The Biological Environment - Biodiversity and Conservation; Marine Reptiles and Mammals.

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The Marine Environment of the Hunter-Central Rivers Region of New South Wales

A review of current knowledge

Edited by Stephen D. A. Smith, Alan Jordan, Robert G. Creese and William Gladstone

NSW GOVERNMENT

Hunter-Central Rivers CMA CATCHMENT MANAGEMENT AUTHORITY

Report prepared for the Hunter-Central Rivers Catchment Management Authority, September 2010

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Chapter 6 Gaps in Existing Knowledge and Directions for Future Research – Dr. Stephen Smith (NMSC) and Dr. Alan Jordan (DECCW).

Chapter 7 Concluding Comments – Dr. Stephen Smith (NMSC).

Institutional acronyms

DECCW	NSW Department of Environment, Climate Change and Water
HCRCMA	Hunter-Central Rivers Catchment Management Authority
I&I NSW	Industry & Investment NSW – Department of Primary Industries (DPI) - Fisheries
MPA	NSW Marine Parks Authority
NMSC	National Marine Science Centre

Note A key to all acronyms used in this report appears in Appendix 1.

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The content of Chapters 5 and 6 is derived from specific issues raised in earlier sections of the report, and refined by expert input from the participants of a workshop convened to identify specific gaps in knowledge. We therefore gratefully acknowledge the workshop participants: Brian Hughes, Anna Ferguson and Hayley Skehan (HCRCMA); Bruce Coates, Peter Davies, Peter Evans, Alan Jordan and David Harasti (DECCW); Bob Creese, Katie Newton and Richele West (I&I NSW – DPI - Fisheries); James Lawson (Newcastle Port Corporation); Andy Meyers (Oceanwatch); David Powter (University of Newcastle); and Stephen Smith (NMSC).

The project has been a protracted one and, consequently, in addition to the primary authors (listed above), a number of people have made important contributions to the report: Stephan Soule stepped in as project officer at very short notice, helping to bring the project to a successful conclusion; Kathryn James provided professional editing and formatting services; and Inge Aean compiled relevant references from a wide range of sources to provide a database of geographically-relevant material.

As the format and content of this report follows that of an earlier report focusing on the Northern Rivers Catchment Management Authority (NRCMA) region, we acknowledge the contribution of those authors (Michael Rule, Alistair McIlgorm and Alan Jordan), and especially Michael Rule who was the project officer.

Finally, we thank the external reviewers (Professor Rod Simpson and Associate Professor Ron West) for their insightful and expert comments that substantially improved the report.

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1 Introduction

1.1 Project overview

Extending from Crowdy Head in the north to Box Head in the south, the marine environment of the Hunter-Central Rivers Catchment Management Authority (HCRCMA) region includes a diverse range of marine communities and is highly valued for economic, recreational and aesthetic reasons. Although a great deal of marine research has been carried out in the region over many years, much of this research has remained dispersed throughout many organisations and is often not easily accessible.

This review was undertaken on behalf of the HCRCMA and contributes to the Hunter-Central Rivers Catchment Action Plan (CAP). The CAP is a whole-of-government approach to natural resource management that has been endorsed by the NSW Government. It is a ten-year regional plan that provides a roadmap to ensure that natural resources are protected and enhanced for the enjoyment and viability of future generations, including the long-term management of our coast and marine environments. For example, this review will contribute to Management Target (MT) 31 – Enhance Marine Shorelines, and MT30 – Improve Marine Habitat, by gathering knowledge and data to improve the delivery of these targets. It is the intention that this review will guide the incorporation and prioritisation of the needs of stakeholders in the marine environment, and will enable the strategic use of funding to effectively manage marine resources in the HCRCMA region.

The aims of this review were to: 1) locate and review all of the relevant information on the marine environment of the region, 2) determine its relevance to management, and 3) identify the primary gaps in knowledge (spatial and thematic). While the review targets fully marine habitats, the strong marine influence in the eastern section of Port Stephens, and the clear importance of this area for both biotic diversity and a range of marine stakeholders, are such that this area was also covered in the report. Thus, for the purposes of this review, the area eastward of a line drawn due northward from Soldiers Point was considered to be within the marine section of the HCRCMA region.

It should be noted that this review was inspired by a similar project that was carried out on behalf of the Northern Rivers Catchment Management Authority (NRCMA) entitled *The Marine Environment of Northern New South Wales: A review of current knowledge and existing datasets* (Rule et al., 2007). The NRCMA marine knowledge review may be used as a companion document, and is referred to herein where the reader may wish to access additional information on a particular topic. The two reviews also provide useful supporting information for the assessment of the condition of NSW Marine Waters under the NSW Government's Monitoring Evaluation and Reporting (MER) program.

The NRCMA review provided a valuable template for this project, and the broad topics examined in this review similarly include: geology and bathymetry, oceanography, primary productivity, flood plumes, ecological habitats, biodiversity and conservation, marine pests, commercial fisheries, recreational fishing, pollution sources, water quality, climate change, marine protected areas, areas of cultural significance, and threatening processes.

At the time of writing, the NSW Department of Environment, Climate Change and Water (DECCW) was completing a collation of available marine habitat and biodiversity spatial information on a state-wide scale – *Seabed Habitat Mapping of the Continental Shelf Waters of NSW*

Jordan et al. (2010). The contents of that report are only briefly summarised in Chapter 2 in order to avoid duplication. Jordan et al. (2010) should be referred to for detailed information on habitats, bathymetry and ecology.

The HCRCMA region

The HCRCMA region is situated in northern NSW, and spans a total of seven Local Government Areas (LGAs). Coastal Councils in the region, from north to south, include Greater Taree, Great Lakes, Port Stephens, Newcastle, Lake Macquarie, Wyong and Gosford LGAs. The HCRCMA marine jurisdiction extends out to the 3 nautical-mile (nm) limit of state waters (Figure 1.1) and contains one marine park: the Port Stephens-Great Lakes Marine Park (PSGLMP). A small section (approx. 2.8 km^2) of Bouddi National Park also contains marine waters and is referred to as the Bouddi Marine Extension. Responsibility for management of these areas rests with DECCW through the NSW Marine Parks Authority (MPA) and National Parks and Wildlife Service (NPWS). The coast of the HCRCMA region encompasses the territory of four Aboriginal nations (Biripi, Worimi, Awabakal and Darkinjung) that have strong associations with the coast and offshore areas such as Broughton Island.

A range of marine habitats is represented in the region, including intertidal beaches and rocky shores, subtidal rocky reefs and subtidal sediments. The recent seabed-mapping project has revealed that a range of communities is found on subtidal reefs in the HCRCMA region, including kelp forests, urchin barrens and sponge/sessile invertebrates. The HCRCMA region is influenced by the East Australia Current (EAC), which results in a blend of tropical, subtropical, warm-temperate and cool-temperate fauna and flora. Although the tropical influence decreases with increasing latitude, and communities are dominated by temperate species, some tropical species can be found in the region, and local photographers have identified many tropical species in locations such as Port Stephens. A number of protected and threatened species are found in the HCRCMA region and include migratory seabirds, marine mammals and iconic species, such as grey nurse and great white sharks. There are a number of grey nurse critical habitat sites in the region, and the Port Stephens area has also been identified as an important aggregation area for juvenile great white sharks.

The waters and marine resources of the HCRCMA region are directly managed by a number of agencies, including: Industry & Investment NSW (I&I NSW – Department of Primary Industries (DPI) - Fisheries); DECCW; Department of Lands (LANDS); and the MPA, which is administered by DECCW. The University of Newcastle is the only organisation located within the HCRCMA region that conducts dedicated research on marine habitats and biota; however, there are many other organisations undertaking marine research in the region. These include: Southern Cross University and the National Marine Science Centre; the Australian Museum; Macquarie University; the University of NSW; the University of Sydney; the University of Technology, Sydney; and the University of Tasmania.

Data sources and format of this review

The data for this project were compiled from a large number of sources, including: primary, published scientific literature; university theses (undergraduate, Honours, MSc and PhD); council and government reports; policy documents; consultancy reports; Environmental Impact Statements (EIS); and various online libraries, web pages and other electronic sources. Unpublished data were made available or described by various institutions and individual researchers. The key data sources are listed at the end of each section. For convenience, all references are listed at the end of the report.

Figure 1.1 The HCRCMA region. The blue area adjacent to the coast shows the 3 nm limit of the HCRCMA jurisdiction, and the green area shows the location of the PSGLMP.

2 The Physical Environment

The physical make-up of marine habitats coupled with their physico-chemical setting (e.g. climate, currents, wave conditions) exerts a strong influence on the biological patterns within a region. For this reason, this chapter sets the scene for Chapter 3 *The Biological Environment* by providing an overview of the geology and distribution of different habitat types, the bathymetry of coastal waters (to the 3-nm limit), the primary oceanographic features, and the influence of rivers and storm events on marine habitats and processes. Although clearly a biological attribute, the subject of pelagic primary productivity (through phytoplankton) is also reviewed in this section because it is tightly coupled to the supply of nutrients and their subsequent distribution by oceanographic features.

2.1 Geology and bathymetry

Overview

This section documents the information that is currently available on the marine geology, bathymetry, surficial sediments and seabed habitats of the Hunter-Central Rivers Catchment Management Authority (HCRCMA) region excluding the estuaries. Much of this information comes from a related HCRCMA-led project that collated existing data on these components of the seabed from single-beam and swath acoustic surveys, sediment surveys and digitised habitats from aerial photographs (Jordan et al., 2010). This information was supplemented with high-resolution bathymetry and acoustic backscatter information from targeted swath acoustic surveys conducted at a number of continental shelf locations within the HCRCMA region. These data layers were used to map the fine-scale distribution and extent of bio-physical seabed habitats (Jordan et al., 2010). Information on the dominant benthic assemblages from a number of rocky reefs in the region was also described.

Overall, the physical structure of the seabed in the HCRCMA region reflects the patterns of bedrock geology, geological history, coastal inputs and sediment transport. A broad description of the geology and morphology of the continental shelf between Tuggerah Lakes and the Manning River is detailed in Boyd et al. (2004) and south of Newcastle by Davies (1979). A key feature of the region, that also influences the structure of the shelf, is the variation in the longitudinal position of the coastline that extends in a more north-east/south-west orientation than in adjacent regions.

2.1.1 Bedrock geology

The geology of the northern NSW coast has been comprehensively mapped by the NSW Geological Survey and Geoscience Australia (e.g. Roy, 1982; Wells and O'Brien, 1995). The distribution of rock types is generally mapped at a 1:250 000 scale along the coast and, based on this mapping, a broad division of geological regions can be defined (Figure 2.1).

The distribution, extent and structure of bedrock within the HCRCMA region are primarily determined by the regional geology and geological history. A number of broad geological divisions occur along the coast dominated primarily by the Myall Block that extends from around Forster to Port Stephens, and the Sydney Basin that extends south from the Swansea area. The first known area of subtidal bedrock occurs between Black Head and Old Bar; this comprises a large area of outcropping of mudstones and sandstones of the Manning Group and other undifferentiated mixed sediments. Similar outcroppings of bedrock between Forster and

Sugarloaf Point are dominated by sandstone, conglomerate and siltstone that form many subtidal areas of bedrock along this section of coast. Many of these are evident as intertidal and shallow areas of bedrock that are separated by sections of the coast dominated by unconsolidated Quaternary sediments. Between Crowdy Head and Sugarloaf Point, bedrock makes up around 27% of the shoreline.

Further south, towards Port Stephens, the bedrock is dominated by rocks of the Nerong Volcanics that form Boondelbah, Cabbage Tree and Broughton islands and the prominent headlands of Port Stephens, Yacaaba and Tomaree Heads (Roberts et al., 1991; Boyd et al., 2004). These volcanics also form the headland of Point Stephens and the rocky shore between Fingal Bay and Birubi Point which is characterised by relatively steep rocky ridges separated by several bays and coves that vary in size and orientation. In these areas, the subtidal bedrock outcropping extends some distance offshore forming large areas of subtidal reef that are evident around Broughton Island and adjacent to most of the shore between Birubi Point and Point Stephens. Large sections of the coast between Sugarloaf Point and Newcastle are also dominated by unconsolidated Quaternary sediments (such as Stockton Bight) resulting in bedrock making up only ~25% of the shoreline.

From Newcastle south to Swansea, the nearshore region is dominated by rocks of the Newcastle Coal Measures. The large areas of bedrock south of Swansea reflect the dominance of the Triassic sandstones along the entire Central Coast, and reduced extent of Quaternary sediments that form ocean beaches. The two major sedimentary units are the Hawkesbury Sandstone (mainly massive quartz sandstone) and the Narrabeen Group (mainly shale and sandstone). In many areas, these sandstone outcrops form areas of bedrock that extend up to 8 km offshore and to depths of 90 m within state coastal waters. This section of the coast consists of ~43% bedrock, which is considerably higher than areas to the north.

Primary data sources

The data for this section came from two primary sources: 1) the NSW Geological Survey 1:250 000 map sheets, and 2) the series of geological maps produced by Geoscience Australia. These maps are also available as a 1:1 000 000 Geographic Information System (GIS) layer entitled Geological Provinces in the Australian Region (ANZCW1205000961).

Additional data sources

Troedson et al. (2004) reviewed and mapped the geology of the NSW coastal margin as part of the Comprehensive Coastal Assessment of NSW.

As part of the National Marine Bioregionalisation project, Geosciences Australia and the National Oceans Office (NOO) mapped the geomorphic features of the Australian Exclusive Economic Zone (EEZ) on a 250-m resolution bathymetric grid (Harris et al., 2003). Data came from numerous sources including the Royal Australian Navy (RAN) Hydrographic Service fairsheet data, RAN Laser Airborne Depth Sounding (LADS) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Ship Track Data.

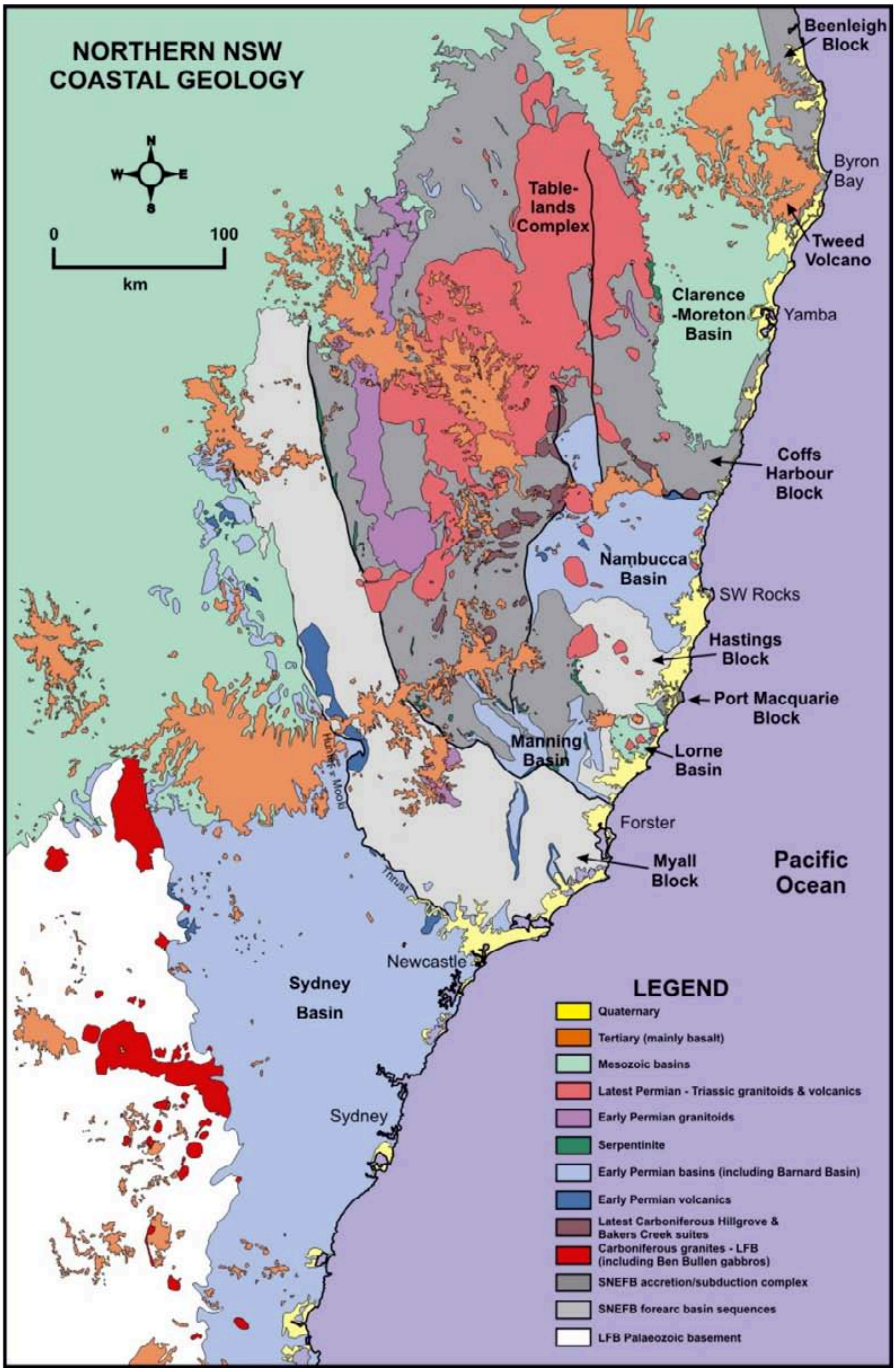


Figure 2.1 The coastal geology of northern NSW showing the broad division of geological regions (Source: Boyd et al., 2006).

2.1.2 Bathymetry

Bathymetric information for the HCRCMA region is available as broadscale data collated from a range of sources identified in Boyd et al. (2004) and Manly Hydraulics Laboratory (MHL) (2009); this is suitable for characterising the broad shelf morphology and extent of depth zones within the region (Figure 2.2). High-resolution bathymetric data are also available from swath acoustic surveys that provide considerable detail on the seabed structure at a fine scale (Jordan et al., 2010). Overall, periods of sea-level change have strongly influenced the current geomorphology of the shelf in the region, with sea level during the last glacial period (up to about 20–15,000 years ago) at least 120 m lower than present and the shoreline located many kilometres offshore. Different erosional and depositional forces acted on the rocks and sediments during that time, with fluvial processes being important in forming many of the present features.

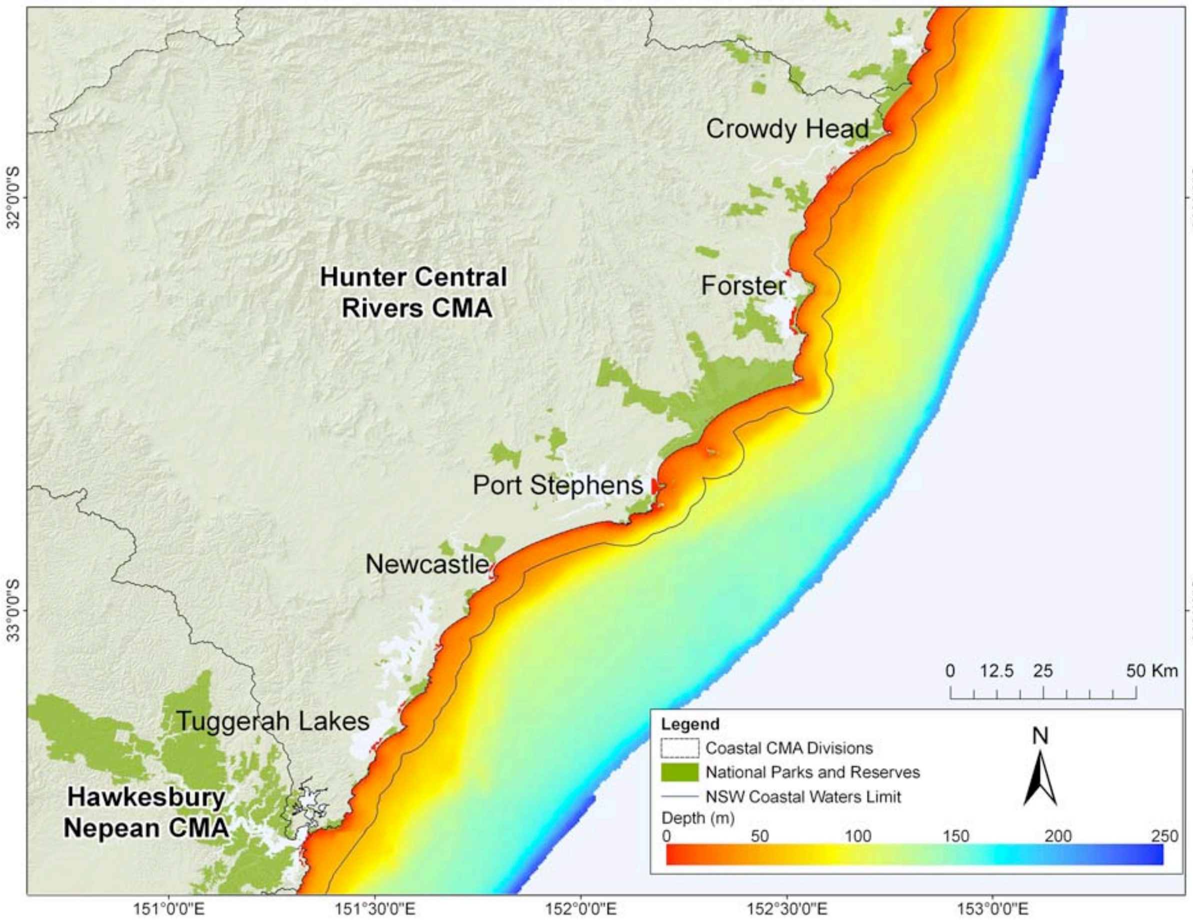


Figure 2.2 Broadscale bathymetry of the HCRCMA region and adjacent continental shelf.

Using the broadscale bathymetry to examine the geometry and slope of the seabed, Boyd et al. (2004) defined a number of distinct seabed morphological units on parts of the continental shelf within the HCRCMA region, with the broad distribution of the units common to the entire east coast continental margin. These units are defined as the shoreface and inner plain, with these being shore-parallel zones, and a number of other units defined within local regions, such as the composite regions offshore of Port Stephens and Cape Hawke (Boyd et al., 2004). Other units are defined further offshore (inner and outer mid-slope and outer plain), but the majority of these are located in Commonwealth waters.

The shoreface zone reflects the influence of wave-sediment transport out to a depth of ~30 m and is well developed off all sandy barriers and absent off most sections of rocky coast (Boyd et al., 2004). Inside the shoreface, along sand beaches, there is a narrow area defined as the nearshore zone which is generally 50-500 m wide and consists of sand bars, rip channels and troughs (Short, 2003). In many areas in the HCRCMA region, this nearshore zone also contains areas of bedrock that extend from intertidal to shallow subtidal depths. The inner plain, which is a relatively flat zone that varies greatly in width along the coast, extends from depths of ~25-75 m (Boyd et al., 2004). This inner plain zone is thought to represent a number of relatively-unmodified, seaward–prograding shoreface and barrier sediments that were deposited under stable to slowly-falling sea-level between ~30,000-60,000 years ago (Roy and Boyd, 1996; Roy et al., 1997). The mid-slope region is steeper and occurs seaward of the inner plain in ~60 m, ~2-20 km offshore.

The extent of these broad zones is determined by along-shelf variability of zone distribution (reflecting variations in the slope of the seabed) and by the differences in the offshore distance of the state coastal waters limit (defined as 3 nm seaward from the mainland and offshore islands). They are also influenced by latitudinal changes in the angle of the coastline and local position of prominent headlands, embayments and offshore islands. Of particular significance, is the maximum depth and width of both specific depth contours and the state coastal waters boundary, defined from a number of cross shelf contour-normal profiles (Figure 2.3). The specific contours relate to those zones defined as shallow (0-25 m), intermediate (25-60 m) and deep (>60 m) in the analysis of seabed habitats throughout NSW (Jordan et al., 2010). Overall, the cross-sections display considerable variability within the HCRCMA region. Firstly, the offshore extent of the shallow depth zone varies from 2.9 km off Forster to 0.5 km off Smiths Lake. In contrast, the offshore extent of the intermediate depth zone varies little between those two locations (both around 4.5 km), with the widest intermediate zone off Old Bar (10.8 km).

The width of the state coastal waters boundary varies, due the presence of islands, from a maximum of 10.4 km offshore of Dark Point (Little Gibber) to a minimum of 5.6 km off Bateau Bay and Stockton Beach (equivalent to ~3 nm) (Figure 2.3). The minimum depth at the boundary is located off Old Bar (32 m) and the maximum depth is offshore from Broughton Island (130 m). Some component of the deep zone (>60 m) is also present in state coastal waters east of Sugarloaf Point.

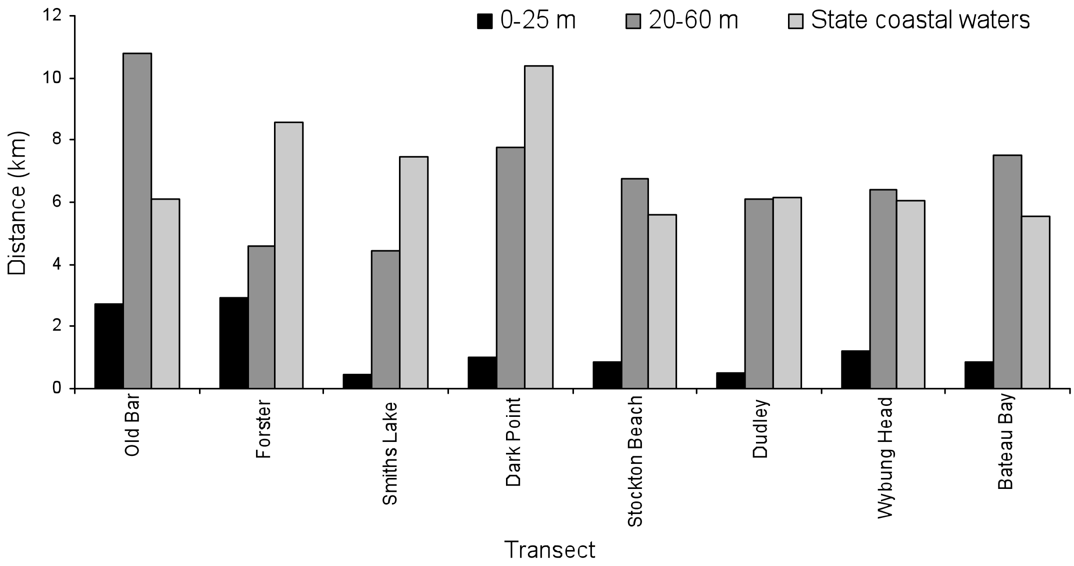


Figure 2.3 Distance (km) from the coast to the 25-m and 60-m contours and state coastal waters boundary on the continental shelf of the HCRCMA region.

The bathymetry derived from swath acoustic surveys reveals a considerable amount of fine-scale detail in the structure of the bedrock and unconsolidated areas. The bathymetry indicates the presence of folds, fault lines and gutters in the bedrock that increases the structural complexity of the seabed. For example, much of the seabed around Broughton Island has a complex bathymetry, with most bedrock strongly guttered, with many gutters up to 15 m deep (Figure 2.4). In addition, caves, tunnels, steep drop-offs and isolated areas of bedrock (bommies) are characteristic of the many areas around the island. In contrast, much of the seabed off the west and north of the island is flatter and dominated by cobbles and boulders.

Other areas in the region, such as offshore from Terrigal, have considerably less fine-scale complexity and lower overall profiles (Figure 2.5). For example, the bedrock drops 15 m over a distance of 150 m from the shore at the western extent of the swathed area, but then takes a further 950 m to descend to 30 m.

The swath bathymetry also reveals fine-scale changes in the depth of the seabed in areas of unconsolidated sediment. These include parabolic sand waves that vary in shape and orientation, but are generally <2 m high. There are also areas where a change in sediment composition occurs coincidently with a rapid change of ~1 m in the bathymetry, such as off the south-western corner of Broughton Island (Figure 2.4).

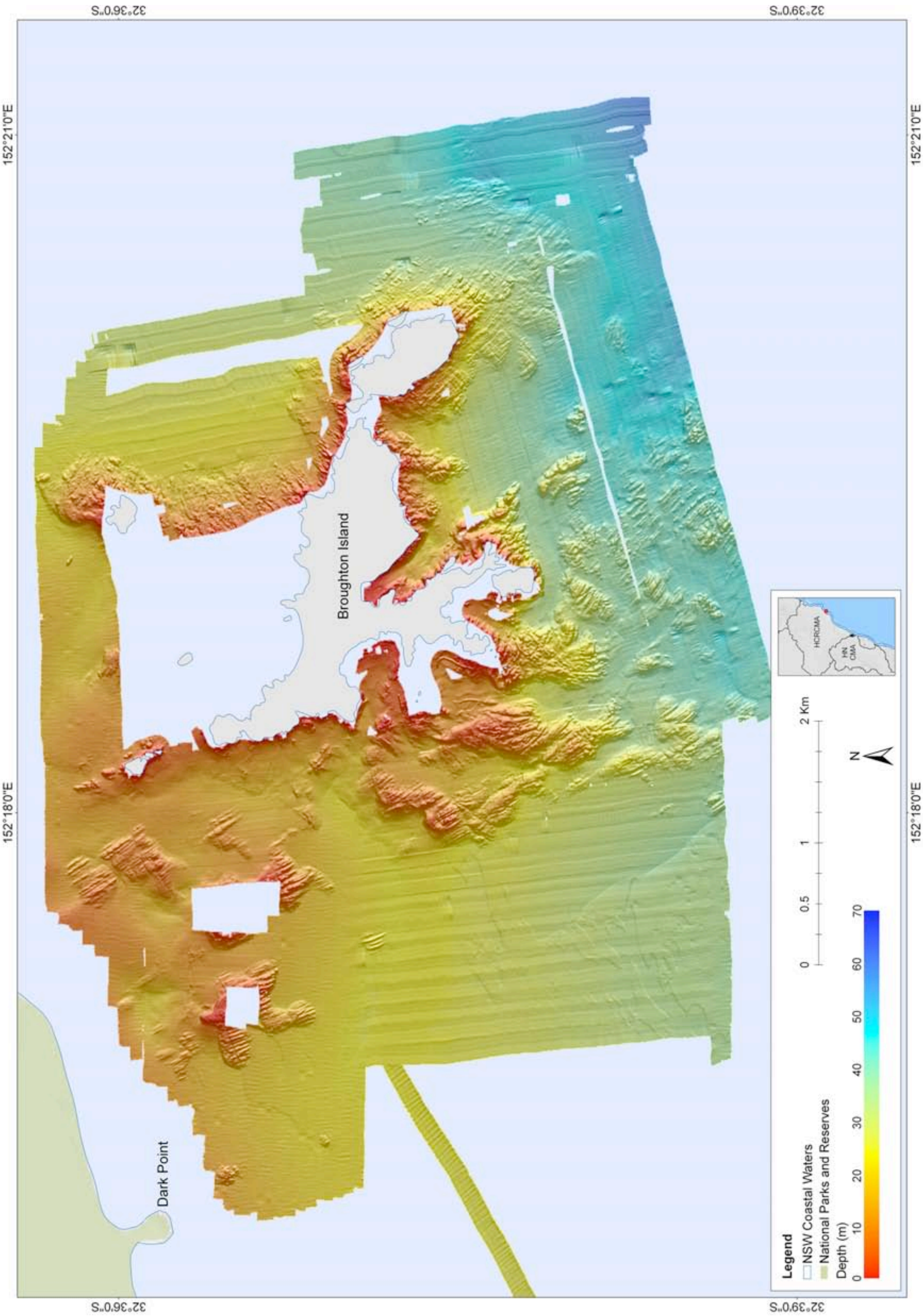


Figure 2.4 Hill-shaded bathymetric model of the seabed offshore of the Broughton Island region (Source: Jordan et al., 2010).

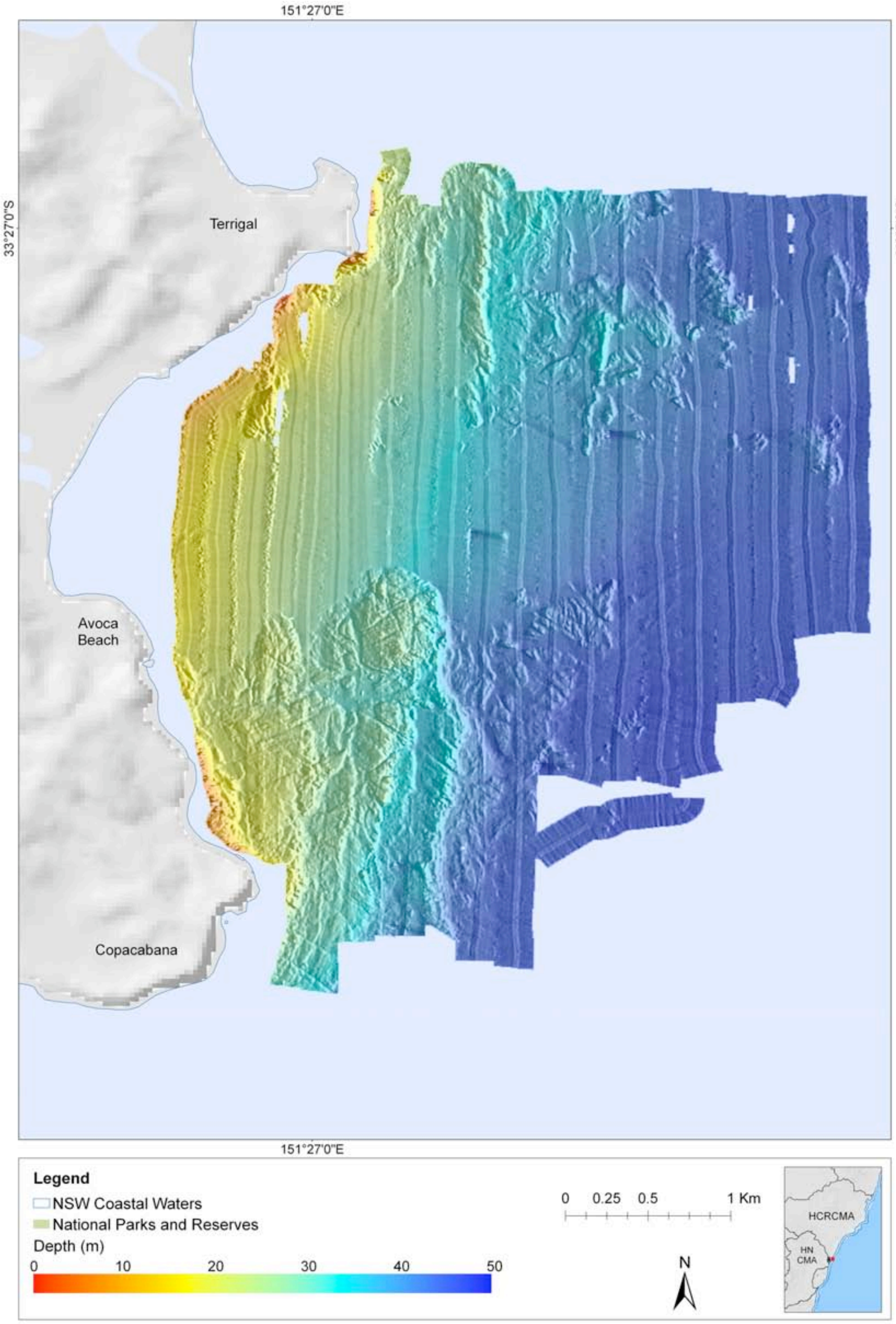


Figure 2.5 Hill-shaded bathymetric model of the seabed offshore of Terrigal (Source: Jordan et al., 2010).

2.1.3 Surficial sediments

Unconsolidated sediments are extensive throughout the inner continental shelf waters of the HCRCMA region. In general, much of the shelf of the region is dominated by clastic sediments from the inner-shelf to ~100-110 m depth, and carbonate-dominated sediments on the outer shelf (Davies, 1979; Boyd et al., 2004). The wide distribution of coarse sediment throughout the inner continental shelf of the region reflects the low input of finer coastal sediments, strong tidal currents and oceanic swells (Boyd et al., 2004). The distribution of grain sizes indicates that the region is characterised by fine sand along much of the inner shelf with a broad area of finer sediments on the mid-shelf, particularly south of Port Stephens and offshore from the Hawkesbury River. This reflects the historical transport of finer sediment from these systems. The distinct areas of coarser sediment on the inner shelf throughout the Port Stephens region are generally associated with areas of outcropping bedrock. This is particularly evident around Broughton Island and Seal Rocks (Figure 2.6). Historical side-scan sonar maps from the Central Coast region also indicate some variability in sediment composition.

Using a collation of historical data, Boyd et al. (2004) examined the broadscale patterns of surficial sediments throughout much of the HCRCMA region. This analysis confirmed that, in general, there are several main classes of sediments on the shelf within state coastal waters, which relate to depth and distance from shore. These are defined as:

- Inner-shelf sand – nearshore sands (generally found between 0-30 m depth with a decreasing grain size with increasing water depth), and inner shelf gravels (which are quartz-lithic in composition and patchily distributed between 20-60 m).
- Mid-shelf muddy sand – poorly sorted with variable mud content (10-80%). The inner boundary of the muddy band is usually clearly defined between 50-70 m in the south but occurs much shallower in the north. It is most common offshore from the major rivers such as the Hunter River.

Outside state coastal waters, the shelf contains mostly:

- Outer-shelf carbonate sand – this has a high carbonate content being composed primarily of a range of bivalves, bryozoa and foraminifera but with localised occurrences of carbonate gravels and minor components of terrigenous sand and mud. This sand generally occurs in a band on the outer shelf at depths as shallow as 60 m in central NSW.

Swath mapping in the central region has revealed fine-scale structuring of unconsolidated habitats on the inner shelf, predominantly as a result of variations in particle size and shell content, and the presence of sand ripples and waves (Jordan et al., 2010). The fine-scale data indicate that, in many places, the broadscale sediment point data are a poor representation of the actual spatial variability in sediment types on the inner shelf. Areas that contain varying amounts of boulders, cobbles and pebbles, also occur, particularly adjacent to areas of rocky reef; these are unlikely to be sampled by sediment grabs and corers. The majority of swath-mapped areas are within the inner-shelf sand region dominated by inner-shelf gravels, although there is evidence that the inner shelf also contains patches of finer nearshore sands. Such patterns are suggested to result from seaward transport of nearshore sands to overlay parts of the coarser inner-shelf gravels during storm conditions that produce downwelling currents.

Swath mapping revealed that the unconsolidated habitats surrounding the reef complex offshore from Black Head consist mostly of a combination of fine and coarse sand. The coarse sand tends to dominate the large areas between the reef systems, with finer sand occurring further from the reef edge, although this pattern tends to be inconsistent, occurring more on the northern side of reefs. A gradation from fine to coarser sands occurs on the south boundary of many of the larger reef patches. Close to the edge of the reef, the unconsolidated areas also contain varying amounts of cobbles, boulders and pebbles that produce higher acoustic backscatter values.

Higher uniform backscatter intensity is evident adjacent to the reefs surveyed in the Seal Rocks region, indicating coarser unconsolidated sediments close to the reef (Jordan et al., 2010). Edith Breakers, and two reef patches, one to its south and one to its east, are joined by an area of coarser unconsolidated sediment. Directly to the east-north-east of Edith Breaker, a section of lower backscatter intensity occurs on a gentle slope (3 m drop over 400 m distance) down to a distinct break. From the southern end of this reef through to the east-north-east, discernable sand wave fields of irregular curvilinear features, characterised by coarser sediments, occur in the troughs between features. This field ends distinctly 250–600 m to the west-south-west of Little Seal Rocks where a discrete boundary is present between the two unconsolidated grain sizes and coincides with a sharp change in bathymetry and slope direction.

There is a buffer of higher-intensity backscatter around much of the reef in the Broughton Island area. Some noticeable unconsolidated sediment features are highlighted by distinct boundaries between uniformly lighter and darker areas in the backscatter image (Figure 2.7). To the south-west of Broughton Island, a distinct area of sediment patterning is present, with a distinct area of coarser unconsolidated sediment that slopes down from the island to a distinct boundary with finer sediments (a lighter shading in the backscatter image – Figure 2.7). This break coincides with an abrupt change in bathymetry and a reversal of the slope direction. The fine sediment rises approximately 2 m, to the west of the boundary, into an area over which scattered features are visible through areas of lower intensity backscatter that occur in troughs between higher areas of finer sediment (Figure 2.7); the troughs are approximately 1 m deep. To the east of Little Broughton, at the base of the reef (shown as the complex area of backscatter – Figure 2.7), is an area of low intensity backscatter 200-400 m wide.

The islands offshore from the entrance to Port Stephens contain small amounts of boulders, cobbles and/or pebbles, particularly adjacent to areas of rocky reef (Jordan et al., 2010). Coarser sediments occur to the south-east of Fingal Island, between the small reef sections, within gutters, extending to the south and west as a large distinct feature which joins with the similar sediments surrounding the bommies off Boulder Bay. There is an example of a gradual transition boundary between finer and coarser unconsolidated sediment to the south of the reefs off Fisherman's Bay. South of Birubi Point, the seabed of Stockton Bight is dominated by soft-sediment habitats, characterised by the ~ 33-km long section of sandy coastline. On a broader scale, sediments have an increasing mud content towards the southern and offshore sections of the area (Boyd et al., 2004). A more consistent pattern in soft-sediments was evident offshore from Terrigal. Here, a large area of sand extends out to ~3 km offshore where an area with much higher backscatter is present; this is likely to reflect a much coarser sediment type (Figure 2.8). This very coarse-grained, gravely sand is also evident in historical side-scan sonar maps from the Central Coast region (Jordan et al., 2010).

Overall, within and immediately adjacent to the numerous rocky reef complexes, the unconsolidated habitats in the HCRCMA region mostly comprise a combination of fine and coarse sand, with coarse sand tending to dominate the large areas between the reef systems and finer sand occurring further from the reef edge. However, this is not a consistent pattern across the region. In many places, close to the edge of the reef, the unconsolidated areas also contain varying amounts of cobbles, boulders and pebbles that result in higher backscatter values in these locations. There are also many areas that have sharp transitions between fine sand and gravely substrates, with coarse sediments generally occurring in depressions up to 1 m deeper than the surrounding fine sediments.

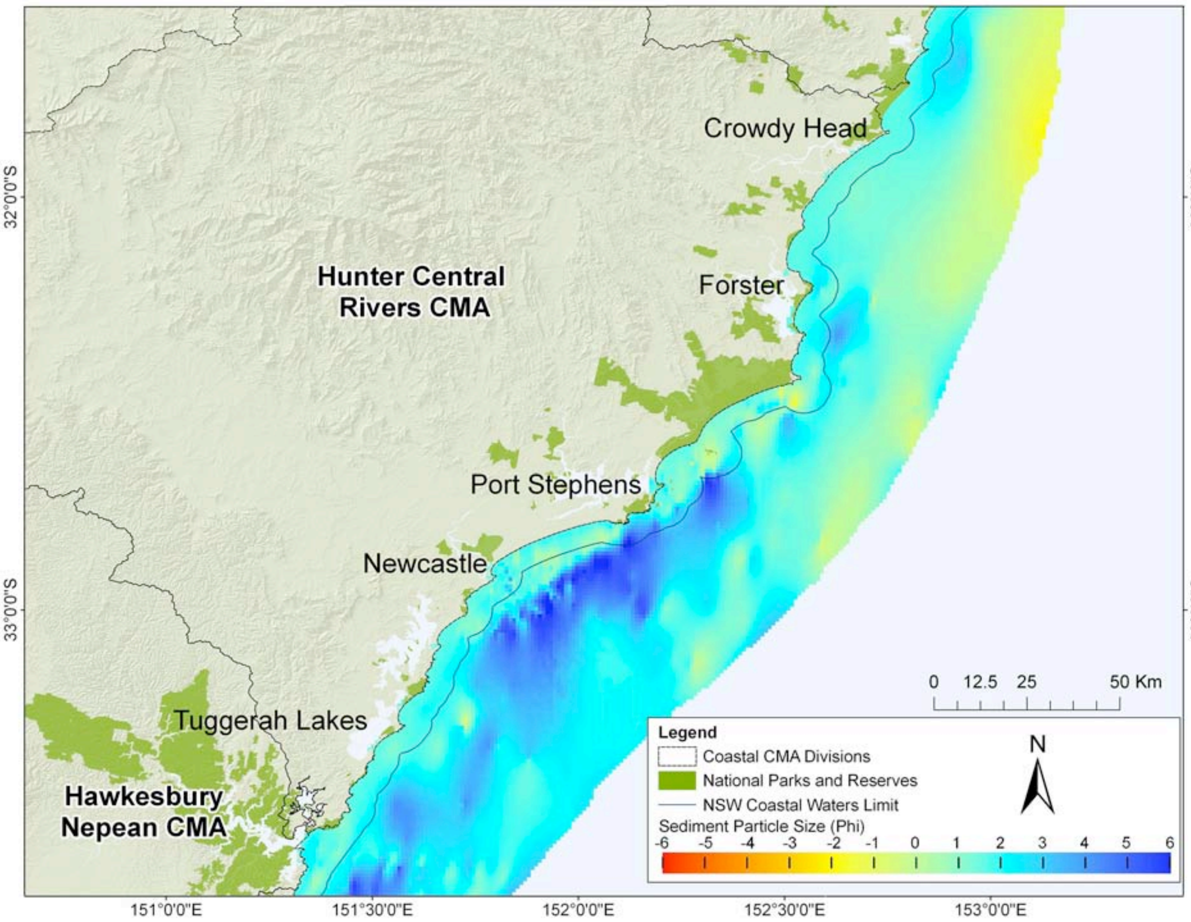


Figure 2.6 Broadscale sediments of the HCRCMA region and adjacent continental shelf.

Primary data sources

The coarse distribution of sediments on the continental shelf of southeast Australia have been relatively well documented (e.g. Shirley, 1964; Davies, 1979; Boyd, 1980; Marshall, 1980; Von Stackelberg, 1982; Ferland and Roy, 1997).

The online database auSEABED was created (Jenkins, 2001) to describe the surficial sediments of the Australian seabed within the Exclusive Economic Zone (EEZ). Point data have been compiled (and collection is ongoing) from numerous sources, and there are currently records for >275,000 sediment samples. Digital GIS data are available for a range of parameters including grain size, sorting, composition (proportions of sand and mud etc.) and carbonate percentage. The Marine Sediments Database (MARS) was designed as part of the National Marine Sediment Database and Seafloor Characteristics Project (Passlow et al., 2005), and is another online database <www.ga.gov.au/oracle/mars> that is maintained by Geoscience Australia. This database holds information from >40,000 samples. Data stored include sample locations, water depths and descriptions of each sample including (where available), quantitative analyses of samples including grain size, mud, sand, gravel and carbonate concentrations, mineralogy and geochemical properties. The data held in this database have been produced into a series of maps (and GIS layers) entitled Sedimentary Features of the Australian EEZ. Maps provide a visual representation of the distribution of carbonate percentage (ANZCW1205000951) in sediments and mean grain size (ANZCW1205000955). These maps are available from Geosciences Australia.

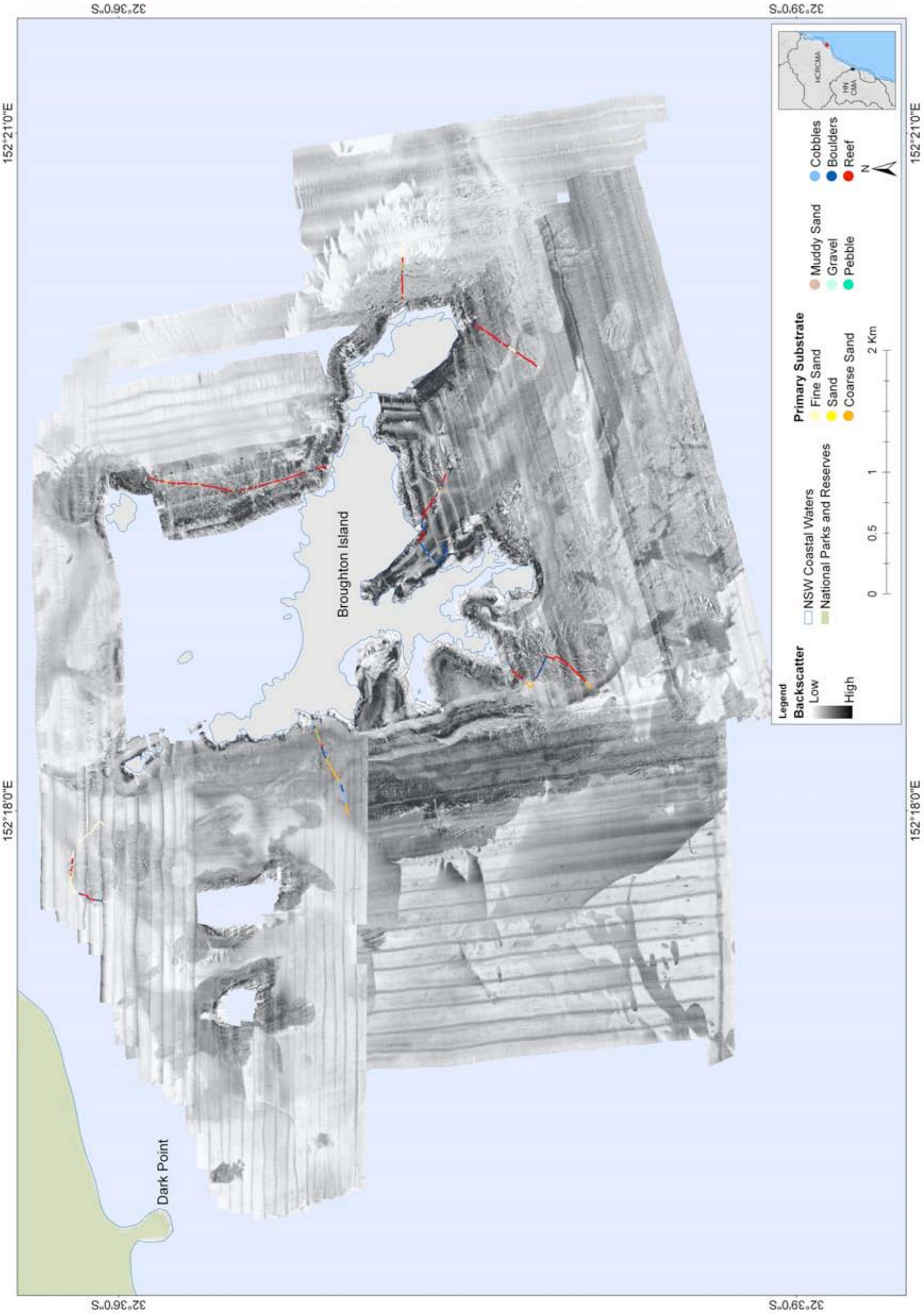


Figure 2.7 Acoustic backscatter of the seabed surrounding Broughton Island (Source: Jordan et al., 2010).

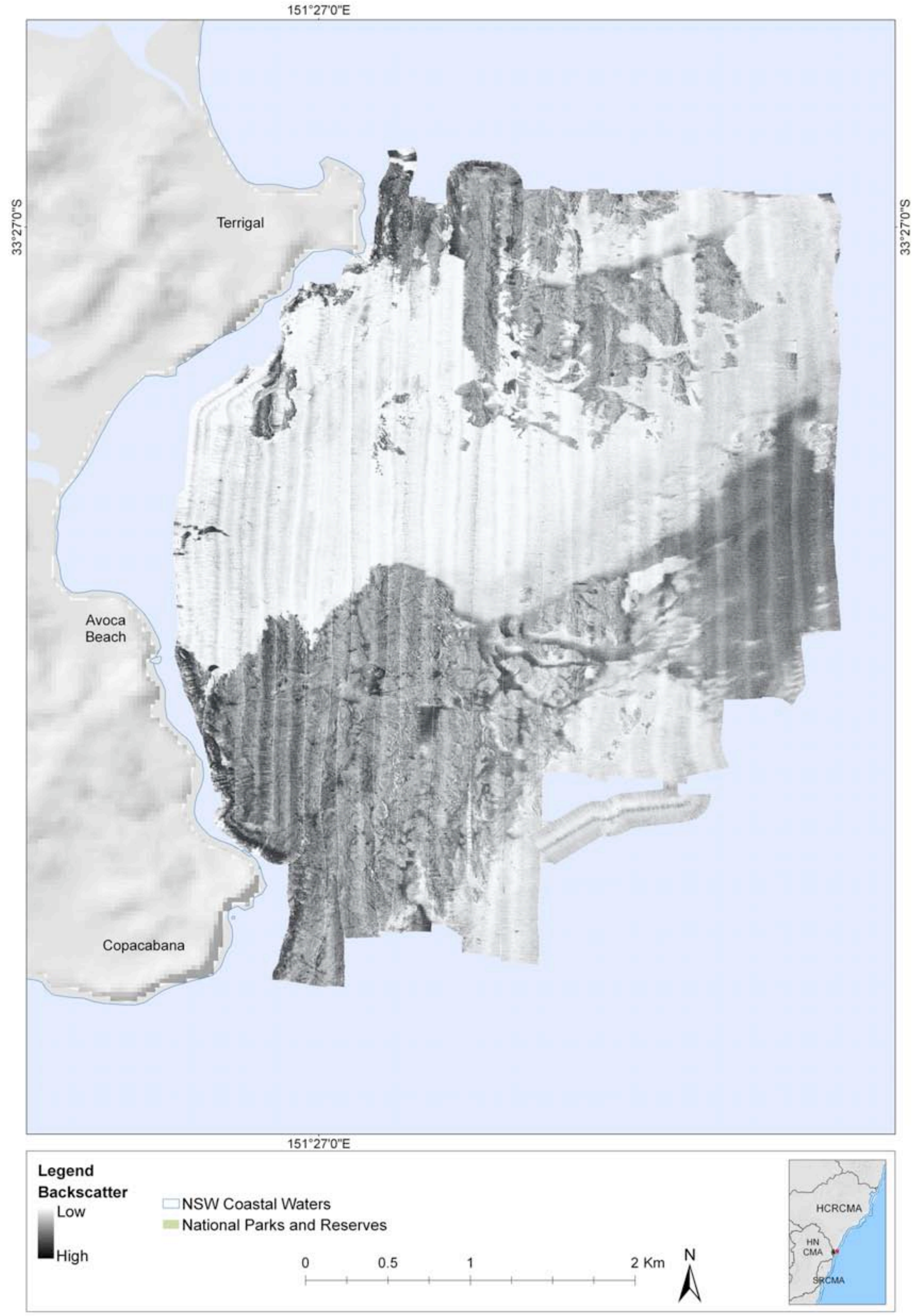


Figure 2.8 Acoustic backscatter of the seabed offshore of the Terrigal region (Source: Jordan et al., 2010).

2.2 Oceanography

Oceanography of the HCRCMA region

The primary drivers of biological and physical patterns on the continental shelf of NSW are the East Australian Current (EAC) and its associated eddies, surface winds, upwellings, coastal-trapped waves and estuarine exports (Table 2.1). The dominant oceanographic features on the shelf of the HCRCMA region are the EAC and the cooler northward-flowing current which generally dominates the inner continental shelf (Cresswell et al., 1983). The EAC meanders southward along the edge of the continental shelf before moving further offshore. The waters entrained by the EAC sometimes extend across the entire shelf into nearshore regions. At other times, the EAC lies further offshore near the edge of the shelf break (~200 m depth) and slope. The EAC is generally stronger during the summer months and reduces in intensity during winter (Ridgway and Godfrey, 1997). The EAC is generally warmer (>24^{o}C) and more saline (>35.65 ppt) than the shelf water (Ridgway, 2007).

The coastal separation point of the EAC is typically near Sugarloaf Point, but it shows inter- and intra-annual variability and may occur as far north as Cape Byron and as far south as Ulladulla. Generally, however, it occurs adjacent to one of the more prominent headlands along the mid-north coast. South of the separation point, large bodies of the EAC break off as warm-core, counter-clockwise eddies 100s of km in diameter. These eddies may extend the influence of the EAC throughout the entire HCRCMA region. The flow direction of the EAC on the western side of these eddies can be southward, with similar velocities to those found further to the north in the main stream of the EAC (Neilson and Cresswell, 1981). The northward-flowing inshore current is associated with clockwise eddies embedded in the western side of the EAC (Huyer et al., 1988). These eddies vary in size and reflect instability in the EAC flow, interaction with the bathymetry of the shelf, and changes in the orientation of the coastline (Cresswell et al., 1983).

The EAC appears to have a strong influence on the development of colder upwelled and/or northward-flowing counter-current waters inshore of the EAC during spring-autumn, and can therefore induce large drops in temperature. Water can be brought towards the surface by Ekman pumping whereby contact of the EAC with the continental shelf forces a bottom layer of water up the slope and onto the shelf. As the current passes over the seafloor, the southward motion sets up a shear with the seafloor and the Coriolis effect drives the water up the slope. Modelling has shown that bottom-layer Ekman pumping alone may not be sufficient to bring slope water to the surface (Gibbs et al., 1998); this occurs when upwelling-favourable northerly winds also blow (Roughan and Middleton, 2002; 2004). In this case, the Coriolis effect forces the surface water to the left in an offshore direction as the wind passes over the sea surface. This process only occurs when the wind blows strongly from the north to north-east for several consecutive days. While slope intrusions can occur anywhere along the coast, and sometimes along large sections, they commonly occur in the Laurieton region where the coastal alignment and shape of the continental shelf create regular upwelling events during spring and summer (Rochford, 1972; 1975).

The combination of a meandering EAC and cold-water intrusions is responsible for the highly anomalous sea-temperature patterns in the shallow waters of the Solitary Islands region (Malcolm et al., in press). The relative influence of the EAC is highly variable at both inter- and intra-annual time scales (Wilkin and Zhang, 2007) with variation cycles of around 4 years that may be associated with El Niño cycles. Longer-term, decadal variability also occurs and is associated with basin-scale dynamics of the South Pacific Gyre and changes in wind patterns (Ridgway et al., 2008). The influence of the EAC reduces considerably during winter and the sea surface temperature (SST) of shelf waters is fairly homogeneous. During summer, the EAC increases in strength reaching speeds of up to 4 knots. The upper layer of the ocean over the inner HCRCMA shelf is generally well mixed down to a depth ~20-80 m and, within this layer, there may be a gradual decrease in temperature with depth. At times, however, the water column may become stratified, particularly during winter.

Internal waves and tides are a significant source of mixing in the ocean and there are indications that internal tides occur in the coastal waters off eastern Australia. These may be larger-scale internal tides and waves (Griffin and Middleton, 1992; Holloway and Merrifield, 1999), or weather-band coastal-trapped waves (Church et al., 1986; Middleton and Bye, 2007). Internal tides may impede the current flow, create a slight northward current inshore of the EAC, and generate mixing (Robertson, 2005; 2006).

