooragang Wetland Rehabilitation Project: History of changes to estuarine wetlands of the lower Hunter River. 82pp.

No. 23 Survey Development Working Group, 2000. Development of the National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. (Volume 1 – 36pp + Volume 2 – attachments).

No.24 Rowling, K.R and Raines, L.P., 2000. Description of the biology and an assessment of the fishery of Silver Trevally *Pseudocaranx dentex* off New South Wales. 69pp.

No. 25 Allan, G.L., Jantrarotai, W., Rowland, S., Kosuturak, P. and Booth, M., 2000. Replacing fishmeal in aquaculture diets. 13pp.

No. 26 Gehrke, P.C., Gilligan, D.M. and Barwick, M., 2001. Fish communities and migration in the Shoalhaven River – Before construction of a fishway. 126pp.

No. 27 Rowling, K.R. and Makin, D.L., 2001. Monitoring of the fishery for Gemfish *Rexea solandri*, 1996 to 2000. 44pp.

No. 28 Otway, N.M., 1999. Identification of candidate sites for declaration of aquatic reserves for the conservation of rocky intertidal communities in the Hawkesbury Shelf and Batemans Shelf Bioregions. 88pp.

No. 29 Heasman, M.P., Goard, L., Diemar, J. and Callinan, R., 2000. Improved Early Survival of Molluscs: Sydney Rock Oyster (*Saccostrea glomerata*). 63pp.

No. 30 Allan, G.L., Dignam, A and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 1. R&D Plan.

No. 31 Allan, G.L., Banens, B. and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 2. Resource Inventory and Assessment. 33pp.

No. 32 Bruce, A., Growns, I. and Gehrke, P., 2001. Woronora River Macquarie Perch Survey. 116pp.

No. 33 Morris, S.A., Pollard, D.A., Gehrke, P.C. and Pogonoski, J.J., 2001. Threatened and Potentially Threatened Freshwater Fishes of Coastal New South Wales and the Murray-Darling Basin. 177pp.

No. 34 Heasman, M.P., Sushames, T.M., Diemar, J.A., O'Connor, W.A. and Foulkes, L.A., 2001. Production of Micro-algal Concentrates for Aquaculture Part 2: Development and Evaluation of Harvesting, Preservation, Storage and Feeding Technology. 150pp + appendices.

No. 35 Stewart, J. and Ferrell, D.J., 2001. Mesh selectivity in the NSW demersal trap fishery. 86pp.

No. 36 Stewart, J., Ferrell, D.J., van der Walt, B., Johnson, D. and Lowry, M., 2001. Assessment of length and age composition of commercial kingfish landings. 49pp.

No. 37 Gray, C.A. and Kennelly, S.J., 2001. Development of discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW. 151pp.

No. 38 Murphy, J.J., Lowry, M.B., Henry, G.W. and Chapman, D., 2002. The Gamefish Tournament Monitoring Program – 1993 to 2000. 93pp.

No. 39 Kennelly, S.J. and McVea, T.A. (Ed), 2002. Scientific reports on the recovery of the Richmond and Macleay Rivers following fish kills in February and March 2001. 325pp.

No. 40 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port of Botany Bay Introduced Marine Pest Species Survey. 69pp.

No. 41 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port Kembla Introduced Marine Pest Species Survey. 72pp.

No. 42 O'Connor, W.A, Lawler, N.F. and Heasman, M.P., 2003. Trial farming the akoya pearl oyster, *Pinctada imbricata*, in Port Stephens, NSW. 170pp.

No. 43 Fielder, D.S. and Allan, G.L., 2003. Improving fingerling production and evaluating inland saline water culture of snapper, *Pagrus auratus*. 62pp.

No. 44 Astles, K.L., Winstanley, R.K., Harris, J.H. and Gehrke, P.C., 2003. Experimental study of the effects of cold water pollution on native fish. 55pp.

No. 45 Gilligan, D.M., Harris, J.H. and Mallen-Cooper, M., 2003. Monitoring changes in the Crawford River fish community following replacement of an effective fishway with a vertical-slot fishway design: Results of an eight year monitoring program. 80pp.

