Seabed habitat mapping of the continental shelf of NSW

This report was compiled by Alan Jordan, Peter Davies, Tim Ingleton, Edwina Foulsham, Joe Neilson and Tim Pritchard of the Waters and Coastal Science Section, Scientific Services Division, Department of Environment, Climate Change and Water.

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Department of Environment, Climate Change and Water NSW
59–61 Goulburn Street
PO Box A290
Sydney South 1232

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Summary

This study details the distribution, extent and structure of seabed habitats on the continental shelf of NSW, with particular focus on habitats within NSW state coastal waters. This involved collating and analysing existing broadscale bathymetric and marine sediment datasets, and seabed habitat data defined from previous single-beam and swath acoustic surveys and aerial photography. This was combined with around 100 square kilometres of new swath acoustic data collected using the NSW Department of Environment Climate Change and Water's (DECCW's) interferometric sidescan sonar system, allowing the development of high-resolution maps of the seabed bathymetry and habitats. Data from approximately 120 kilometres of vessel-towed underwater video surveys also allowed field validation of swath acoustic data and a description of the visually dominant sessile biota over large areas of the seabed.

Analysis of the broadscale bathymetry revealed significant regional and local variations in the depth-structuring of the continental shelf, reflecting regional changes in the angle of the coastline, the local position of prominent headlands and embayments, the presence of offshore islands, and the presence of reefs on the mid-shelf. In addition, variations in the width of the state coastal-waters boundary (5.6–18.4 kilometres) results in considerable regional variability in depth at the boundary (32–132 metres) and, therefore, variability in the range of seabed habitats within NSW waters. The broadscale sediment data indicates significant variations on the inner-shelf, with the patchy occurrence of finer sediments in areas offshore of Yamba, Wooli, Batemans Bay and offshore of the Newcastle, Sydney and Wollongong regions, as well as the presence of coarser sand on the mid- or outer-shelves. Similar areas of coarse sediment were evident on the inner shelf throughout the Solitary Islands, Port Stephens, Sydney and Wollongong regions.

The acoustic mapping involved sending acoustic sidescan sonar beams to the seabed and analysing the reflected signals to measure bathymetry and acoustic backscatter (indicating seabed roughness and hardness). Swath acoustic data was combined with existing mapping layers of nearshore reefs defined from aerial photographs, offshore reefs defined from 1:150,000 Australian hydrographic charts, and seabed habitats digitised from historical sidescan sonar data in the Byron Bay, Sydney and Central Coast regions. These datasets were used to map the distribution and extent of seabed habitats, primarily rocky reef and unconsolidated (soft-sediment) habitats, which were mapped into shallow (0–25 metres depth range), intermediate (25–60 metres) and deep (greater than 60 metres) classes.

Approximately 1500 square kilometres of swath acoustic coverage from NSW continental shelf waters has been collated from various sources allowing a significant improvement in the information available on the distribution, extent and structure of seabed habitats throughout the region. In general, the distribution of rocky reef and unconsolidated habitats reflects the regional patterns of geology, geological history, coastal inputs and transport of sediments. The broad distribution of rocky reef habitats reflects the patterns of bedrock geology, which varies in its geomorphic and textural attributes (e.g. hardness, grainsize, jointing, folding) and resistance to weathering. Along most of the NSW coast there are prominent rocky reef outcrops seaward of most headlands, although the present surveys have also identified significant reef systems in areas on the continental shelf that are not continuous to the shore, or are continuous to the shore associated with offshore islands. There are also a number of significant reef features that occur offshore of ocean beaches in the region.

In most swath-mapped areas, the area of rocky reef habitat was significantly greater than that interpreted from existing hydrographic charts, which mostly indicate locations of significant shoal areas of a larger reef system. Many of the reefs extended into Commonwealth waters within the mid-shelf region. Significant reef systems were mapped for the first time offshore of Yamba, Solitary Islands and the Nambucca region, Black Head, Port Stephens, Terrigal, Batemans Bay and Eden. The high resolution of the swath bathymetry revealed reefs of considerable variability in terms of geomorphic structure (e.g. boulders, gutters, walls, pinnacles) and extent of patchiness,

although there was no obvious latitudinal or cross-shelf trend in reef structure because such variations were often present within the same continuous reef system.

Unconsolidated habitats were often complex, with the sediments on the shelf mostly dominated by inner-shelf sand, mid-shelf muddy sand and outer-shelf coarse sand, although there were localised variations to this broad pattern. Nested within these broad areas, swath mapping revealed significant fine-scale structuring of soft sediments on the inner- and mid-shelves, influenced primarily by the presence of sand ripples, sand waves, and variations in particle size and shell content. There were also areas that contained varying amounts of boulders, cobbles and pebbles, particularly adjacent to areas of rocky reef.

Seabed video footage indicated that the dominant benthic assemblages from shallow-, intermediate- and deep-reef habitats were broadly consistent with previous surveys of these habitats on the continental shelf of NSW, with the patchy distribution of habitats primarily related to depth. Shallow reefs in the northern NSW region were a mosaic of corals, sea urchins, kelp and mixed algal assemblages. Intermediate reefs along the coast were dominated by sponges and other sessile invertebrates, and supported low abundances of kelp and other algae. Deep reefs were dominated by a diverse range of sponges with varying morphologies (e.g. massive, branching, elongate), and sessile invertebrates such as ascidians, gorgonians, and sea whips. Reefs in central and southern NSW supported a similar composition of macrobiota, except that coral habitat on shallow reefs had been replaced with a mosaic of macroalgal beds and sea urchin barrens. Information on the major canopy-forming macroalgal species such as *Ecklonia radiata* will allow further studies to assess potential changes in the abundance and distribution of this species due to climate change.

The mapping conducted within this project has significantly improved our knowledge about the distribution, extent and structure of seabed habitats on the NSW continental shelf. It has also resulted in a single database of continental-shelf bathymetry containing historical datasets and recently acquired high-resolution swath data. This data has revealed extensive areas of nearshore reefs, which has implications for future modelling of impacts from storm events along the NSW coast. In combination with the mapping of estuarine aquatic macrophytes (Creese et al 2009), the map series resulting from this study will significantly improve the information required for sustainable natural resource management. In particular, the information is particularly important for the process of improving the likelihood that marine parks and their zones contain a comprehensive, adequate and representative selection of marine biodiversity. Coastal catchment management authorities will benefit by better understanding the composition of subtidal habitats, improving their capacity to focus investments on activities such as habitat monitoring and protection, and community education. Baseline habitat information is also essential for statewide monitoring, evaluation and reporting, which measures progress towards meeting natural resource management targets and improvements in sustainable natural resource management and biodiversity conservation within marine and estuarine areas of NSW.

1. Introduction

Seabed mapping is being increasingly used to identify the extent, distribution and structure of habitats at scales relevant to resource management and planning. This type of mapping often varies in spatial scale, resolution and classification depending on the mapping objective and data availability. Vegetated intertidal and shallow subtidal habitats such as mangroves, saltmarsh and seagrass have been mapped for many years because they can be easily interpreted from existing libraries of coastal aerial photography (e.g. Blake et al 2000, Barrett et al 2001, Creese et al 2009, Lucieer et al 2009). Aerial photography often provides maps of specific habitats at a fine spatial scale because of its capacity to delineate habitat boundaries and dominant subtidal macrophyte composition in depths to around 20 metres (Kendrick et al 2000). Similar assessments of deeper marine habitats have commenced in Australia in the past decade or so due mainly to recent advances in acoustic technologies that can provide high-resolution data over large areas of the seabed (e.g. Beaman et al 2005, Kloser et al 2007, Ierodiaconou et al 2007, Ryan et al 2007). These assessments have built on a broad understanding of the geomorphology and seascape of many areas of Australia's continental shelf and slope using available coarse-scale bathymetry, sediments and a range of physical attributes (Harris 2007, Heap and Harris 2008, Keene et al 2008).

Due to the range of management applications, available data, methods and survey design, seabed mapping is often conducted at varying spatial scales, with each scale requiring a different level of habitat classification. The recent National Marine Bioregionalisation for Australia defines a spatial framework for classifying offshore seabed areas into provincial bioregions, biomes, geomorphological units, and biotopes (Heap et al 2005, Harris 2007). This complements the Interim Marine and Coastal Regionalisation, which provides a hierarchical spatial planning framework for coastal and continental-shelf waters (Australian and New Zealand Environment Conservation Council (ANZECC) Task Force on Marine Protected Areas (TFMPA) 1998a). These have been used by all governments in Australia in the development of a National Representative System of Marine Protected Areas (ANZECC TFMPA 1998b). However, these scales (mostly hundreds to thousands of kilometres) are considerably coarser than those required for the assessment of biological communities and exploited marine resources, which often exist at scales of metres to kilometres. They are also considerably coarser than the scale at which the majority of current seabed mapping data is collected—in particular within state coastal waters, which are those areas that occur within three nautical miles of the coastline or relevant baselines, all of which occur within the 'shelf' geomorphic unit.

Using the structure of the mesoscale bioregions defined in the ANZECC TFMPA (1998a), bioregional assessments of the NSW continental shelf and estuaries provide a delineation of ecosystem extent and distribution for the shallow habitats of seagrass, mangrove, saltmarsh, nearshore sand and reef habitats, and site data for specific taxa (Breen et al 2004 and 2005). The assessments define a number of ocean ecosystem classes for the NSW continental shelf based on the depth zones of 0–20 metres, 20–60 metres and 60–200 metres. These assessments aim to account for variations in benthic fauna across the shelf (Coleman et al 1997, Gray 1997) and physical features such as sediment composition, currents and temperature (Breen et al 2004 and 2005). The 60-metre depth contour is defined as the approximate outer limit of the inner shelf for much of the NSW continental shelf (Shirley 1964, Davies 1979). There is considerably more biological data available for estuarine and coastal habitats compared to seabed habitats on the continental shelf where spatially referenced biological data is comparatively scarce.

Historically, the continental shelf sediments of south-east Australia have been documented in a number of studies over the past several decades (e.g. Boyd 1974, Davies 1979, Marshall 1980, Colwell 1982, Von Stackelberg 1982, Walsh and Roy 1983, Ferland and Roy 1997, Roy 1998, Boyd et al 2004). The broadscale patterns of surficial sediments along parts of the north and central coast of NSW using a collation of historical data is detailed in Boyd et al (2004). In general, there are several main classes of sediments on the shelf, which relate to depth and distance from shore, with a general trend for terrigenous quartzose sediments on the inner shelf and carbonate-dominated sediments on the outer shelf (Davies 1979, Marshall 1980, Boyd et al 2004). A number of distinct seabed morphological units have also been defined for shelf areas in parts of the NSW central coast, including the shoreface, inner plain, inner and outer mid-slope and outer plain, as well as 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). Such information enables the distribution of a limited number of seabed habitat classes to be further defined; however, the multiple levels at which biological diversity can be defined requires habitats to be mapped and classified at a range of levels within a hierarchical framework.

Many hierarchical levels represented on seabed habitat maps are delineated using airborne or acoustic remote sensing and associated ground truthing, which are commonly based on geophysical features (Zacharias et al 1998, Greene et al 1999, Roff and Taylor 2000, Bax and Williams 2001, Romos et al 2007) or a combination of biological and physical features (Jordan et al 2005a, Ryan et al 2007, Ierodiaconou et al 2007). Such classification schemes reflect the limited capacity of acoustic remote sensors to delineate biotic composition, while recognising the influence of physical factors on benthic communities. It is also important to recognise that the provision of fine-scale habitat maps of biotic classes over large areas of the continental shelf can only be obtained using acoustic remote-sensing tools.

The mapped classes represent those that can be interpreted or interpolated from the remotely sensed data and these are often used as surrogates for the biodiversity that occurs within the surveyed region; however, they are most effective as ‘surrogates’ for species diversity in conservation planning when they are appropriately validated (Ward et al 1999) and when all representative habitats are included (Roff et al 2003). Clearly, the effectiveness of habitats as a surrogate for biodiversity will depend, to some extent, on how well-defined habitats reflect patterns of biodiversity (Gladstone 2005, Winberg et al 2007, Williams et al 2009). Currently, the majority of surrogates used throughout Australia are based on a range of abiotic variables because spatial information on a wide range of assemblages or individual species is limited, and there is evidence that such variables may provide effective surrogates at broad spatial scales (McArthur et al 2010). However, the use of abiotic surrogates may fail to differentiate between similar features that support different biological distributions, which is termed ‘false homogeneity’ (Williams et al 2009).

The fine-scale mapping of habitats on the continental shelf of NSW has progressed in recent years and has built on the nearshore habitat layers used within bioregional assessments (Breen et al 2004 and 2005), and the broadscale bathymetry and sediments analysis in Boyd et al (2004). In addition, information from fishers and single-beam acoustic and video surveys on the continental shelf of the far south of NSW have identified the distribution of ‘soft’ and ‘hard’ seabed megahabitats (those one to 10 kilometres or larger) as well as the physical and biological attributes of mesohabitats (those 10 metres to kilometres in size; Bax and Williams 2001). Historical seabed habitat maps from the Sydney and Central Coast regions have also provided extensive coverage of continental-shelf habitats interpreted from sidescan sonar surveys conducted in the 1980s (Gordon and Hoffman 1989). More recently, sidescan sonar surveys of the Cape Byron region in northern NSW has provided fine-scale maps of seabed habitats on the inner continental shelf (Bickers 2004). The acoustic surveys were complemented with video surveys that described the distribution of dominant sessile macrofaunal and macroalgal assemblages to depths of around 60 metres. Targeted swath acoustic surveys have also been conducted in recent years in several northern NSW regions (Davies et al 2008a and b).

Although there is limited fine-scale data on the spatial extent of seabed habitats on the continental shelf off NSW, numerous site-specific surveys of shelf areas along the NSW coast have defined distinct habitats based on dominant benthic assemblages or assemblage composition. These have recently been summarised for regions north of Sydney (Rule et al 2007, Smith et al 2010). Most of the research focus has been on shallow nearshore reefs, with habitats broadly defined as fringe, turf, kelp, *Pyura*, urchin barrens and sponge habitat (Underwood et al 1991, Kennelly 1995, Andrew and O’Neill 2000, Roberts and Davis 1996). While shallow reef habitats can be described by their dominant benthic biota, they have not been mapped at this level; although, recent video mapping of reefs indicates it is possible over limited areas (Gladstone and Masens 2009). This supports that benthic community composition can be highly variable at a range of spatial scales and often occurs as a mosaic of habitats.

There is some latitudinal variation in the distribution of shallow reef habitats, with such habitats on the north coast of NSW containing an increasing cover of corals, particularly those associated with offshore islands (Harriott et al 1994 and 1999). Inshore reefs in this region are usually characterised by abundant macroalgae (Millar 1990 and 1998), dominated by the kelp *Ecklonia radiata*, and various species of *Sargassum* and *Caulerpa*, with increasing species richness of scleractinian corals offshore (Smith and Simpson 1991, Harriott et al 1994). Such patterns of increasing tropical influence on the north coast is also reflected in cross-shelf variations in reef fish assemblages (Malcolm et al 2010a), which has been used to modify the habitat classification system for the Solitary Islands Marine Park to improve the surrogates used to represent biological diversity (Malcolm et al 2010b).

Limited biological sampling of unconsolidated habitats has occurred on the inner continental shelf of south-eastern Australia; however, these habitats do contain sessile macrofauna (e.g. sponges, ascidians, bryozoans, sea whips), which increase the habitat's diversity and complexity (Mau et al 1998, Bax and Williams 2001, Bickers 2004, Beaman et al 2005). These macrofauna are particularly prevalent in areas of higher current flow. The abundance and diversity of sessile macrofauna often decreases with depth, with deep unconsolidated habitats containing only a few octocorals (soft corals or sea fans) and ascidians (Bax and Williams 2001, Beaman et al 2005).

Such mapping is improving our understanding of the relationships between the broadscale distribution of habitats and fish composition and structure (Williams and Bax 2001), which allow assessment of vulnerability to physical disturbance from fishing (Bax and Williams 2001) and provides information that can improve spatial management of marine resources (Jordan et al 2005b). Of particular importance is the identification of seabed habitats that allows an assessment of the availability of refuges from demersal trawling (Astles et al 2009). Mapping is also important for the development of baseline information on key habitats, which is essential for the ongoing monitoring of ecosystem health (e.g. Kendrick et al 2000). Maps are an effective tool for informing managers, stakeholders and the community about the extent and condition of important seabed habitats. They can also provide an opportunity to investigate those habitats under pressure from humans, and be used in a predictive way to identify habitats/sites that may be threatened by activities such as coastal nutrient and sediment input, fishing and climate shifts.

Although the mapping of seabed habitats has a range of resource management applications, improved information regarding the extent and distribution of specific habitats is particularly important for improving the likelihood that marine parks and their zones contain a comprehensive, adequate and representative selection of marine biodiversity. These are key planning criteria used throughout Australia for locating and zoning marine protected areas (ANZECC TFMPA 1998b). Comprehensiveness refers to the extent to which the full range of ecosystems and habitats in and across all bioregions are included in marine parks; adequacy is the degree to which the size, boundaries and location of marine parks are adequate to maintain biodiversity and ecological patterns and processes, particularly in relation to managing activities that impact on such patterns and processes; and representativeness is the extent to which marine parks reflect the range of biological diversity of ecosystems, habitats and communities (ANZECC TFMPA 1998a). Such criteria have been used to progress the development of a comprehensive, adequate and representative system of marine protected areas in NSW that aims to include a full range of marine biodiversity at the ecosystem, habitat and community/species level (NSW MPA 2001).

Given the limited information on the extent, distribution and structure of subtidal habitats on the continental shelf of NSW, a comprehensive seabed swath-mapping program was instigated to address the increasing need for maps of seabed habitats. This report describes the main physical and biological features of selected areas of the seabed in areas along the NSW continental shelf. Data presented herein includes a synthesis of existing data from previous hydrographic, sediment and aerial-photography surveys, combined with new swath acoustic bathymetry, backscatter and video data, with an emphasis on seabed habitats and associated sessile assemblages.

2. Objectives

The objectives of this study were to map the distribution, extent and structure of seabed habitats throughout NSW coastal waters using swath acoustics.

To achieve this it was necessary to:

- collect high-resolution bathymetric and backscatter data for selected seabed areas using acoustic swath mapping
- collect underwater video footage to validate swath acoustic data, provide an estimate of the accuracy of human interpretation of swath acoustic data and provide information on the distribution of sessile biota
- collate and integrate other relevant existing spatial seabed information.

3. Methods

3.1 Nearshore rocky reef and sand

Digital layers of the distribution of nearshore shallow rocky reefs throughout NSW were taken from spatial data provided by Avery (2005). Habitat layers were created from aerial photographs taken through targeted surveys or provided by the then NSW Department of Land and Water Conservation (now DECCW; see Breen et al 2004 and 2005). Images were scanned at 600 dots per inch, saved as 24-bit colour TIF files and registered to the 1:25,000 coastline. The images were rectified within ArcInfo (Environmental Systems Research Institute (ESRI)) and had an average positional error of 5.7 metres.

Areas interpreted as reef from aerial photographs assumed that no vegetation existed on the sand (i.e. drift algae) and all dark areas in the image were initially classified as reef. Areas covered a minimum mapping unit of 0.03 hectares. The reef delineation process was carried out preserving the maximum detail obtainable from the photograph with boundaries digitised using ArcView 3.2. Often photographs did not allow determination of the outer reef boundary due to increasing water depths and lack of contrast between reef habitat and adjacent unconsolidated areas. Areas not identified as nearshore reef were classified as sand to the same depth limit as that used to define the deeper edge of reefs. Islands were derived from the Australian Maritime Boundaries Information System provided by Geoscience Australia. These data layers are defined in the habitat map series as ‘nearshore reef’ and ‘nearshore sand’.

3.2 Broadscale rocky reef

Areas of rocky reef defined from analysis of the broadscale bathymetry and a small number of single-beam acoustic transects from the Solitary Islands region were collated from Mau (1997) and Mau et al (1998). This data provided the broad location of rocky reef habitats along 10 widely spaced transects between Coffs Harbour and Sandon from the shoreline to the state coastal waters boundary.

3.3 Broadscale bathymetry

Raw broadscale bathymetric data was collated for the NSW coast covering areas not previously included in the broadscale analyses undertaken by Boyd et al (2004). For ease of data handling these areas were nominally broken into subsections equivalent to two degrees of latitude and defined as:

- Brooms Head to Laurieton
- Avoca Beach to Bawley Point
- Bawley Point to Cape Howe.

Data were collated from a variety of sources including several datasets identified by the Manly Hydraulics Laboratory (MHL 2009). Suitable datasets within these areas were selected using the following criteria:

- datasets containing data at depths less than 250 metres
- datasets containing data of at least medium-to-coarse scale (defined as less than 40 points per square kilometre of resolution).

Data was converted to the WGS84 coordinate system and to Australian Height Datum, and then merged and data-constrained to include points at water depths less than 250 metres, which is consistent with the methodology used by Boyd et al (2004), and within the subsection boundaries. A set of zero metre data points were added representing the coastline boundary to produce a final dataset for kriging analysis. To assist in the creation of an interpolated surface from the constrained dataset, a variogram was created with Surfer software (Golden Software, USA) using all depth data and excluding the coastline. The variograms for each section were then used in the kriging analysis of the complete data set.

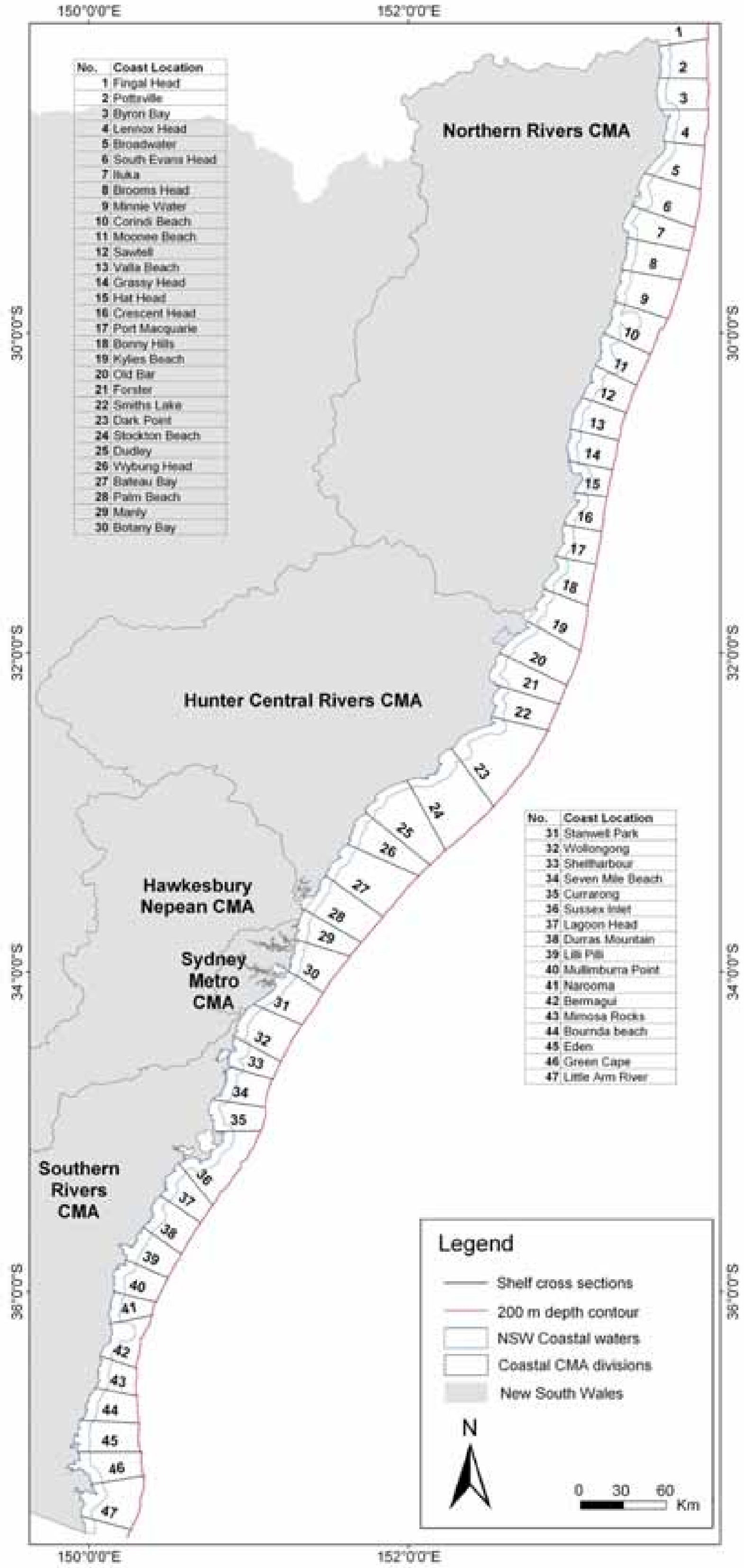
The three resulting interpolated surface grids were then reclipped to their respective subsection boundaries, converted to point data, combined with XYZ data from the two existing broadscale bathymetry surfaces (Boyd et al 2004) and brought into editing software 3D Fledermaus Pro (Interactive Visualisation Systems (IVS) Inc., Canada). The surface was then edited to remove edge effects, overlapping sections and erroneous areas. The final cleaned NSW-wide bathymetric surface for the 0–250 metre depth range was then exported as an XYZ ASCII file.

Preliminary statistical analyses of the difference between the DECCW interpolated broadscale bathymetric surface and the raw data showed that the accuracy of the interpolated surface varied within and between the three sections. The southern-most section performed best, with a median difference of 0.59 metres (SD = 4.81), with the Avoca to Bawley Point section performing second best (median difference 0.7 metres, SD = 4.13 metres), followed by the northern section (median difference 2.84 metres, SD = 3.04 metres). The overall DECCW broadscale bathymetric surface had a median difference of 0.49 metres from the raw data with a standard deviation of 2.74 metres.

Medium resolution bathymetric surfaces were also created for three interest areas on the NSW coast: Broken Bay, Jervis Bay and Batemans Bay. Raw bathymetric datasets identified by the Manly Hydraulics Laboratory (MHL 2009) were used with DECCW swath bathymetry omitted from the analyses. Data from within each of the three areas with a spatial resolution greater than 40 points per square kilometre were selected. Points were then converted to the WGS84 coordinate system and to Australian Height Datum. A set of additional coastline points with depths of 0 metres were also added.

For each of the areas, raw point data was brought into the 3D Fledermaus Pro software for editing. All data were assessed for quality and to determine an appropriate digital elevation model (DEM) surface resolution. The final accepted data points were exported as an XYZ file and imported into ArcGIS (ESRI, 2009) as point data. Kriging analysis was undertaken in ArcGIS, using the Spatial Analyst software extension (ESRI 2009). A spherical semi-variogram model was used and an ordinary kriging method using a search radius of 12 data points applied. The output surface raster cell size varied from 25 metres for Broken Bay and Jervis Bay to 50 metres for Batemans Bay. During the interpolation a mask of the area was defined to constrain the analysis. This was also used, after the kriging analysis, to clip the bathymetric terrain model and mimic the extent of the original bathymetric data.

To assess the general bathymetric characteristics of the NSW continental shelf across the latitudinal gradient, the coastline was divided into 47 evenly spaced (latitudinally) cross-shelf transects (Figure 1). These were used to estimate latitudinal trends in the distance, and maximum and minimum depths from the coastline to the boundaries of defined depth zones on the continental shelf using the broadscale bathymetric data. Transects were oriented perpendicular to the general direction of the shelf depth-contours, contained within the NSW Maritime coastal maps, at each location on the coast. General contour orientation at a scale of several kilometres either side of the cross-section point was prioritised over the coastline orientation at the exact location on the coast for each given latitude.



No.	Coast Location
1	Fingal Head
2	Pottsville
3	Byron Bay
4	Lennox Head
5	Broadwater
6	South Evans Head
7	Iluka
8	Brooms Head
9	Minnie Water
10	Corindi Beach
11	Moonee Beach
12	Sawtell
13	Valla Beach
14	Grassy Head
15	Hat Head
16	Crescent Head
17	Port Macquarie
18	Bonny Hills
19	Kylies Beach
20	Old Bar
21	Forster
22	Smiths Lake
23	Dark Point
24	Stockton Beach
25	Dudley
26	Wybung Head
27	Bateau Bay
28	Palm Beach
29	Manly
30	Botany Bay

No.	Coast Location
31	Stanwell Park
32	Wollongong
33	Shellharbour
34	Seven Mile Beach
35	Currarong
36	Sussex Inlet
37	Lagoon Head
38	Durras Mountain
39	Lilli Pilli
40	Mullimburra Point
41	Narooma
42	Bermagui
43	Mimosa Rocks
44	Bournda beach
45	Eden
46	Green Cape
47	Little Arm River

Figure 1. Position of transects used to estimate continental shelf distances and depths from the broadscale bathymetry.

3.4 Broadscale sediments

Grain size data from sediment samples collected during various studies from the NSW continental shelf and nearshore were collated and a set of broadscale sediment-grain-size maps produced. Data predominantly originated from the auSEABED database, a collated dataset of surficial sediments for the seabed off Australia (Jenkins 1997). Some additional data from various DECCW projects were also included. All data collated is presented as Phi size data and the position of data points used is shown in Figure 2.

Like the broadscale bathymetry, a variogram was created in Surfer to assist in the interpolation of a surface using a restricted dataset. The variogram output was then used in the kriging analysis (Surfer software), similar to the methodology outlined in Boyd et al (2004). The resulting sediment-grain-size surface was clipped to the area of the broadscale bathymetry layer (see section 3.3).

3.5 Historical seabed maps from the central NSW region

Georectified 1:25,000 charts of the Sydney Seabed Information map series were imported into ArcGIS and projected in WGS84 (Zone 56; Gordon and Hoffman 1989). Four charts exist in this map series covering an area from Crackneck Point on the Central Coast in the north to Port Hacking Point in the south. Charts covering Bate Bay (chart number 82310–577), Sydney Heads (chart number 82310–576), and Broken Bay (chart number 82310–575) are based on surveys and interpretation for a Sydney coastal study conducted by the NSW Department of Public Works between 1979 and 1985. The Gosford chart (number 83042–1001) is based on surveys done between 1984 and 1989.

Habitat categories, as defined on these charts, were digitised by hand in ArcGIS at a scale of 1:2000 with streaming set at three map units (metres). Polygons were smoothed using the ET Geowizards extension B-spline smoothing algorithm to eliminate angular features in polygons accidentally created during the digitising process. Quality control involved laying digitised polygons at 50% transparency over original charts and manually correcting conflicting areas.

The original maps define seven seabed types. These include medium- to coarse-grained orange-coloured sand with 40% shell; fine-grained grey-coloured sand with 5–20% mud and 30–40% shell; fine-grained fawn-coloured sand with 30% shell; fine- to medium-grained golden-coloured sand with 10% shell (and up to 60%); areas of reef partly covered by sand; reef materials consisting of shell, reef and coral fragments and small amounts of sand and gravel; and rocky reef. Seabed types were digitised individually and later grouped with the former six seabed types classified as soft sediment, and the latter three seabed types classified as reef. This was done to standardise the classification of seabed types between these earlier studies and the more recent survey work included in this report.

3.6 Field surveys

3.6.1 Sidescan sonar

Swath acoustic data was collected with a GeoSwath interferometric sidescan sonar and associated auxiliary sensors aboard the 8.5 metre catamaran *RV Glaucus* operated by DECCW. The system consists of a pair of 125 kilohertz transducers, a sound velocity sensor and a motion reference unit pole mounted on a V bracket and deployed over the port-side of the vessel (Figure 3), with a differential global positioning system (Omnistar) receiver located onboard. The DMS-05 triaxial accelerometer MRU measures roll, pitch and heave at 10 hertz, which is heading-corrected using a TSS Meridian Surveyor gyrocompass (10 hertz) that is accurate to within 0.1 degrees. Data were logged to a PC using GeoSwath Plus (GS+; GeoAcoustics Ltd, UK)) acquisition and processing software, which was used to post-process and correct depth data using sound velocity depth profiles and tide gauge data.

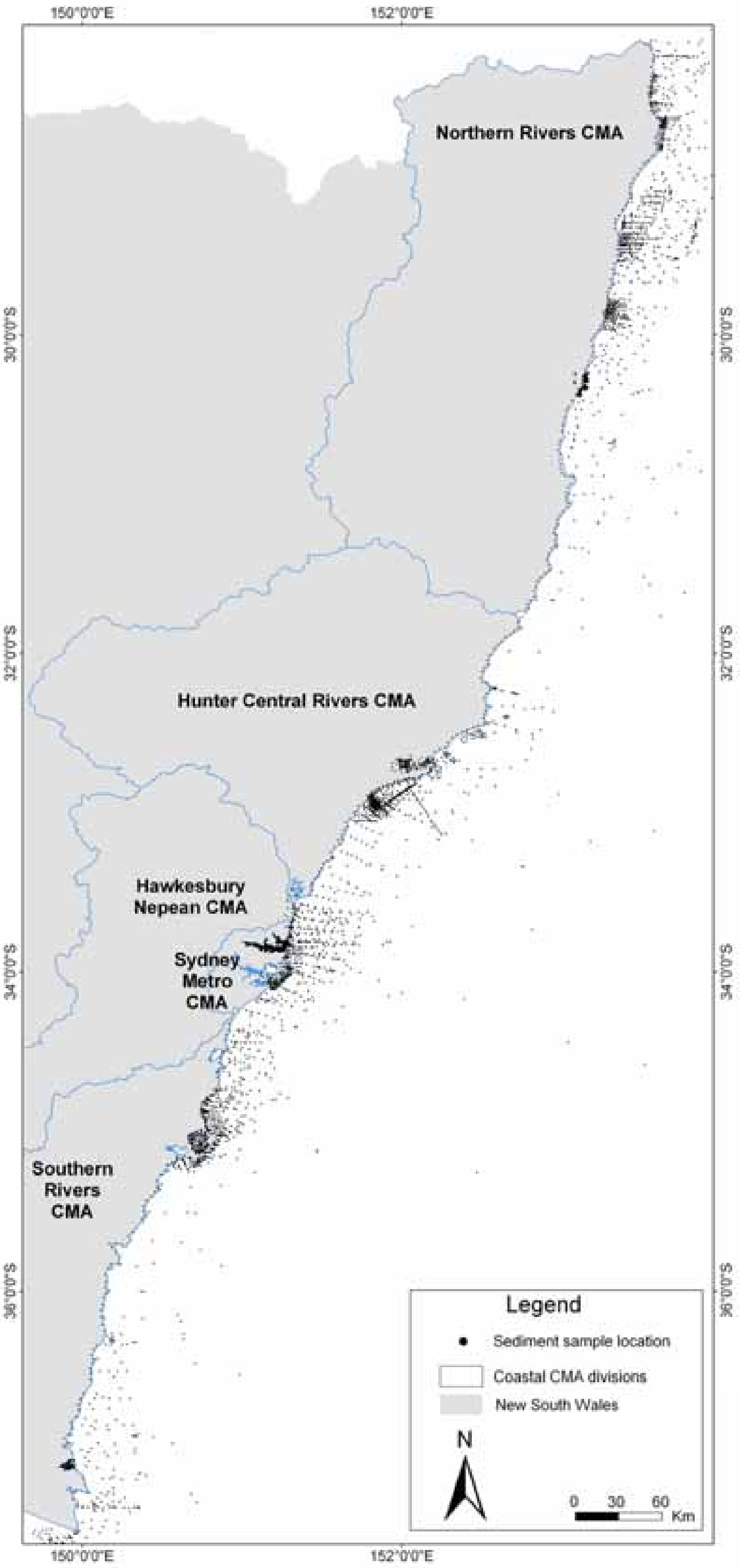


Figure 2. Sediment sample sites used to examine the broadscale distribution of sediments on the NSW continental shelf.

The shallow-water swath bathymetry mapping system collects high-resolution georeferenced depth and sidescan backscatter data. It is configured with port- and starboard-facing transducers and each transducer has one transmit stave and multiple receive staves. The transmitted pulse is similar to that used in conventional sidescan sonar (i.e. very narrow in the along-track direction and very wide in the across-track direction). A series of pings (alternating between port and starboard transducers) radiate from the transmit staves as the vessel moves along and reflect from the bottom, returning to the surface where they are sensed by the receive staves at a series of angles relative to the sea floor. A combination of time-of-return and the phase-delay between the receive staves allows the calculation of depth at a given angle. The amplitude of the returned signal is termed backscatter, which is a product of bottom reflectance and provides an indication of bottom hardness and substrate type.

Figure 3. Set up of pole-mounted Geoswath transducers on *RV Glaucus*.

The width of a given swath and ultimately the coverage over an area are dependent on a number of parameters including water depth, bottom type, sea conditions, vessel speed, sonar power/ping/pulse settings, system-processing speed and sensor performance. Maximum total swath widths achieved for data collected for the current project were limited to 240 metres and occurred at depths of approximately 60 metres over reef or unconsolidated sediments. Poor weather conditions limited the width of swath coverage for each transect. Even though data was collected at up to 150 metres per side (horizontal range), roll artefacts and attenuation of the signal increased with increased distance from the vessel and resulted in paucity or deterioration of data quality at the outer edges of the swath. Thus, data coverage at this range was excluded from the analysis.

Along-track coverage is predominantly governed by coverage speed and sonar ping length/interval. Survey speed was restricted to 4.5–5 knots. Ping frequency was a minimum of 7–8 pings/second (at a ping length of about 150 metres) giving an along-track resolution of less than 0.56 metres at nadir (directly below the vessel). This is above the recommended minimum operational ping rate of two pings per 1.5 metres along-track (along-track resolution 0.75 metres). Data were corrected for heave, pitch, roll and yaw of the vessel using a high frequency motion sensor. All sonar and auxiliary sensor data are time-stamped using a pulse per second correction of the computer clock relative to the universal time clock (UTC) as received from a geostationary satellite ZDA sentence string at the DGPS receiver. Surface water sound velocity was measured at the transducer heads using a Valeport mini-sound velocity sensor. Sound velocity profiles were collected using a Seabird SBE25 or SBE9+ CTD datalogger and binned at 1 metre depth intervals. Sound velocity profiles were used in post-processing to account for ray bending of the acoustic signal associated with changes in water density with depth. Depth data was also corrected for tidal variation using data from the Coffs Harbour, Yamba and Jervis Bay tide gauge stations provided by the NSW Department of Commerce Manly Hydraulics Laboratory. Tides used in post-processing of the data were standardised relative to Australian hydrographic datum.

3.6.2 Acoustic surveys

Field surveys were targeted at a number of specific areas providing a minimum of 30 square kilometres of swath coverage in the catchment management authority regions of the Northern Rivers, Hunter–Central Rivers and Southern Rivers (Table 3.1; Figures 4a and 4b). Many of the reef features that were targeted are marked on the admiralty charts; however, to date, there has not been any fine-scale mapping of the seabed in these areas. In general, transects were positioned to provide complete coverage over areas of interest, or opportunistically when transiting between areas. Adjacent transects were run with between 10 and 25% overlap to improve data coverage at the edges of swaths and provide some quality assurance information for the survey data collected.

Table 3.1. Location, date and coverage of swath acoustic data collected between 2006 and 2009. The locations in bold refer to those that were covered specifically for the catchment management authorities during the course of the project.

Location	**Date**	**Coverage (square kilometres)**	**Depth range (metres)**
Yamba	October 2006	67.9	6–57
Solitary Islands	October 2006	212.7	10–58
Solitary Islands	October 2008	24.0	12–62
Nambucca	September 2008	52.8	5–36
Fish Rock and Black Rock	June 2007	4.5	5–53
Point Plomer	June 2008	20.7	11–62
Port Macquarie	July 2008	9.4	13–59
Cod Grounds	May 2008	16.9	5–63
Cod Grounds (south)	November 2008	10.2	12–65
Mermaid Reef/Curphy Shoal/Giles Shoal	May 2008	46.8	8–42
Black Head	March 2009	20.8	5–31
The Pinnacle (Forster)	September 2006	21.0	14–81
The Pinnacle (Forster)	July 2008	8.7	6–45
Seal Rocks region	August 2006	23.5	5–125
Broughton Island	October 2005	29.6	5–64
Fingal Head region	March 2007	42.0	5–92
Terrigal	July 2008	13.0	3–48
Jervis Bay	July 2007	31.2	5–66
Brush Island	March 2006	32.0	10–93
Tollgate Islands	March 2006	37.8	5–94
Potato Point	April 2006	17.4	7–57
Montague Island	April 2006	13.4	5–96
Eden	May 2009	30.6	5–67

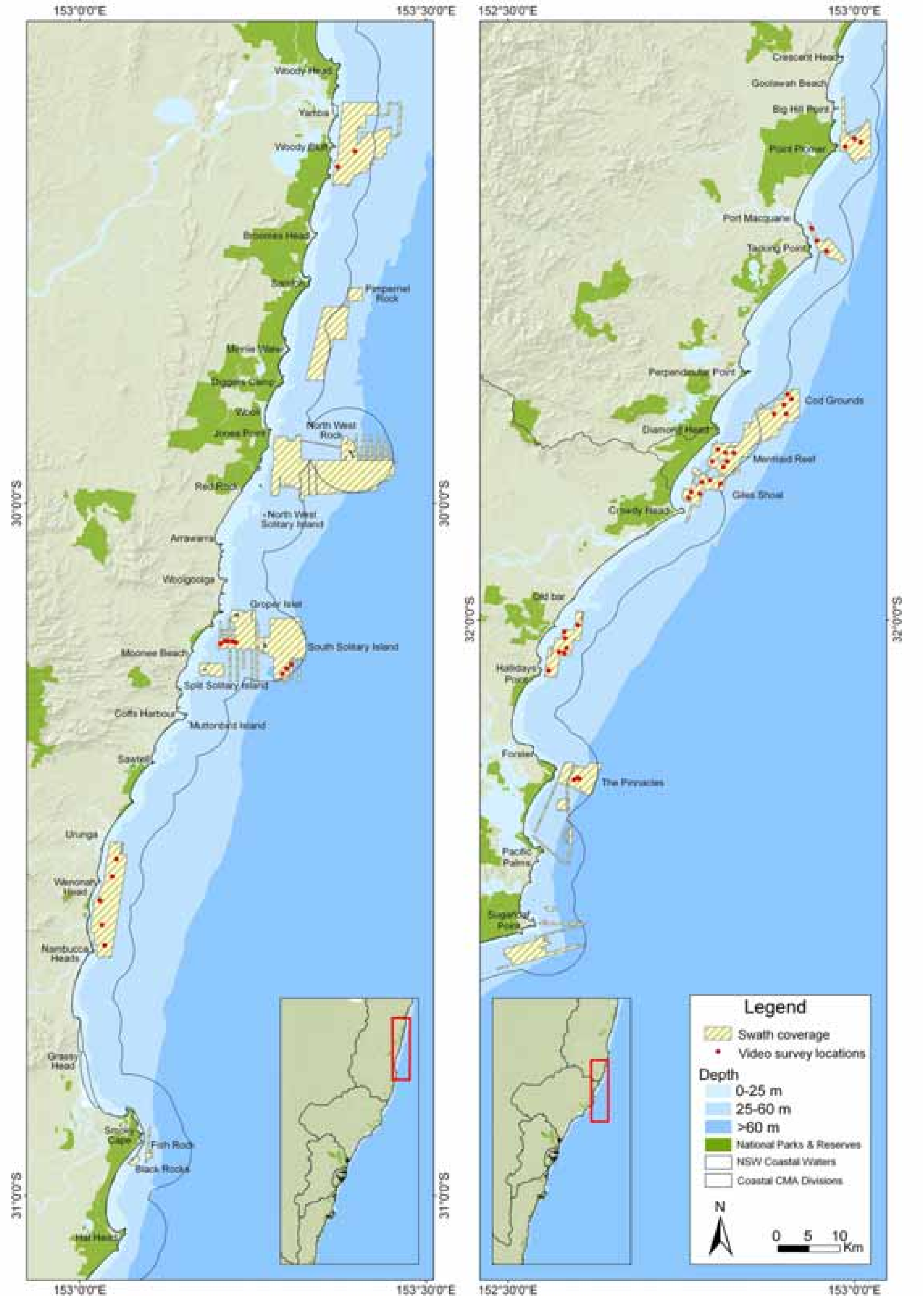


Figure 4a. Coverage of DECCW swath acoustic surveys and video locations within state coastal waters and Commonwealth waters along the northern continental shelf regions of NSW.

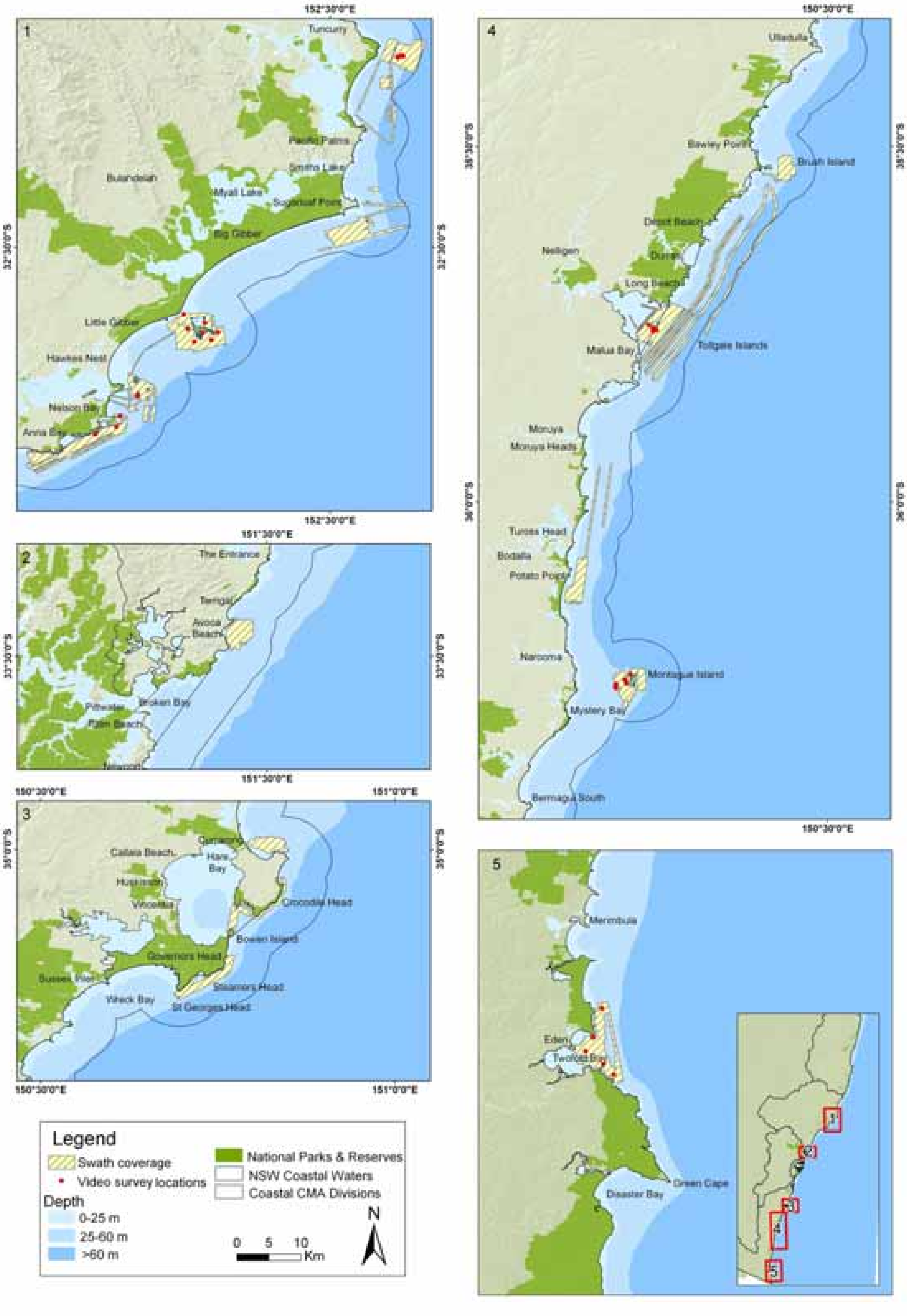


Figure 4b. Coverage of DECCW swath acoustic surveys and video locations within state coastal waters and Commonwealth waters along the central-north, central and south coast continental shelf regions of NSW.

3.6.3 Underwater video surveys

A digital underwater video camera was deployed along selected transects within swath acoustic survey areas to validate seabed mapping interpreted from swath acoustic data and provide some information regarding the distribution of visually dominant benthic biota. Transects were usually positioned across depth gradients in areas of heterogeneous backscatter. This provided an improved understanding of the relationship between backscatter intensity and physical features present on the seafloor. Details of the towed video data collected are shown in Table 3.2.

A custom-made digital underwater video camera (Morphcam) was fixed to a heavily weighted aluminium towfish and connected via cable to an onboard winch, which was used to control the depth of the camera relative to the seafloor. A live video-feed was provided to the vessel, which was used as a guide to manually maintain the position of the camera between 1 and 3 metres above the seabed. Vessel speed averaged around 1 knot whilst underway. Differential GPS location (WGS84), time (UTC), vessel speed (knots), sounder depth underneath the tow vessel (metres), and vessel heading (degrees) were overlayed onto video footage. The position of the camera relative to the vessel was established via an ultra-short baseline system (TrackLink 1500) with a transponder fixed to the camera, and a transceiver and motion reference unit (Xsens MTi) mounted alongside the vessel to correct for pitch, roll, and yaw. The position of the vessel and the camera were logged each second and written to a text file using the software package TrackLink Navigator. The same time-stamp was overlaid on video footage as was logged via TrackLink Navigator. This allowed each frame to be linked to a corrected geographical position using time as the common factor. Positional accuracy for each video frame was estimated at ±5 metres.

Video was captured in colour in areas shallower than 55 metres and in black and white in areas deeper than 55 metres. Video footage with associated overlay was recorded onboard in real time on MiniDV tapes and later copied to computer and compressed to MPEG video files. This compression reduced the total file size of video footage whilst retaining suitable resolution for identifying broad sediment types and recording the presence of visually dominant biota.

Table 3.2. Location, date and linear distance of towed underwater video footage collected during surveys between 2006 and 2009.

Video location	Date	Linear distance (kilometres)	Depth range (metres)
Yamba	October 2006	3.8	10–40
Solitary Islands	October 2006	8.8	10–35
Solitary Islands	October 2008	2	60–68
Nambucca Heads	October 2008–February 2009	7	11–31
Point Plomer	June 2008	4.4	24–43
Port Macquarie	July 2008	5.6	19–41
Cod Grounds	May 2008	5.1	25–53
Mermaid Reef/Curphy Shoal/Giles Shoal	May 2008	16	11–35
Black Head	March 2009	5	13–28
The Pinnacle (Forster)	July 2008	2.5	29–50
Broughton Island	September 2008	6	3–44
Tollgate Islands	March 2006	3.1	10–40
Montague Island	April 2006	3.2	5–30
Eden	May 2009	5	16–25

3.7 Field data processing and analysis

3.7.1 Swath acoustic data

Raw data files were filtered and gridded using the software program GS+ using filter settings listed in Table 3.3. Filtered soundings were gridded as weighted averages of soundings at a resolution of 5 × 5 metres. These grids were then spike filtered, smoothed at a nine-neighbour-cell resolution with 90% centre weighting and interpolated where data gaps were a distance of less than 10 metres. Backscatter data were also gridded (mosaiced) into 2 × 2 metre bins after processing (including trace normalisation) using texture mapping and classification software GeoTexture (GeoAcoustics Ltd, UK). Bathymetric and backscatter layers were exported from GS+ as Surfer grid files and imported to ArcGIS v9.1 (ESRI Software, USA) as a raster image for use within GIS. The coordinate system of the data frame was set as WGS 1984 UTM zone 56.

Table 3.3. Specifications of filter types and corresponding nominal settings used during processing of typical Geoswath sonar data.

Filter	Setting
Signal-to-noise ratio	Filter out <10%
Bin filter	Minimum four pings per bin
Amplitude	Filter out <0.5% signal return
Box	Minimum/maximum slant range 2 metres/125 metres Minimum/maximum horizontal range –5 metres/110 metres Minimum depth 2 metres/60 metres
Across-track	±1 metre at 20 filter points/side 99% learn rate
Along track	2.5 metres bins with ±1-metre tolerance

Standard methods for processing acoustic data have been used on NSW swath-mapping data since surveys first commenced in 2005. Initially, processing was carried out entirely within GS+, with raw sounding data subjected to tide- and sound-velocity corrections and then filtered using a suite of user-manipulated filters to remove spikes, erroneous points, water column soundings and instrument noise. Cleaned, smoothed, spike-filtered and interpolated binned data were then output as DEM grids for digitising. In some areas a number of motion artefacts were evident in the data as consistent rectangular depressions. These were the result of sporadic ‘drop-outs’ of data from the motion reference unit.

An analysis of the sonar processing workflow commenced in mid-2008 and was initiated to examine various aspects of the collection, processing and analysis of data by the survey team. This led to several changes in the operational workflow, which are outlined in Acoustic Imaging (2009). The most significant change was the implementation of the 3D Fledermaus Pro software (IVS, Canada). This has shifted the workflow to include area-based point editing and validation of sounding data using cube modelling. This method of cleaning the data uses a calculated ‘surface of best fit’, which is restrained by an International Hydrographic Organization (IHO) depth uncertainty order value to infer a level of confidence in the sounding dataset. Ultimately, the cube modelling approach resulted in a more statistically robust DEM bathymetric surface.

With these changes to workflow the DEMs produced for the different survey areas were created in different ways. Due to the large volume of data and the significant amount of processing time already expended on many of the survey areas, previous datasets were not completely reprocessed. GS+-gridded DEMs were created for each survey area as an initial surface. As a minimum, XYZs of the GS+ grids were imported into the Fledermaus software package for a final quality control before inclusion into the report. For a select number of datasets, individual sounding XYZs were exported from filtered individual swath files and then imported into the Fledermaus software for editing. Adoption of the fully streamlined workflow, which involves processing in GS+ and then in Fledermaus for area-based point editing, has only occurred for surveys conducted since September 2008. All DEMs, regardless of the workflow method, were exported to ArcGIS to produce bathymetry and seabed habitat maps. Methods used to produce the final DEM for each surveyed area are provided in Table 3.4.