While a great deal of information is available on the physical oceanographic processes on the continental shelf of NSW (e.g. Cresswell et al., 1983; Huyer et al. 1988), much of this is concerned with the numerical simulation of physical processes and *in situ* observations (e.g. Condie, 1995; Oke and Middleton, 2000) which are limited both spatially and temporally. There is little information on spatial and temporal patterns at scales appropriate for planning within the HCRCMA region.

Table 2.1 Oceanographic descriptions of the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) mesoscale bioregions (Commonwealth of Australia, 2006).

Manning Shelf, MAN NSW/55	Coastal oceanographic circulation is dominated by the main stream of the EAC. However, this is the area where, for most of the time (65.6%), the EAC breaks away from the NSW continental shelf in a south-easterly direction. Localised centres of upwelling (24-day upwelling cycles) are found during spring and summer off Laurieton (31°39'S). Their effects on the nutrient loading of the area are similar to the effects of the upwelling areas off Evans Head. The wave climate is characterised by a range of typical breaker heights between 1.4-2.5 m, and a high relative frequency of peak wave energy fluctuations, with a primary peak of wave energy occurring in May and a secondary one in February.
Hawkesbury Shelf, HAW NSW/54	Coastal oceanographic circulation is influenced mainly by mesoscale eddies of the EAC flowing southwards and coastally trapped waves setting northwards. Coral Sea and Tasman Sea water masses meet in this region, forming the Tasman Front. The wave climate is characterized by a range of typical breaker heights between 1.4-2.5 m, and a high relative frequency of peak wave energy fluctuation, with a primary peak of wave energy occurring in May and a secondary one in February.

While outflows from estuaries do not generally exert a strong influence on currents on the NSW shelf, the HCRCMA region has several major rivers and many smaller ones which discharge to coastal waters. There is a daily exchange with the sea during each tidal cycle, but the majority of the annual export of sediment and nutrients occurs during high-flow events. The fresh water discharged by river plumes during floods typically forms a buoyant lens spreading over the top of the ambient shelf water, gradually mixing at the interface with the more saline water below as it moves away from the mouth; this process is affected by the action of wind and waves. In the absence of any wind or shelf currents, the plume water is deflected to the left and tends to favour the northern side of a river mouth on its exit. However, as currents on the east coast of Australia may flow either to the north or to the south depending upon the behaviour of the EAC and local wind and swell conditions, there are considerable differences in the spatial distribution of river plumes.

The rivers of the north coast region discharge large quantities of nutrients onto the shelf during high-flow events, although there are few measurements of nutrient concentrations in these river plumes. The shelf waters of the HCRCMA region generally have low nutrient concentrations compared to other regions of the world (Rochford, 1984), with the EAC being particularly nutrient poor. Surface nitrate levels are low in all seasons but are slightly higher during winter when the EAC has a weaker influence and shelf waters are dominated by flow from the Tasman Sea. Deep water is the primary source of nitrate, and concentrations are highest during spring and summer when conditions for upwelling are most likely to occur. Concentrations are highest around the central area of the shelf between the latitudes of 30º-36º S.

Phosphate concentrations show a similar pattern to nitrate with low levels at the surface and elevated concentrations below the mixed layer. Phosphate concentrations at 50 m, however, are highest during the winter and may be sourced from the northward flow of Tasman Sea water along the shelf, rather than from locally-formed slope intrusions. Silicate concentrations are generally rather low in the sea. The highest silicate concentrations coincide with low salinity waters in the very north of the state waters and may be associated with river exports in this region. A persistent area of higher surface silicate concentrations occurs near the coast between Smokey Cape and Port Stephens. Silicate concentrations at depth show a similar pattern to those of phosphate. Overall, there has been little work on the fate of nutrients and sediment from NSW rivers and their impacts on coastal ecology; this is an area that warrants further research (see Chapter 6).

Primary data sources

Oceanographic information for waters within the HRCMA region is available from a range of sources and includes considerable spatial information with interpolated synthesis of *in situ* observations, satellite data, modelling results and analysis of spatial data layers. These spatial data, including SST, salinity and a range of nutrients, were recently summarised by Davies and Mesley (2010) at a state-wide scale, but this scale is too coarse to adequately describe small-scale variability found within the HCRCMA region. While the Coastal Atlas of Regional Seas (CARS) 2009 provides a useful background dataset that can be used to provide a broad context for finer scale or *in situ* observations, the standard CARS products need to be scaled down to higher resolution for use along the coast.

The Advanced Very High Resolution Radiometer sensors produce four satellite images daily over the east coast of NSW, with SST images produced by CSIRO Division of Marine and Atmospheric Research at approximately a 1 km² resolution. SST data with a 4 km² resolution can also be obtained free from the National Ocean Atmospheric Administration web site. Bluelink provides prediction and analysis of ocean temperatures and currents, and produces forecasts using the Ocean Forecasting Australia Model (OFAM) that is based upon a number of models that have been adapted to Australian seas. The current resolution of Bluelink is still too coarse to resolve small-scale features but future developments may see a downscaled model that has this capacity. Bluelink operational forecasts are available from <http://www.bom.gov.au/oceanography/forecasts/index.shtml>.

SST products have been fairly well validated and the temperatures are reasonably reliable, although it is important not to include pixels that suffer from incomplete cloud masking or from stray radiance from the land. Bluelink products are being developed to eliminate the problems of cloud cover blocking data from satellites. Re-analysis hindcasts from the model (BRAN) stretching back to 1994 will allow better understanding of spatial distribution of oceanographic features in NSW. Furthermore, the Australian Bureau of Meteorology (BOM) are producing routine forecasts of ocean parameters that will assist planning of research into coastal oceanographic processes.

Further information and details on the modelling and analysis of data and access to BRAN can be found at <http://www.marine.csiro.au/bluelink>.

The Integrated Marine Observation System (IMOS) includes deployment of oceanographic moorings at various locations along the NSW coast; none of these are currently within the

HCRCMA region. However, gliders can collect profiling information throughout the water column, and these can be deployed within the HCRCMA region. All IMOS data will be provided on-line through the IMOS ocean portal at <http://imos.aodn.org.au/webportal/>.

2.2.1 Wave climate

The wave climate of the entire NSW coast is generated by five types of pressure systems. Three are cyclonic – tropical, east coast and mid-latitude cyclones, together with high-pressure systems and locally-generated sea breezes (Short and Trenaman, 1992). While these systems affect the entire coast, there is a latitudinal and seasonal variation in their degree of impact (Figure 2.9).

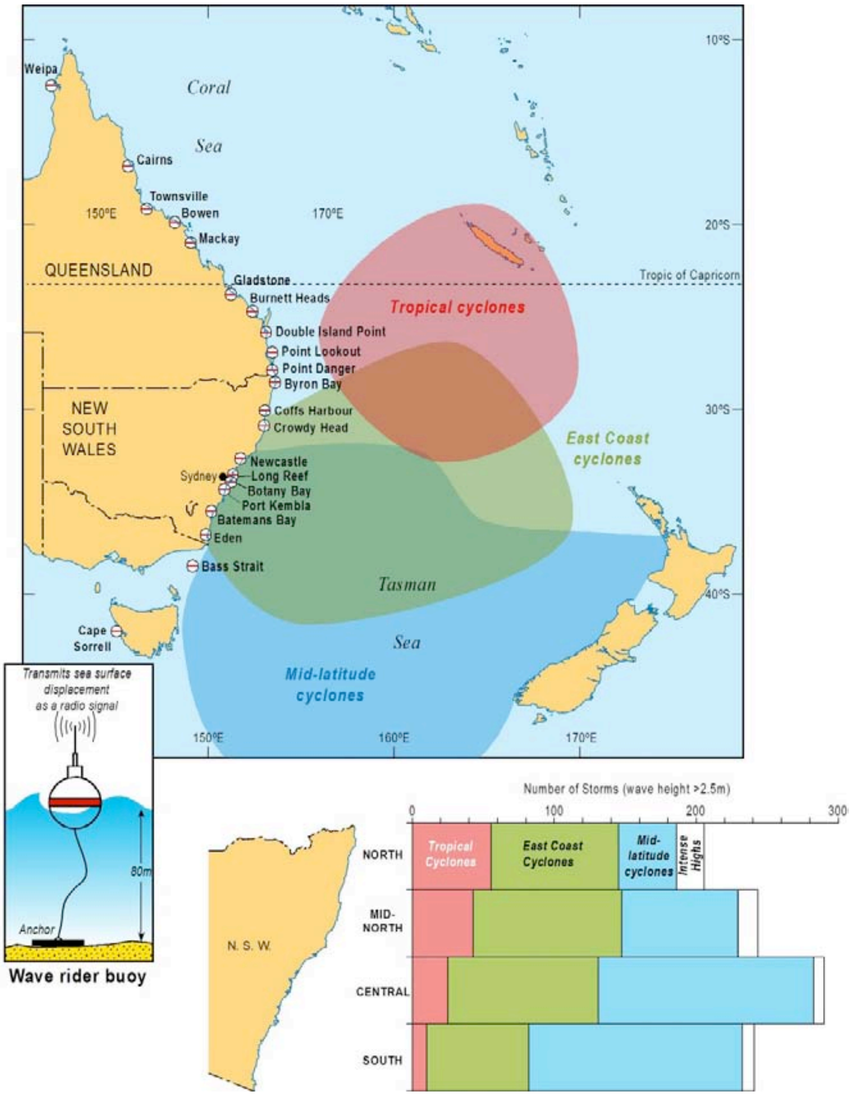


Figure 2.9 Location of Waverider buoys along the east Australian coast, together with the area of tropical, east coast and mid-latitude cyclonic wave generation for waves arriving along the Sydney-Central NSW coast. The lower figure indicates the occurrence of waves >2.5 m that are generated by these cyclones and intense highs along the NSW coast (Source: Short and Woodroffe, 2009).

On average, two tropical cyclones are generated each year in the Coral Sea. They form between ~10-20°S latitude, from November and April, with highest frequency in January-March. Their greatest impact is felt along the central-southern Queensland coast, with the degree of impact decreasing down the NSW coast where they generate north-easterly swell averaging >2 m (Figure 2.9). East coast cyclones (or lows) tend to form over the central NSW coast, moving south-east towards New Zealand. They occur year-round with a late summer-winter maximum. When close to the coast, they can generate strong easterly winds, heavy rain and high seas. As they track east they continue to produce easterly swell averaging >2 m, and generate the largest waves impacting the NSW coast (Short and Trenaman, 1992). Mid-latitude cyclones track continuously south of the Australian continent and provide a year-round southerly swell averaging <2 m, that arrives ~200 days each year and travels up the east coast, gradually decreasing in height. High-pressure systems track across the NSW coast every few days and, when located off the coast, provide a flow of easterly air that generates low to moderate easterly seas. When the high is centred over the coast, warmer conditions usually lead to sea-breeze conditions which generate north-easterly winds and associated short wind waves; these conditions occur for ~14 days a month during summer.

Impact of systems on the coast and marine environment

The three cyclonic pressure systems are each capable of generating strong winds, intense rain and high seas and swell, while the highs and sea breezes tend to generate low to moderate winds and seas. The impact of each system on the coast depends on their location relative to the section of coast under consideration. Along the Hunter-Central Rivers section of the NSW coast, the most severe impact is generated by intense east coast cyclones located close to the coast, and occasional intense high-pressure systems. Both can generate strong north through east winds and intense rain leading to coastal flooding. The cyclones generate the highest waves on the NSW coast leading to shoreline erosion. The cyclone in June 2007, which led to the grounding of the *Pasha Bulker* at Nobbys Beach (Box 2.1), is an example of the extreme winds, rain and seas generated by an intense east coast cyclone (Watson et al., 2007). Along the same section of coast, both tropical cyclones and mid-latitude cyclones tend to generate north-easterly and southerly swell, respectively. When the swell exceeds 2.5 m, it can result in general shoreline erosion.

Box 2.1 The "*Pasha Bulker* storm"

On the night of Thursday 7th June 2007, a low-pressure system, that had been moving down the east coast from northern NSW, intensified off the Newcastle coast. The strong gale resulting from this measured Force 9 on the Beaufort scale, and generated strong onshore winds (with gusts of up to 135 km h^{-1}), high seas (maximum H_{sig} = 6.8 m; maximum H_{max} = 14.1 m) and heavy rainfall, dumping >300 mm in many parts of the Hunter region. The storm caused extensive flooding and cut power to >100 000 homes, and is now listed as the fourth largest general insurance loss since records commenced in 1968. The storm generated international headlines, mainly because of the grounding of the 76 000 t (deadweight), bulk carrier, *Pasha Bulker*, which ran aground on Nobbys Beach on the morning of 8th June. Despite warnings from the Newcastle Port Corporation, the *Pasha Bulker* failed to move far enough offshore to escape the effect of the huge seas and the gale-force onshore winds. After the crew was safely evacuated by helicopter, the primary concern was that the vessel would break up causing a major oil spill. While the hull was breached, little of ~750 t of hydrocarbons leaked into the sea and there was no evidence of oil pollution. Over the next 3 weeks, a number of attempts were made to refloat the vessel with success finally occurring on 2nd July. This incident has been investigated from a number of angles including maritime safety within the region and the potential effects of changing climate and increased frequency and intensity of east coast lows on the NSW coast. For more information see Watson et al. (2007) (Photo: Robert Smith).

The wave climate generated by the combination of all five pressure systems through the year is provided in Figures 2.10, 2.11 and 2.12. Figure 2.10 shows the significant wave height recorded by the Waverider buoys offshore from Byron Bay, Coffs Harbour and Crowdy Head. Waves average 1.5 m with a slight later-summer-early-winter peak, which can be attributed to a combination of tropical and east coast cyclones (Short and Trenaman, 2002). However, the generally flat curve indicates that waves are received year-round with little seasonal variation in wave height. There is also little variation between the three buoy sites indicating that the whole section of coast has a very similar wave climate. Wave period (T_p) averages 9 s, with a slight winter peak when longer-period swell arrives from the south, and a summer minimum when shorter seas also prevail with the swell (Figure 2.11). Again, there is remarkable uniformity between the three buoys. Wave direction at Byron Bay (Figure 2.12) shows an extremely flat-uniform mean direction from the southeast, with a range from northerly (with a slight summer peak associated with sea-breeze conditions) to south and even south-westerly. The dominant south-easterly to southerly swell, is generated by the mid-latitude cyclones, while offshore south-westerly winds produce waves moving offshore at the Waverider buoy, which is located a few kilometres off the coast.

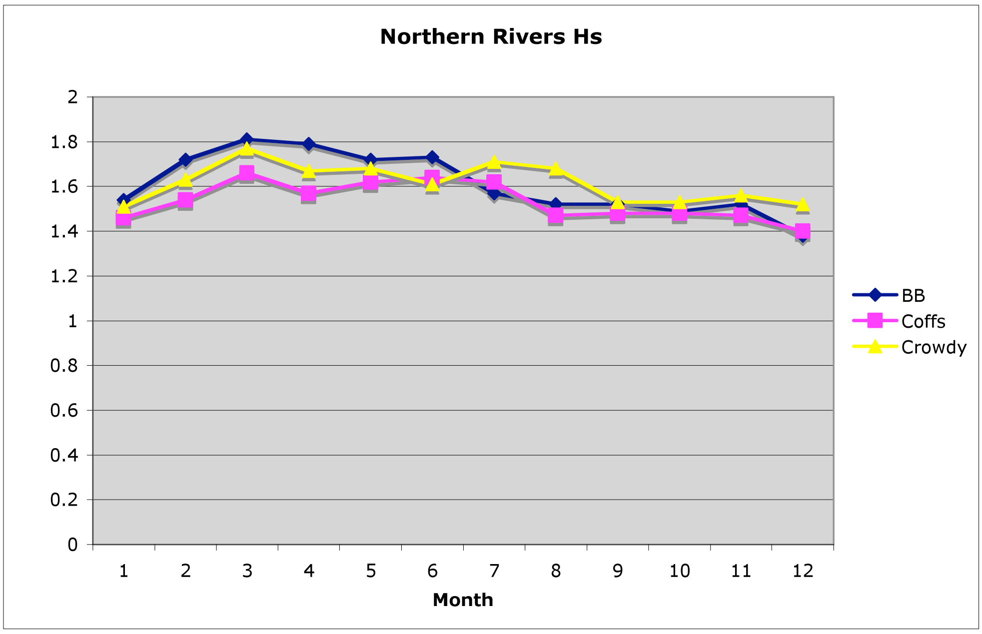


Figure 2.10 Significant monthly wave height (H_{sig}) for Byron Bay (BB), Coffs Harbour (Coffs) and Crowdy Head (Crowdy) Waverider buoys. Data based on statistics supplied by Manly Hydraulics Laboratory (MHL, Department of Services, Technology and Administration (DSTA)) and the Department of Environment, Climate Change and Water (DECCW). Mean annual significant wave height for Byron Bay is 1.65 m, Coffs Harbour 1.58 m and Crowdy Head 1.62 m.

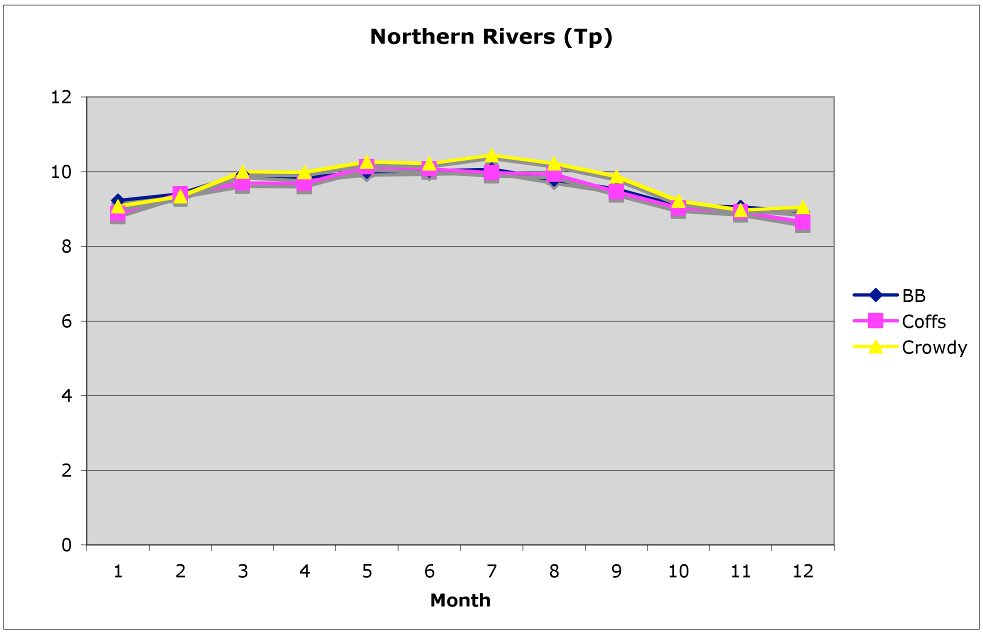


Figure 2.11 Peak monthly wave period monthly (Tp) for Byron Bay (BB), Coffs Harbour (Coffs) and Crowdy Head (Crowdy) Waverider buoys. Data based on statistics supplied by MHL (DSTA) and DECCW. Mean annual peak wave period for Byron Bay is 9.57 s, Coffs Harbour 9.57 s and Crowdy Head 9.71 s.

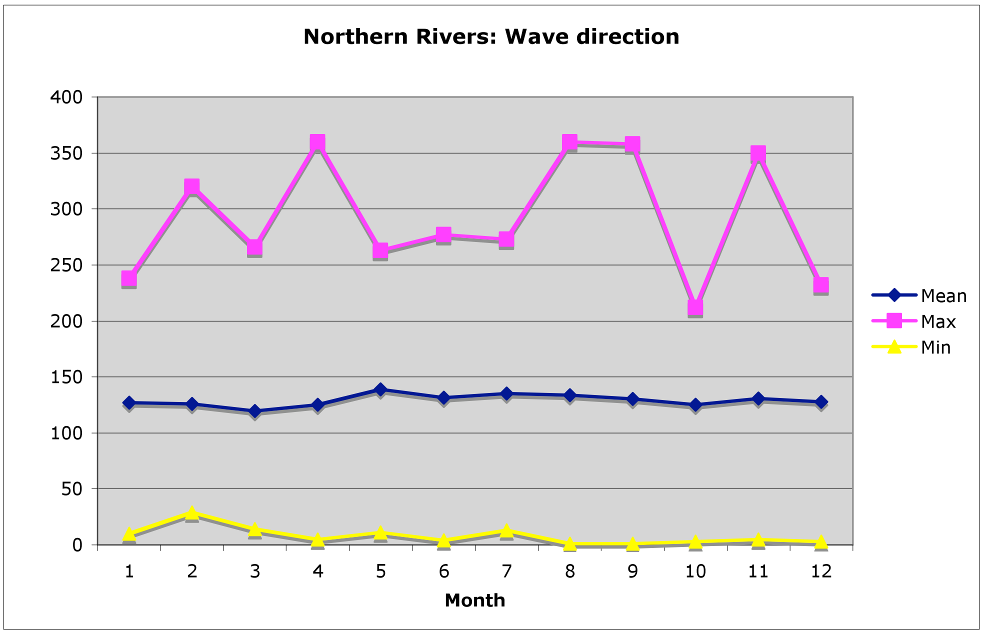


Figure 2.12 Mean, maximum and minimum monthly wave direction (in degrees) for Byron Bay Waverider buoy. Average annual wave direction is southeast. Data based on statistics supplied by MHL (DSTA) and DECCW.

Summary of impacts

The following impacts can be expected along the NSW coast and coastal waters from the five wave-generation systems (or types of pressure systems).

Periodic high seas and swell

These will cause beach erosion, with the maximum storm demand (volume of sand likely to be eroded) for the NSW coast calculated at 200 m^3/m. Beaches will usually recover between major storms, leading to an oscillation in the shoreline position of up to 100 m.

Changes in wave direction

Changes in wave direction generate a shift in the direction of longshore sand transport. While the dominant southerly waves generate a net northerly transport, which reaches 500 000 m^3/year at the NSW-Queensland border, reversals in transport occur during easterly through northerly waves. On embayed sections of coast, this results in beach rotation, where sand is shifted periodically towards one or the other end of the beach, leading to scour at one end and accretion at the other (Short et al., 2000; Ranashinge et al., 2004; Short and Trembanis, 2004).

Strong onshore winds

Strong onshore winds associated with east coast cyclones, and occasionally north-tracking mid-latitude cyclones, lead to accelerated aeolian sand transport, moving sand from the beach to the dunes and activating all bare dune surfaces. Onshore winds also lead to coastal downwelling, which raises sea temperate a few degrees at the coast. Conversely, north-easterly through north-westerly winds lead to upwelling at the coast and a drop in temperature of up to several degrees (Short and Woodroffe, 2009).

Extreme ocean levels

Extreme ocean levels are generated by a combination of high waves leading to wave set-up, storm surge associated with onshore winds, and inverse barometer effect under intense low pressures (cyclonic) systems. In combination, these can lead to an elevation of the sea level by as much as 0.3-0.6 m on the NSW coast (Watson et al., 2007), and are most likely to occur in association with east coast cyclones.

Rainfall

The heaviest rainfall along the northern NSW coast is associated with east coast cyclones located over, or close to, the coast, and occasional intense high-pressure systems. Both deliver moderate to strong northerly through easterly winds and heavy rain, which can lead to coastal flooding.

Worst-case scenario

The worst-case scenario along the Hunter-Central Rivers section of coast is therefore associated with intense east coast cyclones located over or close to the coast. These generate high seas and swell, strong onshore winds, heavy rain which can lead to shoreline erosion, coastal flooding, elevated ocean levels, wind-blown sand transport, and damage by strong onshore winds. Storms of magnitude of the *Pasha Bulker* event have a return interval of 5-10 years, while those of the magnitude of the extreme 1974 storm have a return interval of 20-70 years (Lord and Kulmar, 2000; Watson et al., 2007).

Climate change

Climate change will exacerbate some of the impacts listed above (CSIRO, 2002; Pittock, 2003; McInnes et al., 2007). The projected rise in sea level will, in itself, generate shoreline erosion, as well as increase the height of coastal flooding and extreme ocean levels. In addition, any changes in the frequency, intensity and location of tropical, east coast and mid-latitude cyclones will affect the wave climate and shoreline oscillation and rotation, as well as longshore sand transport. In addition, all three cyclone-types contribute to rainfall patterns along the coast.

Primary data sources

The data summarised in this section are courtesy of MHL and were collected for the NSW Department of Natural Resources (DNR) (now DECCW). These data are available on request from MHL at <http://mhl.nsw.gov.au/www/request.htmlx>. Wave data are summarised annually in a report by MHL.

Additional data sources

As part of the National Marine Bioregionalisation project, CSIRO produced a series of digital datasets and maps showing the annual mean (ANZCW1205000971) and maximum (ANZCW1205000970) wave height, direction (ANZCW1205001038) and period (ANZCW1205000972) from satellite-derived wave height data. Wave height data were estimated from surface wind speeds, and input into the BOM Wave Model (WAV).

The Department of Environment, Water, Heritage and the Arts (DEWHA) holds a digital mapset of the Australian wave climate produced at a national scale (ANZCW0501000407) as part of the CSIRO Coastal Zone Program. This dataset contains data derived from the Geodetic Satellite (GEOSAT) radar altimeter wave-measuring program.

2.3 Primary productivity

Primary productivity in ocean waters is mainly from phytoplankton and is usually measured in terms of chlorophyll concentration. The shelf waters of eastern Australia are generally low in nutrients compared to other regions of the world (Rochford, 1984; Roughan et al., 2003). The clear blue waters of the EAC are particularly oligotrophic. Phytoplankton blooms in coastal waters arise during periods of greater nutrient availability (Hallegraeff and Jeffrey, 1993; Hallegraeff, 1995). Naturally occurring phytoplankton blooms display a developmental sequence. Aggregations of phytoplankton may also occur along fronts where water masses converge.

Nutrients that feed algal blooms are delivered by a number of mechanisms. Possibly the most important and well studied is the phenomenon of coastal upwelling whereby cold water is transported towards the shore from deeper on the slope, below the EAC. When this nutrient-rich water encounters sufficient light, plankton communities are able to thrive (Rochford, 1972; 1975; 1984). The area near Laurieton is well known for coastal upwelling and extensive, naturally-occurring algal blooms have been noted in this area (Hallegraeff and Jeffrey, 1993; Dela Cruz et al., 2008). Sometimes these blooms can include harmful (Ajani et al., 2001), or toxic species such as *Trichodesmium* spp. and *Dynophysis* spp. that are associated with shellfish contamination and consequent serious illness in humans (Quilliam, 2000). Annually-recurrent diatom blooms may be critically important for larval recruitment of both benthic and pelagic species within the region (Hayes et al., 2005). Researchers at the Sydney Institute of Marine Science (SIMS) are currently investigating the importance of the Stockton Bight area as a highly-productive location with great importance as a nursery for fish stocks.

Just as SST can be used to infer currents, chlorophyll images from ocean colour satellite imagery can be used as an indicator of primary productivity. Images of mean chlorophyll concentration created from 5 years of SeaWiFS (Sea-viewing Wide Field-of-view Sensor) ocean colour imagery show the seasonal variation in primary production (Figure 2.13). Most of the productivity is confined to a narrow band along the coast. The area of increased productivity around Laurieton, associated with coastal upwelling, can clearly be seen, particularly in the spring and summer months. The study of the relationship of chlorophyll concentrations to rates of primary productivity is the focus of current research.

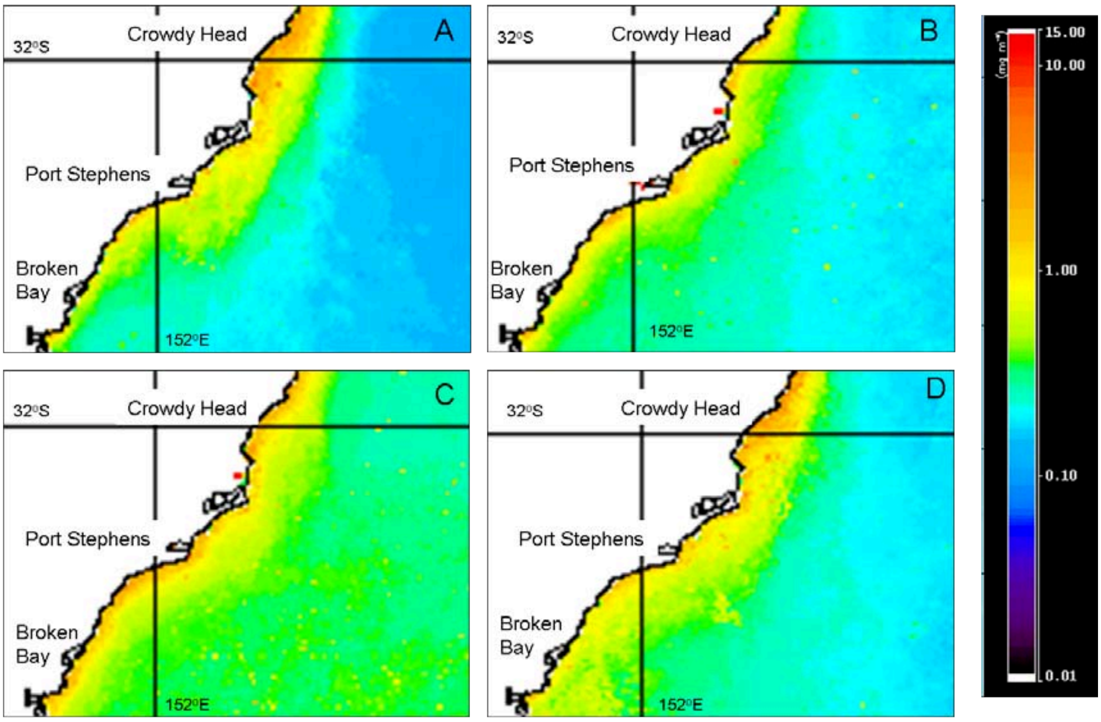


Figure 2.13 Seasonal means of chlorophyll concentrations from SeaWifs data 1998-2002. A Summer, B. Autumn, C, Winter, D. Spring (Images: DECCW).

Primary data sources

The data for this section are mostly derived from published literature cited above (e.g. Rochford, 1972; 1975; Hallegraeff and Jeffrey, 1993; Roughan et al., 2003).

SeaWiFS, MODIS and MERIS Ocean Colour images may be obtained from CSIRO, Division of Marine Research.

Data description and assessment

SeaWiFS Ocean Colour images provide quantitative data on surface chlorophyll concentrations enabling estimations of the concentration of phytoplankton. The SeaWiFS project is directed by NASA, and delivers images at a pixel resolution of approximately 1.1 km. The CSIRO Division of Marine and Atmospheric Research receives SeaWiFS data daily.

Additional data sources

In addition to the SeaWiFS data described above, CSIRO Division of Marine Research have collated data from a range of other sources into a series of national-scale maps as part of the Marine Bioregionalisation Project. The first is a map (ANZCW 1205001066) and a GIS layer (ANZCW 1205001067) summary of important regions of upwelling along the Australian coast, derived from published accounts of the phenomenon. The second series of maps and GIS layers are derived from CSIRO oceanographic surveys conducted between 1959 and 1964 on the vessels *Gascoyne* and *Diamantina*, and display concentrations of carbon ms^{-1} (ANZCW 1205001050). These voyages have also been described in Hayes et al. (2005).

Monthly mean chlorophyll-a concentrations derived from the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite are also available from CSIRO. These images have a coarser resolution than the SeaWiFS images with a pixel size of 4.88 km. Maps and GIS layers generated from these data include primary productivity in each quarter (ANZCW1205000906) and mean monthly ocean colour chlorophyll concentrations (ANZCW1205001047).

Phytoplankton provinces within Australia have been described on the basis of species composition and distribution, and compiled into a map (ANZCW 1205000879) and GIS layer (ANZCW 1205001046) by CSIRO.

2.4 Flood plumes

Nutrient and suspended solid concentrations are elevated within flood plumes (Eyre, 2000; Davies and Eyre, 2005; Devlin and Brodie, 2005), with concentrations depending upon the magnitude of the flood, prior rainfall within the catchment and degree of disturbance within the catchment. The impacts of these sediments upon coastal ecology are largely unknown; however, increased sedimentation of nearshore rocky reefs can lead to changes in benthic community structure (e.g. Smith, 1996).

The freshwater discharge of river plumes during floods typically forms a buoyant lens spreading over the top of the ambient shelf water, gradually mixing at the interface as it moves away from the river mouth. For example, Rochford (1972) reported that surface waters at Evans Head were diluted by the flood discharge of both the Clarence River and the Richmond River at various times. The buoyant plume of freshwater is subject to the action of wind and waves. In the absence of any winds or shelf currents, freshwater plumes tend to be deflected to the north of rivers on exit. However, as discussed in the previous sections, currents on the east coast of Australia may flow either to the north or to the south depending upon the behaviour of the EAC and local wind and swell conditions; river plumes have consequently been observed to travel in either direction. Figures 2.14 and 2.15, respectively, show an aerial photograph and a SeaWiFS quasi-true colour image of a flood discharge from the Hunter River in August 1998. In this case, the plume can clearly be seen flowing to the north from the river, extending into the Port Stephens region. Flow from the Karuah River, exiting at Port Stephens, may also contribute to the plume. Some of the sediments from the plume become entrained in the southward flow of the EAC near Birubi Point and are swept out to sea. Discharge from the Hawkesbury River can also be seen in Figure 2.15, as well as a minor discharge from the Manning River.

Figure 2.14 Photograph of the Hunter River plume during a flood in August 1998 (Photo: Tim Pritchard, DECCW).

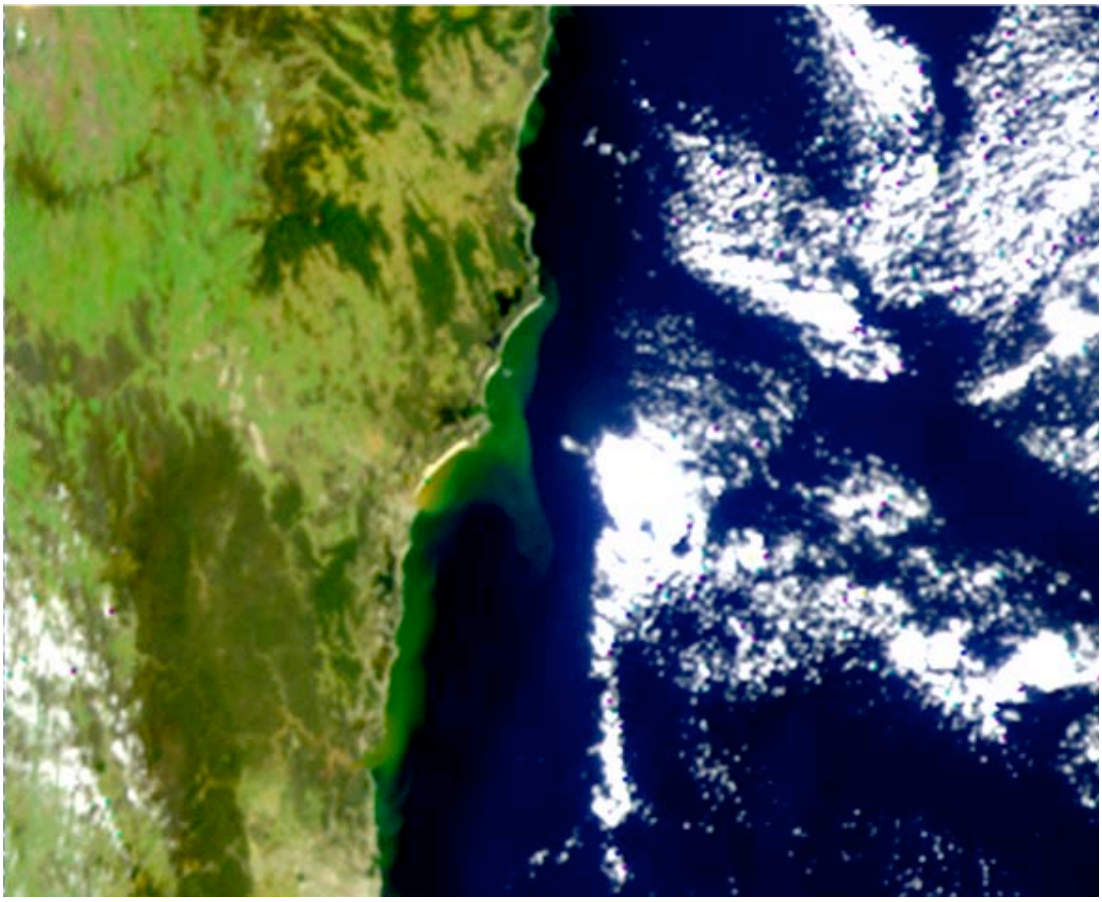


Figure 2.15 SeaWiFS quasi-true colour image showing high-flow river discharge from the Hawkesbury and Hunter rivers, 11 August 1998 (Image: Peter Davies, DECCW).

Freshwater plumes may play an important role in primary production, as phytoplankton blooms have been observed at the plume/ocean boundary. These are thought to be stimulated by elevated nutrient concentrations and increased photic depth as a result of the decrease in suspended sediments through mixing of the plume and oceanic water (Devlin et al., 2001; Davies, 2005; Davies and Eyre, 2005). Additionally, Glaister (1978) examined catches of the school prawn (*Metapenaeus macleayi*) in relation to river discharge, and found that these increased during peak flow times of the Clarence River.

Very little flood plume monitoring has been undertaken in Australia, including in the HCRCMA area; the majority of studies have focused on the effect of flood plumes on the Great Barrier Reef (GBR) (e.g. Devlin et al., 2001; Davies and Eyre, 2005). Research into the spatial and temporal patterns of flood plume composition and distribution along the GBR has demonstrated that the major influences upon plume dispersal are wind direction and strength, discharge volume from the flooded rivers, and the steering effect of headlands and reefs (Devlin et al., 2001; Devlin and Brodie, 2005). It is likely that the dispersal and distribution of flood plumes within the HCRCMA are also influenced by these driving forces. However, when wind conditions are calm during plume development, a combination of the Coriolis effect and prevailing oceanic currents will dominate the dispersal characteristics (e.g. Davies, 2005).

Lee and Pritchard (1999) calculated discharge and nutrient loads from the Hunter River during a flood event in 1998 and estimated that between 27–144 t of phosphorus and 40-190 t of nitrogen were discharged per day. This compares with daily wet-weather averages of 1.3 t of phosphorus and 8.7 t of nitrogen (SKM, 1998) and emphasises the importance of flood events for the export of nutrients to the shelf.

Primary data sources

The data for this section are mostly summarised from published sources (Rochford, 1972; Eyre, 2000; Davies, 2005). Historical data on floods within the region are available through the NSW Natural Resource Atlas (ANZNS0359000183) <http://www.canri.nsw.gov.au/nrdd/records/ANZNS0359000183.html#citeinfo>.

Summaries of studies of river exports in eastern Australia can be found in publications by the Centre for Coastal Biogeochemistry, Southern Cross University <http://www.scu.edu.au/schools/esm/ccb/Publications.html>.

2.5 Storm events and coastal erosion

Recent findings suggest that the climate is changing faster and to a greater extent than previously thought in response to human-induced greenhouse gas emissions. These changes suggest that many parts of Australia's coastline could face considerable risks from inundation, erosion and changing conditions of coastal waters.

The most severe risks will be from coincident events of several hazards. An example of this is sea-level rise coupled with an extreme storm tide and a severe riverine flood from the same weather event. In a highly urbanised area, this combined series of events has the potential to cause large economic impacts. The breaching of key coastal barriers during an extreme event, exposing coastal lakes or estuaries to increased wave and tidal energy could also have severe consequences.

Climate change is likely to drive changes in many of the processes associated with inundation or erosion of the coastline and increase the frequency of individual high-water-level events. With increasing frequency, the likelihood of events occurring simultaneously increases, and what were once seen as rare and independent events may become more common.

Storm surges are temporary increases in coastal sea levels caused by falling atmospheric pressure and severe winds during storms. The magnitude of a storm surge is determined not only by the size of the pressure fall and the wind speed, but also by the characteristics of the coast. For example, wide and shallow continental shelves (such as across northern and parts of the southern Australia) lead to larger storm surges than the narrow continental shelf off NSW.

The combination of rising sea levels and changes in extreme events gives rise to two basic risks on the coasts: inundation and coastal erosion. The severity of the risks in a particular location is affected by a range of factors related to climate, geomorphology and the way low-lying areas have been modified by construction or drainage.

Inundation risk

Inundation risk is best expressed as the likelihood of exceeding a given level of tide, surge and flood height over a particular time horizon. Inundation events vary in frequency and magnitude. Frequency is measured as average recurrence intervals of events. For example, a 1-in-100 year storm tide is the storm tide height that is forecast to be exceeded on average once every 100 years. Magnitude refers to a given level of tide, surge and flood height. Generally, the larger the event, the less frequently it occurs.

Inundation analysis suggests that between 40 800 – 62 400 residential buildings in NSW may be at risk of inundation from a sea-level rise of 1.1 metres and storm tide associated with a 1-in-100 year storm. The current replacement value of the residential buildings at risk is between $12.4 - $18.7 billion (DECC, 2009).

Based on this analysis, NSW has the highest number of residential buildings at risk of inundation around the Australian coastline. However, it should be noted that storm tide was only incorporated into the analysis for NSW (excluding wave setup), Victoria and Tasmania.

Coastal erosion

Australia's coastline has been remarkably stable over the 20th century with sea levels rising by approximately 17 cm over that time. Generally, beaches in Australia appear not to be subject to large-scale receding, except in some localised places where natural recession is occurring (e.g. 90 Mile Beach, Victoria). Revegetation and better coastal management have reversed erosive processes in many places where vegetation removal had made dunes unstable.

Coasts will tend to erode (or accrete) depending on the combined effect of four factors:

- change in mean sea level,
- changes in the frequency and magnitude of transient storm erosion events,
- extent of supply and loss of sediments from nearby sources and sinks, and
- re-alignment of shorelines due to changes in wave direction.

Under equilibrium conditions, the shape of the shore face is governed by a balance between onshore and offshore transport of sediment by surface waves. The shore profile is generally related to a given level of wave activity, inherited topography and sediment grain size.

If sea level rises (assuming no change in the wave climate and sediment supplies), the balance between onshore and offshore sediment transport will change until the shoreline moves upward and encroaches landward. The wave climate may also change, affecting the movement of coastal sediment. This will modify the shore profile, forcing changes from the upper limit of sediment movement at high water level all the way to the limit of sediment movement offshore.

Over recent decades, many Australian beaches have continued to accrete because sediment supply has been sufficient. Adequate sand supply from the lower shore face is typical of most shores with concave profiles, enabling them to keep up with recent sea-level rise.

An important threshold of change is when accreting or stable shorelines begin to recede as a result of sea-level rise and larger surge events; the erosive capacity of accelerated sea-level rise and the increasing frequency of high water level events will at some point outstrip the capacity of natural processes to replenish beaches. This is a key threshold for coastal management.

It is likely that the change from stable to receding beaches may first become apparent on narrow beaches exposed to low to medium wave energy. For example, the persistent erosion of beaches of Redcliffe near Brisbane is consistent with the present-day increase in sea level. Such a change may also result from a decrease in sediment supply.

Local disturbances and changing wave conditions have been the main cause of detectable, systematic coastal erosion to date. However, it is expected that sea-level rise and changes in storms will begin to dominate coastal processes over the next few decades, particularly if the rate of sea-level change continues at the upper range of projections. Current erosion hotspots would be expected to increase in size and magnitude and new localised areas will emerge.

The most vulnerable coasts are those made up of unconsolidated sediments, such as beaches, dunes and sand cliffs on the open coast of leaky embayments and on the shores of coastal lakes and lagoons. Most hard coasts will continue to erode at about the same rate as current sea levels, but soft sedimentary and weathered cliffs, especially those formed in calcarenite, may erode more quickly as more of the coastal face is exposed to wave action.

Coastal recession due to sea-level rise will also be affected by systematic patterns of seabed erosion and sedimentation. These geomorphic effects can be expected in all shoreline environments, including wave-dominated and protected oceanic settings, as well as in estuaries, coastal lakes and wetlands. However, further work is needed to identify where those impacts may occur and how they will play out.

Hunter-Central Rivers CMA region

An assessment of the implications of sea-level rise for the Hunter-Central Coast region was undertaken in mid-2009 (Brunckhorst et al., 2009). The study focused on human settlements, infrastructure and land-use planning, estuaries, their foreshores and broader ecosystems and also included an assessment of 17 flood events.

The study examined climate projections for the years 2030 and 2070 (assuming a sea-level rise of 14.6 cm by 2030 and 47.1 cm by 2070) and analysed ecological, economic and social vulnerability. Each of the three areas of vulnerability was then mapped onto a spatial layer to allow an analysis of potential synergistic or cumulative effects for particular locations and regions. Considerable areas of future human-built environments (residential, commercial and industrial) were identified as potentially at risk of exposure to sea-level rise and increased storm rain intensity and flooding. If town planning were to continue on a business-as-usual basis, vulnerability would rise as summarised in Table 2.2.

Table 2.2 Areas vulnerable to sea-level rise and flood extremes at three locations (Source: Brunckhorst et al., 2009).

Local Government Area (LGA)	2030 area vulnerable to sea-level rise and flood extremes	2070 area vulnerable to sea-level rise and flood extremes
Newcastle	4 969 ha or 50% of the built area	5 456 ha or 49% of the built area
Lake Macquarie	2 022 ha or 11% of the built area	2 491 ha or 11% of the built area
Wyong	3 399 ha or 22% of the built area	5 029 ha or 24% of the built area

The compounding effects of intensity of rainfall, storm events and flooding accompanying sea-level rise are likely to be responsible for most of the damage to the urban built environment, rather than sea-level rise acting alone. Gradual sea-level rise would permit adaptive responses by managers, allow the property market to price in risk and minimise the threat of serious damage. This conclusion does not hold if sea-level rise is abrupt. Ecological communities including mangroves, coastal heaths, coastal banksia, scribbly gum and paperbark forests were also identified as vulnerable to sea-level rise combined with extreme storm events.

The coastline along the Hunter and Central Coast region is also characterised by significant stretches of sandy beaches that are exposed to wind and waves. The study noted that several coastal beach dune areas may be susceptible to beach recession by 2070, such as Stockton Beach, Belmont Beach, Caves Beach, Catherine Hill Bay, Budgewoi Peninsula Beach, The Entrance, North Beach and Shelley Beach. Additionally, a threshold risk of sea-level rise combined with a storm event potentially causing a total breach of a dune area was noted, which could cause significantly greater damage to ecosystems and infrastructure.

Major social vulnerabilities identified included nursing homes, especially at Sandgate, a hospital at Morriset, relocatable home parks at Swansea, Chain Valley Bay and Bonnells Bay, housing commission neighbourhoods, new suburbs in Maryland and Woongarrah, the residential area of north Toukley and retirement villages at Canton Beach, Bonnells Bay, Wyee Point and Belmont. Adaptive planning may help to reduce future settlement vulnerability. Most Councils have implemented some predictive and precautionary revisions to planning schemes and processes. Well-structured adaptive planning could reduce the potential for future damage to urban areas by as much as 46 per cent (Brunckhorst et al., 2009).

The Newcastle flood event of 2007 sharply focused the regional population on risks associated with storms. The flood affected 10 000 – 15 000 properties and inundated more than 1 000 homes (above the floor level). The flood provided a test of Newcastle City Council's research modelling and floodplain planning; the relevance of these was confirmed by this storm event. The models also suggest that the small and steep catchments around Newcastle, and the legacy of development on the floodplain, may lead to a higher flood exposure for properties within the Newcastle area. Newcastle City Council is currently developing a city-wide Floodplain Risk Management Plan to be completed by 2011.

Primary data sources

The data for this section were mostly derived from published sources including: DECCW (2009) Climate Change Risks to Australia's Coast; DECCW (2009) Reforms to Coastal Erosion Management in NSW; DECCW (2009) Sea Level Rise Policy; DECCW (2009) Draft Coastal Risk Management Guide; and NSW Department of Planning (2009) Draft NSW Coastal Planning Guideline, Adapting to Sea Level rise.

Additional data sources

As indicated by state government guidelines, Councils within the Hunter-Central Rivers region are encouraged to complete Coastal Zone Management Plans. To date these include: Local Government Association of NSW (2009) Draft Sea Level Rise Policy Statement; Wyong Shire Council (2009) Draft Climate Change Policy; and Lake Macquarie City Council (2009) Sea Level Rise Preparedness Adaptation Policy.

3 The Biological Environment

Building on the description of physical and oceanographic processes outlined in Chapter 2, this chapter reviews relevant information on the distribution of ecological habitats and the organisms that comprise them. While biological information is sparse for many habitats and groups of organisms, a number of recent studies have commenced the process of filling some of these gaps. As in most regions, there is often a geographical bias in the sites and locations at which most work has been carried out. While the presence of the Port Stephens-Great Lakes Marine Park (PSGLMP) provides a strong focus within the Hunter-Central Rivers Catchment Management Authority (HCRCMA) region, recent work, much of it facilitated by the HCRCMA, has enabled a broader overview of biotic patterns throughout the accessible marine habitats of the region. This body of work is reviewed here.

3.1 Ecological habitats

Overview

The extent and distribution of seabed habitats within the HCRCMA region are generally poorly known, and current knowledge is based almost entirely on broad-scale bathymetric and surficial sediment data and estimations of nearshore rocky reefs from aerial photographs. Nearshore marine habitats were mapped as part of the Manning Shelf and Hawkesbury Shelf bioregional assessments (Breen et al., 2004, 2005). Aerial photographs were used to map nearshore reef and sand habitats in depths of 10 - 20 m, while a limited number of deeper reefs were mapped using boundaries taken from existing nautical charts. Classifications from aerial photography included islands and rocks, beach and intertidal rocky shores. In recent years, the distribution and structure of habitats and biotic assemblage within selected areas of the HCRCMA region have been examined using swath-acoustic surveys by the Department of Environment, Climate Change and Water (DECCW) as part of a statewide seabed mapping program known as HabMap (Jordan et al., 2010).

3.1.1 Habitat classification

Mapping of boundaries within coastal and continental shelf areas is often conducted at very different spatial scales reflecting the range of management applications and the spatial structuring of marine ecosystems. Every scale requires a different level of habitat classification, and, often, different methods and survey design are employed. A recent national marine bioregionalisation for Australia defined a spatial framework for classifying off-shelf seabed areas using bathymetry (Hayes et al., 2005), sediments (Passlow et al., 2005), demersal fish assemblages (Last et al., 2005) and sponges (Hooper and Ekins, 2004) into bathymetric units, provincial bioregions, biomes, geomorphic units and features, and seabed facies (Harris et al., 2003). This complements the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) (Commonwealth of Australia, 2006) which provides a hierarchical spatial-planning framework for coastal and continental-shelf waters (ANZECC/TFMPA, 1998). This framework has been used by all governments in Australia to develop a National Representative System of Marine Protected Areas (NRSMPA) (ANZECC TFMPA, 1998a; 1998b). The spatial framework uses the following hierarchy of ecological definitions:

1) Bioregion: an ecologically-based regionalisation at a particular scale (i.e. IMCRA meso- to provincial scale);

2) Ecosystem: a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit;

3) Habitat: a specific type of environment inhabited either permanently or temporarily by organisms;

4) Community: an assemblage of species occupying a particular habitat or area;

5) Population: a grouping of living organisms of a species;

6) Species: a group of organisms capable of interbreeding freely with each other but not with members of other species; and

7) Individual: a single organism of a species.

As part of the process for developing a system of marine protected areas within NSW a hierarchical classification was used to represent progressively finer scales of physical and biological variation (e.g. Breen et al., 2004; 2005). This was applied within the Manning and Hawkesbury Shelf bioregions, which encompass the HCRCMA region. The levels used in these studies were:

1) IMCRA bioregions;

2) large-scale 'ecosystem' units, which for the continental shelf were based on four cross shelf depth zones (ocean ecosystems);

3) smaller-scale 'habitat' units based on substrate, tidal exposure (primarily subtidal and intertidal reef);

4) finer-scale 'community' level variation based on more detailed physical surrogates, dominant biota or species associations (primarily estuarine); and

5) estimated distributions and abundances of species and populations.

Overall, the delineation of broadscale seabed morphological units provides a useful framework to examine the fine-scale distribution of seabed habitats along the inner and mid-shelf parts of the region of the HCRCMA continental shelf. Most analysis in this report is restricted to areas within NSW state coastal waters, which relates primarily to the shoreface, inner plain and inner mid-slope units defined in Boyd et al. (2004), but will also include the outer mid-slope and locally-defined units in specific locations, particularly east of Broughton Island.

Many hierarchical levels represented on seabed habitat maps are generally delineated using airborne or acoustic remote sensing and associated ground truthing, and are commonly based on geophysical features (Zacharias et al., 1998; Greene et al., 1999; Roff and Taylor, 2000; Bax and Williams, 2001), or a combination of biological and physical features. Such classification schemes reflect the strong influence of depth and seabed hardness on the resulting benthic communities. It important to recognise that the provision of habitat maps representing broad classes over large areas of the continental shelf are only possible through the use of acoustic remote-sensing tools. The primary substrates defined for the NSW continental shelf (rocky reef and unconsolidated habitats) (Table 3.1), represent those that can be accurately mapped using aerial photography, LiDAR (Light Detection and Ranging) and swath acoustics as their boundaries are either optically or acoustically distinct and they can be digitised using a relatively small minimum mapping unit. The mapping of spatial layers at this hierarchical level also reflects the limited capacity of acoustic remote sensors to delineate biotic composition, which is generally defined through video assessment or physical sampling (Table 3.1).

Swath acoustics allows the use of both high-resolution bathymetry and acoustic backscatter to map rocky reef habitats and describe the morphology (e.g. hills, waves) of areas of unconsolidated seabed. The resulting maps of rocky reef have provided a substantial increase in our understanding of the distribution, extent and structure of reef habitats in the HCRCMA region at a number of spatial scales (Jordan et al., 2010). The digitising of historical side-scan-sonar-derived maps of reef and unconsolidated substrates in the Central Coast area also provides a substantial increase in habitat coverage. The acoustic data also reveal considerable fine-scale structuring of unconsolidated substrates, influenced primarily by the presence of sand ripples and waves, and variations in sediment particle size and shell content, with rapid transitions between fine and coarse substrates. In addition, varying amounts of boulders, cobbles, pebbles and gravel, particularly adjacent to areas of rocky reef, generally results in complex patterns of backscatter. This precludes the digitising of the unconsolidated primary substrates into classes more detailed than broad depths (shallow 0 - 25 m; intermediate 25 - 60 m; and deep >60 m).

The need to define a minimum mapping unit means that many small patchy reef areas also remain mapped as unconsolidated substrate, with these areas of mixed reef/sand only able to be described through video assessment over small areas of the seabed. The lack of swath acoustic capacity to delineate the biological communities defined in the study restricted the area over which habitats could be described; descriptions from video assessment are only available over relatively small areas of the seabed and predictive modelling tools have therefore been used to create full spatial maps at this classification level. For logistical reasons, video assessment is restricted to depths >10-15 m in most locations, therefore, several biological facies were not surveyed and information on their distribution was sourced from scuba surveys. There is often uncertainty in the classification reflecting such things as the similarity in reflectance of habitats from remote sensing techniques, the small geographic scale of habitats and the presence of fuzzy boundaries (such as between mud and muddy-sand). This uncertainty is often reduced by presenting maps with habitats defined at higher levels of the hierarchy and including more detailed information on biological facies and/or micro-communities as point or transect data within the spatial layers.

Table 3.1 Physical and biological attributes used to classify marine attributes in the recent mapping of NSW marine waters (Source: Jordan et al., 2010).

	Category	Class	Description
Physical attributes	Substrate Type	Consolidated	Continuous bedrock or boulder reef
		Unconsolidated	Unconsolidated sediments
	Primary Substrate Type	Mud	Mud >75% (includes clay and silt)
		Muddy sand	Mud ~50% and sand ~50%
		Fine sand	Sand dominated by <2 mm grains
		Coarse sand	Sand with >2 mm grains and shell fragments
		Gravel	2 - 10 mm grains
		Pebbles	10 - 64 mm grains
		Cobbles	64 - 256 mm grains
		Boulders	>256 mm (dominant rock size)
		Reef	Reef

	Category	Class	Description
	Percent Primary Cover	% value	% cover of primary seabed features
	Secondary Substrate Type		Same categories as Primary Cover
	Percent Secondary Cover	% value	% cover of secondary seabed features
	Terrain	Flat	<1 cm height
		Ripples	<10 cm height
		Waves	>10 cm height
		Boulders	Boulders
		Gutters	Gutters
Biological attributes	Macroalgae	Macroalgae	Macroalgae present
	Macroalgae Type	Mixed	Mixed red/green/brown algae
		Brown algae	Brown algae present
		Green algae	Green algae present
		Red algae	Red algae present
	Ecklonia	*Ecklonia*	Kelp (*Ecklonia radiata*) present
	Ecklonia % Cover	%	Estimate of % cover of primary canopy
	Sponge	Sponge	Sponges present (morphology if possible)
	Sponge Morphology	Mixed	More than one sponge morphology present
		Erect	Erect sponge present
		Encrusting	Encrusting sponge present
		Massive	Massive sponge present
		Branching	Branching sponge present
		Cup	Cup sponge present
	Ascidians	Ascidians	Ascidians present
	Sea whips	Sea whips	Sea whips present
	Gorgonians	Gorgonians	Gorgonians present
	Hard Coral	Hard Coral	Hard coral present
	Soft Coral	Soft Coral	Soft coral present
	Sea urchins	Sea urchins	Sea urchins present

3.1.2 Rocky habitats

Intertidal rocky habitat

The HCRCMA region contains a large number of rocky intertidal shores. Several surveys have attempted to map rocky shores in the region. The first was conducted by Quint (1982) who examined the flora on each major headland in northern NSW. Each rocky shore was mapped by hand, and major habitats were identified. Griffiths (1982) examined the geomorphology and resident biotic communities of 192 rocky shores south of Fingal Head. More recently Breen et al. (2004) used the Australian Maritime Boundaries (AMB – online as AMBIS) (Geosciences Australia) high-water coastline maps and digitised aerial photographs to estimate the number and length of rocky intertidal shores south of Nambucca as part of the Manning Shelf Bioregion biodiversity assessment. Shores were categorised as either bedrock or boulders, and *in situ* field surveys further categorised habitats. This project estimated the total length of exposed rocky shores, and the area of rock platform and boulder fields in the northern part of the HCRCMA region. This type of mapping has not been completed for the southern section of the HCRCMA region. Otway (1999) used field surveys to score sections of rocky shore for the presence of five "community"-level substrata (platform, boulder, cobble, pool, crevice) that have been correlated with the number of species present for a given shore. As specified by Breen et al. (2005), a combination of the difference between high and low water marks in the Digital Cadastre Database and 1:25000 topographic maps from the Land and Property Information Division (LPI) of the NSW Department of Lands were used to produce a Geographic Information System (GIS) coverage of intertidal habitats and estimate areas of intertidal beach habitat.