No. 46 Pollard, D.A. and Rankin, B.K., 2003. Port of Eden Introduced Marine Pest Species Survey. 67pp.

No. 47 Otway, N.M., Burke, A.L., Morrison, NS. and Parker, P.C., 2003. Monitoring and identification of NSW Critical Habitat Sites for conservation of Grey Nurse Sharks. 62pp.

No. 48 Henry, G.W. and Lyle, J.M. (Ed), 2003. The National Recreational and Indigenous Fishing Survey. 188 pp.

No. 49 Nell, J.A., 2003. Selective breeding for disease resistance and fast growth in Sydney rock oysters. 44pp. (Also available – a CD-Rom published in March 2004 containing a collection of selected manuscripts published over the last decade in peer-reviewed journals).

No. 50 Gilligan, D. and Schiller, S., 2003. Downstream transport of larval and juvenile fish. 66pp.

No. 51 Liggins, G.W., Scandol, J.P. and Kennelly, S.J., 2003. Recruitment of Population Dynamacist. 44pp.

No. 52 Steffe, A.S. and Chapman, J.P., 2003. A survey of daytime recreational fishing during the annual period, March 1999 to February 2000, in Lake Macquarie, New South Wales. 124pp.

No. 53 Barker, D. and Otway, N., 2003. Environmental assessment of zinc coated wire mesh sea cages in Botany Bay NSW. 36pp.

No. 54 Growns, I., Astles, A. and Gehrke, P., 2003. Spatial and temporal variation in composition of riverine fish communities. 24pp.

No. 55 Gray, C. A., Johnson, D.D., Young, D.J. and Broadhurst, M. K., 2003. Bycatch assessment of the Estuarine Commercial Gill Net Fishery in NSW. 58pp.

No. 56 Worthington, D.G. and Blount, C., 2003. Research to develop and manage the sea urchin fisheries of NSW and eastern Victoria. 182pp.

No. 57 Baumgartner, L.J., 2003. Fish passage through a Deelder lock on the Murrumbidgee River, Australia. 34pp.

No. 58 Allan, G.L., Booth, M.A., David A.J. Stone, D.A.J. and Anderson, A.J., 2004. Aquaculture Diet Development Subprogram: Ingredient Evaluation. 171pp.

No. 59 Smith, D.M., Allan, G.L. and Booth, M.A., 2004. Aquaculture Diet Development Subprogram: Nutrient Requirements of Aquaculture Species. 220pp.

No. 60 Barlow, C.G., Allan, G.L., Williams, K.C., Rowland, S.J. and Smith, D.M., 2004. Aquaculture Diet Development Subprogram: Diet Validation and Feeding Strategies. 197pp.

No. 61 Heasman, M.H., 2004. Sydney Rock Oyster Hatchery Workshop 8 – 9 August 2002, Port Stephens, NSW. 115pp.

No. 62 Heasman, M., Chick, R., Savva, N., Worthington, D., Brand, C., Gibson, P. and Diemar, J., 2004. Enhancement of populations of abalone in NSW using hatchery-produced seed. 269pp.

No. 63 Otway, N.M. and Burke, A.L., 2004. Mark-recapture population estimate and movements of Grey Nurse Sharks. 53pp.

No. 64 Creese, R.G., Davis, A.R. and Glasby, T.M., 2004. Eradicating and preventing the spread of the invasive alga *Caulerpa taxifolia* in NSW. 110pp.

No. 65 Baumgartner, L.J., 2004. The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages. 30pp.

No. 66 Heasman, M., Diggles, B.K., Hurwood, D., Mather, P., Pirozzi, I. and Dworjanyn, S., 2004. Paving the way for continued rapid development of the flat (angasi) oyster (*Ostrea angasi*) farming in New South Wales. 40pp.

ISSN 1449-9967 (NSW Department of Primary Industries – Fisheries Final Report Series)

No. 67 Kroon, F.J., Bruce, A.M., Housefield, G.P. and Creese, R.G., 2004. Coastal floodplain management in eastern Australia: barriers to fish and invertebrate recruitment in acid sulphate soil catchments. 212pp.