Under the modified workflow, amplitude, limits, group, signal-to-noise ratio and bottom-tracking filters are applied to raw data files in GS+ and outputs are obtained as GSF file-types containing cube-surface production information. Editing is then continued within the 3D Fledermaus Pro software, where GSF files are built into a PFM data structure/object using PFM build options in the DMagic subprogram. As part of the build process, a surface of best fit is calculated using all the available soundings, with the resulting surface known as a cube surface. The PFM data is then loaded into the Fledermaus software and the cube surface is displayed and coloured by different attributes (e.g. transect line, number of hypotheses) to highlight problem areas.

Problem areas are selected and displayed in a three-dimensional point-editing window. A user-based decision is then made to directly edit the hypotheses or, more commonly, edit individual soundings associated with the problem area. Problem areas may be identified as areas with outliers, where there are more than two or three alterative hypotheses and/or where there is an obvious bias in the edited surface due to a large vertical distribution of soundings. Upon saving of the edited/cleaned soundings in a selected area, recubing of the area automatically occurs. The displayed cube surface is then updated within the Fledermaus display window. Once the cube surface has been validated, the data set as a whole is cleaned through the setting of thresholds above/below the validated cube surface. After cleaning of the entire surface has been completed, the PFM is unloaded back into the original GSF files with all soundings retained and flagged as accepted or rejected. Final data products are then exported directly from Fledermaus (e.g. clean soundings, chart soundings, contours, DEMs, etc).

The bathymetry was viewed as hill-shaded relief to provide quasi three-dimensional images to aid the viewing and habitat digitising process. Backscatter, which was viewed as a greyscale image, was also used to aid the digitising process. Backscatter data assists in the delineation of reef and non-reef in areas of uncertainty associated with motion artefacts in the bathymetric data. Areas of rocky reef were digitised by hand at a constant scale of 1:2000 using a combination of bathymetry and backscatter, with a minimum mapping unit of approximately 20 square metres depending on the complexity of the seafloor features. Overall, rocky reef areas were characterised by regions of relief, greyscale heterogeneity (texture) and higher backscatter intensity (i.e. darker areas), whereas unconsolidated substrates formed regions with relatively little relief, varied to homogeneous textural complexity and weaker (lighter) backscatter.

Reef polygons were cleaned using ArcMap and polygon-shaped files produced for all areas surveyed and compared and aligned to existing nearshore reef boundaries interpreted previously from aerial photography (Avery 2005). In areas of overlap, boundaries mapped from sidescan sonar data were preferentially used. Habitats were represented within shallow (0–25 metres), intermediate (25–60 metres) and deep classes (60–200 metres). Slope was calculated using the Spatial Analyst function in ArcMap 9.2. It was calculated for each 5 × 5 metre grid-cell as the maximum rate of change in value from each cell to its directly neighbouring cells. That is, the maximum change in depth over the distance between the middle of each cell and the middle of each of the eight cells surrounding it.

Table 3.4. Specifications of filter types and the corresponding settings used during processing of sidescan sonar data.

Location name	**DEM surface production: data input file type** **binned grid file type** **edited surface output file type**			
	GS+ editing surface GRD	Fledermaus (IVS, Canada) editing surface PFM		
	SWF point data input GRD binned grid file XYZ grid output (5 × 5 metres)	XYZ binned data PFM binned grid file XYZ grid output (5 × 5 metres)	XYZ point data input PFM cube surface XYZ grid output (5 × 5 metres)	GSF point data (cube) PFM cube surface XYZ grid output (5 × 5 metres) IHO depth uncertainty Order 1
Yamba	X	X		
Solitary Islands region	X	X	X	
Nambucca	X			X
Smokey Cape	X	X		
Point Plomer	X	X		
Port Macquarie	X	X		
Cod Grounds	X	X		
Perpendicular Point/ Crowdy Head				
Black Head	X			X
Port Stephens	X			
Avoca	X	X		
Jervis Bay region	X	X		
Batemans region	X	X		
Eden	X			X

DEM, digital elevation model; GS+, GeoSwath Plus (acquisition and processing software); IHO, International Hydrographic Organization; IVS, Interactive Visualisation Systems.

3.7.2 Underwater video data

Video footage was processed by visually interpreting physical and biological characteristics of the seafloor at point locations at 10 second intervals. At the tow speed of about 1 knot, each of these intervals corresponded to a distance of approximately 6 linear metres along the transect. A single video frame was captured as a still image (JPEG) every 10 seconds from video footage using the FrameShots software package. Each video image was visually assessed and selected physical and biological seabed characteristics were recorded alongside the geographical position of each frame.

Physical composition of the seabed was defined using the classes listed in Table 3.5 (see also Appendix 1). The type and percentage contribution of primary and secondary substrate type was visually estimated at each classified point. Types of biota present were recorded as shown in Table 3.5. Biota types defined were limited to broad classes of algae, large macroalgae and large sessile invertebrates. This reflected the relatively poor resolution of video imagery and often unfavourable water visibility, which restricted the level at which it was possible to distinguish different types of biota. Where possible, organisms were identified to species level (e.g. *E. radiata*). Smaller, more cryptic, or difficult to identify organisms were identified to broad taxonomic groups (e.g. mixed red and brown algal assemblages). Still images were used to build a reference collection of examples of biota types at each location. The percentage cover of primary canopy of *E. radiata* was visually estimated whenever *E. radiata* was present.

Classified video points were imported into ArcGIS as a pointed shapefile with a single point for each classified image. Although the spatial coverage of video was insufficient to interpolate between transects and create a map defining the distribution of biota, the bathymetric position of classified points was used to describe depth-related trends in distribution of biota where present. Interrogation of processed video data at several locations revealed that composition of benthic assemblages varied greatly at small spatial scales (metres) and did not appear to be consistently represented by habitat classes currently defined in the literature. Therefore, instead of grouping biota into habitat classes the presence of selected types of readily identifiable biota were simply recorded.

Table 3.5. Physical and biological attributes of the seafloor classified in each video frame.

	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 millimetre grains
		Coarse sand	Sand with >2 millimetre grains and shell fragments
		Gravel	2–10 millimetres
		Pebbles	10–64 millimetres
		Cobbles	64–256 millimetres
		Boulders	>256 millimetres (dominant rock size)
		Reef	Reef
	Percentage primary cover	Percentage value	Percentage cover of primary seabed features
	Secondary substrate type		Same categories as for primary cover
	Percentage secondary cover	Percentage value	Percentage cover of secondary seabed features
	Terrain	Flat	<1 centimetre height
		Ripples	<10 centimetre height
		Waves	>10 centimetre height
		Boulders	Boulders
		Gutters	Gutters
Biological attributes	Macroalgae	Macroalgae	Macroalgae present
	Macroalgal 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 (*E. radiata*) present
	Percentage *Ecklonia* cover	Percentage value	Estimate of percentage 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

3.7.3 Assessment of interpretation accuracy

Polygons defining the extent of reef created from swath acoustic data were created manually by interpreting hill-shaded bathymetry and backscatter data and hand digitising areas of reef with profile (see section 3.6.1 for review). These polygons have the potential to contain some level of error due to human error in interpreting the data and digitising the individual polygons, as well as error caused by the resolution of the data being coarser than the scale at which substrate changes occur. The physical structure of the reef (patchiness of reefs) can also influence the amount of error in localised regions because complex reef systems are more difficult to accurately digitise. To provide some estimate of the error contained within the digitised dataset of reef polygons, the accuracy of digitised polygons (reef vs unconsolidated) was assessed using classified video points as independent ground-truth data.

A total of 9658 video points within the area of swath acoustic data were classified as reef or unconsolidated according to physical attributes defined during video analysis. All available video data where acoustic coverage was available were included in this analysis. This included classified video point data from Yamba (n = 190), Solitary Islands (n = 1042), Nambucca (n = 1159), Point Plomer (n = 541), Port Macquarie (n = 535), Cod Grounds (n = 456), Mermaid Reef (n = 889), Curphy Shoal (n = 616), Giles Shoal (n = 238), Black Head (n = 757), The Pinnacle near Forster (n = 293), Broughton Island (n = 1058), Port Stephens (n = 982), Tollgate Islands (n = 427), and Montague Island (n = 475).

Video data was assumed to be spatially correct for the purpose of this analysis. Although USBL-corrected video data can encounter a spatial error margin of up to ±5 metres, this would still be within the size of the minimum mapping unit for digitised polygons and therefore acceptable as ground-truth data.

Video points for which the primary substrate type was classified as reef (i.e. bedrock or boulder reef covered more than 50% of the seafloor) were defined as reef. All other points, including areas of sand or mixed substrates where reef accounted for less than 50% of the seafloor were defined as non-reef. Using the ‘select by location’ function in ArcGIS, the number of points for which video data was in agreement with digitised polygons for reef and non-reef were determined, and an error matrix was created. The accuracy of digitised habitats was assessed using the following three complementary measures (i) overall accuracy, which measures the degree of agreement in the matrix or the percentage of points that were classified correctly; (ii) user accuracy, which provides the probability that a classified pixel actually represents that seafloor type, and (iii) the Tau coefficient (T), which represents the percentage of pixels that were classified correctly than would be expected by chance alone. Tau is calculated using the following formula:

where P_0 = overall accuracy, M = number of habitats, i = i th habitat, N = total number of sites, n_i =

$$T = \frac{P_0 - P_r}{1 - P_r} \quad , \quad \text{where } P_r = \frac{1}{N^2}\sum_{i=1}^{M} n_i \cdot x_i \quad ,$$

row total for habitat *I*, and x_i = number of correct assignments for habitat *i*.

4. Results

4.1 Broadscale bathymetry

The shallow- and intermediate-depth zones of the NSW continental shelf defined from the broadscale bathymetry in the present study showed regional and local variations reflecting the depth structuring of the shelf, regional changes in the angle of the coastline, the local position of prominent headlands and embayments, and the presence of offshore reefs (Figure 5). The distance to the shallow-depth zone boundary (25 metres) varied between 0.3 kilometres off Sydney Harbour and Botany Bay to 3.3 kilometres offshore of Corindi, near North Solitary Island, to 3.5 kilometres off the Shoalhaven Bight south of Nowra. The extent of the intermediate-depth zone (25–60 metres) ranged from 1.5 kilometres off Botany Bay and 1.6 kilometres off Shellharbour to 17.5 kilometres just north of Yamba. The majority of wide (greater than 8 kilometres) intermediate-depth areas were located north of Hat Head on the mid-north coast, reflecting the overall shallower slope of the shelf in that region. The small number of wide intermediate areas south of Port Jackson mostly reflected the presence of shallow embayments and/or offshore reefs. These included the Five Islands Group located off Wollongong and the Shoalhaven Bight and the reefs of the Sir John Young Banks off Seven Mile Beach and Crookhaven Bight, which result in a shallower shelf. The width of the intermediate-depth zones was more variable than the shallow-depth zones (70% of widths of shallow-depth zones were between 0.8 and 1.8 kilometres whereas 70% of widths for intermediate-depth zones were between 5 and 15 kilometres).

The overall width of the continental shelf of NSW is defined as the distance to the shelf break (this being characterised by a rapid change in the slope of the seabed) (Bates and Jackson 1987). There are considerable regional variations in the depth of the shelf break and the certainty with which it can be defined. The shelf break between Cape Howe in the far south of NSW to Forster varied predominantly between depths of 130–170 metres and gradually decreased in areas further north to depths of approximately 80–110 metres off northern NSW (Davies 1979, Boyd et al 2004). The distance to the outer edge of the deep zone used in this study (i.e. the 200-metre contour consistent with that defined in the NSW bioregional assessments (Breen et al 2004)) revealed the smallest zone widths of 13.4 kilometres and 13.9 kilometres were off Hat Head and Sawtell (Coffs Harbour region), respectively. The broadest areas occurred off the Stockton Bight with a zone width of up to 46.7 kilometres. This indicated there was considerable regional variability in the width of the NSW continental shelf because the defined depth of the shelf break and the 200-metre contour are generally close due to the rapid increase in depth.

Of particular significance within this analysis is the maximum depth and width of the NSW coastal waters boundary on the continental shelf for these contour-normal profiles. This is represented in the interpolated broadscale bathymetry (Figures 7, 8 and 9), which display considerable regional variability reflecting the depth structure of the shelf and the longitudinal position of the boundary. The width of the boundary varies from 5.6 kilometres immediately north of Terrigal and within Stockton Bight (equivalent to 3 nautical miles) to a maximum of 18.4 kilometres offshore of North Solitary Island (Figure 5). The minimum depth at the boundary is 32 metres located off Evans Head and the maximum depths are offshore of Montague Island (132 metres) and Broughton Island (130 metres) (Figure 6). Deep water is also present in state coastal waters east of Botany Bay (103 metres). The regional patterns indicate that all state coastal water boundaries at depths less than 40 metres are located north of Stockton Beach, whereas all boundaries at depths greater than 80 metres are south of Botany Bay. To the north of Broken Bay, in 96% of profiles, the state coastal waters boundary occurred in the intermediate-depth zone. To the south of Broken Bay, only 35% of the boundaries occurred in the intermediate zone, reflecting the comparatively narrower shelf that exists to the south of the state. No areas of the shelf-break lie within NSW coastal waters.

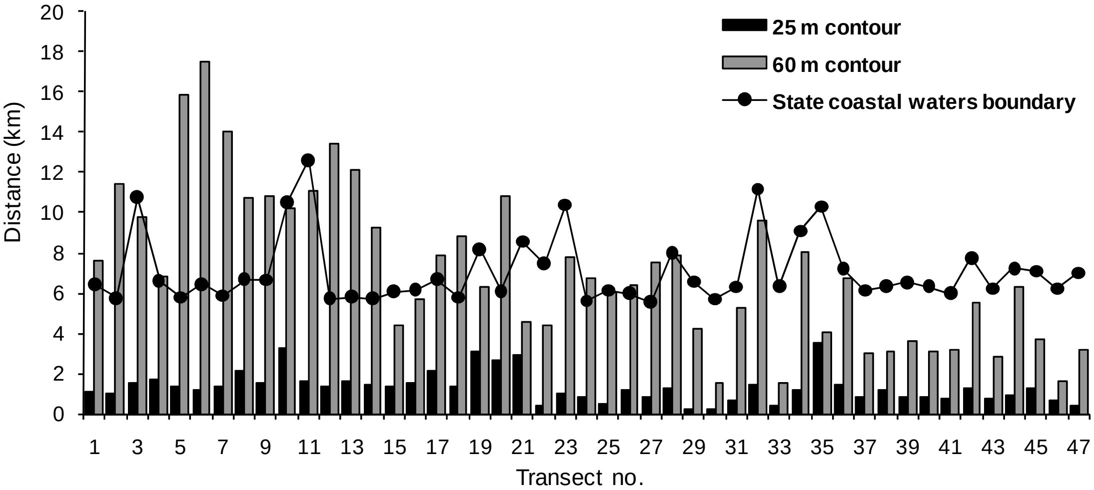


Figure 5. Distance (kilometres) from the coast to the state coastal waters boundary and 25 metre and 60 metre contours on the continental shelf of NSW.

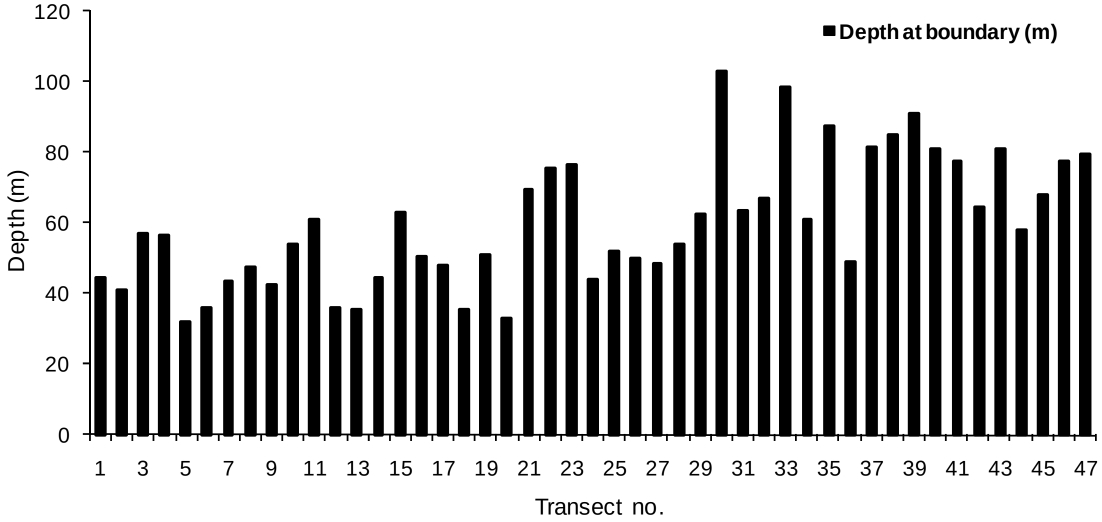


Figure 6. Depth (metres) at the state coastal waters boundary on the continental shelf of NSW.

4.2 Broadscale surficial sediments

The sediments on the shelf of the northern region were dominated by inner-shelf sand, mid-shelf muddy sand and outer-shelf coarse sand, although there were localised variations to this broad pattern (Figure 7). A significant feature of the inner-shelf was the occurrence of finer sediments offshore of the Yamba and Wooli regions, and the presence of relatively coarser sediment in the same depth-range south of Yamba, throughout the Solitary Islands region and offshore of Cape Byron.

A range of sediment types were found on the inner-shelf offshore of Yamba. For the very nearshore, grain size generally decreased with increasing distance offshore. A blanket of fine-grained muddy sands lay off the mouth of the Clarence River extending offshore and to the south. Further seaward, a belt of coarser inner-shelf sands formed the eastern boundary of the nearshore sands and muds. The outer shelf primarily consisted of coarser sediment, with the coarsest sediments in areas east of Nambucca Heads and Sandon and across a broad region offshore of Yamba to the north of Byron Bay.

Surficial sediments throughout the central NSW region were characterised by fine sand along much of the inner shelf and a broad area of finer sediments on the mid-shelf, notably to the south of Port Stephens (Figure 9). These mid-shelf muddy sand areas were particularly prominent offshore of the Hunter River, Hawkesbury River, Port Jackson and Botany Bay, reflecting the historical transport of finer sediment from these systems. There were also distinct areas of coarser sediment on the inner shelf immediately north of Port Jackson, Wollongong and Kiama, and on the inner and outer shelves north and east of the Port Stephens region.

Overall, most of the shelf of the southern region is dominated by clastic sediments on the inner shelf grading to predominantly coarse sediments on the outer shelf (Davies 1979). In the present study, there was a distinct difference in sediment composition north and south of Jervis Bay, with considerable cross-shelf and along-shelf variations evident in the north (Figure 10). The distribution of grain sizes indicates that the region is characterised by coarse to medium sand along much of the inner shelf and a broad area of finer sediments on the mid-shelf, particularly north of Jervis Bay. South of Jervis Bay the mid-shelf consists predominantly of medium-grade sands, with areas of fine sand south-east of Batemans Bay. Distinct areas on the outer-shelf east and north-east of Jervis Bay and east and south-east of Narooma were characterised by coarse sediments. Some of this variability results from the difference in data density along the coast, which causes greater uncertainty in areas of low sample density.

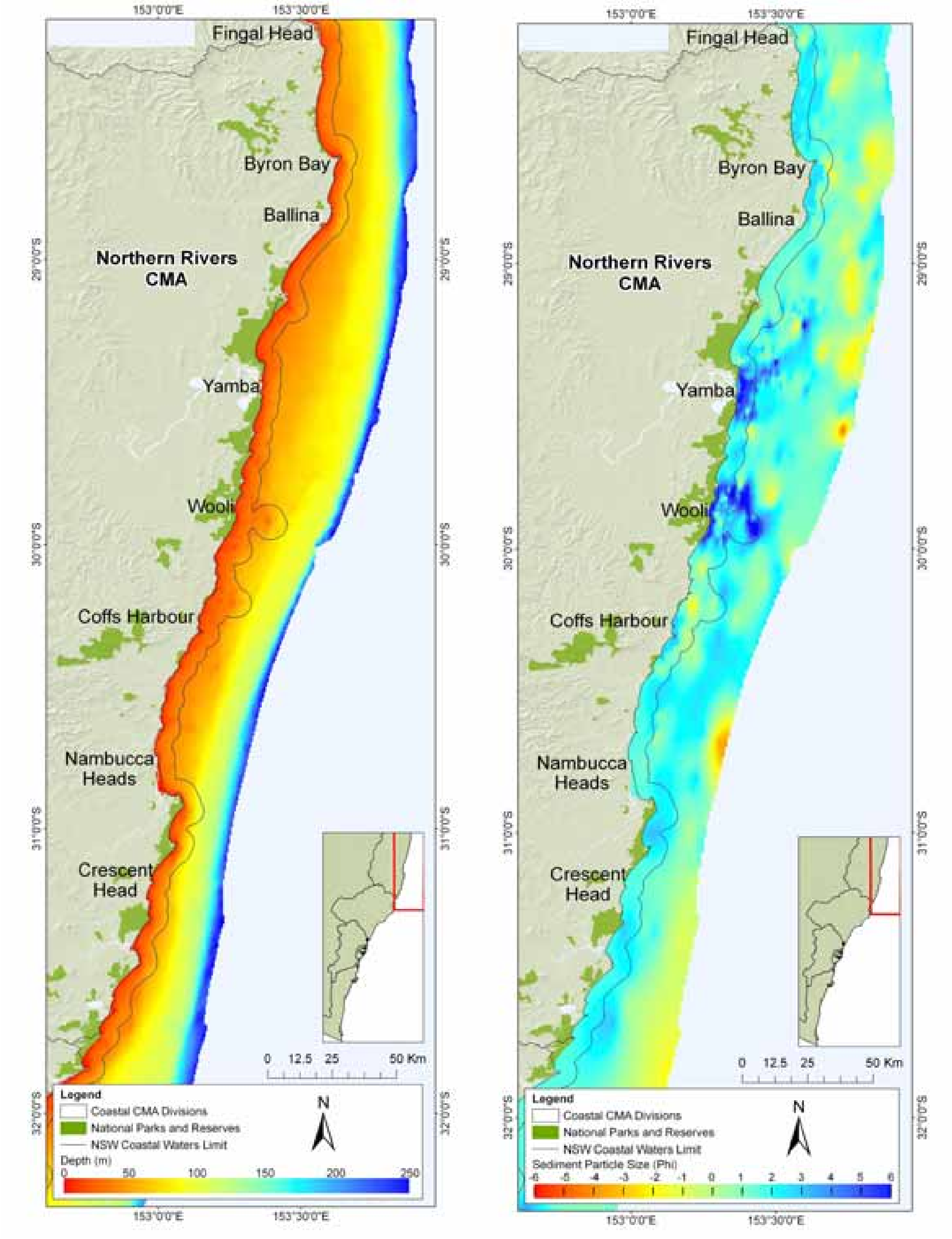


Figure 7. Interpolated broadscale bathymetry and surficial sediment distribution along the northern continental shelf region of NSW. CMA, catchment management authority.

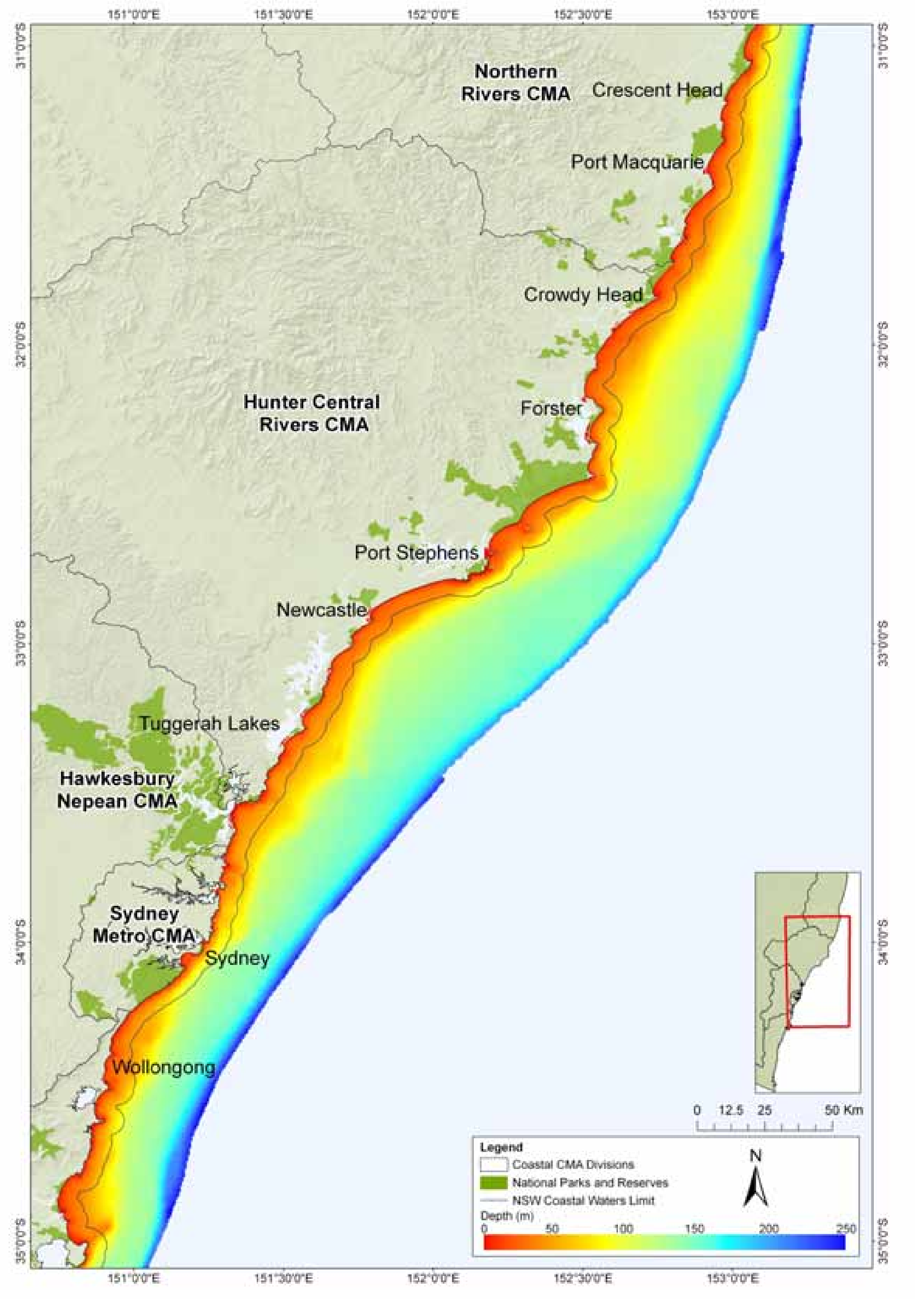


Figure 8. Interpolated broadscale bathymetry of the central and Sydney continental shelf regions of NSW (HCRCMA, HNCMA and SMCMA regions). CMA, catchment management authority.

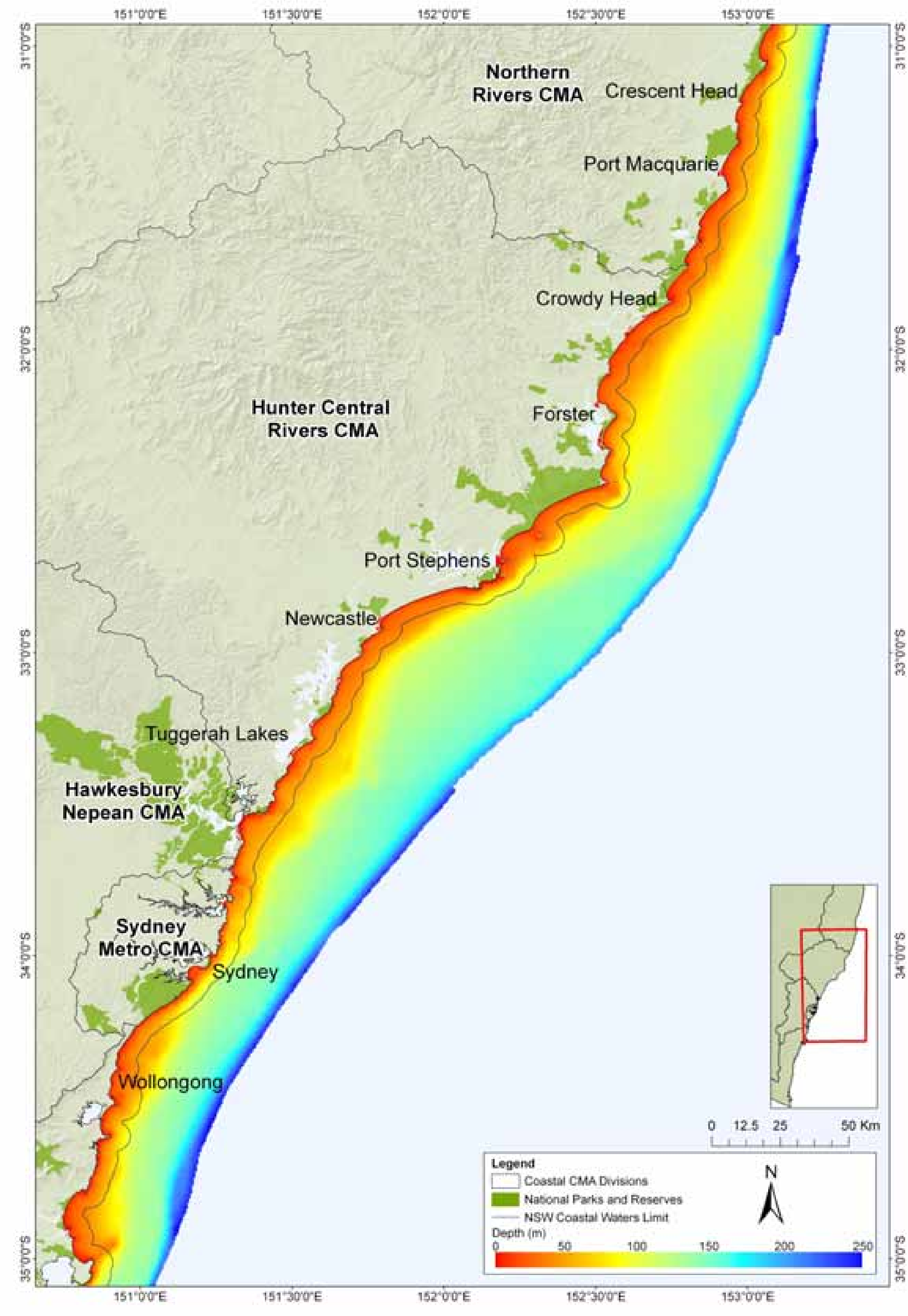


Figure 9. Interpolated broadscale sediments of the central continental shelf region of NSW (HCRCMA, HNCMA and SMCMA areas). CMA, catchment management authority.

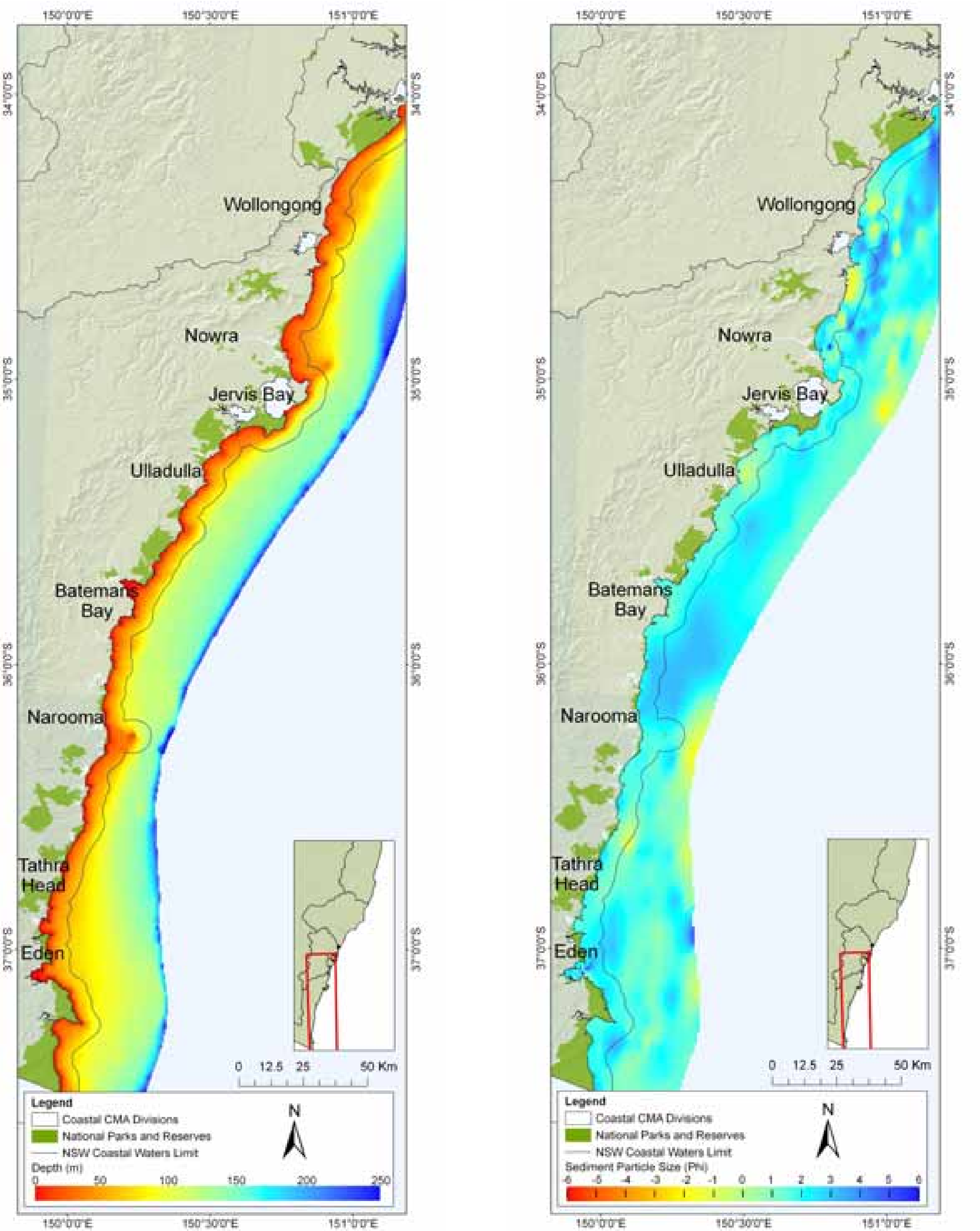


Figure 10. Interpolated broadscale bathymetry and surficial sediment distribution of the southern continental shelf region of NSW (Southern Rivers CMA region). CMA, catchment management authority.

4.3 Seabed habitat extent and structure

4.3.1 Tweed Heads to Lennox Head

The section of surveyed marine waters between Tweed Heads and Lennox Head is characterised by extensive areas of soft-sediment habitat (Figure 11). Characteristically large (kilometres to tens of kilometres) ocean beaches are separated by a number of major headlands with inter-connected subtidal rocky reefs to depths of at least 20 metres. Shallow reef occurs adjacent to Cook Island offshore of Fingal Head, with further reefs up to 7 kilometres offshore (Inner Reef, South Reef and Outer Reef). The full extent and depth distribution of these reefs systems are unknown, although broadscale bathymetry indicates they are around 4–6 metres deep at their shallowest point. A prominent reef that runs offshore of Kingscliff remains visible in aerial photographs for a distance of up to 2 kilometres from shore, indicating it is at a depth of less than 10–15 metres. Part of a large reef system that runs parallel with the coast immediately north of Brunswick Heads extends into intermediate water depths. The extent of additional known reef habitat in this region has been determined by a sidescan sonar survey conducted from an area just north of Brunswick Head to Lennox Head (Bickers 2004).

This surveyed region depicts further reef systems around Julian Rocks and offshore of Cape Byron in an area known as Cape Pinnacle. The reef around Julian Rocks is shallow immediately adjacent to the rocks; however, it extends into intermediate depths as it continues offshore for around 2 kilometres to the north-east. There is also an area of intermediate and deep reef south-east of the Cape Pinnacle Reef, most of which is patchy and of low profile (Bickers 2004). In addition, there are a number of smaller shallow reefs within Byron Bay, Bait Reef being one of the larger and better known of these. An area of shallow reef is also present immediately adjacent to Lennox Head, extending offshore a little less than 1 kilometre.

The soft-sediment areas of the Cape Byron region were classified using sidescan imagery and validated using towed underwater video (Bickers 2004). At depths less than 50 metres the seabed was usually dominated by fine well-sorted sand. Deeper areas were dominated by coarser sediment, particularly in the area east of Cape Byron. Throughout the region there were also several small areas, such as around the Julian Rocks, where there was coarser sediment at depths less than 50 metres. These were characterised by distinct sediment textures and/or morphology (ripples and waves). For example, there was evidence of coarse sediment trapped in large sand waves perpendicular to the exposed beaches between Cape Byron and Ballina, and areas of pebbles adjacent to the seaward side of nearshore reefs at Brunswick and Lennox Heads (Bickers 2004).

4.3.2 Lennox Head to Yamba

Little nearshore shallow reef was evident along the section of coast between Lennox Head and Yamba (Figure 12). A thin section of shallow patchy reef was present between Lennox Head and Ballina that extended several hundred metres offshore. A similar shallow, narrow, patchy reef was located adjacent to the shore along the ocean beaches immediately north and south of Evans Head. A comparatively larger area of nearshore reef occurred south-east of Evans Head and north-east of Woody Head. These shallow reefs are likely to extend further offshore than was mapped because the aerial photos are limited to defining subtidal reefs at depths less than 15–20 metres. Several defined reefs and shoals were apparent in the broadscale bathymetry offshore of the beaches north and south of Evans Head. North Riordan Shoal and South Riordan Shoal were located less than 5 kilometres offshore north of Evans Head. The extent of these reefs is not known from the datasets discussed here; however, shoal depths indicate that they rise to a depth of around 10 metres. South Evans Reef, which is south of Evans Head, is likely to be part of a much larger reef system extending several kilometres from shore. The broadscale bathymetry indicates shoal depths of around 2 metres in several places.

Figure 11. Distribution of known seabed habitats in the region between Tweed Heads and Lennox Head.

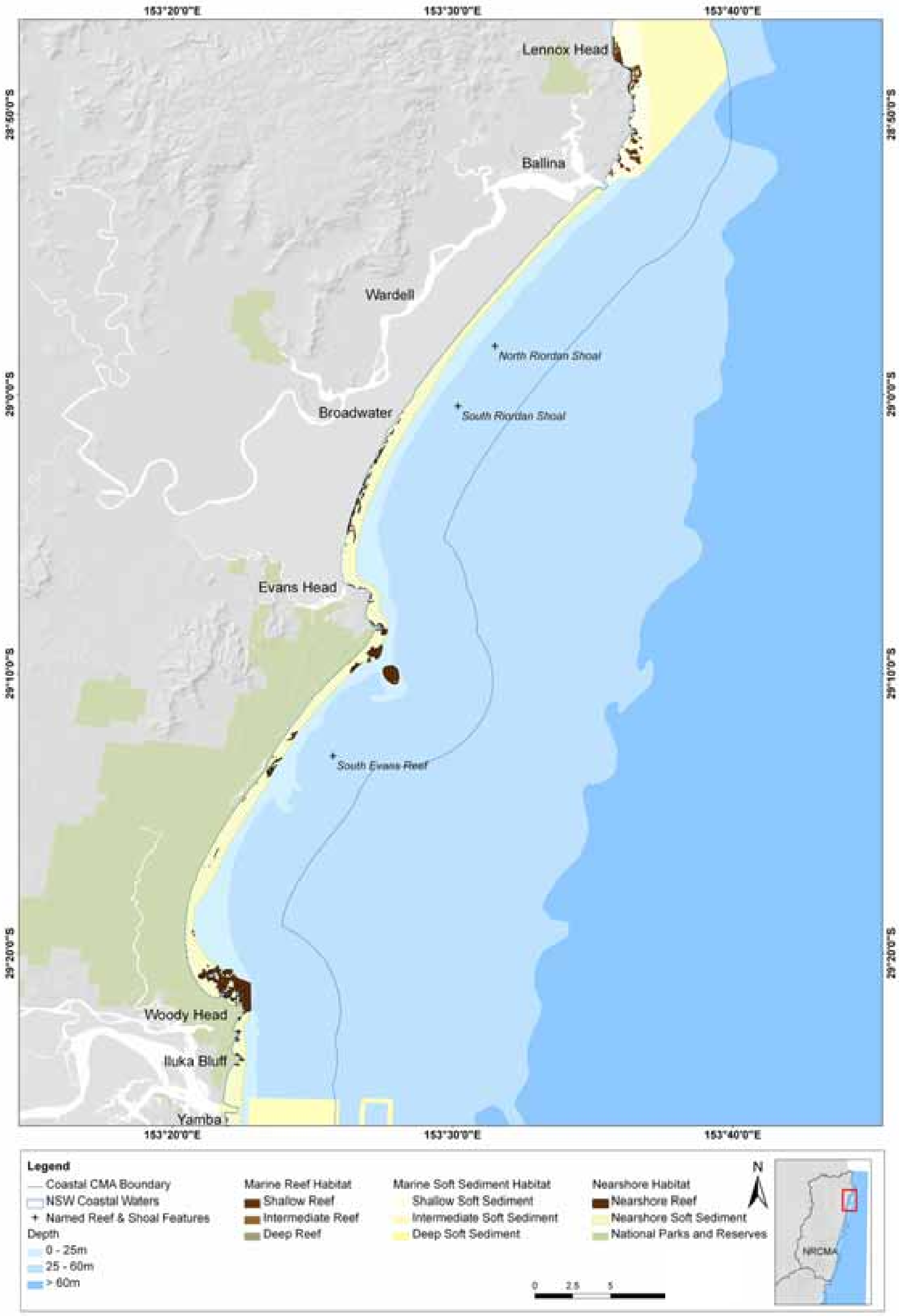


Figure 12. Distribution of known seabed habitats in region between Lennox Head and Woody Head.

4.3.3 Yamba to Woolgoolga

The results of the swath sonar mapping throughout the region between Yamba and Woolgoolga revealed previously undefined detail in the extent and structure of seabed habitats along this section of coast (Figure 13). One of the most significant seabed features of the region is a reef complex which extends almost 9 kilometres to the north-east, offshore from Shelly Beach Head (Figure 14). This reef is dissected by many sand- and gravel-filled gutters which add to the habitat complexity of the system. The majority of the reef system lies around 5 metres above the surrounding seafloor with a gentle downwards slope of 0.23 degrees to the north-east (Figure 15). Some isolated and comparatively steeper sections of the reef rise 12 metres from the seafloor. Evidence of metamorphism can be discerned from examination of the detailed bathymetry model and backscatter mosaics in the form of folds and fault lines. These strata provide a deal of complexity of reef habitat by creating numerous small vertical walls and overhangs. Some of the reef area is actually comprised of groups of boulders and cobbles atop the folded bedrock.

Gutters in the main reef and between reefs appear to occur along fault lines, in old bedrock strata and possibly in old river channels; for example, a significant fault runs north-east/south-west and cuts across bedrock strata. Such sediment in-filled river channels are likely to have formed before the last major sea level rise that occurred between 17,000 and 6000 years ago. These gutters account for the increased rugosity of this portion of the reef, range from 60 to 80 metres wide, and are filled with a mixture of coarse and fine sediments. Two sediment samples taken from within these channels comprised 33% and 22% gravel, respectively. The significant fault in the reef system running in a north-west/south-east direction at a depth of around 38 metres divides two areas of complexity. Changes in the relief of the reef east of this fault appear to be less than those to the west. This may simply be due to a greater proportion of unconsolidated sediments interspersed with the bedrock over this part of the reef. The shallower part of the reef (less than 10 metres) appears less guttered or ‘blocky’ in structure and is presumably contiguous with the Shelly Beach Head outcrop.

Further east from the reef, in water depths of 55–60 metres, was a field of parabolic sand dunes. The dunes were around 150–250 metres in length, 100–300 metres wide and less than 2 metres high and due to their shape appear to be moving in a southerly direction. The backscatter mosaic revealed that the troughs between the leading edge and tails of the dunes were composed of coarser material than the surrounding seafloor (Figure 4.16). It is likely that the dunes were produced by the passage of strong currents over the seafloor, most likely the East Australian Current. A sand bar offshore from the mouth of the Clarence River is another significant sedimentary feature near Yamba. The sand bar extended less than 2 kilometres offshore of the river’s breakwalls and rose to a depth of 7 metres from the surrounding seafloor at 25 metres. The swath coverage did not extend to the inshore edge of this feature.

East of this sand bar and approximately 5 kilometres offshore of the mouth of the Clarence River an arc of darker backscatter (higher intensity) coarse material was seen (Figure 16). This was possibly the southern boundary of the inner-shelf sand body described by Walsh and Roy (1983). There was a corresponding rise in the seafloor (less than 2 metres) above that of the adjacent seafloor directly to the south (this is difficult to see in the figures). If this was the boundary of the sand body described by Roy (1998), then the feature extended further south than previously recorded.

South of the mouth of the Clarence River, extending to the 3 nautical mile limit (state waters) and beyond, was a large area of soft sediments with a higher mud content. Although it was not clearly discerned in the backscatter mosaic, sediments in this area contained significant fine grains (less than 63 micron fraction). This region was of relatively low relief and graded gently across the shelf from the shoreface to around 50 metres depth at the 3 nautical mile line. The composition of this material has been previously recorded to contain up to 40% mud (Walsh and Roy 1983), presumably deposited by the Clarence River. Ten samples were collected from the nearshore mud basin as part of the present study that contained mud concentrations of up to 17.4%, which were considerably lower than that found by Walsh and Roy (1983).

Areas of shallow reef were evident between Shelley Beach Head and Sandon, particularly north-east of Brooms Head (Figure 13). At this point a large reef system extended at least 2 kilometres offshore; however, it is likely this reef extends further to intermediate depths. Rocky reef primarily occurred on the mid-shelf between Sandon and Wooli, as did reefs adjacent to headlands at Sandon, Minnie Water, Diggers Camp and Jones Point. Reefs adjacent to the headlands were mostly shallow, within the 15–20 metre limit of the visibility of the aerial photography, and only extended up to around 1.5 kilometres offshore. A large area of shallow and intermediate reefs located on the mid-shelf south-west of Sandon covered an area of about 10 × 5 kilometres. The area included at least four individual continuous reefs and numerous patchy reefs usually less than 200 metres in length. This reef system extended east into Commonwealth waters and joined the large reef system surrounding Pimpernel Rock. It is likely that more extensive reef habitat exists in this region because many of the reefs identified in swath acoustic surveys had not previously been identified in maps of broadscale bathymetry. This is particularly the case offshore of prominent headlands where only small isolated reefs have previously been identified.

The reefs that were swath-mapped were generally patchy and had low relief, in most places rising around 5–8 metres from the surrounding seabed (Figure 17). The only area where the reef was steeper with a greater relief was due east of Minnie Water, where the reef rose 13 metres from the surrounding area. The rest of the seabed in this area consisted of unconsolidated sediments of varying sediment size and morphology, which was reflected in the variation in the backscatter intensity (Figure 19). A distinct area with lighter backscatter was evident offshore of Minnie Waters, which was likely to consist mostly of fine to coarse sands. In contrast, unconsolidated sediments within the area of patchy reef to the north had a much higher backscatter intensity, and were therefore likely to consist of coarser sands and varying amounts of pebbles and cobbles. Underwater video ground-truthing is yet to be conducted over the reef and unconsolidated habitats in this area.

The section of reef between Wooli and Woolgoolga contained a number of extensive rocky reef systems, many of which were swath mapped (Figure 13). Areas of intermediate reef occurred several kilometres offshore of North West Rock, adjacent to the shallow reef south-west of Jones Point, and approximately 3–4 kilometres south of North Solitary Island. These reefs were considerably patchier than the shallow reefs in the region but had similar relief and slope (Figures 20 and 21). An area of deep reef was identified around 5–6 kilometres south-east of North Solitary Island, characterised by linear features that ran north-east and south-west through the area. The reef features rose an average of 4 metres from the surrounding seabed with fairly uniform low complexity and low rise and fall between the features.

Although swath mapping is not complete for this section of the NSW coast, it is clear that much of the seabed consists of unconsolidated sediments. Sediments of varying grainsize were evident across the area, which was reflected in the variations in intensity and range of textures displayed in the backscatter mosaic (Figure 22). Relatively homogenous areas 1–2 kilometres south and 1–5 kilometres south-east of North Solitary Island were dominated by areas of lighter backscatter, which were likely to consist mostly of fine to coarse sands.

A distinct sand-wave field was visible to the south-east of Butterfly shoals and west of the reefs to the south of North West Rock and North Solitary Island (Figures 20 and 22). Sand-wave height ranged from approximately 2 to 5 metres, with a consistent curvilinear pattern, tending towards a 3 metre average. The consistency of the sand waves within the field decreased towards the east where they tended to be wider and less numerous.

The sand waves were longer on their north side, indicating predominant forces from the north with a shorter, steeper lee side on the south side of the waves. The higher backscatter intensity indicated coarser unconsolidated sediment (Figure 22). The data indicates that coarser-grained sediments accumulate on the lee side of the wave features. The largest of the unconsolidated grain sizes, indicated by the darkest uniform areas, had settled in the absolute base of the troughs between waves. The large trough was dominated by coarser sediments, as seen in runs west/south-west to east/north-east, and was measured using bathymetry. It ranged from about 7 to 10 metres in depth and ran just to the north of the patch of reef south of North Solitary Island (Figure 20).

Like other reefs in the region, unconsolidated sediments within areas of patchy reef further inshore and adjacent to offshore reefs had higher backscatter intensity. These reefs were likely to contain coarser sediments with varying amounts of pebbles, cobbles and boulders.

Extensive shallow reef occurred around North Rock and north-east of Jones Point. Most shallow reefs adjacent to North Solitary Island occurred as narrow fringes around the island, although a ridge extended south of the island. An extensive area of reef on the northern end of the island extended north to North West Rock (Figure 13). Much of the shallow reef swath-mapped offshore of Jones Point was of moderate relief, in some places only rising 3 metres from the surrounding seabed. This was reflected in the low slope of the reef, which was mostly less than 10 degrees (Figure 20). In contrast, the reefs around North Solitary Island and North West Rock, particularly those on the western side, were steeply sloping and extended to intermediate depths only a short distance from shore, in some cases as little as 8 metres.

The coarse-scale bathymetry also identified a large continuous shallow reef around North West Solitary Island and this extended up to 4 kilometres inshore of the island. Several kilometres offshore of North West Solitary Island there was also an extensive intermediate reef system that extended over several kilometres and was made up of a number of discrete reefs. The seabed adjacent to the section of coast between Arrawarra and Woolgoolga contained a number of areas of rocky reef to depths of around 25 metres, but in many places these were not continuous with the shore.

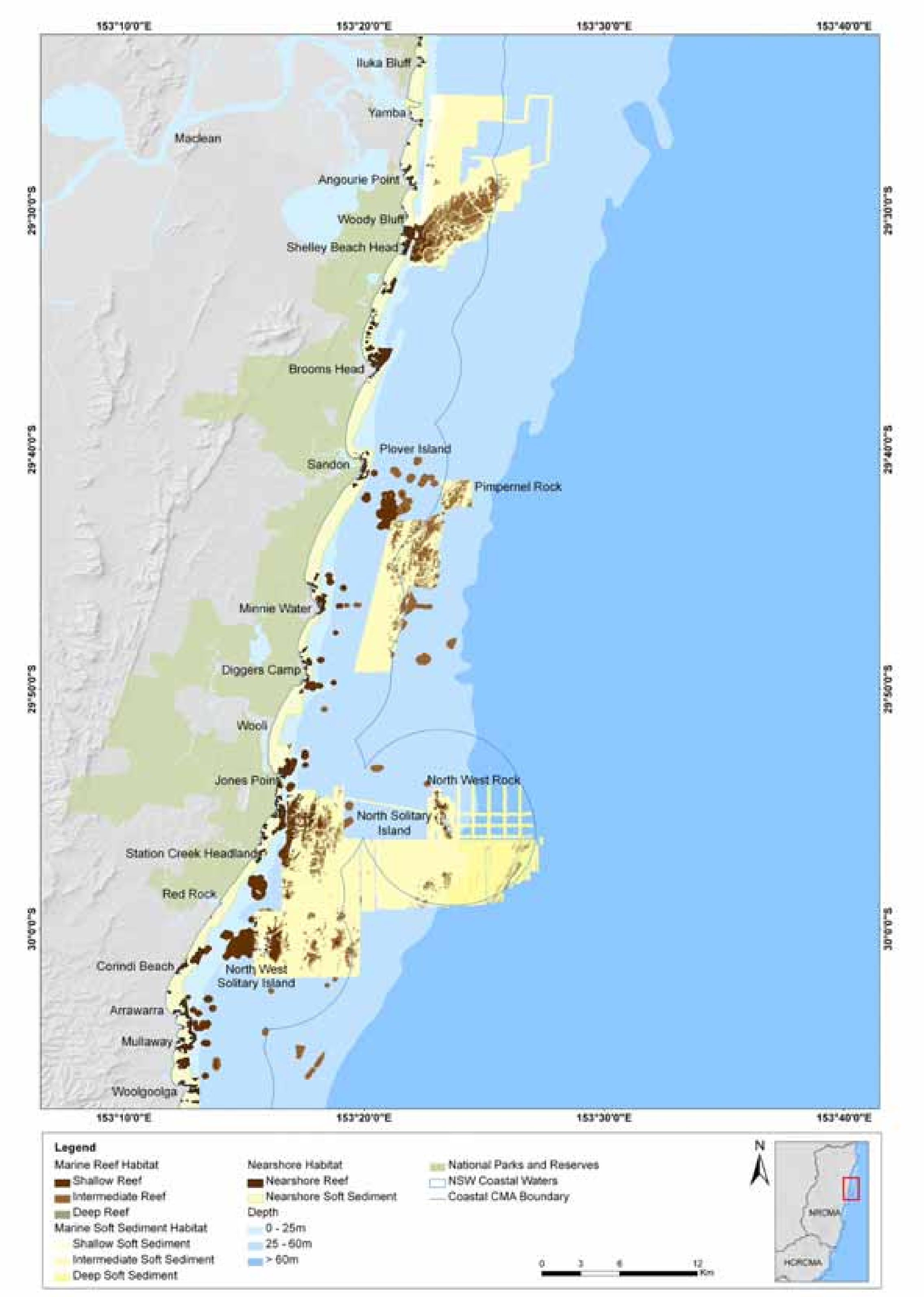


Figure 13. Distribution of known seabed habitats in the region between Yamba and Woolgoolga.