Since the earlier, broadscale description of rocky intertidal habitats, Bill Gladstone and co-workers have conducted extensive surveys of the habitats and biota of the majority of rock platforms in the region. Gladstone (2005) quantified the presence/absence of habitats and mapped their extent on intertidal rocky shores in the Newcastle Local Government Area (LGA). The habitats mapped were: rock platform (high-, mid-, and low-shore), crevices (high-, mid-, and low-shore), rock pools, boulders (on rock platforms and at the base of cliffs), and cobbles. Gladstone et al. (2007) extended this investigation to 26 intertidal rocky shores in the HCRCMA region (in Gosford, Wyong and Lake Macquarie LGAs). A more detailed comparison of habitats was conducted at 15 rocky shores where biodiversity surveys were also performed. Finally, Gladstone and Sebastian (2009) used field surveys to record the presence/absence of crevices, rock pools, boulder areas, cobble areas and 4 sub-habitats within the platform habitat (low shore platform, mid-shore platform dominated by barnacles, mid-shore platform dominated by grazers, high-shore platform) at 16 intertidal rocky shores in the northern section of the HCRCMA region, including the Port Stephens LGA (six shores), Great Lakes LGA (seven shores), and Greater Taree LGA (three shores).

Subtidal rocky habitats

In general, the continental shelf of the HCRCMA region is characterised by an inner zone (shoreward from ~60 m water depth) that contains considerable bedrock either outcropping or close to the surface, and an outer zone (>60 m depth) that is the surface of a sediment wedge up to 700-m thick (Boyd et al., 2004). The broad distribution of consolidated habitats (i.e. rocky reef) within the shelf region reflects the patterns of bedrock geology that has varying geomorphic attributes (e.g. hardness, grain size, jointing) and resistance to weathering. Prominent rocky reef outcrops are present seaward of most headlands along much of the coast. Rocky reef systems are also present in areas that are not continuous to shore, or are continuous to shore but associated with offshore islands. Reef systems can also be found offshore from ocean beaches. In most areas that have been swath mapped, rocky reef habitat is more prevalent than suggested by existing hydrographic charts, which mainly show only prominent features such as shoal areas and larger reef systems. Historically, there has been little fine-scale mapping of rocky reef habitats throughout continental-shelf waters of the HCRCMA region, apart from that conducted on shallow nearshore reefs using aerial photography (Avery, 2004). It must be noted that the location and extent of all subtidal reefs have not yet been mapped, particularly in depths >60 m. A number of known reef and shoal areas are yet to be mapped, including those offshore from Old Bar, Lake Macquarie and Tuggerah Lakes.

The section of coast from Crowdy Head to Seal Rocks is characterised by several large reef systems separated by sandy beaches (Figure 3.1). The first of these extends from the shoreline adjacent to Black Head and Hallidays Point, offshore and to the north-east for up to 10 km (Jordan et al., 2010). It is likely that this reef system is continuous with the nearshore reef mapped further north at Old Bar and offshore at Dennis Shoal where it may extend several kilometres northward. The largest and shallowest reef in the area surrounds an area known as Schnapper Rock, located north-east of Hallidays Point. This reef is ~12 m deep at its shallowest point and only small areas of adjacent reef area extend to intermediate depths. The reef system is characterised by a series of large areas of bedrock with smaller patchy reefs at a number of spatial scales. Reef continues offshore with a gradual increase in depth to around 30 m. There is evidence that the reef area may be considerably larger than indicated by current maps.

There is little evidence of shallow nearshore or offshore reefs for several kilometres south of Black Head to Forster, with a narrow section of nearshore reef starting at Forster breakwater, around Bennetts Head, and to the southern end of Cape Hawke. The exception is at Latitude Rock where shallow reef extends up to ~400 m offshore. Overall, the area between Forster and Sugarloaf Point contains many small subtidal reefs, although few of those south of Forster appear to extend more than 100 - 200 m offshore.

The Pinnacle is a large mid-shelf reef that lies ~2 km east of Cape Hawke and mostly comprises intermediate reef extending for 4 km around a shallower area (Figure 3.1). There are a number of other smaller reefs evident between Seven Mile Beach and Sugarloaf Point, the most prominent of these being Skeleton Rocks.

Between Seal Rocks and Newcastle there are several distinct areas of reef adjacent to the coast and offshore islands, including Seal Rocks, Broughton, Boondelbah, and Cabbage Tree islands, and the headlands of Port Stephens, Yacaaba and Tomaree Heads (Figure 3.2). There are also some areas where reef extends off rocky shore to some distance offshore. The reefs around Seal Rocks are generally complex, with caves and pinnacles, large flat bommies, large boulders and steep drop-offs, and a large number of ridges and gutters, most noticeably around the Edith Breakers area. There are several bommies that rise to within 5 m of the surface, many reefs that extend to depths of ~40 m, and smaller areas of rocky reef adjacent to the main headlands within the area, including Sugarloaf Point and the Big Gibber Headland.

Rocky reefs are widely distributed around Broughton Island, although the location and extent of all subtidal reefs have yet to be mapped, particularly those in depths >60 m (Figure 3.3). Much of the reef on the southern side of the island is continuous from the intertidal zone to depths of ~30 m but, in some areas, to ~50 m. Reefs at shallow and intermediate depth, caves, tunnels, drop-offs and bommies are characteristic of the area, while the deeper section is characterised by large reef patches with deep gutters.

All of the offshore islands at Port Stephens have adjacent reef, with most of the habitat occurring as shallow fringing reef. The exception occurs on the eastern side of Little Island where reef at intermediate depths dominates and extends ~600 - 700 m offshore to the north-east, reaching depths of 43 m at the reef/sand boundary. The reefs are often complex, containing small caves, overhangs, vertical walls, boulders and gutters. Areas of fringing rocky reef also occur adjacent to the two headlands to Port Stephens.

Extensive rocky reef occurs adjacent to most of the shore between Point Stephens and Birubi Point, although it ranges from fringing reef in places to much further offshore in areas such as Fishermans Bay, Boat Harbour and Port Stephens. Several bommies occur offshore from Birubi Point and Boulder Bay that extend into depths of ~19 m and 45 m, respectively. The rocky reefs have varied structures, some consisting of continuous rock, some divided by gutters (although with no dominant orientation), some reef associated with boulders or cobbles, and some existing as patches of reef surrounded by sand.

Extensive nearshore reefs are present south of Stockton Bight, particularly around Newcastle, Swansea, Catherine Hill Bay, Norah Head, The Entrance, Wamberal and Terrigal. Most of this reef is continuous to shore, ranging from 200 m to at least 1.8 km offshore. It is likely that much of the reef extends considerably further than this as mapping here has primarily been from aerial photography. This suggestion is supported by the recent, more extensive side-scan sonar mapping which shows reef extending up to 4.5 km off the north of Wamberal, where patchy reef then extends for a further 1.5 – 2 km (Figure 3.3). Continuous reef is highly prevalent along the section from Avoca Beach to the mouth of Broken Bay, with the only discontinuities being the unconsolidated sediments evident at Avoca Beach, MacMasters Beach and a small beach in the National Park to the south.

Recent swath mapping conducted between Terrigal and Copacabana reveals that the continuous reef adjacent to both headlands slopes steeply offshore. The continuous reef extends to ~1.6 km offshore from Avoca Beach but only to ~600 m off Terrigal, although patchier reef extends almost another 2 km eastward, with much of the reef area being comparatively low in profile.

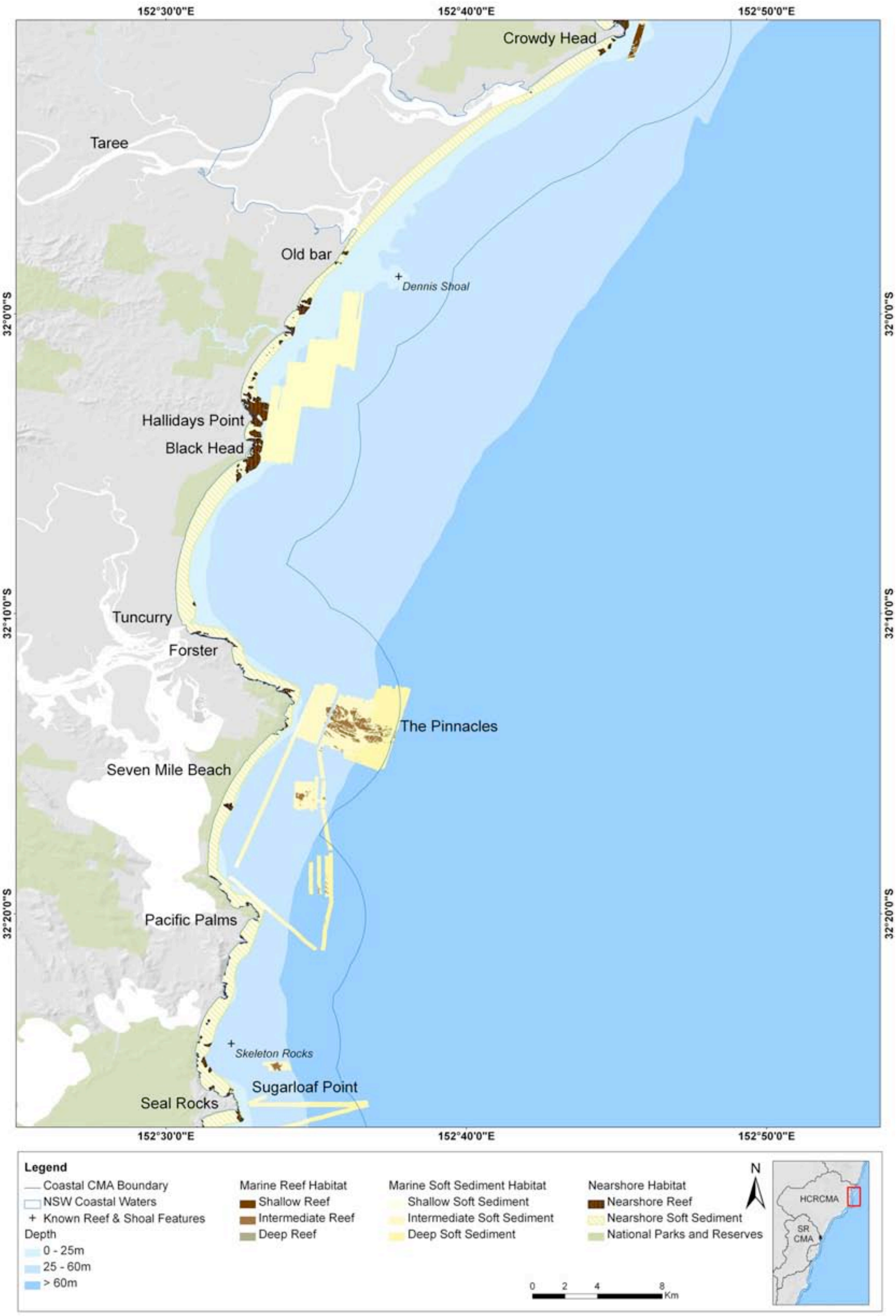


Figure 3.1 Distribution of known seabed habitats within the Crowdy Head to Seal Rocks region (Source: Jordan et al., 2010).

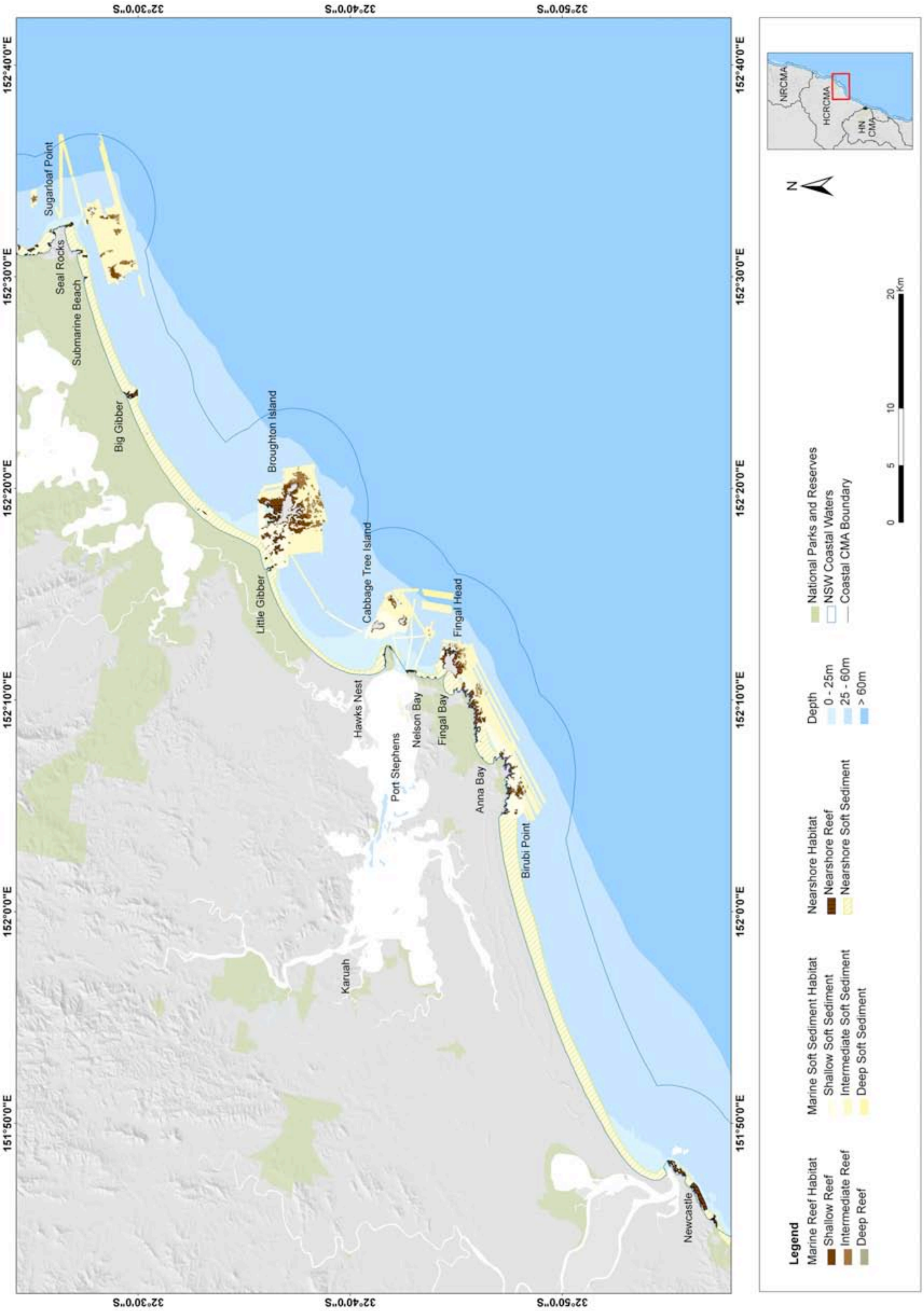


Figure 3.2 Distribution of known seabed habitats within the Seal Rocks to Newcastle region (Source: Jordan et al., 2010).

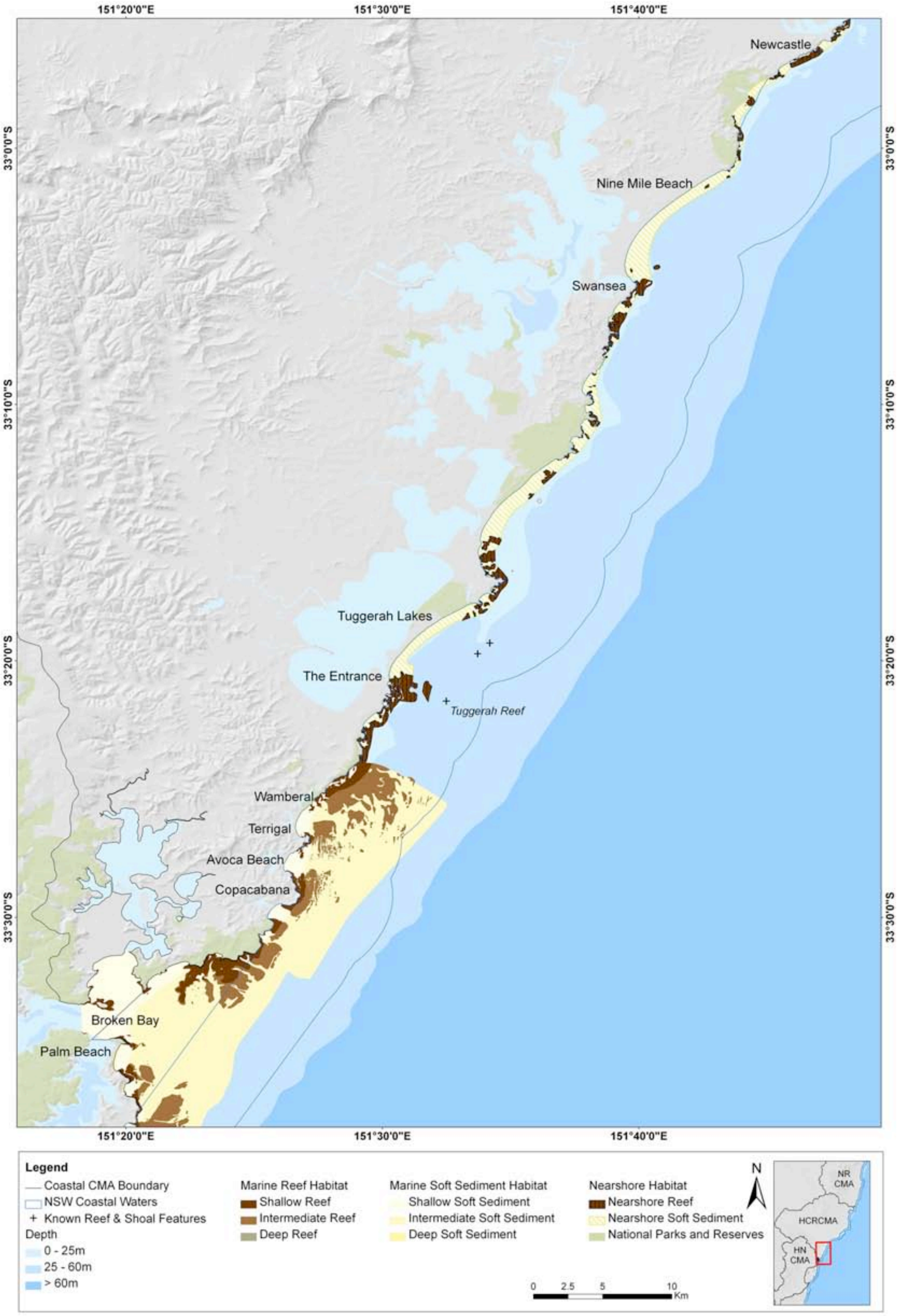


Figure 3.3 Distribution of known seabed habitats within the Newcastle to Broken Bay region (Source: Jordan et al., 2010).

3.1.3 Ecology of subtidal reefs

There has been limited work examining the ecology of subtidal reefs within the HCRCMA region. Much of this has been site-specific, focusing on taxa, such as fishes and/or macroalgae and sessile invertebrates (Roberts et al., 1998; Curley et al., 2002; Gladstone and Owen 2002; Gladstone 2006; Powter and Gladstone 2008; Gladstone 2009).

Some broader ecological mapping of habitats on subtidal reefs has occurred within specific locations in the HCRCMA region (Andrew and O'Neill, 2000; Gladstone and Masens, 2009; Jordan et al., 2010). As indicated in section 3.1.2, there are extensive rocky reefs throughout the HCRCMA region, and these have been mapped as shallow (0 - 25 m deep), intermediate (25 - 60 m) and deep (>60 m). This generally reflects the change from macroalgal-dominated to sessile-invertebrate-dominated communities at ~25 m. Although this pattern varies slightly between locations, it is used to allow a consistent classification to be applied across the region.

Recent habitat mapping, which included benthic video, across different parts of the NSW coast (Jordan et al., 2010) has provided comprehensive descriptions of benthic communities, at a broad taxonomic scale, for a number of specific locations within the region. Examples are presented below for reefs associated with Black Head, The Pinnacle and Broughton Island (see Jordan et al., (2010) for more information). The information is summarised by broad types of biotic assemblages.

Shallow rocky reefs

The distinct ecological habitats that occur on shallow reefs in southern and central of NSW (South West Rocks south to Merimbula) were described by Underwood et al. (1991) based on transects running 100 m seaward from the low tide mark at 5 locations (including Charlotte Head in the HCRCMA region). These habitats have subsequently been used in a large number of studies examining reef habitats and associated species. These are:

- **Fringe habitat** – this occurs just below low tide level to depths of ~3 m and is dominated by a diverse range of algae. The larger algal species *Phyllospora comosa* and *Ecklonia radiata* can dominate the fringe habitat in places, while turfing algae such as *Sargassum* species, red coralline algae, including *Corallina officinalis* and *Amphiroa* sp., as well as the brown algae *Lobophora variegata*, also occur (Underwood et al., 1991). Overall, the algal species composition of the fringe habitat can vary, substantially in extent and composition.
- **Turf habitat** – this habitat is dominated by turfing coralline and filamentous algal species, and is a common habitat on rocky reefs throughout NSW. It is characterised by the absence of the sea urchin *Centrostephanus rodgersii*, although other grazers can be common.
- **Kelp forest habitat** – this usually occurs at depths >2 m, and is characterised by a dense canopy of kelp with an understorey of algae and sessile animals. Along most of the NSW coast, the kelp *Ecklonia radiata* dominates, although some reefs also contain species of *Cystophora* and most contain *Sargassum* (Figure 3.4) (Underwood et al., 1991; Kennelly, 1995). These reefs generally also contain an understorey of geniculate coralline algae and a diverse range of foliose algae, including species of *Zonaria, Rhodymenia* and *Ulva* (Kennelly, 1995; Edgar 1997). Sessile invertebrates are common, comprising ascidians (especially *Herdmania momus* and the cunjevoi *Pyura stolonifera*), bryozoans, barnacles and sponges. While hard coral occasionally occurs, these are more common in similar habitats to the north (Smith and Simpson, 1991).
- **Barrens habitat** – this usually occurs at depths >2 m and is devoid of macroalgae but is often covered with encrusting coralline algae, some filamentous algae, sessile invertebrates and numerous limpets and snails. The sea urchin *Centrostephanus rodgersii* is common in this habitat and strongly influences the assemblage of algal species (Andrew

and O'Neill, 2000; Barrett et al., 2006). Barrens cover around 50% of shallow rocky reefs along the central NSW coast (Andrew and O'Neill, 2000) and 17% in the PSGLMP (Gladstone and Masens, 2009).

- ***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** (Deep Reef *sensu* Underwood et al., 1991) – sponge-dominated assemblages can 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.

While there appears to be some depth-related pattern to these main habitat types, they also tend to occur as a mosaic of large patches on the same reef system and show a high degree of variability between years.

The species composition of algal assemblages is determined primarily by depth, exposure to swell, distance offshore and patterns of recruitment and grazing, and therefore varies within and between reefs. However, significant variability in algal composition and abundance can also occur over small scales on shallow (<20 m) reefs in NSW despite similarities in depth and exposure (Bickers, 2004; Bucher and Hartley, 2004; Smith et al., 2008).

Video surveys from shallow rocky reefs in the central section of the HCRCMA region show a broadly-similar range of ecological habitats as in the Northern Rivers Catchment Management Authority (NRCMA) region (Rule et al., 2007), including *Ecklonia*, mixed algae, *Pyura* and urchin barrens (Jordan et al., 2010). Consistent with the same habitats in the northern region, these areas show variability at both large and small spatial scales. Video surveys have been conducted over reefs at Black Head, The Pinnacles, Broughton Island and Fingal Island, although these have mostly been restricted to depths of 5-10 m, and therefore have not adequately surveyed fringe or turf habitats (Gladstone and Masens, 2009; Jordan et al., 2010).

In general, shallow reef habitats in the region are dominated by a mosaic of *Ecklonia* and barrens habitat. Recent surveys in the PSGLMP indicate that, together, these habitats occupy ~40% of the sea floor on reefs (23 and 17%, respectively) (Gladstone and Masens, 2009), while sponge habitats occupy a further ~16% of reef cover. Many of the reefs in the region comprise extensive areas of boulders, and barrens habitats are dominated by the sea urchin *Centrostephanus rodgersii*. Sponges are relatively dense, with widespread sections of intermediate reef almost entirely covered by a mosaic of erect, massive, branching, and encrusting sponges and other sessile filter-feeders such as bryozoans and gorgonians (Jordan et al., 2010). In contrast, sponges on low-profile shallow reef consist mainly of encrusting growth forms. Ascidians such as *Pyura spinifera* and *Sigillina* are commonly observed on reef habitats across the region.

Shallow reefs offshore from Black Head are dominated by a mosaic of *Ecklonia*, mixed red and brown algal assemblages (Figure 3.4a,b). These occur down to depths of ~25 m, although the mixed reds and browns extent slightly deeper. *Ecklonia* is generally present as a canopy with a cover of between 25 - 50%. The deeper sections of the shallow reef become dominated by sponges where *Ecklonia* is absent (Figure 3.4c,d). Reefs at The Pinnacle differ from those at Black Head in that neither barrens, nor kelp habitats, were observed along the surveyed transects, although most of the reef evaluated was in depths >25 m and consists mostly of mixed red and brown algae (Figure 3.5).

Reefs surrounding Broughton Island comprise a large amount of boulder field, especially between 5 - 25 m; these are often associated with barrens habitat. In contrast, shallow reef consisting of continuous bedrock between 5 - 25 m supported a mosaic of *Ecklonia* and barrens habitat (Figure 3.6). Canopy cover of *Ecklonia* appeared to be greater at depths <20 m compared to cover at depths between 20 - 30 m. The brown algae *Sargassum* is common in areas of mixed cobble and sand substrates and is present between 10 - 24 m (Jordan et al., 2010).

Higher resolution video mapping of rocky reef habitats in the Port Stephens region (Broughton Island, Fingal Head and Boulder Bay) has quantified the extent of a range of ecological habitats, particularly kelp, barrens, turf and sponge (Gladstone and Masens, 2009). The greatest extent of barrens habitat occurred at sites around Broughton Island, with 69% of one shallow site containing barrens. Most sites contained a complex mosaic of habitats dominated by kelp and barrens in shallow depths (0 - 20 m). The average cover of barrens in the shallow sites at all locations combined was 30.5%, which is consistent with previous estimates of extent in the region (Andrew and O'Neill, 2000).

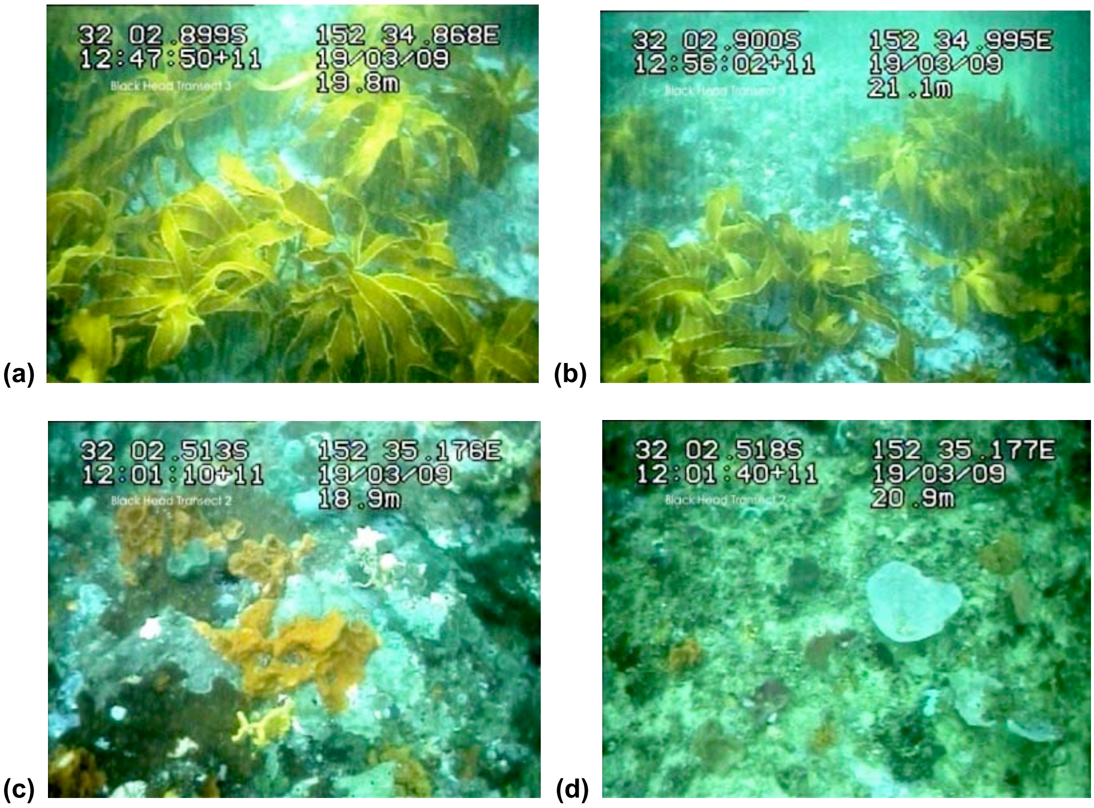
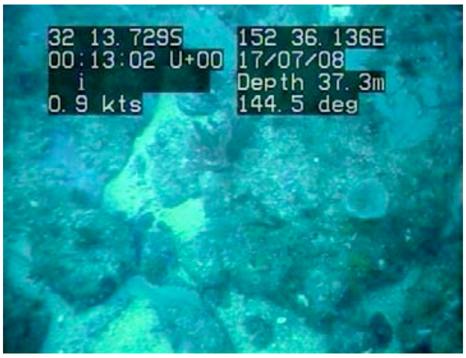


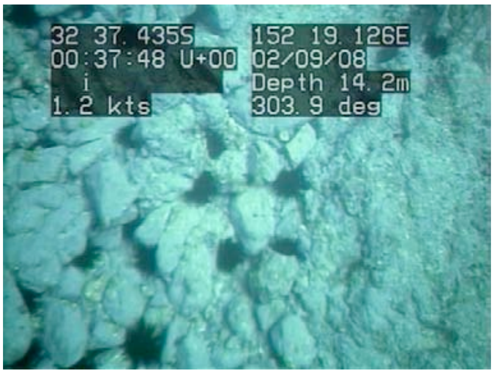
Figure 3.4 Kelp (*E. radiata)* and mixed algal assemblages (a) – (b), and sponge-dominated assemblage (c) – (d) on nearshore reefs at Black Head.

(a) 

(b) 

Figure 3.5 Boulder-dominated reef habitat at The Pinnacle supporting communities of (a) sponges and gorgonians and (b) sea whips.

(a) 

(b) 

(c) 

(d) 

Figure 3.6 Barrens habitat on boulder-dominated reefs (a) – (c) and bedrock reef (d) near Broughton Island.

Rocky reefs at intermediate depths

Very little is known about the benthic assemblages on intermediate reefs in the region as few surveys have been conducted. However, consistent with reefs at these depths in other temperate regions, the community includes a diverse range of sessile species generally dominated by sponges with a range of morphologies. Several macroalgal species (primarily *Ecklonia radiata*) and a range of filamentous red algal species also extend into intermediate depths. Invertebrates most likely include stalked ascidians (sea squirts), black corals, hydrozoans, gorgonians (coral with flexible, often branching, skeleton), anemones, soft corals and bryozoans (sea-mats and lace corals) (Butler, 1995). Variations in the composition of invertebrate assemblage will often reflect patterns in the physical environment. Filter feeders, for example, prefer specific flow rates and current directions.

Video surveys of intermediate reefs within the HCRCMA region have been conducted offshore from Black Head, Foster, Broughton Island and Fingal Head (Gladstone and Masens, 2009; Jordan et al., 2010). On reefs offshore from Black Head, sponges are relatively dense, with widespread sections of reef at depths between 20 - 27 m almost entirely covered by a mosaic of erect, massive, branching, and encrusting sponges and other sessile filter feeders such as bryozoans and gorgonians. Ascidians, including *Pyura spinifera* and *Sigillina* sp. are patchily distributed at depths between 17 - 27 m, with *P. spinifera* generally found amongst sponges in areas of high relief, and *Sigillina* sp. more common in sandy areas between patch reefs or cobble areas.

On The Pinnacle, offshore from Foster, visually-dominant biota on intermediate reefs comprised mixed communities of sponges, gorgonians, ascidians (mainly *Pyura spinifera*), seawhips, mixed red and brown algae, and encrusting coralline algae (Figure 3.5). At depths <40 m, mixed sponge and filamentous algal assemblages were dominant, while on reef areas >40 m there was a shift towards sponge-dominated assemblages, with sea whips and gorgonians also abundant.

Intermediate reefs surrounding Broughton Island support ascidians, including *Pyura spinifera* and *Sigillina* sp. While sponges are present at all depths, they generally have low cover and are dominated by elongate and branching forms (Jordan et al., 2010). Gorgonians are present mostly between 30 – 40 m, but at low densities. Gladstone and Masens (2009) also identified extensive areas of sponge-dominated intermediate reefs around Broughton Island and Fingal Head, although patchy reefs devoid of sponges were also present.

Artificial reefs

Artificial reefs of many types have been deployed for a range of purposes in different regions of the world. They are often used to attract fish for recreational fishers but also have the potential to provide increased reef area that increases regional productivity (their role as attractors/producers is still under debate). Studies on Narrowneck Reef, a geotextile artificial reef, immediately offshore from Main Beach at the Gold Coast in southern Qld., clearly demonstrate their ability to attract large numbers of bait fish and provide habitat for a range of other biota (Edwards and Smith, 2005). Artificial reefs have yet to be deployed in NSW marine waters but have been trialled in estuarine areas of the HCRCMA region (Lake Macquarie). However, there are current plans to create a multi-purpose artificial reef off Avoca Beach on the Central Coast by scuttling the ex-HMAS *Adelaide* (see Box 3.1).

Box 3.1 Ex-HMAS *Adelaide* artificial reef

The former warship, HMAS *Adelaide*, is set to be scuttled 1.7 km offshore from North Avoca Beach. The ship will sit on a sandy bottom in approximately 32 m of water, with several rocky reefs in the surrounding area. The artificial reef will provide a unique recreational diving experience on the Central Coast and a benefit to the local economy. However, it also provides a unique ecological study site. Regular diver surveys (including by the Terrigal Underwater Group – TUG) and baited remote underwater video (BRUV) sampling began in December 2008 at 7 sites (4 rocky reef and 3 sand) near to, and distant from, the reef site collecting data on fish species richness and abundance. A diverse teleost and chondrichthyan fauna was found on the surveyed reef and sand habitats; surveys also indicate considerable temporal variation in presence and abundance of some species. Once the ship is scuttled, the fish and benthic invertebrate assemblages of the artificial reef itself will also be sampled. Sampling is scheduled to continue for a number of years after the ship is scuttled. This will build a comprehensive time series data set on the biodiversity of the artificial reef and surrounding habitats. It will also allow the evaluation of any impacts relating to the establishment of the artificial reef, such as 'production vs attraction' and spillover effects.

3.1.4 Soft-sediment habitats

There is a distinct lack of ecological information from subtidal soft-sediment habitats in the HCRCMA marine region. Such habitats are clearly very extensive throughout the region, and are likely to be the dominant habitat in most sections of the coast (Figure 3.1 – 3.3). These have been mapped into shallow (0 – 25 m), intermediate (25 – 60 m) and deep (>60m) habitats consistent with rocky reef classes, although as yet there is little ecological basis for these specific classes. However, this classification broadly reflects the main classes of sediment discussed in section 2.1.3. Overall, such gradients in sediment type, in combination with depth, can result in considerable differences in macrofaunal composition (Coleman et al., 1997; Beaman et al., 2005).

The fine-scale structuring of soft-sediment habitats detailed in section 2.1.3 is also likely to result in small-scale variations in faunal composition as there is often a strong relationship between habitat structure and macrofaunal diversity in soft-sediment habitats (Thrush et al., 2001). Most of the animals in soft-sediment habitats occur as infauna and are generally dominated by amphipods, bivalves and polychaete worms. In general, areas classified as soft-sediments also commonly contain pebbles, cobbles and boulders, and each type is likely to contain a different suite of flora and fauna (Bax and Williams, 2001; Jordan et al., 2010).

Studies on soft-sediment infauna in the NRCMA region to the north suggest that shallow nearshore communities are highly dynamic, reflecting the high-energy wave environment in which they occur (Smith and Rule, 2001). There is also evidence for a gradation in community structure with increasing depth, with substantial changes occurring between 40 – 50 m (Rowland, 1999; Smith and Rowland, 1999). It is likely that similar patterns occur in the HCRCMA region. In addition, Hacking (2003) reviewed relevant information on subtidal soft-sediment communities offshore from Sydney as part of a background investigation into possible impacts of the extraction of marine aggregate.

Little work has been performed on the soft-sediment infauna of intertidal beaches. Dexter's (1983) description of the sandy beach fauna of NSW included data from a number of sites in the HCRCMA region. However, there has been very little follow-up work since then. Gladstone et al. (2006) evaluated the impacts of estuarine flows across the beach face adjacent to coastal lagoons on the Central Coast and documented both high variability and high apparent resilience by infauna to artificial opening. There are few data over broader scales within the region, although some of the research conducted in the Sydney area is likely to be applicable to the

HCRCMA region (Jones et al., 2008). This lack of information on beach ecology is considered to be a key gap in knowledge as a number of natural and anthropogenic impacts pose considerable threats to beach ecosystems; for example, beach erosion, trampling and off-road vehicles, beach grooming, beach nourishment (Defeo et al., 2009). Many of these impacts are likely to be exacerbated by climate change-related rises in sea level (Jones et al., 2007) (see section 4.5).

Primary data sources

There is little specific data for this region. Jordan et al. (2010) provide recent data on the distribution of unconsolidated habitats at various places within the region. Hacking (2003) reviewed the ecology of offshore sediment communities in NSW; most examples were given from areas around Sydney where more research has been conducted.

3.2 Biodiversity and conservation

Overview

Until recently, research on the marine biodiversity of the HCRCMA region has mainly focused on southern sections of the coast, primarily as a direct result of proximity to the main research centres (Port Stephens and Ourimbah Campus of the University of Newcastle). While a range of datasets were used to inform bioregional planning for the Manning Shelf Marine Bioregion (Breen et al., 2004), this process mostly relied on physical descriptors as surrogates for biodiversity. Thus, the primary marine datasets were for threatened species, birds (NSW National Parks) and from rapid surveys of rocky shore biota conducted over 20 years previously (Griffiths, 1982). Since this bioregional assessment, a substantial amount of additional data have been generated by Bill Gladstone (formerly University of Newcastle; now University of Technology Sydney) and co-workers for rocky shores and shallow subtidal reefs. Indeed, most well-developed rocky shores within the region have now been evaluated using rapid biodiversity assessment methods (Gladstone et al., 2007 – covering the southern half of the HCRCMA region; Gladstone and Sebastian, 2009 – covering the northern half of the region). The declaration of the Port-Stephens Great Lakes Marine Park has also focused data collection within this section of the coast (MPA, 2010). Finally, the initiatives undertaken as part of a DECCW-led, state-wide habitat mapping program through 2008/2009 has substantially increased knowledge on the biodiversity of a range of marine habitats across the region (Jordan et al., 2010). Specific examples of indicative taxa are presented below. The biota associated with rocky reefs, both intertidally and subtidally, far exceeds that available for soft-sediment habitats in the region (Hacking, 2003).

Biodiversity

While the HCRMA region is south of the area widely regarded as being the most important as an overlap between tropical and temperate biotas (the Tweed-Moreton bioregion), it nevertheless forms a part of the eastern overlap zone (Zann, 2000). Eddies of the East Australian Current (EAC) regularly influence shelf waters (see Chapter 2), carrying the larvae of tropical species that recruit, albeit temporarily for many species, to reefs within the region (Booth et al., 2007). Further north, biodiversity is enhanced by the presence of corals and the suite of animals (fish and invertebrates) that relies on these habitat-forming taxa. While corals occur within the HCRCMA region (see below) they are in low diversity and are present at only a few locations. Shallow subtidal reefs, which support high diversity in the NRCMA region, are more likely to be dominated by kelp or urchin barrens in the coastal waters of the HCRCMA region (see section 3.1; Jordan et al., 2010). This reduction in habitat diversity coupled with higher latitude, is likely to result in lower diversity than found in the NRCMA region to the north (e.g. there is a general trend of reduced molluscan diversity from the north to the south of NSW – Smith, 2009).

Conservation

The marine and coastal environment of the HCRCMA hosts a number of species that have conservation status under various NSW, Commonwealth and international schemes. This review covers marine species listed under the NSW *National Parks and Wildlife Act 1974* (hereafter *NPW Act*), which protects all native birds, reptiles and mammals from harm. More recently the *Threatened Species Conservation Act 1995* (hereafter *TSC Act*), came into effect. This legislation allows for the identification and protection of native plants and animals in danger of becoming extinct. The *TSC Act* also provides for species recovery and threat abatement programs. Under this act, species are categorised as being endangered (Schedule 1) or vulnerable (Schedule 2). With respect to marine species, the *TSC Act* only provides for the protection of marine mammals, birds and reptiles, which fall under the jurisdiction of DECCW. Protection for marine fish and algae is provided under the *Fisheries Management Act 1994* (hereafter *FM Act*), and is administered by Industry & Investment NSW (I&I NSW – Department of Primary Industries (DPI) - Fisheries).

Many species are listed under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999* (hereafter *EPBC Act*), which provides protection for endangered species throughout Australian waters. Under this legislation, species are listed as Critically Endangered, Conservation Dependant, Endangered, Vulnerable or Protected. Additionally, some species have been identified and listed by the International Union for the Conservation of Nature (IUCN) on the IUCN Red List of Threatened Species.

In addition to the conservation mechanisms listed above, the HCRCMA region now includes one of the marine parks managed by the NSW Marine Parks Authority (MPA) as part of a NRSMPA. The PSGLMP was gazetted in December 2005 and encompasses a range of habitats from Cape Hawke near Forster, south to Birubi Beach. Further details about the PSGLMP can be found on the MPA web pages <www.mpa.nsw.gov.au/psglmp.html>, and a review of the natural values of the park has recently been completed (MPA, 2010a).

3.2.1 Macroalgae

There has been little research on the diversity and distribution of macroalgae in the marine environment in the HCRCMA region. While a total of 588 macroalgal species representing 243 genera have been recorded from the NRCMA region (as summarised in Rule et al. 2007 from a range of sources), this includes lists from detailed surveys conducted within the Solitary Islands and Lord Howe Island regions that would contain a much higher proportion of tropical and subtropical species. Overall, there remains a paucity of information from most areas within the HCRCMA region.

A list of macroalgal species from several locations in the HCRCMA region is included in the 'Aussie Algae' database, which is maintained by Alan Millar from the Royal Botanic Gardens. The database currently lists 124 species from this region, although some of these may be restricted to the estuarine waters of Port Stephens. Species such as *Macrocystis angustifolia* are also identified from drift specimens but are unlikely to grow in the region. A total of 95 species are identified from Port Stephens. Lists of species by location are available via the online 'Aussie Algae' database that is searchable by algae name or location http://www.aussiealgae.org/index.php.

As the algal database only maintains records for which there are specimens, and currently only a very small proportion of these records are electronically databased, there are limitations to this dataset. Very little information is available for locations other than Port Stephens, Seal Rocks and Newcastle within the HCRCMA region.

3.2.2 Invertebrates

Marine invertebrate assemblages in the region mostly comprise temperate and endemic species but, seasonally, include members of tropically-affiliated taxa that have been transported to the region as larvae entrained in the EAC (Booth et al., 2007). The collections of the Australian Museum provide the most extensive records for the region and a range of published studies provide site-specific information for some taxa, particularly for rocky shores and shallow subtidal reefs in the southern HCRCMA region (Gladstone, 2002; 2005; 2007; Gladstone and Alexander, 2005; Gladstone et al., 2007; Gladstone and Sebastian, 2009). While not formally summarised or published (but see below), observations by marine volunteers and underwater photographers provide an additional, important source of information on species distributions and provide highly site-/location-specific information. One of the best examples of this is the comprehensive photographic inventory of marine life in Nelson Bay compiled by David Harasti <www.daveharasti.com>. The images on this site clearly document the high biodiversity of the location and the mix of temperate, tropical and endemic species (see Box 3.2). Highly-trained volunteers have also contributed to assessments of the impacts of human collecting on the sizes and abundances of 4 common species of intertidal mollusc (Gladstone et al., 2007; Gladstone and Sebastian, 2009) and have documented the biodiversity of shallow reefs in the region as part of the much broader Reef Life Survey program (Edgar and Stuart-Smith, 2009).

Box 3.2 Port Stephens: A biodiversity hot spot

The subtidal habitats lining the southern, sheltered shores of Port Stephens have long been recognised as supporting a diverse suite of marine plants and animals. This has led to the development of a thriving dive industry that draws participants from across Australia and the world. The importance of the region to recreational divers has not, until recently, been matched by specific research into the habitats, communities and processes that result in such diversity. However, some general observations can be summarised that potentially explain at least some of the patterns and processes. The semi-enclosed embayment formed by Port Stephens provides a sheltered environment that supports a large variety of primary producers including those thriving in estuarine (seagrass, mangrove, saltmarsh) and marine (kelp and other macroalgae) conditions. Much of this plant material breaks down to form detritus which, coupled with runoff from terrestrial sources, provides a plentiful food supply facilitating the development of benthic communities dominated by large, habitat-forming, suspension-feeding organisms (e.g. sponges, soft corals, bryozoans, ascidians). These, in turn, provide both habitat and food for a large variety of other animals, including colourful nudibranchs and populations of protected species (e.g. syngnathids – seahorses and pipefish). Many nudibranch species have very specific diets and only occur when their food-source is plentiful. Coupled with the seasonal recruitment of tropical species, transported south by the East Australian Current, this leads to both a high diversity at any one time and, importantly, a high turnover of species. Although this has yet to be verified, these processes result in the high diversity that keeps divers returning to these important marine habitats (Photo: 'Blue-lined octopus', Steve Smith).

Corals

The majority of zooxanthellate corals (also known as reef building or hermatypic corals) are at their southern limit of distribution in the Tweed-Moreton bioregion with the southernmost areas of significant coral cover occurring at Black Rock, South West Rocks (Smith and Simpson, 1991; Harriott et al., 1999; Smith et al., 2006, 2008). However, a number of species has been recorded from the HCRCMA region with some extending at least to Sydney (*Turbinaria* *mesenterina* and *Pocillopora damicornis*) (Smith and Simpson, 1991) and one, *Coscinaraea mcneilli*, having a primarily southern distribution (Veron, 1986; Harriott et al., 1994). Nearshore reefs adjacent to Forster support colonies of at least 4 zooxanthellate species, including *Goniastrea australensis* and *Favites abdita,* which are likely to be at their southern limit of distribution (Smith and Simpson, 1991). *Pocillopora damicornis* can be common in sheltered subtidal locations within the HCRCMA region and has recently been documented in shallow (<12m) reefal habitats at Broughton Island (see section 3.1; Jordan et al., 2010) and forms a substantial component of benthic cover on the shallow reef at Boulder Beach and Cabbage Tree Island, Port Stephens (pers. obs.). By contrast, azooxanthellate corals (those without symbiotic dinoflagellates) are a common component of benthic communities throughout the HCRCMA region often forming extensive primary cover on vertical surfaces and the undersides of overhangs (especially *Culicia tenella*). Many of these azooxanthellate corals are highly colourful and readily observed (Figure 3.7). Little to no work has been conducted on the corals of the region.

Figure 3.7 Colony of an azooxanthellate coral feeding at night at Fly Point, Port Stephens (Photo: Steve Smith).

Molluscs

Molluscs are often the most prominent members of the marine invertebrate assemblages both in terms of diversity and abundance (Beesley, 1998). They occur in all marine habitats and are especially noticeable on rocky shores where a range of gastropod species are the visually dominant taxa on sheltered shores and the upper reaches of exposed shores. Recent investigations on rocky shores and subtidal reefs have indicated that molluscs may also be good surrogates of broader invertebrate communities, both in terms of community patterns and biodiversity (Gladstone, 2002; Smith, 2005): for this reason, they are increasingly being targeted in studies of biodiversity (Smith et al., 2006; 2008; Shokri et al., 2009).

The molluscan fauna of the region has been well documented by malacologists at the Australian Museum, with specimen holdings covering the full range of marine habitats. The molluscan fauna of the HCRCMA region primarily comprises species from the following broad biogeographic groups: cosmopolitan, south-eastern Australian endemics, temperate Australian, and tropical Indo-Pacific (seasonally).

Molluscs have been targeted in a number of recent studies (e.g. Gladstone, 2002; Gladstone and Sebastian, 2009; Smith, 2009) and thus their ranges and regional distributions are comparatively well known. Smith (2009) provided comparative data from surveys of intertidal death assemblages of shelled gastropods and bivalves across the entire NSW coast and found above-average diversity at headland sites adjacent to Port Stephens (Yacaaba Head, Birubi Point) and Dudley Beach within the HCRCMA region. In contrast, all sites to the north of Port Stephens supported assemblages with comparatively low diversity (Smith, 2009).

Opisthobranch gastropods (gastropods without shells including nudibranchs and sea-hares – Figure 3.8) are of particular interest in the HCRCMA region as the subtidal reefs of Port Stephens are a recognised hot spot for these animals (Coleman, 2008). The abundance of food species (see Box 3.2) and the availability of sheltered habitats, result in a high diversity at sites such as Fly Point and the Pipeline. Photographic records compiled by divers over the last few decades have documented many species that are new to science (e.g. *Okenia atkinsonorum* named after the discoverers, David and Leanne Atkinson). Over 160 species of nudibranch have been recorded from Fly Point alone.

The gastropod family Ovulidae (the allied cowries) is another group of molluscs that has received some attention from underwater naturalists within the HCRCMA region. These animals live in association with octocorals (soft corals and gorgonians) and antipatharians (black corals) that are found in greatest abundance in areas of strong current and/or plentiful supplies of suspended organic material. Ovulids are often strikingly coloured making them popular with divers. The waters of Port Stephens support a diverse ovulid fauna numbering at least 12 species (Smith, 2008; <http://www.daveharsti.com>).

Figure 3.8 *Polycera capensis*, a common nudibranch at The Pipeline, Port Stephens (Photo: Steve Smith).

Conservation status of marine invertebrates

Since the comprehensive review of the conservation status of Australian of marine invertebrate in 2002, which found few species to be threatened (Ponder et al., 2002), the I&I NSW Fisheries Scientific Committee has listed a number of species as vulnerable, critically endangered and even "presumed extinct". Only one of those species (a polychaete worm – *Hadrachaeata aspeta* now presumed extinct) has previously been recorded from the HCRCMA region (but from estuarine habitats). With the paucity of information for many taxa, however, it is arguably impossible to adequately assess the status of many species. Rather, Ponder et al. (2002) developed a set of criteria and characteristics that render marine invertebrates vulnerable. These characteristics include:

- the accessibility of habitat (e.g. if collected for food/ornaments or commercially harvested);
- value (i.e. in terms of food, specimens, ornaments);
- distribution;
- direct development;
- fecundity rate;
- maturation rate;
- association with threatened taxa (e.g. as parasites or commensals, food sources) or threatened habitat, and
- rarity.

Primary data sources

The Australian Museum specimen database holds the majority of relevant information on the diversity and distribution of marine invertebrates within the HCRCMA region. Additional, assemblage-wide data are held by Bill Gladstone for many of the rocky shores and shallow subtidal reefs. Informal lists of species in some taxa (fish, nudibranchs), from some key locations, are presented by David Harasti on his web pages devoted to the marine life of Nelson Bay <www.daveharasti.com>.

3.2.3 Fish

Fish are an important economic resource in the HCRCMA region and catches of a number of species reach their highest levels in the state in some of the main fisheries (see section 4.1). Fish assemblages within the region are also very diverse with a dominance of temperate species, and an influx of tropical species over the warmer months. Each year, from approximately December to May, water temperatures in the region are more strongly influenced by the EAC that transports a variety of juvenile and adult tropical species into the region. Water temperature during this period are normally 21 - 24 °C allowing tropical vagrants to settle and establish in areas outside their normal range. This mix of tropical and temperate species increases diversity, albeit temporarily, over summer and autumn. Similar patterns occur to the north of the region (e.g. the Solitary Islands Marine Park – Malcolm et al., 2010a).

A total of 1 408 fish species have been recorded from the HCRCMA region (see Table 3.2) and 675 species (440 genera and 164 families) have been recorded in the PSGLMP to date (MPA, 2009). However, there have been very few detailed studies of fish assemblages within the HCRCMA region. The most extensive data have been compiled from cumulative collections by the Australian Museum and from recent marine-park surveys within the PSGLMP using baited remote underwater video systems (BRUVS) and underwater visual census (UVC) diving surveys.

With the exception of a few specific, accessible and commonly dived sites, detailed inventories of fish diversity are lacking at small spatial scales. The Australian Museum maintains an extensive database of spatially referenced records of fish species across the region, and lists can be generated by locality via the curator of fishes. However, these records refer to specimen holdings and thus do not represent the presence/absence of many species at local scales.

Table 3.2 The number of fish families, genera and species recorded from the HCRCMA region and within the PSGLMP. Data compiled from Australian Museum records, MPA surveys and other data sources.

Locality	Family	Genera	Species	Sources
Entire HCRCMA region	261	796	1408	Australian Museum records (accessed 2010); MPA and D. Harasti unpublished data; and Gladstone (2007a).

Conservation status of fish

There are four species of marine fish that are listed as threatened under the NSW *FM Act 1994* that are found within the HCRCMA region. These are:

- grey nurse shark *Carcharias taurus* (critically endangered),
- southern bluefin tuna *Thunnus maccoyii* (endangered),
- great white shark *Carcharodon carcharias* (vulnerable), and
- black cod *Epinephelus daemelii* (vulnerable).

The grey nurse shark is also listed as critically endangered and the great white shark as vulnerable under the Commonwealth *EPBC Act*. Further information on the status of each of these threatened species is detailed below. In addition, there are several species of fish listed as 'Protected' under the *FM Act 1994* that are found in the region:

- eastern blue devilfish *Paraplesiops bleekeri*,
- elegant wrasse *Anampses elegans*,
- estuary cod *Epinephelus coioides*,
- Queensland groper *Epinephelus lanceolatus*,
- bluefish *Girella cyanea*,
- weedy seadragon *Phyllopteryx taeniolatus*,
- Herbst's nurse shark *Odontaspis ferox*, and
- syngnathiformes (syngnathids, solenostomids and pegasids).

The HCRCMA region is the northernmost range for species such as the pot belly seahorse *Hippocampus abdominalis*, recorded in Port Stephens, and the weedy seadragon, recorded at Broughton Island. Additionally, the first record of the tropical thorny seahorse (*Hippocampus histrix*) in Australia is from Port Stephens (D. Harasti, unpublished data and Australian Museum records).

Grey nurse shark *Carcharias taurus*

Within the HCRCMA, there are 3 sites that have been declared as critical habitat for the grey nurse shark under the *FM Act*. These sites are: 1) The Pinnacle at Forster, 2) Big and Little Seal Rocks, and 3) Little Broughton Island. Over the summer months, grey nurse sharks move into the region and aggregate at various different sites. Gutters in rocky reefs and caves are the preferred habitat for grey nurse sharks (Bansemer, 2009).

Recent research (2008/09) undertaken by Cardno Ecology Lab (CEL) estimated the size of the east-coast population of grey nurse sharks to be 1131 (95% confidence interval (CI): 885 – 1376) (Cardno, 2010). This is an increase on the 443 sharks (95% CI: 263 – 766) estimated by I&I NSW (DPI) from surveys conducted in 2002/03 (Otway and Burke, 2004). The CEL surveys found that very large numbers of grey nurse sharks occurred in the HCRCMA region, with 56% of all sharks counted in a survey period in 2009 occurring in the HCRCMA region. Big Seal Rocks was found to be of particular importance with 83 sharks counted in a single survey (Cardno, 2010).

Great white shark *Carcharodon carcharias*

The great white shark, or white shark, has a worldwide distribution and is known to occur in both temperate and tropical regions. Commonwealth Scientific and Industrial Research Organisation (CSIRO) Marine Research has recently conducted surveys of juvenile white sharks in the Port Stephens region. Over the past three years, the CSIRO team has tagged 25 juvenile white sharks in the Port Stephens area and, through satellite tracking, are starting to gain a good understanding of their movements around the Australian coast (B. Bruce, pers. comm.).

Initial results show that the sharks are present in the Port Stephens region from about September to December, but this can vary from year to year. They then generally move south to the Corner Inlet/Ninety Mile Beach area of eastern Victoria, where they reside from December to April. The sharks then move back up the coast to start the cycle again. One shark swam as far north as Fraser Island in Queensland before returning south to Corner Inlet. Another juvenile shark swam across the Tasman Sea to spend 10 days in New Zealand before heading a further 350 km east of Wellington. In the process, the shark made dives down to nearly 1000 metres (B. Bruce pers. comm.).

Black cod *Epinephelus daemelii*

The black cod was once a widespread species along the NSW coast (Roughly, 1916). However, from the 1950s through to the late 1970s, spearfishers at various locations along the coastline heavily targeted this species (Andrewartha et al., 1970). This concentrated spearfishing effort led to a noticeable decline in black cod numbers, and NSW Fisheries was approached by concerned divers to protect the species in the late 1970s.

During 2009/10, NSW MPA commenced extensive surveys for black cod throughout the PSGLMP. Surveys are undertaken every 6 months, with three surveys completed to date. Data show that both adult and juvenile black cod are found on rocky reefs within the marine park, predominantly living in crevices and caves, and that this region is an important area for this threatened species (MPA, unpublished data). Black cod have also been recorded at other sites in the HCRCMA region including Black Head, Snapper Rock and Catherine Hill Bay (D. Harasti, unpublished data).

Southern bluefin tuna *Thunnus maccoyii*

The bluefin tuna is a highly migratory and pelagic species that inhabits cool-temperate waters between the latitudes of 30 – 45 °S. It is considered to be an occasional visitor to the region as it prefers deeper offshore pelagic waters.

Additional data sources

In addition to those outlined above, a number of other research projects have focused on particular fish species, or particular areas, within the HCRCMA region. Some of the recent fish-related reaserch undertaken in the HCRCMA region includes studies of:

- the Port Jackson shark *Heterodontus portusjacksoni* (Ramos, 2007; Powter et al., 2008a, b, c; 2009; 2010),
- wobbegong sharks at Fly Point and Halifax Park (PSGLMP) (Carraro and Gladstone, 2006),

- the rays *Trygonoptera testacea*, *Trygonorrhina fasciata* and *Myliobatis australis* (Mors et al., unpublished data),
- White's seahorse *Hippocampus whitei* (D. Harasti, unpublished data),
- the tiger pipefish *Filicampus tigris* (D. Harasti, unpublished data),
- the one-spot damselfish *Chromis hypsilepis* (Gladstone, 2007a, b),
- the biology and ecology of wrasse (F. Labridae) (Morton, 2007; Morton et al., 2008),
- juvenile tropical fish surveys (I&I NSW, unpublished data),
- the biodiversity of rocky reef fishes (Coram, 2004; Gladstone, 2007; Lindfield, 2007),
- fish assemblages on rocky reefs in marine parks (Malcolm et al., 2007),
- fish assemblages of unconsolidated habitats (Yona, 2008; L. Edwards, W. Gladstone and T. Trinski, unpublished data), and
- fish assemblages on reefs in proximity to the proposed sinking site for the ex-HMAS *Adelaide* using baited underwater video (G. Graham, W. Gladstone and D. Powter, unpublished data).