No. 68 Walsh, S., Copeland, C. and Westlake, M., 2004. Major fish kills in the northern rivers of NSW in 2001: Causes, Impacts & Responses. 55pp.

No. 69 Pease, B.C. (Ed), 2004. Description of the biology and an assessment of the fishery for adult longfinned eels in NSW. 168pp.

No. 70 West, G., Williams, R.J. and Laird, R., 2004. Distribution of estuarine vegetation in the Parramatta River and Sydney Harbour, 2000. 37pp.

No. 71 Broadhurst, M.K., Macbeth, W.G. and Wooden, M.E.L., 2005. Reducing the discarding of small prawns in NSW's commercial and recreational prawn fisheries. 202pp.

No. 72. Graham, K.J., Lowry, M.B. and Walford, T.R., 2005. Carp in NSW: Assessment of distribution, fishery and fishing methods. 88pp.

No. 73 Stewart, J., Hughes, J.M., Gray, C.A. and Walsh, C., 2005. Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (*Hyporhamphus australis*) and river garfish (*H. regularis ardelio*) in NSW waters. 180pp.

No. 74 Growns, I. and Gehrke, P., 2005. Integrated Monitoring of Environmental Flows: Assessment of predictive modelling for river flows and fish. 33pp.

No. 75 Gilligan, D., 2005. Fish communities of the Murrumbidgee catchment: Status and trends. 138pp.

No. 76 Ferrell, D.J., 2005. Biological information for appropriate management of endemic fish species at Lord Howe Island. 18 pp.

No. 77 Gilligan, D., Gehrke, P. and Schiller, C., 2005. Testing methods and ecological consequences of large-scale removal of common carp. 46pp.

No. 78 Boys, C.A., Esslemont, G. and Thoms, M.C., 2005. Fish habitat and protection in the Barwon-Darling and Paroo Rivers. 118pp.

No. 79 Steffe, A.S., Murphy, J.J., Chapman, D.J. and Gray, C.C., 2005. An assessment of changes in the daytime recreational fishery of Lake Macquarie following the establishment of a ‘Recreational Fishing Haven’. 103pp.

No. 80 Gannassin, C. and Gibbs, P., 2005. Broad-Scale Interactions Between Fishing and Mammals, Reptiles and Birds in NSW Marine Waters. 171pp.

No. 81 Steffe, A.S., Murphy, J.J., Chapman, D.J., Barrett, G.P. and Gray, C.A., 2005. An assessment of changes in the daytime, boat-based, recreational fishery of the Tuross Lake estuary following the establishment of a 'Recreational Fishing Haven'. 70pp.

No. 82 Silberschnieder, V. and Gray, C.A., 2005. Arresting the decline of the commercial and recreational fisheries for mulloway (*Argyrosomus japonicus*). 71pp.

No. 83 Gilligan, D., 2005. Fish communities of the Lower Murray-Darling catchment: Status and trends. 106pp.

No. 84 Baumgartner, L.J., Reynoldson, N., Cameron, L. and Stanger, J., 2006. Assessment of a Dual-frequency Identification Sonar (DIDSON) for application in fish migration studies. 33pp.

No. 85 Park, T., 2006. FishCare Volunteer Program Angling Survey: Summary of data collected and recommendations. 41pp.

No. 86 Baumgartner, T., 2006. A preliminary assessment of fish passage through a Denil fishway on the Edward River, Australia. 23pp.

No. 87 Stewart, J., 2007. Observer study in the Estuary General sea garfish haul net fishery in NSW. 23pp.

No. 88 Faragher, R.A., Pogonoski, J.J., Cameron, L., Baumgartner, L. and van der Walt, B., 2007. Assessment of a stocking program: Findings and recommendations for the Snowy Lakes Trout Strategy. 46pp.

No. 89 Gilligan, D., Rolls, R., Merrick, J., Lintermans, M., Duncan, P. and Kohen, J., 2007. Scoping knowledge requirements for Murray crayfish (*Euastacus armatus*). Final report to the Murray Darling Basin Commission for Project No. 05/1066 NSW 103pp.