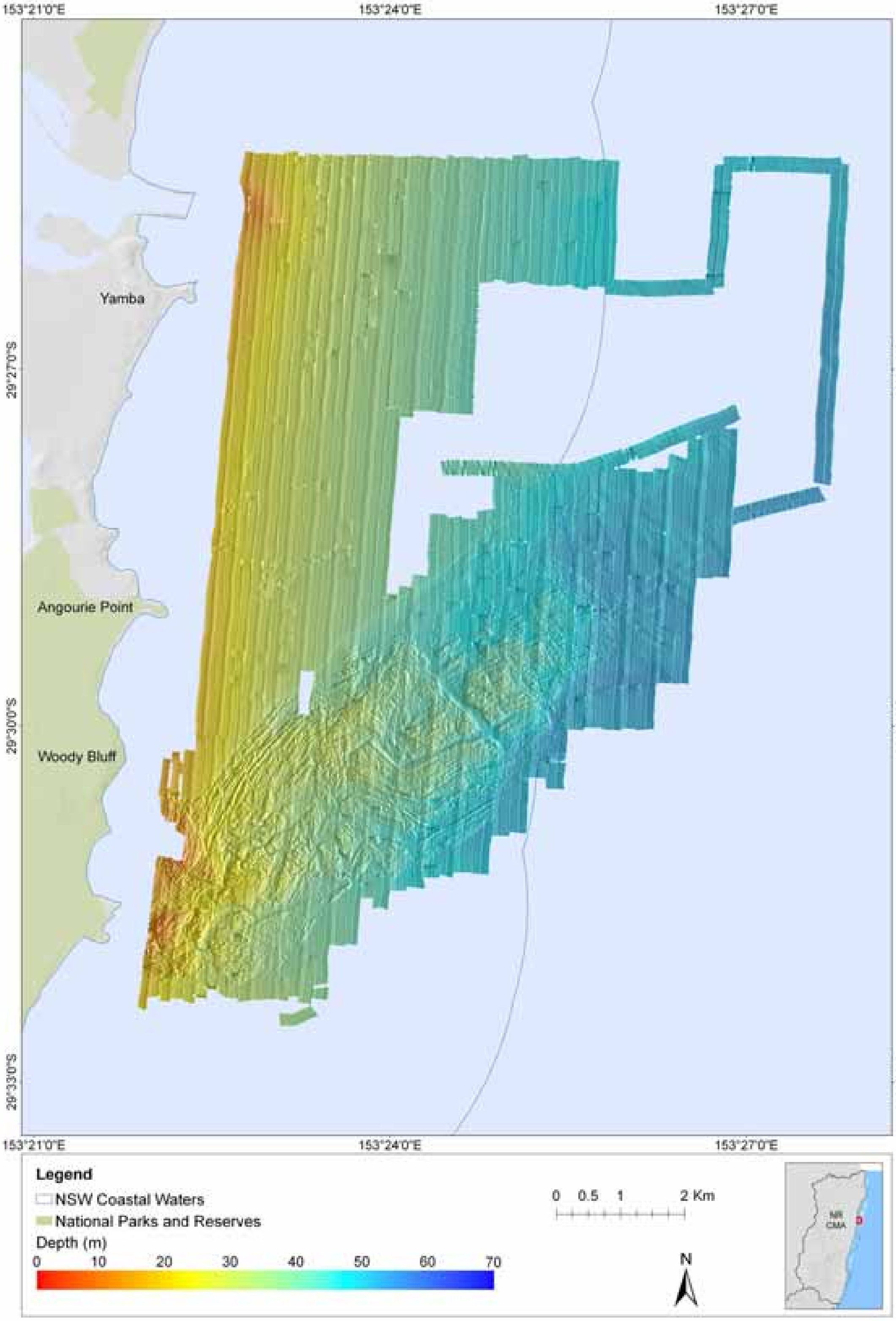


Figure 14. Hill-shaded bathymetric model of the seabed between Shelly Beach Head and the Clarence River.

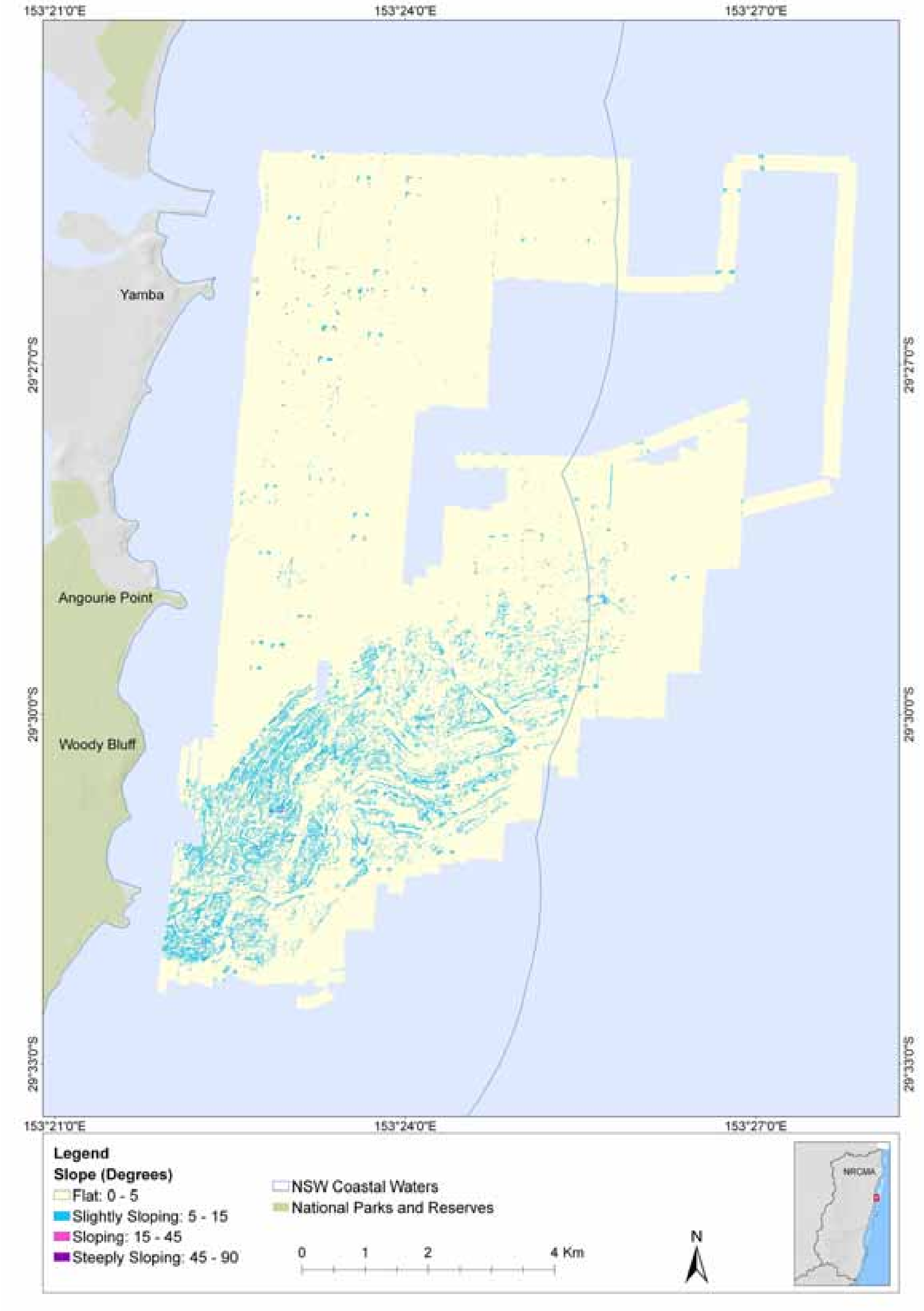


Figure 15. Slope model of the seabed between Shelly Beach Head and the Clarence River.

Figure 16. Acoustic backscatter of the seabed between Shelly Beach Head and the Clarence River, including video classifications of dominant substrate.

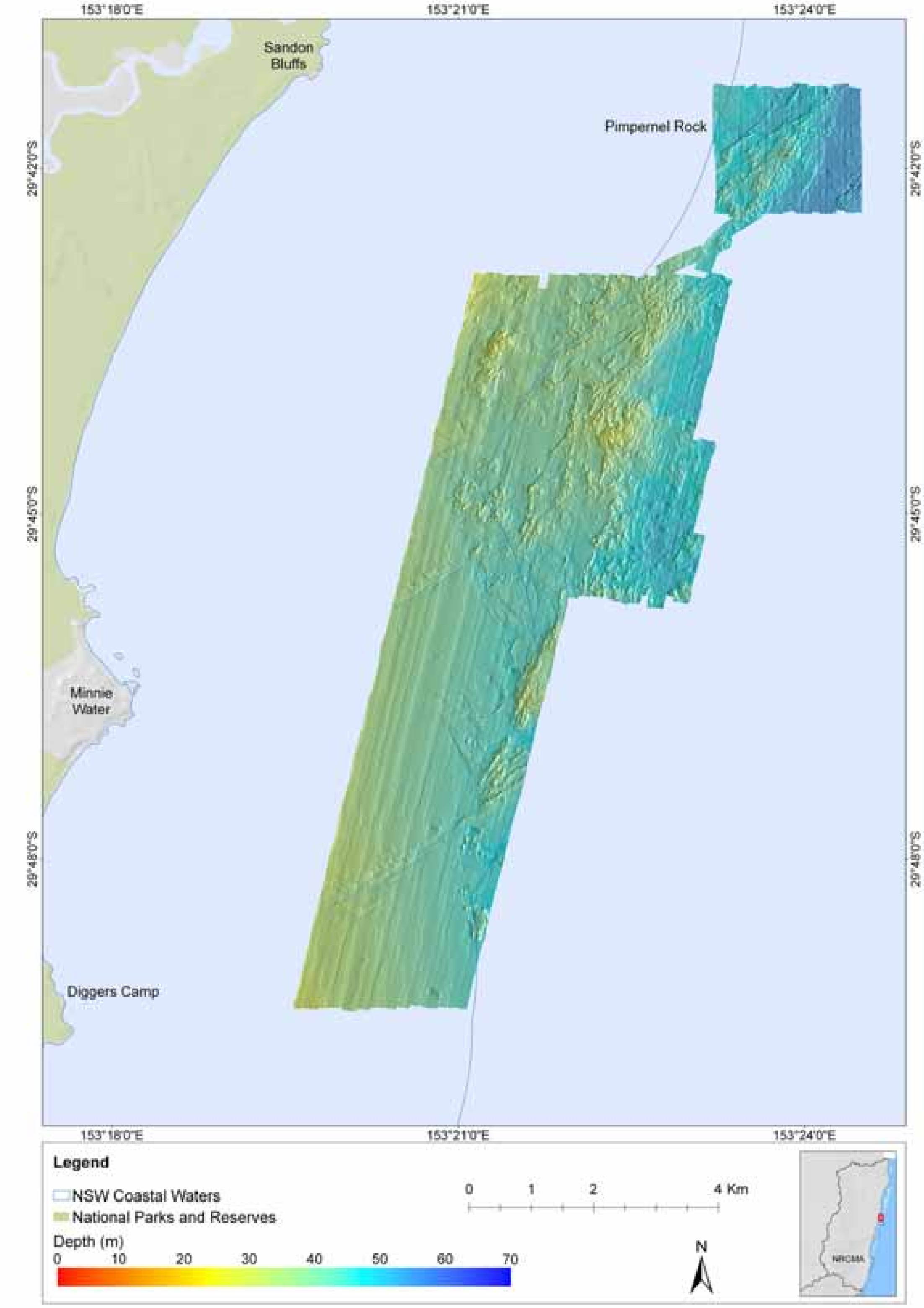


Figure 17. Hill-shaded bathymetric model of the seabed offshore of the Minnie Waters region and within the Solitary Islands Marine Reserve (Commonwealth waters).

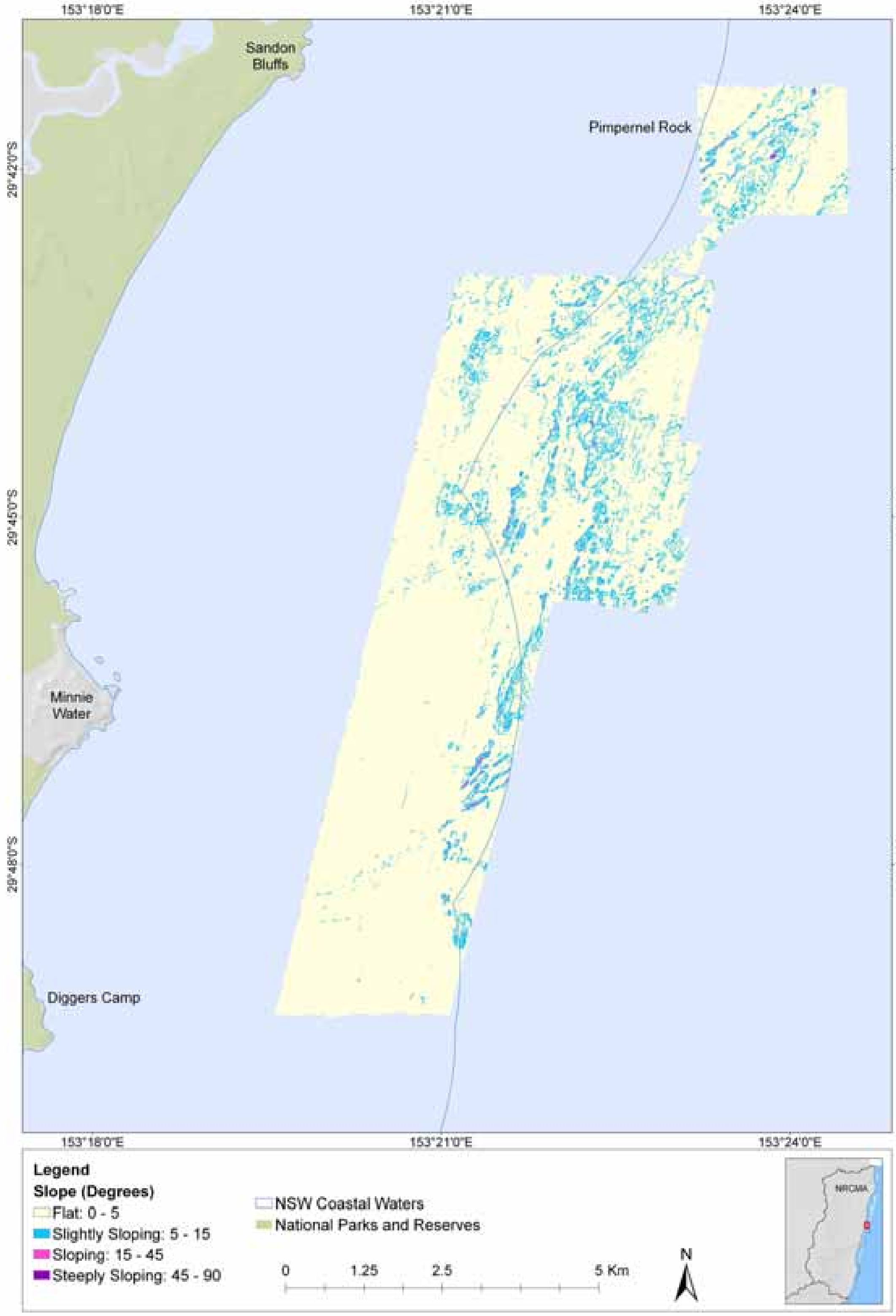


Figure 18. Slope model of the seabed offshore of the Minnie Waters region and within the Solitary Islands Marine Reserve (Commonwealth waters).

Figure 19. Acoustic backscatter of the seabed offshore of the Minnie Waters region and within Solitary Islands Marine Reserve (Commonwealth waters).

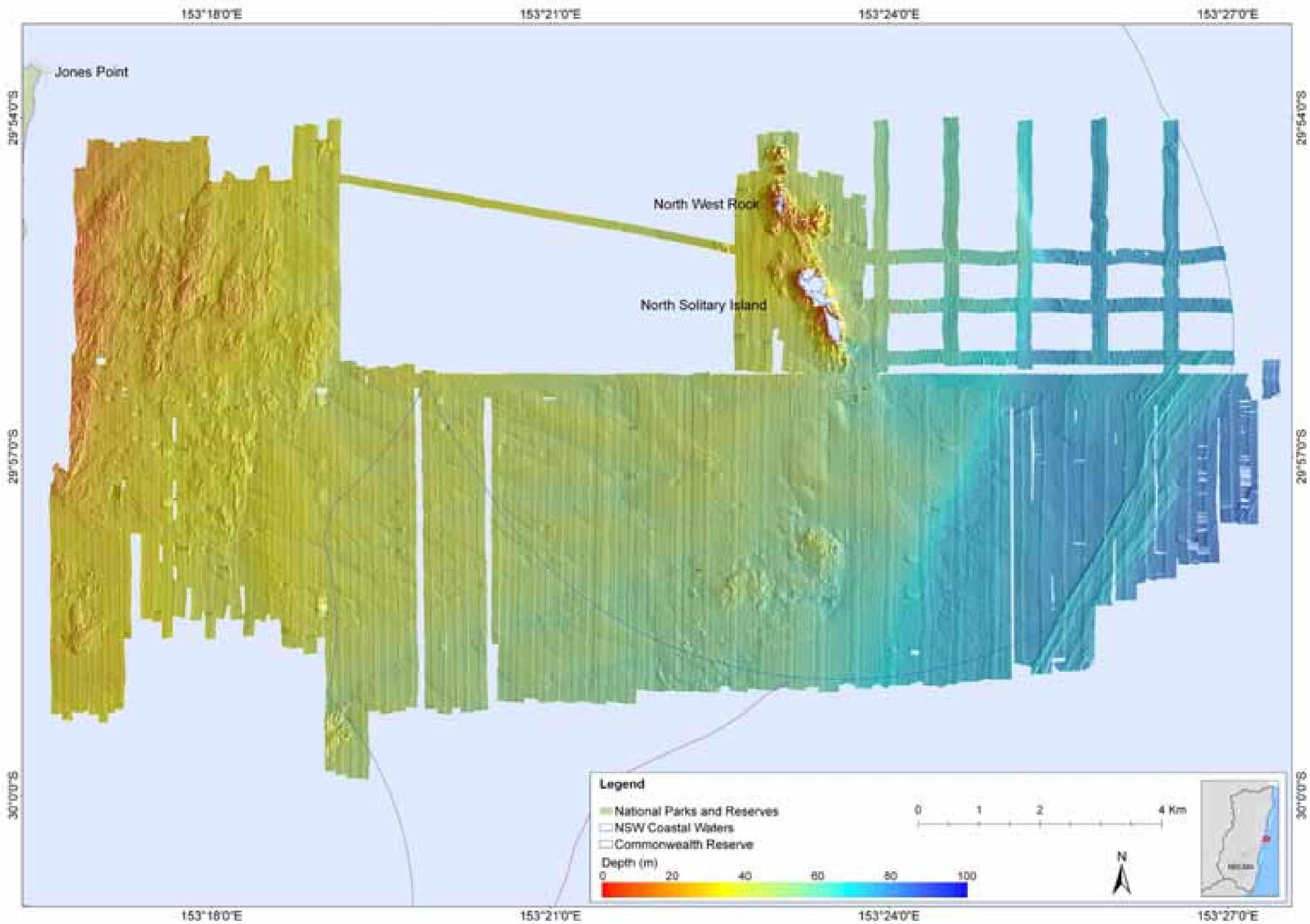


Figure 20. Hill-shaded bathymetric model of the seabed offshore of Jones Point and North Solitary Island.

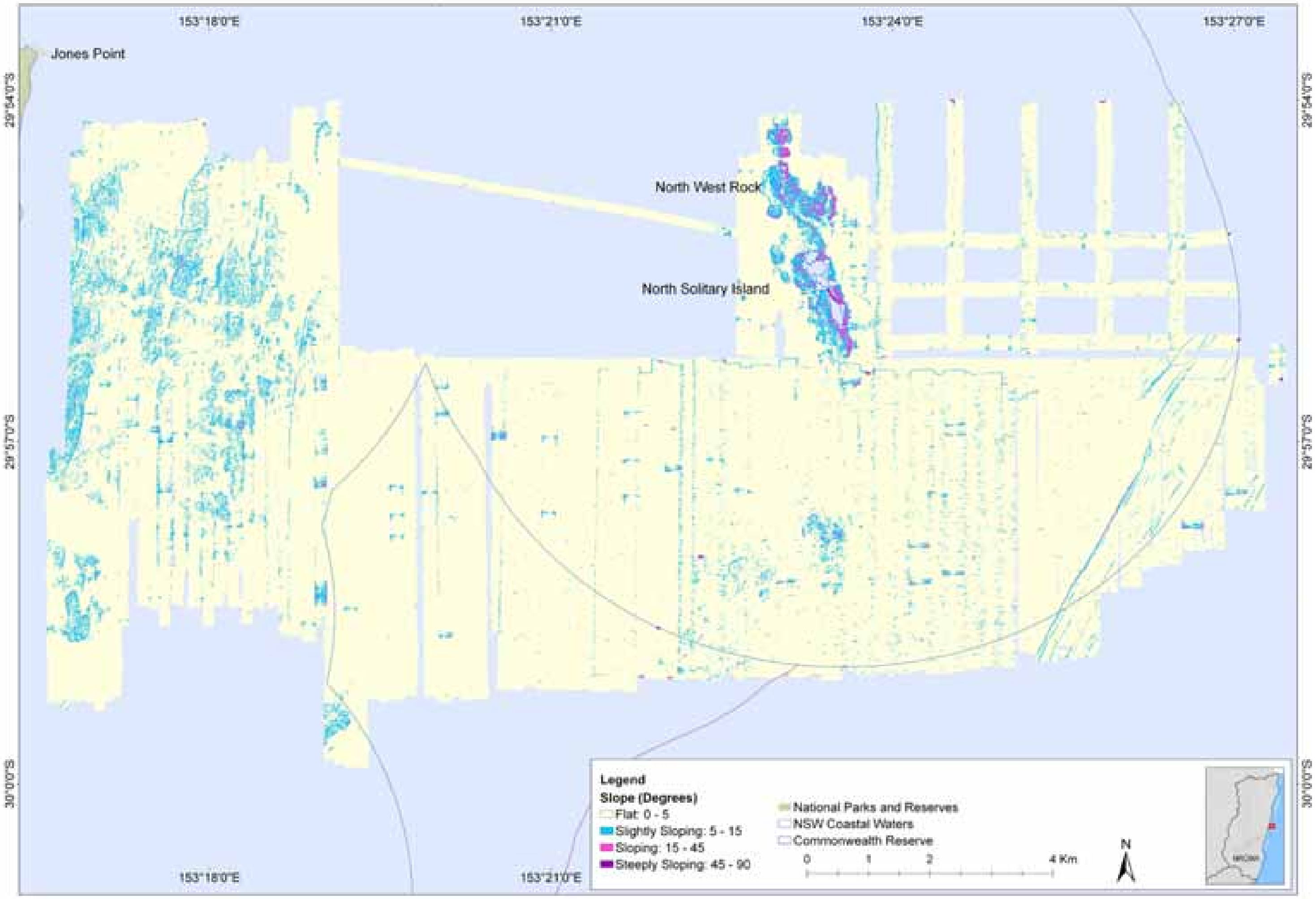


Figure 21. Slope model of the seabed offshore of Jones Point and North Solitary Island.

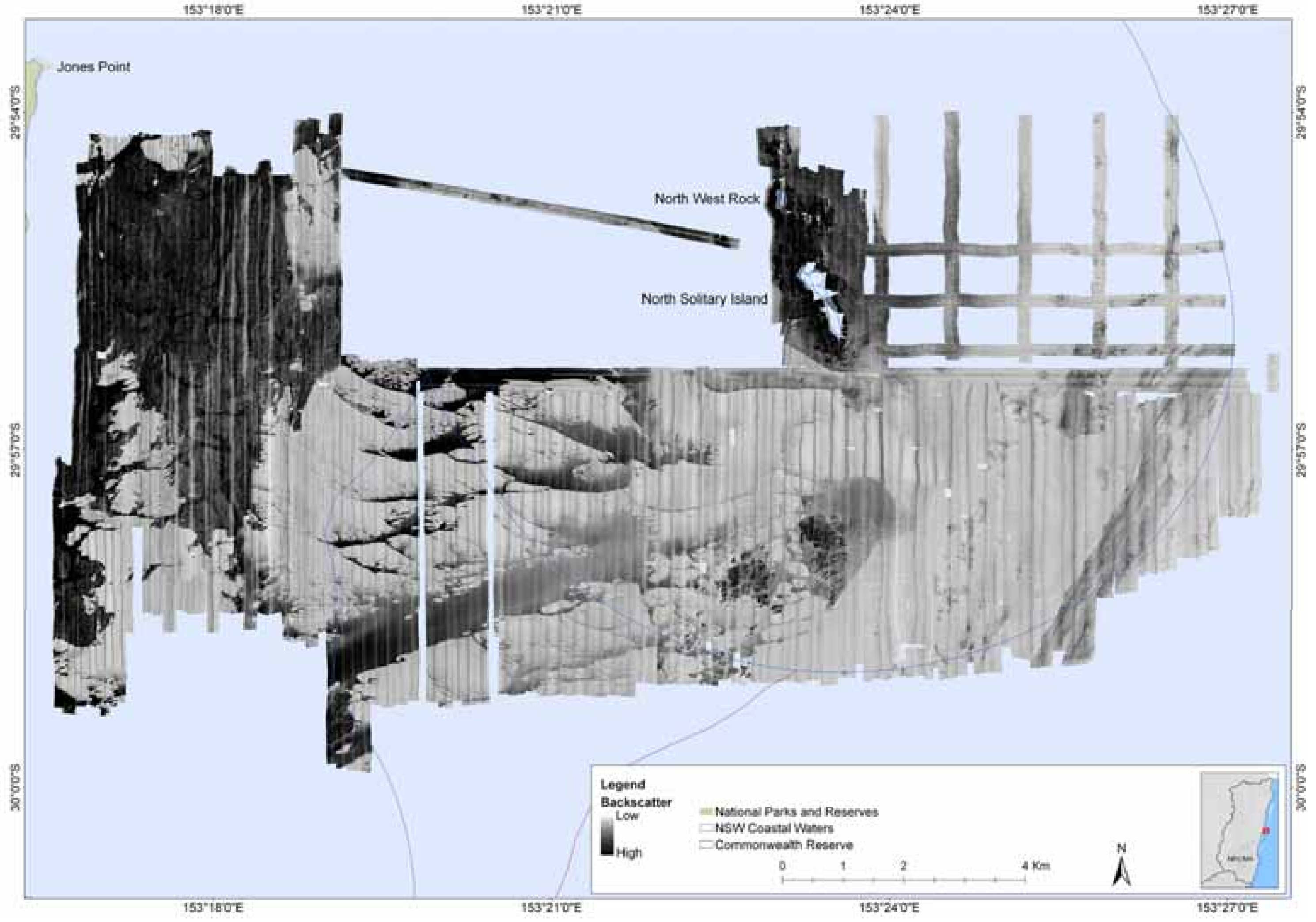


Figure 22. Acoustic backscatter of the seabed offshore of Jones Point and North Solitary Island.

Video surveys of rocky reefs offshore from Woody Head showed that many of the reefs in depths greater than 30 metres consisted of patchy outcrops of low-profile boulder reef, whereas reefs in shallower depths were more continuous, often guttered and with greater complexity and profile. At depths between 10 and 20 metres, benthic biota consisted of mixed assemblages of turfing and encrusting algae and a range of sessile invertebrate species including sponges, ascidians, octocorals, soft corals, anemones and bryozoans. Small patches of kelp *E. radiata* (often less than 5 metres wide) were present at depths between 12 and 20 metres. Kelp at this depth formed a canopy above the reef, below which the reef was covered in a mosaic of algae and sessile invertebrate species (Figure 23). *Sargassum* sp. and *Halimeda* sp. were common, as were many other algal species, although it was not possible to identify many of these from the video footage due to limited resolution. The cover of kelp generally decreased as depth increased to around 18 metres where sponge-dominated assemblages increased in abundance and morphological diversity. Erect, vase, elongate, tubular and branching sponges were common at depths between 15 and 20 metres (Figure 24). Black corals (*Antipathes* sp.), sea pens, sea whips and branching soft corals were also present; however, they were sparsely distributed often with hundreds of metres between them. At depths greater than 22 metres the abundance and diversity of sponge-dominated assemblages decreased, with many sections of boulder habitat appearing to be covered in silt or fine sediment. Sessile invertebrate abundance and diversity was usually lowest in sections of deep reef consisting of cobble and boulders, whereas more continuous reefs that had higher profiles supported greater densities of sessile invertebrates.

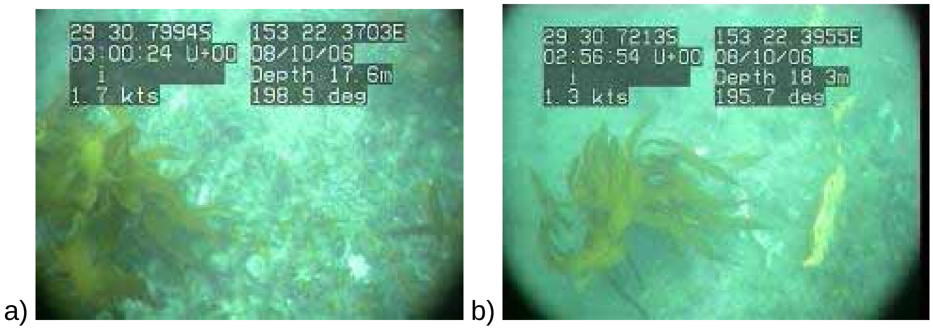


Figure 23. Kelp habitat at Yamba. Note the understory of mixed algae and sponges.

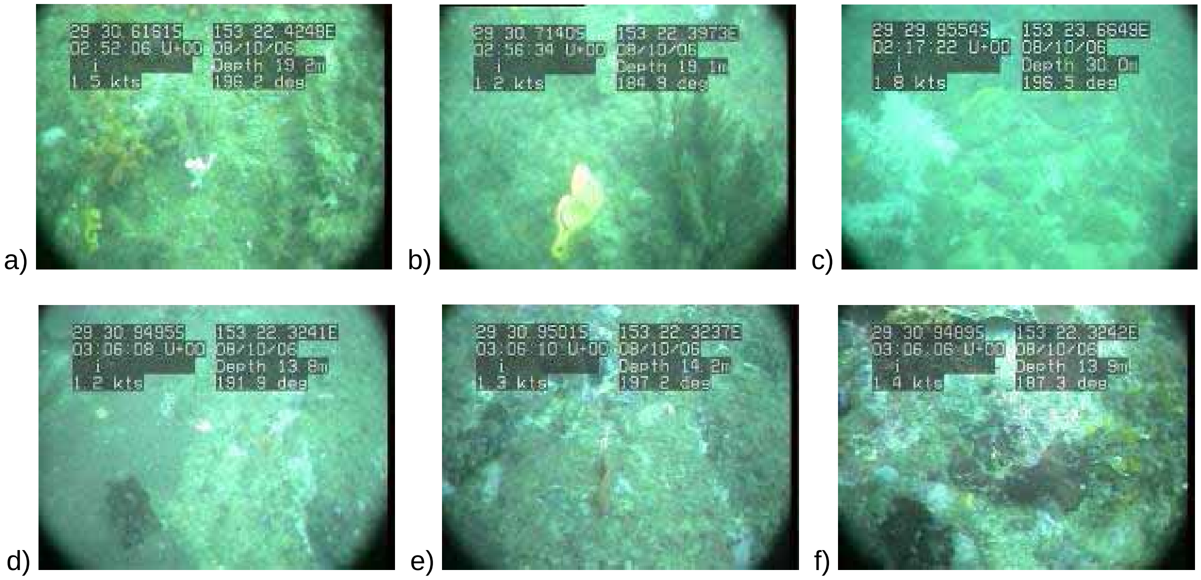


Figure 24. Reef at Yamba supporting sponges (a–e) and green algae, most likely *Halimeda* sp. (f).

4.3.4 Woolgoolga to Scotts Head

Between Woolgoolga and Scotts Head there were a number of extensive rocky reef systems, mostly associated with or adjacent to offshore islands and headlands (Figure 25). Shallow reefs extended offshore of most headlands north of Sandy Beach to Woolgoolga to the extent of the aerial photography coverage, which was a maximum of around 1.1 kilometres (Figure 25). A large area of continuous shallow reef surrounding South West Solitary Island (Groper Islet) extended up to 1.3 kilometres to the west, south and north-east. This reef extended into intermediate water depths on the offshore edge of the main reef system, and another discrete intermediate reef was located around 800 metres south-east of the island; reefs at these depths became increasingly patchy. The reefs in the Groper Islet region were mostly around 5 kilometres to the south of the island in an area of reef known as Sidney Shoals (known locally as 40 Acres Reef), which consisted of a continuous central reef area that rose about 15 metres from the surrounding substrate. This was surrounded by an area of patchy reef with a lower profile that rose an average of 5 metres from the proximate area (Figure 27). Much of the reef was in shallow water depths, extending into intermediate depths to the south and east.

The largest of the mapped reefs in the northern part of this region occurred east and south-east of Moonee Beach, with shallow reef extending over 2 kilometres east and west of Split Solitary Island and continuing into intermediate depths on the eastern edge. An area of shallow reef located around South Solitary Island extended several hundred metres offshore around much of the island (Figures 25 and 30). Several smaller areas of shallow reef were also located around 1 kilometre north-west of the island. Many of these reefs had high slope values, indicating the presence of complex reef-forming ridges and gutters; although several steep areas on the edges of the reef dropped into unconsolidated habitat (Figure 31). An extensive intermediate reef complex was present east of the island, with many individual patches of reef extending at least 3 kilometres to the east and north-east.

An extensive area of deep reef was identified around 5 kilometres east and south-east of South Solitary Island, and was characterised by linear features that ran north-east and south-west through the area (Figure 30). This reef system had a different structure to the surrounding reefs, which were patchy and contained many gutters. Like the deep reef to the south-east of North Solitary Island, this linear reef system rose an average of 4–6 metres from the surrounding seabed with fairly uniform low complexity and only a gentle rise and fall between each reef (Figures 30, 31 and 32).

There were also a number of discrete reefs at varying distances offshore between Split Solitary Island and Coffs Harbour (Figure 25). The reef system surrounding Split Solitary Island included a much larger reef several kilometres to the east, the majority of which was in shallow depths reaching about 5 metres at its shallowest point (Figure 34). The reef system was mostly slightly sloping, although a number of areas had high slope values indicating the presence of steeper walls forming ridges and gutters that dissected the reef (Figures 35 and 36).

Like the swath-acoustic surveyed area in the North Solitary Island region, this area contained a complex spatial arrangement of sediment types and morphologies. There were a number of distinct unconsolidated features with darker backscatter indicating the presence of coarser sediment extending mostly east-west through the area (Figure 28). An area of sand waves extended from Groper Islet to South Solitary Island (Figure 26). There was a sharp transition in some areas to lower backscatter intensity, which highlighted the sand features through the dark areas of coarser sediment that occurred on the leading edge of the waves. There were a number of irregular waves that varied in height (mostly around 1 to 2 metres). At around 2 kilometres to the south-east of Groper Islet a broad depression ran in a north-south direction, which was about 3–5 metres lower than the surrounding bathymetry. Higher backscatter intensity indicated that coarser sediments were located to the east of this change in slope (Figure 28).

Detailed video surveys over the Sidney Shoals area revealed a complex arrangement of unconsolidated sediments dominated by cobbles, gravel, coarse sand and fine sand (Figure 29). Overall, there was no trend between the proportion of fine sand and proximity to the nearest reef edge, although there was an increase in the mean grain sizes of coarse sand and gravel away from the reef (Ku 2007). Areas of lower backscatter represented fine sand. Sharp transitions to areas of coarse sand were evident and these occurred in depressions up to 1 metre deeper than the surrounding fine sand. Similar backscatter intensities were evident more broadly throughout the region indicating that large areas of gravel and cobbles were present on this section of the shelf, particularly surrounding areas of reef. In contrast, video footage from the linear reefs located south-east of South Solitary Island indicated they were covered with a layer of sand (Figure 33).

Several shallow offshore reefs were present between Sawtell and Urunga, although they are likely to extend into depths greater than that defined through aerial photography. There is evidence of this off Sawtell where the reefs systems of Whitmore Shoal and Sawtell Shoal occur about 2 kilometres offshore and may form part of the same reef complex as the coastal reef (Figure 25). The area of seafloor mapped along the Nambucca coast revealed there was a significant amount of reef in the region; however, several areas of the seabed contained patches of reef smaller than the minimum mapping unit that were mapped as unconsolidated habitat. The fine-scale bathymetry revealed five sections of continuous reef or reef complexes extending from the nearshore at depths of less than 10 metres to at least 20–25 metres (Figure 37). Shallow nearshore reef immediately adjacent to the shore appeared to be linked with the main headlands at Nambucca Head, Valla Head and Wenonah Head but were described as patchy in shallow water (less than 10 metres) between the peninsulas (Figure 25). There were large areas of patchy reef in the southern section of the swath survey area, some of which appeared as linear structures oriented in a north-east/south-west direction. These linear reefs were not as apparent in the more continuous reef complexes in the north of the area. The middle and northern reef complexes, however, were characterised by criss-crossing linear faults oriented north-east to south-west and north-west to south-east. Reef usually covered a greater proportion in the north compared to the south of the survey area. Additionally, reefs became increasingly patchy with increased distance from the shore.

The reefs in the area were mostly slightly sloping and dominated by slope values of less than 10 degrees (Figure 38). The slope increased to 20–25 degrees at a small number of locations on the southern-most reef complex north-east of Nambucca Heads. These areas occurred predominantly at depths greater than 20 metres and had a westerly aspect. Generally, reefs in the survey area were of low to moderate relief compared to other surveyed areas in the region (Solitary Islands, Yamba, South West Rocks), with individual reefs and reef complexes rising on average 4–5 metres above the level of the surrounding seafloor.

Maps of acoustic backscatter for the Nambucca area showed two distinct zones, a northern zone dominated by low intensity backscatter on the eastern side of the reef system and a southern zone of higher intensity backscatter located offshore (Figure 39). In the northern area, unconsolidated sediments were dominated mostly by coarse sand. These sediments usually occurred at depths greater than 25 metres offshore of the shallower main reef complexes. The exception to this was directly adjacent to the entrance to the Bellinger River where finer sand is dominant. Bands of coarser sediments with higher backscatter occurred adjacent to reefs and usually separated reef and sand. Some bands of high intensity backscatter material were observed at a distance from the reef. These were interspersed with sand in the very north-east section of the area and were likely to comprise coarser sediments such as gravel and coarse sand.

An area of unconsolidated sediment separated the subtidal reef from the rocky coastline at Hungry Head and deeper reefs from the shore at the entrance to the Bellinger and Nambucca Rivers. To the south, an area of low backscatter indicated that finer sediments existed adjacent to the shore between the Valla and Nambucca reef complexes. In deeper water, however, bands of alternating moderately high- and high-intensity backscatter represented unconsolidated sediments. From the video analysis these areas of coarser-grained sediments were dominated by gravel with coarse sand, cobbles and coarse sand with pebbles (Figure 39).

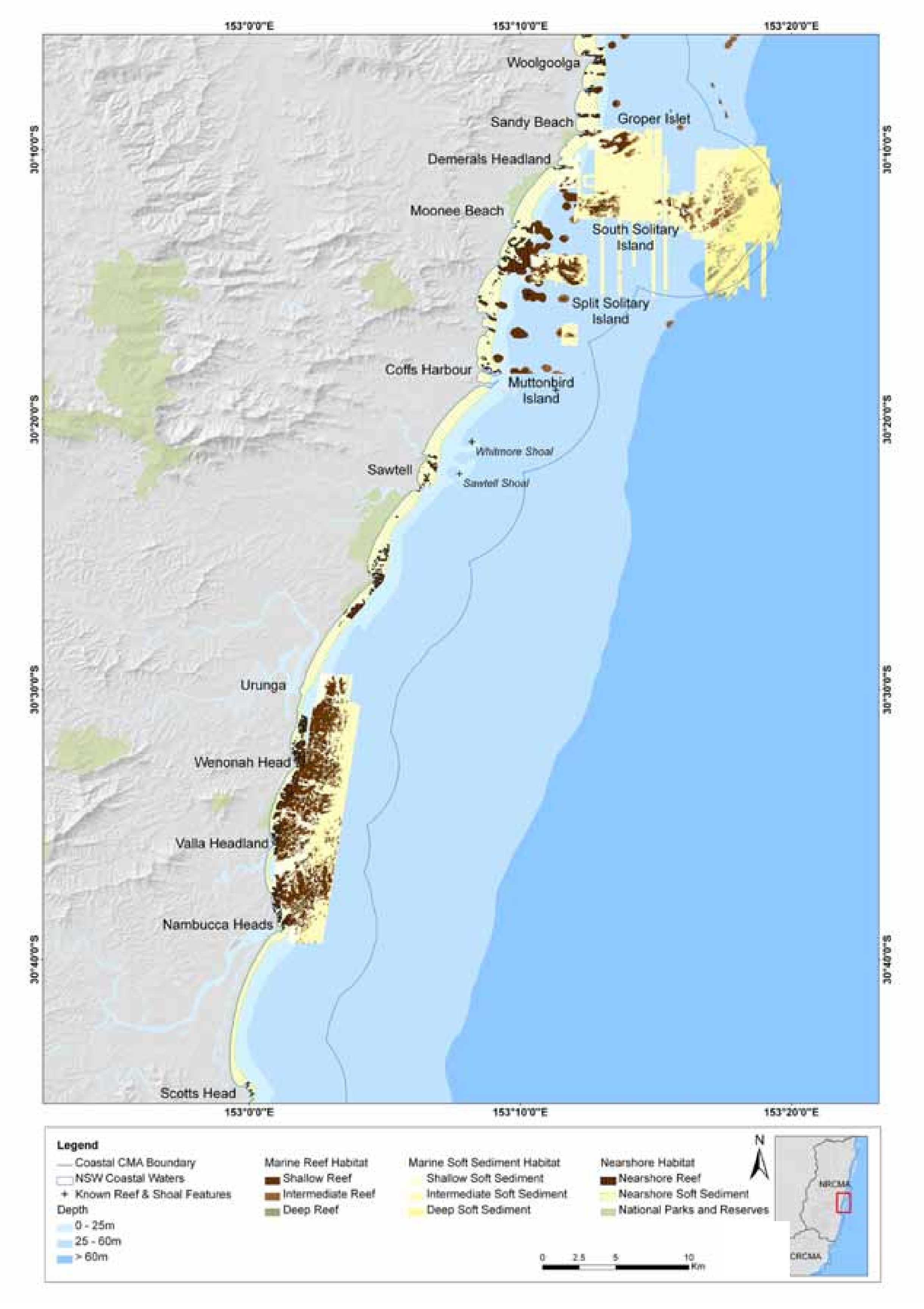


Figure 25. Distribution of known seabed habitats in the region between Woolgoolga and Scotts Head.

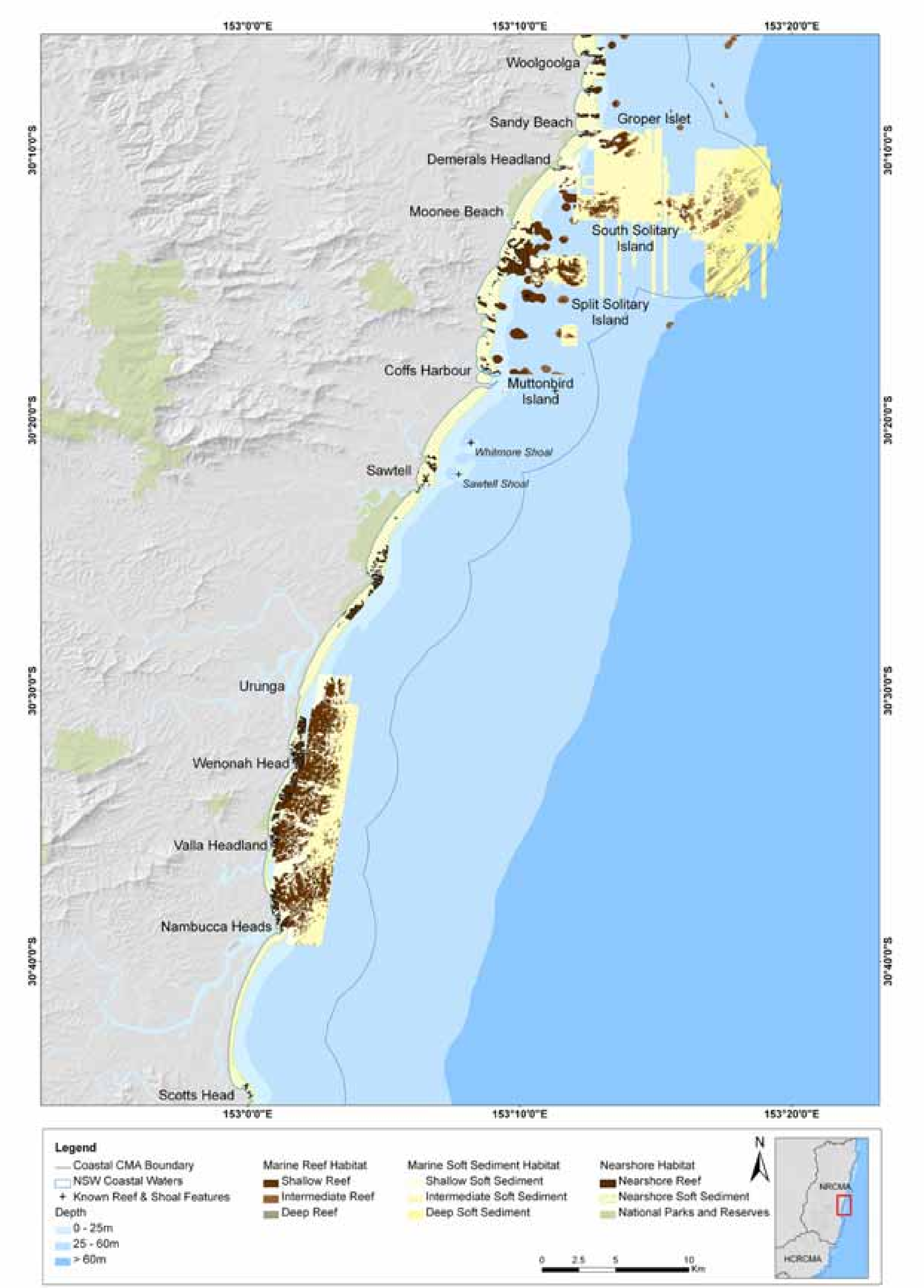


Figure 26. Hill-shaded bathymetric model of the seabed adjacent to and south of South West Solitary (Groper) Island.

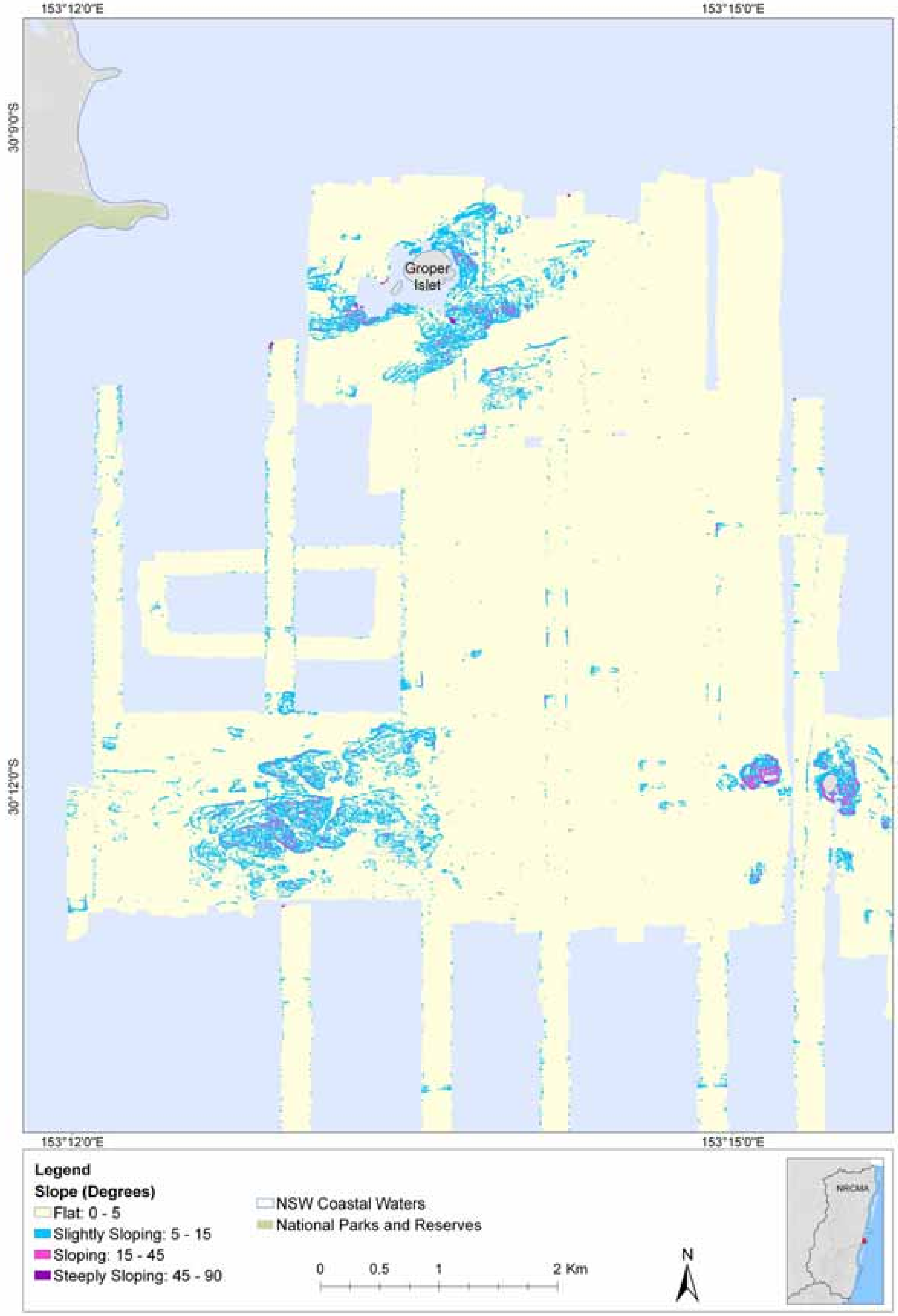


Figure 27. Slope model of the seabed adjacent to and south of South West Solitary (Groper) Island, including Sidney Shoals.

Figure 28. Acoustic backscatter of the seabed adjacent to and south of South West Solitary (Groper) Island, including Sidney Shoals.

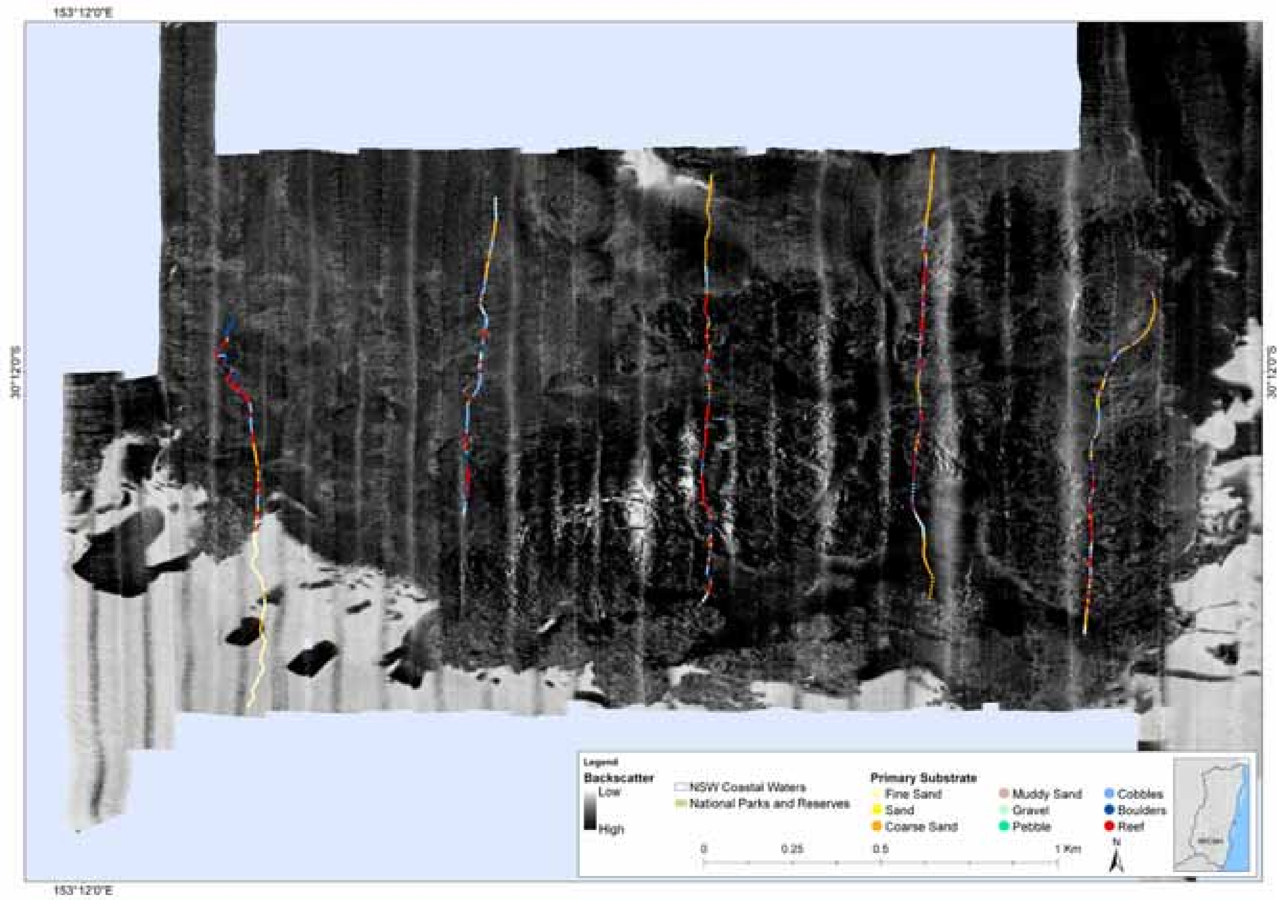


Figure 29. Acoustic backscatter of the seabed in the area known as Sidney Shoals, including video classifications of dominant substrate.