3.2.4 Birds

Birds that depend on marine and estuarine habitats include true seabirds, shorebirds and waders. Some species of waterfowl (sea ducks), birds of prey (sea eagle), kingfishers and passerines (gerygone), are also largely dependent on coastal and marine habitats (Marchant and Higgins, 1990a, b; 1993; Higgins and Davies, 1996; Higgins, 1999; Higgins and Peters, 2002). Other species have broader habitat requirements and utilise terrestrial wetlands of varying salinity that may include estuaries, mangroves or tidal creeks in parts of their range. Several species are seasonal or rare visitors, occupying marine and estuarine habitats within the HCRCMA only occasionally, or for a limited time each year. In total, 136 coastal and marine birds have been recorded from the HCRCMA region (National Parks and Wildlife Service (NPWS) Atlas of NSW Wildlife; Birds Australia Rarities Committee (BARC)) (Table 3.3).

Birds that are wholly or partially dependent on marine and coastal habitats utilise these areas for foraging. Although many other bird species occur in these environments, they are not dependent on the resources these habitats provide. Foraging occurs from intertidal shores, around the waters' surface and, in the case of the little penguin, from within the water column. There is a paucity of information on the specific diet of these birds within NSW waters but general dietary information indicates that some species are piscivores (fish eating), while others have more varied diets including molluscs, crustaceans, cephalopods and insects. Some birds also consume plant material, especially those that also utilise terrestrial wetland habitats. The insectivorous mangrove gerygone does not forage directly from coastal or marine waters but is an obligate mangrove specialist and thus dependent on this coastal habitat.

Many of the birds listed utilise nesting sites adjacent to the marine and coastal habitats where they forage, including sandy beaches, rocky cliffs, mangroves and oceanic/offshore islands. A few species nest in trees, shrubs or reeds growing in saline or brackish water of estuaries and coastal wetlands. Other species utilise nesting sites in adjacent habitats such as coastal heath and forests, while others nest at distant locations (e.g. inland salt lakes), including migratory species that breed in other countries.

Several sites within the coastal and marine environments of the HCRCMA have been classified as significant wetlands for birds (Table 3.4). The Hunter Estuary Wetlands is listed under the Ramsar Convention and is also recognised as an Important Bird Area (IBA, Bird Life International). It is considered to be the most important area in NSW for shorebirds (Smith, 1991) and supports globally-significant populations of several species. Tuggerah Lakes is a listed

IBA and supports globally-significant populations of chestnut teal and sharp-tailed sandpiper. Important habitats for threatened migratory shorebirds include the Manning Estuary, Wallis Lake, Port Stephens, Hunter Estuary Wetlands and Tuggerah Lake (DEC, 2006). Little terns breed at Farquhar Inlet at the Manning Estuary. Thirteen coastal wetlands in the HCRCMA region are listed in 'A Directory of Important Wetlands in Australia' (Environment Australia, 2001) and may also provide key habitat for marine and coastal birds (Table 3.5).

Seabirds breed on a number of offshore islands within the HCRCMA region (Table 3.6). The most important are Cabbage Tree and Boondelbah islands that support the only confirmed breeding site for the vulnerable Gould's petrel in Australia; the site is consequently a listed IBA. The Broughton Island group, along with Cabbage Tree and Boondelbah islands, supports half the NSW breeding population of wedge-tailed shearwaters (Lane, 1979).

Conservation status of marine and coastal birds

There are 123 bird species listed as threatened in NSW of which 36 are marine and coastal. Of these, 29 occur within the HCRCMA region with six species listed as endangered (wandering albatross, southern giant-petrel, beach stone-curlew, Australian pied oystercatcher, black-necked stork and little tern), and 23 as vulnerable under the NSW *TSC Act* (Table 3.3). Gould's petrel and the southern giant-petrel are also listed nationally (*EPBC Act*) as endangered along with the Juan Fernandez petrel and grey-headed albatross, the latter also being listed by the IUCN as internationally endangered. A further three species (Australasian bittern, Hutton's shearwater and black-browed albatross) are also listed by the IUCN as endangered species.

Table 3.3 The marine and coastal birds that have been recorded on the coasts and inshore waters of the HCRCMA region. O= Oceanic; M= Marine; C= Coastal; E= Estuarine; I= Inland; Int= Intertidal; Isl= Island; R= Rocky shore; Reef= Reef. The conservation status of each bird as listed under NSW, Commonwealth (EPBC) and International (IUCN) schedules are also given. LC = least concern; NT = near threatened; P = protected, E = endangered, V = vulnerable, C = critically endangered, D = data deficient. '-' means a species is not listed under the schedule, * indicates which birds are uncommon in the region (adapted from Ganassin and Gibbs, 2005a, b; Rule et al., 2007). Taxonomic nomenclature and common names follow Christidis and Boles (2008).

			Conservation status		
Species name	**Common name**	**Habitat**	**NSW**	**EPBC**	**IUCN**
Actitis hypoleucos	Common sandpiper	C	P	P	LC
Anas castanea	Chestnut teal	E/I	P	-	LC
Anas gracilis	Grey teal*	E/I	P	-	LC
Anas superciliosa	Pacific black duck*	E/I	P	-	LC
Anhinga novaehollandiae	Australasian darter	E/I	P	-	LC
Anous stolidus	Common noddy*	O/Isl	P	P	LC
Ardea intermedia	Intermediate egret	Int/I	P	P	-
Ardea modesta	Eastern great egret	Int/I	P	P	-
Ardea pacifica	White-necked heron	E/I	P	-	LC
Ardenna bulleri	Buller's shearwater	C/O	P	P	V
Ardenna carneipes	Flesh-footed shearwater	C/O	V	P	LC
Ardenna grisea	Sooty shearwater	C/O	P	P	NT
Ardenna pacifica	Wedge-tailed shearwater	C/O	P	P	LC

			Conservation status		
Species name	**Common name**	**Habitat**	**NSW**	**EPBC**	**IUCN**
Ardenna tenuirostris	Short-tailed shearwater	C/O	P	P	LC
Arenaria interpres	Ruddy turnstone*	C/R	P	P	LC
Biziura lobata	Musk duck*	E/I	P	P	LC
Botaurus poiciloptilus	Australasian bittern	E	V	-	E
Butorides striata	Striated heron*	Int/M	P	-	LC
Calidris acuminata	Sharp-tailed sandpiper	C/I	P	P	LC
Calidris alba	Sanderling*	C	V	P	LC
Calidris canutus	Red knot*	C	P	P	LC
Calidris ferruginea	Curlew sandpiper	C	P	P	LC
Calidris melanotos	Pectoral sandpiper	C	P	P	LC
Calidris minuta	Little stint*	E/I	P	P	LC
Calidris ruficollis	Red-necked stint*	C/I	P	P	LC
Calidris tenuirostris	Great knot*	C	V	P	LC
Calonectris leucomelas	Streaked shearwater*	C/O	P	P	LC
Ceyx azureus	Azure kingfisher	E/C	P	-	LC
Charadrius alexandrinus	Kentish plover*	E/Int	P	-	LC
Charadrius bicinctus	Double-banded plover*	C	P	P	LC
Charadrius leschenaultii	Greater sand plover*	C	V	P	LC
Charadrius mongolus	Lesser sand plover*	C	V	P	LC
Charadrius ruficapillus	Red-capped plover*	C	P	P	LC
Charadrius veredus	Oriental plover*	Int/E/I	P	P	LC
Chlidonias hybrida	Whiskered tern	E	P	P	LC
Chlidonias leucopterus	White-winged black tern*	C/I	P	P	LC
Chroicocephalus novaehollandiae	Silver gull	C/I	P	P	LC
Cladorhynchus leucocephalus	Banded stilt*	E/I	P	-	LC
Cygnus atratus	Black swan*	E/I	P	-	LC
Diomedea exulans	Wandering albatross*	O	E	V	V
Egretta novaehollandiae	White-faced heron*	Int/I	P	-	LC
Egretta garzetta	Little egret*	Int/I	P	P	LC
Egretta sacra	Eastern reef egret*	Int/Isl	P	P	LC
Ephippiorhynchus asiaticus	Black-necked stork*	E/C	E	-	NT
Esacus magnirostris	Beach stone-curlew*	C	E	P	NT
Eudyptula minor	Little penguin*	C/O	P	P	LC
Falco peregrinus	Peregrine falcon*	C/Isl	P	-	LC
Fregata ariel	Lesser frigatebird*	O	P	P	LC

			Conservation status		
Species name	**Common name**	**Habitat**	**NSW**	**EPBC**	**IUCN**
Fregetta tropica	Black-bellied storm petrel*	O	P	P	LC
Gallirallus philippensis	Buff-banded rail	Isl/I	P	-	LC
Gelochelidon nilotica	Gull-billed tern	C/O	P	P	LC
Gerygone levigaster	Mangrove gerygone	E	P	-	LC
Gygis alba	White tern	M	V	P	LC
Haematopus finschi	South Island pied oystercatcher	C/I	-	-	LC
Haematopus fuliginosus	Sooty oystercatcher*	C	V	-	LC
Haematopus longirostris	Australian pied oystercatcher*	C	E	-	LC
Haliaeetus leucogaster	White-bellied sea-eagle*	C/I/Isl	P	P	LC
Haliastur indus	Brahminy kite*	C/Isl	P	P	LC
Haliastur sphenurus	Whistling kite*	C/I	P	P	LC
Himantopus himantopus	Black-winged stilt	C/I	P	P	LC
Hydroprogne caspia	Caspian tern	C	P	P	LC
Ixobrychus dubius	Australian little bittern	E/I	P	-	-
Ixobrychus flavicollis	Black bittern	C/E	V	-	LC
Larus dominicanus	Kelp gull*	C/E	P	P	LC
Larus pacificus	Pacific gull	C/Isl	P	P	LC
Lewinia pectoralis	Lewin's rail	E/I	P	-	LC
Limicola falcinellus	Broad-billed sandpiper	C	V	P	LC
Limnodromus semipalmatus	Asian dowitcher*	C	P	P	NT
Limosa haemastica	Hudsonian godwit	E/Int	P	-	LC
Limosa lapponica	Bar-tailed godwit*	C	P	P	LC
Limosa limosa	Black-tailed godwit*	C/I	V	P	NT
Macronectes giganteus	Southern giant-petrel*	O	E	E	LC
Microcarbo melanoleucos	Little pied cormorant	C/I	P	-	LC
Morus serrator	Australasian gannet*	O	P	P	LC
Numenius madagascariensis	Eastern curlew*	C	P	P	LC
Numenius minutus	Little curlew*	E/C	P	P	LC
Numenius phaeopus	Whimbrel*	C	P	P	LC
Nycticorax caledonicus	Nankeen night heron*	Int/E	P	P	LC
Oceanites oceanicus	Wilson's storm petrel*	O	P	P	LC
Onychoprion anaethetus	Bridled tern	Isl	P	P	LC
Onychoprion fuscata	Sooty tern	M	V	P	LC
Pachyptila turtur	Fairy prion	O	P	P	LC

			Conservation status		
Species name	**Common name**	**Habitat**	**NSW**	**EPBC**	**IUCN**
Pandion cristatus	Eastern osprey*	M	V	P	LC
Pelagodroma marina	White-faced storm petrel*	O	P	P	LC
Pelecanoides urinatrix	Common diving-petrel*	O	P	P	LC
Pelecanus conspicillatus	Australian pelican*	C/I	P	P	LC
Phaethon rubricauda	Red-tailed tropicbird	M	V	P	LC
Phalacrocorax carbo	Great cormorant*	C/I	P	-	LC
Phalacrocorax fuscescens	Black-faced cormorant*	M/E	P	P	LC
Phalacrocorax sulcirostris	Little black cormorant*	C/E	P	-	LC
Phalacrocorax varius	Pied cormorant*	C/I	P	-	LC
Philomachus pugnax	Ruff*	E/I	P	P	LC
Platalea flavipes	Yellow-billed spoonbill	E/I	P	-	LC
Platalea regia	Royal spoonbill	C/I	P	-	LC
Pluvialis fulva	Pacific golden plover*	C	P	P	LC
Pluvialis squatarola	Grey plover*	C	P	P	LC
Podiceps cristatus	Great crested grebe*	E/C/I	P	-	LC
Poliocephalus poliocephalus	Hoary-headed grebe*	E/C	P	-	LC
Porzana fluminea	Australian spotted crake	E/I	P	-	LC
Porzana tabuensis	Spotless crake	E/I	P	P	LC
Pterodroma externa	Juan Fernandez petrel*	M	P	P	V
Pterodroma leucoptera	Gould's petrel*	M	V	E	V
Pterodroma macroptera	Great-winged petrel*	O	P	P	LC
Pterodroma neglecta	Kermadec petrel	M	V	V	LC
Pterodroma nigripennis	Black-winged petrel	M	V	P	LC
Pterodroma solandri	Providence petrel*	M	V	P	V
Puffinus assimilis	Little shearwater*	C/O	V	P	LC
Puffinus gavia	Fluttering shearwater*	O	P	P	LC
Puffinus huttoni	Hutton’s shearwater*	O	P	P	E
Recurvirostra novaehollandiae	Red-necked avocet	E/I	P	P	LC
Stercorarius parasiticus	Arctic jaeger*	C/O	P	P	LC
Stercorarius pomarinus	Pomarine jaeger*	O	P	P	LC
Stercorarius skua	Great skua	Isl/M	P	P	LC
Sterna hirundo	Common tern*	O	P	P	LC
Sterna paradisaea	Arctic tern*	M	P	P	LC
Sterna striata	White-fronted tern*	O/C	P	P	LC
Sternula albifrons	Little tern*	C/M	E	P	LC

			Conservation status		
Species name	**Common name**	**Habitat**	**NSW**	**EPBC**	**IUCN**
Sula dactylatra	Masked booby*	M	V	P	LC
Sula leucogaster	Brown Booby	M	P	P	LC
Tadorna tadornoides	Australian shelduck	E/I	P	-	LC
Thalassarche cauta	Shy albatross*	M	V	V	NT
Thalassarche chlororhynchos	Yellow-nosed albatross*	M	P	V	E
Thalassarche chrysostoma	Grey-headed albatross*	M	P	E	V
Thalassarche melanophris	Black-browed albatross*	M	V	V	E
Thalasseus bergii	Crested tern	C/Isl	P	P	LC
Threskiornis molucca	Australian white ibis*	E/C	P	P	LC
Threskiornis spinicollis	Straw-necked ibis	E/I	P	P	LC
Todiramphus sanctus	Sacred kingfisher*	E/I	P	P	LC
Tringa brevipes	Grey-tailed tattler	C/Reef	P	P	LC
Tringa flavipes	Lesser yellowlegs*	E/I	-	-	LC
Tringa incana	Wandering tattler*	C/Reef	P	P	LC
Tringa nebularia	Common greenshank*	C/I	P	P	LC
Tringa stagnatilis	Marsh sandpiper*	C/I	P	P	LC
Tryngites subruficollis	Buff-breasted sandpiper*	E/I	P	P	NT
Vanellus miles	Masked lapwing*	C/I	P	-	LC
Xenus cinereus	Terek sandpiper*	C/I	V	P	LC

Table 3.4 Important wetlands for marine and costal birds within the HCRCMA region.

Important bird areas	Species present
Hunter Estuary	Chestnut teal, sharp-tailed sandpiper, Australasian bittern, red-necked avocet, eastern curlew, straw-necked ibis, black-tailed godwit, great knot, lesser sand plover, Terek sandpiper, broad-billed sandpiper
Tuggerah Lakes	Chestnut teal, sharp-tailed sandpiper, black-tailed godwit, great knot, lesser sand plover
Manning Estuary	Great knot, lesser sand plover, sanderling
Port Stephens	Black-tailed godwit, lesser sand plover, Terek sandpiper
Wallace Lake	Lesser sand plover
Farquhar Inlet	Little tern (breeding)

Table 3.5 Coastal wetlands within the HCRCMA region that could provide important habitat for marine and coastal birds. * wetlands listed as IBAs or Ramsar sites.

Coastal Wetland	Approximate location
Avoca Lagoon	Avoca Beach
Brisbane Water Estuary	Gosford
Budgewoi Lake Sandmass*	Budgewoi
Colongra Swamp*	Budgewoi
Crowdy Bay National Park	Taree
Kooragang Nature Reserve*	Newcastle
Myall Lakes	Bulendelah
Port Stephens Estuary	Port Stephens
Shortland Wetlands Centre*	Newcastle
Terrigal Lagoon	Terrigal
Tuggerah Lake*	Wyong
Wallis Lake and estuaries	Foster Tuncurry
Wamberal Lagoon	Terrigal

Table 3.6 Offshore islands within the HCRCMA region where seabirds breed (after Lane, 1979).

Island	Species breeding
Statis Rock	Silver gull, crested tern, little penguin
Broughton Islands	Crested tern, silver gull, white-faced storm-petrel, sooty shearwater, wedge-tailed shearwater, short-tailed shearwater
Cabbage Tree Island	Gould's petrel, sooty shearwater, wedge-tailed shearwater, short-tailed shearwater, little penguin
Little Island	Crested tern, silver gull
Boondelbah Island	Gould's petrel, white-faced storm-petrel, sooty shearwater, wedge-tailed shearwater, short-tailed shearwater, little penguin

Birds using interitdal rocky shores

Specific surveys of birds using rocky shores within the region have been conducted as part of assessments of the conservation value of these habitats (Gladstone, 2005; Gladstone et al., 2007). Bird data were collated for the Newcastle area by members of the Hunter Bird Observers group over an extending sampling period spanning 1972 – 2005. A total of 20 rock-platform frequenting species were recorded, with a distinct seasonal trend in diversity (18 spp. in summer, 11 spp. in winter). The 20 species includes two listed under the NSW *TSC Act* - the little tern (Endangered) and the sooty oystercatcher (Vulnerable) - and three species covered by the Japan-Australia Migratory Birds Agreement and China-Australia Migratory Birds Agreement (grey-tailed tattler, red-necked stint, ruddy turnstone). The most important roost site on the Newcastle rock-platform system is immediately seaward of Newcastle Ocean Baths; this area typically supports hundreds of birds and is an important habitat for sooty oystercatchers (with the highest regional counts occurring at this site – Gladstone, 2005). Studies on the Central Coast (Gladstone et al., 2007) identified 22 bird species on rocky shores with the highest diversity recorded at Norah head (10 spp.) and Blue Lagoon (7 spp.). Norah Head was found to be an important high-tide roost for gulls and terns and a significant low-tide foraging area for migratory shorebirds (Gladstone et al., 2007).

Primary data sources

Data summarised in this section are mostly derived from Electronic databases and resources and a range of publications. The primary electronic sources are: BARC Summaries <www.tonypalliser.com/barc/barc-home.html>; Birds Australia, IBA (database) <www.birdata.com.au/iba.vm>; DECCW Threatened Species Database <www.threatenedspecies.environment.nsw.gov.au>; Department of Environment, Water, Heritage and the Arts (DEWHA), Species Profile and Threats Database (SPRAT) <www.environment.gov.au/sprat>; IUCN Red List of Threatened Species, Version 2010.1 (database) <www.iucnredlist.org>; NPWS Atlas of NSW Wildlife (database) <wildlifeatlas.nationalparks.nsw.gov.au/wildlifeatlas/watlas.jsp>.

Data description and assessment

The Atlas of NSW Wildlife and Threatened Species Database include search parameters that enable retrieval of data records for the HCRCMA region. Inconsistencies were present in the data retrieved with the Threatened Species Database returning an additional three species not listed by the Atlas of NSW Wildlife: *Procelsterna cerulean* (grey ternlet), *Diomedea gibsoni* (Gibson's albatross), *Diomedea antipodensis* (Antipodean albatross).

The *Handbook of Australian, New Zealand and Antarctic Birds* (HANZAB) (Marchant and Higgins, 1990a, b; 1993; Higgins and Davies, 1996; Higgins, 1999; Higgins and Peters, 2002) provides comprehensive species descriptions for each bird recorded in the Australian, New Zealand and Antarctic regions. Ganassin and Gibbs (2005a) used this information to provide descriptions of the bird species that commonly occur in the marine and estuarine waters of NSW. Their listing does not include a number of the mangrove specialists that occur in NSW but are listed here as they fall within the definition of species dependent on marine or estuarine habitats. Ganassin and Gibbs (2005b) assessed the potential impacts of fishing in NSW on marine and estuarine birds based on documented interactions and occurrence data derived from HANZAB. Christidis and Boles (2008) provide an authoritative and updated account of the systematics and taxonomy of Australian birds and is a valuable reference for verification of the scientific and common name changes that have occurred recently.

Information on key habitats and breeding sites was derived from multiple sources and is unlikely to be comprehensive, but the most important sites have been identified. Much of the information is outdated (Lane, 1979) or has a narrow taxonomic focus (DEC, 2006). Information on birds frequenting rocky shores came from studies of biodiversity values of coastal rock platforms around Newcastle (Gladstone, 2005) and the Central Coast (Gladstone et al., 2007).

3.2.5 Marine reptiles and mammals

The NSW NPWS (now part of DECCW) has statutory responsibility for the protection, conservation and management of native wildlife both on and off parks in NSW under the *NPW Act* and the *TSC Act* legislation. This includes all marine mammals, reptiles and birds in NSW waters (which extend to 3 nm (5.6 km) offshore). Beyond this, in the waters of the Australian Exclusive Economic Zone (EEZ) (to 200 nautical miles offshore), Commonwealth legislation applies and legal responsibility for marine fauna rest with DEWHA. Under the *EPBC Act* all cetaceans, pinnipeds and marine turtles are protected in Australian waters.

Conservation status of marine reptiles

Within NSW, all marine turtles and sea snakes are protected under the *NPW Act*. In addition, the loggerhead turtle *Caretta caretta* is listed as endangered, and the green turtle *Chelonia mydas* and leathery turtle *Dermochelys coriacea* are listed as vulnerable under the *TSC Act* (Table 3.7). With the exception of the loggerhead turtle, all turtle species have conservation status within Australian waters under the Commonwealth *EPBC Act*. Under this Act, loggerhead turtles are listed as endangered. Internationally, the hawksbill *Eretmochelys imbrica* and the leathery turtle are listed as critically endangered on the IUCN Red List of endangered species.

Marine reptiles within the HCRCMA region

Seventeen species of marine reptiles have been recorded from NSW waters. Five species of marine turtle and three species of sea snake have been reported from within the HCRCMA region (Table 3.7) (Llewellyn, 1994; Cogger, 2000; NSW NPWS, 2002a; Ganassin and Gibbs, 2005a, b). The loggerhead turtle *Caretta caretta* is the most endangered of the marine turtles in Australian waters with populations that are thought to have declined by as much as 80% within its range; population modelling suggests that the species faces a high risk of extinction (Limpus and Reimer 1994). There is a continuing decline in the size of the *C. caretta* nesting population at all monitored sites in eastern Australia (Limpus, 2008a). Factors listed as contributing to the decline of the population include: increased predation on nests by introduced predators such as pigs and foxes; disturbance of nesting sites and feeding grounds by human activities; mortality from commercial fishing activities, such as pelagic long-lines and drift-nets; and shark netting and prawn and mollusc trawling (Limpus, 2008a) (see Chapter 5). The adoption of turtle exclusion devices (TEDs) in the commercial fisheries of northern waters has significantly reduced the impacts commercial fishing on this species. Though generally regarded as being outside the species range, *C. caretta* has been reported from the HCRCMA in 2003, 2004 and 2006 at Moon Island, Diamond Beach, Port Macquarie and Shelley Beach. In December 2009, a nesting *C. caretta* from Diamond Beach was monitored by DECCW (NPWS), at the conclusion of the incubation period. Eggs remaining in the nest were examined and found to be infertile and underdeveloped (Ross, pers. obs.).

The green turtle *Chelonia mydas,* which is listed as vulnerable in NSW, is the most reported marine turtle species along the NSW coast and sightings are relatively common as far south as Wollongong; there are thirty records in the Hunter-Central Rivers Catchment region alone. Though the abundance of *C. mydas* is relatively high, there are significant concerns regarding the long-term viability of the populations unless threats from anthropogenic mortality, such as unsustainable harvesting, are removed (Limpus, 2008b). The earliest record for *C. mydas* in the HCRCMA is from 1788 (AM-R12704) recorded from Nine Mile Beach (Tuncurry, NSW). Although data are anecdotal, the nesting of green turtles is increasing on beaches in northern NSW (Geoffrey Ross, pers. obs.). The large number of reported sightings of adult C. *mydas* in Lake Macquarie suggest that a stable population of non-breeding adults may be present within the lake system, though further research on the ecology of this population should be undertaken to confirm its status. Green turtles are also commonly sighted at popular dive sites in the PSGLMP where fatal interactions with fishing gears have also been reported (see Chapter 5).

The hawksbill turtle *Eretmochelys imbricata* is omnivorous; in Australia, it feeds primarily on sponges, algae and seagrass (Whiting and Guinea, 2004). Because the post-hatchling phase of *E. imbricata* disperses throughout the eastern seaboard, there is significant potential for impact from coastal and oceanic long-line, gillnet and prawn fisheries (Limpus, 2008c). Australia has one of the largest remaining *E. imbricata* nesting populations in the world; even so, this population has been declining at a rate of 3–4% per year since at least 1990 (Limpus, 2008c). It is unlikely that *E. imbricata* is common in the HCRCMA region. Indeed, the NSW NPWS Atlas reports that the hawksbill turtle has been recorded on only two occasions – in 1997 at Crowdy Bay and 2000 at Frazer Beach; both were incidental sightings.

The leathery turtle *Dermochelys coriacea* feeds on the medusae of jelly fish (*Catostylus* spp.) and other soft-bodied invertebrates (Eisenberg and Frazier, 1983; Bone, 1998) in coastal waters from southern Queensland to the central coast of NSW (NSW NPWS, 2002b). The species is most commonly reported from: coastal waters in central eastern Australia (from the Sunshine Coast in southern Queensland to central New South Wales), southeast Australia (from Tasmania, Victoria and eastern South Australia), and in south-western Western Australia (Bone, 1998). The population of *D. coriacea* that forages in Australian waters greatly exceeds the abundance of the Australian nesting population. Limpus (2009) suggests that most of these turtles migrate to Australian waters from the larger nesting populations in neighbouring countries. Though *D. coriacea* is recorded from the waters of every state, they are relatively uncommon in the HCRCMA region (Cogger, 2000; Limpus, 2009), with 14 records from the region, most from around Forster, which may indicate that this area is an important offshore foraging site. There are limited census data with which to assess the population status of this species within NSW waters but the eastern-Australian nesting population appears to be declining towards extinction (Limpus, 2009). Given the decline of the nesting population nationally, it is important to note that there are observations of successful nesting near Ballina in 1993 and in December 1995 at Booti Booti (Forster) (Tarvey, 1993; Limpus, 2009).

The flatback turtle *Natator depressus* is endemic to Australian waters, with all recorded nesting occurring on Australian beaches (Limpus et al., 1988). Adult *N. depressus* are carnivorous, feeding principally on soft-bodied invertebrates including soft corals, sea pens, holothurians, and jellyfish (Chatto et al., 1995; Limpus, 2007). Flatback turtles feed in the northern coastal regions of Australia, extending as far south as the Tropic of Capricorn. Their feeding grounds also extend to the Indonesian archipelago and the Papua New Guinea coast. All known breeding sites of the flatback turtle occur in Australia. The eastern Australia stock of *N. depressus* appears to be stable and can be regarded as secure but conservation dependent (Limpus, 2007). Flatback turtles have a preference for shallow, soft-bottomed seabed habitats away from reefs and are rarely seen as vagrants in NSW waters. Post-hatchling records are known from NSW only. There are eleven records of *N. depressus* in the HCRCMA region, from the Entrance to Port Stephens. Interestingly, greater than 50% of the reports have been between 2007 to 2010 (seven).

Approximately 33 species of sea snake occur in Australian waters; however, these are generally found in warm, tropical water (Ganassin and Gibbs, 2005a). Three sea snake species are recorded from the HCRCMA region (Table 3.7): the yellow-bellied sea snake *Pelamis platyurus*, the olive-headed sea snake *Disteira major*, and the elegant sea snake *Hydrophis elegans*. The most commonly reported species is the yellow-bellied sea snake with 16 records from the region. *P. platyurus* is a surface-dwelling species that is a resident of NSW coastal waters (Cogger, 2000). The distribution of the olive-headed sea snake extends from the NSW border northwards across the northern part of Australia; thus the single record from Lion Island on the Central Coast should be considered a vagrant. There are six records of the elegant sea snake *Hydrophis elegans* from the HCRCMA region with reports from the Central Coast to Farquhar Inlet in the north of the region. Sea snakes are vulnerable to demersal fisheries where they may be taken as bycatch (Milton et al., 2009), which may make them susceptible to trawling practices within HCRCMA waters.

Primary data sources

The data for this section were extracted from the following key databases: NSW NPWS Atlas of NSW Wildlife database <http://www.environment.nsw.gov.au/wildlifeatlas/about.htm>; DECCW threatened species database ; DEWHA SPRAT database <http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl>; and the 2006 IUCN Red List.

A comprehensive review of the conservation status and biology of each Australian marine turtle species by Col Limpus is available online at: <http://www.derm.qld.gov.au/services_resources/item_list.php?series_id=200007>.

Data were also extracted from Ganassin and Gibbs (2005a, b) and Cogger (2000).

Data description and assessment

Cogger (2000) examined the records and conservation status across NSW, Australia, and also the international legislation for all marine reptiles recorded in NSW. Each species was scored on a range of biological variables, and ranked in terms of conservation status.

The draft Recovery plan for Marine turtles was released by the Commonwealth in July 2003 and provides a comprehensive review of the species <http://www.environment.gov.au/coasts/publications/turtle-recovery/pubs/marine-turtles.pdf>.

Additional data sources

The recovery plan for marine turtles (Environment Australia, 2003) details the biology and habitat requirements for turtles at each stage of life. It identifies threats, and outlines the necessary steps to promote turtle abundance in Australia <http://www.environment.gov.au/coasts/publications/turtle-recovery/pubs/marine-turtles.pdf>.

A GIS database of all records of the leatherback turtle (ANZCW1205000152) is available from the DEWHA website <http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl>.

Table 3.7 Marine reptiles recorded within the HCRCMA region and the conservation status of each as listed under NSW, Commonwealth (EPBC) and International (IUCN) schedules. P = protected, E = endangered, V = vulnerable, C = critically endangered, D = data deficient. '-' means a species is not listed under the schedule (adapted from Ganassin and Gibbs, 2005a).

		Conservation status		
FAMILY/Species	**Common name**	**NSW**	**EPBC**	**IUCN**
CHELONIIDAE				
Caretta caretta	Loggerhead turtle	E	E	E
Chelonia mydas	Green turtle	V	V	E
Eretmochelys imbricata	Hawksbill turtle	P	V	C
Natator depressus	Flatback turtle	P	V	D
DERMOCHELYIDAE				
Dermochelys coriacea	Leathery turtle	V	V	C
HYDROPHIIDAE				
Disteira major	Olive-headed sea snake	P	P	-
Hydrophis elegans	Elegant sea snake	P	P	-
Pelamis platurus	Yellow-bellied sea snake	P	P	-

Conservation status of marine mammals

All marine mammals found in the HCRCMA region are protected under the *NPW Act* (Table 3.8). The blue whale *Balaenoptera musculus* and dugong *Dugong dugon* are listed as endangered under the *TSC Act*. The humpback whale *Megaptera novaeangliae*, sperm whale *Physeter macrocephalus* and southern right whale *Eubalaena australis*, Australian fur seal *Arctocephalus pusillus* and New Zealand fur-seal *Arctocephalus forsteri* are listed as vulnerable under the *TSC Act*. Blue whales and sperm whales are listed as endangered under the Commonwealth *EPBC Act*, and southern elephant seal, the subantactic fur seal *Arctocephalus tropicalis* and the Australian sea lion *Neophoca cinerea* are listed as vulnerable under this act. The blue whale is the only species found in the region which is also listed under the IUCN Red List as endangered; humpback whales, sperm whales and dugong are listed as vulnerable.

The spinner dolphin *Stenella longirostris,* which occurs within the HCRCMA region, was listed as vulnerable under the *TSC Act* prior to 2000. However, subsequent to Smith's (2001) review of the conservation status of marine mammals in NSW, it was removed from the schedule.

Marine mammals within the HCRCMA region

Forty-two species of marine mammals have been recorded from NSW waters. The marine mammals belong to three separate mammalian orders and comprise 34 cetacean (whales and dolphins) species, seven pinnipeds (seals and sea lions) and one sirenian (dugong). Eight species of cetacean (five baleen whales and three toothed whales) are currently listed on the schedules of the *TSC Act*. The most-frequently recorded marine mammals, as indicated by the Atlas of NSW Wildlife database, are the humpback whale, bottlenose dolphin, and pygmy sperm whale *Kogia breviceps*, leopard seal *Hydrurga leptonyx*, and Australian fur seal. Most species listed on the NSW Atlas database are from stranding events, which potentially biases any relative abundance indices. Though not listed as common in NSW waters, recent data from the Cape Solander Whale Migration Study suggest that the minke whale *Balaenoptera acutorostrata* (that also migrate through HCRCMA waters) may be more common than previously thought (Ross, unpublished data) but rarely strand. None of the marine mammal species found in NSW are restricted to state waters; most have a wide distribution in Australian and international waters and some are migratory.

Increasing community interest in marine mammals has also led to a rapid growth in commercial whale, dolphin and seal watching in Australia (IFAW, 2004). In addition, there has been considerable growth in visitation to coastal national parks where land-based whale watching is undertaken. Humpbacks are regularly sighted within the region, with commercial whale-watching operations centred at Port Stephens, Nelson Bay and Forster.

A total of 33 marine mammal species has been reliably recorded within the HCRCMA region, either as live animals or from stranding records (Smith, 2001; Ganassin and Gibbs, 2005a, b). Of these records, there are 26 species of whale and dolphin (cetaceans), seven species of seal (pinnipeds) and one dugong (sirenid) (Table 3.8). The most commonly recorded of all mammal species is the bottlenose dolphin *Tursiops* spp., which occurs along the entire coast of NSW. Many other species, such as the spinner dolphin and leopard seal *Hydrurga leptonyx* are vagrants or are rarely seen in the region. The most common indication of the presence of some of the whale and dolphin species in the region is from stranding records.

Cetaceans (whales, dolphins and porpoises)

While a number of cetacean species occur within the HCRCMA region (Table 3.8), the spatial and seasonal occurrence of many of these is not known with any certainty. Southern right and humpback whales, and the inshore form of the bottlenose dolphin, generally occur inside the 3-nm limit of the HCRCMA. Other species move between offshore waters, which lie outside the region, and inshore waters, generally in response to changes in prey abundance. The only documented resident population of cetaceans within the region is for the Indo-Pacific bottlenose dolphins *Tursiops aduncus* found at Nelson Bay.

Species that have been reported in the HCRCMA region as vagrants from more northern populations include: Indo-Pacific humpbacked dolphin *Sousa chinensis*, spinner dolphin, and Bryde's whale *Balaenoptera edeni* (single records only). The orca (killer whale) *Orcinus orca*, which more commonly occurs in southern NSW, also occurs occasionally in the HCRCMA region (Smith, 2001).

Humpback whales traverse through HCRCMA waters when migrating from Antarctica to breed in more northerly waters (Paterson and Paterson, 1989; Bannister et al., 1996; Hawkins, 2000). This species migrates northwards mainly between May to August returning south during September to November.

The northern-most limit of southern right whales, *E. australis*, on their migration from Antarctica appears to be around Minnie Waters in NSW (Lat: 29.76 S, Long: 153.29E). This species migrates along the NSW coast between May and November passing through HCRCMA waters. While the specific migration route of each of the species off eastern Australia has not been recorded, it is known that *E. australis* migrates close to the coast, but may, like the humpback whale migration, take a more offshore route when returning south. Risso's dolphin *Grampus griseus* also appears to migrate to NSW on a seasonal basis, the reasons for which are not known (Ganassin and Gibbs, 2005a); only one record exists for the HCRCMA ,from Terrigal Beach on the Central Coast.

With the exception of the *T. aduncus* population in Port Stephens, breeding activity of cetaceans in the HCRCMA region has not been documented. Humpback whales tend to calve off Queensland, although there is evidence that some individuals calve in northern NSW waters during their northward migration (Bannister et al., 1996; G. Ross, pers. obs.). Neonate southern right whale calves are regularly sighted in NSW coastal waters, but the frequency of these sightings in the HCRCMA region is not known. There is a paucity of information on the specific diet of cetaceans occurring in NSW waters. Generally, the dolphins and pilot whales feed on fish, squid and shrimp. Humpback whales have been documented feeding on krill *Euphausia superba* in the southern NSW waters (Smith, 2001) and off Sydney. It is not know whether the distribution of krill extends to the HCRCMA region.

Threats to marine mammals in the HCRCMA region include: collisions with boating traffic; entanglement in nets and traps, long-lines and other fishing gear; and the ingestion of marine debris such as plastics which can cause abrasions, infection, suffocation or blockages if swallowed (G. Ross, pers. obs.) (see Chapter 5).

An extensive, long-term research program by Macquarie University in Port Stephens, which commenced in 1998, has facilitated data collection on dolphin abundance, group and social structure, site fidelity, genetics, acoustics, use patterns and boating impacts.

The Port Stephens' dolphin population is small and comprises Indo-Pacific bottlenose dolphins *T. aduncus,* with ~90 individuals resident within the port. Genetic analysis revealed that these dolphins are genetically distinct from the adjacent coastal dolphins that inhabit the more oceanic waters. The females within the port appear to be highly philopatric to their natal site (Möller et al., 2007). Four main female groups and several male alliances were identified as resident to the area. Female bands and associated calves and juveniles concentrate their activities in different parts of the port with 3 of the 4 bands using the eastern section of the port, where intense dolphin-watching and boating activity occurs (Allen et al., 2007). Currently, the program's focus is the dolphins' long-term social relationships, mate choice and paternity, fine-scale habitat use of social groups, trends in abundance, and protection measures for the population within the recently established PSGLMP.

Pinnipeds (seals and sea-lions)

Seven species of seal have been recorded in NSW waters with five species recorded from the HCRCMA region. None of the pinniped species found in NSW are restricted to the state and most species have a wide distribution in Australian and international waters.

The Australian fur seal suffered a severe decline as a result of commercial sealing that occurred from 1798 to 1923 (Warneke and Shaughnessy, 1985). Prior to European exploitation, the breeding distribution of the species included NSW and southern Tasmania, although at present, the species is yet to recolonise many former breeding locations in Bass Strait (Warneke and Shaughnessy, 1985; Shaughnessy, 1999). Seal numbers are increasing at the extant Bass Strait colonies (Pemberton and Kirkwood, 1994; Shaughnessy, 1999) but the Australian fur seal population is well below its original size (Pemberton and Kirkwood, 1994). Fur seals are also under threat by entanglement or ingestion of plastic debris that is increasingly discarded from boats or washed out to sea (Jones, 1994). The depleted population of Australian fur seals has increased its vulnerability to other threats.

The behaviour of a seal that has come ashore is defined as a 'haul-out'. Seals haul-out for a number of reasons, including to rest, nurse their young, moult, thermoregulate and/or to avoid predators. In most cases, the animals will depart of their own accord within a day or two. Seals that haul-out at busy sites are monitored by DECCW (NPWS) staff to reduce interference from people and domestic animals, and to prevent people from being bitten if they approach the seal too closely. Seals are capable of inflicting severe injuries and can be surprisingly aggressive and agile when frightened. Moreover, seals harbour a range of pathogens which can cause diseases in humans (zoonoses) posing additional risks that must be managed effectively.

The Australian fur seal *A. pusillus* and New Zealand fur seal *A. forsteri* are the most commonly occurring pinniped species in NSW (Warneke & Shaughnessy, 1985); their distributional range includes the HCRCMA region. The occurrence of these species in NSW is mostly concentrated in southern NSW waters especially around regular haul-out sites such as Montague Island. While no regular haul-out sites were recognised by Ganassin and Gibbs (2005a) within the HCRCMA region, seals have been regularly observed hauling-out on Cabbage Tree Island since 2007. The Australian fur seal is known to infrequently come ashore at irregular intervals along the length of the coast within the region; there are also records of New Zealand fur seals hauled-out from Gosford to Seal Rocks. None of these species breed within the region. They feed upon fish, squid and seabirds (Warneke & Shaughnessy, 1985; Smith, 2001).

Other pinniped species recorded from the HCRCMA region include the subantarctic fur seal *A. tropicalis* for which there are five records, with twelve records overall for this species within NSW. The earliest record from within the HCRCMA is of a juvenile male that hauled-out on Wamberal Beach in 1980. The other records are of *A. tropicalis* that hauled-out at Stockton Beach (2007), Port Stephens (2007), Burgess Beach (2008), and Patonga Creek (2009).

The leopard seal *Hydrurga leptonyx* is a common visitor to NSW waters. There are 31 reports of this species in the HCRCMA region (Atlas of NSW Wildlife). The locations are focussed on the Central Coast around Wamberal, McMasters Beach, and Terrigal Beach, with the earliest sighting recorded at Lakes Beach in 1988, and the most recent in 2002 on Wamberal Beach.

The Australian sea lion *Neophoca cinerea* is endemic to Australia, breeding on offshore islands along the western and southern coastline of Australia. They are rare vagrants in to NSW waters, and three haul-outs for this species have been recorded from the HCRCMA region in the Atlas of NSW Wildlife. Two *N. cinerea* were recorded from Seal Rocks, one in 1892 and another in 1915; a third was recorded from Budgewoi in December 1989.

Sirenians (dugongs)

The dugong *Dugong dugon* is a tropical species that occurs across northern Australia from Shark Bay (WA) to Moreton Bay (Qld). It is now represented across its range by small, relatively isolated populations (Smith, 2001). In NSW, the species is classed as endangered under the *TSC Act* and has been reported as far south as Botany Bay where individual animals have stranded. The dugong is an occasional vagrant in the HCRCMA region, usually following unfavourable natural events in Queensland (Allen et al., 2004; Ganassin and Gibbs, 2005a, b). The NPWS Atlas of NSW Wildlife contains 16 records of dugong within the HCRCMA region. Vagrant dugongs tend to be sighted in areas where the seagrasses on which they feed occur; in NSW, this includes estuarine waters. The species does not tend to persist, chiefly due to the constraints of low water temperatures during winter.

Table 3.8 The marine mammal species that have been recorded within the HCRCMA region. The conservation status of each as listed under NSW, Commonwealth (EPBC) and International (IUCN) schedules are also given. LC = least concern; NT = near threatened; P = protected, E = endangered, V = vulnerable, D = data deficient. '-' means a species is not listed under the schedule (adapted from Ganassin and Gibbs, 2005a). Note that some of the whale species occur outside the 3-nm limit.

		Conservation status		
Species	**Common name**	**NSW**	**EPBC**	**IUCN**
Order Cetacea				
Balaenoptera acutorostrata	Minke whale	P	P	LC
Balaenoptera edeni	Bryde's whale	P	P	D
Balaenoptera musculus	Blue whale	E	E	E
Delphinus delphis	Common dolphin	P	P	LC
Eubalaena australis	Southern right whale	V	E	LC
Feresa attenuate	Pygmy killer whale	P	P	D

		Conservation status		
Species	**Common name**	**NSW**	**EPBC**	**IUCN**
Globicephala macrorhynchus	Short-finned pilot whale	P	P	LC
Globicephala melas	Long-finned pilot whale	P	P	LC
Grampus griseus	Risso's dolphin	P	P	D
Kogia breviceps	Pygmy sperm whale	P	P	LC
Kogia simus	Dwarf sperm whale	P	P	-
Lagenodelphis hosei	Fraser's dolphin	P	P	D
Megaptera novaeangliae	Humpback whale	V	P	V
Mesoplodon grayi	Gray's beaked whale	P	P	D
Mesoplodon layardii	Strap-toothed beaked whale	P	P	D
Orcinus orca	Killer whale	P	P	LC
Peponocephala electra	Melon-headed whale	P	P	LC
Physeter macrocephalus	Sperm whale	V	P	V
Pseudorca crassidens	False killer whale	P	P	LC
Stenella attenuate	Pantropical spotted dolphin	P	P	LC
Stenella coeruleoalba	Striped dolphin	P	P	LC
Stenella longirostris	Spinner dolphin	P	P	LC
Steno bredanensis	Rough-toothed dolphin	P	P	D
Tursiops truncates	Bottlenose dolphin	P	P	D
Tursiops adunctus	Indo-Pacific bottlenose dolphin	P	-	-
Order Pinnipedia				
Arctocephalus forsteri	New Zealand fur seal	V	P	LC
Arctocephalus pusillus doriferus	Australian fur seal	V	P	-
Arctocephalus tropicalus	Subantarctic fur seal	P	V	-
Hydrurga leptonyx	Leopard seal	P	P	LC
Neophoca cinerea	Australian sea lion	P	V	-
Order Sirenia				
Dugong dugon	Dugong	E	P	V

Primary data sources

The data for this section were extracted from the following key databases: NSW NPWS Atlas of NSW Wildlife database <http://www.environment.nsw.gov.au/wildlifeatlas/about.htm>;

DECCW threatened species database; DEWHA SPRAT database <http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl>; and the 2006 IUCN Red List.

Data description and assessment

Bannister et al. (1996) and Shaughnessy (1999) detail the action plans for the recovery of cetaceans and seals, respectively, within Australian waters. Both of these action plans have extensive information about species distributions, biology ecology, threats and conservation status. Paterson and Paterson (1989) reviewed the stock recovery of the humpback whale in eastern Australia after 25 years of protection.

Allen et al. (2004) provide an assessment of the occurrence and conservation of dugongs in NSW waters.

Smith (2001) reviewed the conservation status of all mammal species recorded in NSW waters. This review includes detailed descriptions of species distributions and biology and stock information and provided recommendations for changes to the conservation status of several species.

Ganassin and Gibbs (2005b) assessed the potential impact of NSW fishing activities on marine fauna in NSW, and summarised all documented accounts of interactions in NSW. Ganassin and Gibbs (2005a) provide descriptions of the marine mammal species that commonly occur in NSW.

Personal comments and accounts come from the unpublished Cape Solander Whale Migration Study (G. Ross – DECCW).

Additional data sources

DEWHA (2005) provide guidelines about the observation of cetaceans, and about areas of special interest for cetacean observation. These guidelines are currently under review.

Along with the annual humpback whale survey conducted from Cape Byron (25 years data acquisition), whale abundance data, including for humpback and minke whales, are collected from Cape Solander on the southern side of Botany Bay (11 years data collection). Data collected from these sites include the distance of individual pods offshore and the number of animals per pod. These data are held by the Whale Research Centre at Southern Cross University and DECCW.

Mitchell (1997) and Hawkins (2000) reviewed the migration of humpback whales and the physical factors that influence their migration patterns. Hawkins concluded that depth contours appear to influence migratory patterns. Coughlin (1999) examined behaviour of humpback whales near Coffs Harbour, on both northern and southern migrations, and found that behaviour differed on each leg of the migration.

Luciana Möller studied bottlenose dolphin populations and genetic structure off NSW, including within HCRCMA region (Möller et al., 2001; 2002; 2006). Further work was conducted on the population structure and site fidelity of the Indo-Pacific bottlenose dolphin *Tursiops aduncus* at Port Stephens.

Möller et al. (2007) compared the genetic variability of Port Stephens dolphins (enclosed embayment) with dolphins from the open coast. They found that gene flow within each population was high, but that gene flow between the populations was low, suggesting that high site fidelity leads to resource and behavioural specialisation. Möller et al. (2007) hypothesise that habitat type can rapidly promote fine-scale genetic structure in long-lived, highly mobile marine mammals.

Allen et al. (2007) reviewed the practice of self regulation of the Port Stephens dolphin-watch industry. The industry developed a voluntary code of conduct for operators in 1996 that was designed to reduce impacts on dolphin populations within Port Stephens. Results suggest that compliance with the voluntary code is high but that the voluntary code does not provide for the management or compliance of non-commercial whale-watching activities. It also fails to provide direction as to the number of operators undertaking dolphin-watching activities and thus does not effectively reduce impact on Port Stephens dolphin populations. Allen et al. (2007) concluded that the voluntary code was ineffective in minimising impacts on Port Stephens dolphins due to:

- some operators not adhering to all stipulations of the voluntary code,
- repeated exposure of dolphins to numerous dolphin-watching operators and other boats, and
- the lack of discrimination between schools containing calves and those lacking them.

Adsett (2000) examined the interactions between bottlenose dolphins and vessels in a small-scale study on the NSW north coast. This study suggests that dolphin behaviour was affected by vessels coming within 100 m of pods, indicating potential impacts on dolphin populations at Port Stephens from commercial and recreational whale watching.

Phillips (1997) reviewed the factors responsible for mass stranding of cetaceans in NSW.

Semmel (1994) outlined an action plan for marine-mammal strandings on the north coast of NSW. This described beach access, equipment needs and possible rehabilitation locations for stranded animals.

Distribution maps of marine mammals are available from various organisations. DEWHA hold a national-scale GIS coverage of the distributions and migration pathways for blue, humpback and southern right whales. The National Oceans Office (NOO) has additional GIS layers that document dugong distribution. These point data have also been plotted for the eastern-central region by the NOO. The Australian Museum maintains a point-locality database of all mammal specimens held. DECCW provides access to the Atlas of NSW Wildlife online <http://www.environment.nsw.gov.au/wildlifeatlas/about.htm>.

3.3 Marine pests

Marine pests pose a threat to many local marine populations and communities. Pest species can be either introduced species such as the Pacific Seastar (*Asterias amurensis*), or can be naturally occurring species that undergo periodic population outbreaks such as the crown-of-thorns starfish. Both naturally-occurring and introduced pests can have devastating effects on indigenous marine communities directly as predators or competitors for food resources, or indirectly by altering natural habitats. In some areas of Australia such as the Derwent estuary, Tasmania, benthic communities have been severely affected by the presence of introduced pests.

Introduced species

It is generally assumed that marine pests are introduced primarily via commercial ships, either in ballast water or on their hulls. Recreational boats are, however, just as likely to spread many marine pests, especially among estuaries in NSW. Recreational vessels that travel interstate and overseas may also transport marine pests from further a field. Furthermore, some pest species, such as the green alga *Caulerpa taxifolia*, can enter estuaries by being dumped from personal aquaria and so their initial introduction may not be related to shipping or boating activities. Thus, it is highly likely that non-commercial ports, or small estuaries with limited commercial shipping, could contain as many pest species as large primary commercial ports.

The marine pests that are known to occur in NSW are listed in Table 3.9; the table also lists 2 taxa of toxic dinoflagellates which are no longer listed as pests but are still considered a nuisance in NSW waters. Four of the eight marine pests that occur in NSW are known to be present in the HCRCMA (Table 3.9). Two of the other species (*Maoricolpus roseus* and *Sabella spallanzanii*) have a very limited distribution in NSW, being found only in Twofold Bay on the far south coast (but are abundant further south, especially in Port Phillip Bay). A third, the European shore crab *Carcinus maenas*, is not known to occur north of Batemans Bay, although there are historical records of this pest as far north as Sydney.

None of the marine pests in the HCRCMA are distributed widely (Table 3.9). The most high-profile pest is *Caulerpa taxifolia* which was discovered in NSW (Port Hacking) in April 2000. *C. taxifolia* was discovered in Lake Macquarie in February 2001 and spread to numerous sites throughout the southern part of the lake (Figure 3.9). At the peak of its distribution, *C. taxifolia* covered a total area of 16.5 ha in Lake Macquarie. NSW DPI undertook considerable control work (using granulated salt to kill the alga via osmotic stress; Creese et al., 2004; Glasby et al., 2005) in Lake Macquarie. By April 2004, *C. taxifola* was present only at Mannering Park in the southern section of the lake. It is notable that *C. taxifolia* disappeared from some areas of the lake where no control work was done. More control work resulted in the removal of *C. taxifolia* from Mannering Park in May 2006 and the pest has not been found in Lake Macquarie since then.

Table 3.9 Marine pests known in HCRCMA and elsewhere in NSW. CCIMPE is the Consultative Committee on Introduced Marine Pest Emergencies.

Pest classification	Common name	Scientific name	Where in HCRCMA	Elsewhere in NSW
Nationally listed pest (CCIMPE trigger list species)	European fan worm	*Sabella spallanzanii*	–	Twofold Bay
Nationally listed pest (CCIMPE trigger list species)	European shore crab	*Carcinus maenas*	–	Numerous estuaries and lakes south of Batemans Bay
Nationally listed pest (CCIMPE trigger list species)	New Zealand screw shell	*Maoricolpus roseus*	–	Twofold Bay
National noxious fish (ornamental fish)	Japanese goby	*Tridentiger trigonocephalus*	-	Port Jackson, Botany Bay, Port Kembla
Nationally listed pest (CCIMPE trigger list species)	Aquarium caulerpa	*Caulerpa taxifolia*	Brisbane Water, not found in Lake Macquarie since May 2006	Brisbane Water and numerous estuaries and lakes south to Wallagoot Lake
Nationally listed pest (CCIMPE trigger list species)	Broccoli weed	*Codium fragile**	Port Stephens	Numerous locations in Sydney and south
National noxious fish (ornamental fish)	Yellowfin goby	*Acanthogobius flavimanus*	Hunter River	Hawkesbury River, Port Jackson, Botany Bay, Port Kembla

Pest classification	Common name	Scientific name	Where in HCRCMA	Elsewhere in NSW
Noxious species in NSW (*FM Act*)	Pacific oyster	*Crassostrea gigas*	Manning River, Wallis Lake, Port Stephens, Brisbane Water **	Most estuaries south of the Manning, but has been found from Camden Haven to the Tweed
Previously listed on CCIMPE notification list, but no longer listed	Toxic dinoflagellate	*Gymnodinium catenatum*	Port of Newcastle	Botany Bay, Port Jackson, Newcastle Harbour
Previously listed on CCIMPE notification list, but no longer listed	Toxic dinoflagellate	*Alexandrium catanella; A. minutum*	Port of Newcastle	Twofold Bay, Port Kembla, Newcastle Harbour

* The identification of this pest species has been based on microscopic examination only. Recent evidence suggests that the invasive form of this species can be identified only using molecular markers, thus the distribution of this pest is NSW is unclear. This is complicated by the fact that numerous native subspecies of *C. fragile* occur in NSW.

** Surveys for Pacific oysters were done only in estuaries where oysters are farmed, thus Pacific oysters could be present in numerous other estuaries.

C. taxifolia was discovered in Brisbane Water in April 2006, but has only been recorded from a few small sites since that time. The current distribution of *C. taxifolia* in Brisbane Water is similar to that in 2006, covering a total area of 0.76 ha, although most of this area consists of sparse, scattered plants.

Another pest seaweed, *Codium fragile* (previously known as *Codium fragile* ssp. *tomentosoides*) is possibly widely distributed in southern NSW and has been found at numerous sites in the Port Stephens region. However, it is important to note that the identification of this pest species in NSW has been based on microscopic examination only. Recent evidence has suggested that the invasive form of this species can be identified, conclusively, only by using molecular markers (Brodie et al., 2007). Thus, the distribution, and indeed presence, of this pest is NSW is unclear. Where the supposed invasive *C. fragile* has been found, it has only occurred in small isolated clumps of just a few plants. *C. fragile* has not been considered a serious marine pest in NSW and the recent doubts about its identity have complicated the issue. Overseas, this species has had major economic impacts on the aquaculture industry as it can heavily foul marine infrastructure (Carlton and Scanlon, 1985; Bulleri et al., 2006).

Another two marine pests are known to occur in the HCRCMA region but are not listed nationally as pests of significance (Table 3.9) (i.e. which could trigger an emergency response to a new incursion), but they are nonetheless considered noxious. The Pacific oyster (*Crassostrea gigas*) is now widely distributed throughout SE Australia. In NSW, Pacific oysters are farmed commercially only in Port Stephens (and is the only place in NSW where they are not listed as noxious) and this is the estuary in which they are by far the most abundant. The most recent data on the distribution of Pacific oysters in NSW come from surveys that were conducted by NSW DPI research staff, Fisheries inspectors and representatives of the Oyster Farmers Association from 1986 – 1998 (Reid 1986, 1990, 1991, 1992; Reid & McOrrie 1995; Reid & Smith 1999). The surveys were done only in estuaries where oysters are farmed commercially. In all years, surveys consisted of inspections of commercial oyster leases, but in 1986, some other structures such as piles, rocks and mangroves were also surveyed. Abundances of Pacific oysters changed little in HCRCMA estuaries over the surveys from 1986 – 1998. Manning River supports a small population of Pacific oysters relative to the other NSW estuaries, with abundances in Wallis Lake being around the state average. Brisbane Water is in the top 3 estuaries in the state in terms of abundance of Pacific oysters, while Port Stephens the stronghold (due to spat being brought in for commercial purposes).

The introduced goby *Acanthogobius flavimanus* was first discovered in Port Jackson in 1971 and were first recorded in the Hunter River around 1980 (Middleton, 1982). Numerous individuals have been caught as part of NSW DPI research projects from 1984 – present around Kooragang Island, Ironbark Creek, Cobans Creek and Purgatory Creek. Recent DPI surveys (from Oct 2007 – Feb 2008) using seine nets found no introduced gobies at six sites in each of the following HCRCMA waterways: Khappinghat Creek, Wallis Lake, Port Stephens, Wamberal Lagoon, Terrigal Lagoon, Avoca Lake, and Brisbane Water.

Toxic dinoflagellates, which were previously listed on the CCIMPE notification list, have been reported from the Newcastle area. *Alexandrium catenella* and *Alexandria minutum* were found throughout the commercial areas of the Port of Newcastle in 1997 during combined surveys carried out by CSIRO and NSW Fisheries as part of the national port monitoring program for marine pests. These species can potentially bloom and pose a threat to human health, particularly via bioaccumulation in shellfish species. However, as toxic dinoflagellates are extremely widespread, and the risks associated with their presence are relatively low, they no longer appear on the CCIMPE trigger list. The NSW Food Authority monitors for toxic dinoflagellates as part of their NSW Shellfish Program.

Primary data sources

The main data sources of information on marine pests are: the I&I NSW (DPI - Fisheries) marine pests website <www.dpi.nsw.gov.au/fisheries/pests-diseases/marine-pests>; and the Australian Government Marine Pests website <www.marinepests.gov.au/>.

Data description and assessment

Few formal surveys have been done for marine pests in the HCRCMA region, with the main investigations (in Newcastle Harbour as part of a national port monitoring programme for marine pests) conducted in 1997. None of the currently-listed pest species were detected during those surveys <http://www.foodauthority.nsw.gov.au/industry/industry-sector-requirements/shellfish/#Harvest-area-classification>.