No. 90 Kelleway, J., Williams. R.J. and Allen, C.B., 2007. An assessment of the saltmarsh of the Parramatta River and Sydney Harbour. 100pp.

No. 91 Williams, R.J. and Thiebaud, I., 2007. An analysis of changes to aquatic habitats and adjacent land-use in the downstream portion of the Hawkesbury Nepean River over the past sixty years. 97pp.

No. 92 Baumgartner, L., Reynoldson, N., Cameron, L. and Stanger, J. The effects of selected irrigation practices on fish of the Murray-Darling Basin. 90pp.

No. 93 Rowland, S.J., Landos, M., Callinan, R.B., Allan, G.L., Read, P., Mifsud, C., Nixon, M., Boyd, P. and Tally, P., 2007. Development of a health management strategy for the Silver Perch Aquaculture Industry. 219pp.

No. 94 Park, T., 2007. NSW Gamefish Tournament Monitoring – Angling Research Monitoring Program. Final report to the NSW Recreational Fishing Trust. 142pp.

No. 95 Heasman, M.P., Liu, W., Goodsell, P.J., Hurwood D.A. and Allan, G.L., 2007. Development and delivery of technology for production, enhancement and aquaculture of blacklip abalone (*Haliotis rubra*) in New South Wales. 226pp.

No. 96 Ganassin, C. and Gibbs, P.J., 2007. A review of seagrass planting as a means of habitat compensation following loss of seagrass meadow. 41pp.

No. 97 Stewart, J. and Hughes, J., 2008. Determining appropriate harvest size at harvest for species shared by the commercial trap and recreational fisheries in New South Wales. 282pp.

No. 98 West, G. and Williams, R.J., 2008. A preliminary assessment of the historical, current and future cover of seagrass in the estuary of the Parramatta River. 61pp.

No. 99 Williams, D.L. and Scandol, J.P., 2008. Review of NSW recreational fishing tournament-based monitoring methods and datasets. 83pp.

No. 100 Allan, G.L., Heasman, H. and Bennison, S., 2008. Development of industrial-scale inland saline aquaculture: Coordination and communication of R&D in Australia. 245pp.

No. 101 Gray, C.A and Barnes, L.M., 2008. Reproduction and growth of dusky flathead (*Platycephalus fuscus*) in NSW estuaries. 26pp.

No. 102 Graham, K.J., 2008. The Sydney inshore trawl-whiting fishery: codend selectivity and fishery characteristics. 153pp.

No. 103 Macbeth, W.G., Johnson, D.D. and Gray, C.A., 2008. Assessment of a 35-mm square-mesh codend and composite square-mesh panel configuration in the ocean prawn-trawl fishery of northern New South Wales. 104pp.

No. 104 O'Connor, W.A., Dove, M. and Finn, B., 2008. Sydney rock oysters: Overcoming constraints to commercial scale hatchery and nursery production. 119pp.

No. 105 Glasby, T.M. and Lobb, K., 2008. Assessing the likelihoods of marine pest introductions in Sydney estuaries: A transport vector approach. 84pp.

No. 106 Rotherham, D., Gray, C.A., Underwood, A.J., Chapman, M.G. and Johnson, D.D., 2008. Developing fishery-independent surveys for the adaptive management of NSW's estuarine fisheries. 135pp.

No. 107 Broadhurst, M., 2008. Maximising the survival of bycatch discarded from commercial estuarine fishing gears in NSW. 192pp.

No. 108 Gilligan, D., McLean, A. and Lugg, A., 2009. Murray Wetlands and Water Recovery Initiatives: Rapid assessment of fisheries values of wetlands prioritised for water recovery. 69pp.

No. 109 Williams, R.J. and Thiebaud, I., 2009. Occurrence of freshwater macrophytes in the catchments of the Parramatta River, Lane Cove River and Middle Harbour Creek, 2007 – 2008. 75pp.