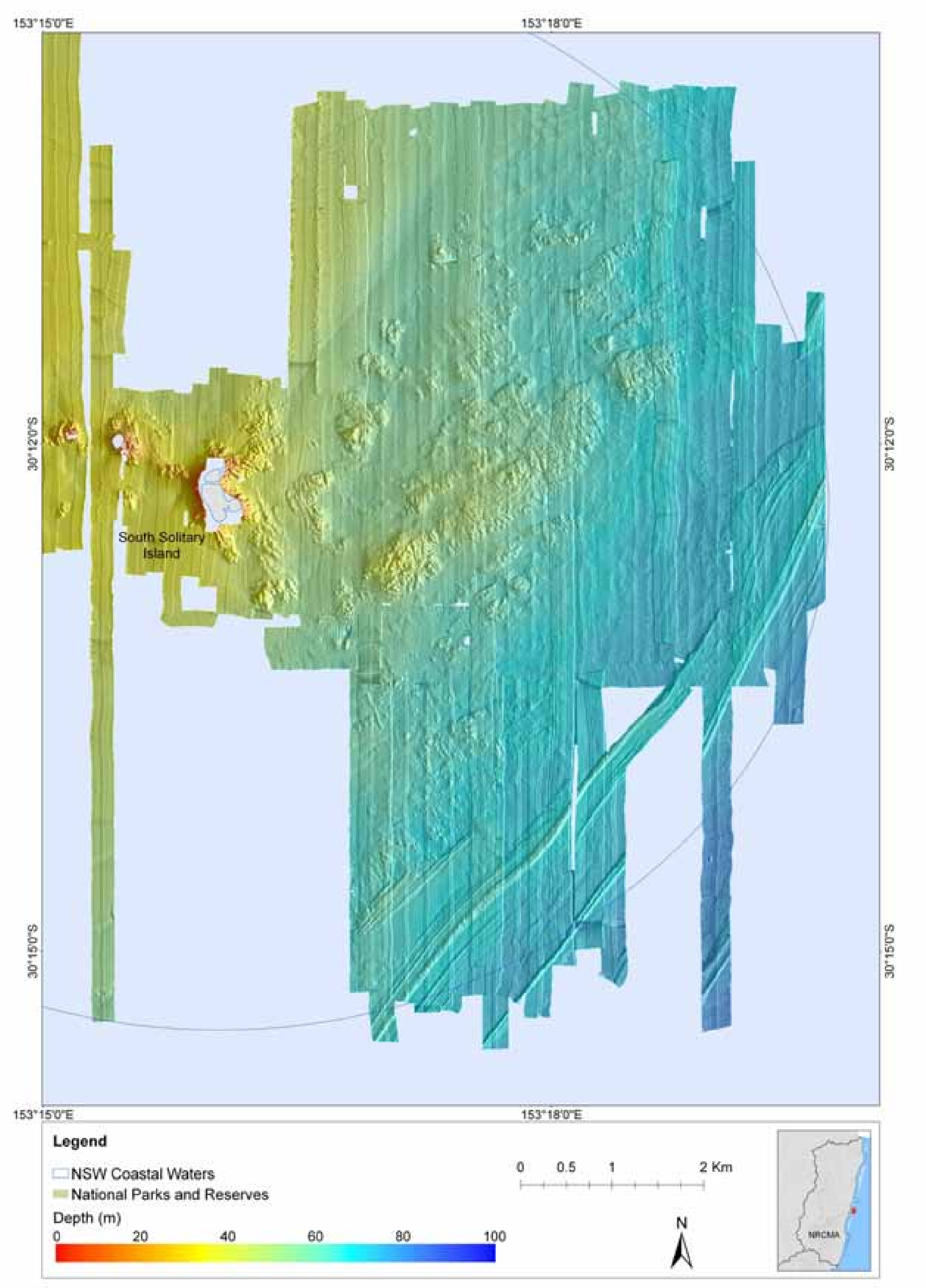


Figure 30. Hill-shaded bathymetric model of the seabed adjacent to and east of South Solitary Island.

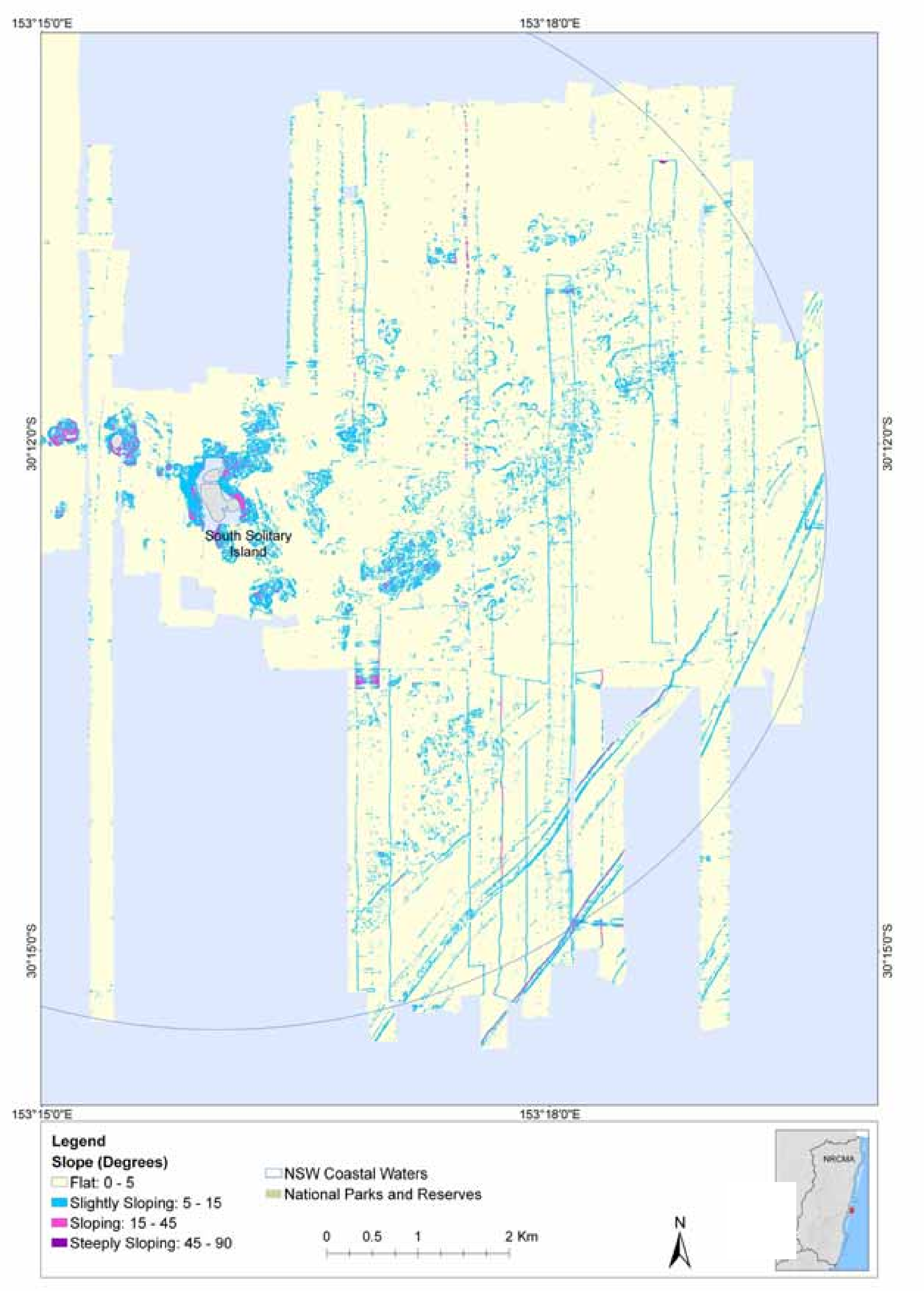


Figure 31. Slope model of the seabed adjacent to and east of South Solitary Island.

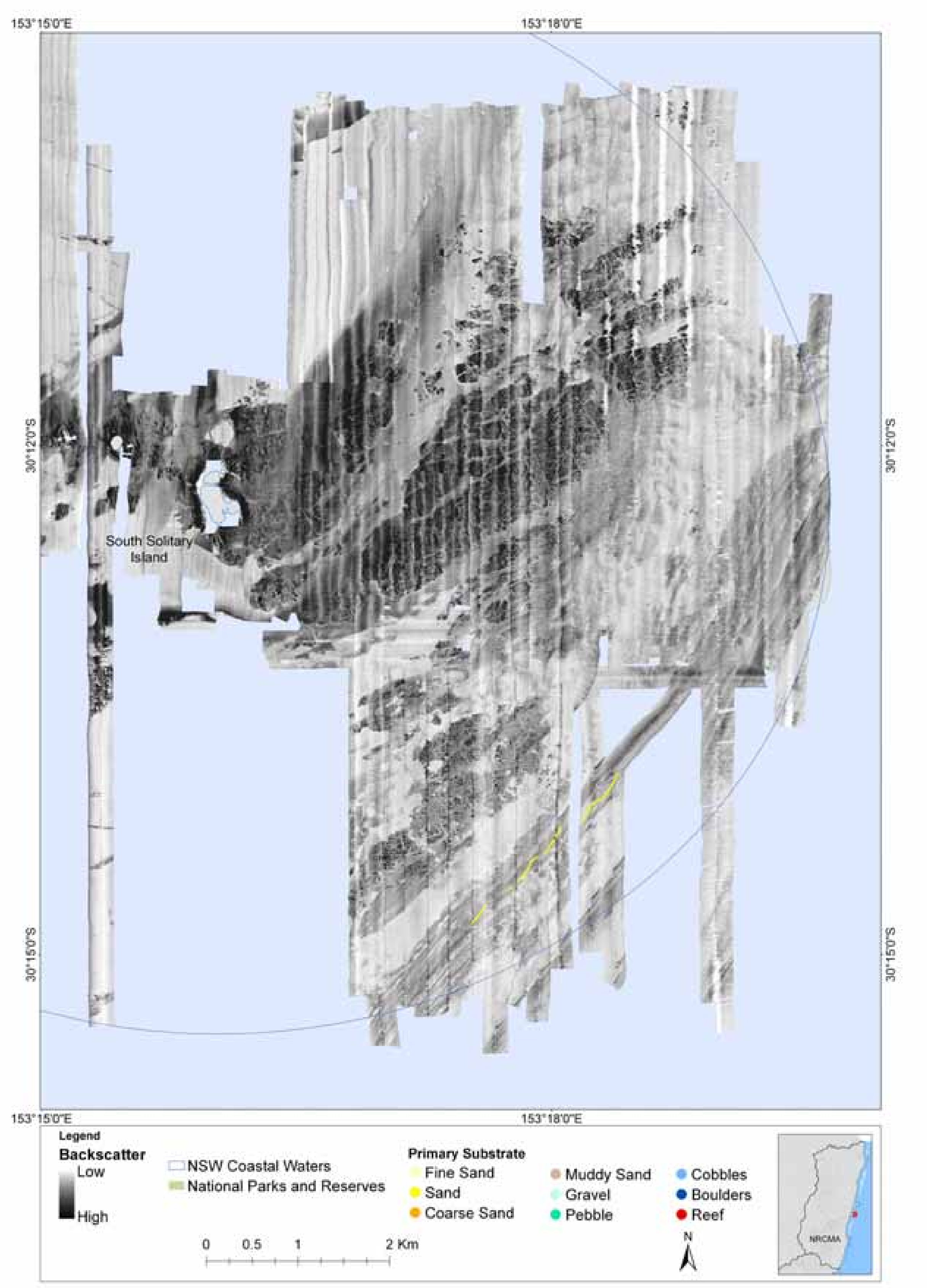


Figure 32. Acoustic backscatter of the seabed adjacent to and east of South Solitary Island.

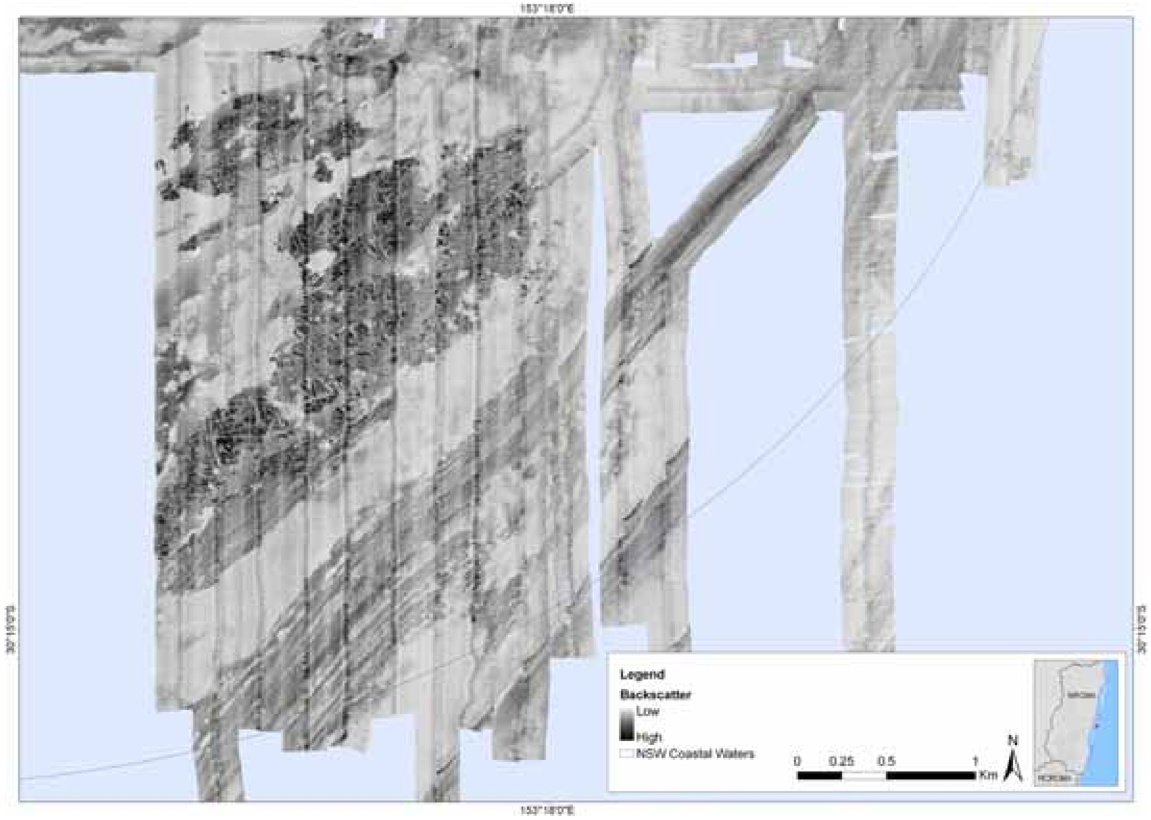


Figure 33. Acoustic backscatter of the seabed adjacent to and east of South Solitary Island.

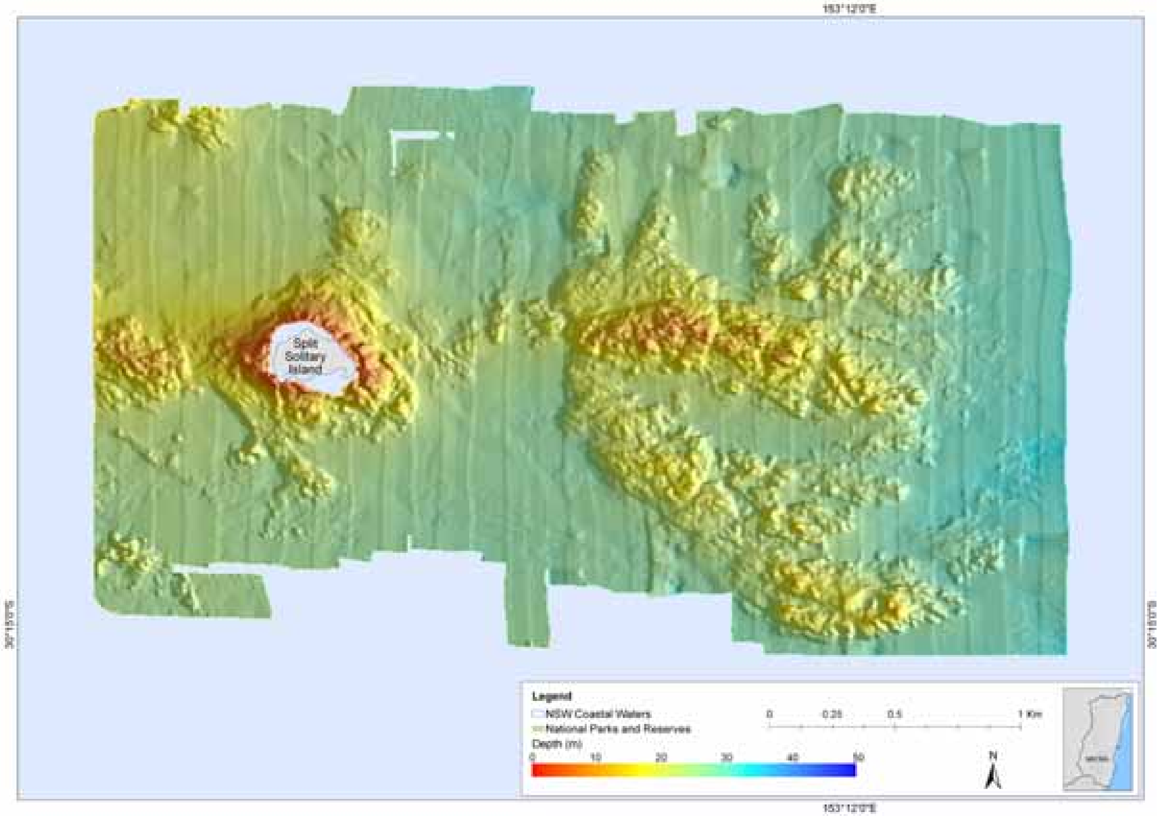


Figure 34. Hill-shaded bathymetric model of the seabed adjacent to and east of Split Solitary Island.

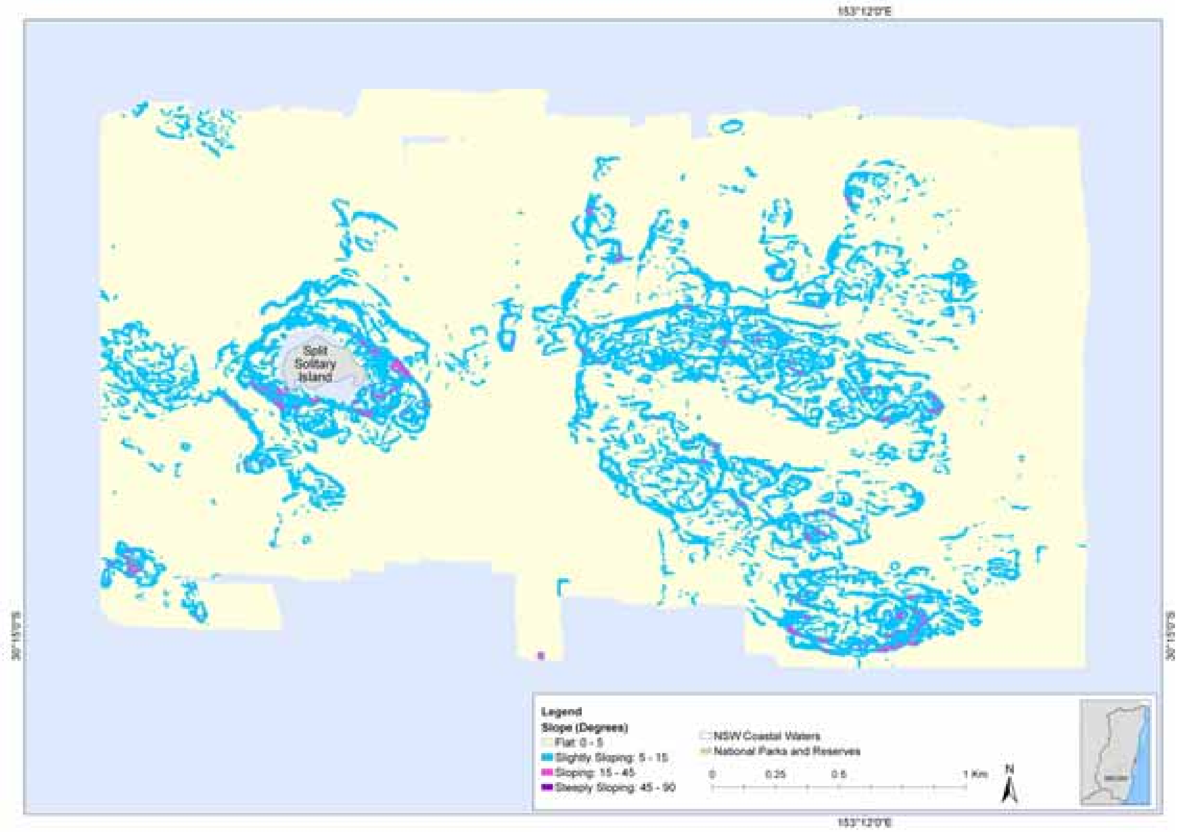


Figure 35. Slope model of the seabed adjacent to and east of Split Solitary Island.

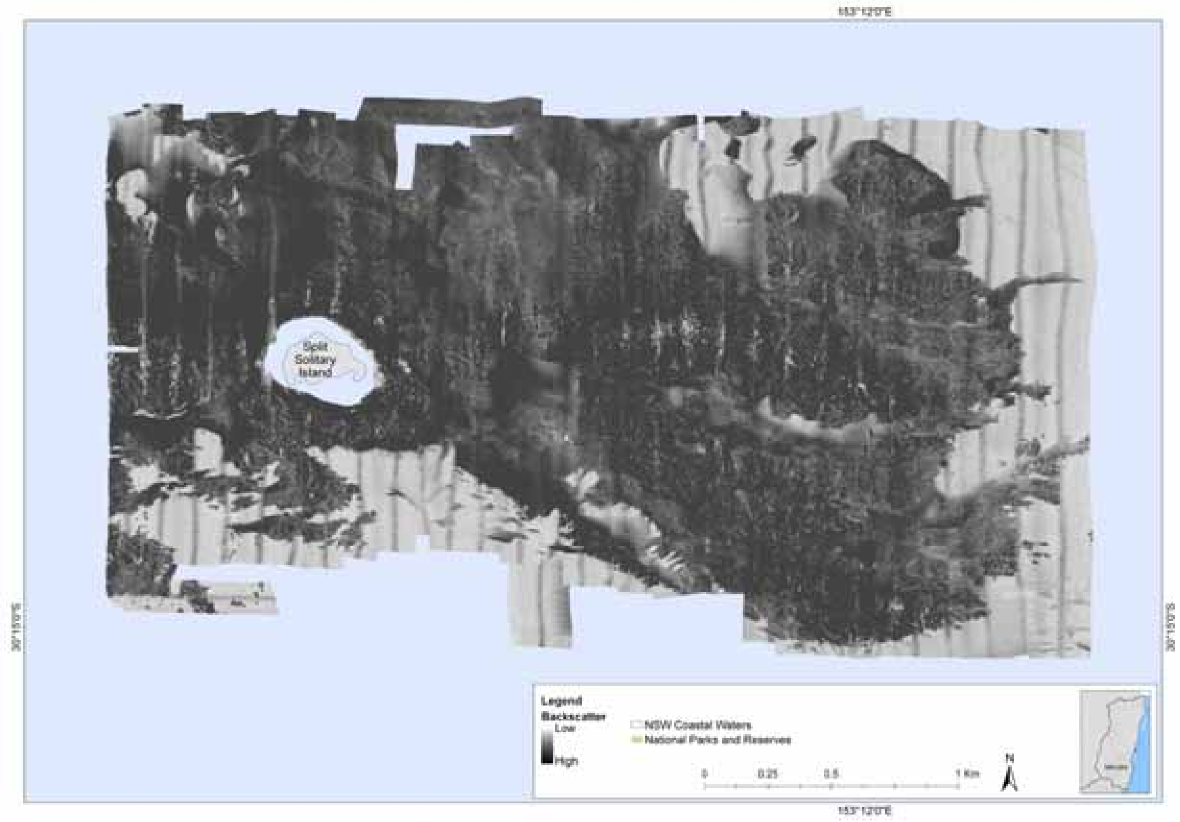


Figure 36. Acoustic backscatter of the seabed adjacent to and east of Split Solitary Island.

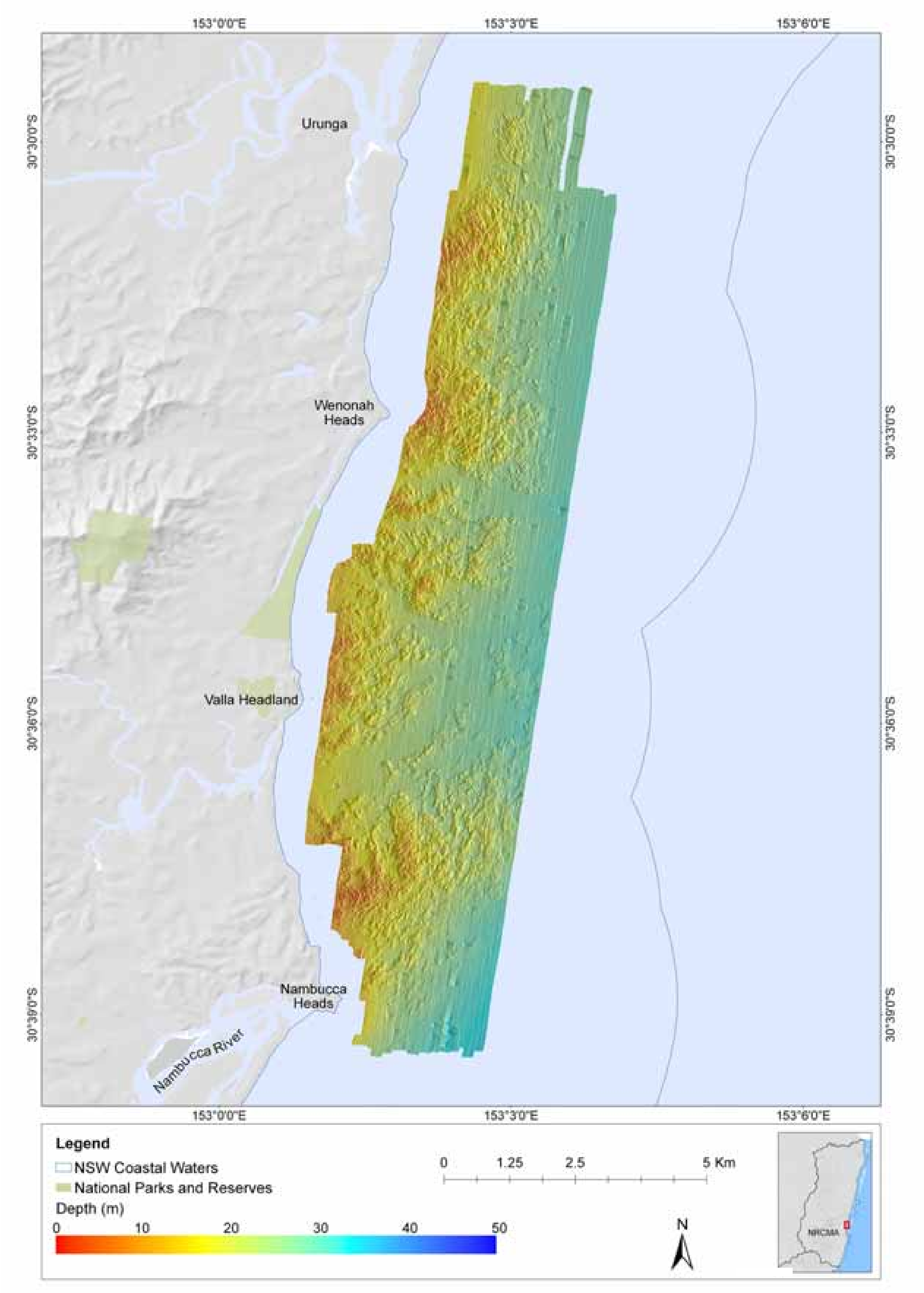


Figure 37. Hill-shaded bathymetric model of the seabed along the Nambucca coast.

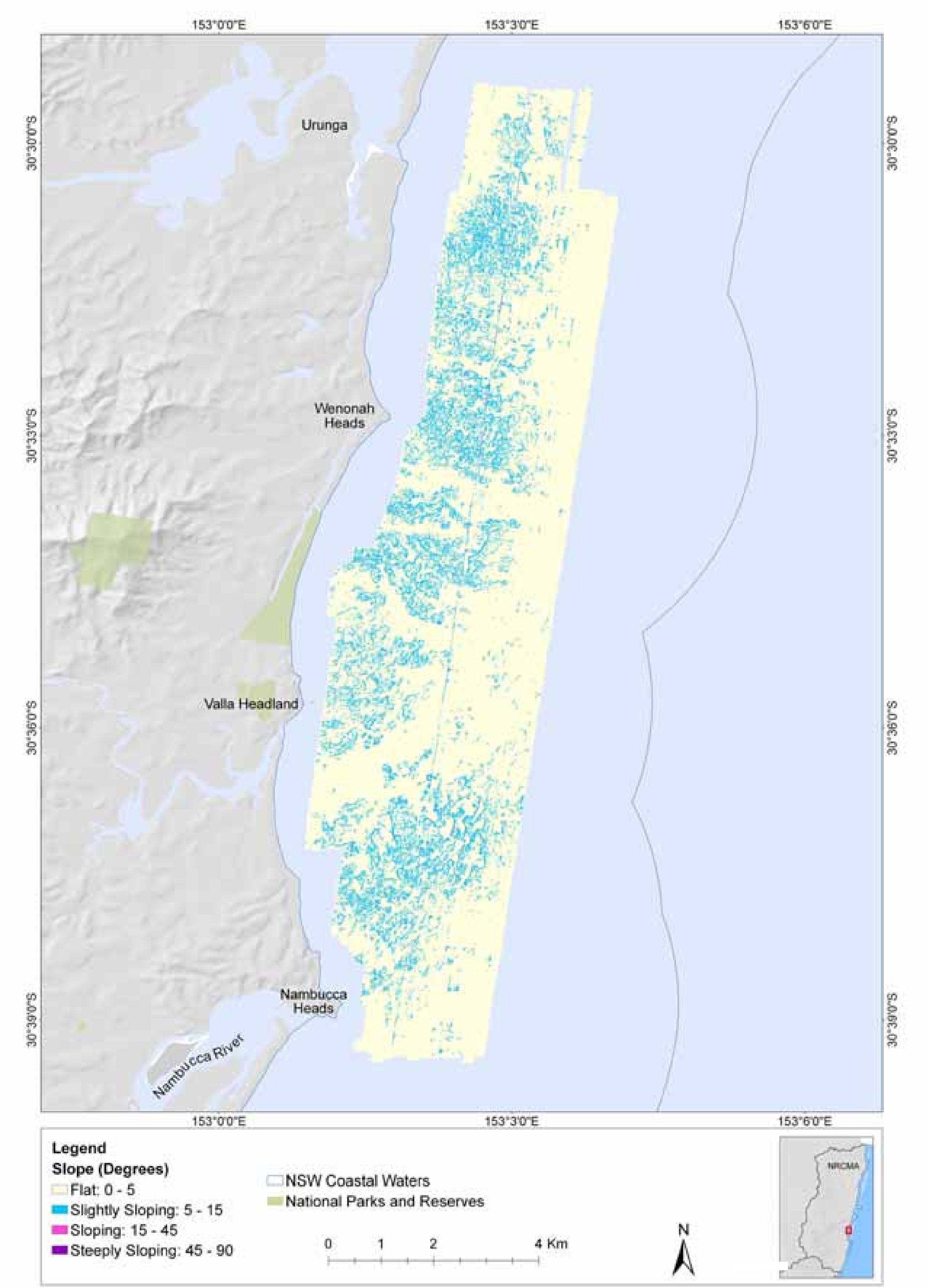


Figure 38. Slope model of the seabed along the Nambucca coast.

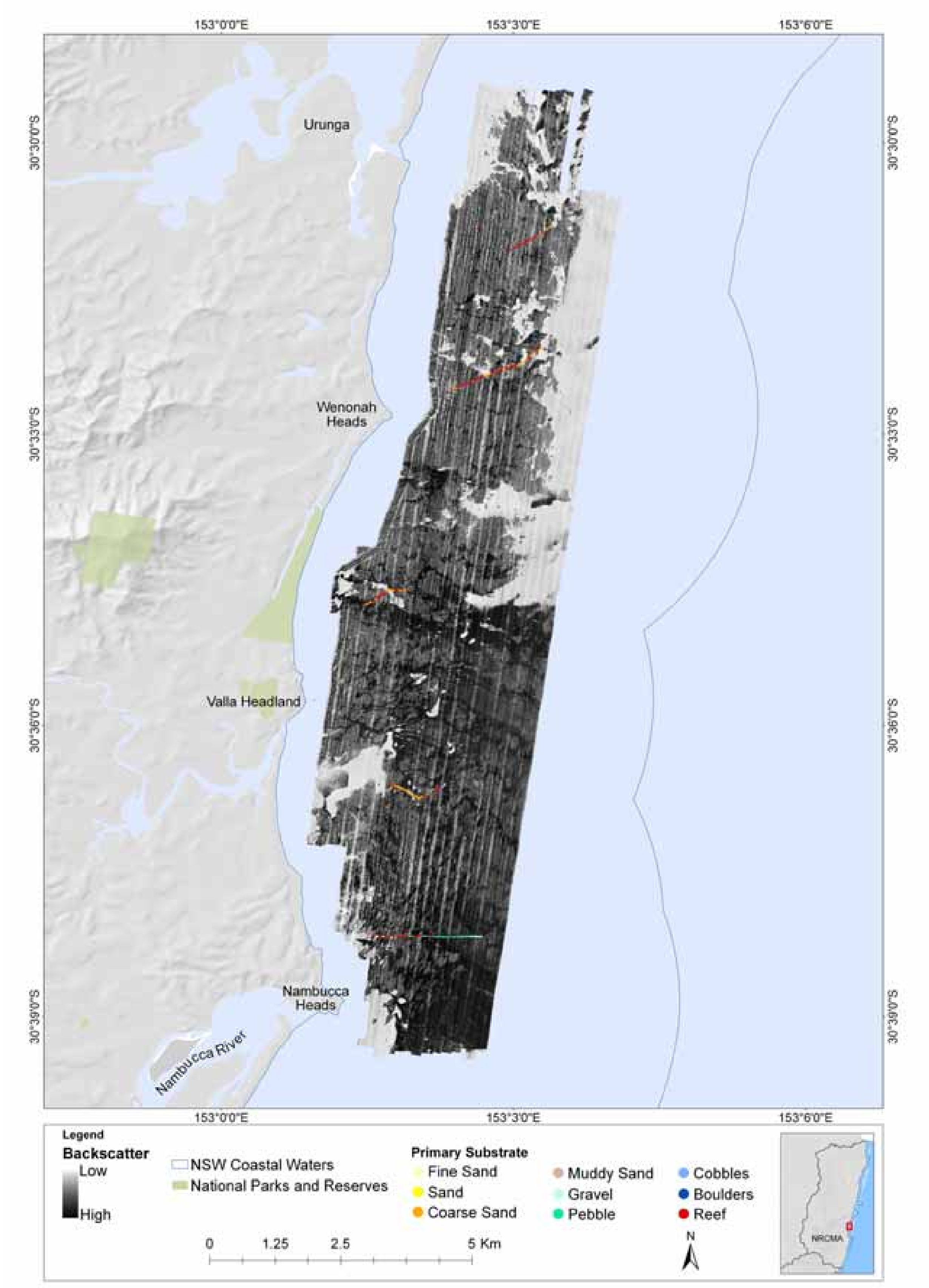


Figure 39. Acoustic backscatter of the seabed along the Nambucca coast.

Video transects in the Solitary Islands region covered 8.8 linear kilometres; six transects totalling 7.1 linear kilometres were done at Sidney Shoals, and one transect covering 1.7 linear kilometres was conducted to the south-east of South Solitary Island. Video footage from Sidney Shoals was collected at depths between 10 and 35 metres (Figures 40 and 41). The seabed in the area was made up of an irregular mosaic of rocky reef with varying relief overlaid with patches of sand and mixed sediments including pebbles, cobbles and boulders. Reef at depths between 10 and 20 metres was dominated by plate, encrusting and massive corals (Figures 41 and 42). Interspersed amongst the corals were encrusting sponges, bryozoans, and sections of bare rocky reef dominated by sea urchins including *Centrostephanus rodgersii* and *Phyllacanthus* spp. Sea urchins were particularly common in sections of reef which were relatively complex and had crevices and ledges (Figure 43). At depths between 20 and 35 metres, reef habitats were a mosaic of *E. radiata* (Figures 40 and 44), sessile filter feeders including sponges (Figure 45), and stands of mixed red, green, and brown algae including stands of the brown algae *Sargassum* sp. *E. radiata* was observed on reef and in areas of mixed reef and sand. Canopy cover of *E. radiata* was greatest at depths between 22 and 26 metres (Figure 40). *E. radiata* was often associated with an understory of mixed algae and sponges because these species occur over a similar depth range. Ascidians such as *Pyura spinifera* were sparse at depths between 12 and 25 metres, and more common at depths between 25 and 30 metres (Figure 41).

Video data from south-east of South Solitary Island surveyed depths between 60 and 72 metres. Footage revealed that reef in the area contained elongate linear sections of high profile reef, and low profile sections of sand and mixed sediments. The reef and mixed sediments in this area supported an abundant and diverse array of sessile invertebrates including sponges, sea whips, and gorgonians (Figure 46). These communities were not limited to areas of continuous reef and were observed in areas of mixed sediment where hard sediments (e.g. reef/cobble/boulder) comprised as little as 10% of the substrate. This suggests that the distribution of these communities of sessile invertebrates may stretch well beyond the areas defined as reef by acoustic habitat mapping; however, given the relatively small area covered by video transects it was not possible to estimate those areas.

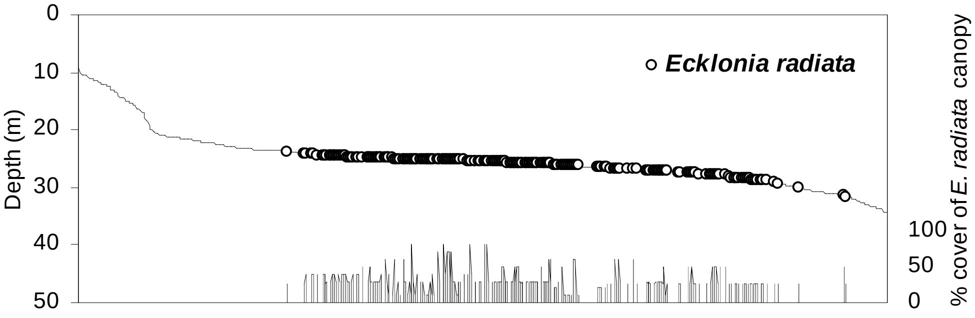


Figure 40. Percentage cover of kelp (*E. radiata*) along video transects (indicated by vertical lines on the x axis) at Sidney Shoals in the Solitary Islands region.

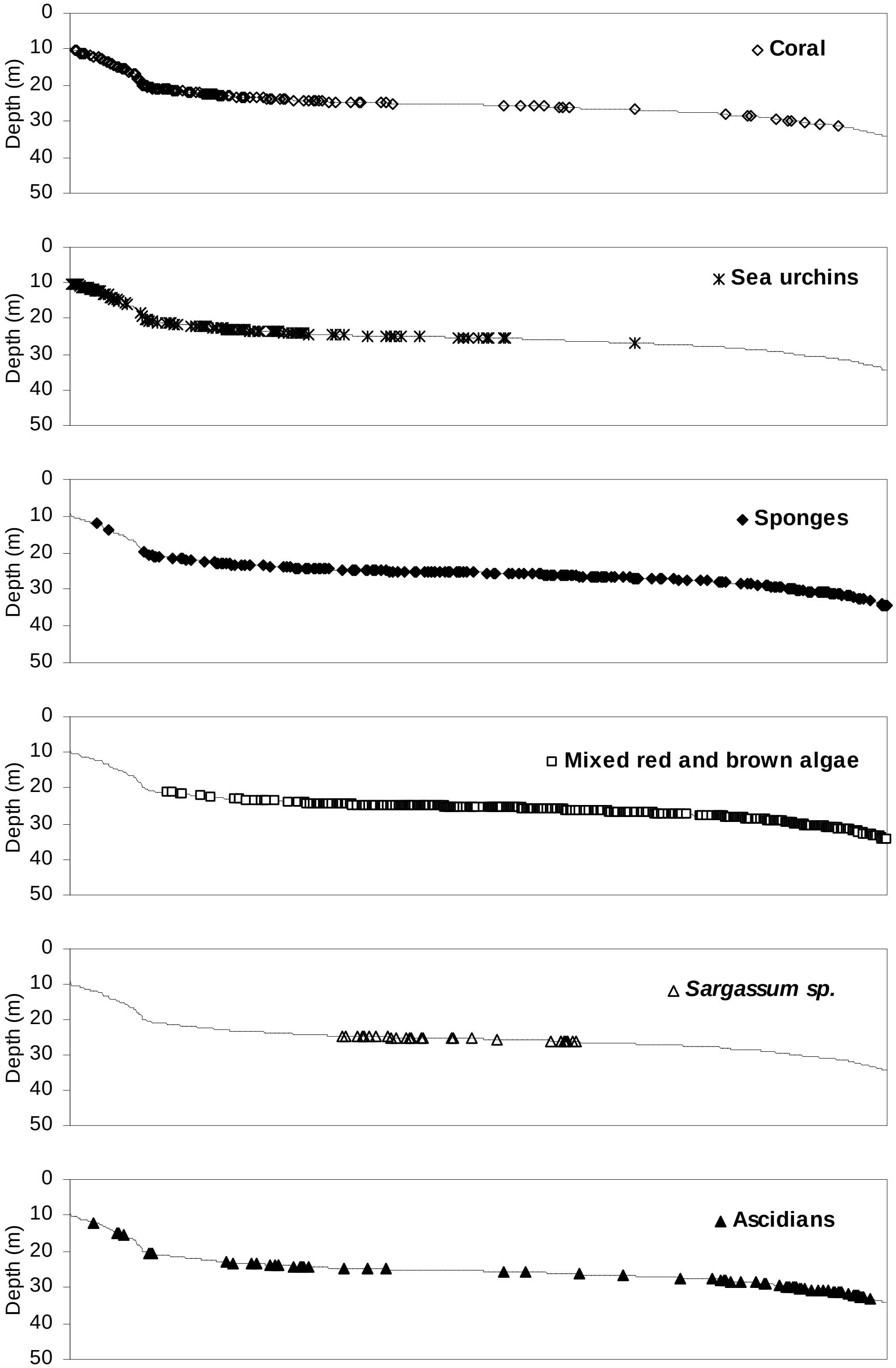


Figure 41. Presence of biota types along video transects at Sidney Shoals in the Solitary Islands region.

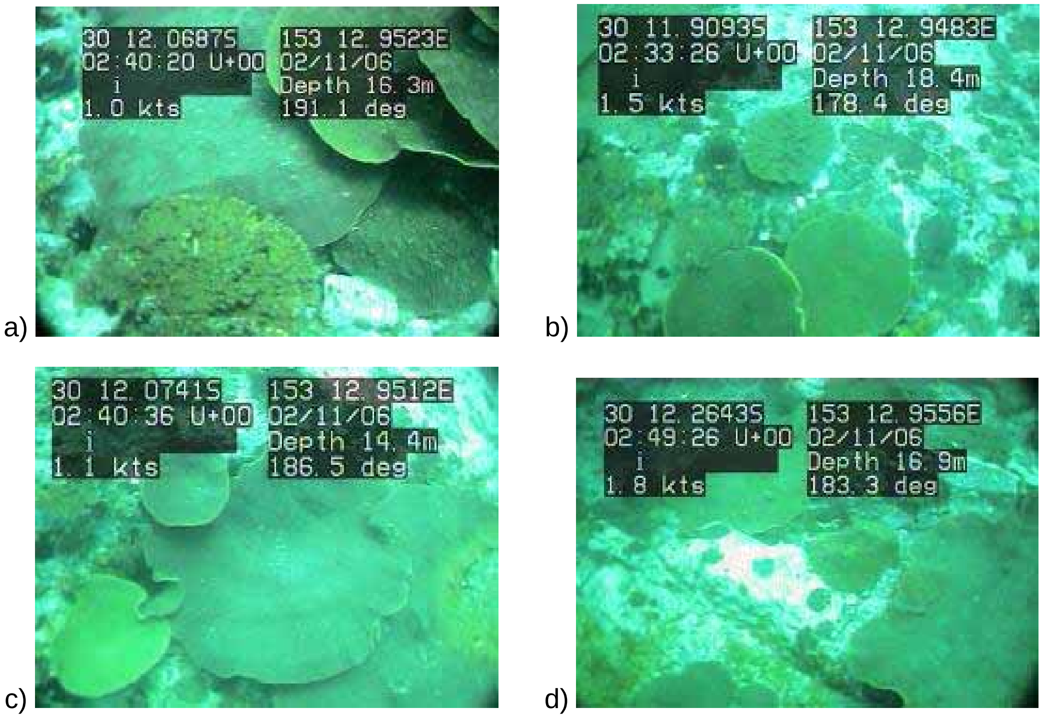


Figure 42. Coral-dominated assemblages at Sidney Shoals. In this area the coral community was dominated by plate corals.

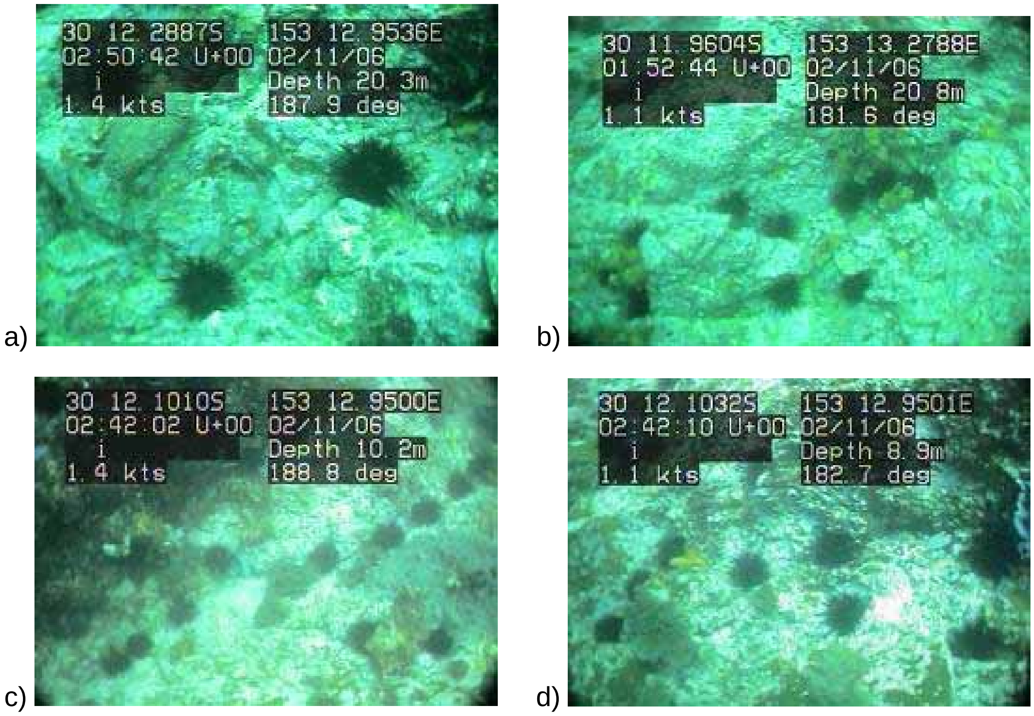


Figure 43. Sea urchins at Sidney Shoals. Note the dominance of the long-spined sea urchin *C. rodgersii.*

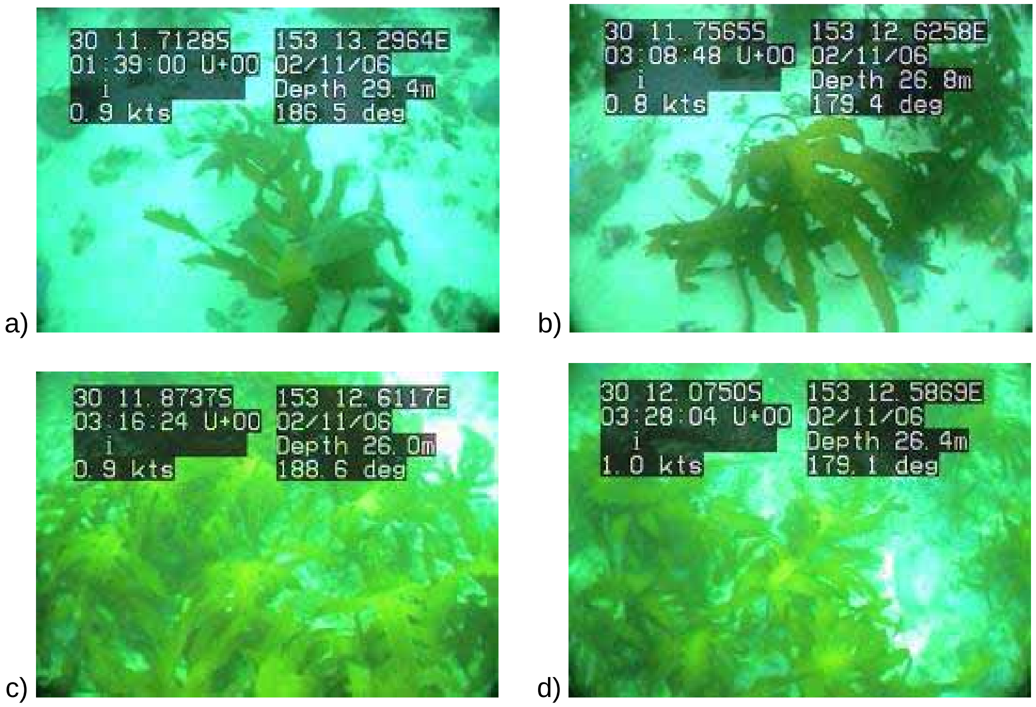


Figure 44. Kelp (*E. radiata*) on mixed sediment (a–b) and reef (c–d) at Sidney Shoals.

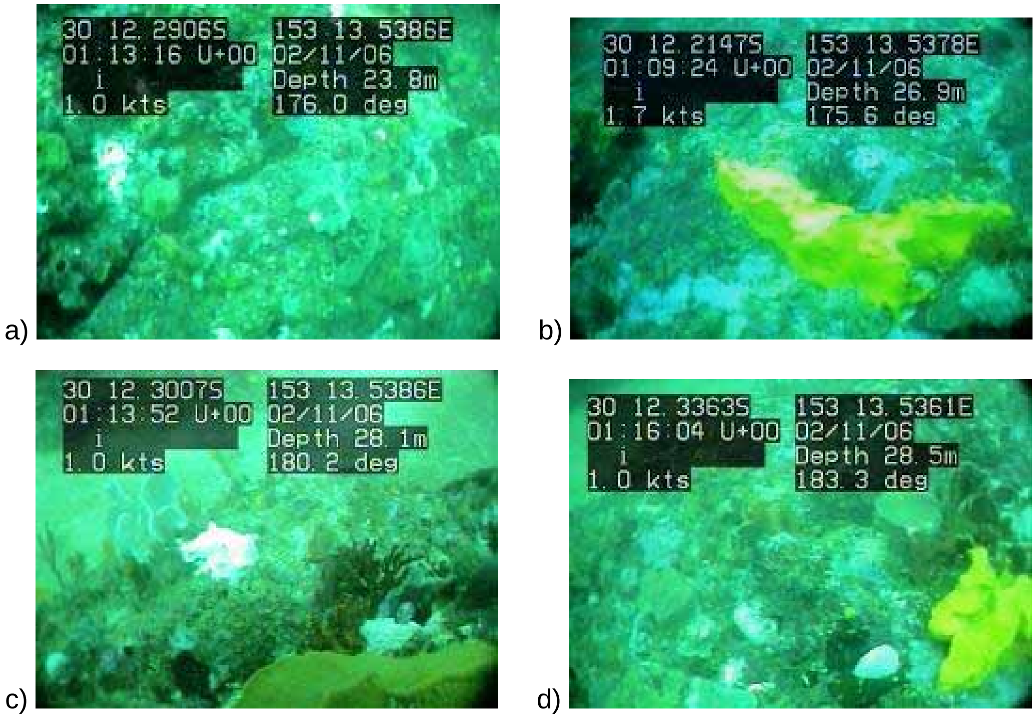


Figure 45. Sponge-dominated assemblages on reef at Sidney Shoals.