Estuaries and lakes in the HCRCMA region have not been searched systematically for marine pests. In the case of *C. taxifolia*, surveys have generally been done in places where there has been a supposed sighting of the species. Field surveys for seagrass have, however, been done in all HCRCMA estuaries over the last 5 years and these surveys are capable of detecting *C. taxifolia*. Pacific oyster surveys were restricted to estuaries where oysters are commercially farmed and surveys for *C. fragile* and introduced fishes have not been systematic throughout the HCRCMA region, or indeed the rest of the state.

Additional data sources

A new national port survey protocol for marine pests is now in place, but there is no defined funding mechanism for such surveys. Assuming that funding can be found, the only HCRCMA area that would be surveyed as part of the national port monitoring system would be Newcastle Harbour.

4 Human Uses and Impacts

This chapter reviews the major uses of marine resources and habitats within the Hunter-Central Rivers Catchment Management Authority (HCRCMA) region including fishing (both commercial and recreational), pollution sources and their impacts, general water quality, and the potential impacts of climate change. As for other chapters, the different sections review the information available in both published sources and in relevant databases and provide succinct summaries of the key issues.

4.1 Commercial fisheries

Overview

Six commercial fisheries currently operate within the Manning Shelf Marine Bioregion. In addition, there are several fisheries that operate within estuaries, but these have not been reviewed here. For the purposes of reporting, Industry & Investment NSW (I&I NSW) collects fisheries data (areas of operation, catch and effort, species caught etc.) for each marine fishery across bands that are 1° latitude wide (Figure 4.1). Each of the marine fisheries operates over an area larger than the Manning Shelf jurisdiction, both latitudinally and in terms of offshore distance (NSW state waters only extend out to 3 nautical miles (nm)). However, under agreement with the Commonwealth government, NSW manages many fisheries (including recreational ones) out to the Exclusive Economic Zone (EEZ) (200 nm). Therefore, summarising data for commercial fishing within the HCRCMA region is very problematical because reporting boundaries for the fisheries do not coincide with the Manning Shelf bioregional boundaries.

Due to issues of confidentiality, commercial catch data, including the number of fishing businesses, for specific reporting zones and regions, cannot be presented. Instead, general catch trends occurring within the Manning region are provided. Furthermore, stock assessments of key species are currently reported by fishery rather than by species per fishery (Scandol et al., 2008). This is different from previous years where catch analysis was done on each fishery (Tanner and Liggins, 2000a, b, c). Therefore, descriptions of the key species targeted are provided for each fishery, but the catch trends are presented in a table for all fisheries, highlighting particular trends in relevant fisheries. Catch data are discussed for each of the zones which lie within, or overlap, the Manning Shelf region (which approximately corresponds with the area covered by the HCRCMA), but the data from the southern area of the Manning Shelf Bioregion can only be considered as a rough guide to fishing trends as the southern limit of Zone 6 extends below the bioregional boundary.

The number of fishing businesses in each fishery was extracted in July 2006. Due to significant changes in the structure of all the fisheries since the introduction of share management, buyouts for marine parks and changes to the reporting regime, it is not possible to obtain an accurate current assessment of active fishing operations for each fishery. The most recent economic analysis of each fishery was done by McIlgorm (2004b), which means that the economic data presented are six years old.

I&I NSW, as a legislative requirement, has produced comprehensive environmental impact statements (EIS) for each of the fisheries reviewed below. The activity, long-term catch and effort trends, potential impacts of the fishery, biology of the key target species, and any management issues relevant to each fishery are discussed in these documents in considerably more detail than is possible here. The following sections provide only a broad overview of commercial fishing operations within the Manning Shelf Bioregion. For a more thorough examination, the reader is referred to the EIS reports.

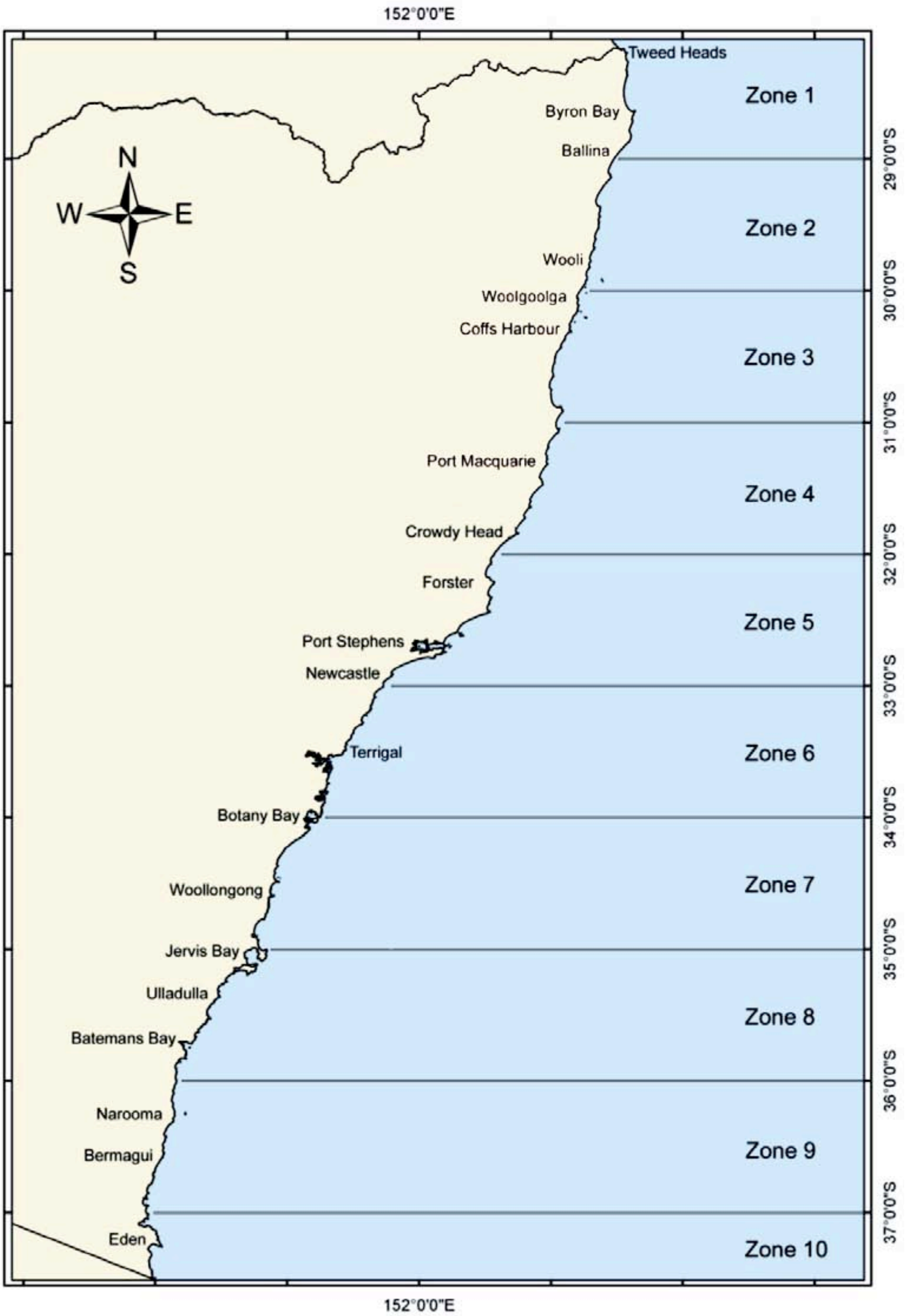


Figure 4.1 Major areas of operation and reporting zones for NSW Department of Primary Industries (DPI) - Fisheries. The HCRCMA region spans three NSW DPI reporting zones (Zones 4-6) (adapted from NSW Fisheries, 2002).

4.1.1 Ocean Trawl fishery

Summary of the fishery

The Ocean Trawl (OT) fishery operates throughout the year in both nearshore and offshore waters to approximately 80 nm offshore along the length of the Manning region. The fishery is divided into two components, Ocean Prawn Trawling (OPT) and Fish Trawling (FT), both of which use demersal otter trawl nets. Trawling for prawns occurs along the entire length of the NSW coast, but trawling for fish is only permitted south of Smoky Cape. The OT fishery produces over 4 000 t of seafood across NSW annually which was valued at approximately $36 million in 2004 (McIlgorm, 2004; NSW DPI, 2004b). As at July 2006, 299 fishing businesses held entitlements to operate in one or more sectors of the OT fishery.

There is considerable overlap in the species caught by both components of the ocean trawl fishery. The primary species taken in this fishery are school whiting, tiger flathead, sand flathead, silver trevally, fiddler shark, eastern king prawns, school prawns, octopus, cuttlefish, southern calamari, and Balmain bugs.

Ocean Prawn Trawling

The OPT fishery is the most valuable fishery in NSW and is worth around $32 million at first point of sale each year. Approximately half of the reported annual catch is prawns. The OPT fishery generally targets eastern king prawns and school prawns, but some royal red prawns and greasyback prawns are also taken. Royal red prawns are only harvested outside the 3-nm limit of state waters (NSW DPI, 2004b).

Within the HCRCMA region, the OPT fishery is divided into three sectors; the inshore fishery encompasses coastal waters out to 3 nm, the offshore fishery extends from 3 nm out to 80 nm, and the deepwater fishery includes waters east of the 80 nm offshore fishery limit. As at August 2006, a total of 251 fishing businesses hold endorsements to operate in the inshore sector, 224 in the offshore sector and 63 in the deep water sector (NSW DPI, 2007).

Fish Trawling

Trawling for fish is restricted to waters south of Smoky Cape. Although the total catch from the FT fishery is about the same as for prawns in terms of biomass, it is worth considerably less at first point of sale (NSW DPI, 2004b). The FT fishery targets a large number of species, including silver trevally, tiger flathead, redfish, John Dory and numerous species of sharks and rays. In August 2006, 64 fishing businesses held endorsements to operate in the OT fishery. These endorsements allow trawling in waters out to 80 nm from the coast (NSW DPI, 2007).

Biology of major species:

Eastern school whiting *Sillago flindersi*

Eastern school whiting (also known as redspot whiting) inhabit the sandy seabed in ocean waters to a depth of 80-100 m, and extend along the coast from southern Queensland to eastern Victoria (Westernport Bay) and north-eastern Tasmania. Eastern school whiting are reported to attain a length of 32 cm, but few are seen exceeding 25 cm. Maturity occurs at about 2 years of age (14 - 16 cm in length), and they reach a length of about 25 cm after 7 years. Most fish caught are 15 - 20 cm in length. Both eastern school and stout whiting frequently occur together in prawn-trawl catches off northern NSW and, historically, fishers reported landings of both species as 'school whiting'. Growth rates are faster in the north of its distribution than in the south. They produce broods of 30 000 - 110 000 eggs which are spawned and develop in the plankton. The whiting diet varies throughout the lifecycle, consisting of polychaetes and amphipods as juveniles, and crustaceans and prawns as adults.

Tiger flathead *Neoplatycephalus richardsoni*

Tiger flathead are endemic to Australia, and occur along the mainland coast from Coffs Harbour to Portland Victoria, and also in Tasmania. This species is generally found on seabed mud and sand habitats in depths of 10 - 400 m. Fish move up into pelagic waters at night to feed. This species has a medium lifespan and reaches maturity at 3 - 5 years (30 - 36 cm). Males exhibit a slower growth rate than females. Females are highly fecund, producing 1.5 - 2.5 million eggs each, which develop in the plankton. The diet of this species changes depending on lifecycle stage, with adults consuming small fish, and juveniles consuming crustaceans and krill.

Silver trevally *Pseudocaranx dentex*

This species has a wide distribution and occurs in estuarine and coastal waters from North West Cape (WA) to southern Queensland. It is also found in Tasmania and northern New Zealand. This species has different habitat requirements depending on life history stage, with juveniles inhabiting estuaries, bays and shallow continental shelf regions, while adults can be found schooling on the continental shelf, inshore reefs, open sand or gravel habitats, and in large bays and inlets. It is relatively long-lived and slow growing and can mature at small sizes (18 - 20 cm), although full maturation is not reached until a length of 26 - 28 cm. It spawns from spring to autumn with females having moderate fecundity (30 000 - 220 000 eggs). Larvae occur in coastal waters throughout this period and may enter estuaries before settling out as juveniles. Although mature fish occur most often in ocean waters, they also enter estuaries at certain times. Its diet includes worms, molluscs, and benthic and planktonic crustaceans.

Fiddler shark *Trygonorrhina* spp.

This species has a relatively narrow distribution across southern Queensland and NSW. It is found in coastal bays, inhabiting seagrass and sandy habitats. Its growth rate, size at maturity and longevity are unknown, but this may be a long-lived species. It is a live-bearing species with a low fecundity, producing only three embryos during each reproductive cycle. Its diet includes benthic fish and invertebrates.

Eastern king prawn *Penaeus plebejus*

King prawns are endemic to eastern Australia, occurring from Mackay, Queensland to north east Tasmania to depths of 220 m. Only one population of this species is found in this area. There is no information on the larval stages of king prawns in the wild but it is thought that these conform to the general pattern found in other penaeids with a larval stage of 2 - 3 weeks. Larvae hatch from the egg and develop in the plankton though a series of moults into post-larvae which settle to the seafloor. Juveniles occur on either bare or vegetated substrata in estuaries and oceanic embayments. They emigrate from estuaries over spring and summer and move northwards, over long distances, for what is thought to be the purposes of spawning. They spawn predominantly in waters from northern NSW to the Swains Reef, Queensland. The species has a fast growth rate, lives for 3 years and reaches maturity at 45 - 60 mm (carapace length - CL). It is an opportunistic omnivore and feeds on small crustaceans, polychaetes, bivalves and foraminifers.

School prawn *Metapenaeus macleayi*

Endemic to eastern Australia, school prawns occur from Tin Can Bay in Queensland to Corner Inlet in Victoria in depths to 55 m. There are several populations of school prawns in this area. There is no information on the larval stages of school prawns in the wild but it is thought that these also conform to the general pattern found for other penaeids and so probably have a larval stage of 2 - 3 weeks. Juveniles are found in estuaries on fine- to medium-grained sandy substrata. Adults are mostly oceanic and are often found in turbid waters adjacent to estuaries. Immature and mature prawns migrate offshore from estuarine waters between November and April each year and stay within approximately 120 km of the estuary from which they emigrated. This species has a fast growth rate, lives for 12 - 18 months, and reaches maturity at variable stages along the coast. In the Hunter River, maturity is reached at 23 - 25 mm CL. It spawns in waters of about 55 m depth off NSW between February and May. It is an opportunistic omnivore and feeds on small crustaceans, polychaetes, bivalves and foraminifers.

Balmain bug *Ibacus peronii*

Bugs occur in eastern Australia in waters up to 150 m in depth on sand, mud and gravel habitats. It has a fast-medium growth rate, short lifespan and reaches maturity at 49.7 - 54.9 mm CL (for females) and 55.2 mm (for males). This species produces broods of about 37 000 – 55 000 eggs that develop on the female before a pelagic stage is entered.

Octopus (several species)

Octopus are found in south-eastern Australia, where they occupy seagrass, coastal reef and continental shelf reefs and sediments to a depth of 500 m. Octopus generally have a fast growth rate, short-medium longevity and reach maturity at 15 cm. They have a low fecundity and lay demersal eggs. These active predators feed on crustaceans, gastropods, bivalves, and soft sediment organisms. There is currently a lack of data on the species comprising this group.

Cuttlefish *Sepia* sp.

Cuttlefish are found in shallow coastal waters to a depth of 35 m. They have a fast growth rate and relatively short lifespan. The age of cuttlefish at maturity and their fecundity levels are unknown, but, like octopus, they lay demersal eggs. The diet includes demersal fish and crustaceans.

Southern calamari *Sepioteuthis australis*

Calamari occur in south-eastern Australia in inshore waters less than 100 m in depth. They have a fast growth rate and short lifespan. They lay demersal eggs and have an unknown fecundity level. Calamari diet includes prawns and fish.

Catch and effort data trends for the Manning bioregion

Across the OT fishery, trawling for eastern king prawns is concentrated mainly off the north coast of NSW, with the majority of trawling occurring north of Newcastle, in depths between 20 - 200 m. Trawling for school prawns in this fishery occurs mainly in shallow waters adjacent to the estuaries. The catch taken from, and effort occurring within, the Manning region cannot be adequately reported, as the reported catch is combined across all three sections of this fishery. A similar situation exists for the FT sector of this fishery, where the proportion of the catch taken from within the 3-nm limit of the Manning region cannot be distinguished from the catch information that is obtained out to 80 nm.

Information on the catch trends of the primary species captured by this fishery is only available at a state-wide level (Table 4.4). Of the primary species described above, the catch trends of school whiting, silver trevally and Balmain bugs appear to be in current decline (Tanner and Liggins, 2000a, b, c; Scandol et al., 2008). Catches of the remaining species currently appear to be stable. Sharks were found to be at high risk and four species of finfish, along with the above-mentioned overfished finfish species, were found to be at moderately high risk from the operation of this fishery before the implementation of its management strategy (NSW DPI, 2004b). There is a paucity of basic biological and ecological information for most target species in this fishery.

Fisheries management controls

A licence and endorsement is required to fish in this commercial fishery. The number of endorsements issued is limited and strategies have been put in place to reduce the latent fishing capacity in this fishery. These businesses can fish at any location within the boundary of their endorsement.

Other management controls include: restrictions on the type of gear that can be used, and size and capacity of boats; the mandatory use of bycatch reduction devices (BRDs) in prawn trawl nets (see NSW DPI 2007 for a full list of approved BRDs); size limits on a number of fish taken in the fishery; and trip limits that restrict the number of finfish species that can be landed on each fishing trip to 12. As at July 2009, fishers are required to report their landings and effort to I&I NSW at the end of each month on a daily catch return form. Research is currently being done by I&I NSW to assess the status of targeted stocks in this fishery. Stock assessment priorities are based on: 1) size of catch level and value within the fishery, 2) trends in total and fishery catch, 3) biological knowledge, and 4) the extent to which it is targeted by other fisheries. I&I NSW has currently assigned resource assessment priority to (in order): eastern king prawn, school prawn, school whiting, fiddler shark, sand flathead, Balmain bug, royal red prawn, tiger flathead, octopus, cuttlefish, southern calamari and silver trevally. Parts of the OPT component of this fishery are subject to seasonal closures (Table 4.1) for the purposes of protecting and conserving areas of key habitat, to manage the volume of fishing effort in an area, and to minimise by-catch and the impacts of the fishery (NSW DPI, 2004b). Areas of closure are reviewed and updated annually.

The OT fishery EIS (NSW DPI, 2004b) contains a detailed description of the fishery's operation, management controls, catch and harvested species, an environmental assessment of its activities, a proposed management strategy for the fishery, and an assessment of its adequacy. NSW Commercial Fisheries Statistics (Pease and Grinberg, 1995; Tanner and Liggins, 2000a, b, c; Scandol et al., 2008) summarise catch, value and effort information on mandatory catch return forms submitted by commercial fishers across certain time periods. Commercial catch data are held on a database within I&I NSW.

Table 4.1 Areas and seasons of closures for the OT fishery within the Manning region (Adapted from NSW DPI, 2004a).

Location	Location of closure	Method	Time
Crowdy Head	The ocean waters within the boundary, between 32°02.650′ S and 152°42.150′ E, and north to 32°01.570′ S and 152°42.420′ E	Otter trawl (prawns)	All year
Port Stephens	The whole of the waters within the area bounded by Shark Island (Pt Stephens), Sugarloaf Point (Seal Rocks), Yagon Gibber, along the 10 fathom depth contour (inside Broughton Island, Inner Island and Dry Rock, etc), Yacaaba Head and the northern extremity of Tomaree Point	Otter trawl (prawns)	All year
Newcastle	All waters enclosed latitude 32°55.000′ S, then generally in a south-easterly direction to a point latitude 32°57.300′ S, longitude 151°52.000′ E	Otter trawl (prawns)	All year
Bouddi	The whole of the waters of that part of the South Pacific Ocean adjacent to Bouddi National Park, enclosed within the following boundaries: the eastern headland of Bullimah Beach, then along a line drawn generally north-easterly along the highwater mark on the foreshore of Bouddi National Park, to Bombi Point.	All fishing	All year, 5 years

One of the major problems with obtaining data from this fishery is that catch information from the Manning region is reported as a combination of all three sectors (inshore, offshore, deep water), and thus information from within the 3-nm limit is unavailable. Further, catch is reported according to the 1°-latitude zones, and statistics over smaller spatial scales are not available. Stock assessment information is at a very basic level for most species taken in this fishery, and stock status is unknown for many target species.

Other major issues within this fishery include problems with the reporting of catch and effort by fishers, problems with the inappropriate selectivity of gear, bycatch estimates and the discarding of commercial species. Bycatch remains one of the most critical issues in the OT fishery, with large quantities of juvenile commercial and non-commercial species discarded throughout NSW. A full list of species captured by a fishery-independent assessment is provided in NSW DPI (2004b). Further research is needed to determine the consequences of bycatch on fish stocks. In addition to the impacts listed above, the use of demersal otter trawl gear may cause substantial damage to benthic environments (Hutchings, 1990) through removing fauna and disturbing habitat.

Primary data sources

The OT fishery EIS (NSW DPI, 2004b) is available from <www.dpi.nsw.gov.au>, and NSW Commercial Fisheries Statistics are available from the I&I NSW Fisheries Library at the Cronulla Fisheries Centre.

4.1.2 Ocean Trap and Line fishery

Summary of the fishery

The Ocean Trap and Line fishery (OTL) operates in both inshore and offshore waters along the length of the Manning coast out to 80 nm. There are six endorsement types in this fishery, and three of these occur within the Manning region (Table 4.2). For most species, fishing occurs throughout the year, but the harvest of spanner crabs is seasonal, and only occurs north of Korogoro Point (near Hat Head) between November and January (NSW DPI, 2006). The OTL fishery uses a number of different gear types, including traps, dillies, and both active (handlining, trolling, jigging, poling) and passive line-fishing techniques (setlines, trotlines, driftlines and droplines). The OTL fishery produces approximately 2000 t of seafood annually, and is valued at around $10 million at first point of sale per year.

The primary species taken in this fishery are Australian bonito, bar cod, gummy sharks, leatherjackets, rubberlip morwong, silver trevally, snapper, spanner crab, yellowfin bream, and yellowtail kingfish. Blue-eye trevalla is also a primary species within this fishery, but it is captured off the continental shelf that lies outside the 3-nm boundary of the Manning Shelf (NSW DPI, 2006). Some of the important target species in this fishery display sex-change at various stages of the lifecycle. For example, yellowfin bream are protandrous, and change from male to female during growth.

As at July 2006, a total of 478 fishing businesses held an endorsement to operate in the OTL fishery across NSW. Not all endorsed businesses operate in this fishery each year, and thus, there is a considerable latent (i.e. unused) effort in the fishery (estimated at 40 - 50%; NSW DPI, 2006).

Table 4.2 The three endorsement types in the OTL fishery that allow a fisher to operate within the Manning shelf bioregion, and the number of entitlements as at July 2005 (adapted from NSW DPI, 2006).

Endorsement type	Endorsement description	Number of entitlements
Spanner crab (southern zone)	Authorises the use of a spanner crab net (dillie net) to take spanner crab for sale from ocean waters that are south of a line drawn east from the southern breakwall at Yamba. (These fishers generally work north of Hat Head.)	9
Line fishing (western zone)	Authorises the use of line methods to take fish from ocean waters that are west of the 100 fathom (183 m) depth contour. This endorsement does not authorise the holder to take school or gummy shark from waters that are south of a line drawn east from the northern point of the entrance to Moruya River. The endorsement does not authorise the taking of deepwater species blue eye trevalla, ling, gemfish, hapuku and bass grouper.	474
Demersal fish trap	Authorises the taking of fish for sale from ocean waters by bottom set fish traps.	277

Biology of major species

Australian bonito *Sarda australis*

Bonito are distributed from southern Queensland to Tasmania and also occur in New Zealand. There is very little information about the biology of this species: however, it probably has a fast growth rate and is relatively short-lived. This species spawns in coastal and offshore waters and its larval development is pelagic.

Gummy shark *Mustelus antarcticus*

Gummy sharks are distributed from Geraldton (WA), around the southern Australian coast, to at least Port Stephens in NSW. They may also occasionally be found in Queensland waters. This species is demersal and is found from the shallow subtidal to depths of approximately 80 m, although it has been recorded in waters up to 350 m deep. It has a medium longevity and slow growth rate. It gives birth to live young and pregnant females carry an average of 14 pups. Length at maturity is 80 cm for males and 85 cm for females. Spawning occurs in coastal waters during spring and summer. Its diet includes crabs, lobsters, tetraodontid fishes and octopus.

Leatherjacket

Leatherjackets comprise a mixed group of species, including chinaman/ocean leatherjacket (*Nelusetta ayraudi*), black reef leatherjacket (*Eubalichthys bucephalus*), rough leatherjacket (*Scobinichthys granulatus*), and velvet leatherjacket (*Parika scaber*). In recent years, landings have been dominated by chinaman/ocean leatherjackets. This species occurs in southern Australian waters from Cape Moreton (Qld) to North West Cape (WA), including Tasmania, and is found in waters from 2 - 200 m. Juveniles occur in seagrass, over sand and rocky reefs, close to shore in bays and estuaries. Research from the Great Australian Bight also suggests that this species schools according to size, with cohorts of larger fish occurring in deeper water. It is probably short-lived, has a fast growth rate, and reaches maturity at 3 - 4 years of age at a length of 31 cm. It spawns in coastal and offshore waters, and lays its eggs on the seafloor. Developing larvae are pelagic. The diet of chinaman/ocean leatherjackets includes fish, invertebrates and salps. The biological characteristics for the other species within this group are unknown.

Rubberlip/grey morwong *Nemadactylus douglasii*

This species occurs in south-eastern Australia from Moreton Bay (Qld) to Wilson's Promontory (Vic). It can also be found along the east coast of Tasmania to Storm Bay and is also present around the north island of New Zealand. The biology and life history characteristics of this species are poorly understood in Australian waters. Rubberlip morwongs are demersal and are commonly caught near reefs at depths of 10 - 100 m. It is long-lived and has a slow growth rate. It spawns in coastal and offshore waters and the eggs and larvae are pelagic. Its diet includes fish, crustaceans and other invertebrates.

Silver trevally *Pseudocaranx dentex*

See description in section 4.1.1

Snapper *Pagrus auratus*

In Australia, snapper occurs in waters from Hinchinbrook Island (Qld) around southern Australia, to Barrow Island (WA). It is common in New Zealand and is occasionally found off the north coast of Tasmania. Juveniles can be found around inlets, bays and other shallow, sheltered marine waters, often over mud and seagrass. Adults can be found near reefs, over mud and sand substrata, and offshore to the edge of the continental shelf, across a depth range of 1 - 200 m. It is long-lived and its growth rate is rapid for juveniles and slower for adults. It spawns repeatedly during winter to spring in coastal waters, and development is pelagic. Maturity is reached at 22 - 33 cm or 2 - 5 years of age. Its diet includes crustaceans, bivalve molluscs and small fish.

Spanner crab *Ranina ranina*

On the east coast of Australia, spanner crabs occur from Yeppoon (Qld) to Nowra (NSW). This is likely to be a single reproductive stock. This species is found on sandy substrata in coastal waters up to 70 m depth. It is long-lived when compared to other crustaceans, and has a slow growth rate. It spawns from October to February in coastal waters, and large females are able to produce two batches of eggs each season with each batch averaging around 120 000 eggs. Females mature at 70 - 75 mm CL, which is attained at 2 years of age. Eggs are attached to the female until hatching, and larvae develop in the plankton. Spanner crabs are opportunistic feeders, and the diet may include urchins, bivalve molluscs, crustaceans, polychaete worms and fish.

Yellowfin bream *Acanthopagrus australis*

Yellowfin bream are endemic to Australia, and occur from Townsville (Qld) to Gippsland Lakes (Vic). In NSW waters, they are found primarily within estuaries and along nearshore beaches and rocky reefs. Spawning typically occurs during winter-summer, in surf zones near estuary entrances. Eggs and larvae are pelagic, but the larvae enter estuaries and settle out of the plankton at about 1.3 cm long. Small juveniles live in sheltered shallow water habitats while larger juveniles occur in slightly deeper waters, and are particularly common around rocky reefs. It is a long-lived, slow growing species. Maturity is reached at 22 cm and the species undertakes extensive pre-spawning migrations. Its diet includes small fish, molluscs, crustaceans and worms.

Yellowtail kingfish *Seriola lalandi*

In Australian waters, this species occurs from southern Queensland to central Western Australia, including the east coast of Tasmania, and around Lord Howe and Norfolk islands. Kingfish spawn during spring-summer probably in deep, offshore waters. Eggs and larvae develop in the plankton, and larval kingfish hatch within 2 - 3 days. Schools of juvenile kingfish can be found in offshore waters around the continental shelf, while solitary or small groups of adults can be found near rocky shores, reefs and islands. Tagging programs have shown widespread movements of kingfish from NSW to New Zealand (and *vice versa*) and many large-scale movements (> 500 km) have been recorded along the NSW coast. It is a long-lived species and juveniles have a rapid growth rate. This species is an opportunistic feeder and its diet largely includes fish, squid, and crustaceans.

Catch and effort data trends for the Manning bioregion

Due to the catch reporting procedures used in this fishery, the proportion of the OTL catch that was taken from within the 3-nm limit of the HCRCMA area cannot be distinguished from the catch information that is obtained out to 80 nm. The catch and effort trends of the primary species harvested by this fishery have not been calculated regionally. Catch trends of primary species for all fisheries are presented in Table 4.4. Production across all commercial fisheries has declined over the long-term for seven primary species: kingfish, snapper, silver trevally, Australian bonito, rubberlip/grey morwong, yellowfin bream and spanner crab.

Fisheries management controls

A licence and endorsement is required to fish in this commercial fishery. There are a total of six types of endorsements (three within the Manning region) and the number of endorsements issued is limited. OTL fishers who have the relevant endorsement types which allow fishing within the 3-nm boundary of the Manning region can use all permitted line-fishing techniques and fish traps to target fish and dillies to target spanner crabs (Table 4.2). Apart from spanner crab endorsement holders, these fishers can operate along the entire length of the NSW coast. Apart from the 183 m depth limit on fishers that hold a line-fishing (western zone) endorsement, these fishers can also operate out to 80 nm (NSW DPI, 2006). Other management controls include the restriction on the type of fishing gear and its use (e.g. the number of lines and hooks that can be used on some gear types within 3 nm is limited), restrictions of the size and capacity of fishing boats, size limits on 13 finfish species that can be taken in the fishery, and trip limits that restrict the number of finfish species that can be landed on each fishing trip to eight. Fishers are required to report their landings and effort at the end of each month on a monthly catch return form. Research is being undertaken to assess the status of targeted stocks in this fishery, particularly spanner crabs. The specific management arrangements for this fishery are outlined in the management strategy for this fishery (NSW DPI, 2006).

Research needed for the effective management of this fishery is categorised into five priority areas: 1) resource assessment of primary and key secondary target species, 2) quantification and reduction of by-catch, 3) economic research, 4) ecosystem impacts of trap and line fishing, and 5) impacts of fishing on threatened species.

The OTL fishery EIS (NSW DPI, 2006) contains a detailed description of the fishery's operation, management controls, 30-year catch trends and harvested species, an environmental assessment of its activities, a proposed management strategy for the fishery, and an assessment of its adequacy. NSW Commercial Fisheries Statistics (Tanner and Liggins, 2000a, b, c) summarise catch, value and effort information on mandatory catch return forms submitted by commercial fishers across certain time periods. The status of all species caught in this fishery was most recently reported in Scandol et al. (2008). Commercial catch data are kept by I&I NSW on a database. Stock assessment information is at a very basic level for most species taken in this fishery, and stock status is unknown for some target species. Kingfish, snapper and silver trevally are growth overfished, while wobbegong sharks, gummy sharks, mixed sharks, bar cod and black-spot pigfish were found to be at high risk (NSW DPI, 2006). Nine finfish species were found to be at moderately-high risk from the operation of this fishery before the implementation of its management strategy. There is a paucity of basic biological and ecological information for most target species in this fishery.

Other issues within this fishery include problems with the reporting of catch and the possible interactions with threatened species, particularly with grey nurse shark and black cod. There have been no fishery-wide estimates of either the composition or rates of discarding of bycatch. However, Stewart and Ferrell (2001) collected discard information from 34 trap fishers across NSW and found that a large number of small or undersized fish were discarded.

Primary data sources

The EIS for the OTL Fishery (NSW DPI, 2004b) is available from <www.industry.nsw.gov.au>; NSW Commercial Fisheries Statistics are available from the I&I NSW Fisheries Library at the Cronulla Fisheries Centre.

4.1.3 Ocean Hauling fishery

Summary of the fishery

The Ocean Hauling (OH) fishery operates throughout the year on beaches and inshore waters along the length of the Manning region, out to 3 nm. Some ocean beaches and inshore waters within this area are closed to the operation of this fishery (Table 4.3). On average 3 500 t of fish are taken each year by this fishery, at a mean value of around $6 million at first point of sale (McIlgorm, 2004). This fishery uses purse-seine nets, three types of hauling nets, and lift nets. Off-road vehicles are used to access beach sites. The OH fishery targets approximately 20 finfish species, of which sea mullet, Australian salmon, yellowfin bream, sea garfish, luderick, sand whiting, pilchards, yellowtail, blue mackerel, sweep, sprat, jack mackerel, dart, silver trevally, anchovy, and bonito are the principal species (NSW Fisheries, 2002a).

Table 4.3 The following table is one Section 8 closure under the Regulation covering beach closures in the OH fishery, first implemented 21 February 1997.

Region 4	Closed beaches	Period of closure
That part of NSW lying generally between the parallel 31° 44′ south latitude and the parallel 33°25′ south latitude	Main Beach (Forster) Pebbly Beach Boomerang Beach (Pacific Palms) Blueys Beach Koolgardie Beach All beaches bounded by Nobby's Head and the southern extremity of Dudley Beach Gravelly Beach Moonee Beach	From 1 March 2002 to 28 February 2005

There are three classes of endorsement in the OH fishery; those with Class A (skipper) and Class B (crew) endorsements are restricted to operating within designated ocean hauling zones, while Class D (purse seine) endorsement holders can use purse-nets along the length of the NSW coast within 3 nm. Class A endorsements are further divided into four categories: General Purpose; Garfish Hauling; Garfish (Bullringing) Hauling; and a Pilchard, Anchovy and Bait net authority. Within the Manning region, 63 Class A and 70 Class B endorsements were held in May 2001.

Biology of major species

Sea mullet *Mugil cephalus*

Sea mullet have a wide distribution, and occur around much of the Australian coastline and in many temperate and subtropical areas worldwide. In NSW waters, mullet are found primarily within estuaries and inshore waters. Spawning occurs in surface waters at sea, typically during autumn to early winter. The larvae enter estuaries and the small juveniles subsequently live in sheltered shallow-water habitats. Between late summer and early winter, adult sea mullet (2 or more years old) leave estuaries in large schools and then travel northward along the open coastline to spawning grounds. Short migrations by so-called 'hard-gut' (sub-adult) individuals also occur periodically, possibly in response to heavy flooding and consequent loss of food resources. This species is targeted by this fishery on its annual pre-spawning run. It is a fast growing species, and its diet includes microscopic plants, macroalgae and detritus.

Australian salmon *Arripis trutta*

Australian salmon occur in continental shelf waters and in estuaries of NSW, Victoria and Tasmania. Juveniles inhabit sheltered coastal waters and estuaries. The species aggregates to spawn on the south coast of NSW between Lakes Entrance and Bermagui, from November to February. Spawning of this species occurs in the surf zone, and fish disperse north and south after spawning. Some fish also appear to aggregate on the far south coast of NSW during winter. Maturity is reached at 4 years (39 cm). It is a predator that feeds on fish, including sea garfish and pilchards.

Yellowfin bream *Acanthopagrus australis*

See section 4.1.2

Eastern sea garfish *Hyporhamphus australis*

Garfish occur in the ocean waters of Queensland, NSW and Victoria, and also Lord Howe and Norfolk islands. It is also found in the lower reaches of estuaries. The life history is poorly understood, but juveniles are known to occur in estuaries and spawning most likely occurs in coastal waters.

Luderick *Girella tricuspidata*

This species is widely distributed from Noosa in Queensland to Tasmania and South Australia and is also found in New Zealand. In NSW waters, luderick are found primarily within estuaries and around nearshore rocky reefs. Spawning typically occurs during winter in surf zones near estuary entrances and, prior to spawning, this species undertakes a northerly migration along the NSW coast. The larvae enter estuaries and the small juveniles subsequently live in sheltered shallow-water habitats. Larger juveniles occur in slightly deeper waters, and are particularly common around estuarine reefs; adults usually return to estuarine waters after spawning. This species grows relatively slowly and reaches maturity at around 25 cm. Its diet primarily consists of green macroalgae, although it also includes other foods such as small invertebrates.

Sand whiting *Sillago ciliata*

Sand whiting occur along the entire eastern coastline of Australia, from Cape York (Qld) down to eastern Tasmania, and in New Caledonia and Papua New Guinea. In NSW waters, whiting are found within estuaries and in coastal waters off ocean beaches. Spawning typically occurs near river mouths during summer months. Most larvae enter estuaries, with the small juveniles preferring shallow water. Following spawning, adults may enter estuarine waters or remain along ocean beaches. This species grows relatively slowly and matures at 24 - 26 cm. Its diet includes polychaete worms, crustaceans and molluscs.

Yellowtail scad *Trachurus novaezelandiae*

This species occurs in all Australian states except the Northern Territory. Yellowtail inhabits coastal waters and the lower reaches of estuaries. Adults are associated with rocky reefs, while juveniles occur over shallow, soft substrata. Spawning occurs in summer and autumn in NSW waters, and maturity is reached at 3 years (20 - 22 cm). It is relatively long-lived.

Blue mackerel *Scomber australasicus*

Blue mackerel are widely distributed across all Australian states except the Northern Territory. This species inhabits estuarine and continental shelf waters, with older fish occurring further offshore. Spawning occurs in summer, and it grows relatively quickly. The life history of this species is poorly understood.

Sweep *Scorpis lineolatus*

Sweep are most abundant in NSW waters but they also occur in southern Queensland, Victoria and Tasmania. Adults and juveniles are associated with coastal and estuarine reefs. The biology of this species is poorly understood. Spawning times and locations, age and size at maturity are all unknown. It is relatively long-lived.

Catch and effort data trends for Manning bioregion

The OH fishery is currently fished at maximum capacity. The total catch in this fishery has steadily increased from 500 t to greater than 3 300 t per year over the past 15 years. OH fishers target different mixes of species in each of the regions along the NSW coast. Comparing catches between regions can only be done for methods that are restricted to regional boundaries, such as beach-based hauling. The Manning region is the highest contributor of bream and sea mullet (approximately half the catch for the state) as well as eastern sea garfish. Catches of luderick and Australian salmon are the second highest contribution to the state's total for these species. Sandy sprat (whitebait) and pilchards are taken in largest quantities in northern regions. For the remaining species, the Manning region contributes only a small amount to the state's total catch.

The catch and effort trends of the species harvested by this fishery have not been calculated regionally. Catch trends of primary species for all fisheries are presented in Table 4.4. Commercial catches of sea mullet, Australian salmon, yellowfin bream, sea garfish, sand whiting, pilchards and sweep appear to be in decline.

Fisheries management controls

A licence and endorsement is required to fish in this commercial fishery, and the number of endorsements issued is limited. Other management controls include restrictions on the type of gear that can be used, size and capacity of boats, and size limits on a number of fish taken in the fishery. Fishers are required to report their landings and effort at the end of each month on a daily catch return form. Research is being undertaken to assess the status of targeted stocks in this fishery.

The EIS for the OH fishery contains a detailed description of the fishery's operation, management controls, catch trends and harvested species, an environmental assessment of the fishery activities, a proposed management strategy for the fishery, and an assessment of its adequacy NSW DPI, 2004b). NSW Commercial Fisheries Statistics (Tanner and Liggins, 2000a, b, c; Scandol et al., 2008) summarise catch, value and effort information on mandatory catch return forms submitted by commercial fishers across certain time periods. Commercial catch data are kept by I&I NSW on a database. There is a paucity of basic biological and ecological information for most target species in this fishery (NSW Fisheries, 2002a). Stock assessment information is at a very basic level for most of the species targeted in the fishery, and the stock status is unknown for some target species. Stocks of sea garfish and silver trevally are thought to be overfished. There are problems with reporting of catch, and no estimates of bycatch are available. However, reported landing data and anecdotal evidence suggests that the fishery operation tends to target single species, and that discards are low (NSW Fisheries, 2002a).

Primary data sources

The EIS for the OH Fishery (NSW DPI, 2004b) is available from <www.industry.nsw.gov.au>; NSW Commercial Fisheries Statistics are available from the I&I NSW Fisheries Library at the Cronulla Fisheries Centre.

4.1.4 Lobster fishery

Summary of the fishery

The lobster fishery targets the eastern rock lobster (*Jasus verreauxi*), and operates throughout the year in both inshore and offshore waters along the length of the Manning region out to approximately 80 nm. The fishery is divided into the nearshore and offshore sectors. Most of the harvest in this fishery is taken using baited lobster traps, although some hand picking may occur in shallow, inshore waters. Some offshore traps are only used seasonally. While eastern rock lobsters are the main target species, other lobsters, such as the southern rock lobster (*Jasus edwardsii*), tropical rock lobster (*Panulirus longipes*) and painted rock lobster (*Panulirus ornatus*) are also caught occasionally. The NSW lobster fishery is a small but valuable fishery worth approximately $6.7 million in 2007/08 (TAC Committee, 2010).

To take lobsters commercially, fishers must be endorsed in this fishery; 141 shareholders were endorsed in August 2006. Of these, 11 lobster shareholders were located in the Manning region, 11 in Wallis, 25 at Port Stephens, five in Hunter and 11 on the Central Coast. These fishers can relocate their operations within the area of the fishery along the whole NSW coast, without restriction. Port Stephens is one of four major regions for the lobster fishery along the NSW coast.

Biology of eastern rock lobster

The eastern rock lobster inhabits waters off the east coast of Australia from Tweed Heads southwards around Tasmania and west to the Victoria/South Australia border. The highest abundance of this species is in NSW, the only state in which it is fished commercially. The species lives for over 10 years, attains a maximum length of 100 cm and can weigh in excess of 8 kg. It takes 3 - 5 years from hatching to reach the minimum legal harvest size, and an additional 4 - 5 years for females to reach the average size at maturity of 16.7 cm CL. Spawning occurs in waters north of Port Stephens from September to January (spring through to summer) in depths of less than 50 m. Eggs are carried by females and released in early to mid summer.

The distribution of rock lobsters across habitats and along the coast is related to size and age. There are several planktonic stages during the lifecycle of this species. After hatching, phyllosoma larvae spend approximately one year in oceanic waters off the coast before moulting into a puerulus larvae. Pueruli swim across the continental shelf and settle in rocky-reef habitats along the NSW coast. After moulting through several puerulus stages, juvenile lobsters spend several years on these shallow rocky reefs. It is believed that lobsters then aggregate and move *en masse* offshore (at a size of about 12 cm CL) and migrate from the south to the north coast of NSW. Adult rock lobsters generally live in aggregations in depths greater than 10 m and may extend across the continental slope. Large (and sexually mature) lobsters are found at their greatest abundance on the north coast of NSW.

Catch and effort data trends for Manning bioregion

Since 1994, the lobster fishery has only been permitted to take a certain amount of catch of eastern rock lobster each year (Total Allowable Catch – TAC). There have been concerns regarding the decreased abundance of the spawning stock of eastern rock lobsters off NSW since 2000/01. In response to this, the TAC was reduced from 135 t in 2003/04 to 102 t in 2004/05. Recent signs of recovery in the spawning stock have led to the TAC being raised to 131 t for 2010/11 (TAC Committee, 2010). The lobster fishery is one of the few fisheries in NSW where the catch and effort information is collected and assessed on a spatial basis (Pease and Grinberg, 1995; Tanner and Liggins, 2000a, b, c; TAC Committee, 2010). The catch and effort trends for broad latitudinal zones off the NSW coast are illustrated in Figure 4.2. In the northern section of the region, and in less than 10 m of water, lobster catch and effort declined from 1997 to 2003. Catch appears stable in other depths in this latitudinal zone. One of the factors affecting the recent decrease in spawning stock involves increased targeting of the spawning stock during the past 3 - 4 years. It appears that 3 - 4 relatively poor years of puerulus supply to the north coast (1996/97 – 1999/00 on the far north coast and 1996/97 – 1998/99 on the mid north coast, see Liggins 2004) subsequently resulted in 3 - 4 years of relatively poor abundance of small legal-sized lobsters (10.4 cm CL +) in depths <10 m during the period 2000/01 to 2002/03 (Figure 4.2). During the same period, catches and catch rates of medium-sized (13 - 16 cm CL) migrating lobsters on the mid- and outer-continental shelf of the north coast were also poor relative to the previous few years (Figure 4.2). As a consequence of the relatively poor abundances of small lobsters in depths <10m, and medium-sized lobsters on the mid- and outer-shelf (100 - 200 m), fishers had no alternative but to increasingly target the grounds (typically 10 - 30 m depth) on which larger lobsters (including spawning stocks) are present. Decreased catches and catch rates have been taken by fishers on these grounds (10 - 30 m depth) since 2000/01 (Figure 4.2) and changes in the size-distribution of catches from these grounds observed during this same period are consistent with a 'fish-down' of the stock that was present on these grounds in 1999/00. Catch rates and size-distributions obtained from the fishery-independent survey of spawning stock during this period are consistent with this explanation.

The 3 - 4 years of relatively poor abundance of pueruli on the north coast between 1996/97 and 1999/00 were followed by 4 - 5 years of increased abundances (since 1999/00 on the mid-north coast and 2000/01 on the far north coast, Liggins, 2004). As would be predicted on the basis of puerulus abundances, catches and catch rates of small lobsters improved dramatically in 2002/03 on the mid-north coast (Figure 4.2) and in 2004/05 on the far north coast (TAC Committee, 2010).

Analysis of total catch, effort and catch rates since 1969/70 show a strongly increasing trend for 7 years, peaking in 2007/08 (TAC Committee, 2010). In 2008/09 the catch rate was somewhat reduced and it is likely that the complete 2009/10 catch rate will also be lower than the 2007/08 peak. The reduced catch rate in the last 2 years is widespread across depths and is stronger in the southern regions (i.e. south of 33 degrees latitude). This pattern is expected from the relatively weak puerulus settlement 3 - 5 years ago and the predicted reduction of the exploitable biomass through the current and next few years.

Overall, the catch and catch rate data support interpretations that the stock is broadly stable with inshore catches fluctuating in response to patterns of puerulus settlement and deeper catch rates showing continued recruitment of immature lobsters into the spawning stock.

A substantial decrease in the catch rate of all sized lobsters occurred across both the far-north and mid-north coasts between 200/01 and 2003/04, and this was followed by reductions in the TAC and a decrease in the maximum legal size from 20 cm to 18 cm. On the far-north coast, catch rates of most size classes in the past 5 years remain low, although they are slowly increasing from this low base and the 2008/09 catch rates were about half of the pre-2001 levels. However, on the mid-north coast, there has been a significant recovery of the catch rates and size composition in the past 3 years, and especially the last 2 years. This includes a significant accumulation of lobsters larger than the maximum size limit in the population. The catch rates of mature female lobsters from standardised, fishery-independent trap surveys in the mid- and far-north coasts indicate that the number of mature females in the population has steadily increased from a low point in about 2001/02; in 2008/09 this catch rate was back to earlier (1998-1999) levels (TAC Committee, 2010).

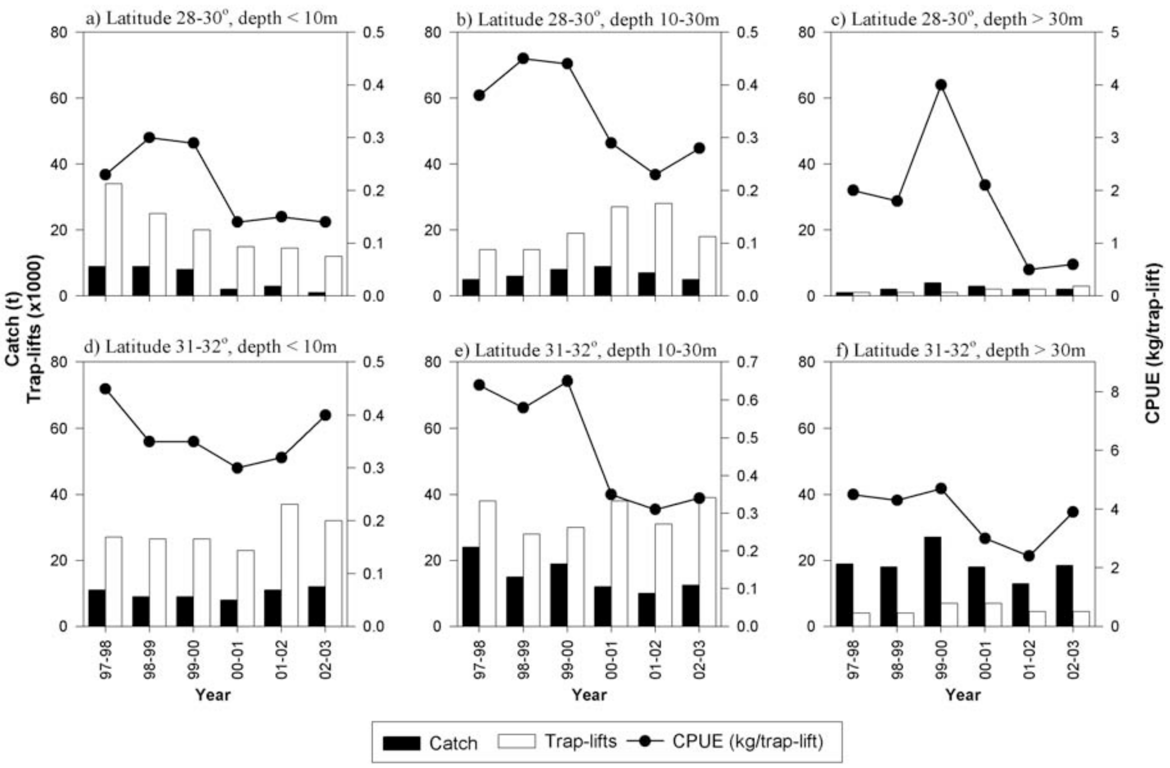


Figure 4.2 Spatial and temporal (1997/98 to 2002/03) patterns in catch (t), effort (trap-lifts) and catch per unit effort (CPUE) (kg/trap-lift) for the commercial catch of lobsters in NSW (Source: Liggins, 2004).

Fisheries management controls

Since 1994, this fishery is only permitted to harvest a set amount of eastern rock lobster (TAC) each year. An independent committee reviews and sets this TAC annually. This amount is set at 131 t for 2010/11 (TAC Committee, 2010). This fishery can only harvest eastern rock lobsters with a CL of 10.4 - 18 cm. Other controls include restrictions on the type and operation of gear, size and capacity of boats, and tagging of commercially harvested lobsters. Fishers are required to complete a daily log sheet and monthly summary form. An annual assessment of the eastern rock lobster resource in NSW is conducted in order to set the TAC. There is a management strategy for this fishery.

The EIS for the lobster fishery (NSW DPI, 2004a) contains a detailed description of the fishery's operation, management controls, catch and effort trends, details of harvested species, an environmental assessment of the fishery's activities, a proposed management strategy for the fishery, and an assessment of the adequacy of this strategy. NSW Commercial Fisheries Statistics summarise the catch, value and effort information on mandatory catch return forms submitted to I&I NSW by commercial fishers across certain time periods. Commercial catch data are kept on a database.

Bycatch remains an issue in this fishery and a large number of non-target species are trapped. This is a result of the non-selectivity of the traps that are used to harvest lobsters. Many non-target species are only caught in small numbers and are sold as a by-product of the fishery, and are not discarded. This fishery is known to have a negative effect on several other demersal species such as hermit crabs, wobbegong sharks and rubberlip morwong (NSW DPI, 2004a).

Primary data sources

The EIS for the lobster fishery is available from <www.industry.nsw.gov.au>; NSW Commercial Fisheries Statistics are available from the I&I NSW Fisheries Library at the Cronulla Fisheries Centre; the annual assessments of the NSW eastern rock lobster fishery are available from <www.industry.nsw.gov.au> (Montgomery and Chen, 1996; Montgomery et al., 1997; Montgomery et al., 1998; Liggins et al., 1999, 2000, 2001, 2002, 2003; Liggins, 2004).

4.1.5 Sea urchin and turban shell fishery

Summary of the fishery

Harvesting of sea urchins and turban shells occurs along the NSW coast on rocky shores and reefs in depths shallower than 30 m. The target species in this fishery are the purple sea urchin the red sea urchin and Turban shells. This fishery operates throughout the year with fishers gathering catch by hand. Some fishers may use a large hook to remove sea urchins from holes in reefs.

Biology of major species

Purple sea urchin *Centrostephanus rodgersii*

This species is found on nearshore reefs to a depth of about 30 m from northern NSW to Victoria and Tasmania. It is most abundant on reefs from Jervis Bay to Montague Island. In cooler waters (south of Sydney), this urchin spawns from June to May, and maturity is reached within 3 years (> 6 cm).

Red sea urchin *Heliocidaris tuberculata*

The red sea urchin is mainly confined to depths of less than 6 m and is less abundant than the purple sea urchin, although dense aggregations occur between Montague Island (near Narooma, NSW) and Broughton Island (near Port Stephens, NSW). This species spawns from February to October.

Turban shells *Turbo torquatus*

This species occurs from NSW to Western Australia, including Tasmania. Turban shells are found in intertidal and shallow subtidal areas to depths of about 20 m.

Catch and effort data trends for the HCRCMA region

The Manning region falls across two regions of this fishery – southern half of Region 1 (Tweed Heads-Newcastle) and northern half of Region 2 (Newcastle to Currarong). The majority of the catch is taken in southern regions (Regions 3 - 5). Apart from the red sea urchin, the species targeted by this fishery are currently under-exploited. Purple urchin harvest peaked at 68 000 kg in 2001 and has fluctuated around 60 000 kg in subsequent years. The largest harvests occurred in regions 3, 4 and 5. Red sea urchin harvest peaked in 2000, but subsequent catches have declined sharply to <12 000 kg from 2002-04. Red urchins may be fully fished in regions 3 and 4, but are relatively under-fished in regions 1 and 2. Turban shell harvest was 6 500 kg in 2001, most of which was taken from region 3. There has been a steady increase in turban shell catches in region 2 since 2000. The dramatic increase in catch to 17 000 kg in 2004 was primarily due to a single diver.

Fisheries management controls

Fishers require a licence and endorsement to operate in this fishery. There were 37 entitlement holders in this fishery in 2005, 11 of which were active (endorsed). The fishery is separated into five regions, and fishers' activities are not restricted to specific regions. Other management strategies used in this fishery include: closures, a TAC on red sea urchins (endorsement holders in region 1 can currently take 216 kg of this species each per annum), a minimum legal commercial harvest length of turban shells (75 mm), mandatory daily catch reporting, and reporting on stock status.

Data description and assessment

A Review of Environmental Factors (REF) for the sea urchin and turban shell fishery (NSW DPI, 2005) has been completed and is available from the Cronulla Fisheries Centre library. This review outlines the operation of this fishery, its catch trends, issues and management arrangements and incorporates an environmental assessment of this activity. Overfishing is a potential threat, particularly to the red sea urchin. There are current problems with catch reporting.

4.1.6 Abalone fishery

Summary of the fishery

This fishery harvests the blacklip abalone (*Haliotis rubra*) by hand-gathering from rocky reefs along the NSW coast, in depths shallower than 40 m. The fishery operates throughout the year. Blacklip abalone is most abundant on the far south coast of NSW, while in areas further north it becomes progressively less abundant and more patchily distributed. Few harvestable abalone are found north of Coffs Harbour (The Ecology Lab, 2005). Historically, harvesting in this fishery extended from the mid-north coast of NSW to the Victorian border but, on occasion, occurred further north (e.g. Coffs Harbour). Since the area between Port Stephens and Wreck Bay (i.e. within the Manning region) was closed to this fishery in 2002 as a result of an outbreak of the *Perkinsus* parasite, the commercial fishery in NSW effectively now operates only between Wreck Bay and the Victorian border. This is demonstrated by the catch history of Region 1 (from Tweed Heads to Wreck Bay). Abalone harvests from this region were equivalent to those reported in the other five reporting regions of this fishery prior to 1995, but since then had declined to < 5 t in 2003 (The Ecology Lab, 2005).

Primary data sources

The EIS for the Abalone Fishery (The Ecology Lab, 2005) is available from <www.industry.nsw.gov.au>. This EIS contains: a detailed description of the fishery's operation, management controls, catch and harvested species; an environmental assessment of the fishery's activities; a proposed management strategy for the fishery; and an assessment of the adequacy of this strategy.

4.1.7 NSW commercial fishing catch and effort reporting

I&I NSW has introduced revised catch and effort reporting arrangements for the NSW commercial fishing industry commencing from July, 2009. The revised reporting arrangements have been developed to address requirements for finer scale (spatial and temporal) information and are expected to provide an improved information base to support fishery management and planning processes, to enable more robust stock assessments to be completed, and to contribute to the maintenance of export approvals provided by the Australian government under the *Environmental Protection and Biodiversity Conservation Act 1999* (*EPBC Act*). For full details of the reporting requirements refer to <www.dpi.nsw.gov.au/fisheries/commercial/info/catch-effort>.

The reporting period remains monthly with la requirement to submit log sheets within 28 days of the end of each calendar month. The log sheet is designed to capture fishing activity at an 'event-based' scale. For reporting purposes, a fishing event is defined as any unique combination of date fished, location fished, fishing endorsement activated, and fishing method used. When fishing in multiple adjoining fishing locations, fishers are required to report the 'location where most fish were caught' rather than each location fished separately. In the trawl fishery where multiple shots are made in multiple adjoining fishing locations, fishers are required to report the 'start location of the shot that landed the most fish'.

A grid based spatial scale has been developed for use in the ocean based fisheries (replacing the previous "ocean zone" based system). The new scale comprises "Grid Codes" at a 1 degree scale where each grid code is further sub-divided into 100 "Site Codes" at a 6 minute scale.

Table 4.4 A summary of the catch trends of the primary species harvested for 6 commercial fisheries in NSW. OPT – ocean prawn trawl, FT – fish trawl, EPT – estuary prawn trawl, OH – ocean haul, OTL – ocean trap and line, EG – estuary general. Note that 2 of these fisheries, EPT and EG, are not described above because they are restricted solely to estuaries. They are included in this table for the sake of completeness, given that this an overall summary of fish catches (apart from lobsters, abalone, sea urchins and turban snails).