No. 110 Gilligan, D., Vey, A. and Asmus, M., 2009. Identifying drought refuges in the Wakool system and assessing status of fish populations and water quality before, during and after the provision of environmental, stock and domestic flows. 56pp.

ISSN 1837-2112 (Industry & Investment NSW – Fisheries Final Report Series)

No. 111 Gray, C.A., Scandol. J.P., Steffe, A.S. and Ferrell, D.J., 2009. Australian Society for Fish Biology Annual Conference & Workshop 2008: Assessing Recreational Fisheries; Current and Future Challenges. 54pp.

No. 112 Otway, N.M. Storrie, M.T., Louden, B.M. and Gilligan, J.J., 2009. Documentation of depth-related migratory movements, localised movements at critical habitat sites and the effects of scuba diving for the east coast grey nurse shark population. 90pp.

No. 113 Creese, R.G., Glasby, T.M., West, G. and Gallen, C., 2009. Mapping the habitats of NSW estuaries. 95pp.

No. 114 Macbeth, W.G., Geraghty, P.T., Peddemors, V.M. and Gray, C.A., 2009. Observer-based study of targeted commercial fishing for large shark species in waters off northern New South Wales. 82pp.

No. 115 Scandol, J.P., Ives, M.C. and Lockett, M.M., 2009. Development of national guidelines to improve the application of risk-based methods in the scope, implementation and interpretation of stock assessments for data-poor species. 186pp.

No. 116 Baumgartner, L., Bettanin, M., McPherson, J., Jones, M., Zampatti, B. and Kathleen Beyer., 2009. Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin. 47pp.

No. 117 Astles, K., West, G., and Creese, R.G., 2010. Estuarine habitat mapping and geomorphic characterisation of the Lower Hawkesbury river and Pittwater estuaries. 229pp.

No. 118 Gilligan, D., Jess, L., McLean, G., Asmus, M., Wooden, I., Hartwell, D., McGregor, C., Stuart, I., Vey, A., Jefferies, M., Lewis, B. and Bell, K., 2010. Identifying and implementing targeted carp control options for the Lower Lachlan Catchment. 126pp.

No. 119 Montgomery, S.S., Walsh, C.T., Kesby, C.L and Johnson, D.D., 2010. Studies on the growth and mortality of school prawns. 90pp.

No. 120 Liggins, G.W. and Upston, J., 2010. Investigating and managing the *Perkinsus*-related mortality of blacklip abalone in NSW. 182pp.

No. 121 Knight, J., 2010. The feasibility of excluding alien redfin perch from Macquarie perch habitat in the Hawkesbury-Nepean Catchment. 53pp.

No. 122 Ghosn, D., Steffe, A., Murphy, J., 2010. An assessment of the effort and catch of shore and boat-based recreational fishers in the Sydney Harbour estuary over the 2007/08 summer period. 60pp.

No. 123 Rourke, M. and Gilligan, D., 2010. Population genetic structure of freshwater catfish (*Tandanus tandanus*) in the Murray-Darling Basin and coastal catchments of New South Wales: Implications for future re-stocking programs. 74pp.

No. 124 Tynan, R., Bunter, K. and O'Connor, W., 2010. Industry Management and Commercialisation of the Sydney Rock Oyster Breeding Program. 21pp.

No. 125 Lowry, M., Folpp, H., Gregson, M. and McKenzie, R., 2010. Assessment of artificial reefs in Lake Macquarie NSW. 47pp.

No. 126 Howell, T. and Creese, R., 2010. Freshwater fish communities of the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments: a 2004 status report. 93pp.

No. 127 Gilligan, D., Rodgers, M., McGarry, T., Asmus, M. and Pearce, L., 2010. The distribution and abundance of two endangered fish species in the NSW Upper Murray Catchment. 34pp.

No. 128 Gilligan, D., McGarry, T. and Carter, S., 2010. A scientific approach to developing habitat rehabilitation strategies in aquatic environments: A case study on the endangered Macquarie perch (*Macquaria australasica*) in the Lachlan catchment. 61pp.