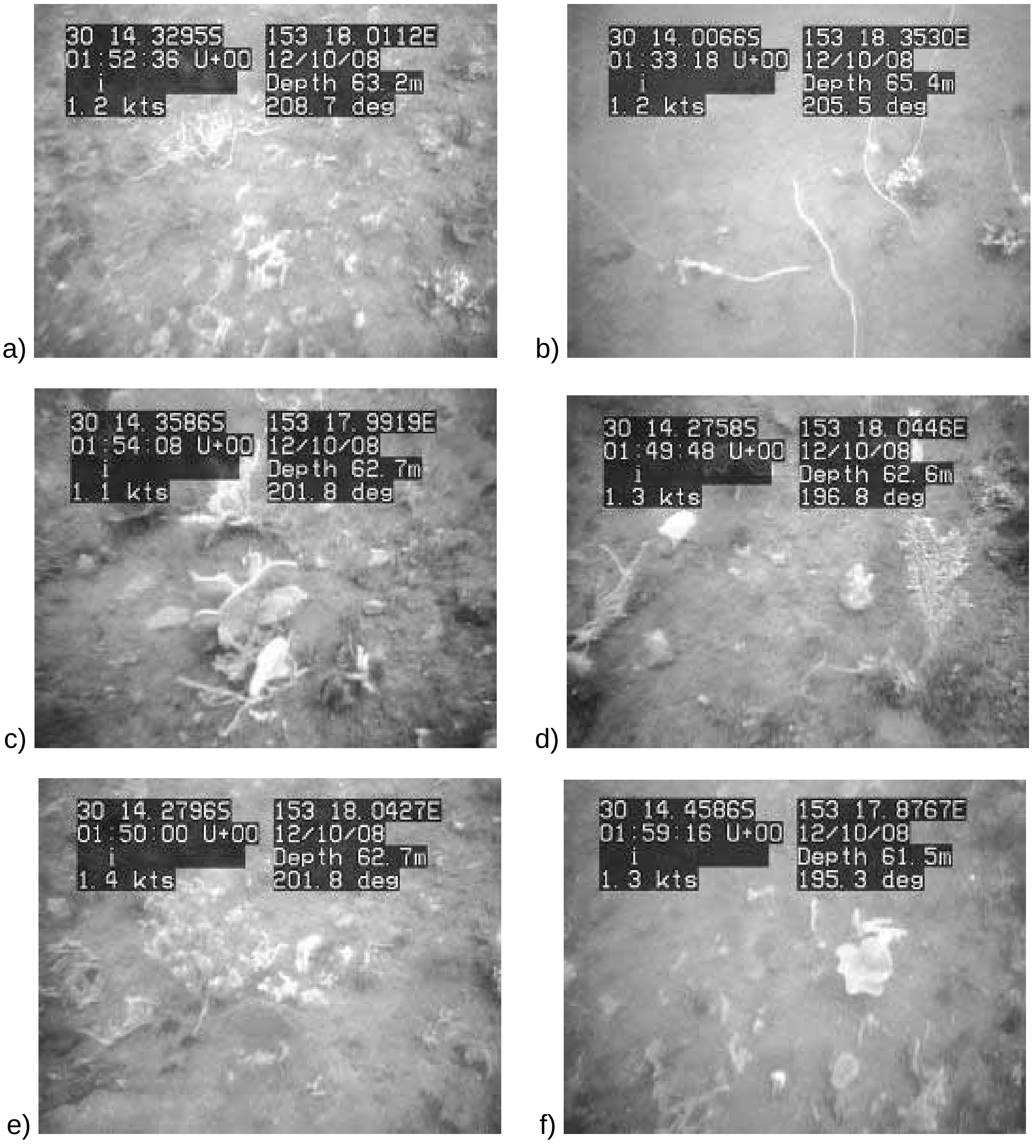


Figure 46. Sessile invertebrates including sponges, gorgonians and sea whips south-east of South Solitary Island.

In the Nambucca area, video footage covering 7 kilometres was collected along five transects at depths of 11 to 31 metres. The area was characterised by extensive areas of reef and mixed reefs and habitats dominated by a cover of kelp *E. radiata* and/or mixed algal assemblages of red, brown (e.g. *Sargassum* spp.) and green algae (e.g. *Halimeda* sp. and *Caulerpa* sp.). Assemblages of mixed algae were also common in unconsolidated habitats that contained pebbles and/or cobbles and boulders.

E. radiata was common and widespread in areas of reef and mixed reef/sand substrate, with canopy cover decreasing with increasing depth (Figure 47). The morphology of *E. radiata* plants appeared to differ to those in nearby areas. *E. radiata* at Nambucca had a distinctly elongated stalk and fine fronds (Figure 48) compared to the short stalk and broad fronds of those observed nearby at Sidney Shoals. In the depths surveyed by video there was no evidence of coral-dominated habitat and corals were present primarily as an understory to *E. radiata*.

After *E. radiata*, brown algae and sponges were the next most dominant groups identified from video footage. Sponges were most common at depths between 20 and 31 metres, and generally occurred as an understory to *E. radiata* (Figure 47). It is possible that the towed video imagery collected as part of this study underestimated the amount of algal, sponge and coral communities present as an understory to *E. radiata*, given that these communities may not have been visible underneath the often dense primary canopy cover (Figure 49). Ascidians were observed on reef between 17 and 25 metres in areas devoid of *E. radiata* (Figure 47).

Unconsolidated habitats containing gravel, pebble and cobble mixed with coarse sand were often observed between sand and rocky reef areas. These substrate types often supported algal communities including green and brown algae (Figure 50). Areas of dense green algae were relatively uncommon and were usually observed growing as an understory in areas dominated by *E. radiata*. The green algae *Halimeda* sp. and *Caulerpa* spp. were infrequently observed between depths of 10 and 26 metres (Figure 51). Video footage revealed two species of *Caulerpa*, one of which appeared to be physically similar to the invasive algae, *Caulerpa taxifolia*, which is not currently known to occur in the Nambucca region (Creese et al 2004).

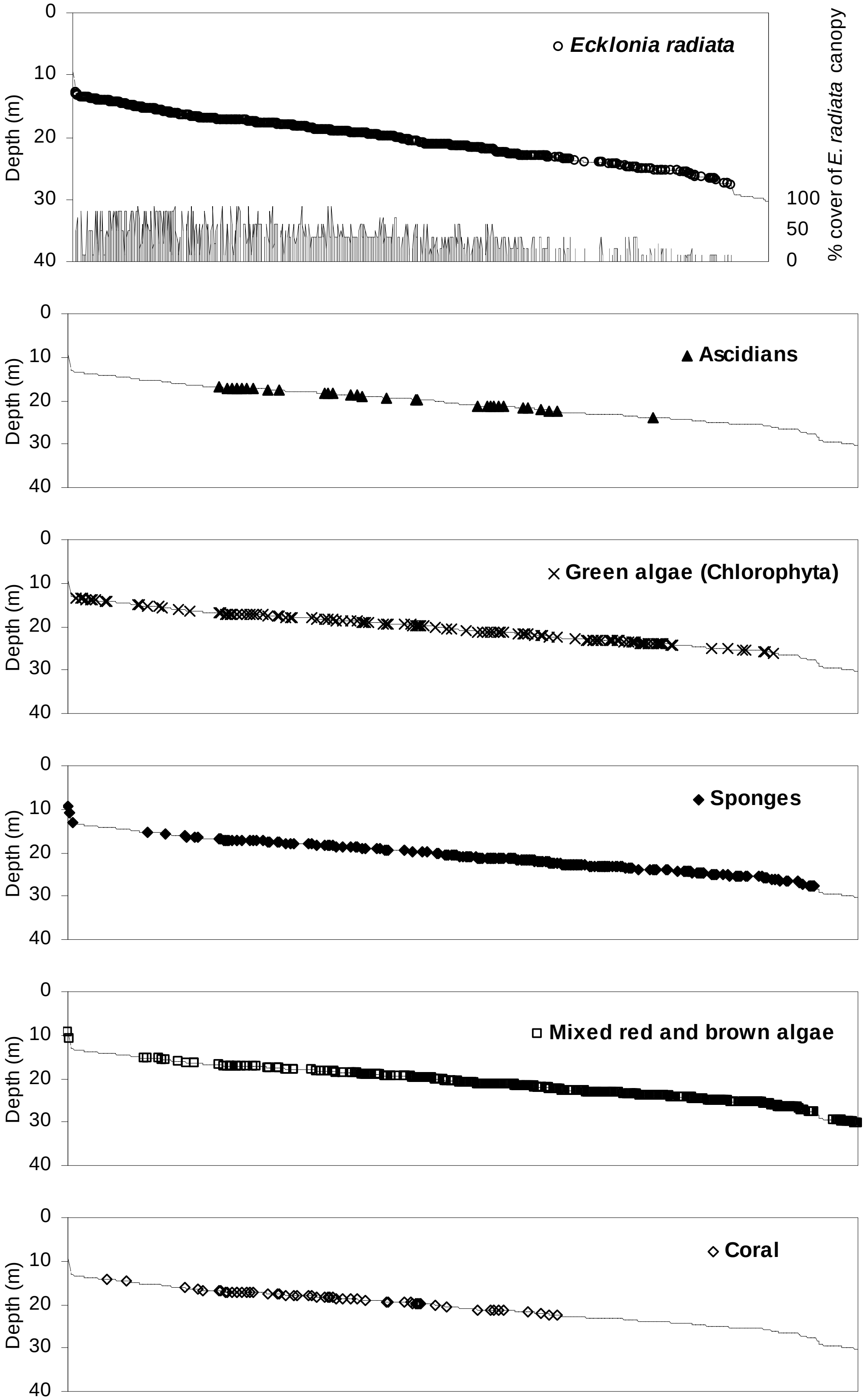


Figure 47. Presence of biota types along video transects in the Nambucca region.

Figure 48. Kelp (*E. radiata)* on reef habitat offshore from Nambucca Heads. Note the elongate stalks (a) and (c), fine fronds (d), and dense canopy (e) and (f).

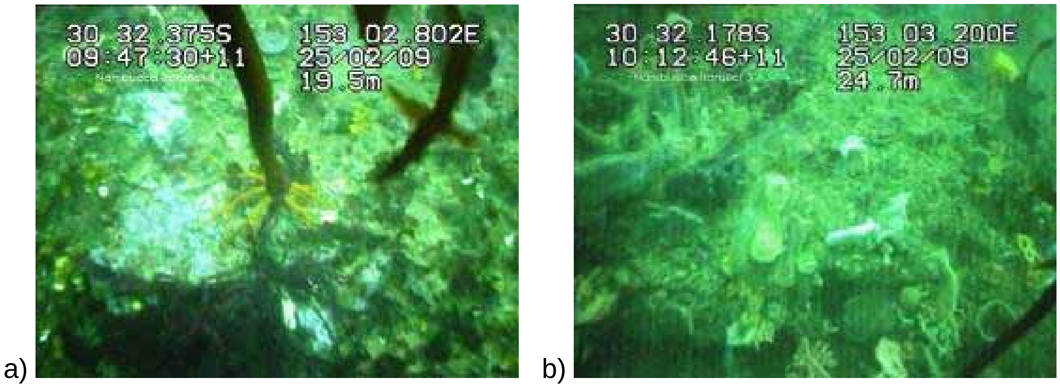


Figure 49. Algal (a) and sponge (b) communities exist as an understory to adult *E. radiata* plants. Note the *E. radiata* holdfasts (a) and stalk (b) suggesting that a primary canopy of *E. radiata* may be present above the camera.

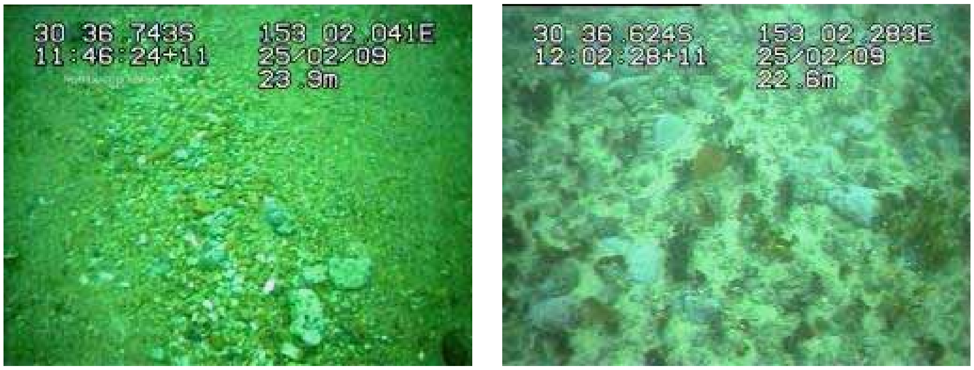


Figure 50. Unconsolidated substrate with pebble and cobbles (a) and mixed cobble and sand with green and brown algae (b).

Figure 51. A dense stand of green algae *(Caulerpa* spp*.)* on reef.

4.3.5 Scotts Head to Tacking Point

The region between Scotts Head and Tacking Point is characterised by a number of prominent headlands separated by large ocean beaches and few areas of nearshore reef. There was no indication from the broadscale bathymetry of the presence of shoal areas, which implied that if reefs were present they would have little relief. A number of small areas were swath-mapped in this region, the northern most of which was an area of approximately 6 square kilometres offshore of Smokey Cape. This covered the known features of Fish Rock and Black Rock, which lie south-east and south of Smokey Cape, respectively, and emerge above sea level as distinct rocky features (Figures 52 and 53). Around Black Rock the depth of the reef habitat was primarily less than 20 metres. However, the slope of the reef was considerably greater on the north-eastern side of the Rock, with the depth increasing from intertidal to around 25 metres over an area of 500 metres (Figure 54). The digitised seabed habitat around Black Rock indicated the presence of a broad mostly continuous shallow rocky reef around the rock that extended up to 240 metres in a westerly and southerly direction where it continued to the edge of the surveyed area. Around Black Rock the unconsolidated sediments appeared consistent in backscatter intensity and were therefore expected to be broadly similar in sediment particle size (Figure 55). The reef/sand boundary was very distinct on all sides of Black Rock.

In contrast, the seabed around Fish Rock was made up of shallow- and intermediate-depth rocky reef that was mostly continuous on the western side and patchy around the remainder of the Rock (Figure 53). A large area of intermediate reef also occurred to the west and south-west of Fish Rock. The bathymetry around Fish Rock was considerably more complex than that for Black Rock, with a number of features with evident profiles above the seabed occurring at varying distances around the Rock. Steep-sided reef occurred immediately adjacent to the Rock and there were a number of distinct reef features on the southern side (Figure 54). The backscatter around Fish Rock indicated there was some variation in sediment type (Figure 55). The reef/sand boundary was less obvious than that for Black Rock, with reef habitat grading to unconsolidated habitat as an indistinct boundary.

Scour effects associated with currents in the lee of islands and headlands were very evident at Fish Rock and somewhat evident at Black Rock. An elongated scour channel 7–8 metres deep, up to 15 metres at its deepest, almost 1 kilometre long and 200 metres wide was located in the lee inshore and 100 metres to the south-west of Fish Rock (Figure 53). Scour was also evident east and south-east of Fish Rock (7–10 metres deep and becoming increasingly deeper at depths over 100 metres) with a maximum decrease of 16 metres in depth from the surrounding area. The full extent of this south-east depression was not covered in the swath survey; however, given the extent of the boundaries of the scour, it was estimated the depression extended to depths of more than 16 metres because its seaward edge graded away into deeper water of 47–52 metres at the edge of the survey area to the south and east. Slightly higher backscatter intensity within the depressions indicated the scour area behind Fish Rock contained comparatively coarser sandy substrate than the surrounding area (Figure 55).

North of Smoky Cape, in shallow water (10–20 metres deep) east of Green Island, was an area of sand waves that extended for approximately 1–1.5 kilometres north and south of the island occurring at a frequency of 5–7 metres, amplitudes of 0.2–0.3 metres with crests oriented in a north-east/south-west direction. A small number of larger sand waves oriented east north-east/west south-west occurred south and south-east of Smoky Cape (less than 800 metres offshore) in water 10–15 metres deep. A band of north-west/south-east oriented sand waves to the west of Fish Rock were present in water 30–33 metres deep. The crests/troughs of the waves were 60–110 metres long and the heights were 0.3–0.5 metres.

A second area the swath acoustic surveys covered was located offshore of Point Plomer. The seabed was predominantly covered by reef which had low relief, rising about 2–4 metres above the surrounding seabed (Figures 52 and 56). The reef gently sloped from depths of about 20 to 42 metres for about 3 kilometres, although the slope increased more rapidly closer to the shore. At a finer scale, the highly variable slope of the seabed within the larger reef coverage indicated that it was complex and contained many individual reef features which formed a series of shallow gutters (Figure 57). The reef ridges and gutters were oriented north-east/south-west in the northern part of the survey area, and north-west/south-east in the southern part of the survey area. The gutters were filled with a range of unconsolidated sediments including cobbles, gravels and sand with grit. The largest of these gutters was located around 1.5–2 kilometres offshore, running approximately north-south, it was over 150 metres wide, about 1.5–2.5 metres deep and filled with sand and shell grit. A series of sand waves positioned 30–40 metres apart and less than 0.4 metres high covered an area of around 150 × 650 metres in shallow water east of Point Plomer. The sand waves were in 20–25 metres of water with crests oriented in a north-west/south-east direction.

The relatively low backscatter intensity in the area from Racecourse Head to a point 1500 metres north-east of Point Plomer indicated that unconsolidated sediments dominated this part of the surveyed area (Figure 58). These sediments were uniform, very gently sloping and were only interrupted by several bands of uniformly darker backscatter 150–350 metres wide by 1000–1200 metres long. One of these bands was observed 1400 metres to the north-east of Racecourse Head (Figure 58). A small section of sediments with variable backscatter were observed due east of Big Hill Point.

Five hundred metres to the east of Point Plomer was a similar area of distinctive texture within 18–25 metres of water. The sediments in this area were less uniform in profile than those to the north but presented as interlaced sediments of low to intermediate backscatter. In this southern section of the survey area low backscatter material occurred predominantly in shallow water to the south-east (in water less than 25 metres deep) and to the north and south of the main reef complex. An area of low to intermediate backscatter within the gutter feature divided the reef into eastern and western sections. Unconsolidated sediments that were interspersed between the patchy reefs appeared highly variable across the area. The complexity of reef habitats in the survey area were evident in the digitised layer (Figure 52). The large complex reef system offshore of Point Plomer was evident, but there was no evidence of the offshore extension of reef running from the rocky headlands of Big Hill Point and Delicate Nobby; however, reefs starting in deeper water cannot be discounted. The full offshore extent of the reef adjacent to Point Plomer was not confirmed, although there was evidence that it extended east of the limit of the current survey area.

Further south, in the area offshore of Tacking Point, the seabed was characterised by a complex array of patchy reefs that extended throughout the survey area (Figure 59). This contrasted to the bedrock structure offshore of Point Plomer and indicated that a different overall geology and geomorphology occurred in this area, which is dominated by the Port Macquarie Block. The reefs in the area surveyed with swath acoustic mapping extended about 15–50 metres in depth and at least 4 kilometres offshore. There was no evidence that the reef was continuous with the shallow reef that extended from the shoreline between Tacking Point and Port Macquarie. The majority of the reef was in water of intermediate depths and contained discrete patches of reef that varied considerably in extent and distribution. The amount of reef decreased in the southern and deeper parts of the survey area, with many patches of reef that were smaller than the defined minimum mapping unit. The majority of the reef system was slightly sloping, with only very small areas with higher slope (Figure 60).

The backscatter data indicated that some variation in seabed hardness occurred throughout the survey area. Sections of intermediate backscatter intensity were observed between individual reefs within the main area of the reef complex and adjacent to the shallow reef system 1–1.5 kilometres east south-east of Port Macquarie (Figure 61). The areas with the lightest backscatter intensity were likely to be finer-grained sediments such as sand and fine sands, with the intermediate backscatter suggesting coarser sediments were present.

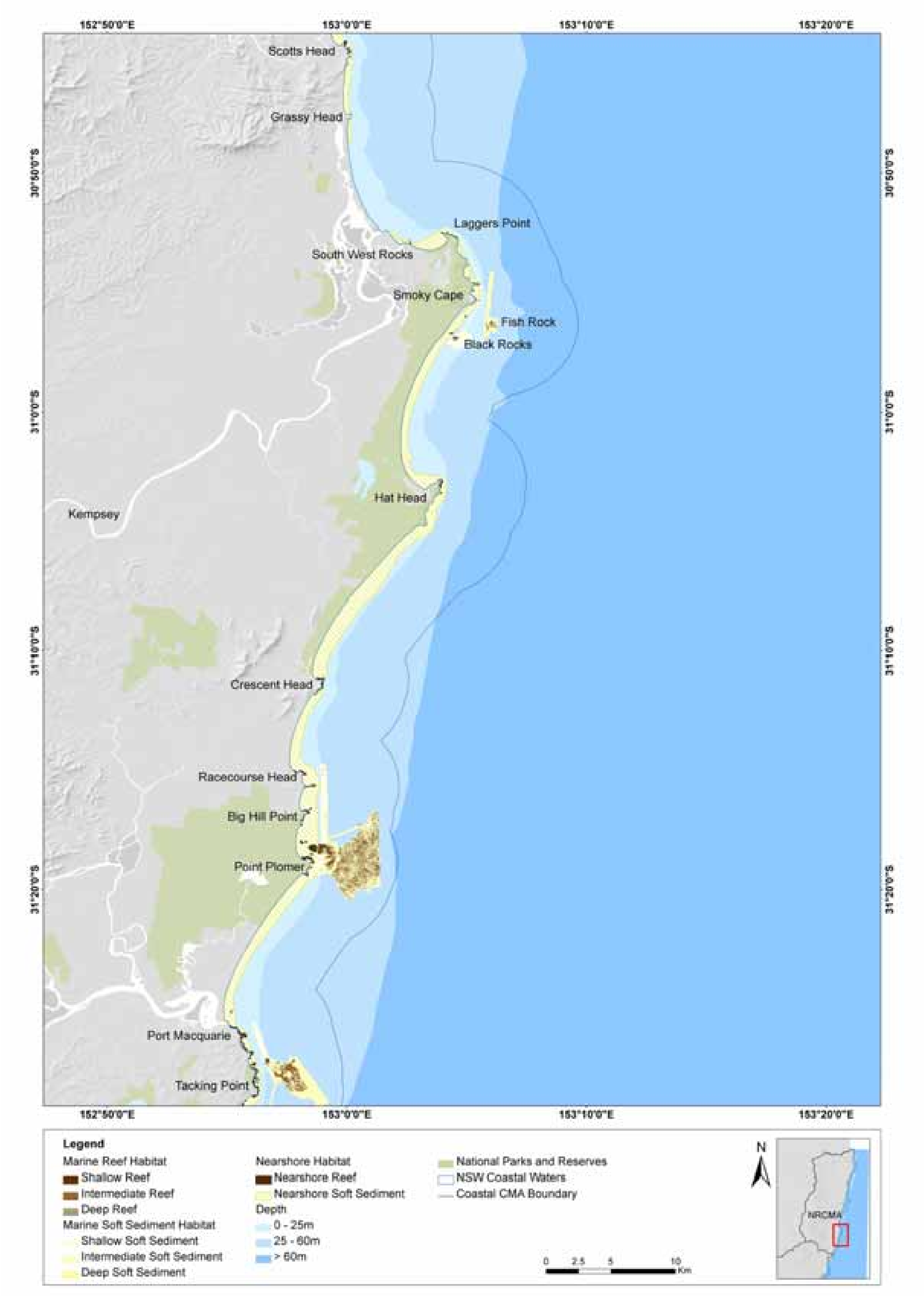


Figure 52. Distribution of known seabed habitats within the region between Scotts Head and Tacking Point.

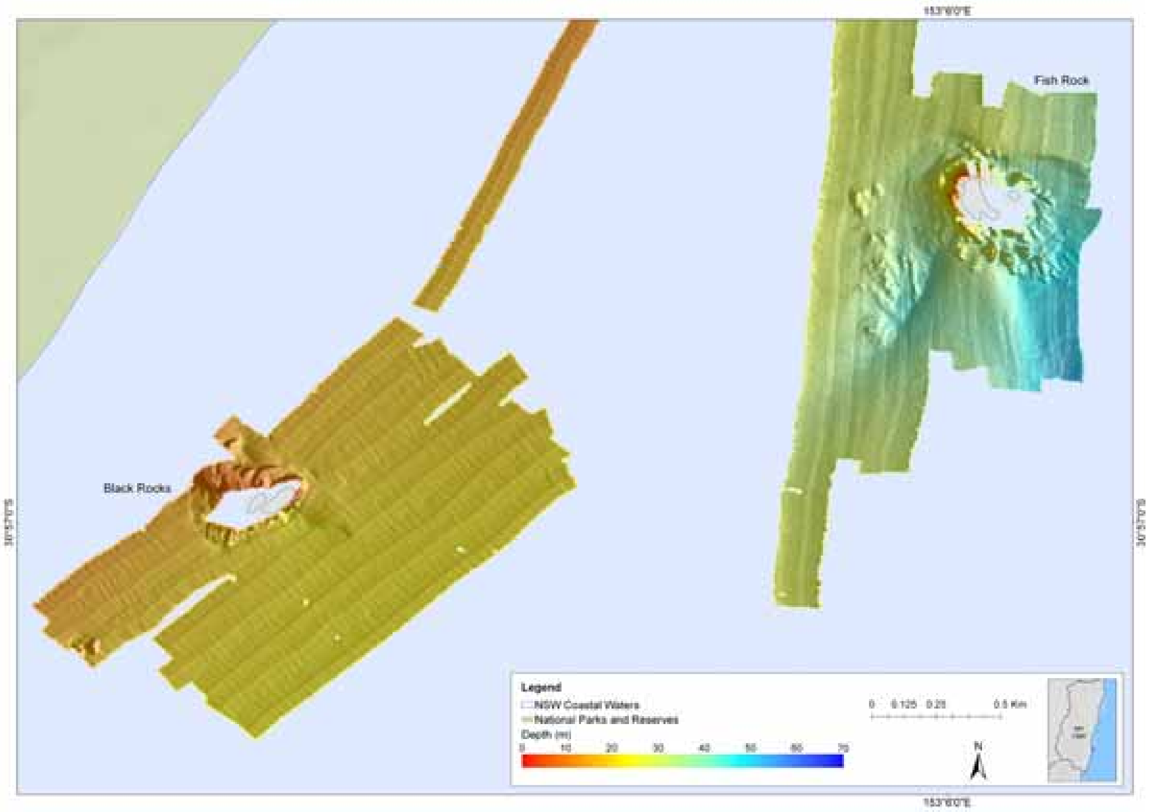


Figure 53. Hill-shaded bathymetric model of the seabed in parts of the Smokey Cape region.

Figure 54. Slope model of the seabed adjacent to South West Rocks.

Figure 55. Acoustic backscatter of the seabed adjacent to South West Rocks.

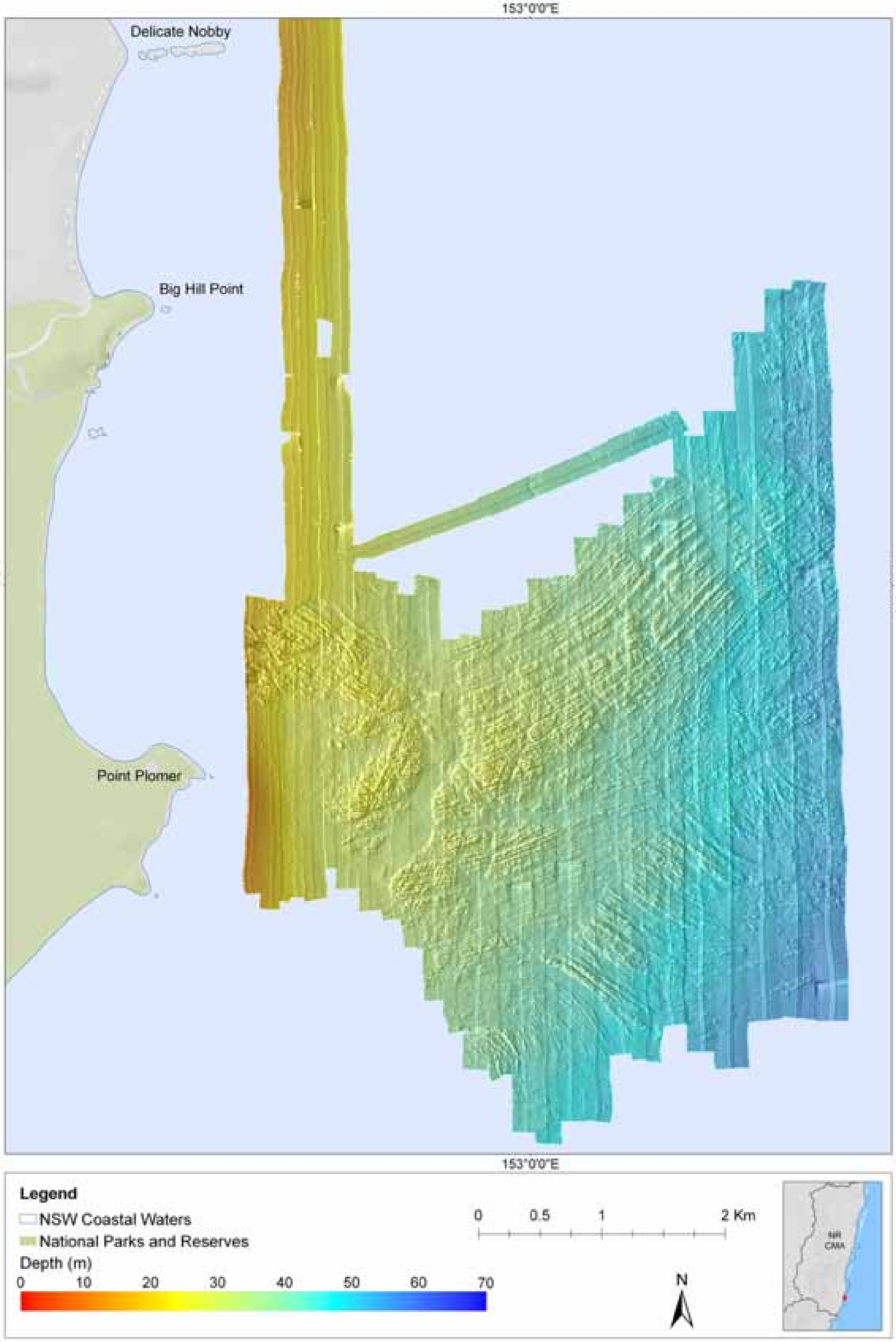


Figure 56. Hill-shaded bathymetric model of the seabed offshore of Point Plomer.

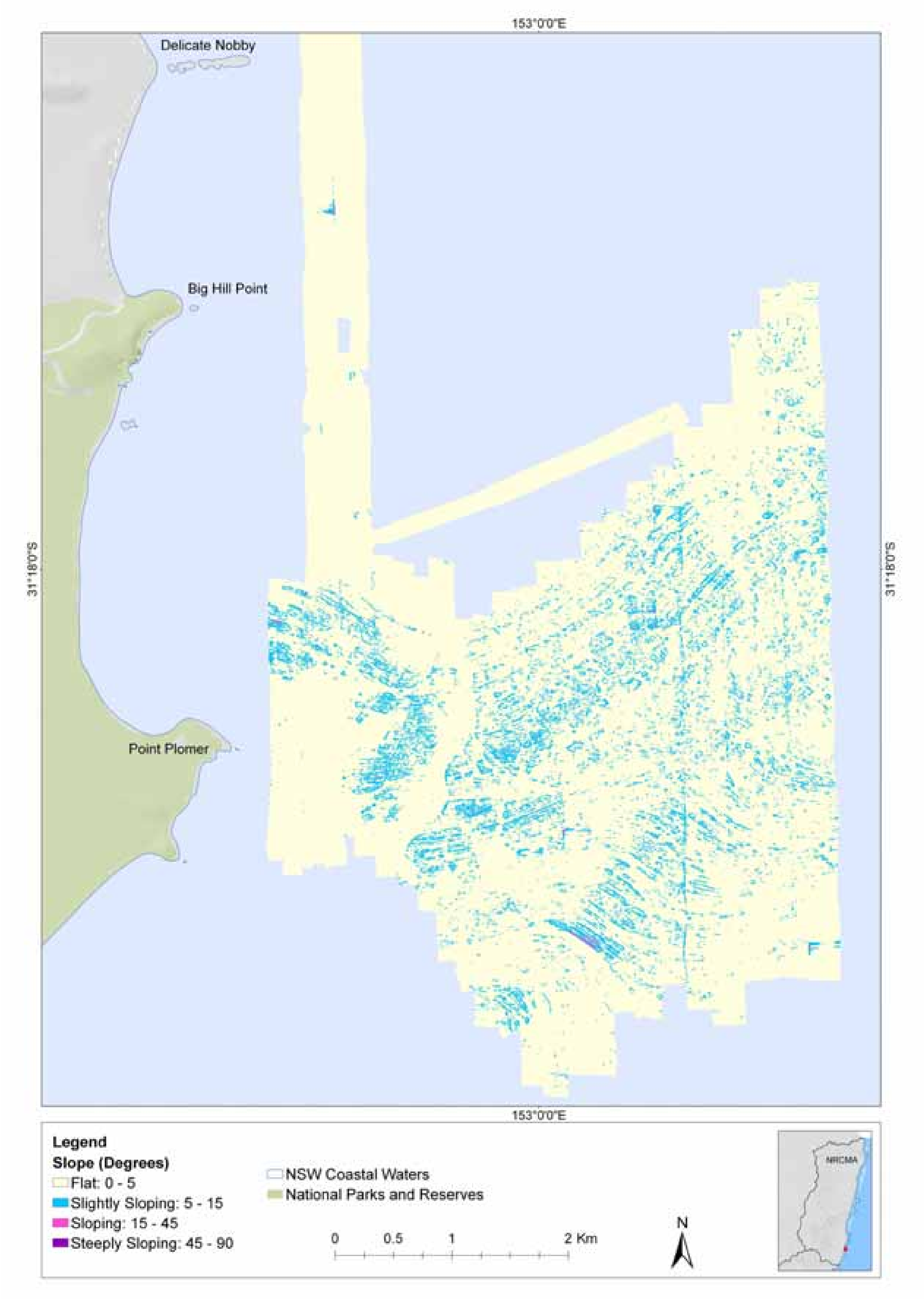


Figure 57. Slope model of the seabed adjacent to Point Plomer.

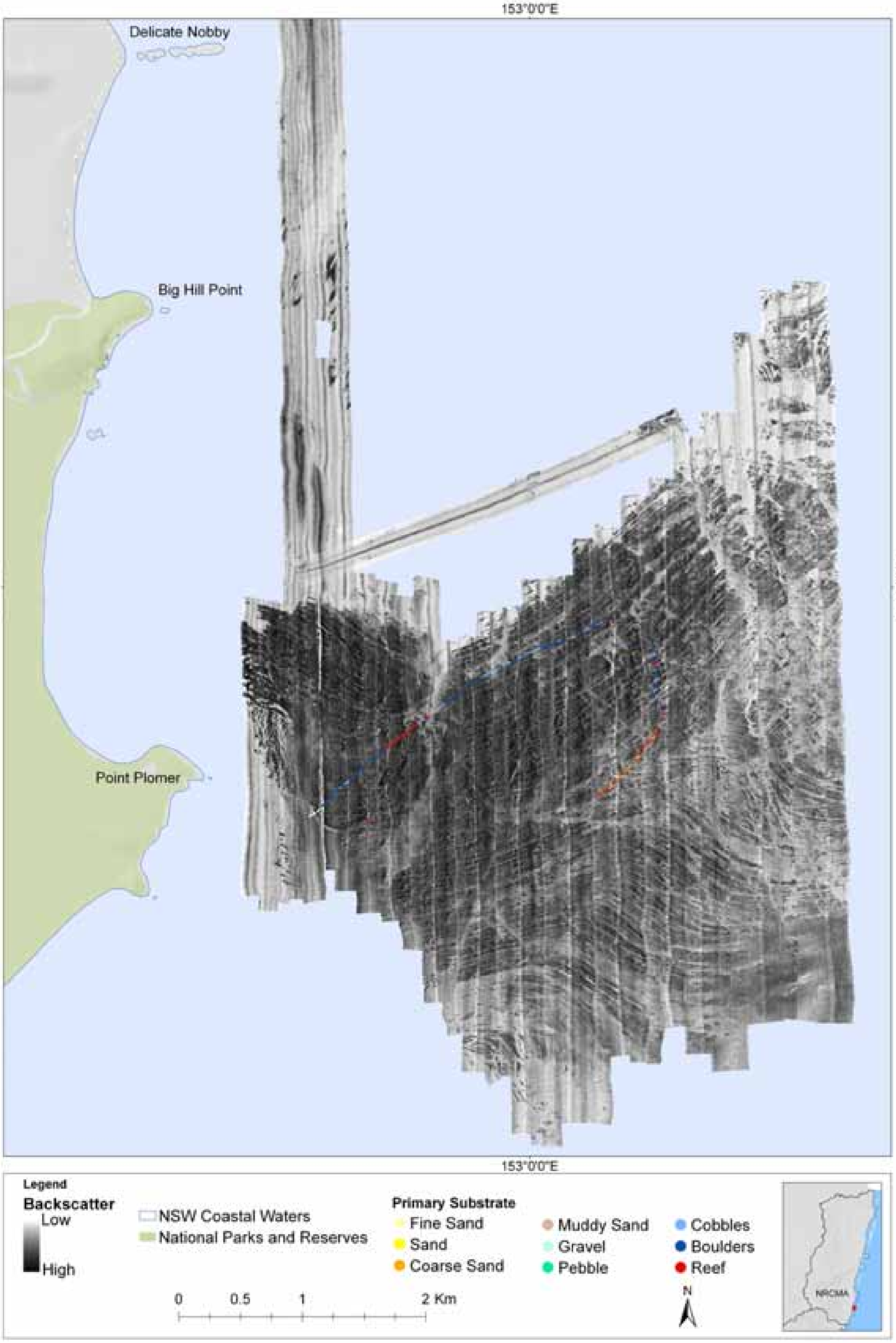


Figure 58. Acoustic backscatter of the seabed adjacent to Point Plomer.

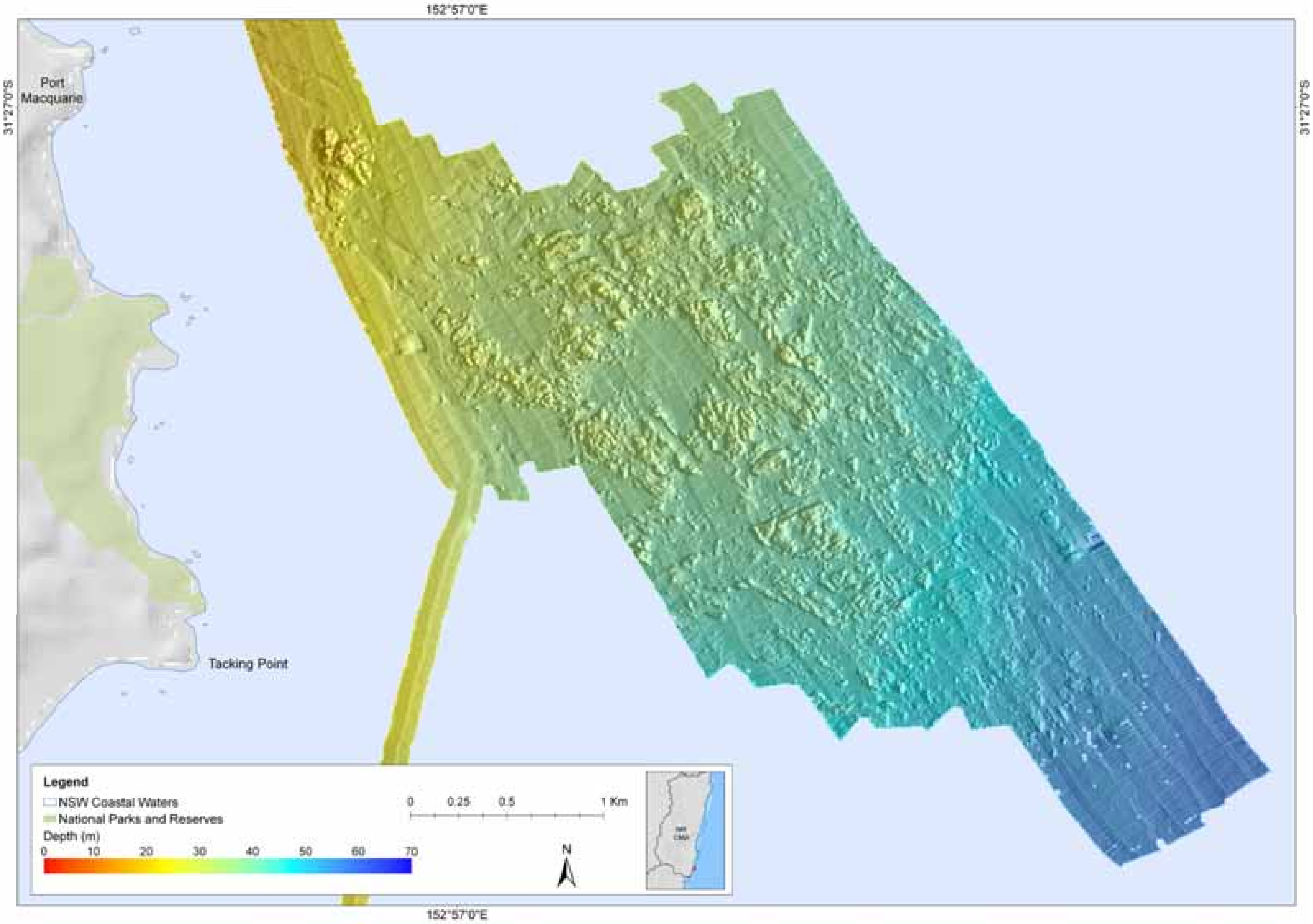


Figure 59. Hill-shaded bathymetric model of the seabed offshore of Port Macquarie.

Figure 60. Slope model of the seabed offshore of Port Macquarie.

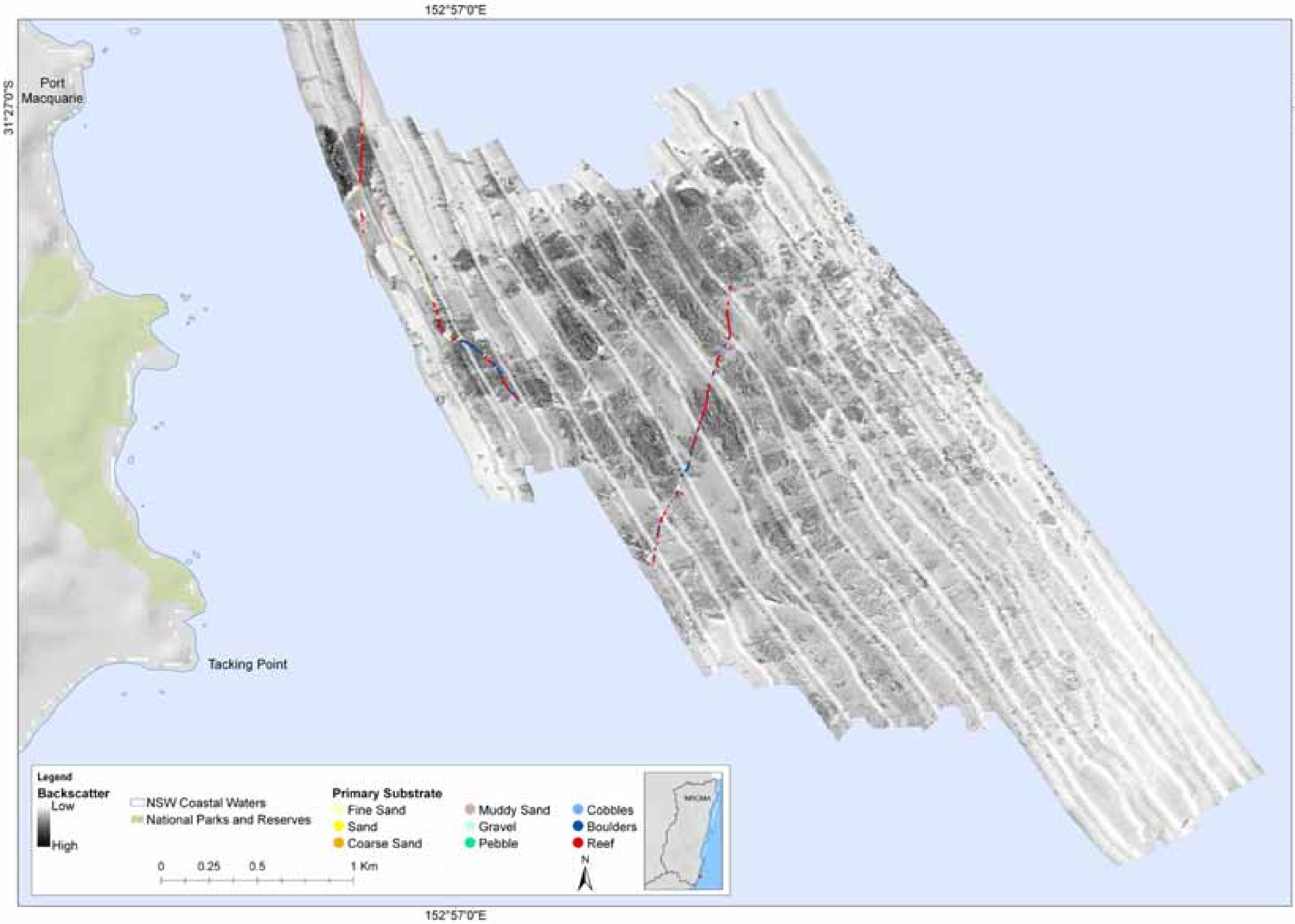


Figure 61. Acoustic backscatter of the seabed offshore of Port Macquarie.

Video surveys were conducted in areas swath-mapped offshore from Point Plomer on three transects along 4.4 linear kilometres at depths between 24 and 43 metres. The reef offshore of Point Plomer was discontinuous and dominated by low profile reef with patchy boulder and reef outcrops interspersed with sand veneer patches, coarse sand and cobble-filled gutters. Gutters were common and found across all depths surveyed. The biota associated with these patchy reefs was relatively uniform across the depths surveyed and was dominated by patchy and sparse sponge assemblages, extensive stands of mixed red and brown algal communities, and sparse sessile invertebrates, particularly ascidians (Figures 62 and 63). Gorgonians were observed, although appeared uncommon. Where sponges were present, their morphologies were dominated by encrusting and massive sponges, whereas branching and elongate forms were comparatively rare. Sea-urchin-dominated barrens habitat and *E. radiata* were not recorded in areas surveyed at Point Plomer. Unconsolidated habitats were dominated by coarse sand with waves and ripples. There was widespread evidence of burrowing organisms in soft sediments, with bioturbated sediments observed in areas of sand, particularly at depths exceeding 25 metres.

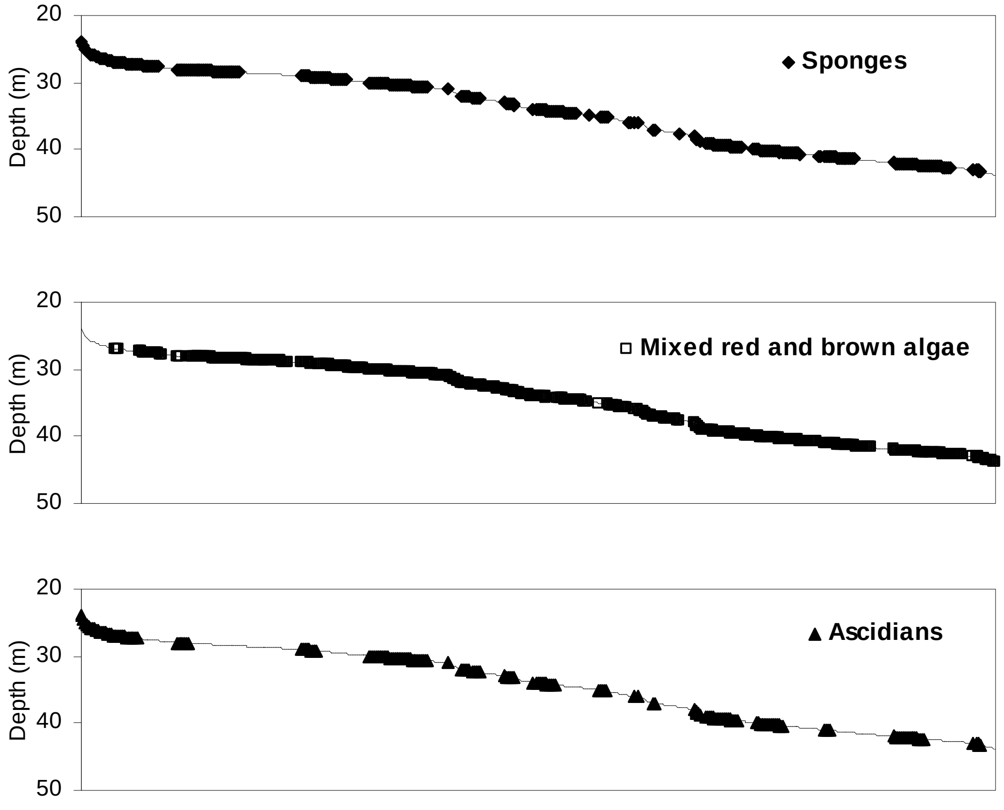


Figure 62. Presence of biota types along video transects offshore from Point Plomer.

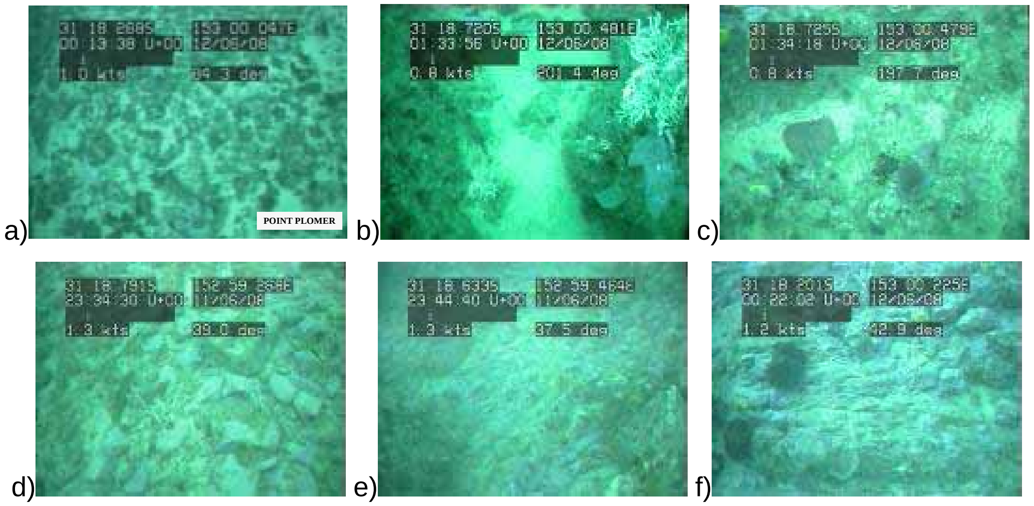


Figure 63. Reef and mixed reef/sand habitats offshore of Point Plomer. Note the presence of brown algal assemblages (a), low densities of sponges (b), (e) and (f) and a gorgonian (b).

Reef habitat offshore from Port Macquarie was dominated by assemblages of mixed algae and sessile invertebrates, consisting primarily of sponges, ascidians, gorgonians, and sea whips (Figure 65). Poor water visibility limited the extent to which much of the biota present could be identified from video footage. Physically, the reef had a relatively complex profile, with steep gutters, walls, areas of boulders interspersed with sandy areas, and sections of mixed cobble and sand. Sandy substrates consisted of patchy sections of muddy sand and fine-grained sand with shell grit.

Stalked ascidians *P. spinifera* were particularly abundant in areas of continuous reef at depths shallower than 25 metres, whereas *Sigillina* sp. were common in areas of mixed cobble and sand between 30 and 40 metres deep (Figure 65). Corals, gorgonians, and sea whips were widespread although present at low densities and generally observed alongside sponges (Figure 66). A single stand of kelp (*E. radiata*) was observed on a patch of reef 24 metres deep (Figure 64); however, other stands of *E. radiata* may have been present adjacent to the survey areas as loose drifting fronds of *E. radiata* were observed on sandy and mixed cobble/sand habitats. The absence of sea urchins in survey areas was notable particularly because the reefs surveyed were within the common depth range for sea urchins, such as *C. rodgersii*.

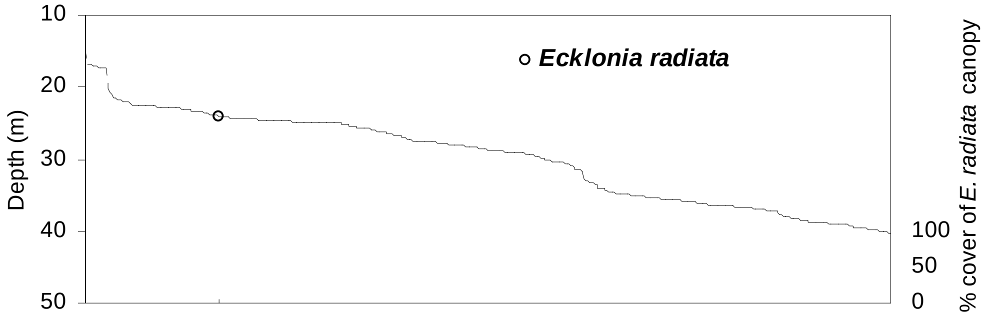


Figure 64. Presence of kelp (*E. radiata*) along video transects near Port Macquarie and percentage cover of kelp (indicated by vertical lines on the x axis) along video transects near Port Macquarie.

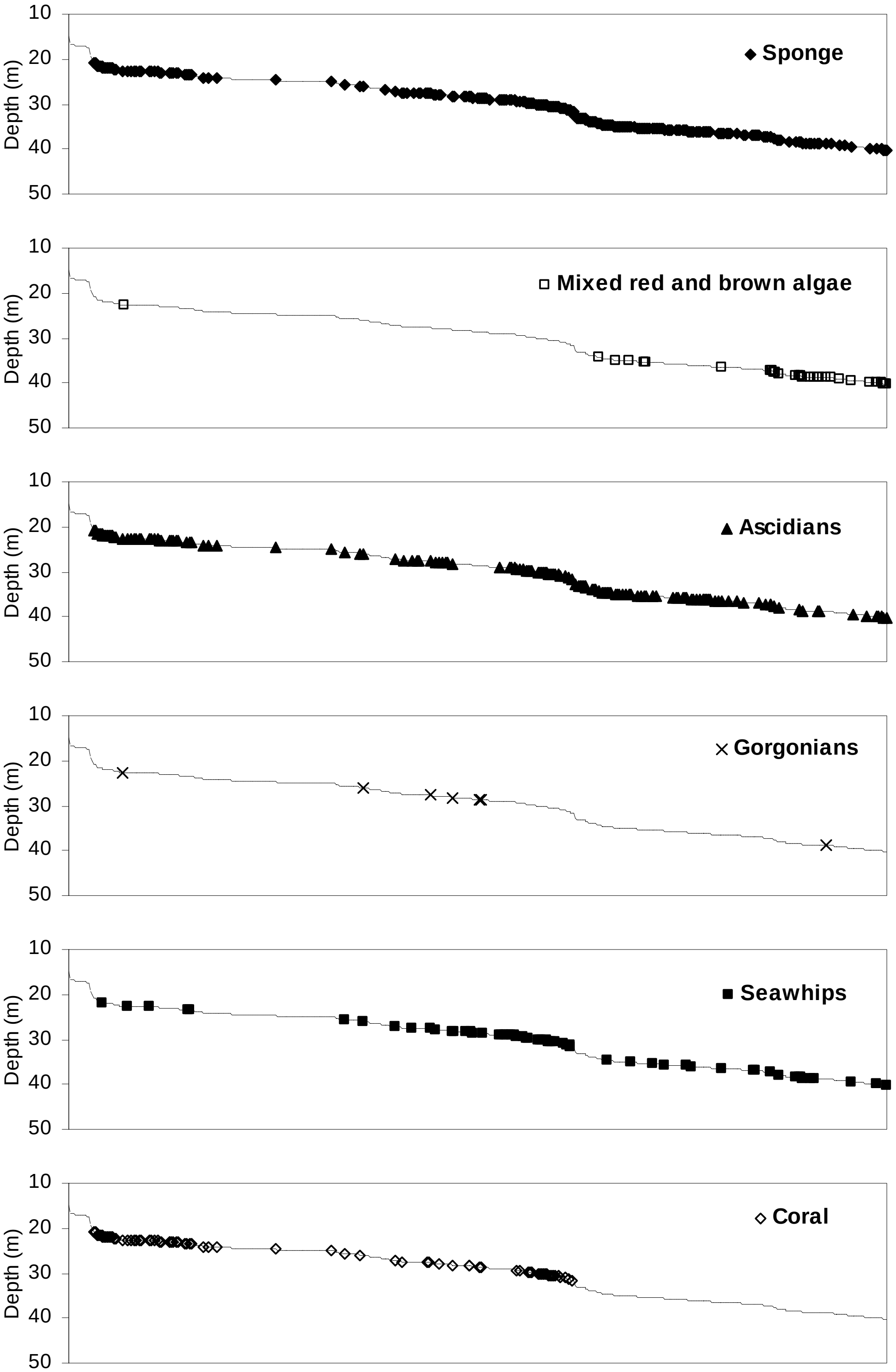


Figure 65. Presence of biota along video transcects near Port Macquarie.