Species	NSW catch trends
Eastern king prawn	Unstandardised catch rates have remained variable but relatively stable over time in NSW but have increased in Queensland. From 2003/04 onwards there has been a significant reduction in NSW catch due to reduced fishing effort (fuel-price effect) and cyclical trends in abundance of prawns. Catches in the EPT fishery in the Hunter showed a peak in 1999/2000 and declined rapidly over the next 2 years. 2008/09 landings in the Hunter EPT was less than 0.4 t. Catches in the EG fishery in the Manning area peaked at 30 t in 1992/93 then decreased to between 9 and 15 t. 2008/09 landings in the EG fishery in the Manning region was about 25 t. Ocean prawn trawling lands over 90% of the entire catch in NSW. Ocean prawn trawl landings for NSW peaked at 1200 t in 2000/01 and has since declined. 2008/09 landings in the OPT were approximately 250 t.
School prawn	Catch rates in estuaries are variable but stable (no clear trends are evident). Abundance is not high enough for ocean fishery to be commercially viable in years of low river discharge, but there are peaks in ocean production in flood years. Catches in the EPT fishery in the Hunter showed a peak in 2000/2001 and declined rapidly over the few years to a low of about 22 t in 2006/07. 2008/09 landings in the Hunter EPT have increased to approximately 88 t. Catches in the EG fishery in the Manning area peaked at about 200 t in 2000/01 then decreased and fluctuated between 130 and 80 t. 2008/09 landings in the EG fishery in the Manning region was about 235 t. EPT lands over 50% of the entire NSW catch. OPT catch has been steady since 2003/02 at around 50 to 100 t. 2008/09 landings in the OPT were approximately 160 t.
Grey morwong	Over 80% of NSW catch taken by OTL, the remainder by FT. From a high of 143 t in 1997/98 there has been a steady decline in catches by OTL to about 38 t in 2002/03 and has remained steady since. Long term decline in the average size of landed fish indicates the stock has been depleted.
Silver trevally	There has been a significant decline in commercial landings of silver trevally since the mid 1980s, from about 1000 t per annum to less than 200 t per annum in since 2007/08 for all fisheries. Catches in OFT peaked in 2003/04 at 292 t and have declined to 65 t in 2008/09. OFT takes over 50% of the entire NSW catch. Catches of from estuarine waters have declined significantly following the declaration of a Recreational Fishing Haven in Botany Bay in 2002 to around 11 t in 2008/09.
Cuttlefish	Reported landings of cuttlefish in NSW were 150 – 250 t (t) in the mid 1980s and peaked at 450 t in 1994/95 and annual landings have since been between 200 and 300 t OPT takes around 80% of the catch. 2008/09 landings in the OPT were about 33 t. Because of the mixed-species nature of the catches, there have been no stock assessments for any cuttlefish species in NSW.

Species	NSW catch trends
Octopus	Commercial landings of octopus in NSW occur throughout the year but vary seasonally. Catches are greatest between January and May, with a peak in March. OPT takes over 90% of the entire NSW catch. Catches in this fishery peaked have been in decline since 2003/04 from 500 t to around 80 t in 2008/09. Catches in the EPT fishery in the Hunter have shown large fluctuations throughout its history between 0.02 and 0.12 t. 2008/09 landings in the Hunter EPT were about 0.03 t. It is estimated that about 70-80% of the NSW octopus landings comprise southern octopus, mainly from northern NSW, with gloomy octopus another 10-20% of the commercial catch.
Shovelnose rays	The commercial catch is taken almost totally by the Ocean Trawl Fishery with FT taking between 60 and 75% of the entire NSW catch. Catches in FT peaked in 2006/07 at about 102 t and has since declined to 72 t in 2008/09. The commercial landings have been relatively stable at around 120-150 t since the mid 1990s when 'fiddler/banjo shark' and 'shovelnose/sand shark' were first given separate species categories on commercial catch recording forms. The majority of the catch is eastern shovelnose ray (*Aptychotrema rostrata*) mainly from ocean prawn trawling and ocean fish trawling; smaller landings of fiddler rays (*Trygonorrhina* sp.) although this species is often discarded; there are also minor landings of the large white-spotted guitarfish (*Rhynchobatus australiae*) from northern NSW.
Southern calamari	Catches have declined since 1997/98 from about 147 t to 31 t in 2008/09. FT take over 80% of the entire NSW catch with 28 t landed in 2008/09. EG catches for the entire NSW coast in peaked in 2000/01 at 6 t and declined since to around 0.4 t in 2008/09.
Bluespotted flathead	Landings stable at around 120-160 t during the past decade. Sharp decline in catches in 1989/90 due to a change in the reporting requirements (only catches after this time should be considered for NSW). FT take 50-60% of the total NSW catch. FT catches in the Manning region have ranged been between 50 and 70 t over the past 10 years with about 59 t caught in 2008/09.
Bugs	85% of catch (about 200 t annually) harvested from northern NSW and southern Queensland waters; OPT take over 90% of the entire NSW catch. Catches peaked in OPT in 2003/04 at 78 t has since declined to 36 t in 2008/09 but length composition and catch rates are stable. The two large species of bugs (*I. chacei* and *I. peronii*) are not differentiated in catch returns but sampling will be used to assess the catch composition.
Eastern school whiting	Annual landings by OPT increased to about 600 t by mid 1980s before declining to around 400 t in the early 1990s due to a softening of the export demand. With increased domestic and export demand, landings again increased significantly to exceed 800 t per year by the late 1990s. Catches since 2004/05 have been steady in both FT and OPT of about 400-600 t. Catches by the OT in the Manning region peaked at 400 t in 2005/06 and have declined to about 250 t in 2008/09.
Tiger flathead	Ocean trawling catch rates have been relatively stable in recent years. FT takes over 90% of ocean trawl catch, peaking in 2005/06 at 270 t. Catches by FT in 2008/09 were 207 t. Landings relatively stable in last 5 years. Large decline in NSW reported catches in the mid 1990s due to changes in reporting catch taken in Commonwealth waters.
Snapper	95% of snapper harvested taken by the Ocean Trap and Line Fishery. Since the mid-1980s catches have decreased from around 750 t and has stayed at around 200 t from 2001/02 to 2005/06. Catches peaked at about 300 t in 2007/08 and have declined to 240 t in 2008/09. The main harvest season for snapper in the commercial sector is winter-spring. Increasing the minimum legal length appears to have improved the state of the snapper stock.

Species	NSW catch trends
Yellowtail kingfish	The commercial harvest of kingfish decreased from around 600 t in the mid-late 1980s to around 100 t in the late 1990s. Indications are that the fishing mortality rate remains relatively high. Catch rates increased after banning of trapping in 1996 to a peak in 2001/02 of 265 t. Both catch and catch rate now appear to be stabilizing to around 130 t in 2008/09.
Bonito	Annual commercial landings have generally been between 100 t and 150 t in the OTL fishery which takes over 90% of the catch in NSW. Catches peaked in 1998/99 at 275 t, landings have returned to previous levels with 183 t taken in 2008/09. The peak period for harvesting is from March to June.
Gummy shark	Total across ocean fisheries is approximately 50 t per year. Between 50 and 80% of the NSW catch is taken by the OTL fishery, the remainder by OT fishery. Since 1990/91, catches of gummy sharks have increased to a maximum of 70 t (in 1995/96) decreasing to 23 t in 2003/04. Catch in the OTL fishery in 2008/09 was 46 t. Predominantly a Commonwealth fishery.
Leatherjackets	OTL takes over 80% of the total NSW catch with smaller catches in EG, FT and OPT. From 1984/85 catches ranged between 150-200 t Since 2000/01, catches have increased from 125 to 580 t in 2008/09. Stock abundance appears to have increased significantly since 1999/2000
Spanner crab	Majority of the fishery (~90%) occurs in QLD. Declining trend in catch rates from the mid-1990s (expected as the stock was fished down). Catches in OTL have declined from 300 t in 1997/98 to about 68 t in 2008/09. Both the Queensland and NSW populations have been fished down but catch rates are now relatively stable in both fisheries.
Yellowfin bream	Catches declined during the 1990s, at least partly attributable to phasing out the use of pound (figure six) nets in Port Stephens and adjoining coastal waters and a decline in the amount of fishing effort in estuaries. Over 70% of the NSW catch is take by the EG fishery. Catches in this fishery have been around 300 t with 194 t landed in 2008/09. EG catches in the Manning region peaked in 1993/94 at about 250 t and have declined to a steady catch of about 100 t in 2008/09. Commercial landings have stabilised in recent years, and the age and length compositions of catches have remained relatively stable, indicating no declines in older fish.
Blue-eye trevalla	99% of catch taken by OTL. Decline over last decade in directed fishing effort in the NSW continental slope line fishery has led to reduced landings but with relatively stable catch per unit effort. Catches peaked at about 100 t in 1999/01 and declined to 30 t in 2008/09. There are no concerning trends in the NSW fishery at present, decline in catch along with effort has resulted in a stable CPUE.
Sea mullet	OH and EG take about 50% catch each. Catches in OH have fluctuated between 1200 and 2200 t and EG catches have been relatively steady at around 1600 t. Catches in the Manning region by EG have been steady at approximately 600 t. Recent catch rates in both the estuarine and ocean fisheries in NSW give no cause for concern about the current status of the stock.
Australian salmon	Majority taken by OH fishery. Landings are highly variable and not expected to be a good indicator of abundance. Landings have increased since 2005/06 from 600 to 1500 t in 2008/09.
Eastern sea garfish	Over 90% NSW catch is taken by the OH with remainder taken by EG. OH is distinctly seasonal and varies from between December and May on the south coast of NSW and between March and June with a few winter/spring catches on the north coast of NSW. Catches in OH fishery have declined from around 280 t in the early 1990s to a low of only 21 t in 2002/03. Catches have remained at around 30 t since.

Species	NSW catch trends
Luderick	Over 80% of NSW catch taken by EG fishery. Catches in EG peaked at about 500 t in 1999/01 have declined to around 270 t in 2008/09. Catches in the Manning region by EG have followed a similar pattern with catches around 160 t for the last 10 years.
Sand whiting	Over 85 % of NSW catch taken by EG fishery. Catches in EG have been steady at 130 t since 1999/01 but have declined since 2007/08 to about 99 t in 2008/09. Catches in the Manning region for EG have fluctuated around 40-60 t since 1999/01 with a peak in 2007/08 of about 90 t.
Yellowtail scad	OH take over 80% of NSW catch. Since 1997 catches in OH has been between 300 and 500 t Catches in the Manning region by EPT have been steady of about 0.2 t since 2004/05.
Blue mackerel	Over 95 % of NSW catch taken by OH. Annual landings have fluctuate between 300 and 500 t since the mid 1980s. Fluctuations likely reflect changes in stock availability due to recruitment variability, and changes in the distribution of fish due to oceanographic processes.
Sweep	Between 60 and 90% NSW catch is taken by OTL with the remaining catch taken by OH. Seven years of stable landings of around 20 t after a big decline between 1997/98 and 1999/2000. Catch rates increased in 2004/05 in OTL to about 40-50 t and remained steady since.

4.1.8 Economic and social importance of commercial fishing

Economic importance

There are several measures of the economic importance of commercial fishing and its contribution to the local economy. Here, a review of revenue and profitability estimates for the HCRCMA region is provided.

Revenue

The basic measure of revenue for the HCRCMA region is developed from data collected by NSW DPI (Fisheries) such as catch and effort and from fish price sales data from the Sydney fish markets. The Sydney market price data are held by DPI as a monthly average price for a given commercial species. Monthly average price data have been used to estimate the gross revenue from commercial activities in NSW fisheries for a large range of species (McIlgorm, 2001a, b). This method ('Sydney index') was used in all of the NSW DPI Environmental Impact Statements and is the best-available information across the commercial fishing industry (NSW DPI, 2001; 2002; 2004b; 2006). The availability of the Sydney price data and local catch records enables the estimation of an imputed revenue for the HCRCMA region. It imputes the Sydney market price and thus is likely to be a minimum estimate of revenue at first point of sale. The commercial fisheries data are gathered on a fishery-by-fishery basis from records across all of the managed fisheries held by NSW DPI. Estimates of fishery revenue for the HCRCMA in 1999 - 2000 are presented in Table 4.5. The revenue at first point of sale from the HCRCMA zone 4 region was $18.24 million in 1999/2000 across all commercial fisheries. This equates to approximately 27.5% of the $66.28 million of total revenue for NSW fisheries over that period.

Of the total from the HCRCMA region, ~38% came from the Estuary General Fishery (EGF) alone. The EGF is not only an important component of the overall revenue for the HCRCMA but this region also generates 40% of the state-wide revenue for this fishery. The offshore fish and prawn trawl fishery accounts for 31% of total revenue with trap and line/rock lobster fishing accounting for a further 23% of total revenue. In 1999/2000, the ocean-based trawl fisheries in the region contributed ~53% of the total revenue from fish trawl production for NSW.

These estimates were generated prior to the industry adjustments through the Recreational Fishing Haven and Marine Park process during the 2000/2003 period. The total revenue is therefore likely to be substantially lower than this in 2006 but is currently unknown.

Profitability

Specific economic surveys examining industry profitability have been undertaken as part of the NSW DPI EIS process; these examined the profitability of fishing businesses in the NSW fishing industry during 1999/2000 (McIlgorm, 2000) and 2001 (Roy Morgan, 2001b). These surveys are industry-wide and the specific profitability of commercial fishing in the HCRCMA region has not been explicitly examined. However, for a fishery such as the Ocean Trawl (prawn and fish trawling), significant activity took place in the HCRCMA. The profitability figures from the Ocean Prawn Trawl are available in McIlgorm (2004) and generally indicate low economic profitability in the fisheries of the HCRCMA region.

Table 4.5 State-wide fishery revenue in different fishery zones and districts of the HCRCMA region in 1999/2000 ($'000, Sydney Fish Market Price Index) (Adapted from NSW DPI 2001). EG = Estuary General; EPT = Estuary Prawn Trawl; OFT = Ocean Fish Trawl; OH = Ocean Haul; OPT = Ocean Prawn Trawl; OTL = Ocean Trap and Line; RL = Rock Lobster.

Zone	District	EG	EPT	OFT	OH	OPT	OTL	RL	Total	% of state revenue
4	**Manning**	1 193	8	38	258	420	445	288	2 650	4.0%
4	**Wallis Lake**	2 272	48	40	266	614	495	600	4 335	6.5%
4	**Port Stephens**	860	0	925	200	1 430	312	829	4 556	6.9%
4	**Hunter**	1 555	287	1 003	57	1 187	282	133	4 504	6.8%
4	**Central Coast**	1 061	182	50	106	1	645	154	2 199	3.3%
	Total ($)	6 941	525	2 056	887	3 652	2 179	2 004	18 244	27.5%
	% of HCRCMA region	38%	3%	11%	5%	20%	12%	11%	100%	
	% of state total	40%	14%	53%	20%	16%	22%	44%	28%	

Seafood processing industry

Little is known about the annual revenue of the seafood-processing activity in the HCRCMA region. Traditionally, much of this activity has been based around the Fishermans Co-operative system. The key Co-ops in the HCRCMA region are based in several of the fishing towns e.g. Manning Co-op, Newcastle Co-op. The Wallis Lake Co-Op is a major seafood and oyster producer. Each of these co-operatives has a manager and part-time casual staff for sales and processing.

Fish is sold locally and also sent to Sydney fish markets (e.g. the more valuable lobsters). Estuarine species produced by the Estuary General Fishery are popular with local consumers. Tourists are also important consumers of fish in takeaway fish and chip outlets and in local restaurants offering seafood.

Social importance

The NSW DPI Fisheries EIS process also incorporated a social survey of all NSW fishers (McIlgorm, 2001a; Roy Morgan, 2001a). These data are held by NSW DPI, and the social aspects of fishers in each commercial fishery are described in the DPI EIS publications (NSW DPI, 2001). The Australian Bureau of Statistics (ABS) hold census-generated employment data that can identify the number of fishers in each postcode and local government area (ABS, 1996; 2001b, c). These data were accessed for the 1996 census and presented in McIlgorm (2001a, b) and NSW DPI (2001). A summary from the HCRCMA region is provided in Table 4.6. There were 442 registered fishers in the HCRCMA region, though many of these were fishing on a part-time basis. Since the time of compilation of the data (2000) there has been a significant reduction in the number of fishers due to restructuring. Small-scale commercial fishing has been an important part-time activity for many people in this region and contributes to income, wellbeing and passing the time.

The proportion of the labour force employed in commercial fisheries is highest in the Wallis Lake area where approximately 2.8% are employed in commercial fisheries in each postcode. Commercial fishers contribute the lowest proportion of workers in the Central Coast region where the population is largest. In many areas, commercial fishing is one of the, presumably few, employment opportunities. The Socio-Economic Index for Areas (SEIFA), which has a "norm" of 1 000, suggests that the HCRCMA region contains areas of significant socio-economic disadvantage (ABS, 2001a). The Harrington and Mayfield areas have the lowest SEIFA values of below 900 marked by high levels of unemployment (17 - 18%). Commercial fishers comprise <0.5% of the local workforce in all of these rural areas.

Table 4.6 Social index data for NSW fishing communities in the HCRCMA region at the postcode level (Source: ABS (1996, 2001b); BRS and NSW DPI) (Adapted from NSW DPI , 2001).

Zone	Home District	P. code	Town/Suburb	No. Fishers	Total Population	Unemployed (%)	SEIFA	Med. Ind. Income (wk)	Employed in C.F. (%) of labour force
4	MANNING	2427	HARRINGTON/COOPERNOOK	24	1,473	18	883	160-199	0.71
4	MANNING	2430	TAREE/OTHERS	35	28,312	14	950	200-299	0.71
4	MANNING	2443	LAURIETON/OTHERS	21	8,093	20.6	909	160-199	0.595
4	WALLIS LAKE	2423	BUNGWAHL/OTHERS	17	3,247	14.5	939	200-299	2.78
4	WALLIS LAKE	2428	FORSTER/TUNCURRY/OTHERS	88	19,457	15.1	939	200-299	2.78
4	PORT STEPHENS	2301	NELSON/SALAMANDER BAYS/OTHERS	27	25,046	11.1	997	200-299	1.04
4	PORT STEPHENS	2315	NELSON BAY/OTHERS	54	8,393	14.3	966	200-299	1.04
4	PORT STEPHENS	2324	TEA GARDENS/OTHERS	20	19,123	13.6	937	200-299	1.91
4	HUNTER	2280	BELMONT/OTHERS	10	22,225	10.5	989	200-299	0.05
4	HUNTER	2281	SWANSEA/OTHERS	15	11,349	14.3	935	160-199	0.05
4	HUNTER	2295	STOCKTON/OTHERS	12	5,058	12.8	918	200-299	0.555
4	HUNTER	2304	MAYFIELD/WARABROOK	18	13,925	17.6	890	200-299	0.07
4	CENTRAL COAST	2250	ERINA/OTHERS	10	57,810	7.7	1025	300-399	0
4	CENTRAL COAST	2251	AVOCA BEACH/OTHERS	11	29,370	8.5	1032	200-299	0
4	CENTRAL COAST	2256	WOY WOY/OTHERS	12	14,168	11.1	941	200-299	0
4	CENTRAL COAST	2257	EMPIRE BAY/OTHERS	10	25,326	11.6	957	200-299	0
4	CENTRAL COAST	2261	BERKELEY VALE/OTHERS	19	32,623	14.1	935	200-299	0
4	CENTRAL COAST	2259	MANNERING PARK/TACOMA/ OTHERS	40	46,846	10.6	972	200-299	0

Primary data sources

NSW DPI Fisheries data records are held in a database, and are summarised in EIS reports. ABS census data for 1996 and 2000 are available for a small charge from <www.abs.gov.au>. Data on monthly average price at the Sydney Fish Market are held by NSW DPI.

Data description and assessment

The information on both the socio-economic importance of commercial and recreational fisheries in the HCRCMA region is usually found incorporated into larger-scale, state-wide or national studies. There are also several small studies of the economic importance of commercial fishing at a local scale; however, there are few of these and they are often dated and of inconsistent quality. NSW DPI receives monthly average fish prices from the Sydney Fish Markets, which enables estimates of fishers' revenues and income.

The NSW DPI Fisheries data records for commercial fishing catches and effort on a monthly basis are maintained across the 1° latitude reporting bands. They are confidential and are released in aggregate to protect fisher identity. The NSW DPI catch and effort data are reasonably reliable at an aggregated level, but are not designed to address local issues. Fishing data are currently not collected and analysed at a fine enough spatial or temporal scale. Thus, for commercial fisheries in the HCRCMA region, it is difficult to relate fishing effort to specific locations within the region.

ABS census data are available on request. From these, it is possible to get employment information for given postcodes of local government areas. ABS also calculates the Socio-Economic Index For Areas (SEIFA) which is available for each post code (ABS, 2001a). While these data are not based on fisheries activities, they provide a national socio-economic index for areas and communities where the fishers live.

4.2 Recreational fishing

Recreational fishing is one of the most important and popular leisure activities in Australia, and the beaches, estuaries and rocky headlands of the Manning region of NSW are heavily exploited areas (Steffe et al., 1996b). Across NSW, an estimated 998,501 ± 33,686 anglers participated in some recreational fishing activity in 2000/01 (NSW Fisheries, 2002b). In 2000/2001, recreational fishers in NSW harvested approximately 13 million finfish, 1.3 million baitfish, 500 000 crabs and lobster, 1.2 million shellfish and 160 000 squid and cuttlefish (NSW Fisheries, 2002b). Recreational fishing in the Manning region has not been studied specifically. However, the region was incorporated into other studies of recreational fishing – gamefish tournaments (Murphy et al., 2002; Park, 2007), state recreational fishing surveys (NSW Fisheries, 2002b), and charter- and trailer-boat surveys (Steffe et al., 1996, 1999).

When fishing in NSW marine waters, recreational fishers are required by law to pay the NSW Recreational Fishing Fee. This applies to all forms of fishing including spear fishing, hand-lining, hand-gathering, trapping, bait collecting and prawn netting. All money raised by the NSW Recreational Fishing Fee is placed into the Recreational Fishing Saltwater Trust and is spent on improving recreational fishing in NSW. The trust funds research, management and habitat restoration programs. Recreational fishers in NSW are permitted to catch fish and invertebrates for food and sport throughout the year from marine, estuarine and fresh waters by using fishing line gear, traps, nets, spearguns, other hand-held implements and by hand-gathering (Ganassin and Gibbs, 2005b). NSW Fisheries (2002b) reported that ~200 species were recorded in catches from the NSW recreational fishery, of which the key species included flathead, bream, whiting, tailor and luderick. NSW Fisheries (2002b) estimated that the recreational catch across NSW was approximately 30% of the commercial catch for these species.

For management and reporting purposes, NSW DPI separate the activities of this fishery into several components: diving (including spear fishing), sportfishing, and charter boat and gamefishing. Continual catch and effort information is only obtained for the charter boat and fishing tournament components of this fishery. Catch and effort information on the other components of this fishery is obtained only through sporadic directed studies. The NSW recreational fishery is managed by NSW DPI, who are responsible for setting catch and size limits and distributing recreational fishing licenses.

Summary of available catch and effort information for the HCRCMA region

Quantitative data on fishing effort, harvest rates and the species composition of recreational catch specifically for the Manning region are generally lacking. The following information was collated from recreational fishing reports that included the Manning region but also incorporated a wider area than just the Manning. Therefore, the effort and catch data will be an over-estimate for the Manning region.

In 2000/01, 131 348 recreational fishers were active in the Hunter with 74 441 on the mid-north coast (which incorporates some of the northern rivers region). This represents 13.1% and 7.5%, respectively, of the total number of recreational fishers in NSW (NSW Fisheries, 2002b). During 1997/98, a total of 64 charter boats operated within the Manning region with Port Stephens having the highest proportion of these (45 boats – 70.3% of the total for the region) (Steffe et al., 1999). Overall, the central region of the charter boat survey, which included Sydney and Wollongong, had the largest proportion of the charter boat fleet (10.4%). In 1993/94, there was a total of 103 780 trailer-boat trips in the central coast region with the highest occurring on weekend days (c. 30% of total state effort) (Steffe et al., 1996). However, the central coast in this study spanned from Sugarloaf Point in the north to the mouth of the Shoalhaven River in the south, an area vastly larger than the Manning region. In this central coast region, 128 species were retained by trailer-boat anglers. The top 10 species by number were blue spotted flathead (13.4%, 68 t), sliver trevally (10.1%, 87.5 t), snapper (10%, 70.5 t), yellowtail and jack mackerel

(7.7%), silver sweep (7.3%, 37.2 t), southern calamari (4.3%), slimy mackerel (4.2%), maori wrasse (3.9%), longfinned seapike (3.9%) and blue morwong (3.8%, 37.7 t) (Steffe et al., 1996).

Gamefishing tournaments in the Manning region are primarily centred around Port Stephens. Monitoring of gamefishing tournaments between 1993 - 2005 found that 41% of the total state-wide effort was from Port Stephens with 10 912 vessel days (Park, 2007). Port Macquarie had 757 vessel days. The largest effort for billfish occurred in waters south-east of Port Stephens (6 988 hours of fishing) which also experienced the largest effort for sharks (1 084 hr). These large efforts were largely due to the inter-club tournament held at Port Stephens which runs for 4 days and uses 230 vessels (Park, 2007). Murphy et al. (2002) found that, in gamefishing tournaments from Port Stephens in 1997, 80% of the effort for billfish and tuna occurred within 20 nm of the coast; in 1998, 50% of the effort was between 20 - 40 nm of the coast. Of the gamefishing tournaments in NSW, Port Stephens caught the highest number of billfish and sport fish, these being striped marlin (160), black marlin (214), blue marlin (34), and mahi mahi (425).

Economic and social importance of recreational fishing

There is limited information on the economic and social importance of recreational fishing for the HCRCMA region. However, where data are available, these show considerable expenditure on recreational fishing activities. For example, a national survey (Campbell and Murphy, 2005) estimated that recreational fishing expenditures totalled >$67.5 million in the Newcastle/Lakes region which represented 15.2% of the total recreational fishing expenditure in NSW.

Fisheries management controls

A licence is required to fish recreationally in NSW. Other management controls include bag and size limits, gear restrictions, time and area closures, the daily reporting of charter-boat catches, and ongoing research into recreational fishing. In 2002, a number of Recreational Fishing Havens (RFH) were established in NSW following the removal of commercial fishing effort to improve opportunities for recreational fishing. All of the RFHs are situated in estuaries, and there are currently no havens in marine areas. Within the Manning region, Recreational Fishing Havens have been established in the Manning River and Lake Macquarie.

Primary data sources

The primary data for this section come from published sources (Steffe et al., 1996; 1999; NSW Fisheries, 2002b; Murphy et al., 2002; Henry and Lyle, 2003; Park, 2007). These reports are all available from the I&I NSW Fisheries library, Cronulla. Angling Research Tournament Monitoring Program data are available from I&I NSW. Observational data on trailer-boat effort were collected by volunteer coastal patrol groups along the coast. This information is currently in raw format and has yet to be entered into a database or published (Aldo Steffe, pers. comm. with C. Ganassin). Data on harvests from charter boats in NSW are held on a database maintained by I&I NSW (Nick James, pers. comm. with C. Gannassin).

Data description and assessment

Henry and Lyle (2003) collected nationally-consistent and comparable fishery statistics for the non-commercial components of Australian fisheries. The survey also collected information on the number of fishers, their demographic profile, expenditure associated with fishing, and the attitude and awareness of fishers to prominent fisheries-management issues. Analyses in this study were conducted at the national and state level. As the information in the database from this study has yet to be analysed to the regional level in NSW, data on the recreational fishing activities occurring within the Manning region are currently unavailable.

Steffe et al. (1996) estimated the total fishing effort, harvest and harvest rates in the marine waters of NSW (using trailer boats, cruisers and gameboats, and charter boats), and related estimates of the total harvest obtained by the recreational fishing population to the allocation of resources between recreational and commercial users. Steffe et al. (1999) examined data from the charter fishing industry, and provided a comprehensive register of charter-fishing boats based in NSW and a detailed description of the charter-fishing-boat industry that operated in the coastal and estuarine waters of NSW during 1997/98. NSW Fisheries (2002) provides an interim report on recreational fishing in NSW and involved a 12-month survey of recreational fishing for 2000/01. The study was part of a broader national initiative to obtain fisheries statistics on non-commercial components of Australian fisheries. The survey obtained estimates of participation, fishing effort and catch by recreational fishers. It was done at a state level and no regional-level information was given.

Murphy et al. (2002) estimated catch-per-unit-effort for species taken in gamefishing competitions from fifteen coastal ports in south-eastern Australia, for seven fishing seasons over a period of seven years (between 1993/94 and 1999/2000). Trends in recreational fishing success for the principal gamefish species were analysed. Park (2007) analysed data from the Gamefish Tournament Monitoring Program of I&I NSW from 1993/94 to 2004/05. The report analysed catch trends in the main target species, changes in angling behaviour in targeting of species, spatial demographics of target species, and the interaction between gamefishing and long-line fishing.

More comprehensive data are needed from every aspect of the recreational fishing sector. Further monitoring of the levels of recreational fishing effort and harvest over larger spatial scales is needed to better understand the effects of recreational angling on finfish resources. Future studies need to use comparable, quantitative methods for surveys and should be conducted across locations simultaneously, so that direct comparisons can be made between areas. The impact of the recreational fishery on fish stocks within the Manning region is currently unknown; however, given that many resources are shared with the commercial sector, and harvests in this fishery are substantial, the impact to fish stocks may be of considerable importance. In addition, the impact of recreational fishing to benthic habitats is unknown. Data concerning the economic importance of recreational fishing in the Manning region are particularly weak.

Additional sources of data

Vineburg (1994) and Brown (1994) reviewed the breeding biology of several recreationally-important species from northern NSW. These species included yellowfin bream, dusty flathead, luderick, snapper, mulloway, sand whiting and tailor. Ganassin and Gibbs (2005b) list all of the types of recreational fishing gear permitted in NSW waters. For each gear type, a description of the species targeted by the gear, the allowable dimensions, the method of use, and the habitat of use, are provided. This report also examines the possible interactions between different gear types and marine fauna (mammals, birds and reptiles) within NSW waters.

4.3 Pollution sources

4.3.1 Sewage outfalls

Sewage outfalls that discharge treated effluent to the ocean are a potential source of pollution in coastal waters. The impacts of sewage outfalls on coastal water quality and biota in the vicinity of the outfall will depend upon the level of treatment, the volume and quality of the effluent, and the dilution efficiency. The dilution efficiency of the effluent plume will depend upon the location and design of the outfall and the ambient oceanographic conditions at the point of discharge.

There are seven ocean outfalls that discharge effluent to the ocean in the HCRCMA. The characteristics of the discharge points are summarised in Table 4.7 and the water quality of the effluent in Table 4.8.

Table 4.7 General characteristics of ocean outfalls in the HCRCMA area.

OUTFALL	Location	Outfall design	Area Serviced	Treatment	Discharge	Dilution Efficiency Rank /17 *
Forster	Janies Corner	Shoreline discharge	Forster, Pacific Palms	Tertiary/UV disinfection	200 L/s	8
Boulder Bay	Boulder Bay	Offshore with diffusers	Nelson Bay, Shoal Bay, Fingal Bay, Anna Bay, Boat Harbour, Dutchmans Bay, Lemon Tree Passage, Mallabulla, Salamander Bay and Soldiers Point	Secondary with continuous flow aeration	4.3 ML/day	3
Burwood Beach	Offshore from Burwood Beach	1.5 km offshore pipe with 10 risers	Newcastle - Wallsend	Secondary plus biosolids	44 ML/day	2
Belmont Beach	Offshore from Belmont Beach	1.5 km offshore	Toronto and Belmont	Secondary	20 ML/day upgrading to 28 ML/day	1
Norah Head	Norah Head	Submerged shoreline disposal at 4m depth	Mannering Park, Wyong South, Gwandalan, Toukley and Charmhaven	Tertiary/Trickle (Toukley) IEEAS (others)	21 ML/day	9
Wonga Point	Wonga Point	Shoreline discharge	Bateau Bay	Tertiary with continuous flow aeration	10 ML/day	16
First Point	Winney Bay	Submerged Shoreline discharge	Kincumber, Woy Woy	Tertiary	10 ML/day	13

* Source: Ingleton and Large (2004)

Table 4.8 Water quality of discharge from outfalls within the HCRCMA region (1997 – 1998).

	Effluent	NH_4	TKN	NOx	OrgN	TN	TP	NFR	GREASE
	Flow (KL/year)	Load (t/yr)	Load (t/yr)	Load (t/yr)	Load (t/yr)	Load (t/yr)	Load (t/yr)	Load (t/yr)	Load (t/yr)
Forster	1 937 282	0	0	0	0	14.9	18.1	10	8.8
Boulder Bay	3 019 360	2.8	96	1.2	21.1	97.2	20.5	19	2
Burwood Beach	18 916 100	503.2	613.2	0	11.6	0	85	521	28
Belmont Beach	11 893 640	118	154	0	27.7	0	22.9	197	8.7
Norah Head	7 609 991	44.5	0	50	29	120.2	59.4	172	20.6
Wonga Point	3 033 320	10	0	43.1	9	103.4	25.8	18	14.3
First Point	14 508 720	13.7	0	0	0	440.4	135.6	98	5.2

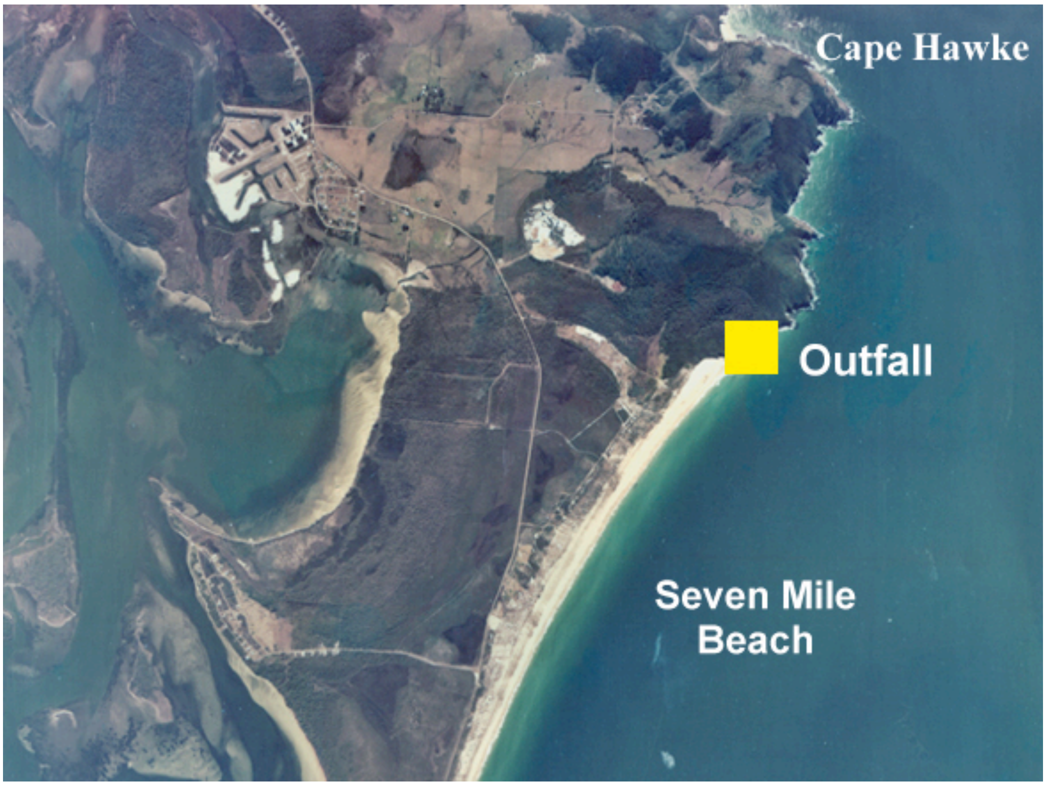


Figure 4.3 Location of the Forster outfall.

Forster outfall

The Forster outfall was constructed in 1980 (Manidis Roberts, 1993) at Janies Corner/Shark Point, a rocky point at the northern end of Seven Mile Beach (Figure 4.3). The pipeline was trenched through the rock shelf and covered with small boulders set into concrete. The pipeline discharges on the northern side of the headland ~50 m from the end of the point and within the surf zone of a small pocket beach (Shark Beach), although anecdotal evidence suggests the pipeline has been broken off at the shoreline. The outfall, which discharges tertiary-treated and UV-disinfected effluent, has been examined for impacts.

Monitoring of faecal coliform bacteria in the receiving waters indicated that Primary Contact Recreation criteria were considered to be met within 200m of the outlet, and the Protection of Human Consumers of Seafood guidelines were considered to be satisfied within 600 m (MHL, 1997). The Ecology Lab (1993) found evidence of changes to the intertidal algal community ~20 m either side of the outfall as well as minor changes to the subtidal benthos and fish community.

More recent monitoring by MidCoast water (TEC, 2001; MHL, 2002) indicates some localised impacts from the outfall, although no evidence of bioaccumulation was found. There was an increase in *Ulva* near the point of release that is likely to result from increased nutrients from the outfall. The report also found reduced kelp, an increased abundance of seastars and sponges, and an absence of sea urchins near the release site (TEC, 2001). While it was not possible to definitively attribute causation of the observations to the outfall, the consistent differences from reference sites suggest the outfall is playing a part (TEC, 2001).

During dye testing, effluent from the outfall was retained within the embayment for up to 22 hours in worst-case scenarios. Modelling suggested that the current outfall design was acceptable for peak loads forecast up to 2021. It was also recommended that repair and extension of the outfall to 2.5m below the waterline should be investigated to improve initial dilution (MHL, 2002).

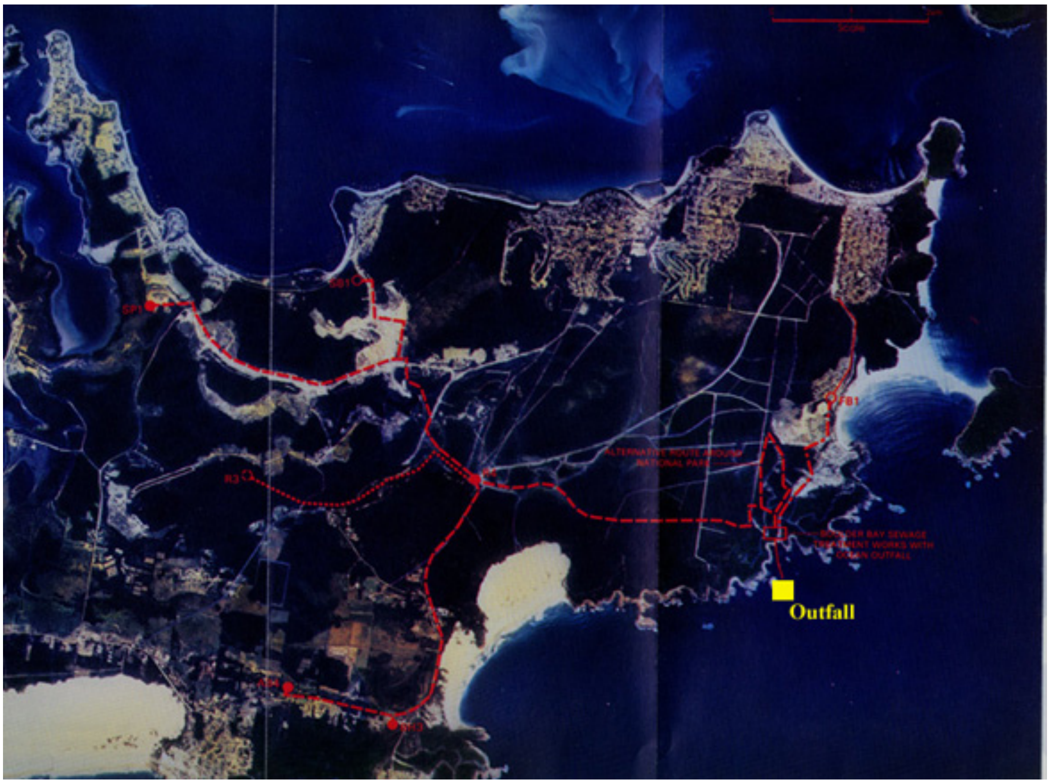


Figure 4.4 Location of the Boulder Bay outfall.

Boulder Bay outfall

Boulder Bay outfall services the area south of Port Stephens (Figure 4.4). The temporary shoreline outfall was replaced by an 800 m-long offshore diffuser pipeline within Boulder Bay that discharges in 20 - 25 m of water. The outfall discharges around 9 ML/day of secondary-treated effluent. The treatment process consists of fine screening and grit removal, two aeration activated sludge reactors, and two secondary clarifiers. This outfall produces good dilution characteristics (Ingleton and Large, 2004). Manly Hydraulics Laboratory (MHL) (2008) examined the dilution efficiency of the Boulder Bay outfall under future growth scenarios and found that ambient nutrient concentrations were already close to the Australian and New Zealand Environment Conservation Council's (ANZECC) trigger values. Consequently, an increase in effluent discharge, under the present treatment regime, would lead to nutrient concentrations above trigger levels within Boulder Bay. Modelling found the effluent plume to be largely confined to Boulder Bay and the immediately adjacent shoreline. Upgrades of the Boulder Bay Waste Water Treatment Plant (WWTP) are currently underway with a proposal to increase capacity and flow; treatment will remain at secondary level. The impacts of the Boulder Bay outfall have been determined for both encrusting biota (Roberts et al., 1998) and fish assemblages (Ajani et al., 1999).

Figure 4.5 Location of Burwood Beach outfall.

Burwood Beach outfall

Burwood Beach outfall (Figure 4.5) was designed for 220 000 equivalent persons (EP) and currently services a catchment of ~180 000 people (HWC, 2010). The effluent is discharged via a 2.7-m diameter pipe that extends 1900 m from the shore. There are 9 risers for the discharge of effluent and one which discharges sludge. The discharge of biosolids is unique in Australia and has been the subject of recent studies to assess the health risks (Roser et al., 2010). Modelling in this study found that the plume from the outfall generally moved out to sea, but occasionally moved onshore in a diluted form. The study suggests that bathers may experience increased risk of contacting gastrointestinal complaints from contamination from the outfall <5% of the time. Surfers, who swallow more salt water than bathers, may be at greater risk (<25%). These results are consistent with those from Beachwatch that rate these beaches highly for recreational water quality. The biosolids were found to pose a very low risk due to the small volume being discharged. A $43 million upgrade is planned for the Burwood WWTP.

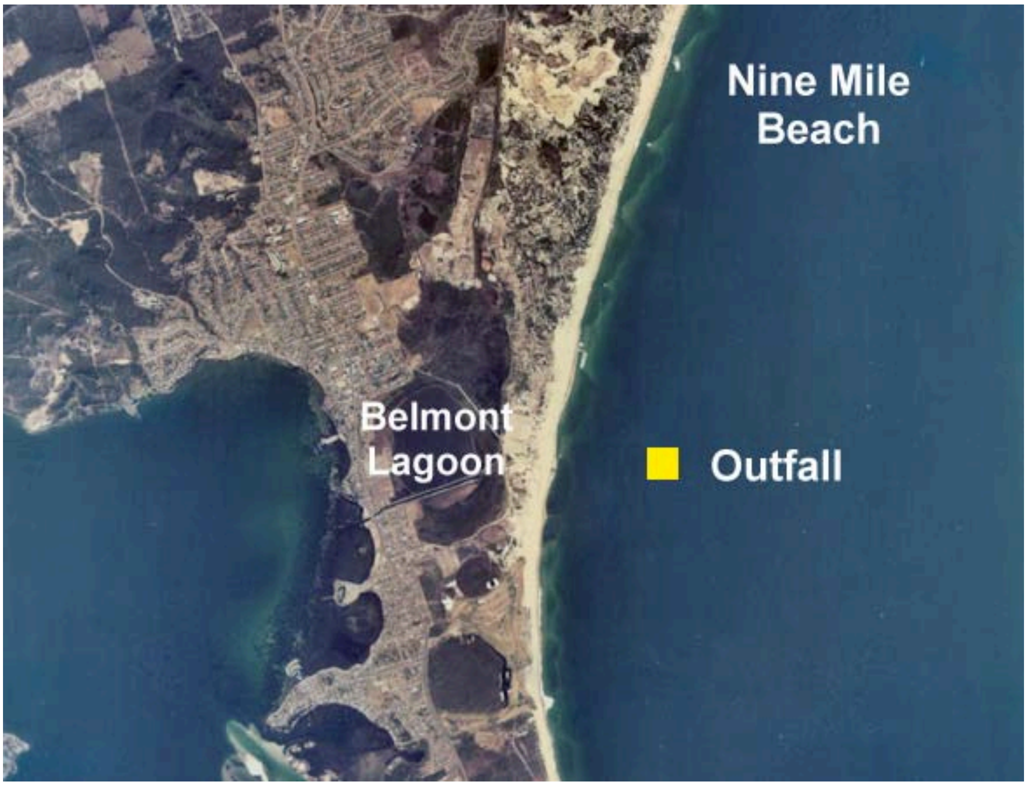


Figure 4.6 Location of Belmont Beach outfall.

Belmont Beach outfall

The Belmont ocean outfall serves the Belmont and Toronto WWTPs (Figure 4.6). The current design is for 85 000 EP at 20 ML/day (HWC, 2010). Hunter Water Corporation (HWC) has been discharging additional effluent during wet weather while construction works are underway. The offshore outfall consists of a trenched 1600-mm pipeline extending ~1500 m offshore. The linear diffuser is ~120 m long with 55 risers each with a nozzle 110 mm in diameter. The diffuser is in depths ranging from 22 - 24 m.

Beachwatch data suggest that there is little or no impact on recreational water quality at beaches near the Belmont outfall. Cole (1990) found elevated levels of contaminants in fish in the Newcastle area, but it is not clear that this was related to the sewage outfall. A study by Ajani and Wansborough (1996) studied trace-metal concentrations in sediments and oysters off Newcastle and Sydney; only three (technical Chlordane, DDE and DDD) of the 17 organochlorines tested were detected in deployed oysters. However, because of the low frequency of detection, no impact-versus-control comparisons could be made. Trace-metal concentrations in oysters were within or below the range of concentrations found in oysters deployed offshore from Sydney and those found to occur naturally in other estuarine areas of NSW. Trace-metal concentrations in sediments were comparable to concentrations found in Sydney. All mean trace-level concentrations were below those considered to have adverse biological effects.

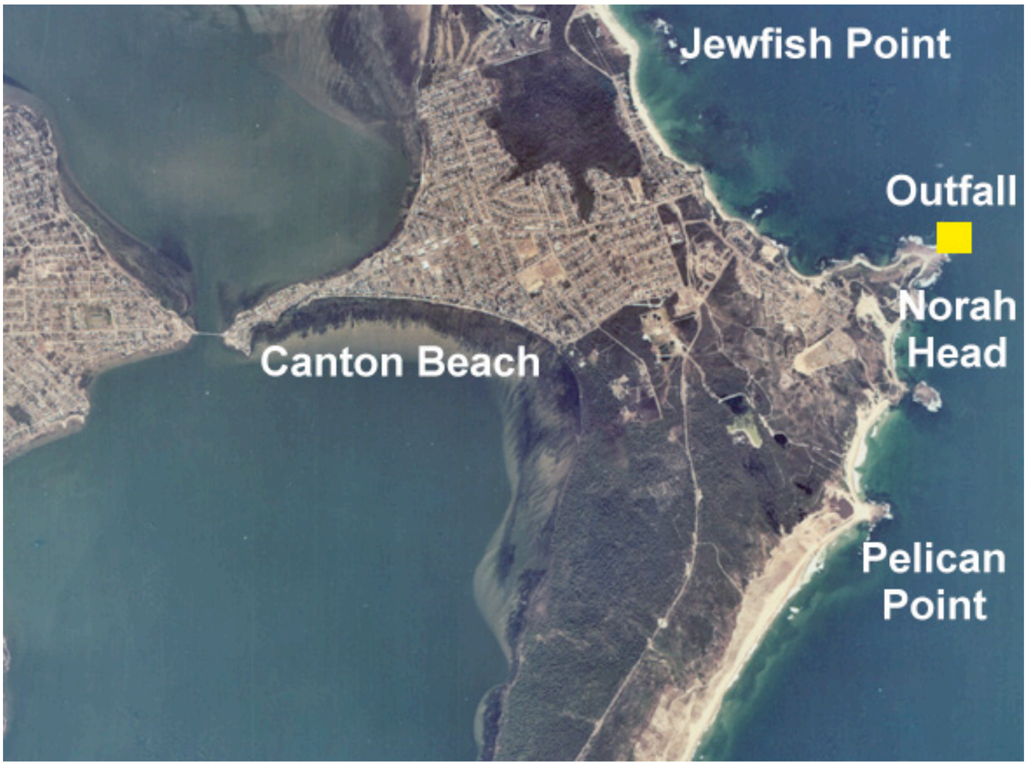


Figure 4.7 Location of Norah Head outfall.

Norah Head outfall

The Norah Head outfall (Figure 4.7) is one of the largest in the HCRCMA region, discharging ~22 ML/day of secondary-treated sewage from the combined flows of Mannering Park, Wyong South, Gwandalan, Toukley and Charmhaven WWTPs. The outfall was commissioned in 1988 and is located at Norah Head. It has three stainless-steel nozzles, each with a diameter of 280 mm, located ~4 m below mean sea level.

Various studies have indicated that the Norah Head outfall has little environmental impact. Beachwatch report good recreational water quality at beaches near Norah Head. Roberts and Scanes (2000) found a higher species richness of sponges at sites near the outfall relative to reference sites.

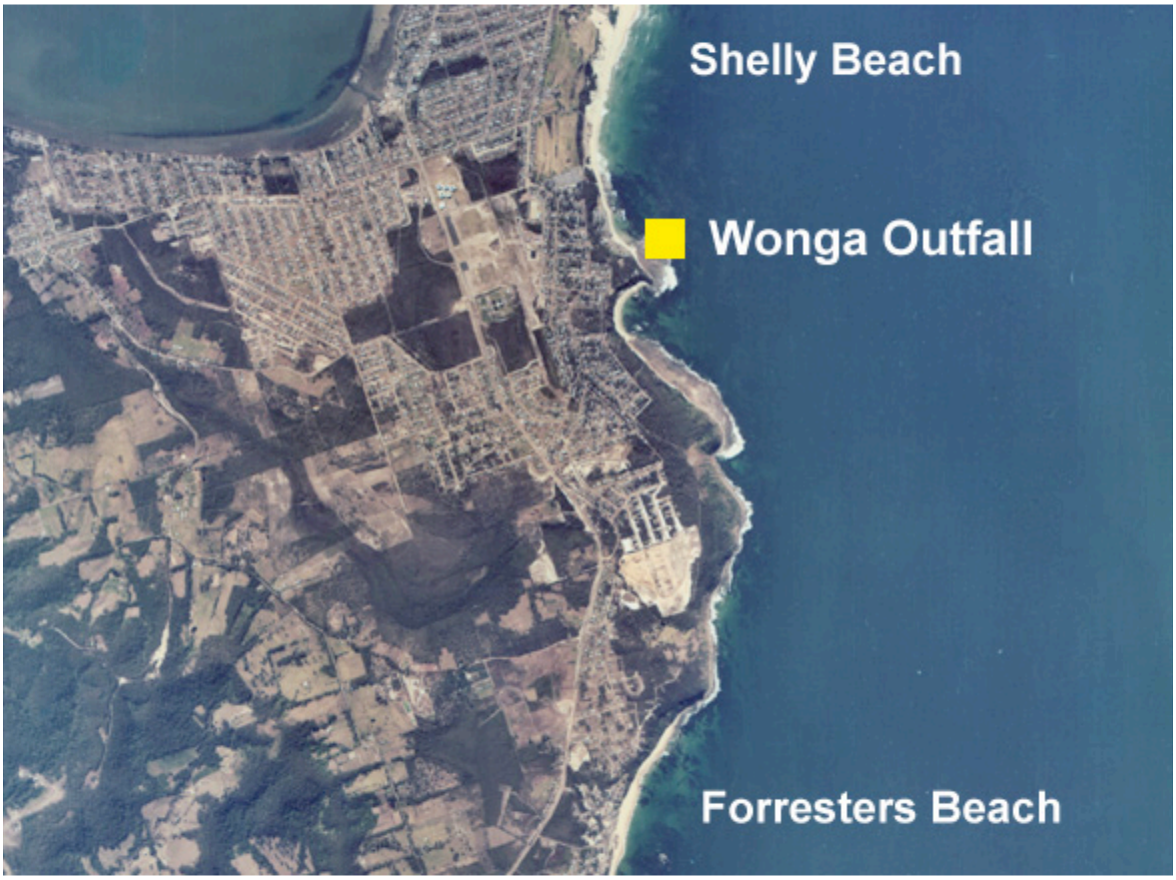


Figure 4.8 Location of Wonga Point outfall.

Wonga Point outfall

The Wonga Point outfall (Figure 4.8) discharges secondary-treated effluent from a pipeline outfall located just below low tide on the edge of a rock platform. The outfall services Bateau Bay WWTP which uses a continuous extended aeration activated sludge (CEASS) process with trickling filters and disinfection by chlorination. The discharge volume is ~10 ML/day. The effluent plume has the potential to be pushed into Bateau Bay and Shelly Beach as well as onto the rock platform near the outfall during high tides (above 1.3 m) (MHL, 1978).

Beachwatch monitoring shows that both Shelly Beach and Bateau Bay are safe for swimming in all months of the year (Beachwatch, 2009a, b). Previous studies by DECCW (unpublished) noted a very slight effect on water clarity and salinity in the vicinity of the plume but no discernable effect on benthic communities.

Figure 4.9 Location of First Point outfall.

First Point outfall

First Point outfall (Figure 4.9) is located on the Three Points system just north of Broken Bay. The outfall is located in Little Cove (also known as Winney Bay). Ocean circulation in the area is dominated by the East Australian Current (EAC). Dye studies have shown that the effluent forms a buoyant plume 1 - 2 m thick within Little Cove, but mixes rapidly at the shear zone with the longshore currents at the mouth of the cove. The outfall discharges 10 ML/day, at a rate of 640 L/s, of secondary-treated effluent from Kincumber WWTP (conventional activated sludge) and Woy Woy WWTP (extended aeration activated sludge). The outlet consists of a 900-mm diameter pipe attached with an orifice plate that has a 500-mm diameter orifice. The outlet discharges at the edge of the rock bench, ~4 m below low-tide level.

Studies have noted that the outfall creates decreased visibility in the area of discharge that leads to a transition from algae to filter-feeding sedentary organisms on vertical faces of subtidal reefs. The impacts were limited to a narrow band within 10 m of the outfall (Laxton and Laxton, 1989; Binnie and Partners, 1990). There was also some evidence of increased *Pyura gibbosa* amongst kelp communities at a distance of 200 m from the outfall (Laxton and Laxton, 1989).

Primary data sources

The data for this section primarily come from a CD of compiled information on sewage outfalls in NSW. The CD outlines the general characteristics of each of the 32 ocean outfalls in NSW and contains location photos and effluent quality data from 1996, 1997 and 1998. The studies pertaining to each of the outfalls are also reviewed and there is also a general review on the impacts of sewage outfalls on marine ecosystems.

Additional data sources

Additional data for this section can be found in the series of reports by MHL commissioned to assess the oceanography and the dilution field at commissioning, or, subsequently, as part of the review process for upgrades (e.g. MHL, 1978; 1998a, b; 1992; 1993). Several reports and scientific papers address the impacts of the HCRCMA outfalls directly (Roberts and Scanes, 2000; Roser et al., 2010), and there is a body of scientific papers that more generally examine the impacts of sewage discharge on marine ecology.

There are several state-wide databases that hold information about NSW WWTPs and outfalls. An inventory of NSW WWTPs is maintained by the Department of Energy, Utilities and Sustainability (DEUS) (ANZNS0359000515), while the National Oceans Office (NOO) maintains a national-scale sewerage waste facility (ANZCW1205000665) database. NSW DPI Fisheries maintains a database and Geographic Information System (GIS) coverage of all sewage discharge points in NSW estuaries (ANZNS0364000082).

It should be noted that much of the information on water quality, and other environmental impacts, at many of the outfalls, is dated. Thus, environmental effects may be different to those documented previously due to changes in effluent discharge rates (i.e. resulting from increasing human populations). This is considered further in Chapter 6.

4.3.2 Shipping

The coastal waters of the HCRCMA region, and immediately offshore, experience some of the heaviest shipping traffic on the NSW coast (Figure 4.10). The majority of ships leaving the Port of Newcastle travel along the coast just east of the HCRCMA region. The number of ships varies from year to year but the spatial pattern is fairly similar with ships regularly passing within 3 nm of the shore at certain points (Fingal Head and Sugarloaf Point).

The majority of ships visit the Port of Newcastle; 2 992 shipping movements (1 426 ship visits) were reported for the 2006/2007 financial year with 3 277 shipping movements (1 566 ship visits) between 2007/2008, representing a 10% increase over that period (Newcastle Port Corporation, 2009). It is expected that the Port improvements will lead to increased shipping traffic through the port. These shipping movements were primarily bulk coal transfers (88.88 million t of a total of 93.31 Mt traded through the Port in 2007/2008 – Newcastle Port Corporation, 2008).

Newcastle Port Corporation (NPC) records the position of all ships lying within the offshore anchorage ("Fair Weather Anchorage"). Since the grounding of the *Pasha Bulker* during a storm in 2007 (see Box 2.1), ships are advised to anchor outside the 3-nm limit and must be ready to move if weather conditions turn unfavourable. Ships must anchor south of 32º 58' S. NPC records show that, on any given day since 2007, the number of ships in the anchorage varies from 12 - 85 with an average of 40 ships. Ships have anchored as far south as Barrenjoey Headland and remain in the anchorage for an average of 17 days (Newcastle Port Corporation, pers. comm.).