No. 129 Stewart, J., Hughes, J., McAllister, J., Lyle, J. and MacDonald, M., 2011. Australian salmon (*Arripis trutta*): Population structure, reproduction, diet and composition of commercial and recreational catches. 257 pp.

ISSN 1837-2112 (Fisheries Final Report Series)

No. 130 Boys, C., Glasby, T., Kroon, F., Baumgartner, L., Wilkinson, K., Reilly, G. and Fowler, T., 2011. Case studies in restoring connectivity of coastal aquatic habitats: floodgates, box culvert and rock-ramp fishway. 75pp.

No. 131 Steffe, A.S. and Murphy, J.J., 2011. Recreational fishing surveys in the Greater Sydney Region. 122pp.

No. 132 Robbins, W.D., Peddemors, V.M. and Kennelly, S.J., 2012. Assessment of shark sighting rates by aerial beach patrols. 38pp.

No. 133 Boys, C.A. and Williams, R.J., 2012. Fish and decapod assemblages in Kooragang Wetlands: the impact of tidal restriction and responses to culvert removal. 80pp.

No. 134 Boys, C.A, Baumgartner,L., Rampano, B., Alexander, T., Reilly, G., Roswell, M., Fowler, T and Lowry. M. 2012. Development of fish screening criteria for water diversions in the Murray-Darling Basin. 62pp.

No. 135 Boys, C.A, Southwell, M., Thoms, M., Fowler, T, Thiebaud, I., Alexander, T. and Reilly, G. 2012. Evaluation of aquatic rehabilitation in the Bourke to Brewarrina Demonstration Reach, Barwon-Darling River, Australia. 133pp

No. 136 Baumgartner, L., McPherson, B., Doyle, J., Cory, J., Cinotti, N. and Hutchison, J. 2013. Quantifying and mitigating the impacts of weirs on downstream passage of native fish in the Murray-Darling Basin. 79pp.

No. 137 Boys, C.A, Baumgartner, B., Miller, B., Deng, Z., Brown, R. and Pflugrath, B. 2013. Protecting downstream migrating fish at mini hydropower and other river infrastructure. 93pp.

No. 138 Hughes, J.M. and Stewart, J. 2013. Assessment of barotrauma and its mitigation measures on the behaviour and survival of snapper and mulloway. 152pp.

No. 139 Ochwada-Doyle, F.A., McLeod, J., Barrett, G., Clarke, G. and Gray, C.A., 2014. Assessment of recreational fishing in three recreational fishing havens in New South Wales. 29pp.

No. 140 Walsh, C. T., Rodgers, M. P., Thorne, N. J. and Robinson, W. A., 2013. Thermoshock Fish Mortality Investigation. 32pp.

No. 141 Boys, C.A., Navarro, A., Robinson, W., Fowler, T., Chilcott, S., Miller, B., Pflugrath, B., Baumgartner, L.J., McPherson, J., Brown, R. and Deng, Z., 2014. Downstream fish passage criteria for hydropower and irrigation infrastructure in the Murray-Darling Basin. 119pp.

No. 142 Cameron, L., Baumgartner, L. and Miners, B., 2012. Assessment of Australian bass restocking in the upper Snowy River. 102pp.

No. 143 Walsh, C., Rodgers, M., Robinson, W. and Gilligan, D., 2014. Evaluation of the effectiveness of the Tallowa Dam Fishway. 89pp.

ISSN 2204-8669 (NSW Trade & Investment – Fisheries Final Report Series)

No. 144 Ghosn, D.L., Collins, D.P. and Gould, A., 2015. The NSW Game Fish Tournament Monitoring Program 1994 to 2013: A summary of data and assessment of the role and design. 200pp.

No. 145 Boys, C., 2015. Changes in fish and crustacean assemblages in tidal creeks of Hexham Swamp following the staged opening of Ironbark Creek floodgates. 47pp

No. 146 Jordan, A. and Creese, R., 2015. Ecological background to the assessment of shore-based recreational fishing on ocean beaches and rocky headlands in sanctuary zones in mainland NSW Marine Parks. 102pp.