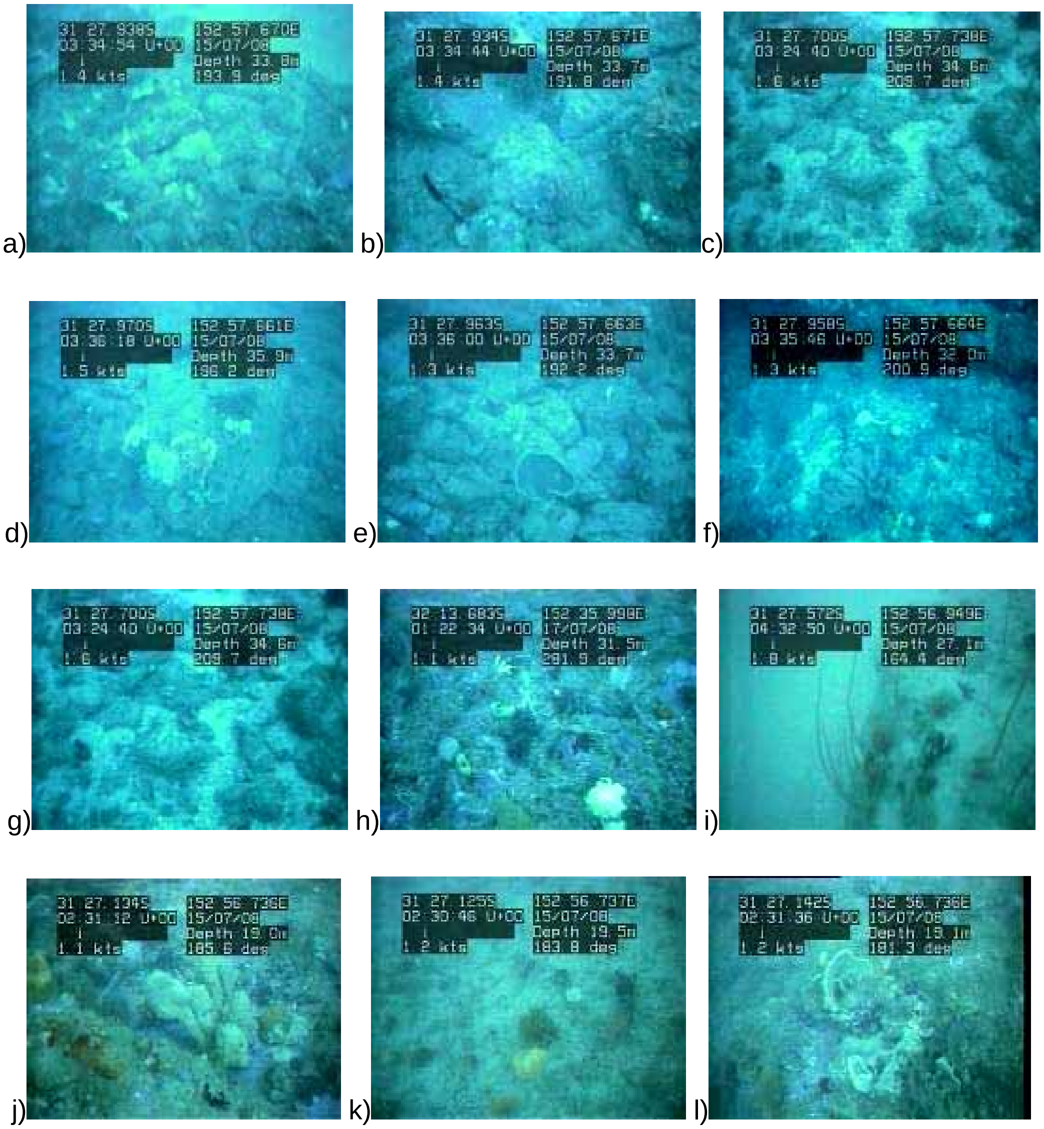


Figure 66. Reef habitat offshore from Port Macquarie. Note sponges present in all images, ascidians *Sigillina* sp. (b), *P. spinifera* (h) and (j), and sea whips (i).

4.3.6 Tacking Point to Crowdy Head

Little nearshore reef and no offshore reefs were identified from the broadscale bathymetry examined between Tacking Point and Perpendicular Point. The only mapped area of shallow nearshore reef was adjacent to the headland and beach of Bonny Hills, about 6 kilometres north of Perpendicular Point, with several patches of isolated reef extending several kilometres offshore (Figure 67). Swath mapping revealed that the area offshore of Diamond Head and extending to Crowdy Head contained a large amount of rocky reef habitat of varying complexity (Figure 68). The mapped reefs in this area extended north from just offshore of Crowdy Head into Commonwealth waters to include the pinnacle within the Cod Grounds Commonwealth Marine Reserve. The broadscale bathymetry showed there was a moderately rough seafloor in the northern part of this area, suggesting that the reef complex extended further north beyond the entrance to Camden River towards Tacking Point.

The seabed in the Commonwealth waters area consisted of a series of large blocky reef outcrops that rose up to 10 metres above the surrounding reef and appeared to be made up of a different material than the surrounding cobble fields. The area was dominated by a main pinnacle-reef system in the north-east of the mapped area, where depths ranged from 21 metres to a maximum of 46 metres in the south-east. The reef formed a roughly circular outcrop approximately 800 metres wide. The eastern side had a relatively low slope of up to 10 degrees, whereas on the western side the slopes were steeper with the terrain falling away to 50 metres over a horizontal distance of 300 metres, resulting in a moderate slope of around 25 degrees (Figure 69). This pinnacle reef was surrounded by areas of distinct reef ridges oriented north-east/south-west creating a series of gutters 1–2 metres deep, 10–20 metres wide, as well as boulders and cobbles that overlay the bedrock formations. Video footage showed that the gutters were typically filled with cobbles and sand. The backscatter data indicated that this seabed type interlaced with the surrounding sand areas (Figure 70). These sand fields were covered in ripples, which were spaced approximately 100–200 millimetres between crests. The troughs of the sand ripples were filled with relatively small amounts of coarser fragmented shell material. The crests of the ripples were oriented in an east-west direction, indicating the sediment was moving in a southerly direction, most likely in response to the south-flowing East Australian Current. The sands appeared to be relatively fine; however, they gave a stronger backscatter signal because of the coarser shell grit contained within the troughs. Areas of weaker backscatter were likely to indicate areas of relatively fine sand devoid of or with a minor coarser shell-grit component.

The most northerly mapped pinnacle was the shallowest of three main peaks within the reef complex extending over an area of several kilometers toward the south-west. The deeper peaks and associated reef were similar in size (horizontal area) as the main pinnacle but did not appear to have gutters with a consistent orientation. Extending south-west into state waters was a series of reef complexes with typical dimensions of 2–3 kilometres across and rising approximately 20 metres from the surrounding seabed. Immediately inside the state waters boundary, between 3.5 and 5.5 kilometres east of Diamond Head, there was an extensive area of patchy reef at a depth of about 25–40 metres. A series of north-east/south-west oriented linear ridges appeared 7 kilometres north-east of Diamond Head at a depth of 35–40 metres. These features were 1–2 metres in height but appeared to consist of unconsolidated sediments, which were apparent by their low intensity backscatter signature.

Mermaid Reef, located south-east of Diamond Head, is the largest and shallowest of the main reef systems in the area. A proportion of this reef is intertidal and is a noted feature on naval faring sheets. The bathymetric data from this survey showed that the reef dropped sharply from the 10 metre contour, reaching depths of around 26 metres over a distance of about 200–500 metres from the shallowest point (Figure 71). Shallow reef dominated the area adjacent to the outcrop, with large areas of intermediate reef extending to the south-east, east and north-east. Intermediate reef was predominantly low profile with the steeper sections mostly restricted to the edges of the reef complex (Figure 72).

There was no definitive boundary to this reef system in the alongshore direction, with patchy reef covering areas from the main outcrop to adjacent complexes and to the limits of the current survey. Patchy reefs, intermixed with areas of moderate backscatter intensity and variable texture, extended to depths of around 50 metres at the limit of state waters to the north-east. Alternating lenses and bands of moderate and low intensity backscatter in deeper water and toward the eastern boundaries of the survey area defined a series of sand waves. These waves were less than 100 metres across and 100–300 metres wide with a relief of several metres. Mermaid Reef was more or less continuous with adjacent complexes to the north and south separated by bands of low backscatter intensity sands less than 1 kilometre across. The main extension of the reef system ran north-east of Mermaid Reef up to a distance of around 4 kilometres. At around 2 kilometres north/north-west of the northern tip of the Mermaid Reef complex was another reef system in relatively shallow water that extended over several square kilometres and consisted of a large number of moderately sloping reef walls.

Further to the south, separated by a distance of approximately 2 kilometres, lies the feature known as Curphy Shoal. This reef was oriented roughly north-east/south-west with the shallowest point around 9 metres deep with an average depth of around 30 metres (Figure 74). Almost rectangular in shape, the reef was approximately 700 metres across and 2.3 kilometres long and became increasingly patchy with increased distance from the main reef. The reef habitat was mostly continuous shallow reef due east from the main shoal, increasing in depth to intermediate reef into Commonwealth waters. A smaller reef system that was discontinuous with and 3 kilometres to the north-west of Curphy Shoal, lay close to shore at depths less than 20 metres.

Giles Shoal is further south-west towards Crowdy Head. This reef was detected at depths of around 10–30 metres, with intermediate sections of reef restricted primarily to the eastern side (Figure 74). The reef had a series of gutters running through it at different angles, predominantly oriented north-west/south-east, which were formed by the tilted and folded rock strata. These gutters were up to 8 metres deep and the bottom of the gutters were covered with cobble, gravel and coarse sand. Some of the highest gradient reef slopes for the Point Perpendicular to Crowdy Head area occurred on the walls of these gutters (Figure 75). It is likely that the rocks which form these reefs are extensions of the volcanic rocks of Crowdy Head. Due east of Crowdy Head there was another significant reef complex which was likely to be continuous with the nearshore reef adjacent to the headland. Most of the northern section of the reef that was surveyed occurred at depths of less than 20 metres, with increasing depths to the south. Given the extent of reef in this area it is likely that this reef system continues east of the current survey area.

Surrounding all of these reef systems in state waters were extensive unconsolidated habitats that varied in depth, sediment grain-size composition, and amount of shell material and morphology (e.g. ripples, waves). Low-intensity backscatter, representing fine to coarse sands, dominated unconsolidated sediments over the survey area (Figure 76). However, a number of areas of consistent moderate- to high-intensity backscatter comprised sediments that were likely to contain varying proportions of coarse sand, pebbles, gravel and boulders. This was represented in areas north-east, north and west of the Mermaid Reef area where there were regions of high backscatter measuring between 500 and 700 metres across (Figure 73). Video data showed the surface of this substrate comprised unconsolidated material ranging from cobbles to boulders interspersed with up to 40% coarse sand. There were also a considerable number of large gutters (hundreds of metres in size) intersecting the reef throughout the area. The backscatter and video sampling indicated that these gutters were usually dominated by pebbles.

The seabed between Mermaid Reef and Curphy Shoal has not been comprehensively mapped, but is likely to be dominated by low and moderate intensity backscatter sands. Closer to Curphy Shoal a 400-metre-wide band of higher and relatively uniform backscatter was apparent to the north, east and west of the main reef area (Figure 76). These areas appeared to consist predominantly of cobble and coarse sand. To the south-east of Curphy Shoal the backscatter was more variable in intensity. A series of thin (less than 30 metres wide and 100 metres long), irregular-shaped lenses of intermediate backscatter material were observed in the sandy habitat that stretched from the north-west edge of the shoal towards Kylies Beach. Similarly, small thin irregularly shaped lenses or bands of intermediate to high intensity backscatter were observed along the southern edge of Curphy Shoal. The transition from high intensity to low intensity backscatter along the southern edge of the reef was usually more distinct than the northern edge where the boundaries appeared more gradational. The backscatter intensity indicated that most of the gutters within the Curphy Shoal reef complex contained coarser unconsolidated sediments such as pebbles and cobbles.

A number of smaller reefs directly adjacent to Kylies Beach were surrounded predominantly by low intensity backscatter sandy sediments. Small bands of relatively uniform intermediate backscatter material separated reef and sand, with larger bands connecting these smaller reefs to one another.

Similarly, a band of intermediate to high backscatter sediment connected Curphy Shoal to the north-eastern extent or eastern arm of Giles Shoal, which was generally surrounded by sediments of relatively low backscatter intensity. Fine to coarse sandy sediments were apparent to the north, south and west of the main reef of Giles Shoal. These sediments were interspersed between reefs predominantly along the southern end of the main reef, on either side of and between the two northern arms of the shoal, between Giles Shoal and Crowdy Head, and south of Crowdy Head reef. The broadest areas of relatively uniform intermediate and high backscatter occurred in two sections, the first in a band (50–100 metres wide) in the north-west of the main reef, and the second further to the north-west in shallow water and at the edge of the survey coverage. Backscatter was more variable throughout the Giles Shoal reef complex and its adjoining arms. A 1200–1400 metre band of unconsolidated sediment separated Giles Shoal and Crowdy Head reefs. At Crowdy Head, unconsolidated low backscatter sediments dominated and appeared to directly abut the reef. Very little intermediate- to high-intensity backscatter material was apparent around the edges of the reef and was predominantly observed within the reef boundary.

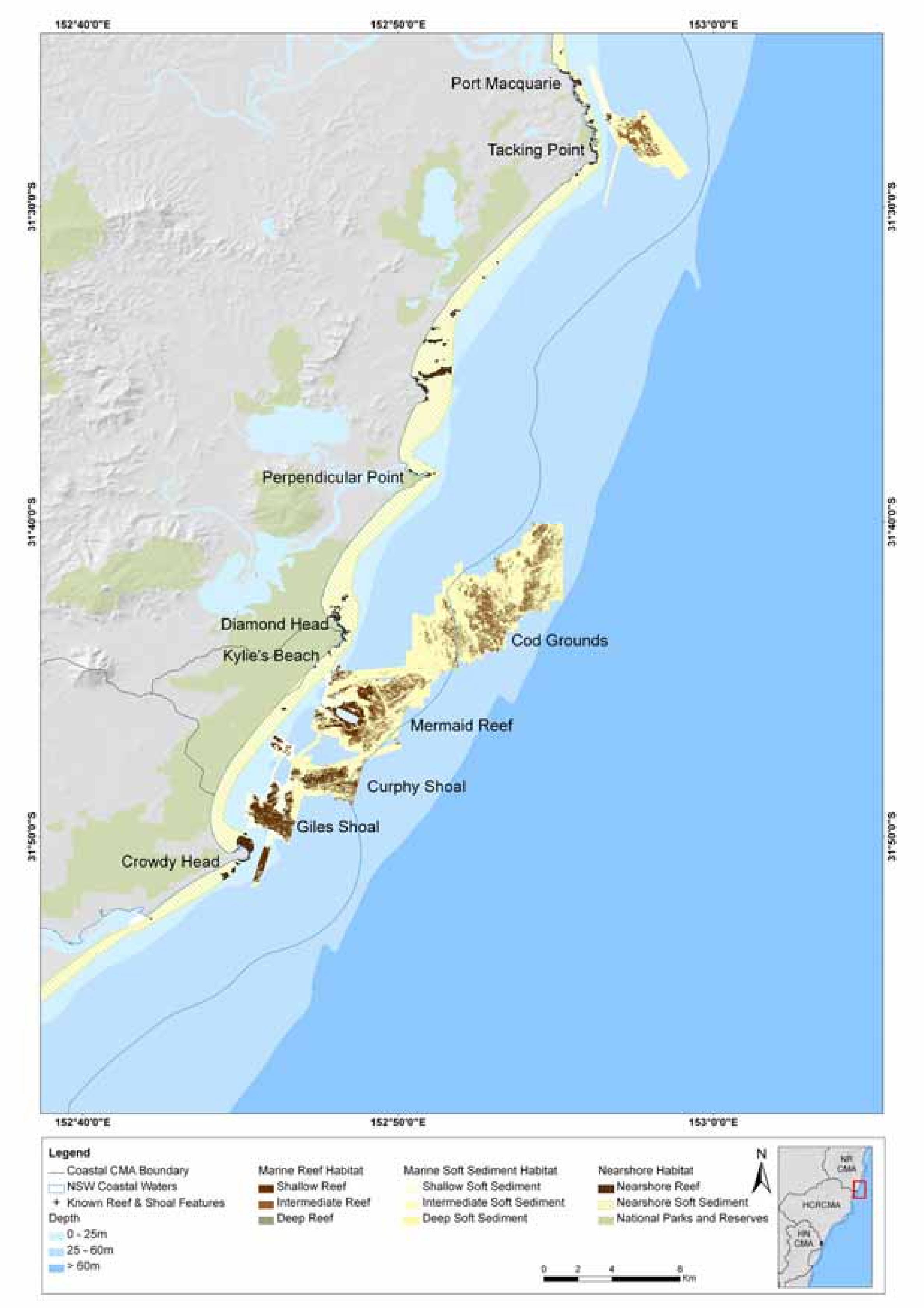


Figure 67. Distribution of known seabed habitats within the Tacking Point to Crowdy Head region.

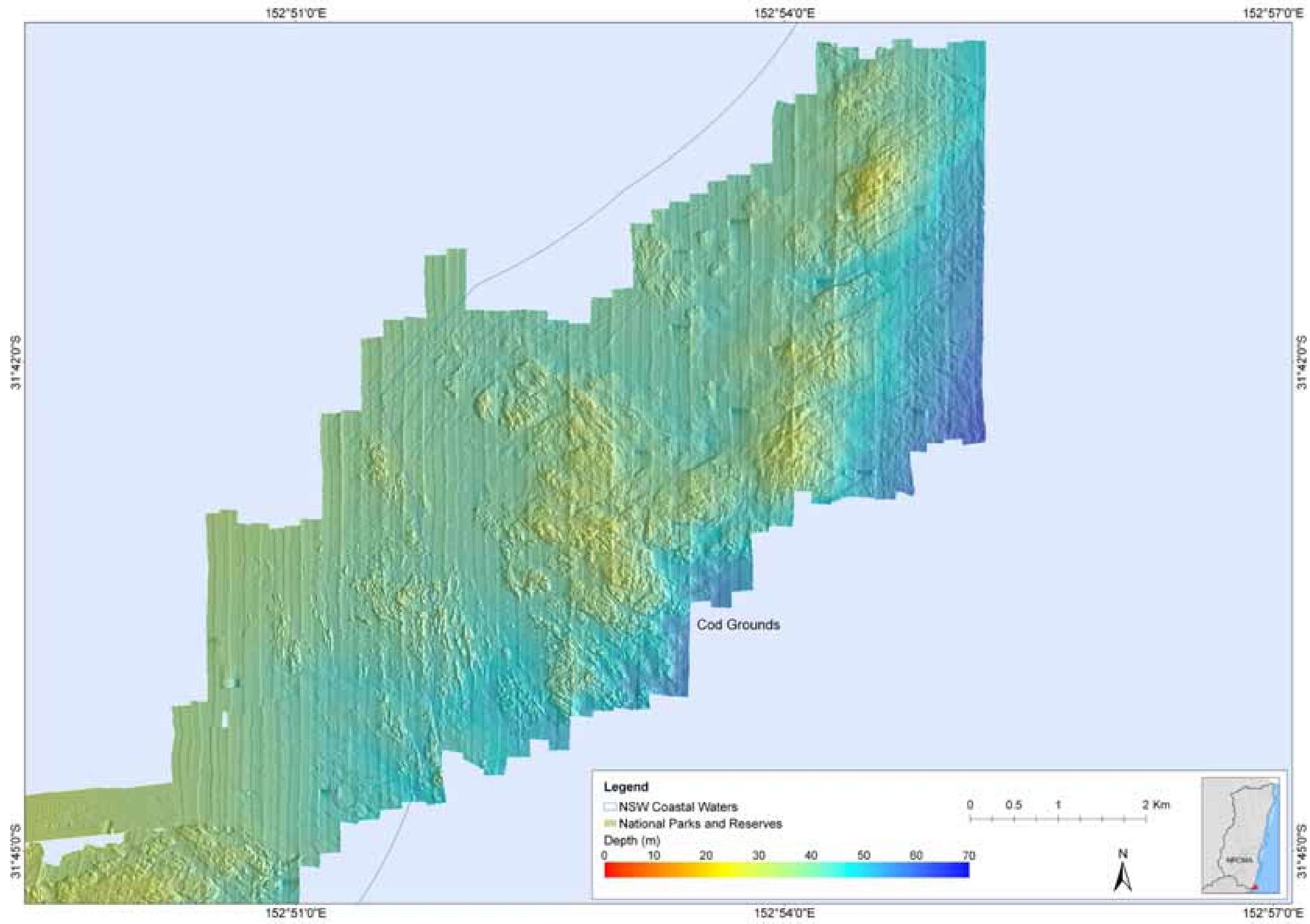


Figure 68. Hill-shaded bathymetric model of the seabed offshore of the region between Perpendicular Point and Diamond Head.

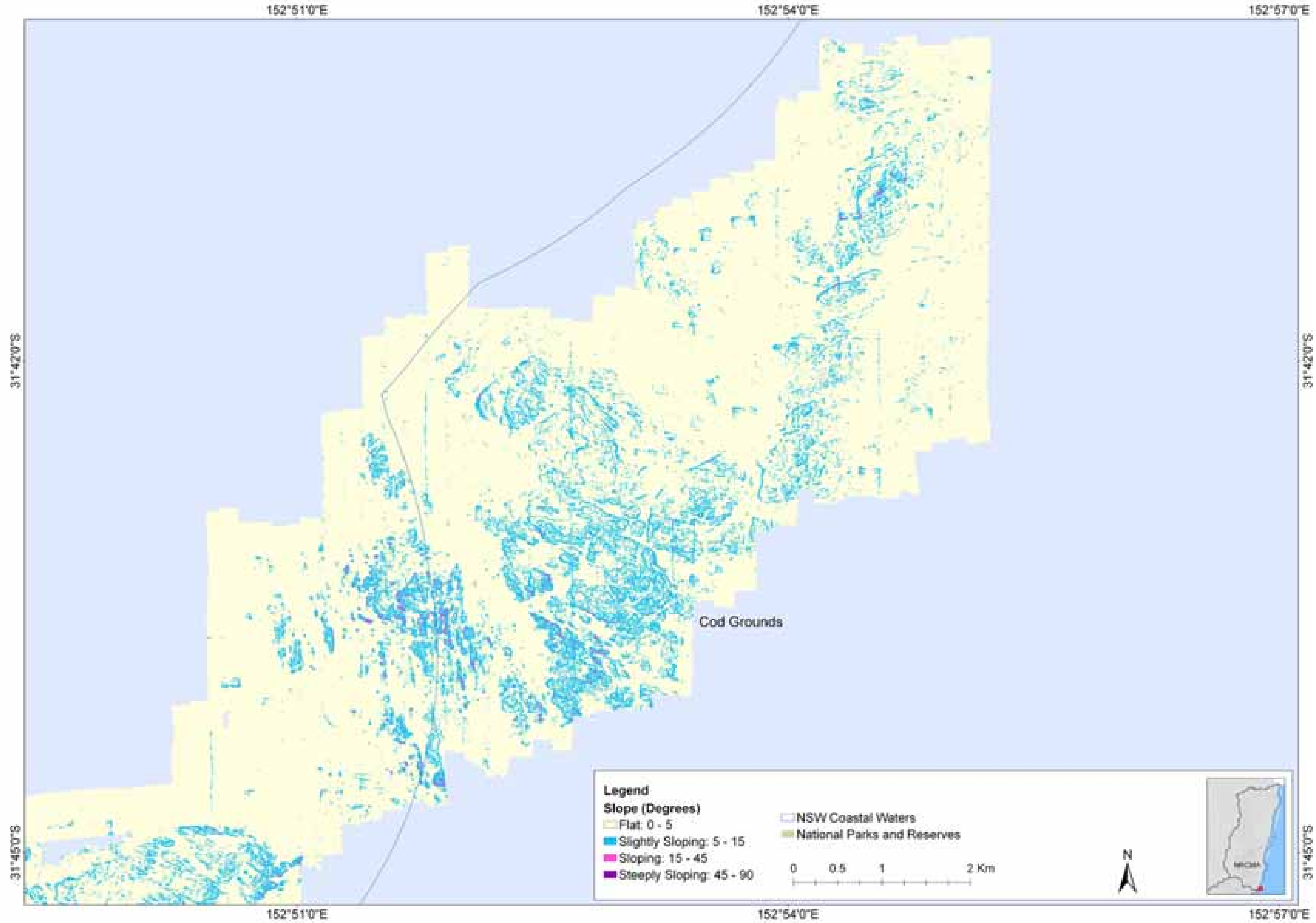


Figure 69. Slope model of the seabed offshore of the region between Perpendicular Point and Diamond Head.

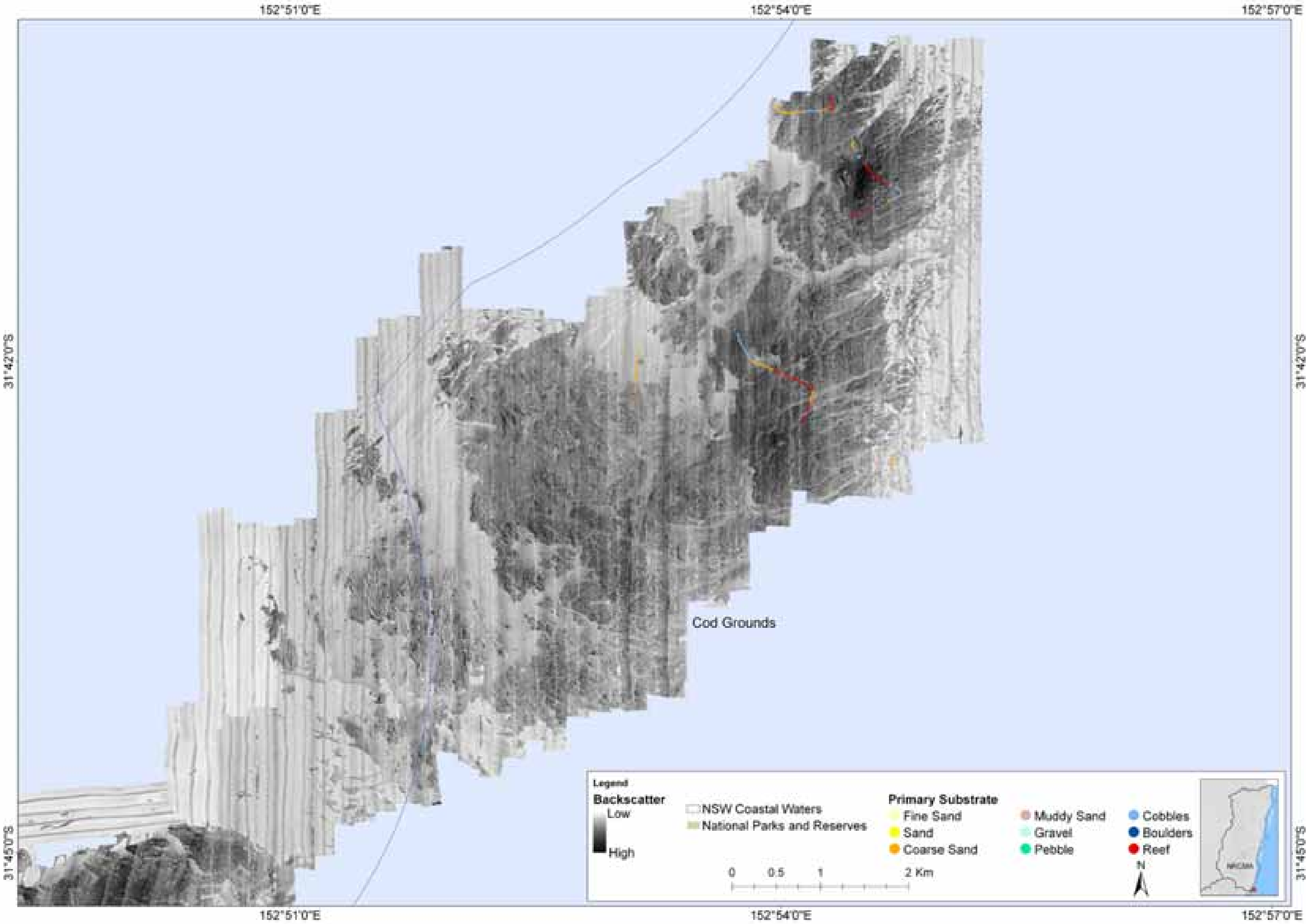


Figure 70. Acoustic backscatter of the seabed offshore of the region between Perpendicular Point and Diamond Head.

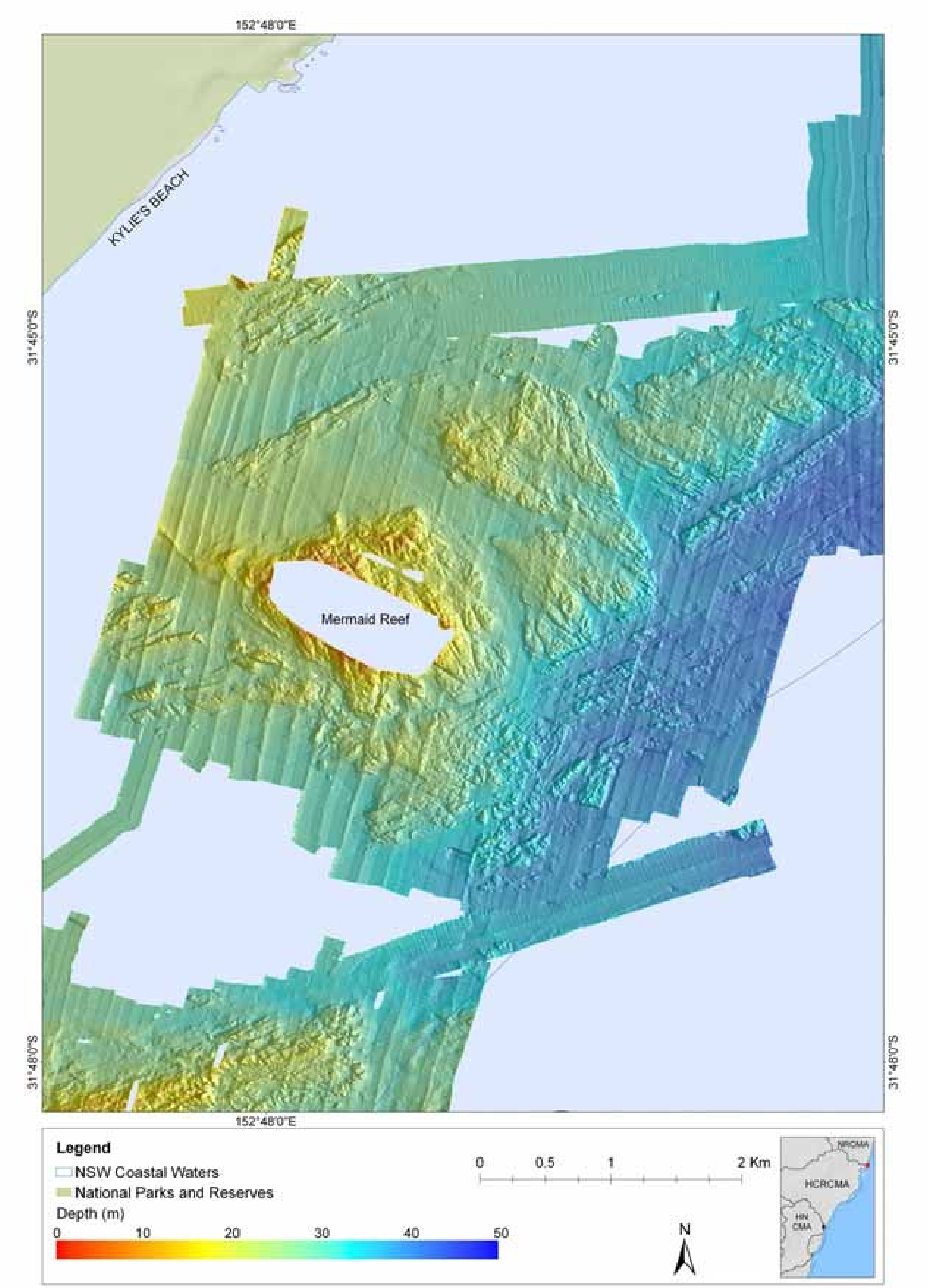


Figure 71. Hill-shaded bathymetric model of the seabed in the Mermaid Reef region offshore of Crowdy Head.

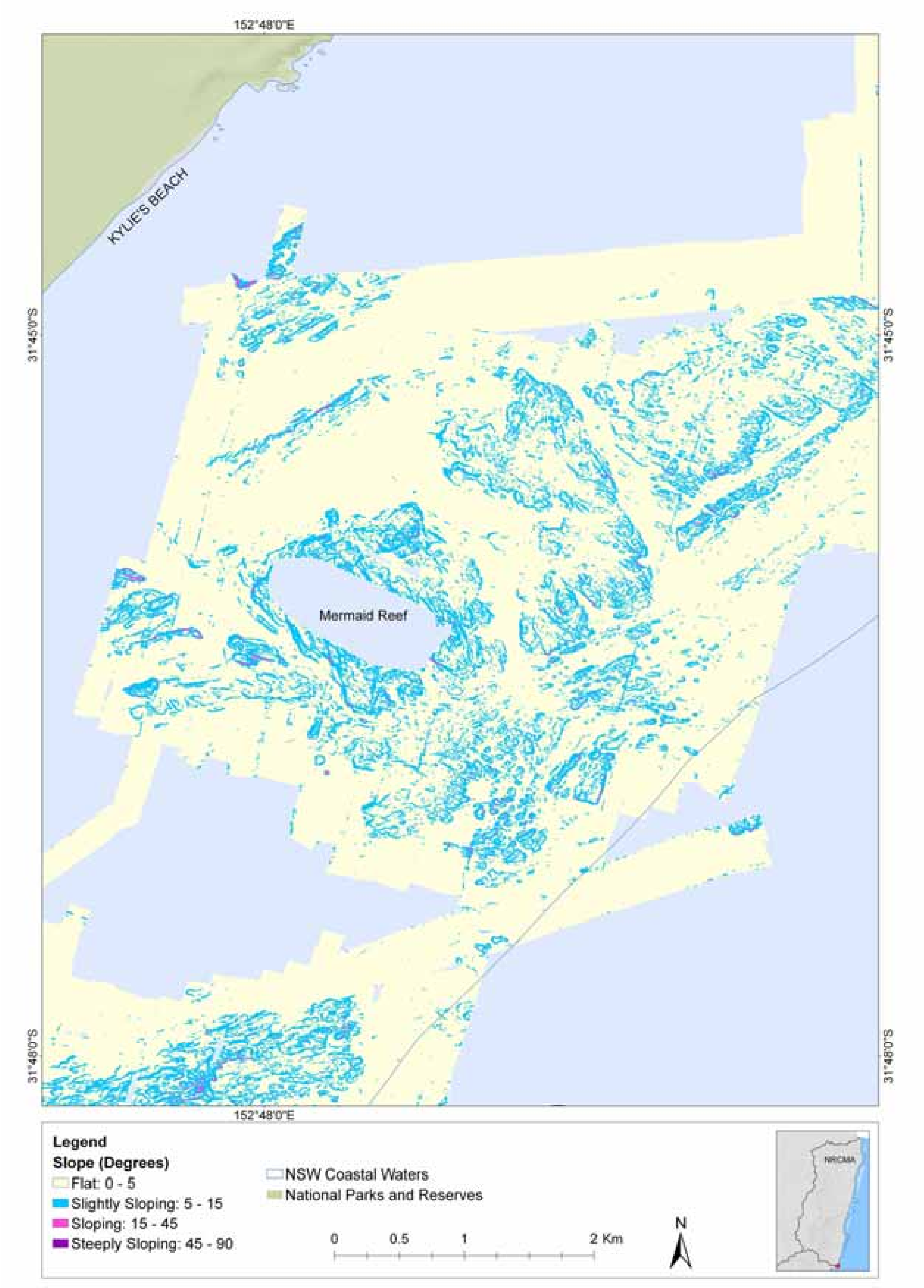


Figure 72. Slope model of the seabed offshore of the region between Perpendicular Point and Diamond Head.

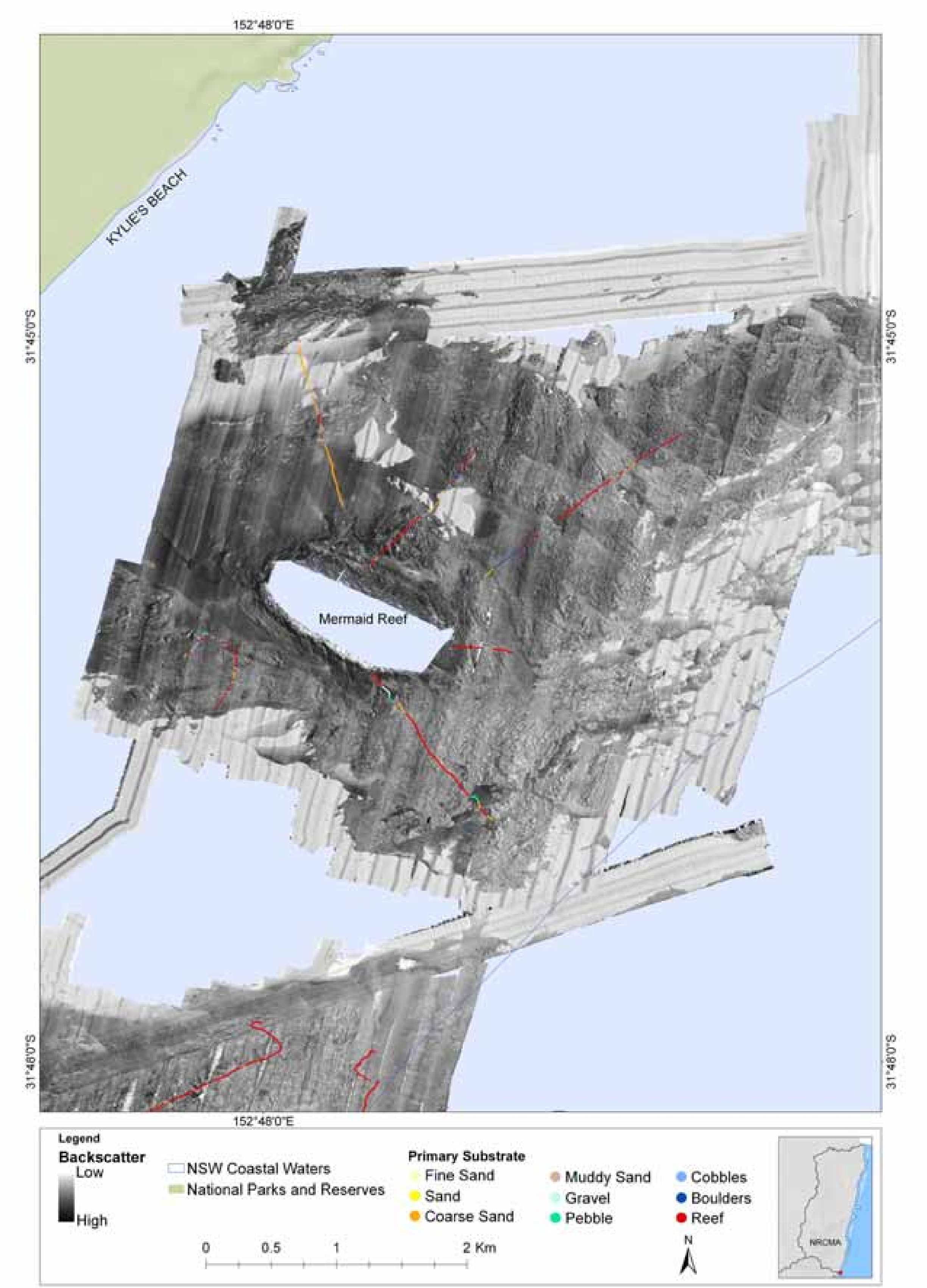


Figure 73. Acoustic backscatter of the seabed of the Mermaid Reef region offshore of Crowdy Head.

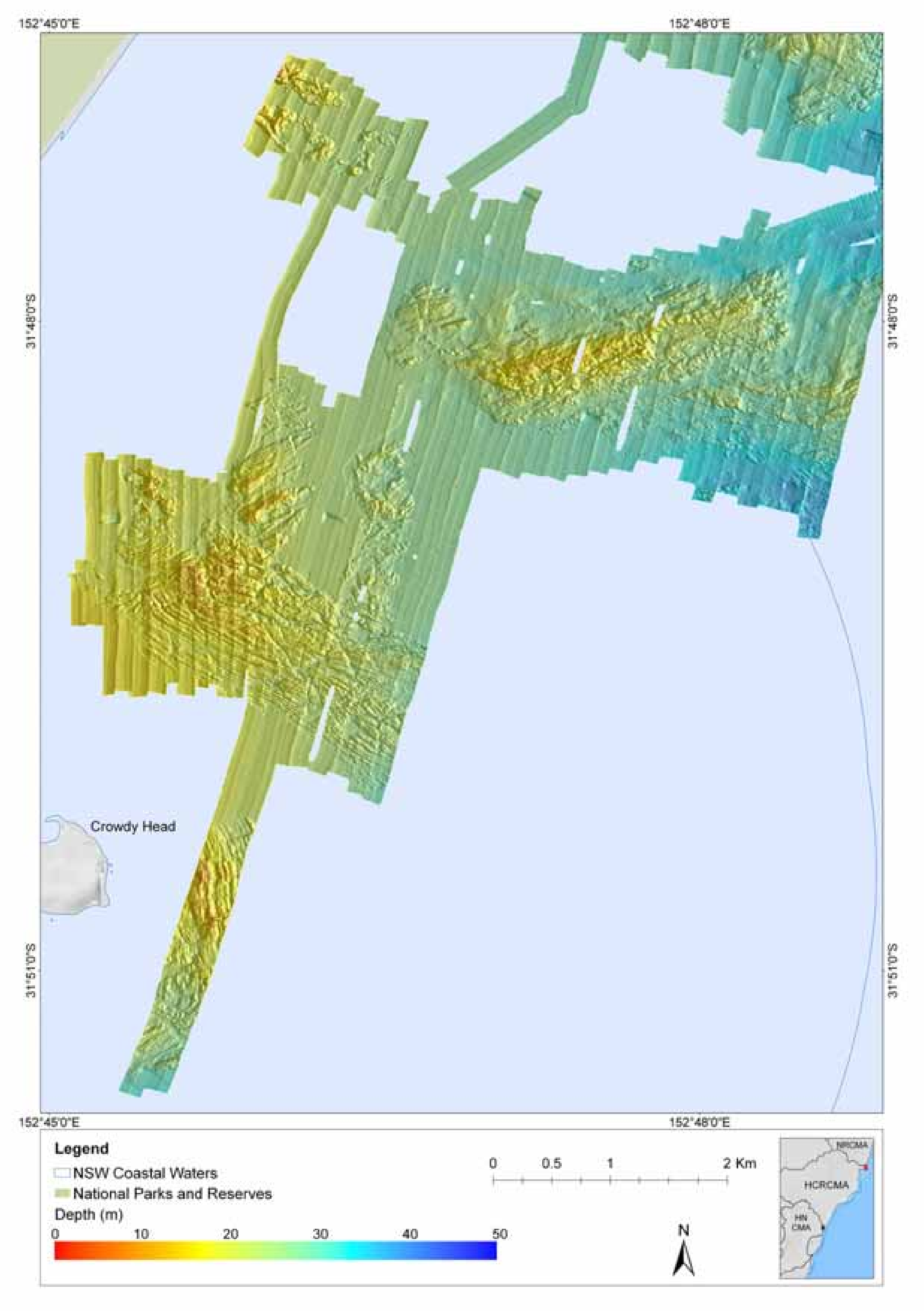


Figure 74. Hill-shaded bathymetric model of the seabed from the Giles Shoal and Curphy Shoal regions.

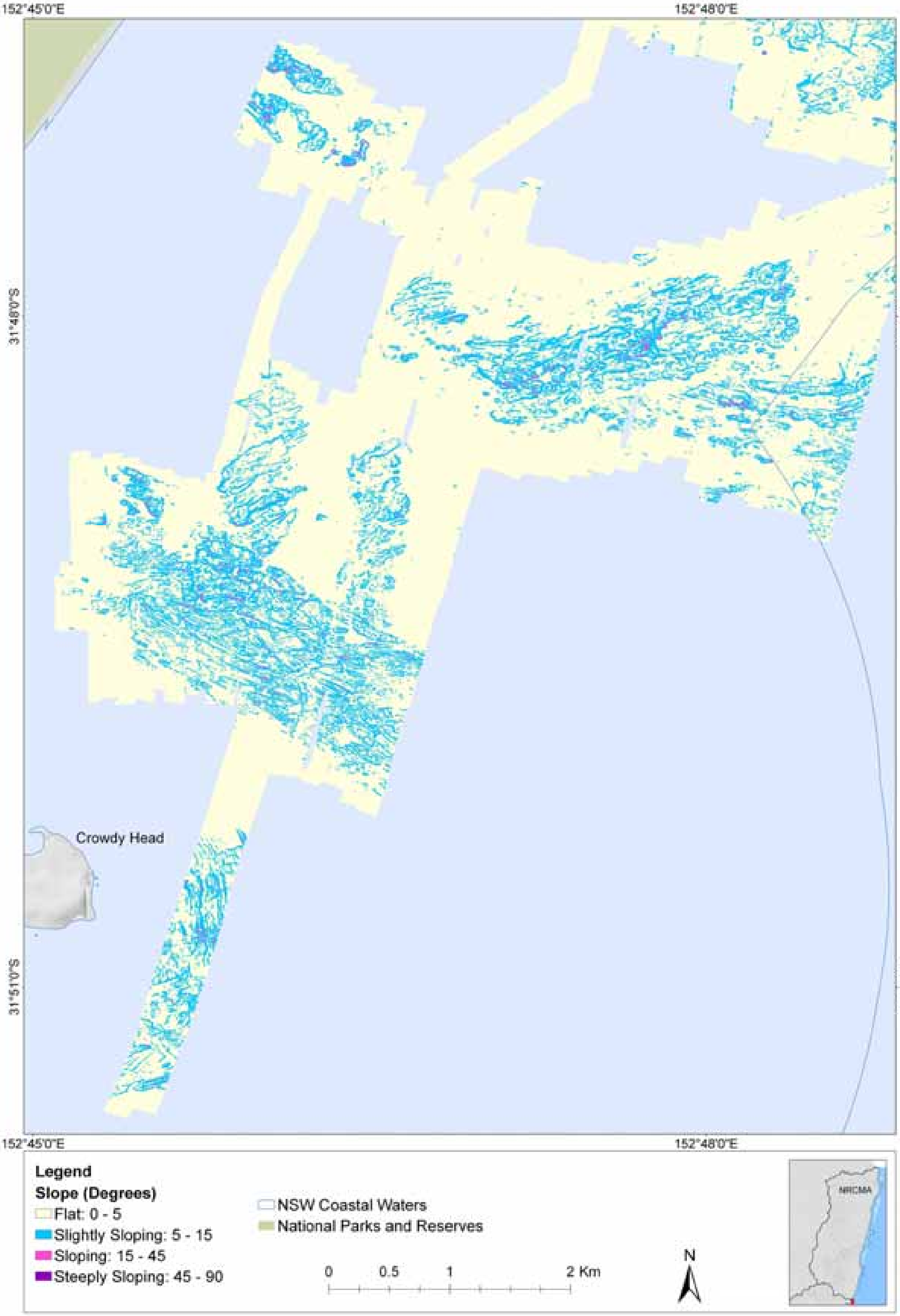


Figure 75. Slope model of the seabed of the Giles Shoal and Curphy Shoal regions offshore of Crowdy Head.

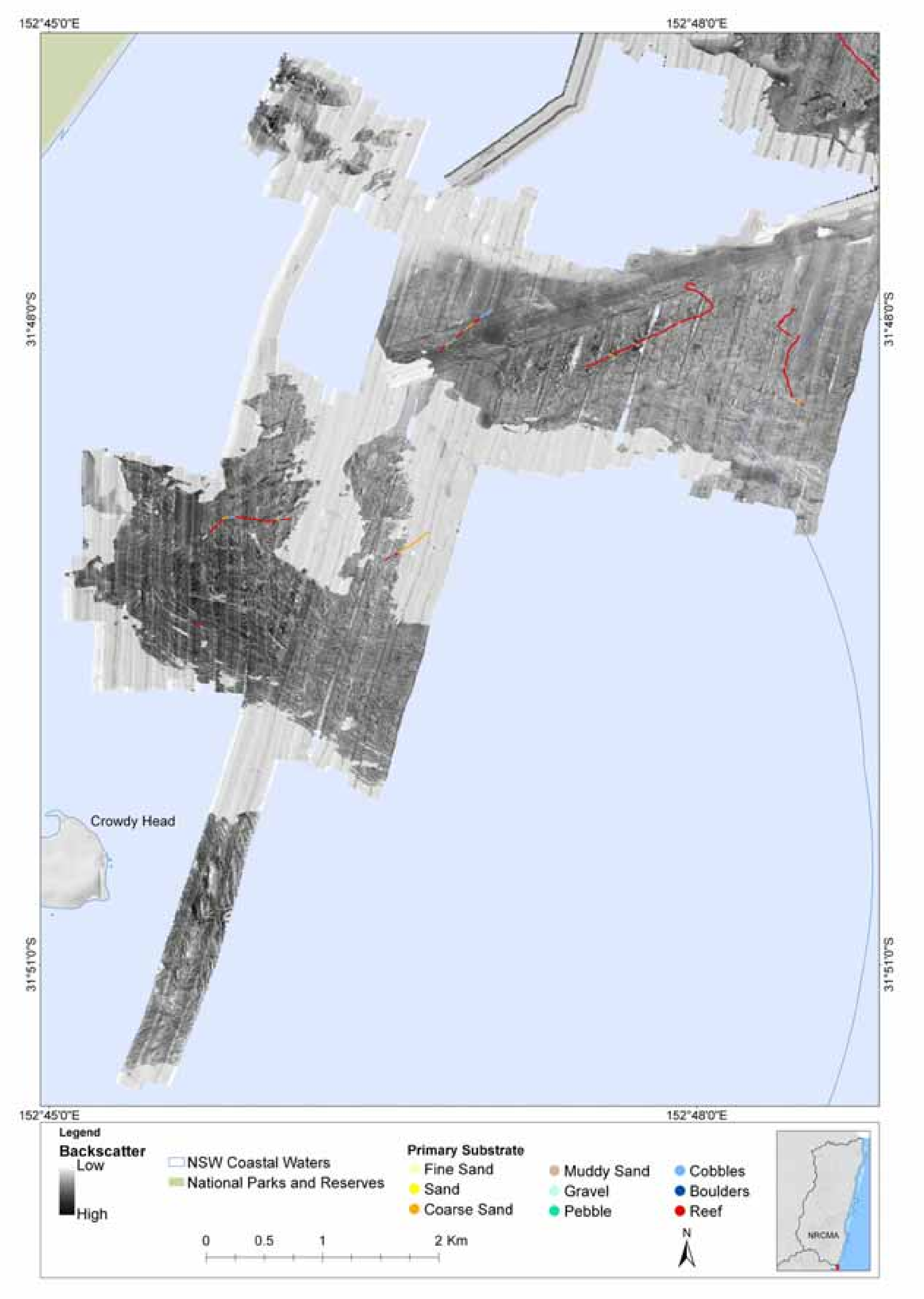


Figure 76. Acoustic backscatter of the seabed from the Giles Shoal and Curphy Shoal regions.

Video surveys at the Cod Grounds showed that in physical terms, the reef was dominated by high profile continuous bedrock reef and boulders. Biologically, sponges, particularly encrusting and massive sponges, were abundant in reef areas at depths between 30 to 55 metres (Figures 77 and 78). Erect and branching sponges were usually found at depths greater than 35 metres. Sea urchin barrens, typified by the presence of the long-spined sea urchin *C. rodgersii*, were relatively common at depths between 25 to 30 metres. Ascidians (most likely *P. spinifera* and *Sigillina* sp.) were observed at depths of 30–40 metres. Assemblages of mixed brown algae were common on reef areas, particularly in areas of low profile reef at depths shallower than 40 metres (Figure 79). Kelp (*E. radiata*) was not recorded in any video transects at the Cod Grounds.