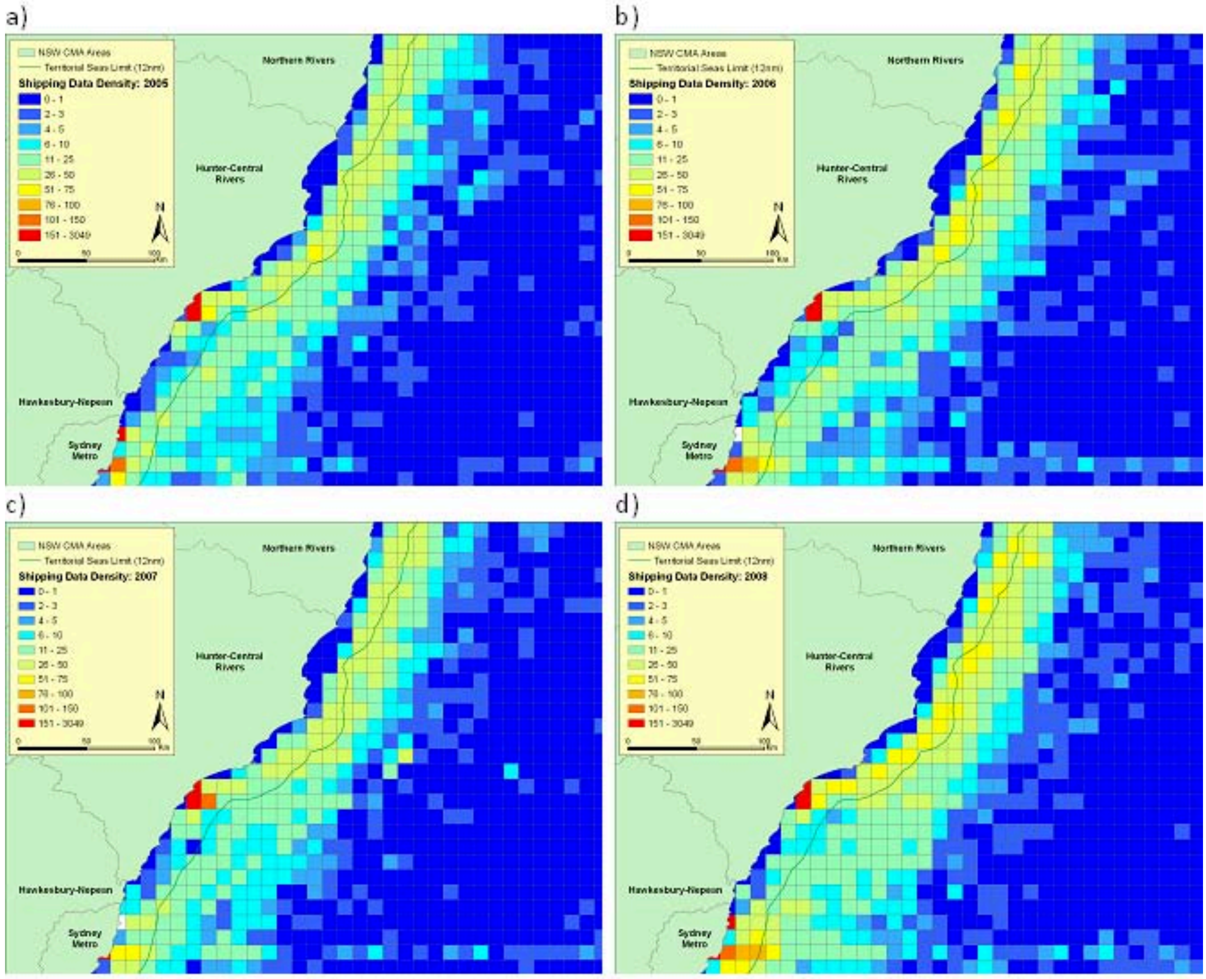


Figure 4.10 Density of AUSREP (Australian Ship Reporting) ship locations per year for the area of the HCRCMA from 2005 to 2008. The 12-nm line is indicated in blue (Data courtesy of the Australian Maritime Safety Authority (AMSA)).

Primary data sources

NPC data are available on request. Summary statistics can be found in the NPC annual reports. Australian shipping statistics are available from AMSA.

Data description and assessment

NPC maintains a database of all ships entering and departing the Port. All ship details are recorded including, destination, port of origin and cargo. Monthly and annual statistics are available on request. Daily positions of ships in the anchorage are recorded as distance and bearing from Nobbys Head, however, these are not currently archived.

AMSA maintains data from shipping activities across the whole of Australia. All ships entering Australian waters are required to report their position daily using the AUSREP reporting system. Reporting to AUSREP is voluntary for Australian-registered commercial ships, but is complied with by the majority of vessels. These data are only used to determine major shipping patterns and define shipping lanes. Available data do not provide ship identifications or vessel call-signs. Reporting point data from 2001 - 2004 have been used by Geosciences Australia to create maps and GIS coverage of the major shipping lanes for the whole country (ANZCW0703008908).

Additional data sources

NOO created a mapset and GIS coverage of the major shipping and boating features of the NSW coastline (ANZCW1205000588) for the National Marine Atlas. These maps display point data about shipping densities, yacht clubs, marinas, boat ramps and shipwrecks. NOO also mapped the major shipping routes and ports (ANZCW1205000675), and the number of ship visits to each port (ANZCW1205000667) within NSW waters during 2002.

4.3.3 Oil spills

Oil spills in the marine environment can have wide-spread impacts and long-term consequences for wildlife, fisheries, coastal waters and marine habitats. The impacts from spilt oil in the marine environment may include: the mortality of sea birds, mammals and other fauna; physical damage or permanent loss of foreshore and marine habitats; and the smothering of intertidal biota (AMSA, n.d.).

AMSA, in conjunction with the Department of Environment, Climate Change and Water (DECCW), has carried out a detailed analysis of the risk posed by oil spills to the NSW coast. McEnally et al. (1989) and Carter (1995a, b) detailed all coastal resources within the HCRCMA region, and assigned an environmental sensitivity categorisation (extreme, high, moderate and low) to each (Table 4.9). Extremely sensitive resources include those which may be severely damaged or destroyed by an oil spill, and/or are of international significance and/or would be impossible to restore following a spill. Extremely sensitive resources include birds protected under international treaties, mangroves and saltmarshes. Attempts at cleaning spills may often be ineffective and may increase damage to the resource (McEnally et al., 1992).

Highly sensitive resources include those that may be severely damaged by a spill, and/or are of regional significance, and/or would be difficult and expensive to restore following a spill. Highly sensitive resources include oyster leases, marine mammals and reptiles, and corals. Cleaning of these resources may only be partially effective following a spill (McEnally et al., 1992). Moderately sensitive resources are capable of being damaged, but will recover from an oil spill quickly; they can be cleaned reasonably easily and may not normally come into contact with floating oil. Resources in this category include boats, moorings and recreational beaches. Low sensitivity resources are those which should survive an oil spill with little damage, but which could become damaged if the clean-up is not appropriately managed. Low sensitivity resources include exposed rocky shores and boat ramps (McEnally et al., 1992). In the event of an oil spill in NSW waters, first priority is given to the protection of extremely sensitive and highly sensitive resources. Second priority is given to prime recreational resources such as public beaches.

Table 4.9 Summary of the oil spill risk categories and the reasons for each resource being listed in each category. An example of each coastal resource within the HCRCMA region is also provided. Data compiled from McEnally et al. (1989) and Carter (1995a, 1995b).

Category of Sensitivity	Coastal resource	Reason for Categorisation	Examples of sites in HCRCMA
Extreme	Mangroves and saltmarshes	Oil causes dieback of mature plants and the destruction of seedlings. These areas are also very important for local primary production, sediment accumulation, maintaining biodiversity and as nursery areas for some fish and invertebrates.	Port Stephens supports one of the largest areas of mangroves in NSW, and the largest area of saltmarsh in NSW.

Category of Sensitivity	Coastal resource	Reason for Categorisation	Examples of sites in HCRCMA
	Intertidal seagrass beds	Exposure at low tide would result in complete coverage in the event of an oil spill.	Wamberal, Terrigal Lagoons and Avoca Lake.
	Roosting and feeding areas of internationally protected birds	Birds and their habitats are extremely sensitive to oil spills.	Examples of significant bird areas in the HCRCMA region include: nesting sites at the mouth of the Manning, and on islands in Port Stephens area; Kooragang Island and the Hunter Estuary; Moon Island and at the mouth of Lake Macquarie; Red Head Point; and dunes near Budgewoi. During summer, large numbers of terns and shearwaters feed close to the shore and migratory birds visit the area.
High	Roosting and feeding areas of non-protected birds	Birds that spend a significant time in the water are highly vulnerable to spills (e.g. the little penguin and some cormorant pieces).	Little penguins are known to breed on Moon and Bird Island.
	Oyster leases	The impact of an oil spill can lead to severe economic damage.	Wallis Lake and Port Stephens provide a large proportion of oyster production in NSW. In addition, the Hunter Estuary has some significant leases.
	Marine mammals	Oil contamination of food sources and physical damage from contact with oil pose a risk to marine mammals in an oil spill.	Seals, dolphins and whales are common in the area both offshore and in some protected bays.

Category of Sensitivity	Coastal resource	Reason for Categorisation	Examples of sites in HCRCMA
	Subtidal seagrass beds	These beds are important habitat for fish and invertebrates. They are known sediment traps and contribute significantly to primary production. They are not considered at extreme risk as they have limited tidal exposure.	Seagrass beds are present in the following areas: Manning River, Wallis Lake, Port Stephens, Lake Macquarie, Tuggerah Lakes, Wamberal Lagoon, and Terrigal Lagoon.
Moderate	Commercial fisheries	Pelagic resources generally have direct contact with oil only rarely. However, they can still be affected by dispersed oil in the water column causing tainting of fish flesh. Oil can indirectly affect larvae, fishing equipment, and cause habitat damage.	There are 5 main fishery cooperatives in the region. Fish, prawns, crabs and crayfish are targeted using various methods. Newcastle also harbours a significant commercial fleet.
	Recreational fisheries	See above	There is a large recreational fishing effort in the region especially at: Port Stephens, Forster-Tuncurry (beach angling), Seal Rocks and surrounding reefs, and in the southern lakes (Lake Macquarie and Tuggerah Lakes).
	Nursery grounds and spawning sites	These areas can be damaged by dispersants and dispersed oil droplets although they can be easily recolonised.	Coastal beaches along the entire coast.
	Boats and moorings	Little lasting damage but expensive cleanup.	Present in large numbers in the HCRCMA region.
	Beaches and pools as recreational resources	Oil-spill risk is lower as oil can be cleaned relatively quickly without losing recreational value.	Coastal beaches along the HCRCMA coastline.

Category of Sensitivity	Coastal resource	Reason for Categorisation	Examples of sites in HCRCMA
Low	Rocky coastline	Exposed nature and self-cleaning ability (strong wave action) leads to low sensitivity.	Significant examples include: Crowdy Head, Red Head, Hallidays Point, and the region between One mile Beach and Cape Wake.

Primary data sources

The NSW Oil Response Atlas is now available in GIS format from <www.amsa.gov.au/Marine_Environment_Protection/National_Plan/General_Information/Oil_Spill_Response_Atlas/>.

Data description and assessment

The NSW Oil Response Atlas is contained within the national Oil Spill Response Atlas (OSRA) which was produced by AMSA. OSRA's primary aim was to systematically compile all relevant geographic and textual data into a standard GIS format for the majority of Australia's maritime and coastal environments. It covers chemical spill contingencies in addition to oil spill information. The OSRA contains environmental information on coastal and marine habitats and is an essential tool in contingency planning and for decision-making during a marine pollution incident. It also provides details of sensitive marine and coastal areas that could be affected in the event of a pollution incident as well as providing logistical information for managing authorities.

The OSRA helps to prioritise foreshore ecosystems and biological resources and provides information on response options for any spill. Details of the oil spill resources (e.g. dispersants, absorption booms) held at each port facility and at other harbour facilities are provided. Other datasets held within the OSRA include: wildlife and man-made resources present Australia wide, geomorphological maps, shoreline sensitivity to oil spills, human-use resource considerations, and logistical and infrastructure information to support a spill response.

Additional data sources

NSW Maritime (2005) have outlined the response procedures for oil spills in NSW waters as part of the NSW State Disaster Plan (DISPLAN).

4.3.4 Dredging and marine debris

Dredging

While maintenance dredging occurs in a number of the estuarine areas of the HCRCMA region, the only marine areas affected by such activities are offshore from Newcastle. Dredging of the Hunter River commenced in the mid-1800s and is now a continuous activity and one of the focal areas of the NPC. The purpose of dredging is to provide navigable channels within the Hunter River to ensure safe use by shipping. Sediments from the dredge-borrow area (channels and berths) are mostly removed using the trailing-suction dredger, *David Allan*, and transported approximately 1.5 nm south-east of Nobbys Head where they are released in a designated spoil ground. Dredging activities are currently licensed to a maximum of 500 000 m^3 per year which involves ~1 000 trips to the spoil ground. While there has been interest in reuse of dredged material, there are a number of issues that need to be addressed to realise this potential (Haines et al., 2009).

In 2005, development consent was granted to dredge the south arm of the Hunter River to facilitate the establishment of a third coal terminal within the Port. Stage 1 of this project was completed in May 2010 with much of the clean spoil used as fill at the coal terminal site; the rest was dumped at sea. Additional offshore dredge-spoil dumping is also being conducted as part of the Hunter River Remediation Project (HRRP) conducted by BHP Billiton. This project aims to remove and treat ~650 000 m^3 of contaminated sediments adjacent to the former Newcastle Steelworks site at Mayfield. Uncontaminated sediments are transported offshore for disposal with plans to do the same for treated sediments (BHP Billiton, n.d.; 2010).

The potential impacts of dredge-spoil dumping primarily relate to: smothering of biota, altering the sediment characteristics of the receiving area, and the toxic effects of any pollutants contained in the spoil. Biota living in high energy, nearshore environments in NSW may be largely unaffected by infrequent dumping of small volumes of clean sediment (Smith and Rule, 2001); however, the scale of spoil dumping offshore from Newcastle is such that impacts can be expected over a large scale. While there have been few specific studies, there is evidence that much of the spoil is rapidly transported outside the spoil grounds and thus the area of impact is greater than that of the immediate dumping ground itself (Norman et al., 1992). In addition, past sampling of the fine fraction of surficial sediments detected discernible trace-metal enrichment along the inner shelf adjacent to the spoil ground. Concentrations in the sand fraction were also marginally elevated, but over a comparatively smaller spatial scale (1 to 2 km north-east) reflecting their lower mobility (Matthai and Birch, 2000a, b). There has been few studies of the impacts of spoil dumping operations on the physico-chemical conditions in the affected area and none on the ecological impacts. This issue is further addressed in Chapter 6.

Marine debris

Marine debris is classified as a key threatening process under both state and Commonwealth legislation. Most studies worldwide have indicated that plastics are the major contributor to marine debris although a range of other materials is commonly encountered. World attention has recently been strongly drawn to the issue of marine debris through the discovery of the North Pacific Garbage Patch (e.g. Moore et al., 2001), where floating plastic debris is present in densities of over 350 000 pieces km^{-2}, covering an area of approximately 1.7 million km^2. Impacts on marine organisms have received some attention, mostly related to entanglement by, and ingestion of, various plastics by larger organisms. In Australia, entanglement or ingestion of marine debris has been recorded to affect at least 77 species of marine animal (Ceccarelli, 2009). Until very recently (see below), there have been very few studies of prevalence, sources, fates and effects of marine debris at scales relevant to the HCRCMA region.

In the Northern Rivers Catchment Management Authority (NRCMA) region, studies of beach-cast litter have been conducted in northern NSW (Frost and Cullen, 1997). In addition, studies of debris on subtidal reefs between the Tweed and South West Rocks indicated that sites that are important for conservation (i.e. with high biodiversity of indicator organisms) also have high debris loads; this is possibly because of the services that these diverse areas provide for fishing and other recreational activities (Smith et al., 2008).

Two recent studies by Gladstone (2009) and the NSW Marine Parks Authority (MPA) (2010b) provide the first assessments of marine debris load on subtidal reefs within the HCRCMA region. One survey (MPA, 2010b) focused on 13 sites within the Port Stephens-Great Lakes Marine Park (PSGLMP) while the other was a collaborative study involving 3 volunteer groups from across the HCRCMA region (Forster, Charlestown, Terrigal). Surveys in the PSGLMP used timed swims (45 min.) by a pair of divers covering approximately 500 m^2 of reef. Debris loads were low at most offshore sites and, as a result, and in order to maximise the clean-up outcomes, the final surveys focused on specific sites with known, moderate to high debris loads. In total, ~16 ha of reef was cleaned within the PSGLMP. Most sites outside Port Stephens contained little or no debris (max. was 6 pieces of fishing line per hectare at The Pinnacle) while all sites within Port Stephens contained debris, mostly fishing-related (ranging from 4 items ha^{-1}

at Fly Point to >100 ha^{-1} at the Breakwall – Figure 4.11). The study also targeted discarded traps and removed 22 from an area of just over 100 ha.

In the second study (Gladstone, 2009), members of 3 underwater volunteer groups (Great Lakes Underwater Group – GLUG, Charlestown Dive Social Club, and Terrigal Underwater Group – TUG) were trained in quantitative methods for assessment of fish biodiversity, abundances of urchins (*Centrostephanus rodgersii*), and marine debris. Thirteen sites were evaluated between Forster and Terrigal and debris load was low at most sites. A total of 34 debris items were recorded with the maximum debris load (17 pieces) recorded from Moon Island off Swansea. Sites adjacent to Forster had very low loads (1 item across all reefs) and sites at Terrigal contained 9 items. Fishing-related debris was most prevalent (56%) (Gladstone, 2009).

Figure 4.11 Some of the debris removed from the Breakwall at Port Stephens (Reproduced from MPA, 2010b).

In addition to these more formal studies of marine debris, the shores of the HCRCMA region are targeted for debris removal at least once per year during Clean Up Australia Day. In addition, many divers across the region participate in the annual Project AWARE clean-up activities targeting subtidal habitats. In 2009, volunteers from the HCRCMA region were part of the 46 registered groups Australasia-wide that collected >7.5 t of debris from subtidal reefs and >11 t from shorelines (Project AWARE, 2010).

Other impacts

Many other activities have the potential to affect marine habitats within the region but data on the extent of the activities and types and magnitudes of impact are mostly lacking. For example, off-road vehicles are used on many of the region's beaches and comprise a popular attraction at the northern end of Stockton Beach. Such activities have been shown to have detrimental effects on the animals living in the intertidal zone and the plants and animals (e.g. birds) inhabiting the dunes (e.g. Defeo et al., 2009). Diving activities have also been shown to potentially damage the more sensitive components of marine benthic communities (e.g. Rouphael and Inglis, 2001) – this activity is particularly popular around the Port Stephens area both within Nelson Bay and at the offshore islands. Specific assessments of such impacts are lacking for the region.

Primary data sources

The majority of information on dredging and spoil-dumping activities is held by NPC. While these data are available on request (but were not made available for this review). Specific information on marine debris in the HCRCMA region comes from reports by Gladstone (2009) and MPA (2010b) to the HCRCMA. Project AWARE <http://www.projectaware.org/> and Tangaroa Blue <http://www.oceancare.org.au/site/> maintain databases on marine debris and provide resources to encourage and facilitate marine cleanup activities.

Data description and assessment

There is a paucity of information on most aspects of dredge-spoil dumping offshore from Nobbys Head. Studies that have been conducted indicate a potentially widespread effect across the inner shelf through transport of sediments under high-energy conditions and through deposition of spoil containing trace metals. With the exception of those listed above, there are no studies quantifying the prevalence, source and impact of debris in marine habitats. This is surprising given its status as a key threatening process at both state and national level.

4.4 Water quality

Trace metals

Very few studies of the concentrations of trace metals have been conducted within the HCRCMA region. Apte et al. (1998) examined the concentrations of 10 trace metals along the New South Wales coast (including sites off Terrigal) and found that metal concentrations were amongst the lowest recorded in the southern hemisphere and agreed well with concentrations found in the open ocean. There was no evidence of any natural terrestrial influence on trace metal concentrations in coastal waters in the HCRCMA region. As mentioned above, inner shelf sediments adjacent to the Port of Newcastle have elevated concentrations of trace metals associated with disposal of spoil (from dredging of the Hunter River) offshore from Nobbys Head (Matthai and Birch, 2000a, b).

Recreational water quality

Beachwatch and the Beachwatch Partnerships Program

Water quality for Primary Contact Recreation is monitored in NSW by DECCW under the Beachwatch program and by local Councils under the Beachwatch Partnership Program. Table 4.10 lists the locations of monitoring at ocean beaches within the HCRCMA region under these programs. The Beachwatch annual reports (Beachwatch, 2008a, b; 2009a, b) show that the beaches monitored in the HCRCMA were some of the cleanest in NSW with 100% compliance with Beachwatch guidelines in 2008.

The only recorded failure from the HCRCMA region was a single low-level contamination of faecal coliforms measured at Newcastle Ocean Baths and Canoe Pool during wet weather in December 2007.

Table 4.10 Ocean beaches in the Beachwatch and Beachwatch Partnerships Program.

Site Name	LATITUDE	LONGITUDE	Council
Zenith Beach	-32.72193	152.18441	Port Stephens Council
Box Beach	-32.73307	152.18220	Port Stephens Council
Fingal Bay	-32.74466	152.17143	Port Stephens Council
One Mile Beach	-32.78068	152.11591	Port Stephens Council
Birubi Beach	-32.78530	152.07640	Port Stephens Council
Stockton South Beach	-32.91230	151.78800	Newcastle City Council
Nobbys Beach	-32.92592	151.79208	Newcastle City Council
Newcastle Beach	-32.93211	151.78526	Newcastle City Council
Bar Beach	-32.94404	151.76559	Newcastle City Council
Merewether Beach	-32.94978	151.75703	Newcastle City Council
Burwood North Beach	-32.95867	151.74513	Newcastle City Council
Burwood South Beach	-32.96131	151.74125	Newcastle City Council
Glenrock Lagoon Beach	-32.96410	151.73844	Lake Macquarie City Council
Dudley Beach	-32.97442	151.73068	Lake Macquarie City Council
Redhead Beach	-33.01561	151.71991	Lake Macquarie City Council
Blacksmiths Beach	-33.08201	151.65752	Lake Macquarie City Council
Swansea Heads Little Beach	-33.08899	151.66336	Lake Macquarie City Council
Caves Beach Bathing	-33.11200	151.64630	Lake Macquarie City Council
Frazer Beach	-33.18793	151.62299	Wyong Shire Council
Birdie Beach	-33.20606	151.60625	Wyong Shire Council
Budgewoi Beach	-33.23872	151.57007	Wyong Shire Council
Lakes Beach	-33.25423	151.56331	Wyong Shire Council
Hargraves Beach	-33.26552	151.56256	Wyong Shire Council
Jenny Dixon Beach	-33.27180	151.56395	Wyong Shire Council
Cabbage Tree Bay	-33.27701	151.56885	Wyong Shire Council
Lighthouse Beach	-33.27992	151.57295	Wyong Shire Council
Gravelly Beach	-33.28556	151.57153	Wyong Shire Council
Soldiers Beach	-33.28824	151.56878	Wyong Shire Council
The Entrance	-33.34832	151.50275	Wyong Shire Council
North Entrance	-33.33466	151.50667	Wyong Shire Council
Blue Bay	-33.35517	151.50180	Wyong Shire Council
Toowoon Bay	-33.36171	151.50065	Wyong Shire Council
Shelly Beach	-33.37324	151.48790	Wyong Shire Council
Blue Lagoon	-33.37934	151.48593	Wyong Shire Council

Site Name	LATITUDE	LONGITUDE	Council
Bateau Bay Beach	-33.38464	151.48315	Wyong Shire Council
Terrigal Beach	-33.44790	151.44690	Gosford City Council
Avoca Beach	-33.46990	151.43640	Gosford City Council
North Avoca Beach	-33.45830	151.44030	Gosford City Council
McMasters Beach	-33.49910	151.42530	Gosford City Council
Copacabana Beach	-33.49130	151.43290	Gosford City Council
Forrester's Beach	-33.41360	151.46480	Gosford City Council
Killcare Beach	-33.53260	151.36000	Gosford City Council
Pearl Beach	-33.54520	151.30810	Gosford City Council
Umina Beach	-33.52821	151.31553	Gosford City Council
Wamberal Beach	-33.43060	151.44840	Gosford City Council

Primary data sources

The primary sources of data are published papers (Apte et al., 1998) and from the Beachwatch annual reports (Beachwatch 2008a, b; 2009a, b). Beachwatch data from all monitored beaches are available from <http://www.environment.nsw.gov.au/beachsoeapp/>.

Data description and assessment

Apte et al. (1998) examined trace-metal concentration at five locations along the NSW coast. At each location, three sites were sampled that were separated by 4 - 6 km. The concentrations of silver (Ag), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn) were examined. Concentrations of all metals were comparable to those found in the surface waters of the open Pacific Ocean, and the study concluded that fluvial inputs and coastal processes were of limited importance in determining trace-metal concentration in NSW waters.

Under the Beachwatch program, local Councils collect monthly water samples thst are analysed for both faecal coliforms and enterococci bacteria. Seasonal (summer and winter) compliance data are updated each October when the *Beachwatch State of the Beaches* annual report is released. Data are updated in the middle of the following month for all sites. Sets of statistics on annual compliance and monthly water quality, as well as data from individual samples, can be downloaded from the web page.

Besides these studies, and the regular monitoring of faecal coliforms around sewage outfalls, there is very little information for the HCRCMA region. Not all beaches or waterways are monitored, and thus changes in water quality at these sites are difficult to detect.

Additional data sources

National Health and Medical Research Council (NHMRC) (1990) water quality guidelines provide recommended safe levels of faecal coliforms and enterococci bacteria in recreational water. A new version of these guidelines was published in 2005 (NHMRC, 2005), but these have not yet been adopted in NSW. The ANZECC fresh and marine water quality guidelines (ANZECC, 2000) also outline acceptable levels for bacteria, nutrients and toxicants.

Beachwatch produced an information package and field manual for any parties interested in monitoring recreational water quality (DEC, 2004). This manual provides background information and guidelines for collecting and analysing water samples.

4.5 Climate change

The scientific evidence for global warming, climate change, and their potential impacts, are summarised in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2007a; 2007b; 2007c). This is widely acknowledged as the authoritative reference on climate change science and a basis for policy formulation on greenhouse gas emissions reduction and adaptation. The main findings of the IPCC 2007 Fourth Assessment are:

- Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and changed land use, while increases in methane and nitrous oxide are primarily due to agriculture.
- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.
- For the next two decades, a warming of ~0.2°C per decade is projected for a range of emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at the year 2000 levels, a further warming of ~0.1°C per decade can be expected.

Climate change is therefore recognized as one of the most important issues facing the world. This is particularly true in countries like Australia, where approximately 80% of the population reside within 50 km of the coast (CSIRO, 2002). NSW is faced with the prospect of long-term changes in climate, brought about by increasing concentrations of greenhouse gases in the Earth's atmosphere over the past 100 - 200 years (Hennessy et al., 1998). Predictions based on climate models and current emission levels suggest that, over the next 50 - 100 years, average global temperatures will rise between 1.4 - 5.8° C (Hennessy et al., 2004b). Climate change scenarios for NSW suggest that coastal temperatures may rise between 0.2 - 1.6° C by 2030 with a number of serious consequences for coastal human communities and infrastructure, and for marine populations and communities. The key predictions that potentially affect the marine environment in central NSW are briefly discussed below.

Physical changes

Sea level

One of the most widely predicted changes associated with climate change, is the rise in global sea level. The NSW Department of Environment and Climate Change (now DECCW) (DECC, 2007) recommend that an increase of 0.91 metres (m) by 2100 is adopted for the NSW coast, based upon the IPCC's Fourth Assessment report and work by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (IPCC, 2007a; McInnes et al., 2007). IPCC (2007a) predictions are that average global sea level rise (ignoring ice-flow melt) may be between 0.18 - 0.59 m by 2090 - 2100. There is large uncertainty relating to the contribution of ice-flow melt, with an initial projection of a further 0.2 m sea level rise, giving an adjusted global range of 0.18 - 0.79 m by 2100. Recent modelling by CSIRO (McInnes et al., 2007) indicates that, in addition to the global sea level rise, mean sea level along the NSW coast may increase by up to 0.12 m as a consequence of thermal effects on the EAC. Combining the relevant global and local information, sea level on the NSW coast is expected to rise by 0.18 - 0.91 m by 2090 - 2100 (DECC, 2007).

Sea level rise is predicted not to be uniform across the globe due to the influence of currents, water temperature, and other more complex factors (Peltier, 2009). This variation is also evident at the scale of the Australian continent with the highest sea level rise predicted for the NSW coast (Figure 4.12).

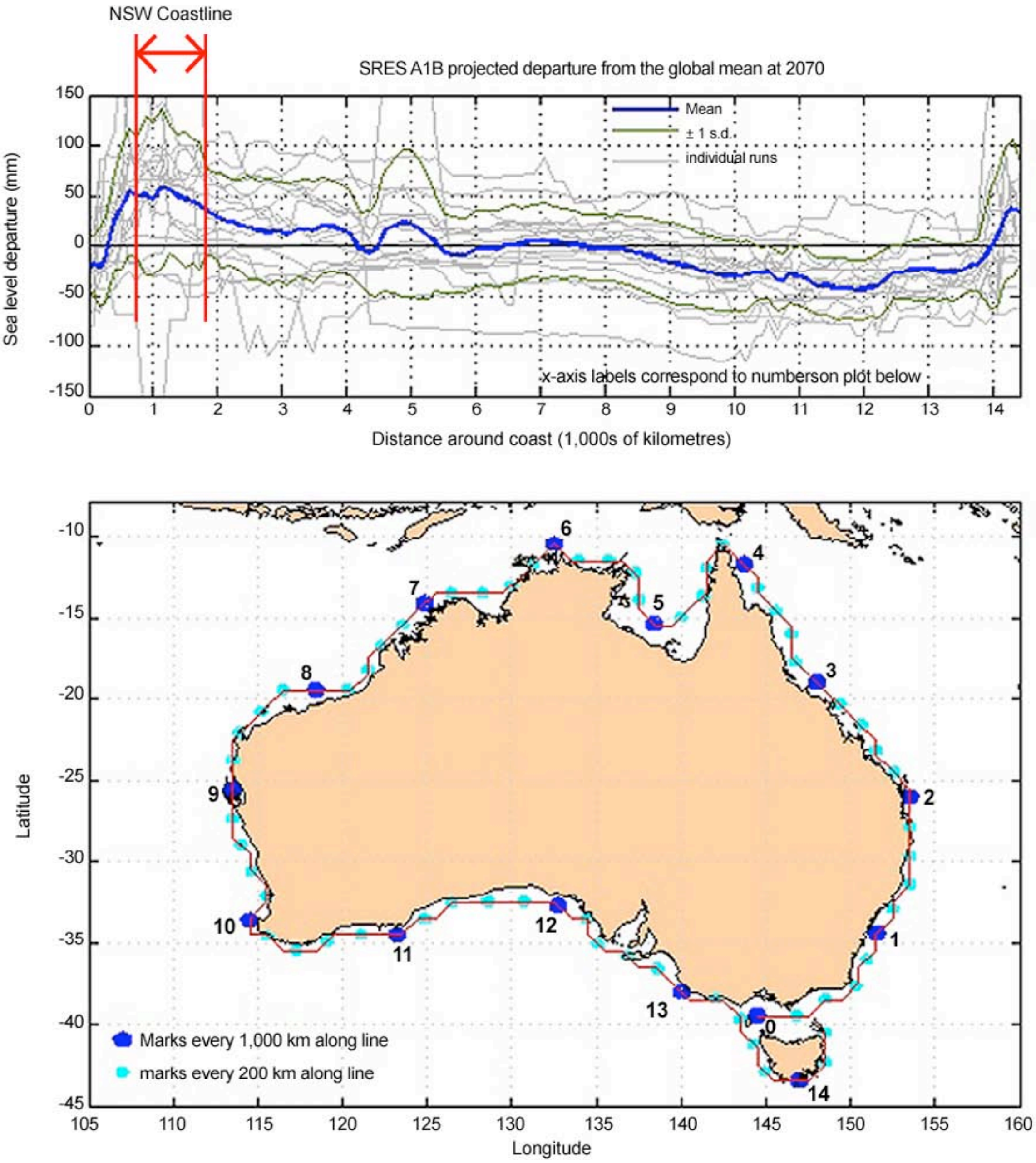


Figure 4.12 Regional variation in projected sea level rise along the Australian coastline by 2070 for a mid-range greenhouse gas emissions scenario (Source: CSIRO 2008). Note: numbers positioned around coastline are shown on the x-axis of the top graph.

CSIRO modelling results projected that sea level rise along the NSW coast would be up to 8 cm greater than the global average by 2030, and 12 cm greater by 2070 (McInnes et al., 2007). This regional variation is associated with a projected strong warming of the sea surface temperatures

(SST) in the region and a strengthening of the EAC. Linear interpolation and extrapolation of these upper-limit projections were used to predict a 0.1 m rise by 2050 and a 0.14 m rise by 2100. This, in part, explains the differences in the NSW benchmark figures from those adopted for Victoria (Victorian Coastal Council, 2008) and proposed for Queensland (Queensland Department of Environment and Resource Management, 2009a; 2009b).

Sea level rise will raise the average water level of oceans and estuaries. This will affect high and low tide levels and a range of other processes responsible for shaping the NSW coastline. Determining how the coast and estuaries will respond is complex as this will be driven by a range of local conditions. However, some generalities can be expected:

- increased or permanent tidal inundation of land by seawater;
- recession of beach and dune systems and, to a lesser extent, cliffs and bluffs;
- changes in the way that tides behave within estuaries;
- saltwater extending further upstream in estuaries;
- higher saline water tables in coastal areas; and
- higher coastal flood levels due to a reduced ability to effectively drain low-lying coastal areas.

El Niño Southern Oscillation

Weather patterns in Australia are strongly linked to the El Niño Southern Oscillation (ENSO), which is measured as the Southern Oscillation Index (SOI). Under current climate change scenarios, a more intense ENSO is predicted to result in fewer tropical and east coast cyclones during negative SOI (El Niño) years, and more frequent and more intense tropical and east coast cyclones during positive SOI (La Niña) years (McInnes et al., 1998; Hennessy et al., 2004a; 2004b). While the average wave climate of NSW may change little, the spatial and temporal variability of the wave climate will increase, with fewer waves from the north and east during negative SOI periods, and more and higher waves from these areas during positive SOI periods. Several authors (Short et al., 2001; Ranasinghe et al., 2004; Short and Trembanis, 2004) suggest that this is likely to induce enhanced beach rotation to the north during negative SOI periods, and enhanced rotation to the south, coupled with more severe beach erosion, during positive SOI periods.

Tropical cyclones

The wave climate of northern NSW is strongly affected by tropical cyclones (e.g. Short and Woodroffe, 2009). The frequency and intensity of cyclones are likely to be affected by climate change; however, the nature of these changes is difficult to predict under current climate models (CSIRO, 2002). It is possible that tropical cyclones will be more intense and track more pole-ward, particularly during years with positive SOI (Walsh, 2004). This is likely to have a significant impact on the beaches of northern NSW, as more and higher waves arrive from the northeast and east, resulting in greater beach erosion and enhanced rotation of beaches to the south, focusing erosion on the northern end of beach systems.

Mid latitude cyclones

Mid-latitude cyclones also contribute to the wave climate of northern NSW (e.g. Short and Woodroffe, 2009) and climate change is likely to result in a decrease in the number, but an increase in the intensity, of these cyclones. This may impact the wave climate of northern NSW by reducing the frequency of waves arriving from the south, but increasing the height of those waves (Walsh, 2004). As wave energy is a function of the wave height, total wave energy from the south may increase, which would, in turn, enhance northward sand transport and beach rotation.

Biotic impacts

Although difficult to predict, all coastal ecosystems will be affected in some way by climate change. However, nearshore environments, that face inundation from sea-level rise and shoreline erosion, leading to loss of habitat, are most likely to be affected. These include macroalgal-dominated reefs, mangroves, saltmarshes, seagrass and beach environments. While this review of marine knowledge of the HCRCMA region focuses on marine habitats per se, the strong links between estuarine productivity and processes, and marine habitats, justifies a brief summary of climate change impacts on key estuarine habitats as well as those that are fully marine.

Macroalgae

Macrolagae occur in waters all around Australia, from encrusting species that consolidate coral reefs to the giant kelp forests in southern waters. There may be 3 000 – 7 000 species in Australian waters, many of which are undescribed (McCarthy and Orchard, 2007). Distributions of kelp species in Australia and elsewhere are determined by temperature, nutrients, turbidity, light penetration, wave action and sand scour, and the relative prevalence of herbivores and their predators (Dayton, 1985; Steneck, et al., 2008). Large declines of giant kelp and other macroalgae have been attributed to rising sea temperature (Edyvane, 2003), but deforestation, agriculture, urban development and other land-use practices can alter sedimentation and runoff characteristics, affecting kelp/algal habitats. Macroalgal habitats are likely to be sensitive to climate change with southern macroalgal assemblages likely to be most affected. Composition of the algal habitats is likely be modified, and species richness will change (DECC, 2009).

Mangroves

Mangrove communities are diverse assemblages of trees and shrubs that are found fringing much of the tropical and subtropical coastline of Australia in wave-sheltered areas. Mangroves act as an important buffer between land and sea, filtering terrestrial discharge, decreasing the sediment loading of coastal waters and maintaining the integrity of coastlines (Lovelock and Ellison, 2007). Mangroves are highly productive systems, performing a valuable role in nutrient and carbon cycling. Mangroves act as a nursery and breeding habitat for marine species such as fish, crabs and prawns, including many commercially valuable species (Kathirisan and Bingham, 2001; Manson et al., 2005); they also support populations of a variety of terrestrial organisms, such as birds.

Mangroves have been shown to be both adaptable and resilient. While they can be aggressive colonisers, they remain under threat from coastal development, modification of river catchments and pollution. The major climate change threats to mangroves are considered to be associated with rising sea level and alteration of rainfall patterns, especially a reduction in rainfall in conjunction with increasing temperatures. Mangroves grow in calm intertidal areas, on shorelines with a low profile; therefore, a small rise in sea level may inundate large areas of mangroves (Lovelock and Ellison, 2007; Gilman et al., 2008). However, the potential response of mangroves to sea-level rise and inundation is complex and will depend on coastal dynamics. If the rate of vertical sediment accumulation (or accretion) by mangrove communities exceeds sea-level rise, then mangrove areas might not alter or might even increase. Conversely, if sea-level rise exceeds accretion, mangroves will retreat landwards (Gilman et al., 2008).

Saltmarshes

Coastal saltmarsh ecosystems are fragile areas of saltwater wetland habitat occupied by communities of salt-tolerant vegetation. These plants are usually low (<0.5 m tall) and adapted to harsh growing conditions, such as high salinity, full light exposure and moisture extremes. They provide extensive ecosystem services, including biofiltration, gas regulation, carbon and nutrient retention, physical protection of coastlines during storms, and habitat for fauna, algae and microbial communities, many of which are unique. Organic material is transferred between saltmarshes, mangroves and coral reefs (on tropical coasts) by a variety of processes and, in particular, by mobile fauna through grazing, predation and excretion (Lovelock and Ellison, 2007).

Many changes in climate variables will affect the physiology, ecology and resilience of saltmarshes. These include increases in atmospheric CO^2 concentrations, warming of air and sea temperatures, rising sea level, increasing tidal amplitudes, potential colonisation by mangrove propagules carried on flooding tides, changes in ocean circulation, rainfall patterns, and frequency and intensity of storms. Reduced rainfall can also lead to salinisation and mangrove invasion of saltmarsh and freshwater wetlands. The primary impact of climate change, however, is likely to be sea-level rise (Voice et al., 2006).

Responses to past increases in sea level suggest an inland migration of saltmarshes. Reductions in the area of saltmarsh are also likely if accretion cannot keep pace with rising sea level, especially in areas with a low tidal range, where rainfall is reduced, and where sediment inputs are not sufficient to contribute to the maintenance of surface elevation. Of primary concern is the impact on saltmarshes due to 'coastal squeeze' where human modification of the coastal zone by building structures, such as roads and sea walls, prevents landward migration of saltmarshes. In addition, other anthropogenic activities have decreased the resilience of saltmarshes to climate change: humans have cleared and modified saltmarshes, disrupted connectivity, increased nutrient inputs, and altered sediment dynamics. Loss of biological diversity is also a likely outcome of reductions in saltmarsh area and the encroachment of mangroves into freshwater marshes. Sediment trapping, carbon sequestration and nutrient cycling will be reduced by declines in wetland cover, resulting in higher turbidity and higher nutrient loading in nearshore waters. Carbon and nutrient subsidies to nearshore waters would also be reduced, resulting in reductions in the productivity of nearshore food webs (Voice et al., 2006).

Seagrasses

Australia has the world's highest diversity of seagrasses and the most extensive seagrass beds (DECC, 2009). Of the ~60 species found globally, over half occur in Australian waters (King et al., 1990; Jernakoff et al., 1996; Walker et al., 1999). Seagrass beds play a vital role in nutrient and carbon cycling and act as a buffer between the land and the sea. They also baffle water flow, trap sediments and filter coastal waters. Seagrass beds form important habitat for many species of fish and crustaceans, including exploited species; declines in seagrass cover are consequently often detrimental to local economies (Hindell, 2006). Studies in NSW suggest that 70% of fish caught commercially and recreationally are associated with seagrasses or mangroves at some stage of their life cycles (Zann, 2000). Seagrasses also support internationally important populations of endangered species, such as fish, green turtles and dugongs (Hughes et al., 2009).

Seagrass beds are under threat from both anthropogenic and natural impacts. Natural events, such as coastal erosion, abnormally high temperatures, cyclones, storms and heavy and prolonged rainfall (resulting, for example, in large-scale plumes of turbid water discharging from rivers) can all damage or destroy seagrass beds. Recovery of seagrass communities from disturbance may take many years, depending on the severity and extent of impact. Seagrasses are likely to be vulnerable to climate change and, in particular, to warming temperatures and altered rainfall, wave and storm regimes. These factors may negate potential increases in productivity due to increased CO^2 levels (DECC, 2009).

Temperature is a major factor controlling the biogeographic distributions of seagrasses in Australian waters (Walker and Prince, 1987; Jernakoff et al., 1996). As climate warms, tropical species are expected to extend their ranges southwards and, depending on resource availability and dispersal abilities, temperate species will retreat. This will result in shifts in community composition as a consequence of variability in the rates of species responses. In southern Australia, the southward migration of temperate species is limited by the availability of coast and also by the estuarine modification resulting from the high density of human populations. As the greatest warming of Australian waters is predicted off south-east Australia, it has been suggested that some cold-temperate seagrass beds may be highly vulnerable to climate change (Campbell et al., 2006).

Beaches

Biotic communities inhabiting beaches are characterised by species adapted to a highly dynamic environment; these include: microbes, primary-producing microscopic algae and invertebrates (mostly nematodes, crustaceans, polychaetes and molluscs). The total abundance (and productivity) of these organisms decrease with increasing body size, while biomass follows the opposite trend (Schlacher et al., 2008). More is known about the macrofauna (organisms retained by a 1 mm mesh), than meiofauna and microbes which are important in carbon cycling. The remaining discussion focuses on macrofauna.

The species richness and abundance of beach communities are driven by a combination of physical processes, the most important of which are latitude, tidal range, sand-grain size and beach-face slope (Schlacher et al., 2008). Climate change is likely to operate at the community level by decreasing the effective latitude, thereby increasing macrofaunal species richness, but decreasing total abundance (Defeo and McLachlan, 2005). In terms of community composition, warming would most severely affect those species living close to their upper thermal limit, and especially those unable to acclimatise or adapt. Although temperature effects on beaches are expected to be subtle (Brown and McLachlan, 2002), species lacking dispersive larval stages (for example, some crustaceans) could be at particular risk of extinction. Moreover, even dominant filter feeders, such as bivalve molluscs, can be highly sensitive to temperature change, which in some cases can result in mass mortalities, with dramatic consequences for community structure (Riascos et al., 2009). If increased storm activity contributes to the suspension of fine sediments and their offshore transport, the increase in mean grain size on beaches will result in declining abundance and species richness. This effect has been demonstrated on small scales, where coarse tailings from mining operations cause localised declines in community abundance (McLachlan, 1996). Ocean acidification is likely to affect both the physical and the biological components of beaches, the latter because many sediments have high (often biogenic) carbonate fractions, and the former because many beach species have calcified exoskeletons (outer shells). However, due to a complete absence of studies, the magnitude of these effects remains unknown (Jones et al., 2004).

Sea-level rise driven by climate change will affect beach communities through habitat loss and fragmentation, but this will be restricted largely to areas suffering from coastal squeeze. As sea level rises, supralittoral habitats (i.e. habitats above the high tide mark) will be lost first (Dugan et al., 2008), eliminating fauna of greatest concern for conservation – especially turtles and birds (Schlacher et al., 2008). Where habitats are lost, the unique fauna of the beach may be replaced by surf zones or engineered coastal-defence barriers (such as sea walls), with associated changes in biodiversity and ecosystem function (Jones et al., 2004).

The HCRCMA region

Rising sea levels are likely to have a major impact on biodiversity in the HCRCMA region. A number of ecological communities may be threatened and most communities are likely to undergo some change in composition. Salt-water wetlands on the immediate coastline are likely to be affected by rising waters. Other coastal low-lying communities, such as wet heaths, coastal forests and freshwater wetlands, are likely to be at risk from erosion, salt-water inundation of water tables, and increased sedimentation on the floodplains. Salt-water migrating further upstream is likely to have implications for farm irrigation and groundwater. Increased temperatures, drier conditions in winter, and the potential for more frequent bushfires, are likely to have an impact on ecosystems across the region.

The major impact on the region's coastal zone is likely to be from sea level rise and resulting inundation and erosion. Rising sea levels may exacerbate flood risk around estuaries and in coastal rivers and floodplains. In addition, any increase in rainfall intensity in severe storms may impact on flood risk more broadly across the area. Infrastructure located on the large, low-lying floodplains of the Hunter River and Karuah/Myall River systems, as well as adjacent to the estuaries, will be particularly vulnerable.

In 2007, the NSW Government carried out a project to identify low-lying areas in the Hunter and Central Coast areas at risk from sea level rise resulting from climate change (DECC, 2008). High-resolution terrain surveys, using Light Detection and Ranging (LiDAR) technology, were conducted to map low-lying areas in the Wyong, Lake Macquarie, Newcastle City and Port Stephens Council areas. The project identified a range of infrastructure and land-use categories below one metre elevation that could be affected by rising sea levels. These included:

- >160 hectares of residentially-zoned land,
- ~73 km of roads,
- >3 000 hectares of rural zoned land,
- >6 000 hectares of conservation lands, and
- > 1 500 existing addresses.

The proximity of development to the coast will make these areas vulnerable to the impacts of coastal erosion. Key infrastructure that is likely to be affected as water levels rise include Newcastle Port facilities and low-lying roads adjacent to estuaries such as Lake Macquarie, Port Stephens and Wallis Lake.

In 2009, DECCW (formerly DECC) identified existing NSW residential buildings at risk of inundation from a sea-level rise of 1.1 m and a 1-in-100 yr storm tide (DECC, 2009). Four of the 11 areas at greatest risk are within the Hunter and Central Coast region and include Lake Macquarie, Wyong, Port Stephens and Newcastle.

The predicted environmental changes resulting from climate change are likely to have many consequences for coastal and marine communities within the HCRCMA region. The wave climate may become more extreme due to the increased intensity of tropical, east coast and mid latitude cyclones, which poses a direct threat to coastal infrastructure and nearshore biotic communities (see section 2.5). Higher waves are likely to arrive more frequently from the northeast, east and the south as a result of this increased activity, which will enhance longshore sand transport and beach rotation. Consequently, beaches will become more dynamic, responding to greater periods of higher wave energy. Coastal erosion will be enhanced and, because of the more extreme wave climate, beaches will recover more slowly. As beach rotation affects longshore sediment transport, the enhanced erosion and, particularly northward rotation, could also lead to accelerated net longshore transport and associated net beach erosion on many of the beaches of central and northern NSW. Any further sea level rise will further exacerbate these effects (DECC, 2009).

Primary data sources

The primary data for this section were extracted from government reports including: DECC reports on climate change risks to Australia's coast (DECC, 2009); the summary of climate change impacts for the Hunter Region (DECC, 2008); the high resolution terrain mapping of the NSW Central and Hunter Coasts for assessments of potential climate change impacts (NSW Department of Planning, 2008); and Port Stephens Council local adaptation pathways program for climate change assessment (BMT WBM, 2009).

Data description and assessment

CSIRO have examined the fine-scale effects of climate change scenarios for NSW, using historical data and climate models (CSIRO, 2002; Hennessy et al., 1995a;b; 1998; 2004a, b). Effects were modelled under a range of different scenarios including no changes to greenhouse gas emissions and a range of emission-reduction scenarios. This project found that sea levels and mean temperatures in NSW have been rising over the past 50 - 100 years. They also predicted future levels of change from these data under each scenario, and examined potential impacts to coastal and biotic communities.

In terms of the HCRCMA region, the CSIRO models of future change provide a good basis for planning. They provide comprehensive predictions of sea-level and temperature rise, changes in ENSO, which will lead to changes in cyclonic and rainfall events, and extreme weather events. Predictions of climate change impacts are lacking for many biotic communities.

5 Management Arrangements, Areas of Cultural Importance and Threatening Processes

This chapter provides a description of some of the social and cultural values of the marine resources of the HCRCMA region and the specific approaches applied to their management. The need for such management arrangements is examined by outlining the key threatening processes and a range of other threats to the region's marine habitats and biota.

5.1 Marine protected areas

Marine Protected Areas in NSW aim to conserve marine biodiversity, maintain ecological processes and provide for a range of sustainable uses of the marine environment. In accordance with state and Commonwealth planning policies, a key objective of marine planning within marine parks is to achieve comprehensive, adequate and representative protection of ecosystems and habitats, and in doing so protect the full range of biological diversity found within their boundaries (ANZECC TFMPA, 1998).

Marine Parks are designed to cater for multiple uses, and generally extend from the uppermost tidal limits of estuaries to the 3 nm, offshore limit of NSW coastal waters. The NSW Marine Parks Authority (MPA) is required to prepare a zoning plan for each marine park under the *Marine Parks Act 1997* (*MP Act*). This plan outlines what activities can be undertaken in different areas of the Marine Park, primarily through the application of four types of zones: sanctuary, habitat protection, general use, and special purpose.

The Hunter-Central Rivers Catchment Management Authority (HCRCMA) region is located within both the Manning Shelf Bioregion and Hawkesbury Shelf Bioregion, which, in combination extend from just south of Coffs Harbour to the mouth of the Hawkesbury River (Figure 5.1). Twenty percent of the state's coastline, measuring 362 km, lies within the boundaries of these bioregions, representing an ocean area of approximately 1 721 km^{-2}. This HCRCMA region contains one Marine Park (Port Stephens-Great Lakes Marine Park – PSGLMP) which covers 98 000 ha (including estuaries) and represents ~42% of the region (Table 5.1). The PSGLMP lies wholly within the Manning Shelf Bioregion; there are no Marine Parks in the Hawkesbury Shelf Bioregion.

Table 5.1 Regional location of the Marine Park within the HCRCMA.

Marine Parks – HCRCMA region	Zone type	% of HCRCMA marine region
Port Stephens-Great Lakes Marine Park	Sanctuary Zone	6.0%
	Habitat Protection Zone	20.5%
	General Use Zone	15.7%

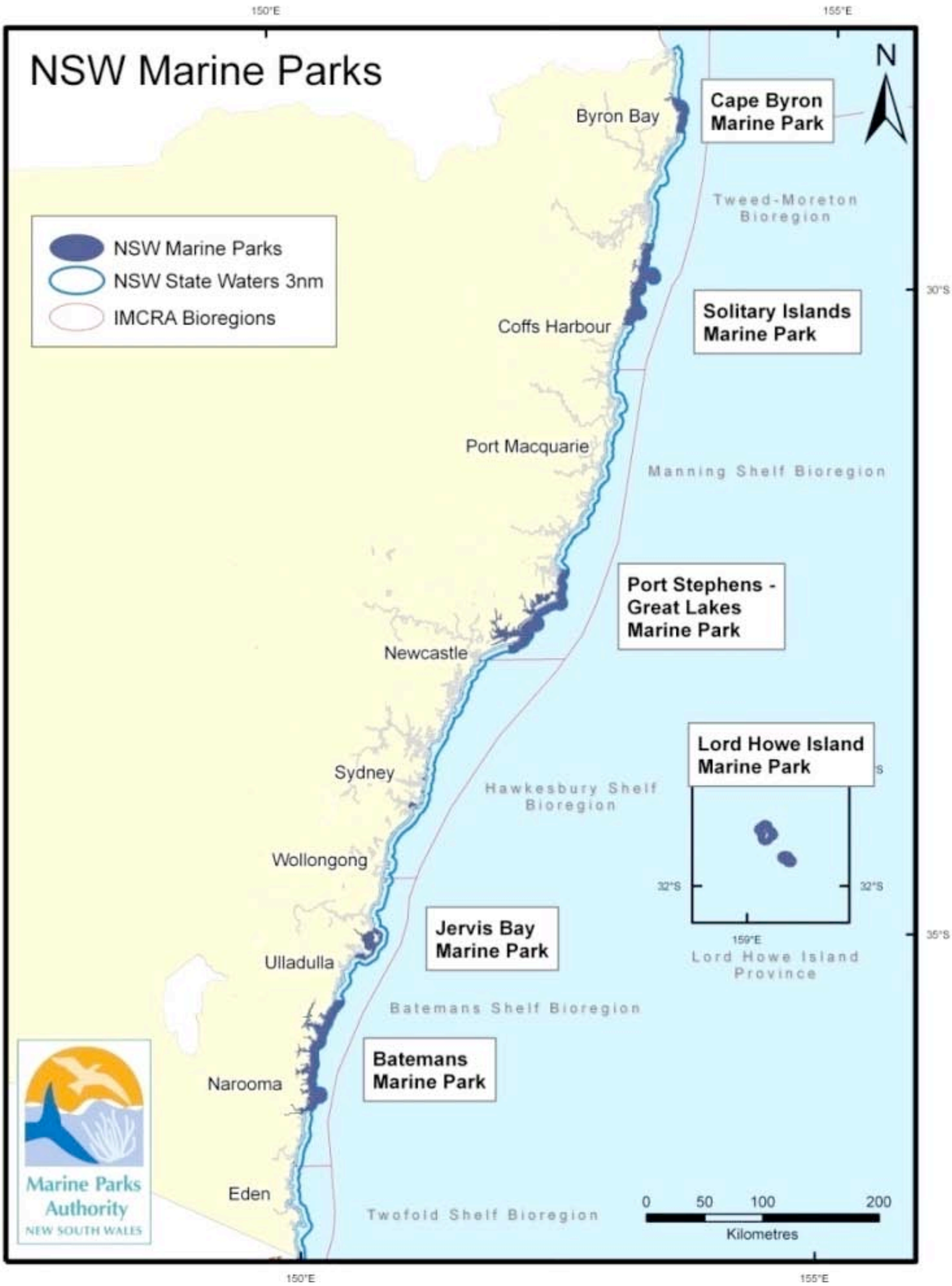


Figure 5.1 Extent and distribution of marine parks throughout NSW.

Aquatic Reserves in NSW are declared under the *Fisheries Management Act 1994* (*FM Act*). They are relatively small in area and are generally designed to protect a particular feature of the marine environment at a local level, or one that is under particular threat. There are currently thirteen Aquatic Reserves in NSW; while most of them are located in the Hawkesbury Shelf Bioregion, they are all outside the HCRCMA region.

The only other Marine Protected Area in the HCRCMA region is a small (287 ha) marine extension adjacent to the Bouddi National Park (the Bouddi National Park Marine Extension) which was established in 1973. While covering only a relatively only small area of marine habitat, recent surveys have indicated that it has a measurable effect in conserving marine resources targeted by recreational fishers (Gladstone, 2001).

A key objective of Marine Park planning is to achieve comprehensive, adequate and representative protection of ecosystems and habitats; however, because mapping of estuarine and marine habitats is currently incomplete, it is not possible to accurately assess the exact level of representation of each defined habitat type. The habitats used to assess representation are defined within a hierarchical classification scheme, and there is ongoing research to improve both habitat mapping coverage (e.g. Jordan et al., 2010) and the classification scheme (e.g. Malcolm et al., 2010b). Such research will improve the likelihood that the habitats used are effective surrogates, which are components shown or assumed to be related to biological diversity that are more easily measured or mapped than species diversity itself. In addition, the habitats are only used to assess the level of representation within sanctuary zones.

There is a requirement that zoning plans are reviewed after the first 5 years of operation, and every 10 years thereafter. The purpose of the review is to determine whether the zoning plan for the Marine Park remains appropriate for meeting the objects of the *MP Act*. A set of criteria, based on the national and state criteria for zoning Marine Protected Areas, is used to assess the zoning plans. The review of zoning plans may result in changes in the relative proportion of each zone type in a particular Marine Park. Zoning plans for the PSGLMP were established in 2007 and the first zoning reviews are scheduled to commence in 2012. Zoning reviews result in a publically-released report from the MPA that is finalised a maximum of 12 months from the commencement of the review process.

The specific management arrangements for the PSGLMP are detailed in a series of documents that are downloadable from the NSW MPA web pages <http://www.mpa.nsw.gov.au/psglmp.html>.

Regulation of impacts on specific species is also achieved by the declaration of fishing closures and fishing restrictions in key locations. Within the HCRCMA region, gear restrictions apply for line fishing in the area from Stockton Beach to Big Gibber, from the beach to 500 m seaward: these are in place to reduce the risk of harming great white sharks. Fishing exclusions are also in place around The Pinnacle, Seal Rocks and Little Broughton Island which are considered to be critical habitats for the critically endangered grey nurse shark.

5.2 Areas of cultural significance

The understanding and appreciation of Aboriginal culture and heritage has changed in recent times, from the limited scientific definition of archaeological sites, to a much broader understanding that Aboriginal people have a commitment to care for Country and therefore should be responsible for the co-management of natural resources. Aboriginal people view their environment as a holistic landscape rather than individual ecologies. Landscapes represent collections of natural-resource issues with many values (vegetation, habitat, water resources, places, knowledge, stories, landscapes, objects, flora, fauna, water) that together provide a single coherent value, with particular meaning for Aboriginal people (HCRCMA, 2009).

Our association with Aboriginal culture and heritage should be maintained and practised so that all people in the HCRCMA region can respect and understand Aboriginal cultural heritage values. Knowledge of the past, and connecting values with Aboriginal people in the region, can also teach us about what we can provide for our future. It is important to note that Aboriginal people continue to undertake cultural practices and follow traditional protocols, therefore, it is essential to maintain and improve Aboriginal culturally significant landscapes so that they are available for present and future generations (HCRCMA, 2009).

Archaeological evidence, government records and oral history all indicate the importance of marine and estuarine areas of NSW to Aboriginal people. The history of coastal occupation is known to extend to more than 20 000 years ago (Jones, 1988); however, evidence of coastal occupation from >5 000 years ago is sparse, and only 16 sites in NSW have material dated older than this (NSW DEC, 2005).

Areas of cultural significance are defined by the aesthetic, historic, scientific, social or spiritual value for past, present and future generations. Cultural significance can be embodied in a place itself, its setting, use, associations, meanings, and related objects (NSW DEC, 2005).

The Department of Environment, Climate Change and Water (DECCW) (formerly NSW Department of Environment and Conservation (DEC)) has produced a comprehensive Aboriginal Cultural Heritage Data Audit as part of a Comprehensive Coastal Assessment. This report audits and evaluates Aboriginal cultural heritage data and information, with a focus on the Aboriginal Heritage Information Management System (AHIMS) database. Culturally-important areas, artefacts and sites, history of occupation, previous studies and data sources are discussed in considerably more detail than is possible here. The following sections provide an overview of culturally-significant areas within the HCRCMA region, but for a more thorough examination, the reader is referred to DECCW. In this review, terminology is consistent with the NSW DEC (2005) audit.

Aboriginal nations

At the time of European contact, Aboriginal society in NSW coastal areas was organised into 'tribes' or 'nations', which were composed of a number of smaller family groups known as 'bands' or 'clans'. Natural geographic features such as mountains, rivers and creeks often defined territorial boundaries of the various groups. The knowledge of the territories of various nations and language/dialect groups at the time of European contact resides with Aboriginal people, past and present (NSW DEC, 2005). Detailed documentation of language groups and territories exists for some coastal areas of NSW, but for others, information is limited.