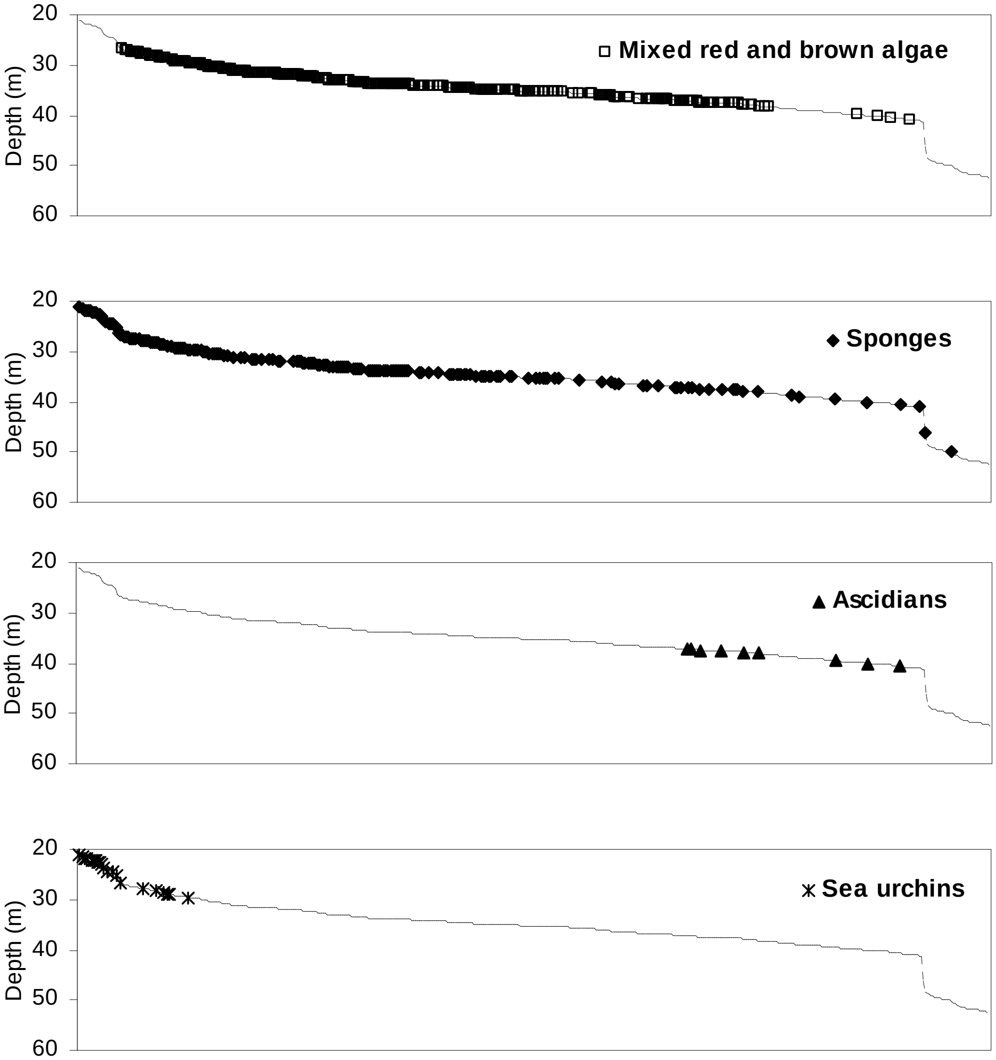


Figure 77. Presence of biota types along video transects at the Cod Grounds.

Figure 78. Reef habitat at Cod Grounds showing boulder reef with some encrusting sponges and mixed algal assemblages.

Figure 79. Unconsolidated habitat at Cod Grounds consisting of mixed cobbles and sand. Note the ascidian *Sigillina* sp. (a) and algal assemblages (a–c).

A total of 13 video transects were conducted along approximately 16 linear kilometres at Mermaid Reef, Curphy Shoal and Giles Shoal at depths of 11–35 metres. Because these reefs were connected as part of a larger reef system they were grouped for analysis. Much of the reef surveyed in these areas was covered by mixed algal assemblages and sponges (Figure 80). The only notable exception to this was observed in sections of shallow reef (10–20 metres), where sea urchin barrens (Figure 81) or large stands of *E. radiata* (Figure 82) dominated. *E. radiata* canopy cover appeared to be greater in the shallower range (10–15 metres) of its distribution. The stalked ascidian, *P. spinifera*, was common at all locations, especially in areas of high profile reef (Figure 83).

Unconsolidated habitats were composed of combinations of sand (predominantly coarse sand mixed with shell fragments), cobbles and boulders. All unconsolidated habitat observed was in low profile areas where the vertical relief was less than 1 metre over a distance of 10 metres. Sand habitats were dominated by coarse sand with waves and ripples in the surface structure. Shell particles were common in troughs between wave and ripple crests. Mixed algal assemblages were common in unconsolidated habitats that contained pebbles and/or cobbles and boulders. Sponges were less abundant in unconsolidated habitats compared to reef habitats; however, erect and branching sponges were recorded growing on individual rocks in areas of unconsolidated sediments at depths greater than 25 metres. Sessile ascidians (most likely *Sigilinna* sp.) (Figure 84), hydrozoans and gorgonians were observed in unconsolidated habitat dominated by cobble at depths greater than 20 metres.

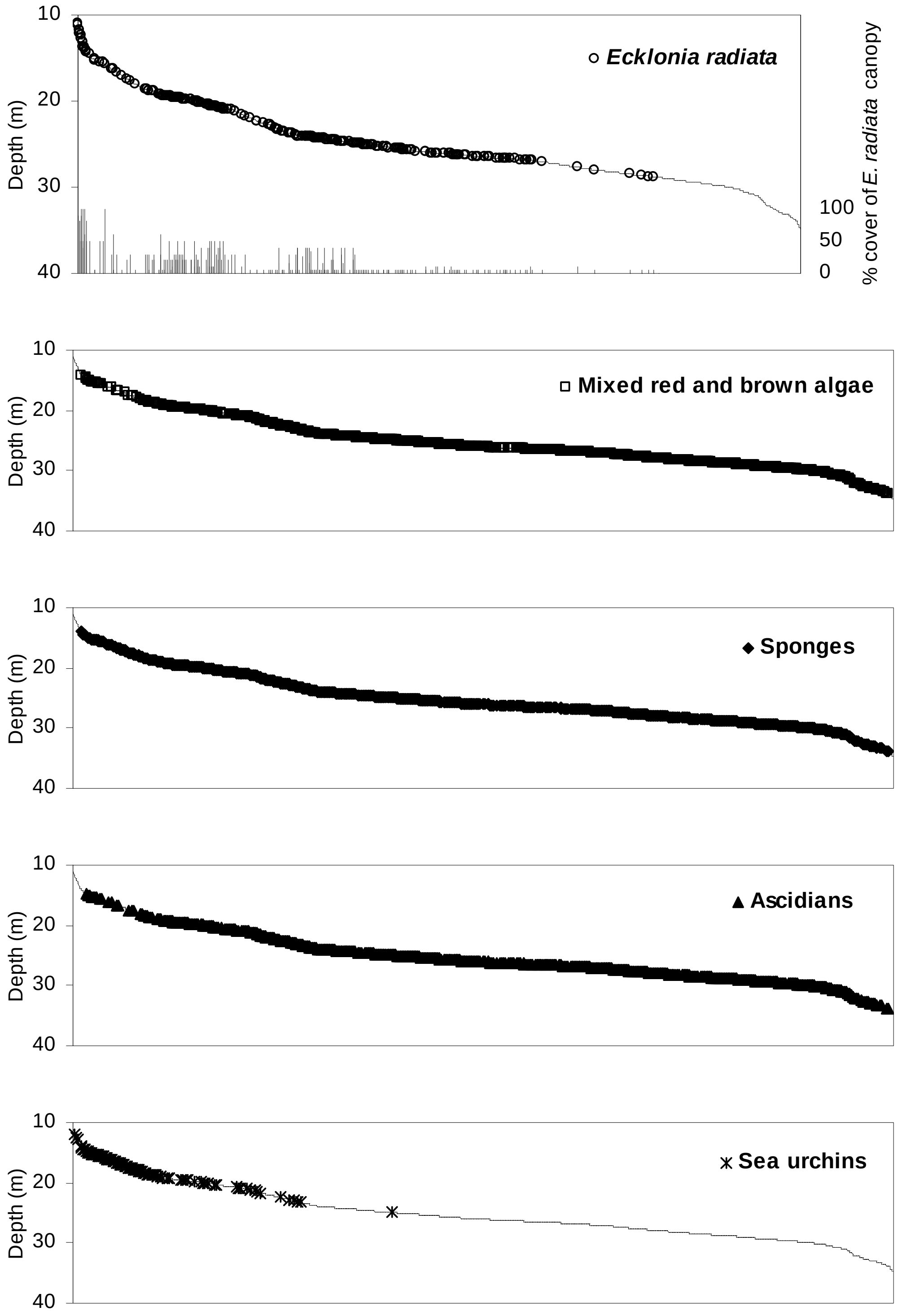


Figure 80. Presence of biota types along video transects at Mermaid Reef, Curphy Shoal and Giles Shoal.

Figure 81. Sea urchin barrens were a dominant habitat at Mermaid Reef (a) and (b), and Curphy Shoal (c).

Figure 82. Kelp (*E. radiata*) dominated the habitat at Giles Shoal (a) Mermaid Reef (b) and Curphy Shoal (c).

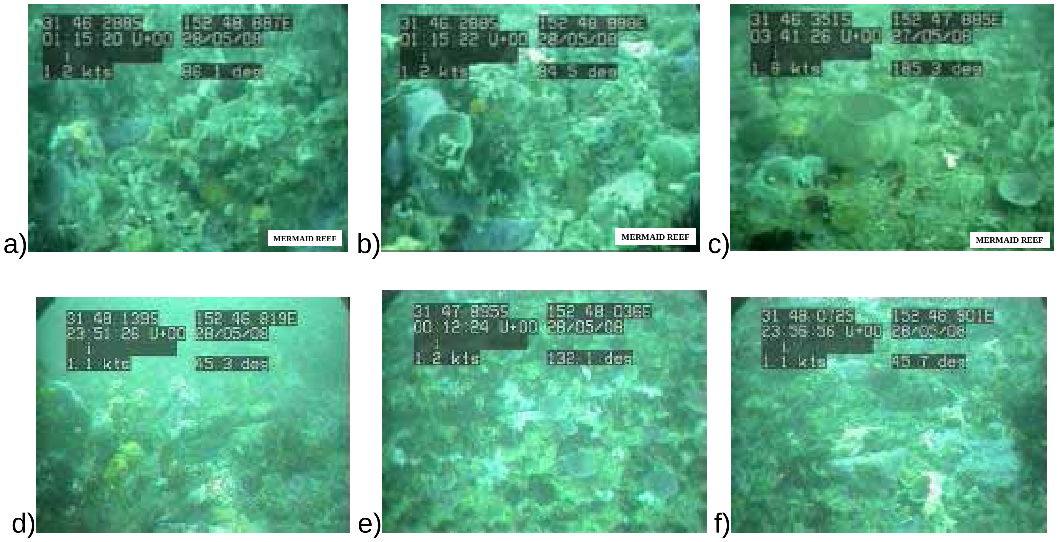


Figure 83. Sponge-dominated habitat at Mermaid Reef. Note the presence of *P. spinifera* (d) and mixed brown algae amongst cup sponges (e).

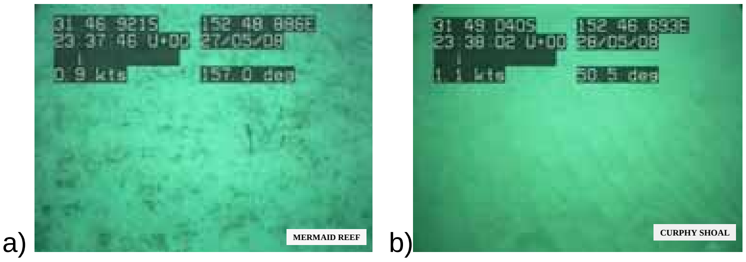


Figure 84. Mixed cobble and sand habitat with ascidian *Sigillina* sp. at Mermaid Reef (a) and sand with ripples near Curphy Shoal (b).

4.3.7 Crowdy Head to Seal Rocks

The section of coast from Crowdy Head to Seal Rocks was characterised by several large reef systems separated by a number of long (greater than 8–10 kilometres) sandy beaches (Figure 85). The first of these reefs extended from the shoreline adjacent to Black Head and Hallidays Point offshore and to the north-east for up to 10 kilometres. It is likely that this reef system is continuous with the nearshore reef mapped further north at Old Bar and offshore at Dennis Shoal. There was also evidence in the broadscale bathymetry that this reef system extended several kilometres north of Dennis Shoal. The largest and shallowest of the main reef systems in the area surrounded an area known as Snapper Rock, located about 6 kilometres north-east of Hallidays Point (Figure 85). This reef was around 12 metres deep at its shallowest point with only small sections of the adjacent reef area surveyed extending to intermediate depths (Figure 86). The entire reef system consisted of a series of large areas of bedrock with smaller patchy reefs at a number of spatial scales. There was no evidence of an increase in patchiness with increased distance from shore; however, the eastern extent of the reef was likely to extend beyond the current survey coverage. Many areas of continuous reef were 1–2 kilometres across and rose up to 20 metres from the surrounding seabed. Much of the reef consisted of a series of gutters running north-west/south-east through the area, which are formed by the tilted and folded rock strata. These gutters were up to 5 metres deep, with the bottom of the gutters covered with cobble, gravel and coarse sand. The reef system was mostly low profile with an average rise of around 4–6 metres from the surrounding substrate, with the steeper sections mostly restricted to the middle of the reef complexes (Figure 87).

There was no specific boundary to this reef system because of the large areas of continuous reef connected by areas of patchy reef throughout the region. Reef continued offshore in gradually increasing depths to around 30 metres. The reef system at Black Head was considerably larger than that currently mapped for the area. Additional reef was surveyed inshore, offshore, and to the north of that identified in broadscale bathymetry. The unconsolidated habitats surrounding the reef complex offshore of Black Head consisted mostly of a combination of fine and coarse sand (Figure 88). Coarse sand tended to dominate the large areas between the reef systems, with finer sand occurring further from the reef edge, although this tended to be inconsistent and occurred more frequently on the north side of reef areas. A gradation from fine to coarser sands occurred on the south boundary of many of the larger reef patches, seen as a darkening of the backscatter extending out from the reef edge. In many places close to the edge of the reef, video footage revealed that unconsolidated areas also contained varying amounts of cobbles, boulders and pebbles that also resulted in higher backscatter values.

From several kilometres south of Black Head to Forster there was little evidence of shallow nearshore or offshore reefs (Figure 85). A narrow section of shallow nearshore reef, that was mostly continuous and less than 100 metres wide, was present between the Forster breakwater and the northern end of Seven Mile Beach. The only location where reef extended further offshore was at Latitude Rock where shallow reef extended up to about 400 metres from shore. Overall, the bedrock between Sugarloaf Point and Forster was dominated by siltstone that formed many small subtidal reefs along this section of coast, although south of Forster few appeared to extend more than 100–200 metres offshore.

The only large mid-shelf reef was at The Pinnacles, an isolated reef located about 2 kilometres due east of Cape Hawke south of Forster (Figure 85). Swath-mapping revealed mostly intermediate reef extending for 4 kilometres around a shallower area identified in the broadscale bathymetry. The main reef ran almost east-west with a smaller pinnacle present on the southern side and extensive reef extending to depths of around 50 metres (Figure 89). The majority of the reef had a fairly low profile, although it rose slowly about 10 metres from the surrounding substrate on either side of the major peak (Figure 90). The swath bathymetric data also revealed considerable variations in the geomorphic structure of the reef, with continuous reef grading to patchy reef in the north-east, distinct linear features with gullys between them to the south, and patchy reef in the north-west. Video analysis also showed there were considerable areas of cobbles and boulders present within the reef system itself. The unconsolidated habitats surrounding The Pinnacle reef appeared mostly uniform and primarily consisted of a combination of fine and coarse sand (Figure 91). The coarse sand tended to dominate the areas closer to the edge of the reef where the seabed interspersed with varying amounts of boulders. To the south-east of the surveyed area there was a large area of coarser sediments with darker backscatter. To the north east and south-east of the reef, there were linear sand features highlighted by changes from low to moderate backscatter intensity. To the north-east these seemed to be depressions of less than 1 metre in a predominantly finer sandy substrate within which coarser sediment had settled. To the south-east the backscatter intensity was marginally higher than the north-east and hence was predominantly a coarser sandy substrate. The lighter linear features were indicative of rises in the bathymetry that were composed of finer sand than the surrounding substrate.

A small isolated reef that was entirely restricted to intermediate depths was identified 3.5 kilometres offshore of Seven Mile Beach (Figure 85). A number of other smaller reefs were evident between Seven Mile Beach and Sugarloaf Point, only some of which were swath mapped. The most prominent of these was Skeleton Rocks, which was located approximately 3 kilometres north-east of Sugarloaf Point and extended above mean sea level. An isolated reef was also mapped several kilometres south-east of Skeleton Rocks, and this consisted of a very small shallow section and a large area of intermediate reef that was about 500 metres wide.

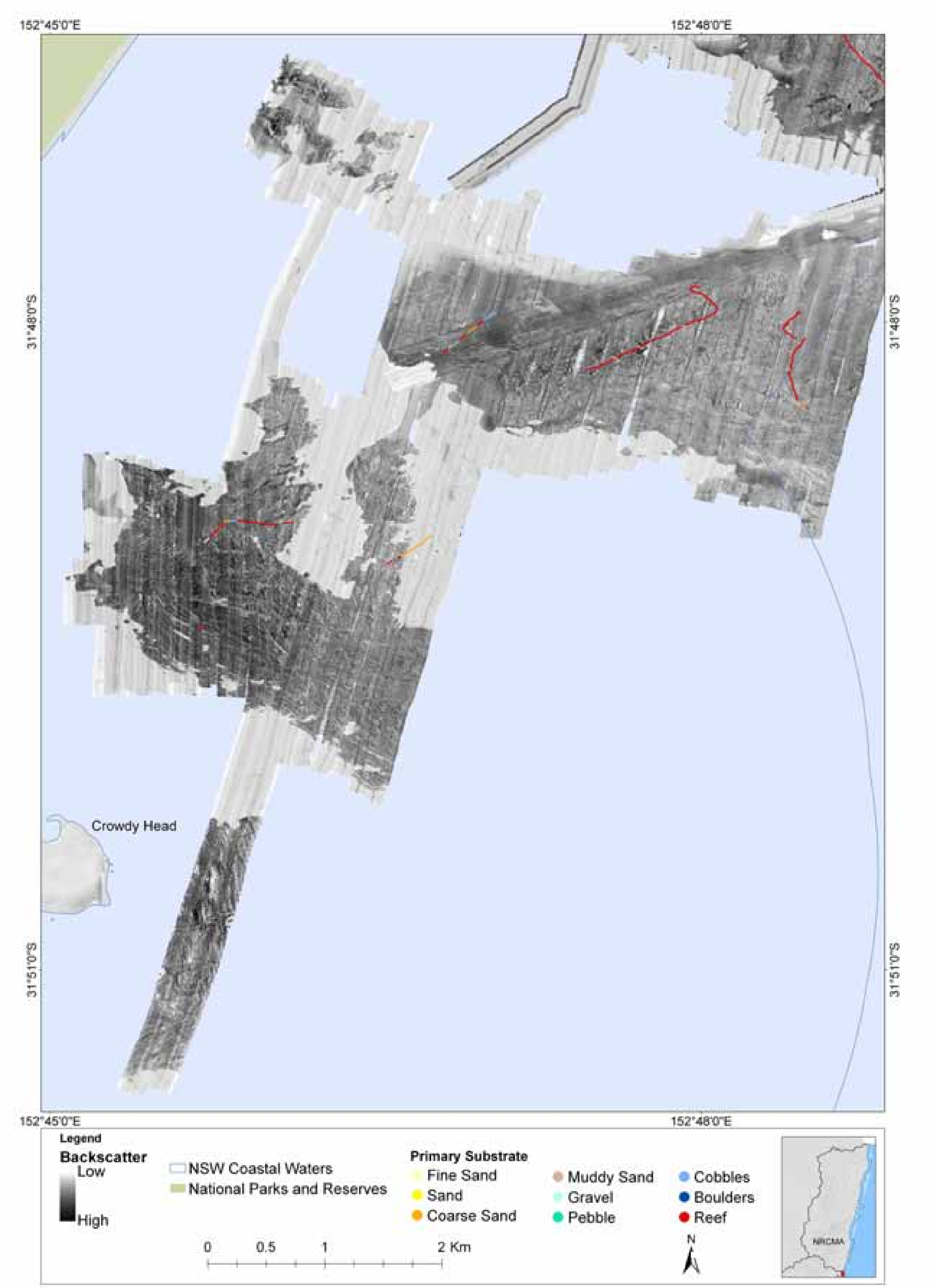


Figure 85. Distribution of known seabed habitats within the Crowdy Head to Seal Rocks region.

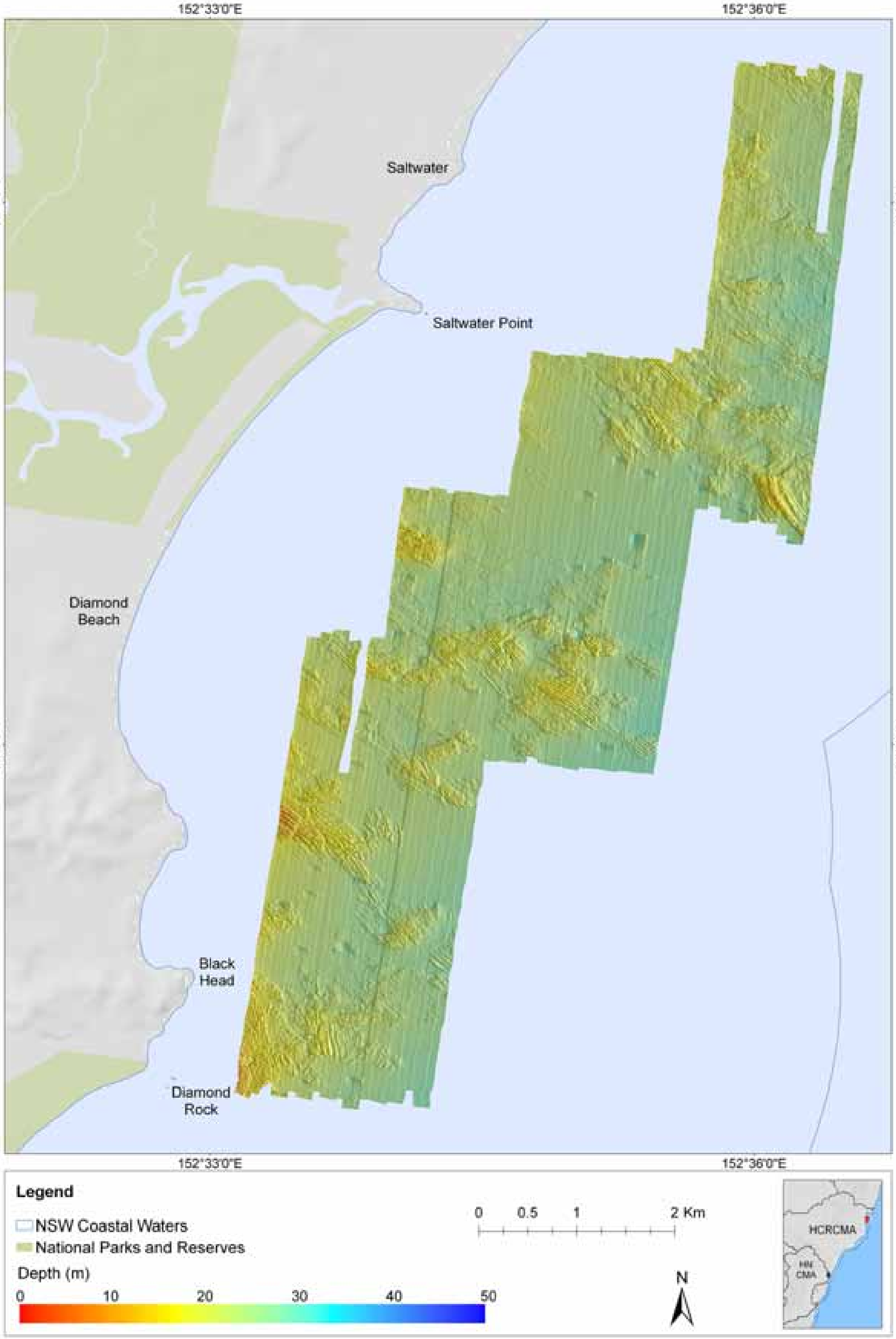


Figure 86. Hill-shaded bathymetric model of the seabed offshore of the Black Head region.

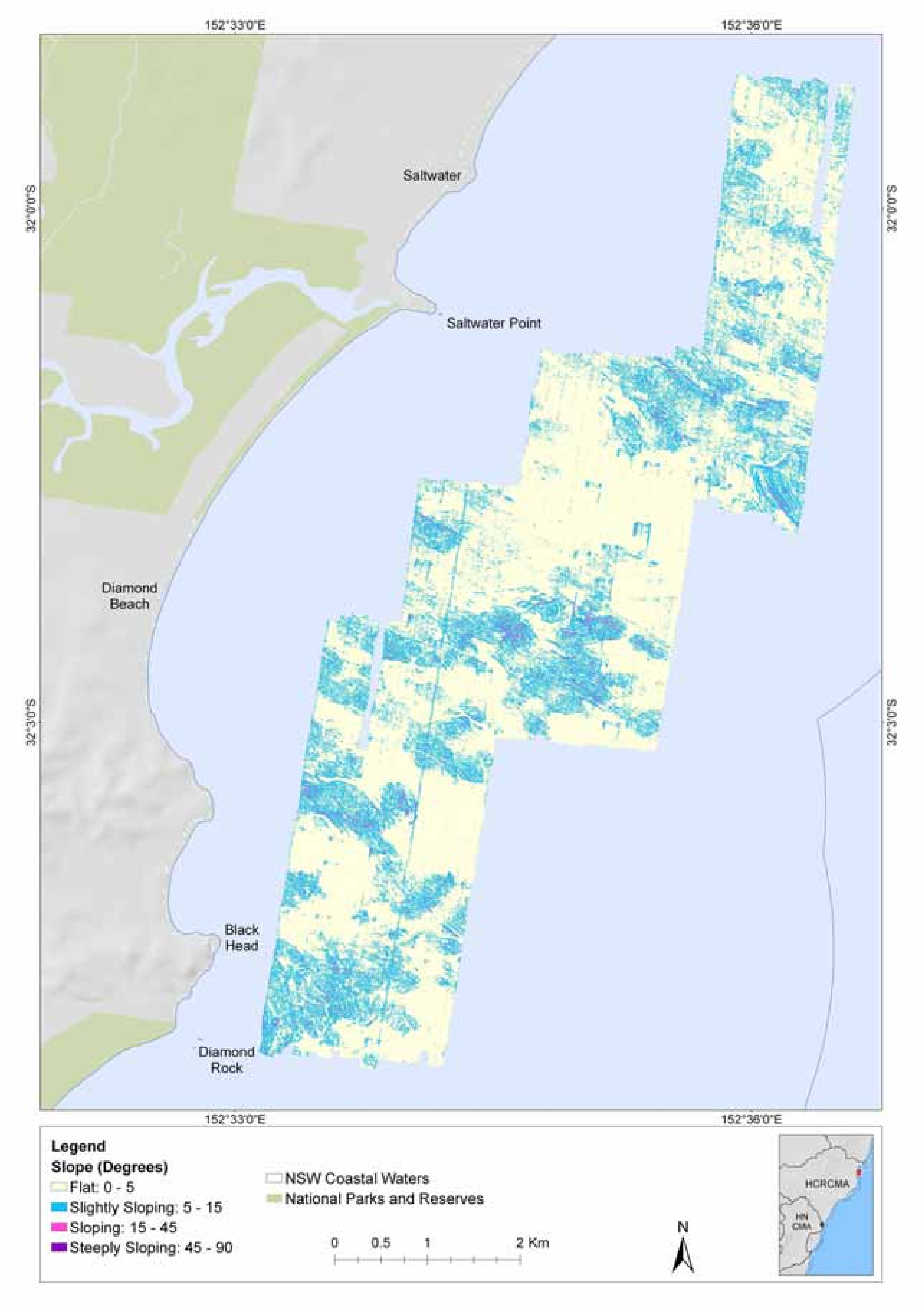


Figure 87. Slope model of the seabed adjacent to the Black Head region.

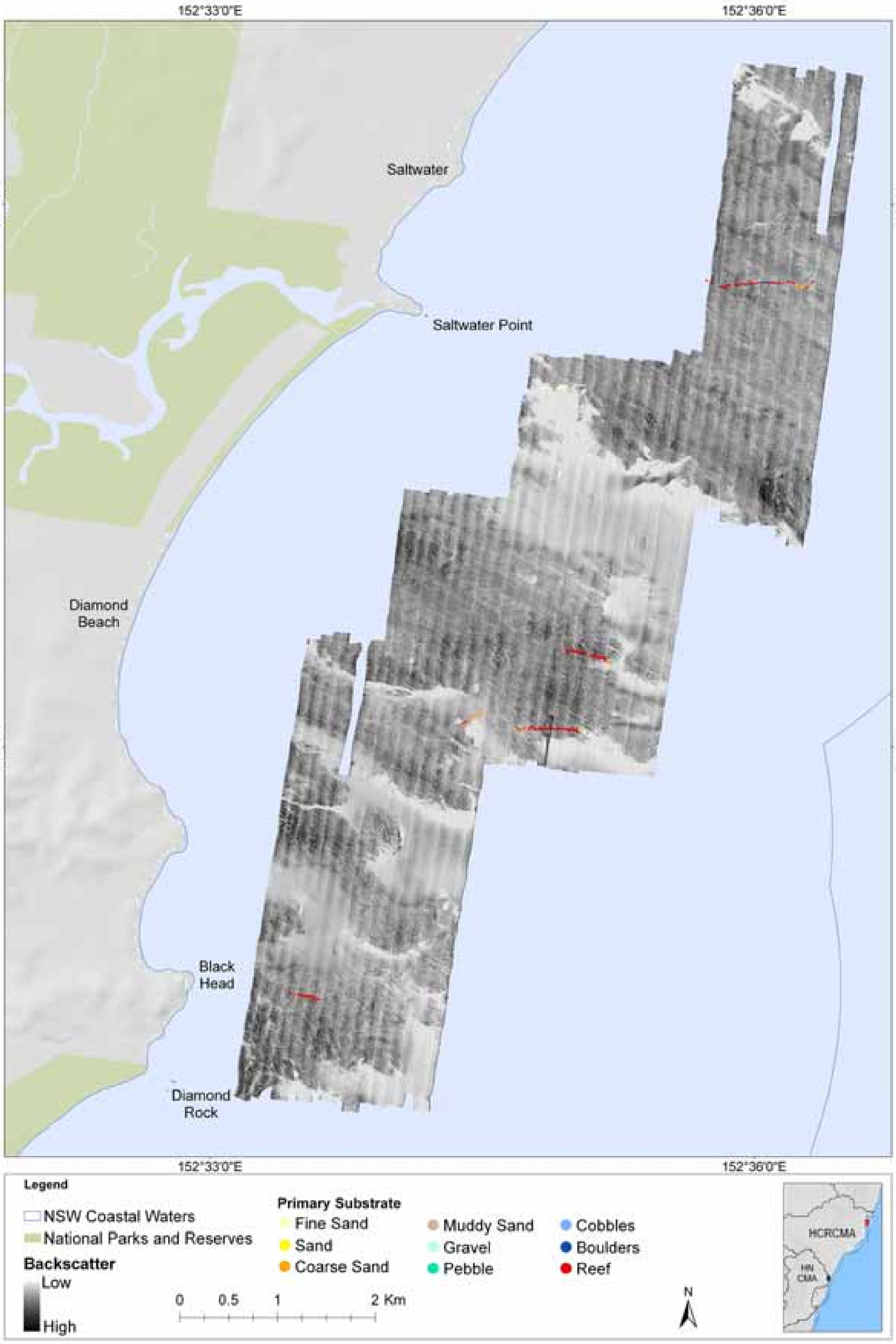


Figure 88. Acoustic backscatter of the seabed within the Black Head region.

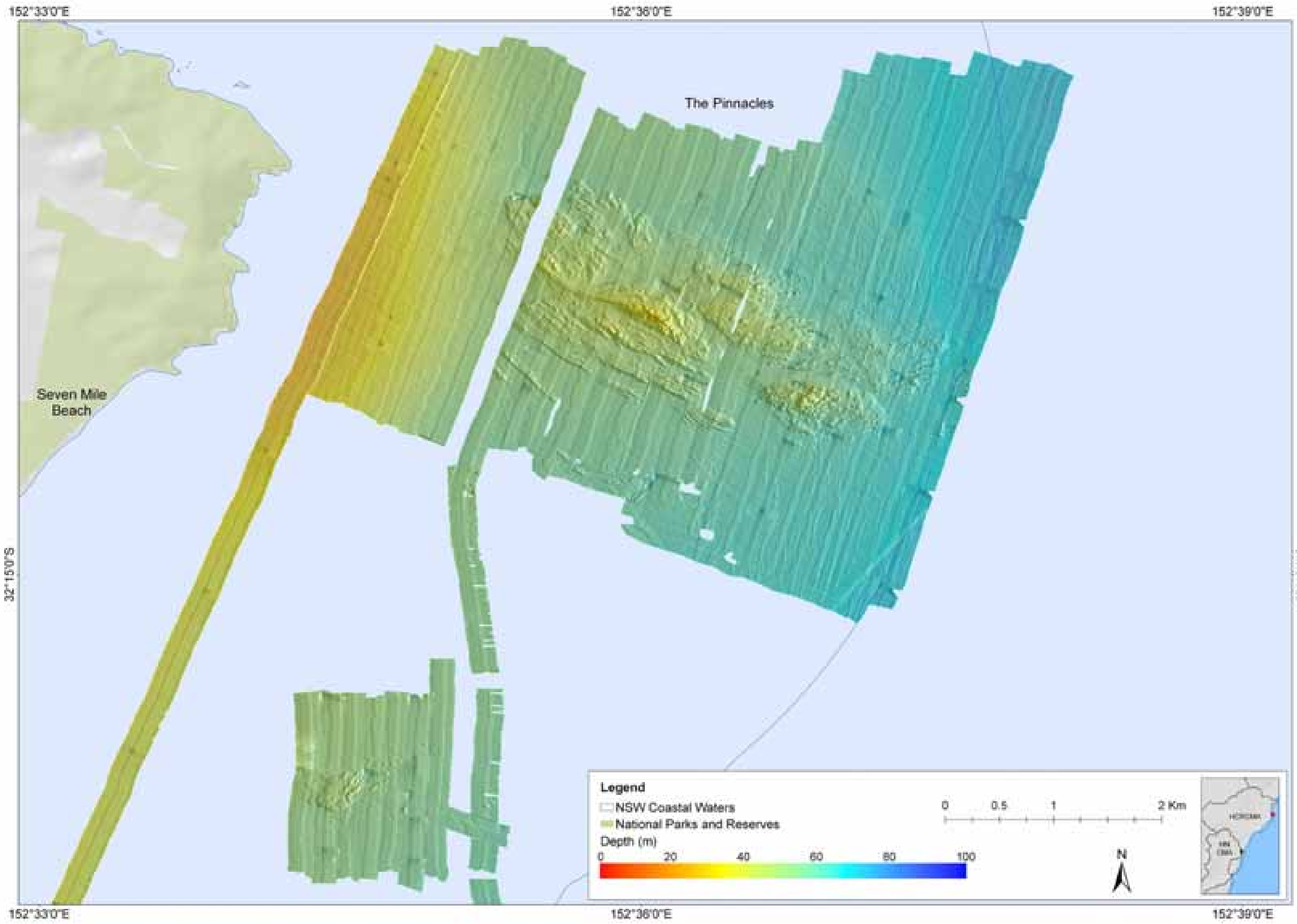


Figure 89. Hill-shaded bathymetric model of the seabed of The Pinnacles region.

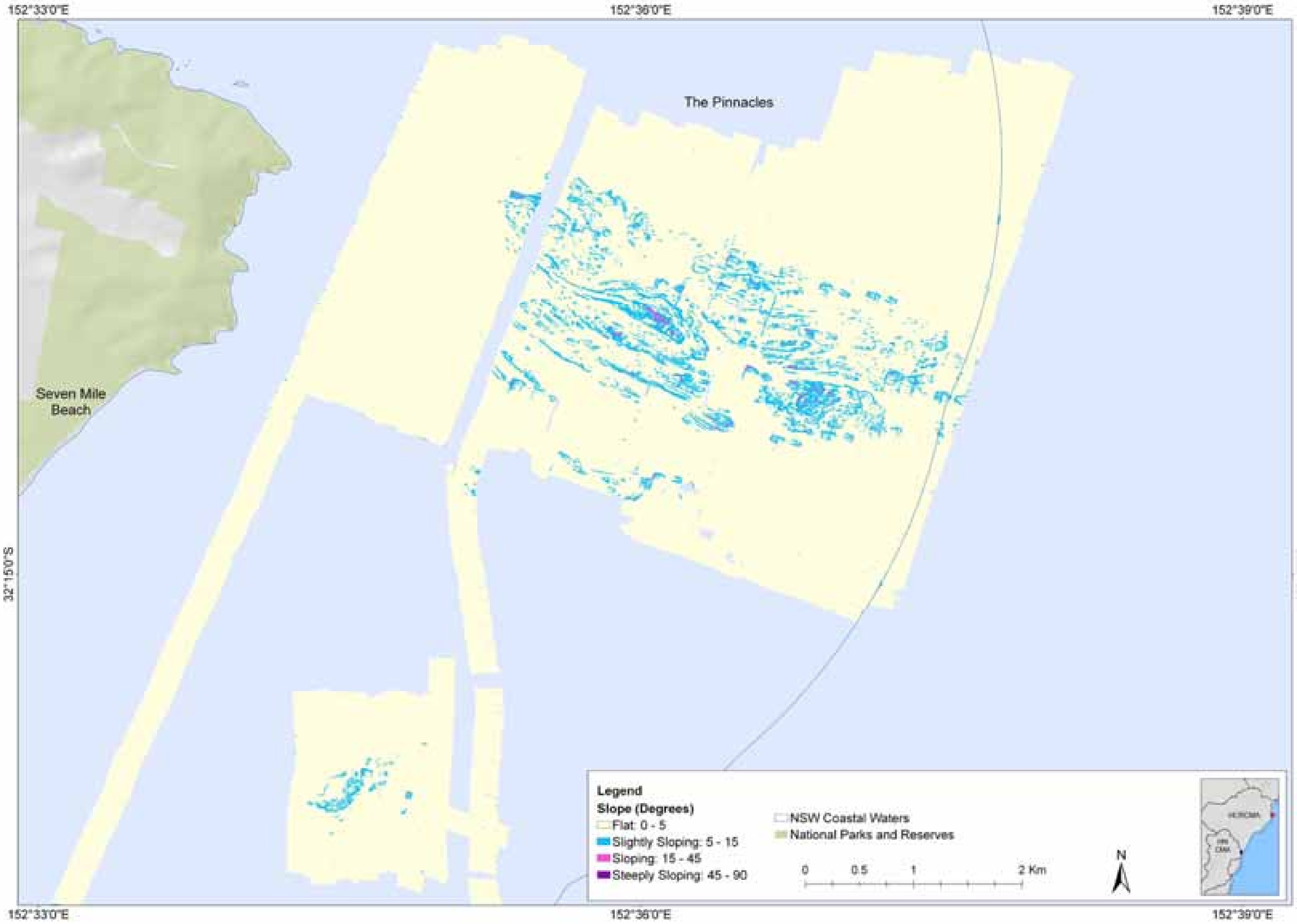


Figure 90. Slope model of the seabed surrounding The Pinnacles region.

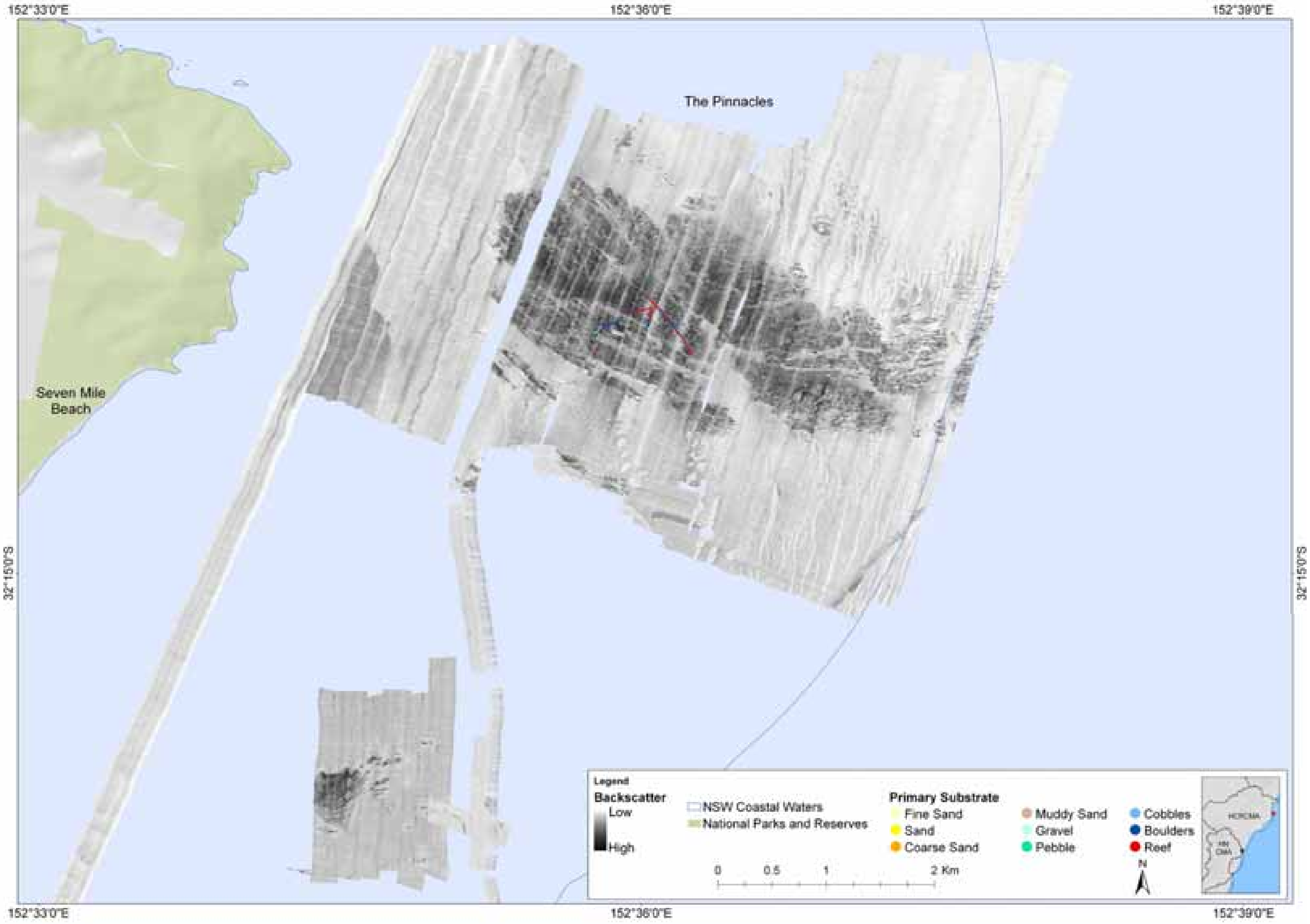


Figure 91. Acoustic backscatter of the seabed surrounding The Pinnacles region.

Video surveys from the reefs offshore of Black Head revealed the relatively shallow (15–25 metres) continuous reefs and areas of mixed reef and sand were dominated by a mosaic of *E. radiata*, mixed red and brown algal assemblages and sponges (Figure 92). *E. radiata* occurred between 13 and 27 metres, and reached the highest densities and cover at 20–25 metres (Figure 93). Ascidians, including *P. spinifera* and *Sigillina* sp., were patchily distributed at depths of 17–27 metres. *P. spinifera* was generally found amongst sponges in areas of high relief, whereas *Sigillina* sp. was more common in sandy areas between patch reefs or cobble areas. Sponges were relatively dense, with widespread sections of reef at depths of 20–27 metres almost entirely covered by a mosaic of erect, massive, branching and encrusting sponges and other sessile filter feeders such as bryozoans and gorgonians (Figure 94). Inadequate image resolution and inherent difficulties in identifying most sessile invertebrates resulted in classifications being restricted to the dominant groups in Figure 92.

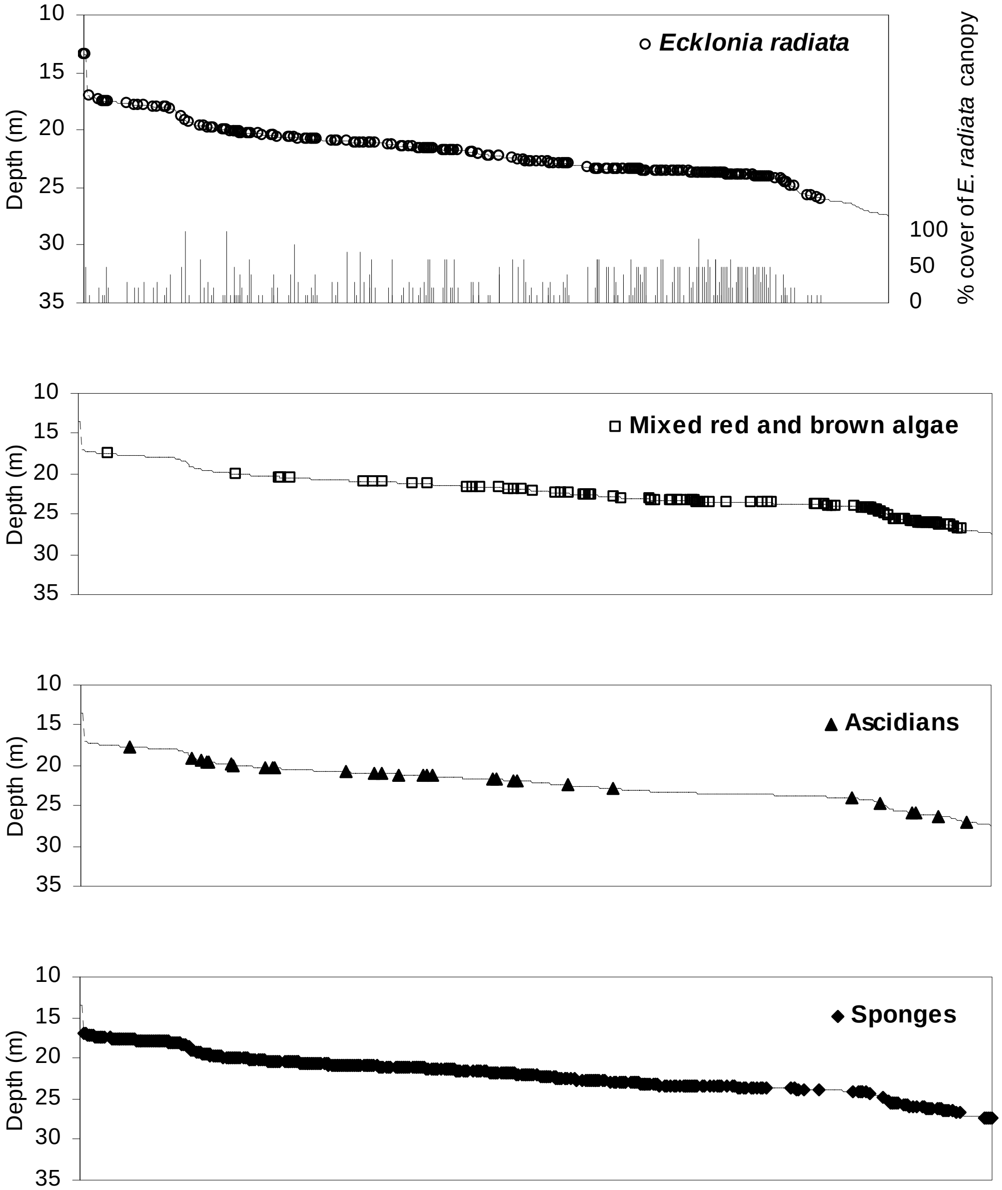


Figure 92. Presence of biota along video transects offshore from Black Head.

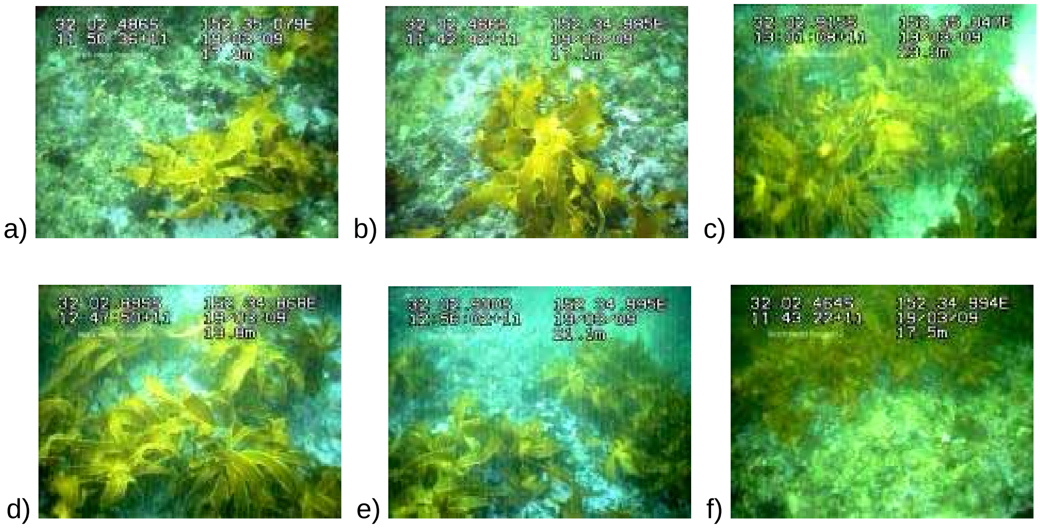


Figure 93. Kelp (*E. radiata)* and mixed algal assemblages on nearshore reefs at Black Head.

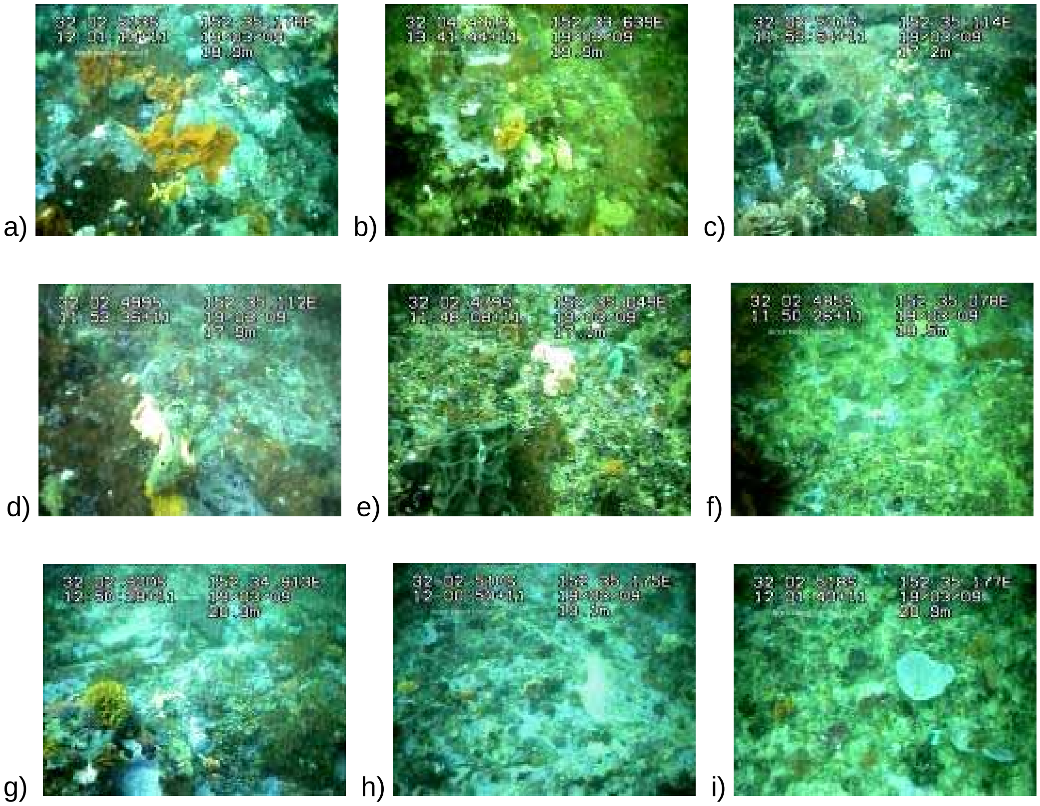


Figure 94. Sponge-dominated benthic assemblages on reefs offshore from Black Head.

Reef habitat at The Pinnacle was dominated by high-profile reef, with patchy boulder and reef outcrops interspersed with sand veneer patches and coarse sand and cobble- or boulder-filled gutters. Steeply sloping walls were common and found across all depths surveyed. Visually dominant biota on reefs consisted of mixed communities of sponges, gorgonians, ascidians (mainly *P. spinifera*), sea whips, mixed red and brown algae, and encrusting coralline algae (Figure 95). At depths shallower than 40 metres, mixed sponge and algal assemblages appeared dominant, whereas in reef areas deeper than 40 metres sponges became more dominant, with sea whips and gorgonians also abundant (Figure 96). Urchin barrens and *E. radiata* were not observed along video survey transects.