The HCRCMA coastal region encompasses the territories of five Indigenous nations (Table 5.2): Biripi (Birpai), Worimi, Awabakal, Kuring-gai, and Darkinung (Darkinjung). Each of these was composed of a number of clans or sub-groups, however, recorded knowledge of some of these is limited.

Table 5.2 Aboriginal 'nations' and groups along the coastal zone of the HCRCMA region. Data were extracted from NSW DEC (2005). Note: spelling of group names and territories of different Aboriginal groups may be considered to be different by some Aboriginal people.

'Nation' or 'Tribe'	Boundaries of Territory	Sub-groups
Biripi (Birpai)	A language group that occupied land extending from north of Port Macquarie to Tuncurry and inland to Gloucester.	Boundaries of this group are not well recorded. The general consensus of the local Aboriginal communities at Purfleet, Taree and Forster is that both Worimi and Biripi descendants have attachment to the land along the coast between Cape Hawke and Wallaby Point (Saltwater Reserve).
Worimi	Occupied land between Barrington Tops and Forster in the north and Maitland and the Hunter River in the south.	Enright (1900) and Sokoloff (1974) have identified ten local groups ('nurras') that comprised the Worimi nation.
Awabakal	Awabakal territory, though centred on the Lake Macquarie area, extended north to Newcastle and Mount Sugarloaf, inland along the Hunter River and south to the northern part of the Tuggerah Lakes. The boundaries of the Awabakal at the time of European contact are not well recorded and European observers were not able to unequivocally establish the relationships between different groups of Aboriginal people in the region.	Unclear if the 'Wollombi Tribe' was a clan of the Darkinung or Awabakal.
Kuring-gai	The territory occupied by the Kuring-gai nation extended from the northern side of Sydney Harbour to Lake Macquarie.	At least four clan groups referred to in the literature – 'Tuggerah Beach', Erinan, Narara and 'Brisbane Water' clans.
Darkinung	Inland group whose territory extended from Wollombi and Putty in the west, down to Colo and Macdonald Rivers to the Hawkesbury and Brisbane Water, Tuggerah Lakes and their hinterlands to the east.	Unclear if the 'Wollombi Tribe' was a clan of the Darkinung or Awabakal.

Aboriginal sites

Site features and site groups

Aboriginal objects and places are often referred to as 'Aboriginal sites', 'relics' or 'cultural material' – all being physical evidence of the use of an area by Aboriginal people. There are also areas of high significance to Aboriginal people with no physical evidence but of great spiritual value. Aboriginal sites can be found in and around towns and cities, popular beaches, along river banks and tracks, on open plains, rocky and steep terrain and in dense forests – different landscapes and cultural practices produce different types of sites (HCRCMA, 2009). An Aboriginal site is usually considered to be any place which has the remains of prehistoric and historic occupation, or is of contemporary significance (Jones, 1988). A total of 20 different site features are recognised by DECCW who maintain the AHIMS database of Aboriginal objects, artefacts and sites. Aboriginal sites may also have an important cultural association such as places associated with stories, places from where hunting or gathering occurred, and places where people were born or died (NSW DEC, 2005).

For descriptive and management purposes, AHIMS organises site features into categories or themes (Site Groups) that represent related cultural activities (Table 5.3). Themes include: Occupation Site and Living Places, Procurement or Manufacturing Places, Art Places, Ceremonial or Story Places, Burial Places, and Other Post-Contact Places. Within the HCRCMA region, a large proportion of site features are stone artefacts (AR), shell deposits (middens) (S), scarred or carved trees (MT), burials (B), grinding grooves (GG), or rock art (A). Table 5.4 shows the distribution of these Site Groups by Local Government Area (LGA). It is important to note the limitations of the data contained in the AHIMS database, as it can only represent a proportion of the total number of Aboriginal sites, that is, those that have been officially recorded. It is likely that local Aboriginal people would possess knowledge of many more Aboriginal sites.

Table 5.3 Aboriginal Site Features and Site Groups (themes) used by AHIMS to classify Aboriginal artefacts and places. Abbreviations provided are used in the following tables. Data extracted from NSW DEC (2005).

Site group	Aboriginal heritage site feature
Occupation site/living place (OS/LP)	Artefact (AR); Shell (S); Non-human Bone/Organic Material (BOM); Hearth (H); Habitation Structure (HS); Earth Mound (EM); Potential Archaeological Deposit (PAD)
Procurement/manufacturing place (P/MP)	Aboriginal Resource and Gathering (ARG); Modified Tree (MT); Fish Trap (FT); Grinding Groove (GG); Ochre Quarry (OQ); Stone Quarry (SQ); Water Hole (WH)
Art (Art)	Art (A)
Ceremonial/story place (C/SP)	Aboriginal Ceremony and Dreaming (ACD); Ceremonial Ring (CR); Stone Arrangement (SA)
Burial place (Burial)	Burial (B)
Other post-contact place (P-CP)	Conflict (C)

Table 5.4 The number of Aboriginal Site Features and Site Groups recorded in the AHIMS database. Data are separated into LGAs; see Table 5.3 for definition of abbreviations. Data extracted from NSW DEC (2005).

	Local Government Area							
Site Feature Group	Greater Taree	Great Lakes	Port Stephens	Maitland	Newcastle	Lake Macquarie	Wyong	Gosford
OS/LP	254	522	775	161	70	541	198	1040
P/MP	22	22	46	13	8	71	82	717
Art	1	1	5	0	0	12	50	1368
C/SP	18	12	8	3	2	5	3	83
Burial	5	7	6	1	0	1	1	9
P-CP	0	0	1	0	0	0	0	0

Significant areas

In NSW, cultural heritage areas that are assessed as being of high significance can be protected under the NSW *National Parks and Wildlife Act 1974* (*NPW Act*). Areas can be declared as Aboriginal Areas or Historic Sites, or as Aboriginal Places. The declaration of an Aboriginal Area or Historic Site provides protection to areas associated with a person, event or historical theme, which contain a building, place, feature or landscape of cultural significance. Aboriginal Places can be declared if they are, or were, of special significance to Aboriginal culture. In addition, a number of National Parks and reserves in NSW with significant Aboriginal heritage values are subject to Aboriginal co-management arrangements whereby the Government and local Aboriginal people share responsibility for the management of the park (NSW DEC, 2005).

Within the HCRCMA region, there are no Aboriginal Area or Historic Site declarations; however, there are several culturally-significant coastal areas that have been listed as Aboriginal Places and other areas that are subject to Aboriginal co-management arrangements (Table 5.5). There are also a number of places currently being investigated for possible nomination as Aboriginal Places. The only area in close proximity to the HCRCMA region that has been declared as an Aboriginal Area is at Mooney Mooney (art site), in Gosford LGA.

Primary data sources

Most of the data in this section were extracted from the Comprehensive Coastal Assessment audit of Aboriginal cultural data (NSW DEC, 2005), and the AHIMS database maintained by DECCW. Published literature (e.g. Jones, 1988), the Hunter-Central Rivers Catchment Action Plan (CAP), and other HCRCMA publications were also used.

Data description and assessment

The Comprehensive Coastal Assessment audit of Aboriginal cultural data is an extremely comprehensive review of all existing data from NSW. The review provides detailed information about each LGA along the coast of NSW. For each area, the number of Aboriginal Sites and Site Groups are listed, as well as details of significant areas protected under NSW legislation. This audit sourced data from the AHIMS database, and provides an overview of the history of Aboriginal data management in NSW. Many unpublished sources such as government reports, theses and oral history are captured in the audit.

The AHIMS database holds information about every Aboriginal object and place recorded from NSW. Additionally, the database maintains an index of all archaeological and other survey reports. Information held for every record in the database includes the name, feature type, map grid co-ordinates, date of recording, and the name of the recorder. The database is accessible by contacting DECCW directly.

Table 5.5 Culturally-significant sites declared as Aboriginal Places. Places that are under investigation for declaration as Aboriginal Places are also listed. Data extracted from NSW DEC (2005).

Name	Feature(s)	LGA	Size (ha)
Aboriginal Places:			
Three Brothers	Story Places	Greater Taree	2 132
Saltwater	Spiritual Place	Greater Taree	13
Farquar Park	Camping and Ceremonial area	Greater Taree	33
Dark Point	Conflict, Burial and Occupation area	Great Lakes	647
Pulbah Island	Spiritual Place	Lake Macquarie	68
Aboriginal Co-Management:			
Worimi Conservation Lands, Stockton Bight	Various and Extensive	Port Stephens	4 200
Name	**Feature(s)**	**LGA**	
Places subject to investigation:			
Bulahdelah Mountain	Ceremonial, Occupation	Great Lakes	
Broughton Island	Occupation place	Great Lakes	
North Arm Cove, Carrington	Stone Arrangements	Port Stephens	
Birubi Point, Anna Bay	Spiritual, Occupation	Port Stephens	
Mount Sugarloaf	Story Place	Lake Macquarie	
Warre Warren	Art	Gosford	
Kincumber Mountain	Art, Social Values	Gosford	
Daleys Point	Art, Historic Values	Gosford	

5.3 Threatening processes

Overview

Most, if not all, coastal and marine habitats around Australia are under direct and/or indirect pressure from a range of anthropogenic activities. The increasing population, both nationally and regionally suggests that these pressures are likely not only to continue, but also to intensify. The HCRCMA region is subject to a range of threats that are generic for coastal waters around

Australia (i.e. they occur across much larger spatial scales). However, there are also a number of threats that, due to specific activities within the region, need to be given more emphasis within this review (e.g. shipping-related impacts). Consequently, this section provides a broad review of threatening and key threatening processes within the region, providing specific information as to their relative importance. Where appropriate, the chapter reproduces some of the general and comprehensive background information from Rule et al. (2007). Threats specific to the HCRCMA region have been identified from the extensive reviews provided in other chapters and during a workshop involving key stakeholders from the HCRCMA region (see Acknowledgments).

5.3.1 Key threatening processes

A key threatening process is defined in under the *Threatened Species Conservation Act 1995* (*TSC Act*) as 'any process that threatens, or could threaten, the survival or evolutionary development of species, populations or ecological communities'. This legislation covers populations and communities excluding fish species. Key threatening processes for fish and marine vegetation are listed under the *FM Act*. Key threatening processes can also be listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*).

A key threatening process can be nominated if: 1) it adversely affects two or more threatened species, populations or ecological communities, or 2) it could cause species, populations or ecological communities that are not currently threatened to become threatened. Once a key threatened process is listed under either the *TSC Act* or the *FM Act*, a threat abatement plan can be produced. These plans outline the actions necessary to manage the threatening process, explain how the success of these actions will be measured, identify the authorities that will be responsible for carrying out the recommended actions, and, if possible, provide a cost estimate and timetable for implementing the plan.

Thirty-four key threatening processes are currently listed under the *TSC Act*, and a further seven are listed under the *FM Act*. The 'Current shark meshing program in NSW waters' is listed under both Acts. A total of six key threatening processes (Table 5.6) directly threaten marine populations and communities within the HCRCMA region. 'Predation by the European Red Fox' poses a direct threat to nesting sea and shore birds such as the Sooty Oystercatcher, and 'Death or injury to marine species following capture in shark control programs on ocean beaches' threatens marine species such as turtles, humpback whales and populations of the grey nurse and great white shark.

Impacts of hook and line fishing on threatened and protected fish species

Hook and line fishing poses a threat to populations of species listed as protected, vulnerable or threatened under the NSW *TSC Act*, such as the grey nurse shark and black cod. These species form aggregations in specific habitats along the NSW coast, and while many of these have been protected within marine parks or have been listed as critical habitats, fishing is still allowed in some areas. There is plenty of anecdotal evidence of interactions between these threatened species and fishing activities (Figures 5.2 and 5.3); however, a more rigorous assessment of impact is hampered by the lack of adequate population data for species at risk (see Chapter 6). Recent surveys within the region (MPA, 2009), and along the broader NSW coast (e.g. the Northern Rivers Catchment Management Authority (NRCMA) region), are helping to address this knowledge gap.

Table 5.6 Key threatening processes, species likely to be at risk and the potential impacts directly relevant to the HCRCMA region.

Key threatening process	Resources known or likely to be at risk	Potential impacts
1) Hook and line fishing in areas important for the survival of threatened fish species (direct)	- Grey nurse shark - Black cod - Other protected species	- Hooking - Capture - Injury and/or mortality
2) Introduction of non-indigenous species to New South Wales coastal waters (direct)	- Marine and estuarine benthic communities	- Smothering - Overgrowth - Competition and predation with/on indigenous taxa - Habitat modification
3) Entanglement in or ingestion of anthropogenic debris in marine environments (direct)	- All turtles, cetaceans, seals, dugongs, and seabirds	- Ingestion and entanglement - Injury and/or mortality
4) Human-caused climate change (direct)	- Many communities - Shorelines	- Range expansions/reductions - Loss of habitat through sea-level rise; local extinctions - Changes in composition of biotic communities - Disruption of critical cyclic patterns (e.g. reproduction) - Increased coral bleaching and/or disease - Changes in the frequency and intensity of storm effects (esp. East Coast Lows) - Changes to primary production (e.g. upwelling, flood plumes)
5) Predation by the European Red Fox (direct to birds)	- All birds that nest on beaches - possibly some turtles	- Predation - Injury and/or mortality - Loss or reduction of reproductive output
6) Current shark meshing program in NSW waters (direct)	- All marine species that travel close to shore	- Entanglement - Injury and/or mortality

Introduction of non-indigenous species to New South Wales coastal waters

The introduction of exotic species into waters of the HCRCMA region is discussed in Section 3.3. The risk of introductions is particularly high in this region because of the international shipping traffic that provides an opportunity for transport by ballast water and hull fouling. Introduced species pose a direct threat to indigenous marine communities through competition for food resources or space, predation, or through the alteration of habitats. While the Port of Newcastle area (and adjacent marine and estuarine habitats) is most at risk from introductions, comprehensive surveys are limited by poor visibility and access due to high levels of shipping traffic. The last survey of the port was completed in 1997 as part of a state-wide program (see section 3.3).

Entanglement in, or ingestion of, anthropogenic debris in marine and estuarine environments

The impacts and status of knowledge of marine debris in the HCRCMA region are examined in Section 4.3.4. The threat of entanglement or ingestion of marine debris (and, in particular, plastics), is a process that potentially threatens all marine biota, particularly large vertebrate fauna such as whales, turtles and seabirds. For example, recent evidence from within the PSGLMP indicates that turtles enter discarded fishing traps resulting in mortality (Figure 5.2). Entanglement in debris (such as rope or fishing line – Figure 5.3) may cause strangulation, lacerations, infections and the loss of limbs (Jones, 1994), and may also reduce mobility and increase the likelihood of predation. Ingestion of debris may result in mortality through starvation, and decreased digestive capacity. Sub-lethal effects of entanglement or ingestion of marine debris include a reduction in fitness and ability to successfully reproduce, catch prey and avoid predation. The long-term impacts of marine debris are largely unknown, however, plastics may persist for very long periods of time (Frost, 1994). Floating marine debris may provide habitat for sessile invertebrates; this has been suggested as an important potential mechanism for the introduction of exotic species in some regions (e.g. Barnes, 2002; Smith, 2002). The Department of Environment, Water, Heritage and the Arts (DEWHA) has recently revised the threat abatement strategies to address this key threatening process (DEWHA 2009).

Figure 5.2 A turtle trapped in a discarded trap, Port Stephens (Photo: NSW MPA).

Figure 5.3 Entanglement in rope led to the mortality of this turtle in Port Stephens (Photo: NSW MPA)

Human-caused climate change

The potential effects of climate change have been extensively discussed in Sections 2.5 and 4.5. Such effects are likely to be widespread, affecting a great number of processes and consequently influencing most marine habitats and communities either directly or indirectly. Rising sea levels may remove important intertidal habitats and lead to local extinctions, potentially having a flow-on effect due to changes in connectivity over a range of scales. While there has been considerable focus on the impacts of increased ocean temperatures on tropical taxa such as corals, little is known about potential impacts on cooler-water assemblages (e.g. sponges, octocorals), which provide much of the biogenic structure on the reefal habitat in the HCRCMA region (see Chapter 3). Seasonal changes in temperature are also known triggers for reproductive activity in many species (e.g. offshore breeding migration by the pomacentrid fish *Chromis hypsilepis* on the Central Coast – Gladstone, 2007) and thus altered temperature dynamics may potentially reduce the viability of such populations. Storm activity is a key factor governing the dynamics of marine communities and so changes to the frequency and intensity of severe events is likely to result in changed patterns over a range of spatial and temporal scales. These effects are likely to be manifest both in terms of the physical effects of altered wave climate and the impacts of fresh-water run off (carrying nutrients and toxicants) and the spatial and temporal extent of river plumes. Finally, rising sea levels not only have the potential to affect infrastructure and the built environment but may also change the distribution of a range of important biotic habitats. In some cases, such as rocky shores, whole intertidal platforms may disappear altering local communities and affecting connectivity along the coast. The scale of such effects ultimately depends on the size of the changes occurring due to climate change.

Predation by the European red fox

Predation by foxes only affects organisms that utilize shore habitats such as shore and sea birds and possibly nesting turtles (although the latter have only rarely been reported in the HCRCMA region). Many birds such as the Pied oystercatcher and Little tern nest on beaches and hind-dune areas. Predation by foxes poses a serious threat to these ground-nesting species, through predation on adults, chicks and eggs. The Fox Threat Abatement Plan for NSW (NSW NPWS, 2001) outlines priorities for fox control, procedures for identifying threatened species at greatest risk from fox predation, and sites at which fox control is most critical.

Death or injury to marine species following capture in shark control programs on ocean beaches

This key threatening process is particularly relevant as shark nets are deployed adjacent to 21 beaches in the HCRCMA region, from Stockton south to Terrigal (Green et al., 2009). Catches by these nets include many non-target animals (e.g. mammals and reptiles) as well as protected species of shark. Since 1950, the Shark Meshing Program (SMP) in NSW has resulted in the incidental capture of 143 dolphins (from 3 species), 98 turtles (3 spp.), 6 dugong, 4 seals (2 spp.), and 1 penguin as well as >15 000 sharks from 13 species (Green et al., 2009). Within the HCRCMA, there are particular concerns for the impacts of the SMP on great white (listed as Vulnerable) and grey nurse (listed as Critically Endangered) sharks – this is warranted based on the catch-rates of these species at specific sites within the HCRCMA region. For example, between 1990/91 and 2007/08, meshing activities off Stockton Beach netted a total of 190 sharks including 19 great whites (Green et al., 2009). This area is known to be an important nursery for great whites and is consequently the focus of ongoing studies on this threatened species (see Section 3.2.2). Capture of grey nurse sharks have declined substantially since the first 3 decades of the SMP but they are still entangled in shark nets periodically (Green et al., 2009). The SMP is currently under review by I&I NSW (Department of Primary Industries (DPI) - Fisheries).

Other pressures

In addition to the key threatening processes impacting endangered species outlined above, there are a number of other pressures that pose a threat to marine habitats and organisms within the HCRCMA region (Table 5.7). The following does not provide a complete list of pressures within the region, but reflects issues raised by authors of relevant sections of the review, and by stakeholders during a targeted workshop. Many of these will have localised impacts or will affect specific resources; however, all need consideration in the context of marine management strategies. Several of the pressures listed below have received extensive analysis and review in the literature. For example, as part of the Industry & Investment NSW (I&I NSW – DPI - Fisheries) Environmental Impact Statement (EIS) process, a detailed analysis of all environmental, ecological, water and air quality threats has been conducted for each commercial fishery (see Section 4.1). Such extensive analysis is beyond the scope of this review, which provides a qualitative overview based on existing research in each field and the likely impacts identified from the literature reviewed in previous chapters.

Commercial fishing

Commercial fishing operations pose a considerable threat to marine systems in the HCRCMA region. These threats have recently been examined, and risk analyses have been performed for specific issues (e.g. NSW DPI, 2004a, b; 2006). The main threats are associated with: harvesting and bycatch; gear deployment, use and loss; and boating operations. The first two are considered to have high potential impact while the threat posed by vessels is generally considered to be minor (NSW DPI, 2006).

The potential over-harvesting of commercially important species has been identified as an important issue in the I&I NSW (DPI - Fisheries) EIS reports. Many species are thought to be over-harvested or are being fished at unsustainable levels (NSW DPI, 2006). Basic biological information and data from stock assessments are generally lacking; a precautionary approach to management of commercial fisheries in NSW is therefore being adopted (NSW Fisheries, 2002). Many fishing methods used in commercial fisheries in NSW are unselective, and bycatch consequently remains an important threatening issue. Some fisheries have attempted to reduce bycatch and increase selectivity by using a range of bycatch reduction devices (BRDs), and I&I NSW (DPI - Fisheries) has a specific unit that is continuously testing and improving fishing gears. While much of this work focuses on estuarine fisheries, the strong linkages between estuaries and marine habitats suggest that addressing the issue of bycatch in these habitats will benefit marine systems. Threats from trapping are particularly important to demersal species such as wobbegong sharks and hermit crabs which readily enter traps (NSW DPI, 2004a).

Recent evidence from the HCRCMA region also suggests that fish trapping may be an important cause of turtle mortality (D. Harasti, pers. comm. – Figures 5.2 and 5.3). Accurate bycatch estimates are lacking for most fisheries, and very little information is available about the fate of discarded species.

The gear used in commercial fishing operations can threaten marine communities and habitats in a number of ways. Firstly, the deployment of traps and trawl gear can affect reef and soft sediment habitats. Both have the potential to disturb epibenthic (biota growing upon the substratum) communities, and trawling over soft-sediments may also affect infaunal (animals living within the sediment) assemblages (NSW DPI, 2006). Gear loss from most fisheries poses a serious threat to marine life, through entanglement and 'ghost fishing' (Ganassin and Gibbs, 2005).

Table 5.7 Additional pressures identified for the HCRCMA region.

Pressures	Potential impacts	Resource at threat
Commercial fishing		
Harvesting		
Overfishing	Depletion of spawning stock	Many commercial species
Bycatch	Injury/mortality	Any species, depending on gear
Gear usage		
Gear deployment	Damage to habitats	Subtidal reefs, soft sediments, attached biota
Loss of gear	Ghost fishing, marine debris	Any species, depending on gear lost; those affected by marine debris
Entanglement	Injury and/or mortality	Threatened and protected species
Boat operations		
Water quality	Pollution	Many communities
Noise	Disturbing migrating species	Whales/dolphins/turtles
Debris	Entanglement, ingestion, habitat fouling	Those affected by marine debris
Boat strikes	Injury and/or mortality	Any large organism
Recreational harvesting		
Incidental catches of threatened or protected fish species	Injury and/or mortality	Protected and threatened fish species
Overfishing	Decline of populations Reduction in production	Many popular species
Interaction with commercial fisheries	Decline of populations Reduction in production	Any species targeted by both (e.g. snapper)
Rocky shore harvesting (food, bait, shells)	Decline of species abundances and sizes Trampling	Invertebrates such as urchins and snails Algae

Pressures	Potential impacts	Resource at threat
Lost fishing gear/debris	Entanglement, ingestion, habitat fouling	Those affected by marine debris
Shipping/boating		
Oil spills	Mortality, habitat loss (temporary), local extinction	Subtidal reefs, intertidal communities, soft sediment communities, seabirds and mammals
Groundings	Habitat destruction, localised mortality	Shallow reefs and sand bars
Marine debris	Entanglement, ingestion, habitat fouling	Seabirds, mammals and turtles, subtidal reefs
Introduced pests	Competition, predation, overgrowth, local extinctions	All benthic communities
Ship/boat strikes	Injury and/or mortality	Any large organism
Anchoring	Habitat damage and modification	Mostly soft sediment habitats and taxa associated with these habitats
Marine Pollution		
Sewage effluent disposal	Increased nutrient run-off Eutrophication Increased algal growth Toxicant contamination	Nearshore reefs Harvested species near to outfalls
Storm water run-off/flood plumes	Changes in salinity Freshwater plumes	Nearshore reefs/intertidal communities
Agricultural practices	Increased nutrient run-off Eutrophication	Nearshore reefs/intertidal communities
Dredging	Smothering of habitat and organisms Increased sedimentation Re-suspension of toxicants Removal of habitat Removal of fauna Accumulation of organic matter	Soft sediment communities Local reefs
Coastal development	Increased sedimentation Reduced light penetration Increased nutrient run-off	Nearshore reefs, coral communities

Recreational fishing

The difficulty and cost of collecting accurate catch data is a key issue for the management of recreational fishing. Recreational fishing potentially poses threats to a number of popular species. While harvests may be considerably lower than for commercial fishing, the impact of the interaction between commercial and recreational fishing may be significant. This is particularly true for species such as snapper and yellowfin bream where the extent of the recreational harvest is unknown. Recreational fishers may pose a threat to some threatened species that may be hooked or speared unintentionally. Recreational fishers may also threaten intertidal invertebrate communities through trampling and harvesting species such as urchins and a range of molluscan taxa (see Chapter 6) (Ponder et al., 2002; Alexander and Gladstone, in review).

Shipping

The Port of Newcastle is an area of intense shipping activity and this potentially poses a number of threats to the broader HCRCMA region. Although there have been few recorded oil spills in the region to date, there is nevertheless the potential for this to occur. The grounding of the *Pasha Bulker* in 2007 provided an important example of the potential for a major shipping incident. Because an oil spill was averted, the impact was much smaller than it could have been. Three subsequent investigations (by the Australian Transport Safety Bureau, NSW Maritime, and the Australian Maritime Safety Authority (AMSA)) have provided recommendations to minimise the risk of future, similar incidents and to streamline responses by the relevant authorities (AMSA, 2009). While contingency planning has been conducted for the whole of the NSW coastline (Oil Spill Response Atlas (OSRA) – see section 4.3.2 and 4.3.3), this information is now dated and does not incorporate the extensive, recent data resulting from mapping of marine habitats. This is a clear gap in knowledge (see Chapter 6).

Anchoring by vessels awaiting access to the Port of Newcastle potentially affects a large tract of subtidal soft-sediment habitats in the HCRCMA region. By far the majority of anchoring occurs outside state waters but some vessels anchor within 3 nm of the coast. The potential impacts of anchoring are considerable and include damage to soft-sediment communities (which may be extensive when anchors drag) and modification of benthic topography (affecting the dynamics of benthic communities and the ability of commercial, demersal trawlers to fish effectively). In addition, a recent survey by the Newcastle Port Corporation using side-scan sonar identified at least 60 sets of anchoring gear (anchor and chains) offshore from Newcastle. These not only modify habitats but also pose a substantial risk of entanglement for demersal trawlers. The impacts of anchoring are largely anecdotal and require appropriate evaluation (see Chapter 6).

Marine pollution

Pollution of the marine environment within the HCRCMA region is most likely to occur as a result of coastal development or maritime accidents (see above). Given the increasing human population in the region, especially in the southern region (Central Coast), coastal development, including land clearing and construction, is likely to pose a threat to nearshore environments. Coastal development may lead to increased run-off of nutrients and sediments, which is likely to increase sedimentation rates and turbidity of nearshore waters.

Impacts from sources such as sewage outfalls have generally been shown to have relatively localised effects on marine communities. However, there is a lack of information on the biotic impacts for many outfalls in the region (see Section 4.3.1). Even where rigorous studies have been conducted (e.g. Boulder Bat outfall – Roberts et al., 1998; Ajani et al., 1999), most of this information was gathered some time ago and so the current status of impacts is largely unknown; this has been identified as a specific knowledge gap in Chapter 6.

The limited data available on the impacts of dredge-spoil deposition offshore from Newcastle suggest this activity is a source of heavy-metal pollution on the inner shelf. However, the spatial extent of this is poorly known and there have been few attempts to determine potential impacts on biota in the receiving habitats, or on the potential for accumulation through trophic pathways.

An important consideration for the urbanised sections of coastline within the region is how different types of impact may interact. Thus, the level of impact of press stressors (e.g. sewage outfalls) may change with changing levels of other stressors (e.g. terrestrial run-off and changes in turbidity). In addition, while this report focuses primarily on marine habitats and processes, there is a strong interaction between estuarine and marine habitats; pollution in rivers and estuaries will ultimately have an impact on the adjacent marine habitats. *In situ* studies of pollutants and their effects rarely take such interactions into consideration and may thus misinterpret the risks posed by these pollution sources.

Primary data sources

Data concerning key threatening processes were mostly derived from online resources listed by:

DEWHA <http://www.environment.gov.au/biodiversity/threatened/ktp.html>;

NSW DECCW <http://www.environment.nsw.gov.au/threatenedspecies/index.htm>; and

I&I NSW <http://www.dpi.nsw.gov.au/fisheries/species-protection/conservation>.

Other data came from numerous sources that have all been listed in previous sections.

6 Gaps in Existing Knowledge and Directions for Future Research

Introduction

From the preceding chapters, it is apparent that there are a large number of data gaps for the marine resources of the Hunter-Central Rivers Catchment Management Authority (HCRCMA) region. Some of these can be considered generic for much of the Australian coast while some are relatively specific to the HCRCMA region. The approach taken in this chapter is, therefore, to give emphasis to those identified as priority gaps relevant to the HCRCMA region while more generic gaps are only briefly listed. A comprehensive review of the latter is presented in Rule et al. (2007). Priority areas were identified in a workshop during which key stakeholders, and authors of different sections of the report, highlighted specific gaps from their field of expertise. Focus was given to those gaps with immediate relevance to the Hunter-Central Rivers Catchment Action Plan (CAP).

6.1 Specific gaps and issues

Distribution of geomorphic habitats

This gap is highly relevant to the Hunter-Central Rivers CAP which aims to improve protection of priority marine habitat; this can only be achieved with knowledge of the distribution of different habitat types. At the time this report was compiled, only ~20% of coastal habitats (to the 3-nm limit) of the HCRCMA region have been mapped at high resolution. In addition, there are a number of relevant historical mapping datasets that have been identified that have yet to be converted into digital products and added to the habitat-mapping database (e.g. side-scan coverage). Recent coverage of areas south of Newcastle by Light Detection and Ranging (LiDAR) airborne mapping methods to generate bathymetry (generally to 2-3 times Secchi depth) also has the potential to provide high-resolution data that can be used to map nearshore reefs. Thus, there is considerable scope for substantial improvement in data coverage by collating and further analysing existing data sources.

The general consensus of the Gaps Workshop was that the following were key areas that should be prioritised for mapping:

1. Wallis Lake to Old Bar (noting that some coverage adjacent to the Black Head region is already available),
2. throughout the Port Stephens-Great Lakes Marine Park (PSGLMP) (noting that around 30% of the marine component PSGLMP has been mapped to date), and
3. the southern boundary of the HCRCMA region to Stockton Bight.

It is further suggested that priority should be given to areas offshore from heavily urbanised/developed areas and erosion hotspots.

Improved understanding of the distribution of ecological habitat classes

Given the limited scope (spatially and/or thematically) of ecological investigations within marine habitats of the HCRCMA region, it is clear that this issue needs to be addressed to provide:

1. basic inventory data for the dominant taxa within the region,
2. quantitative baseline data to inform investigations of key ecological processes (e.g. kelp forests and urchin barrens),
3. quantitative data against which future impacts (e.g. urbanisation, climate change) can be assessed, and
4. data enabling a sound basis for adaptive management (e.g. future marine parks).

There are spatial gaps for most habitat types within the HCRCMA region and, as reviewed in Chapter 3, very little data exist for some prominent habitats, even though they are extensive and relatively accessible for study (e.g. intertidal sandy beaches). Rocky intertidal shores are the best known, with research by Gladstone and co-workers (see section 3.1.2) providing habitat descriptions and species lists for most sites within the region. While the fauna inhabiting soft sediments are generally less diverse than adjacent rocky substrata, they are nevertheless unique habitats that support different suites of biota. Previous work has recognised that different types of beaches support different suites of fauna; this has been used to develop a bleach classification system for NSW (Hacking, 1998a, b), based on relationships described in Brown and McLachlan (1990). The lack of basic data on beach fauna within the region, coupled with the increasing anthropogenic impacts on these systems (sea-level rise and its management (e.g. beach nourishment), and off road vehicles are both highly relevant in this region), highlights the need for more work on these habitats. Similarly, subtidal soft sediments are largely unstudied within the region, despite the fact that they are under threat from at least 3 major impacts (dredge-spoil dumping, extensive anchoring, potential aggregate mining).

While the ecology of subtidal reefs is better known and has been the target on many recent studies, there are still large gaps in the information required to ensure their effective management. The mapping of urchin barrens is considered to be of high priority given the prevalence of this habitat and the likely role of anthropogenic processes in its dynamics. This objective is a high priority within both the state-wide Monitoring, Evaluation and Reporting (MER) and the specific research program for the PSGLMP; preliminary mapping has consequently commenced at various sites within the region (e.g. Gladstone and Masens, 2009; Jordan et al., 2010). Priority should be given to reefs in the PSGLMP (e.g. as an indicator of management effectiveness) and reefs surrounding the proposed site for the ex-HMAS Adelaide. There is also a need to determine the most effective way to conduct such studies (e.g. the possibility of towed-video surveys to supplement the MER work on shallow reefs). The interpretation of patterns requires a sound understanding of underlying processes, which can only be determined from studies conducted over broad spatial and temporal scales.

Mapping and ecological assessment of unique habitats

Habitat mapping not only provides details about the distribution of different physical habitats but can also highlight disjunct distributions of biological communities and the occurrence of unique habitats. For example, although data collection is currently incomplete, the presence of a soft-coral-dominated assemblage (*Dendronephthya* sp.) in shallow unconsolidated habitats within Port Stephens is considered to be both unusual and potentially important for marine biodiversity and ecosystem function. There is also some evidence of a distinct seabed feature in around 60 - 70 m of water that represents the old coastline at previous sea level periods. Such features have been mapped in several places in northern NSW and there is an expectation that it also occurs in the HCRCMA region. Such habitats need to be assessed to better understand their importance at a range of spatial and temporal scales. This approach will inform smaller-scale management of key habitats within the region.

Identification of biodiversity hotspots

It is likely that specific locations within the HCRCMA region contain areas that are higher in diversity than other locations, and therefore require particular attention and protection. At present there is little information on specific 'biodiversity hotspots', and a number of physical surrogates are therefore used that are known to facilitate high species richness in particular locations. This mainly relates to shallow rocky reef habitats, with areas of high reef complexity (i.e. a mixture of rugosity and patchiness) generally containing a higher number of species due to the increased surface area, number of microhabitats and capacity for both macroalgal and sessile invertebrate assemblages at the same location. Many areas of complex shallow reef have been mapped in the HCRCMA region, and further ecological assessment of these is required. While the emphasis here has been on reefal habitat, there is a clear need for extension of these analyses to the full range of habitats present within the HCRCMA region. At this stage, rocky intertidal shores are the only habitats for which sufficient comparative data are available to confidently identify locations with high diversity and conservation value (Gladstone, 2002; 2005; Gladstone et al., 2007; Gladstone and Sebastian, 2009 – and see below).

Biodiversity inventories

While inventory data for some taxa, such as fish (see section 3.2.2), are relatively comprehensive, site-specific species lists are lacking for most taxa in most habitat types within the HCRCMA region. Some relevant data are contained in a number of databases (e.g. at the Australian Museum and the Royal Botanic Gardens), and these should be evaluated for coverage and gaps. There is likely to be considerable overlap with taxonomic lists collated within the Northern Rivers Catchment Management Authority (NRCMA) Marine Knowledge Review (Rule et al., 2007), particularly within the southern area of that region. Further work on reviewing existing databases and conducting site-specific studies is required. Given the likely poleward shift of species as a result of climate change, there is considerable merit in establishing long-term monitoring of species composition at key sites across the region (especially for fish for which the most comprehensive data are currently available).

Assessing the effectiveness of marine park zones

As the primary tool for managing marine habitats within the region, great reliance is placed on marine park zoning for delivering conservation benefits. A potential problem here is that there is often an assumption that protected areas are achieving their objective (of effective management); data are clearly required to test this assumption. Therefore, the Marine Parks Authority has several projects underway within the HCRCMA region that are examining the long-term effects of zoning arrangements within the PSGLMP. This has recently been summarised in the new NSW Marine Parks Authority (MPA) Strategic Research Plan 2010 - 2015 that identifies research priorities and current, proposed and anticipated projects. There is also a range of projects examining issues around biodiversity surrogates, an area of research required to ensure zones include an adequate representation of biodiversity. Further research is required to examine this issue in more detail within the HCRCMA region.

Geographical representation of Marine Protected Areas

While the PSGLMP provides protection for a range of representative habitats and communities in the middle section of the HCRCMA region, this is aimed at providing representative protection within the Manning Shelf Bioregion. Waters south of Stockton are within the Hawkesbury Bioregion; the only Marine Protected Area in the HCRCMA section of this bioregion is the small area (287 ha) of the Bouddi Marine Extension. This area has been protected since 1973 and has had demonstrable benefits to marine biota including increased diversity and density of fishes (Gladstone, 2001). Given the high population growth on the Central Coast and the consequent pressure on marine habitats, it is timely to perform a rigorous study of sites that would benefit from protection in this section of the coast. While some recent work has identified potential candidate sites (Gladstone et al., 2007; Gladstone 2009), further work is needed to identify areas with high conservation value that are also threatened by current levels of impact/usage.

Primary productivity and linkages between estuarine and marine habitats

While ocean colour data are available for surface waters of the HCRCMA region, a key gap is our ability to interpret these due to a lack of information on nutrient inputs and freshwater flows from adjacent terrestrial areas. Given the importance of estuarine habitats in the region, and the contribution that these are likely to make to marine productivity, quantification of marine-estuarine linkages is considered critical for understanding processes affecting primary productivity. Most estuaries within the region have been modified to some extent (with extreme modification, for example, in the Hunter River) and understanding of the flow-on effect of these anthropogenic impacts to adjacent marine habitats is also urgently required (also, see below). For example, agriculture (e.g. fertilisers, water extraction), industry, coal-loading and shipping-related activities in the Hunter River and its catchment are likely to have considerable downstream effects on marine habitats. Acquisition of other, basic oceanographic/physico-chemical data should be considered through the establishment of a network of data loggers (e.g. for sea temperature) and a central repository for the data.

The distribution and abundance of Threatened and Protected species

Current data indicate that the HCRCMA region is of considerable importance for a range of Threatened and Protected species. For example, nearshore habitats adjacent to Stockton Beach and immediately to the north of Port Stephens are important nurseries for great white sharks (see section 3.2.2). In addition, a number of sheltered locations within the region support substantial populations of Syngnathids (seahorses and pipefish). Recent surveys of black cod (MPA 2010) have proved to be a cost-effective way of gathering demographic data on key species. Wherever possible, data on the relative abundance of key taxa should be compiled. These data would complement and expand on previous one-off studies that have tentatively identified areas with high conservation value within the region (Gladstone and Sebastian, 2009).

It is strongly recommended that these studies are followed up to gain similar information for other threatened and protected species, and biological/ecological information to facilitate more informed management of this suite of species.

Shipping-related impacts

A number of potential issues have been identified that are related to the high volume of shipping within the HCRCMA region, and especially in the area from the Central Coast northward to Seal Rocks. The first issue, about which there is very little information, is the impact of anchoring on benthic communities. Most anchoring occurs offshore from Newcastle as vessels await access to the port (mostly for coal-loading). While most ships anchor outside state waters, anchoring also occurs within 3 nm of shore. There is anecdotal evidence of changes in local topography (pits and depressions in the sediment) that are likely to affect benthic infauna and sessile invertebrates that commonly occur in soft-sediment habitats. Changes to habitats may also occur due to the loss of anchoring gear. The soft-sediment communities of the region have received very little attention (see section 3.1.4) and so the scale and importance of impacts are unknown.

The potential for the introduction of marine pests through ballast water and hull fouling is also considered to be a key issue. While ballast disposal guidelines have been developed for ships operating within Australian waters (DAFF, 2008), data on compliance with these is lacking. Given the high volume of shipping traffic within the region, this issue is particularly relevant for the HCRCMA region. A greater understanding of risks is needed, as is research on the current status of marine pests in locations such as the Hunter Estuary.

Shipping traffic poses potential risks associated with oil spills, either incidentally or as a result of a maritime accident; the case of the *Pasha Bulker* in 2007 exemplifies this. There are a number of priority issues related to managing and assessing these risks. Firstly, the oil spill atlas for the region requires updating with the recently-collected habitat mapping information (see Chapter 2). There has been a substantial recent increase in the knowledge of marine habitats and communities in the region and this needs to be reflected in current and future contingency planning. Also, the data need to be made more accessible and useable (e.g. by conversion to spatial data layers in GIS). Secondly, it is recommended that a risk matrix is generated to highlight locations or features that have higher risks of maritime incidents (e.g. Sugarloaf Point which is close to existing shipping lanes).

The maintenance of navigable channels and berths for the Port of Newcastle involves almost continual dredging, with most of the spoil deposited within the 3-nm limit of state waters. The limited studies that have been conducted to date indicate measurable increases in trace-metal concentrations in the vicinity of the deposition site, and also more widely across the shelf (Matthai and Birch, 2000a, b). There have been few studies of the impacts on biological communities and this is considered to be a key gap. In addition to the direct impacts of the dredged material (smothering, toxicity, changed sediment characteristics), transport of material may also introduce different species to the receiving areas. This may have considerable consequences if these species are invasive or marine pests (see above).

Marine pollution

The broad ecological impacts of sewage outfalls within the region are largely unknown (see section 4.3.1). Given the substantial population growth, especially in the southern sections of the HCRCMA region, effluent management is a key sustainability issue. Most of the data currently available are for water quality measures taken as part of routine monitoring by Councils. Very little effort has been expended on assessing biological impacts. A desk-top study reviewing existing data is recommended as a first step in assessing the scale of this gap. This should not only review the spatial and thematic coverage of previous and ongoing studies but also their relevance to current discharge parameters (volume and quality).

Despite the fact that marine debris is recognised at state, national and international levels as a Key Threatening Process, very little data are available for the HCRCMA region on its sources, fates, prevalence, and impacts. There are clear opportunities to gather information to address specific questions using the range of volunteer groups that regularly remove litter from intertidal sites (Land Care groups, participants in events such as Clean Up Australia Day). Coordinated activities using standardised methods have commenced for subtidal habitats along the NSW coast (e.g. the underwater research groups such as Solitary Islands Underwater Research Group (SURG), who recently gained external funding to perform quantitative surveys of marine debris in the Solitary Islands Marine Park, and Great Lakes Underwater Group (GLUG)); similar standardisation of methods could be extended to intertidal habitats, such as beaches. Data generated by such activities provide an indication of debris hotspots and the most prevalent types of litter; this information facilitates targeted management activities to ameliorate ongoing risks to marine habitats and biota (e.g. Smith, 2010).

Commercial fisheries

As indicated in section 4.1, assessment of the impacts of commercial fishing within the region is hampered by the historical scale of reporting. Thus, it is difficult to determine actual fishing effort within the region because of the large size of the reporting zones (see Figure 4.1). Reporting zones changed in July 2009 (NSW DPI, 2009) and the new procedures will facilitate the acquisition of data at much finer scales; the new scale comprises broad grid codes (1-degree scale) with each grid code further sub-divided into 100 site codes (6-minute scale) (NSW DPI, 2009). This will allow a more informed overview of catch and fishing effort, for the full range of commercial species, and enable adaptive, finer-scale management (but note that most individual site codes relevant to the HCRCMA region still include areas outside the 3-nm limit of state waters).

While the recent changes to reporting scales will help to address the key issue of stock assessment at spatially relevant scales, there are a number of other major gaps in knowledge associated with the commercial fishing industry. One of the primary issues is that basic biological and ecological information is lacking for most of the species targeted in each of the main fisheries – indeed, this is a common gap to all of the multi-species fisheries in the region (see section 4.1). There are also a number of information gaps that are more specific to each of the fisheries.

While bycatch is an issue that is relevant to many of the different fisheries operating in the HCRCMA region, it is particularly relevant to the ocean trawl sector. The issues include inappropriate selectivity of gear, problems with reporting bycatch, and the discarding of commercial species. Large quantities of juvenile commercial and non-commercial species are discarded throughout NSW and further research is needed to determine the consequences of bycatch on fish stocks.

The impact of gears on benthic habitats is also a potential problem. For the ocean trawl fishery, demersal otter trawl gear may cause irreversible damage to benthic environments (Hutchings, 1990) through removing fauna and disturbing habitat. Smaller scale impacts may also occur to benthic habitats through the deployment of traps in the ocean trap and line fishery. While the impacts to the benthos of many types of fisheries have been assessed in different regions of the world, specific impacts have not been determined at the scale of the HCRCMA region.

Additional issues for which there is currently little information include basic economic research across most fisheries and impacts of fishing on threatened and protected species (mostly for the ocean trap and line fishery and for grey nurse shark and black cod).

Recreational fishing (including harvesting on rocky shores)

With the exception of a number of broader-scale surveys of recreational fishers (see section 4.2), there is little information on recreational fishing for the HCRCMA region. The impact of the recreational fishery on fish stocks is currently unknown but, given that many resources are shared with the commercial sector, and harvests in this fishery are substantial, the impact to fish stocks may be of considerable importance. In addition, the impact of recreational fishing to benthic habitats is unknown. Although recreational fishing is likely to generate substantial income for some locations within the region, data on economic importance are particularly lacking. In addition to reduction in fish stocks, recreational fishing activities may also be associated with impacts such as the generation of marine debris (Smith et al., 2008; MPA, 2010b). Monitoring of recreational fishing effort and harvest is needed to better understand the effects of recreational angling on finfish resources. Future studies need to use comparable, quantitative methods for surveys and should be conducted across locations simultaneously so that direct comparisons can be made between areas. In addition, the importance of this sector to local and regional economies should be evaluated.

There is increasing evidence that recreational harvesting of shore and shallow subtidal marine biota is increasing adjacent to urbanised areas. While most of this harvesting is regulated by bag limits, cumulative effects on key taxa may result in cascading ecological effects. For example, large tubinid molluscs (*Turbo torquatus*, *T. militaris* and *T. undulatus*) are dominant grazers on the mid to low intertidal and shallow subtidal regions of rocky shores. Collection of these species is intense in some areas as evidenced by low abundances and piles of discarded shells. Work by Gladstone and Sebastian (2009) clearly demonstrates the reduction in abundance and size of molluscan species that occurs due to collecting. The scale of this issue is currently unquantified and, thus, a first step in this process is to address this data deficiency.

Other recreational activities

Many additional recreational activities have the potential to affect marine habitats and marine biota within the region. Given current population densities and increasing urbanisation, especially in the southern part of the region, the frequency of such activities is likely to increase. For this reason, it is important to determine the types and magnitudes of these impacts and the specific sensitivities of key components of the receiving habitats. For example, beach driving using off-road vehicles, boating, whale and dolphin watching, and diving are all popular activities that are often focused in relatively small areas. While this might limit the spatial scale of impacts, such intensity of use may pose significant threats to specific habitats and biota. There is a clear need to address this gap by careful documentation of the scale and intensity of different activities. This process, coupled with a review of impacts recorded elsewhere, can be used to prioritise research to foster a balance between recreational use and environmental impact, ensuring long-term sustainability.

6.2 Generic gaps

There are many generic gaps that have been identified more broadly for NSW marine habitats in a previous review of data coverage (Rule et al., 2007); these are summarised below (Tables 6.1 - 6.3) (and provide a brief summary of some of the issues listed above). Specific comments, together with the agency that should take the primary lead in addressing these gaps, are included in the tables. In some cases, studies to address these issues are already underway (see Chapters 4 and 5).

Table 6.1 Summary of the assessment of existing data and specific recommendations for each topic covered in the biological environment theme (modified from Rule et al., 2007). 'Agency' refers to the NSW Agency that chould take primary lead (often in collaboration with other research organisations) in addressing the knowldeg gaps identified.

Topic	Component	Recommendations	Agency
Biodiversity and conservation	Algae/ invertebrates	Systematic surveys of all habitats should be conducted in conjunction with taxonomic experts	I&I NSW/ DECCW
	Fish	Increased data collection for threatened species (see above)	I&I NSW
	Birds	Surveys of breeding habitats across region	DECCW
	Mammals	Surveys to identify the existence of areas important for marine mammals	DECCW
Threatened species	Critical habitats	Undertake systematic surveys of important areas across the region	I&I NSW/ DECCW
	Distribution and migration	Implement long-term studies of migration patterns	I&I NSW/ DECCW
	Population/ genetic connectivity	The genetic and population structure for species other than grey nurse shark need to be established	I&I NSW/ DECCW
	Biology/ecology	General research into the reproductive biology and ecological requirements of most species are needed	I&I NSW

Topic	Component	Recommendations	Agency
Marine pests	Distribution	Risk analysis to determine which species may be introduced, and likely points of invasion, followed by systematic surveys of these areas	I&I NSW
	Impacts	Assess potential impacts in habitats likely to be affected by pest species	I&I NSW
Genetic connectivity	Fate of larvae/dispersal	Examine potential dispersal patterns for important species. Identify sources of larvae for local populations	I&I NSW
	Population structure (particularly for commercial and threatened species)	Increase the range of species for which genetic information is collected and assessed. Implement population and genetic studies for all threatened species	I&I NSW
Mapping of habitats	Distribution/ types	Undertake high resolution mapping in waters outside MPAs to determine the adequacy of existing MPAs	DECCW
	Surveys of habitat structure/benthic communities	Systematically survey important habitats for baseline data of community structure and biodiversity	I&I NSW/ DECCW

Table 6.2 Summary of the assessment of existing data and specific recommendations for each topic covered in the human uses and impacts theme (modified from Rule et al., 2007). 'Agency' refers to the NSW Agency that chould take primary lead (often in collaboration with other research organisations) in addressing the knowldeg gaps identified.

Topic	Aspect	Recommendations	Agency
Commercial fisheries	Stock assessment	Detailed stock assessments for all species at high or moderate risk of over fishing	I&I NSW
	Biology of target species	Implement biological studies of all important commercial species	I&I NSW
	Reporting zones	Provide timely data from the revised reporting zones so that information can be obtained at more relevant scales for the HCRCMA region	I&I NSW
	Impacts on environment	Impact assessments for each major fishery in region	I&I NSW
	Bycatch	Implement systematic surveys of bycatch so that estimates of discard rates and bycatch mortality can be made in each fishery	I&I NSW
	Gear selectivity	Implement studies to increase efficiency and selectivity of gear in each fishery	I&I NSW
	Interactions with recreational fishing	Examine any potential interactions particularly for species targeted by both recreational and commercial fisheries	I&I NSW

Topic	Aspect	Recommendations	Agency
Recreational fishing	Catch and effort data	Implement region-wide surveys of catch and effort to determine whether new management arrangements are necessary	I&I NSW
	Important recreational areas	Identify key areas for recreational fishing and ensure proper management	I&I NSW
	Discard mortality	Implement studies of released fish to determine mortality rates, and to determine best-practices for recreational fishing	I&I NSW
Pollution sources	Baseline data from nearshore communities	Initial systematic surveys of benthic communities in areas likely to be affected by human population expansion. Implement monitoring programs across the region	DECCW
	Marine debris	Initial surveys of subtidal habitats to determine volume and potential impacts of debris. Risk assessment to identify important sources of debris, and long-term monitoring of debris load in nearshore habitats	DECCW
	Dredging	Implement quantitative surveys of dredging operations, and impacts to benthic communities. Compile data on volume and frequency of dredging operations in the region	DECCW
Water quality	Recreational beaches	Systematic monitoring and reporting of water quality from important recreational waterways and beaches	DECCW
	Baseline data, impacts of marinas/industry and sewage effluent	Investigate the effect marine industry may have on local communities. Monitor these for any long-term changes	DECCW
Climate change	Impacts to infrastructure	Model individual beaches/coasts for impacts of projected climate change and implement mitigation procedures	DECCW
	Impacts to marine communities	Assess risk to sensitive communities and implement long-term monitoring programs in important areas	DECCW

Table 6.3 Summary of the assessment of existing data and specific recommendations for each topic covered in the management theme (modified from Rule et al., 2007).

Topic	Aspect	Recommendations	Agency
MPAs	Habitat distribution	High resolution mapping of habitats	DECCW
	Ecological processes	Conduct research into ecological processes (particularly sources of larvae, threats to communities)	DECCW
	Effectiveness and appropriateness of zoning	Implement monitoring programs of key variables to examine effectiveness of current zoning schemes	DECCW
Cultural heritage	Important marine areas/artefacts	Identify important areas and artefacts in region. Provide adequate management	DECCW
	Resource use and management	Identify key resources and implement management strategies for those resources	DECCW

7 Concluding Comments

It is clear from this review that the marine sector of the Hunter-Central Rivers Catchment Management Authority (HCRCMA) region contains a wide diversity of habitats and organisms, and that these provide a large range of services to many people. These services may be as simple as the enjoyment derived from a walk along an ocean beach, through to the more tangible economic benefits of thriving marine-based industries (e.g. fishing and tourism). While the uses are diverse, they all ultimately depend on preservation of ecosystems as functional wholes. For this reason, all activities need to be managed sustainably. This document represents part of the process of ensuring long-term preservation of amenity and sustainability of use.

This document has reviewed a large range of knowledge about the marine habitats, organisms and processes within the coastal waters of the HCRCMA region. However, through necessity, topics have, for the most part, been only briefly summarised. Readers should therefore consider this document a jumping-off-point to the large number of authoritative sources cited throughout the report. We have also deliberately kept extensive lists of species to a minimum, focusing on broad descriptions of the status of knowledge, and providing general figures on the approximate number of species at the regional scale. More detailed information, often at the scale of specific localities, is available through some of the different databases cited in the report.

Unfortunately, a document such as this is out of date as soon as it has been published – this is both good and bad. While this is frustrating for the authors and editors ("bad"), the "good" is that many active research projects are currently underway, spread across a large number of marine habitats and research/management organisations; the results of these studies will help to fill some of the gaps identified during this review process. This gradual filling of knowledge gaps will be facilitated by careful investment into the future. If this document helps to guide this process, then it has served its primary purpose.

Review documents are inevitably "backward" focused (i.e. summarising existing knowledge), but this process, if comprehensive, allows clearer vision for future directions. Insights that are specifically relevant to the HCRCMA region, as well as more generic issues that have been identified elsewhere but may not yet threaten the coastal resources of the region, are summarised in Chapter 6. However, it is also highly likely that other issues may emerge which have not been given adequate coverage herein. For example, interest has been expressed in offshore gas exploration and sand mining off the Central Coast, both of which have the potential to adversely affect coastal habitats and biodiversity. Future investment, therefore, needs not only to address the keys gaps identified here, but also allow for collection of adequate data to inform, and thus sustainably manage, these emerging threats.

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Appendix 1: Glossary of Acronyms

ABS .... Australian Bureau of Statistics
AHIMS .... Aboriginal Heritage Information System
AMB .... Australian Maritime Boundaries
AMSA .... Australian Maritime Safety Authority
ANZECC .... Australian and New Zealand Environment Conservation Council
AUSREP .... Australian Ship Reporting
BARC .... Birds Australia Rarities Committee
BOM .... Bureau of Meteorology
BRAN .... Bluelink Reanalysis
BRD .... Bycatch Reduction Device
BRUV .... Baited Remote Underwater Video
CAP .... Catchment Action Plan
CARS .... Coastal Atlas of Regional Seas
CCIMPE .... Consultative Committee on Introduced Marine Pests
CEASS .... Continuous Extended Aeration Activated Sludge
CEL .... Cardno Ecology Lab
CI .... Confidence Interval
CL .... Carapace Length
CPUE .... Catch Per Unit Effort
CSIRO .... Commonwealth Scientific and Industrial Research Organisation
DAFF .... Department of Agriculture, Fisheries and Forestry
DEC .... Department of Environment and Conservation
DECC .... Department of Environment and Climate Change
DECCW .... Department of Environment, Climate Change and Water
DEUS .... Department of Energy, Utilities and Sustainability
DEWHA .... Department of Environment, Water, Heritage and the Arts
DISPLAN .... Disaster Plan
DNR .... Department of Natural Resources
DPI .... Department of Primary Industries
DSTA .... Department of Services, Technology and Administration
EAC .... East Australian Current
EEZ .... Exclusive Economic Zone
EIS .... Environmental Impact Statement
ENSO .... El Niño Southern Oscillation
EP .... Equivalent Persons
EPBC Act .... Environmental Protection and Biodiversity Conservation Act
FM Act .... Fisheries Management Act
GBR .... Great Barrier Reef
GEOSAT .... Geodetic Satellite
GIS .... Geographic Information System
GLUG .... Great Lakes Underwater Group
HANZAB .... Handbook of Australian, New Zealand and Antarctic Birds
HCRCMA .... Hunter-Central Rivers Catchment Management Authority
HRRP .... Hunter River Remediation Project
HWC .... Hunter Water Corporation
I&I NSW .... Industry & Investment NSW
IBA .... Important Bird Area
IFAW .... International Fund for Animal Welfare
IMCRA .... Integrated Marine and Coastal Regionalisation of Australia
IMOS .... Integrated Marine Observation System
IPCC .... Intergovernmental Panel on Climate Change
IUCN .... International Union for the Conservation of Nature

LADS .... Laser Airborne Depth Sounding
LANDS .... Department of Lands
LGA .... Local Government Area
LiDAR .... Light Detection and Ranging
LPI .... Land and Property Information
MARS .... Marine Sediments Database
MER .... Monitoring, Evaluation and Reporting
MERIS .... Medium Resolution Imaging Spectrometer
MHL .... Manly Hydraulics Laboratory
MODIS .... Moderate Resolution Imaging Spectroradiometer
MP Act .... Marine Parks Act
MPA .... (NSW) Marine Parks Authority
NHMRC .... National Health and Medical Research Council
NMSC .... National Marine Science Centre
NOO .... National Oceans Office
NPC .... Newcastle Port Corporation
NPW Act .... National Parks and Wildlife Act
NPWS .... National Parks and Wildlife Service
NRCMA .... Northern Rivers Catchment Management Authority
NRSMPA .... National Representative System of Marine Protected Areas
OFAM .... Ocean Forecasting Australia Model
OH .... Ocean Hauling (Fishery)
OSRA .... Oil Spill Response Atlas
OPT .... Ocean Prawn Trawl (Fishery)
OT .... Ocean Trawl (Fishery)
OTL .... Ocean Trap and Line (Fishery)
PSGLMP .... Port Stephens-Great Lakes Marine Park
RAN .... Royal Australian Navy
REF .... Review of Environmental Factors
RFH .... Recreational Fishing Haven
SeaWiFs .... Sea-viewing Wide Field-of-view Sensor
SIMS .... Sydney Institute of Marine Science
SKM .... Sinclair Knight Mertz
SMP .... Shark Meshing Program
SOI .... Southern Oscillation Index
SPRAT .... Species Profile and Threats Database
SST .... Sea Surface Temperature
TAC .... Total Allowable Catch
TED .... Turtle Exclusion Device
TFMPA .... Task Force on Marine Protected Areas
TSC Act .... Threatened Species Conservation Act
TUG .... Terrigal Underwater Group
UVC .... Underwater Visual Census
WAV .... (Australian Bureau of Meterology) Wave Model
WWTP .... Waste Water Treatment Plant

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