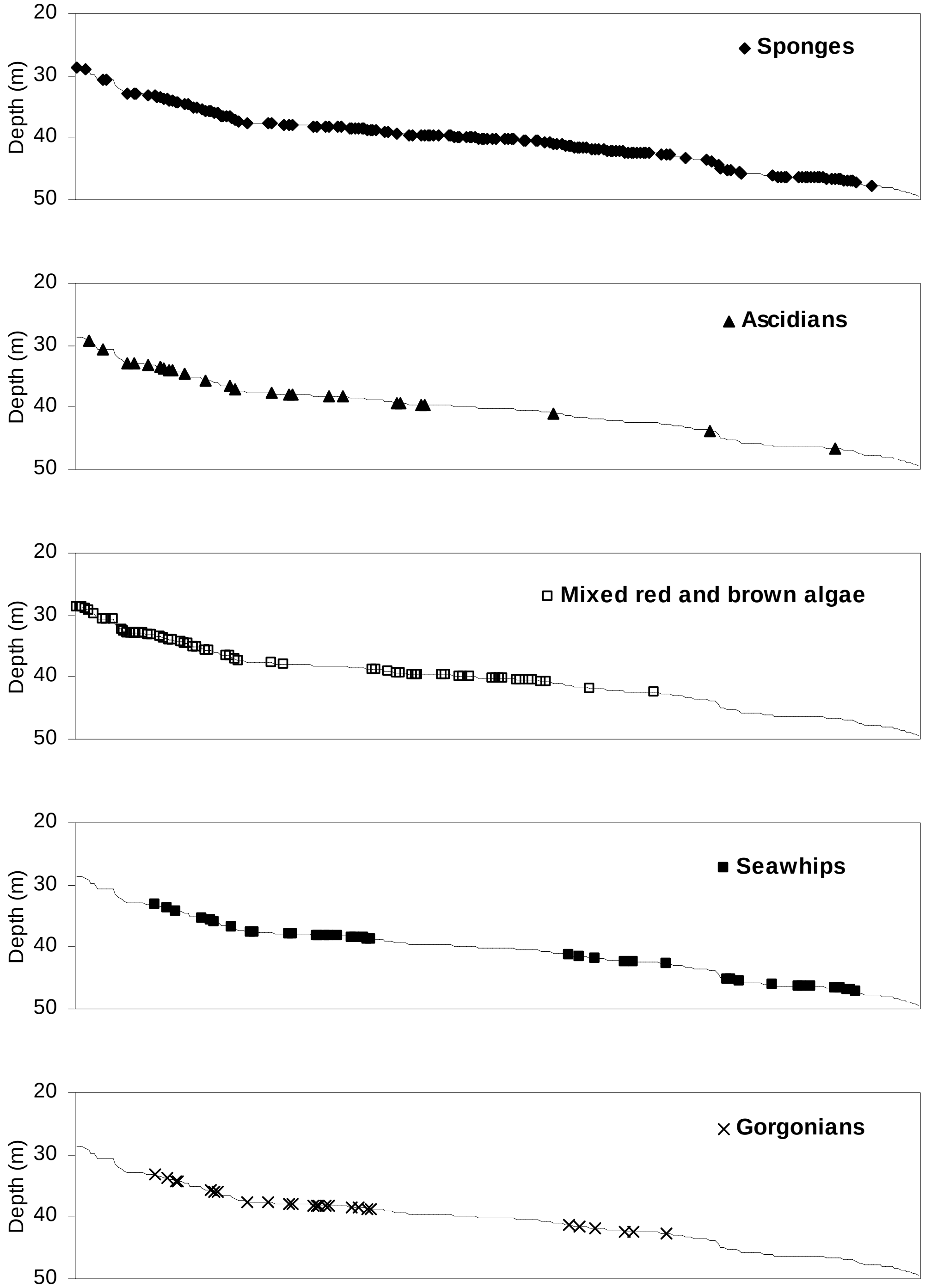


Figure 95. Presence of biota along video transects at The Pinnacle.

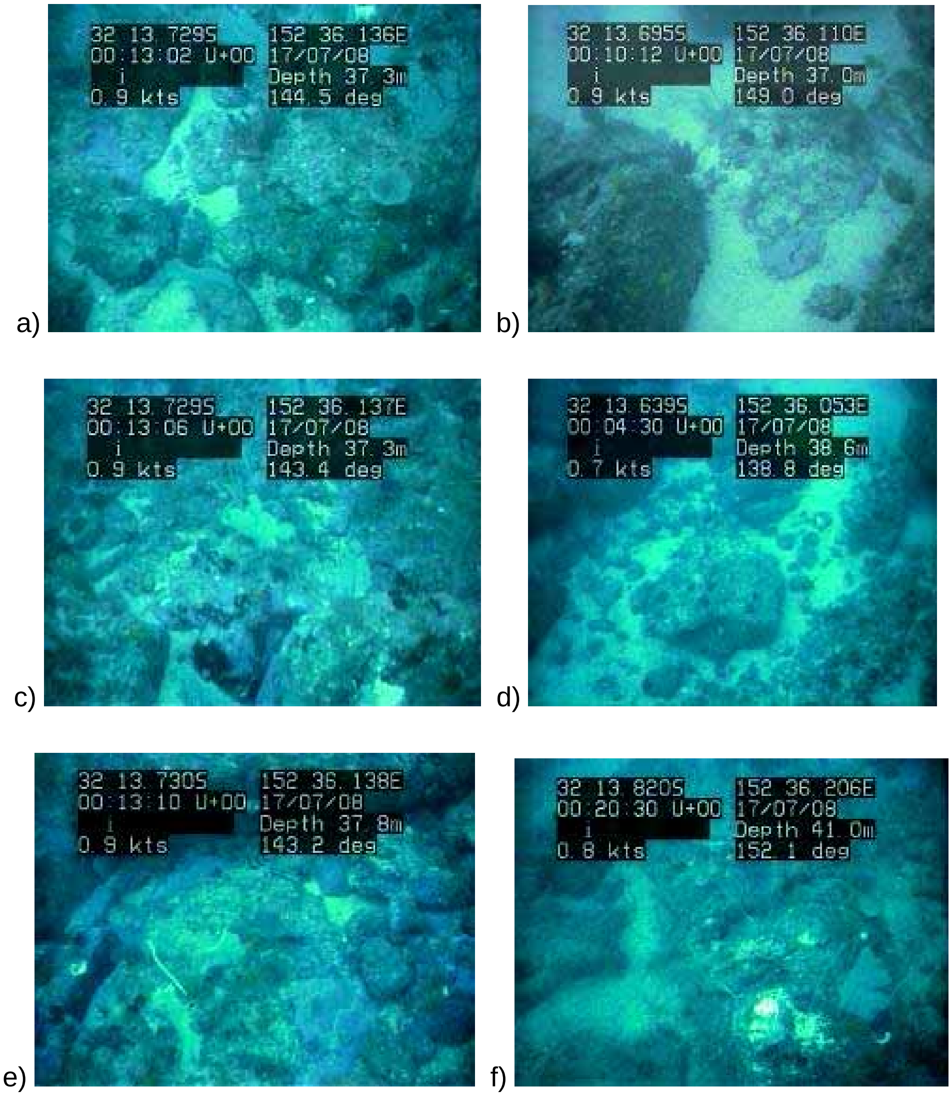


Figure 96. Boulder-dominated reef habitat at The Pinnacle supporting assemblages of sponges, gorgonians and sea whips.

4.3.8 Seal Rocks to Newcastle

The region between Seal Rocks and Newcastle was characterised by several distinct areas where bedrock outcrops on the inner shelf formed subtidal reefs and offshore islands. This included the islands and adjacent reefs around Seal Rocks, Broughton Island, Boondelbah and Cabbage Tree Islands, and the prominent headlands of Port Stephens, Yacaaba and Tomaree Heads (Figure 97). The section from Birubi Point to Tomaree Head was characterised by relatively steep rocky ridges adjacent to the intertidal zone separated by several bays and coves that varied in size and orientation. In many areas the bedrock extended some distance offshore forming large areas of subtidal reef.

Starting in the north, swath surveying in the Seal Rock s region covered a number of areas of rocky reef associated with well known features, including Edith Breaker, Little Seal Rocks and Seal Rocks (Figure 97). The reefs consisted of caves and pinnacles, large flat bommies, large boulders and steep drop-offs some at angles up to 53 degrees from the horizontal (Figures 98 and 99). There was also a large number of ridges and gutters on the reefs, most noticeably around the Edith Breakers area, oriented north-west/south-east. Many of the reefs extended to depths of about 40 metres, and several bommies rose to within 5 metres of the surface. Smaller areas of rocky reef were observed adjacent to the main headlands within the area, notably the reef extending 200 metres off the north of Sugarloaf Point and around the offshore island in Sugarloaf Bay, and the reef stretching over 600 metres south from Sugarloaf Point and surrounding Seagull Islands to the extent of the aerial photography. Further south the Big Gibber Headland continued as reef about 1 kilometre offshore to the south/south-east and was likely continue past its current mapped extent given the limitations of aerial photography.

Higher uniform backscatter intensity was seen adjacent to the reefs surveyed in this area, indicating coarser unconsolidated sediments settling closer to the reef (Figure 100). Edith Breakers and two reef patches to the south and east were joined by a pulse of coarser unconsolidated sediment. Directly to the east/north-east of Edith Breaker there was a section of lower backscatter intensity that occurred on a gentle slope (3 metres over a 400 metre distance) down to a distinct break. At this point the backscatter intensity increased (i.e. the backscatter darkened and there was a distinct change in slope up towards the reef feature). From the southern end of this reef section to the east/north-east there was a discernable sand-wave field of irregular curvilinear features characterised by coarser sediments in the troughs between each feature. A sharp change in bathymetry and slope direction showed that this field distinctly ended 250–600 metres to the west/south-west of Little Seal Rocks where a discrete boundary was present between the two unconsolidated grain sizes.

To the south subtidal rocky reefs were widely distributed around Broughton Island; however, the location and extent of all subtidal reefs have not been mapped, particularly those at depths greater than 60 metres (Figures 97 and 101). Much of the reef on the southern side of the island was continuous from the intertidal zone to depths of about 30 metres, with some areas extending to depths of 50 metres. Shallow and intermediate depth reefs, caves, tunnels, drop-offs and bommies were characteristic of the area. A very notable feature of the reefs in the Broughton Island area was the extent of intermediate reef that occurred in relatively sheltered waters. This was particularly apparent off the south-east of Little Broughton Island where continuous reef characterised by large gutters was present up to 1.2 kilometres offshore. Other reefs that occurred off the southern end of Broughton Island varied from this in their structure. The deeper section was characterised by large reef patches with deep gutters oriented mostly north-west/south-east. The shallow section included reef that was continuous to shore, deeply guttered but without a predominant orientation (Figure 102). These two sections of reef comprised a large complex reef system that extended into deep water close to shore. In contrast, reefs off the west and north of the island were mostly shallow (at depths less than 20 metres) and dominated by cobble and boulders in many places.

An area of higher intensity backscatter was observed around much of the reef in the Broughton Island area (Figure 103). Some noticeable unconsolidated sediment features were highlighted by distinct boundaries between uniformly lighter and darker areas in the backscatter image. To the south-west of Broughton Island there was a distinct area of soft sediment patterning with a distinct area of coarser unconsolidated sediment that sloped down from the island to a distinct boundary with finer sediments (seen as a lighter colour in the backscatter image). This break coincided with an abrupt change in bathymetry, with the fine sediment rising about 2 metres in height to the west of the boundary into an area over which scattered features were visible through areas of lower intensity backscatter. Overall, the distribution of unconsolidated habitats around Broughton Island was complex.

All of the islands offshore of Port Stephens (Boondelbah, Cabbage Tree and Little Islands) had adjacent reefs that mostly occurred as shallow fringing reef. One exception occurred on the eastern side of Little Island where reef at intermediate depths dominated and the reef extended 600–700 metres offshore to the north-east to depths of up to 43 metres at the reef/sand boundary. The reef structures were often complex, containing small caves, overhangs, vertical walls, boulders and gutters (Figure 105). Areas of fringing rocky reef also occurred adjacent to the two headlands at Port Stephens: Tomaree Head, which had shallow reef coverage extending up to 270 metres offshore (within the aerial photograph coverage) and Yacaaba, which had a very narrow band of shallow reef extending no more than about 170 metres off the coast.

Extensive rocky reef occurred adjacent to most of the shore between Birubi Point and Fingal Bay (Figure 104). The reef was not evenly distributed along the coast and ranged from a narrow fringe of less than 100 metres in some sections to a more extensive offshore reef in areas including Fishermans Bay (1.8 kilometres), surrounding Boat Harbour (up to 700 metres) and Point Stephens (1 kilometre). There were also several ‘bommies’ offshore of Birubi Point and Boulder Bay that extended into depths of about 19 and 45 metres, respectively. The rocky reefs had varied structures, some consisted of continuous rock, some were divided by gutters with no dominant orientation, some were associated with boulders or cobbles, and some existed as patches surrounded by sand. Overall, the reefs in this area had complex structures with the many gutters of varying size and depths, in places, creating vertical walls and overhangs (Figure 105).

Unconsolidated habitats were extensive throughout the inner continental shelf of the region. These habitats were dominated by coarse sediments, reflecting the absence of finer coastal sediments, strong tidal currents and oceanic swells. The swath-mapping data revealed significant fine-scale structuring of unconsolidated habitats. Higher intensity backscatter provided evidence of small amounts of boulders, cobbles and/or pebbles around offshore islands, particularly adjacent to areas of rocky reef. To the south-east of Fingal Island high backscatter intensity between reef areas and continuing to the south-east indicated coarser sediments existed between the small reef sections and within gutters. These sediments appeared to extend to the south and then to the west of Fingal Island as a large distinct feature that joined with similar sediments surrounding the bommie off Boulder Bay. Other than these coarser sediments, the area was dominated by smooth, fine unconsolidated sediments that gently sloped offshore, shown as lighter areas in the backscatter (Figure 106). To the south of the reef off Fishermans Bay there was a gradual transition boundary between finer and coarser unconsolidated sediment grain sizes, evidenced by the backscatter intensity gradually increasing from the light areas surrounding the reef.

Aerial photography confirmed that south of Birubi Point the seabed of Stockton Bight was dominated by soft-sediment habitats, which were characterised by sandy substrate adjacent to a section of coastline about 33 kilometres long. On a broader scale the sediment has an increasing mud content towards the southern and offshore sections of the area (Figure 9).

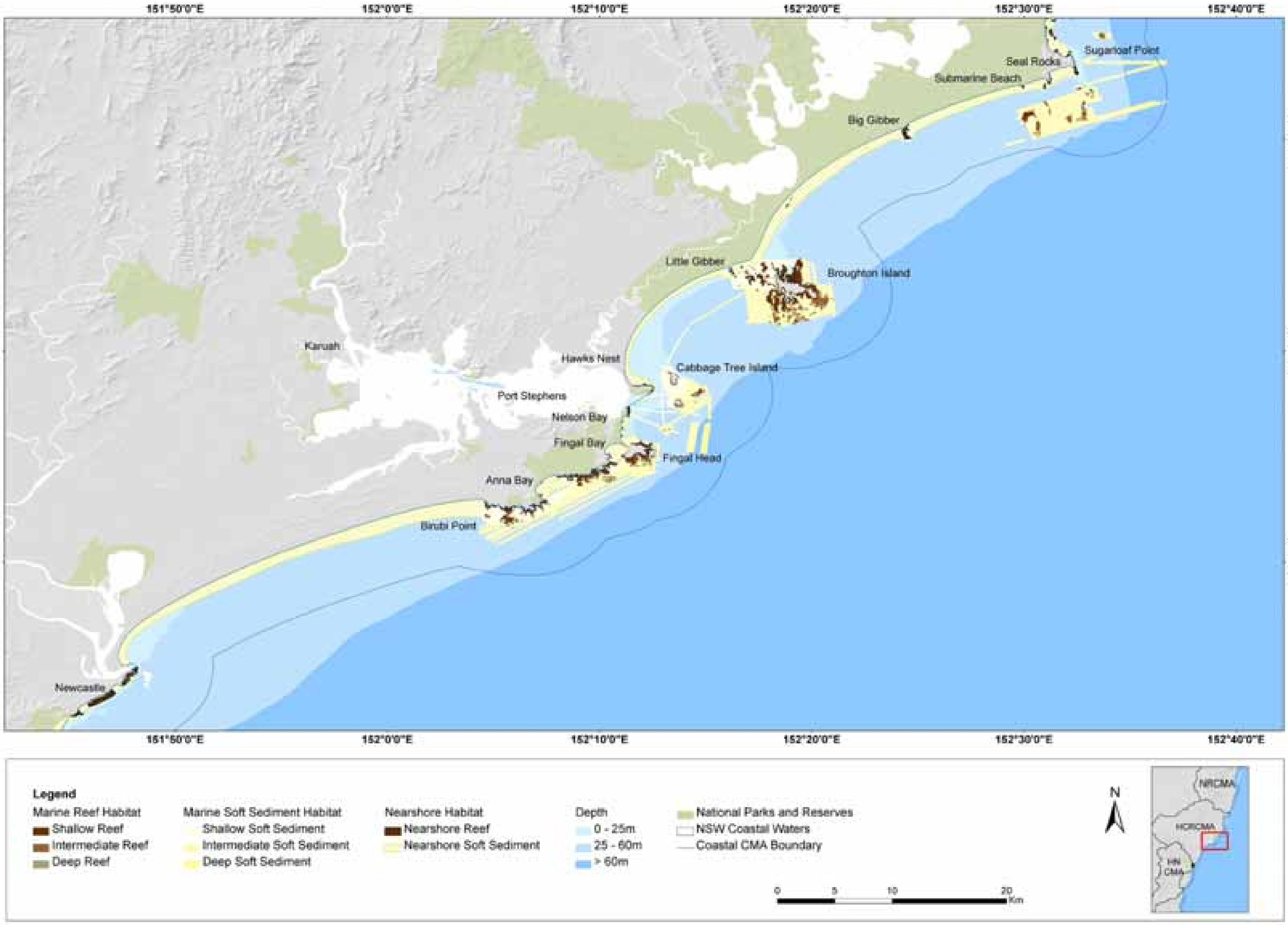


Figure 97. Distribution of known seabed habitats within the Seal Rocks to Newcastle region.

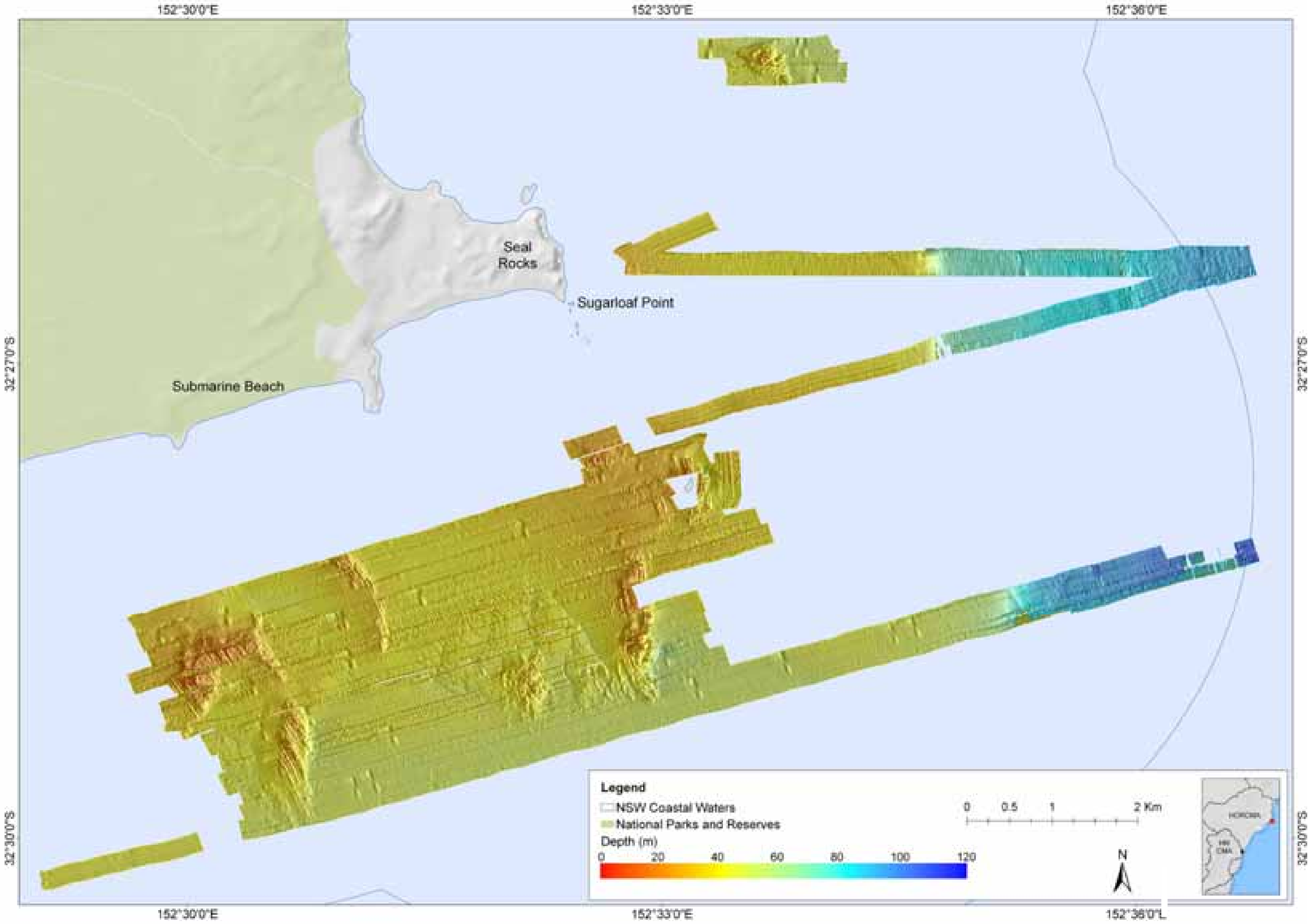


Figure 98. Hill-shaded bathymetric model of the seabed adjacent to Seal Rocks.

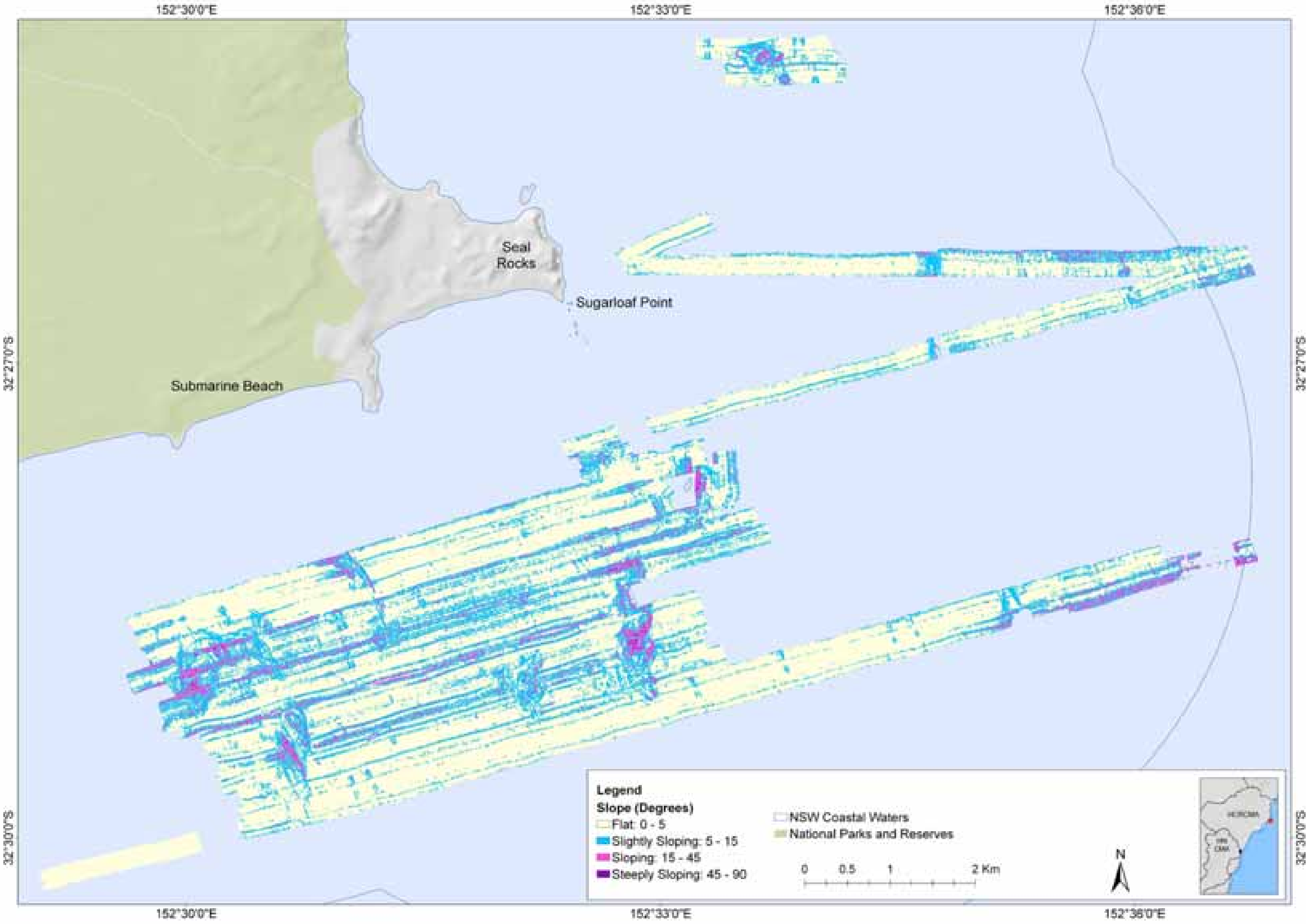


Figure 99. Slope model of the seabed surrounding Seal Rocks.

Figure 100. Acoustic backscatter of the seabed surrounding Seal Rocks.

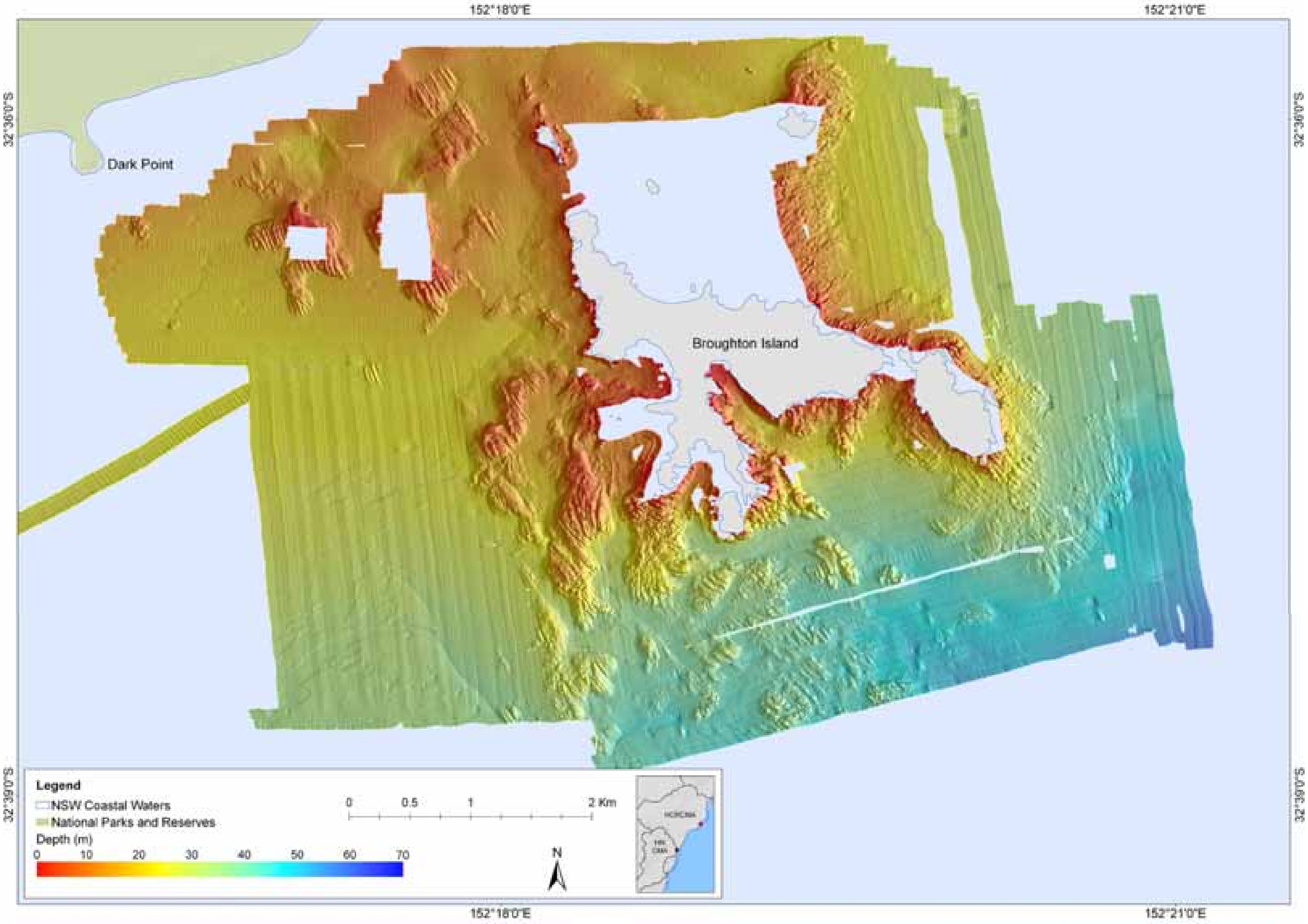


Figure 101. Hill-shaded bathymetric model of the seabed adjacent to Broughton Island.

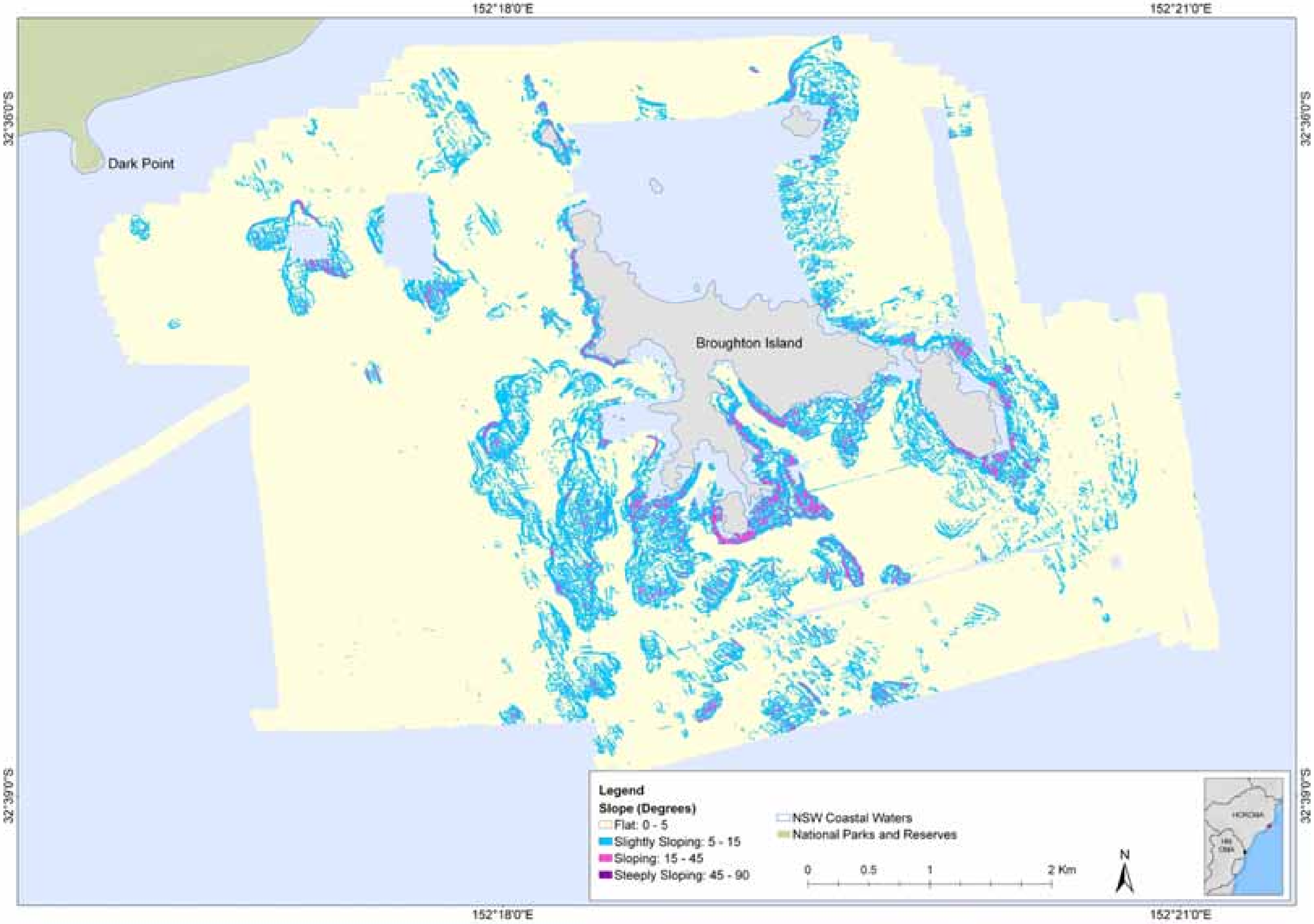


Figure 102. Slope model of the seabed surrounding Broughton Island.

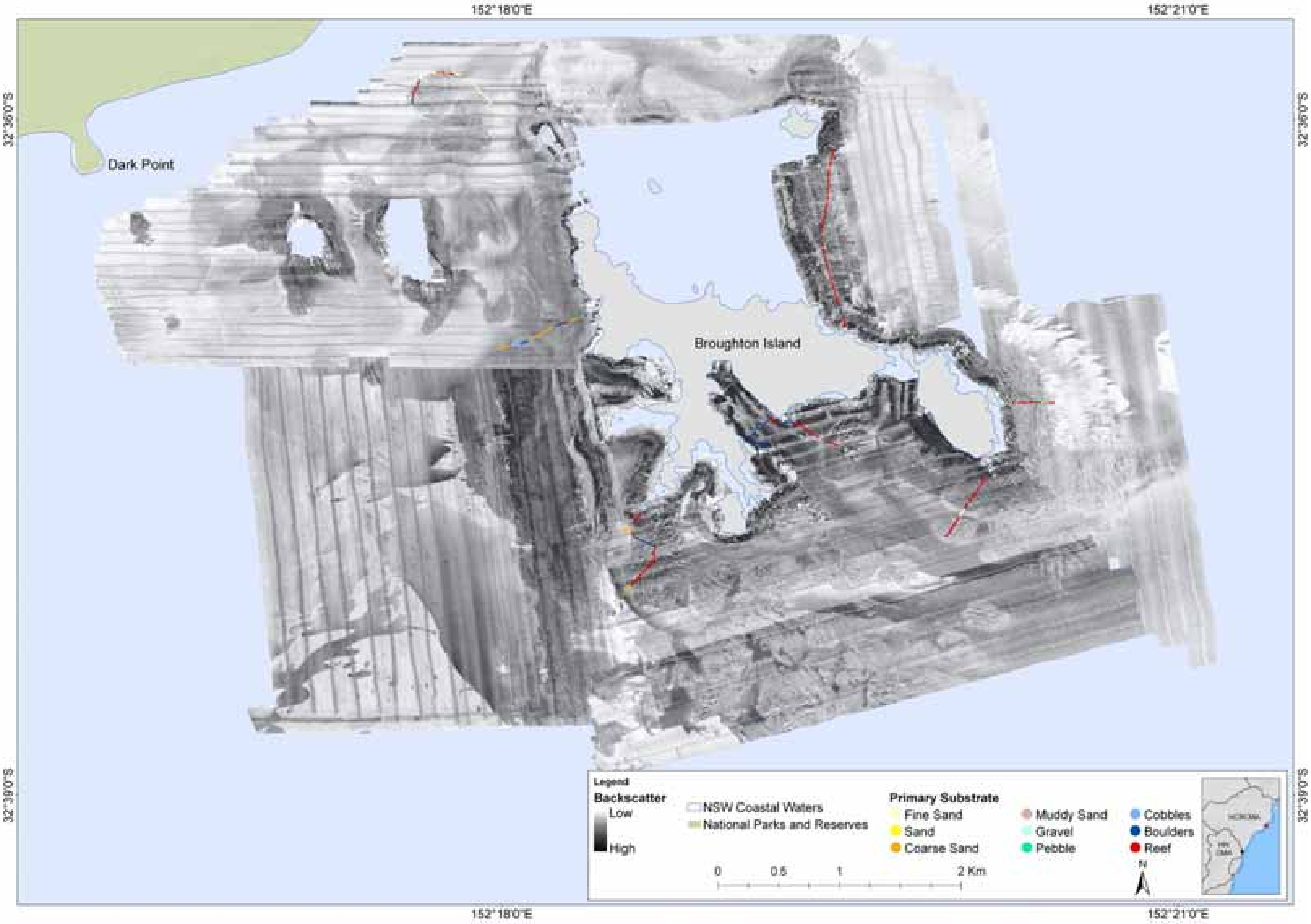


Figure 103. Acoustic backscatter of the seabed surrounding Broughton Island.

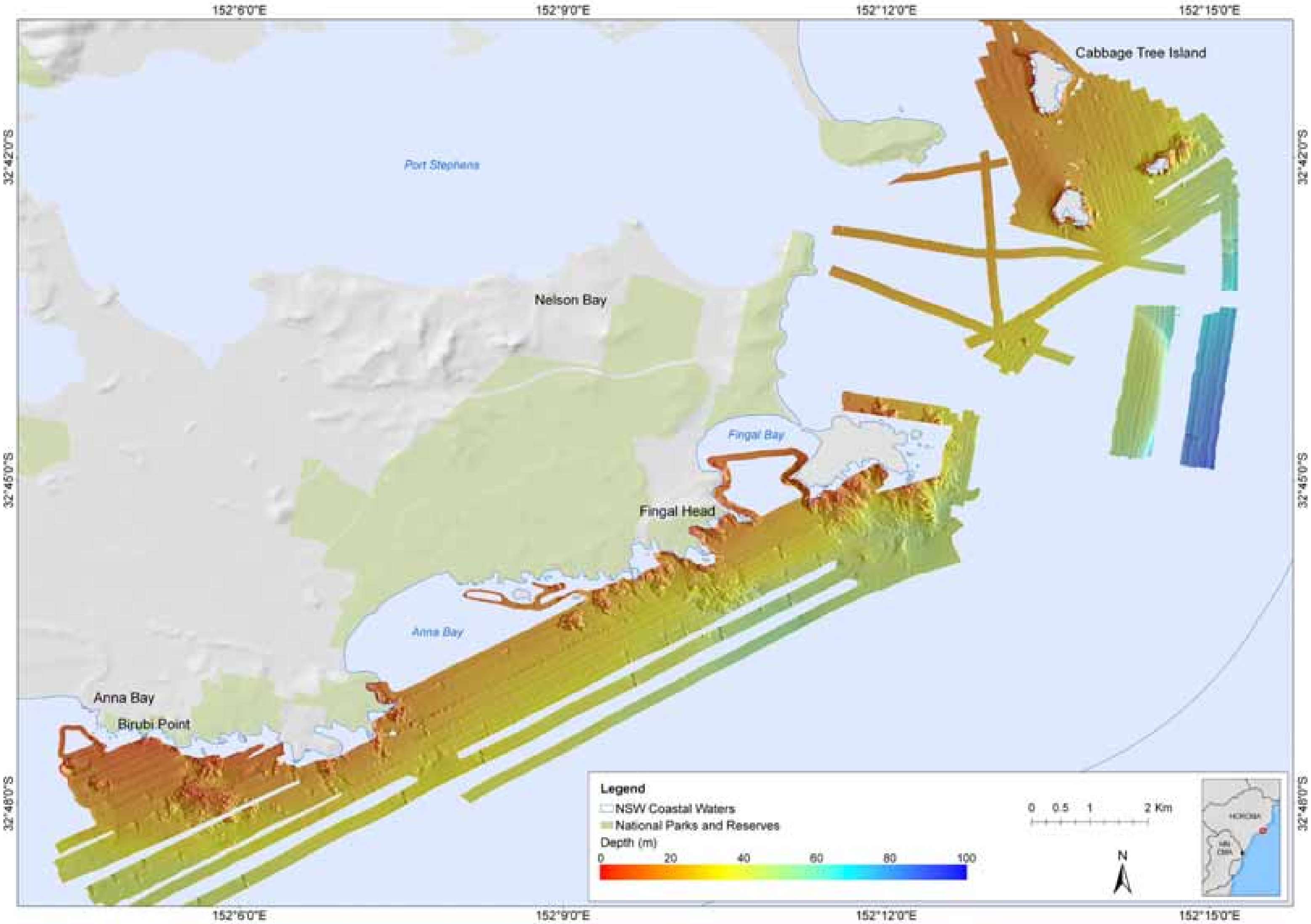


Figure 104. Hill-shaded bathymetric model of the seabed adjacent to the region between Fingal Head and Birubi Point.

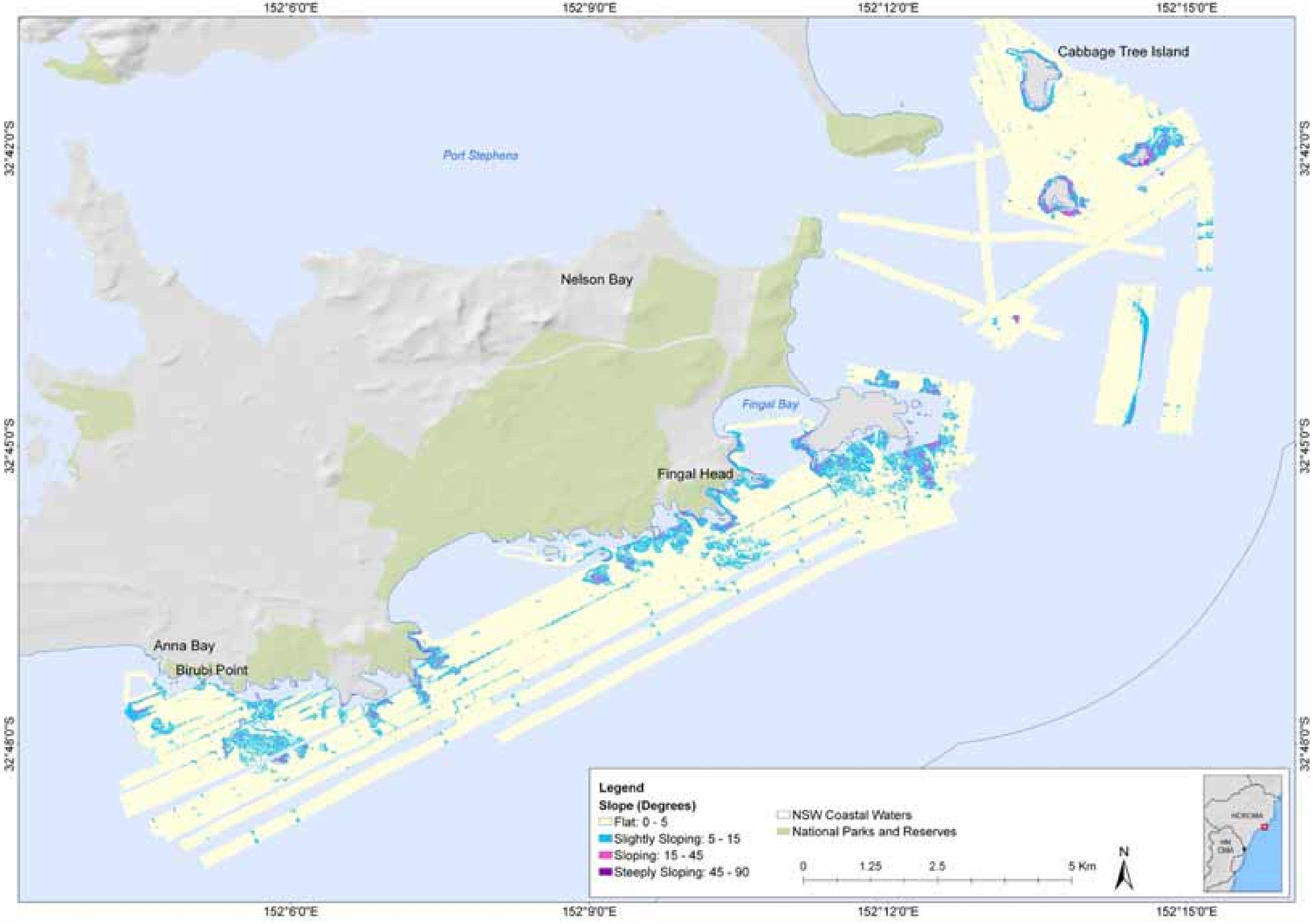


Figure 105. Slope model of the seabed adjacent to the region between Fingal Head and Birubi Point.

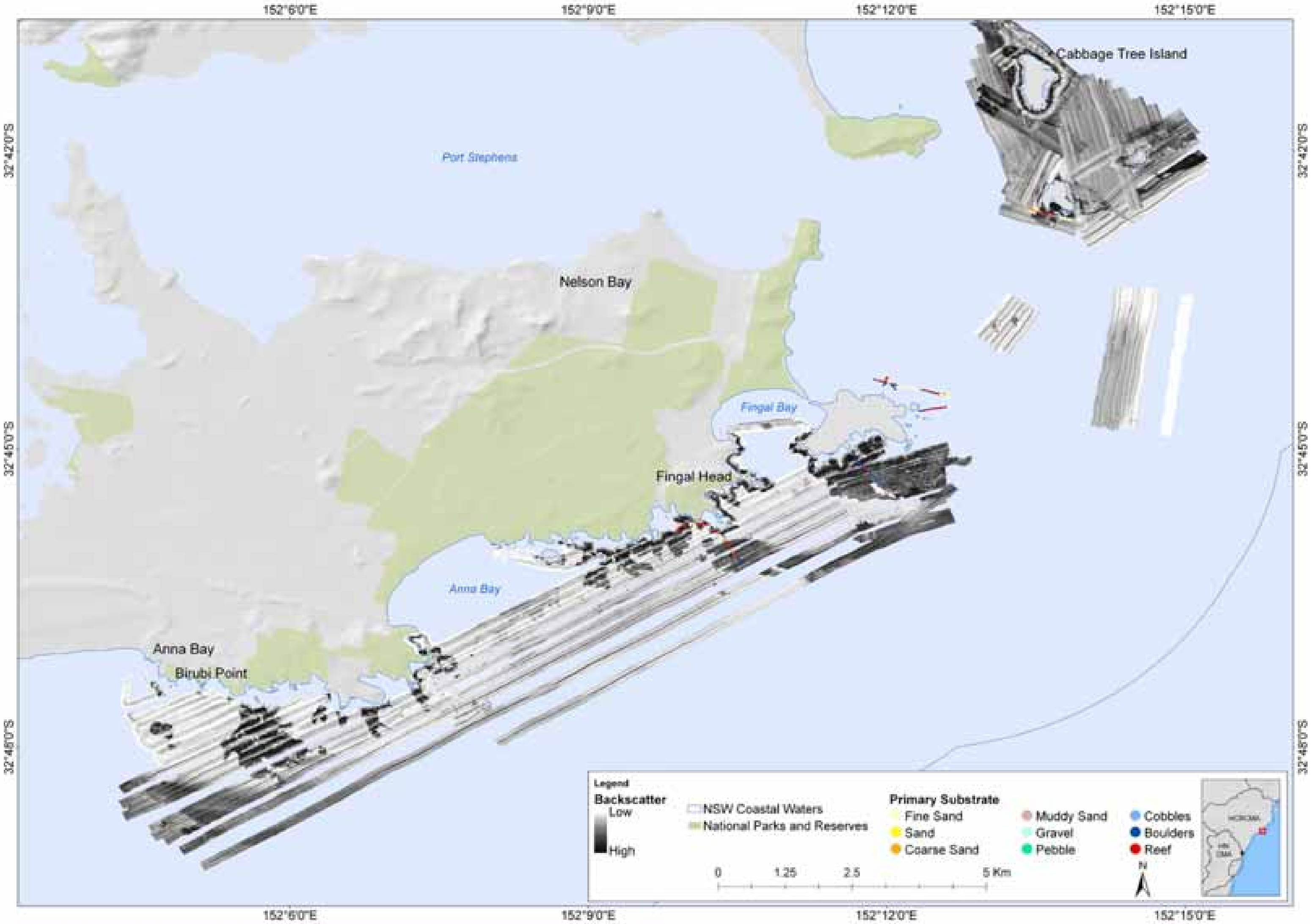


Figure 106. Acoustic backscatter of the seabed adjacent to the region between Fingal Head and Birubi Point.

Reefs surrounding Broughton Island were generally high-profile and composed of boulder fields and bedrock. Boulder field reefs, especially those at depths between 5 and 25 metres, were often associated with sea urchin barrens habitat that was dominated by the long-spined sea urchin, *C. rodgersii* (Figures 108 and 109). Shallow bedrock reef habitats at depths between 5 and 25 metres supported a mosaic of *E. radiata* and sea urchin barrens habitat. *E. radiata* was present on boulders, cobble beds or fixed to rock outcrops in areas of mixed reef and sand. Canopy cover was greater at depths shallower than 20 metres compared to depths between 20 and 30 metres (Figures 107 and 110). The brown alga, *Sargassum*, was common in areas of mixed cobble and sand substrates and was present at depths of 10–24 metres (Figure 108). Mixed red and brown algal assemblages were widespread and common to depths around 30 metres. Ascidians including *P. spinifera* and *Sigillina* sp. were observed on reef habitats at depths of 15–43 metres (Figure 108). Coral was sparse and most often observed at depths less than 12 metres. Sponges were observed across all depths surveyed (Figure 108); however, the cover of sponges was relatively sparse. At depths less than 25 metres the sponges observed consisted mainly of encrusting and massive sponges. Elongate and branching sponges were observed at depths greater than 25 metres (Figure 111).

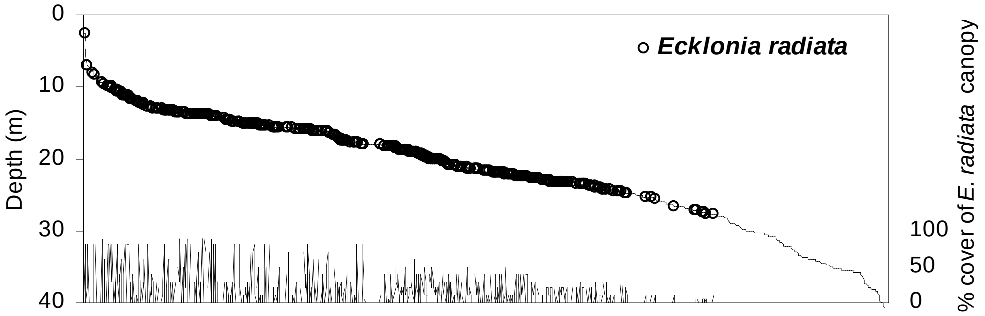


Figure 107. Presence of kelp (*E. radiata*) along video transects near Broughton Island.

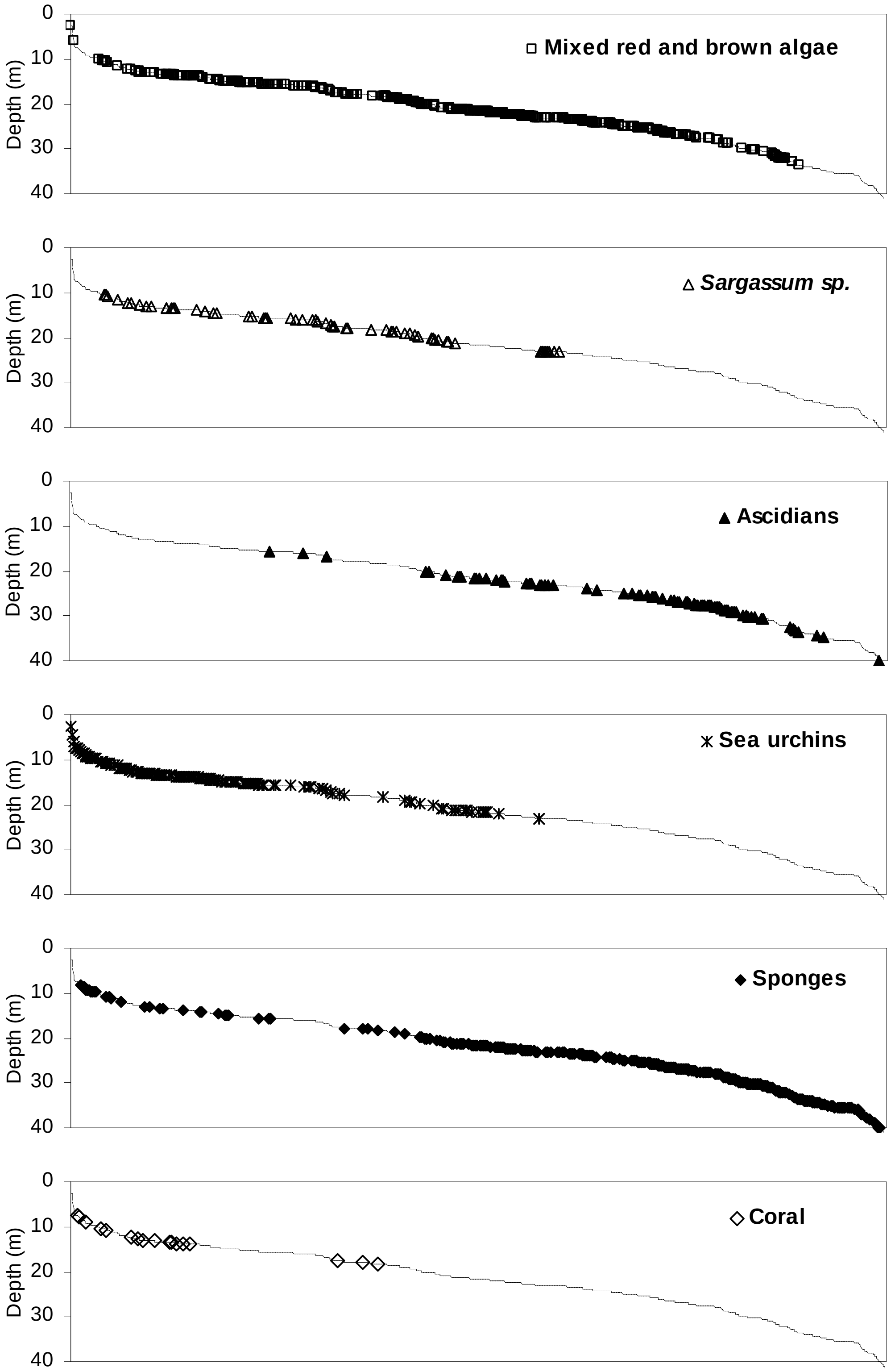


Figure 108. Presence of biota along video transects near Broughton Island.

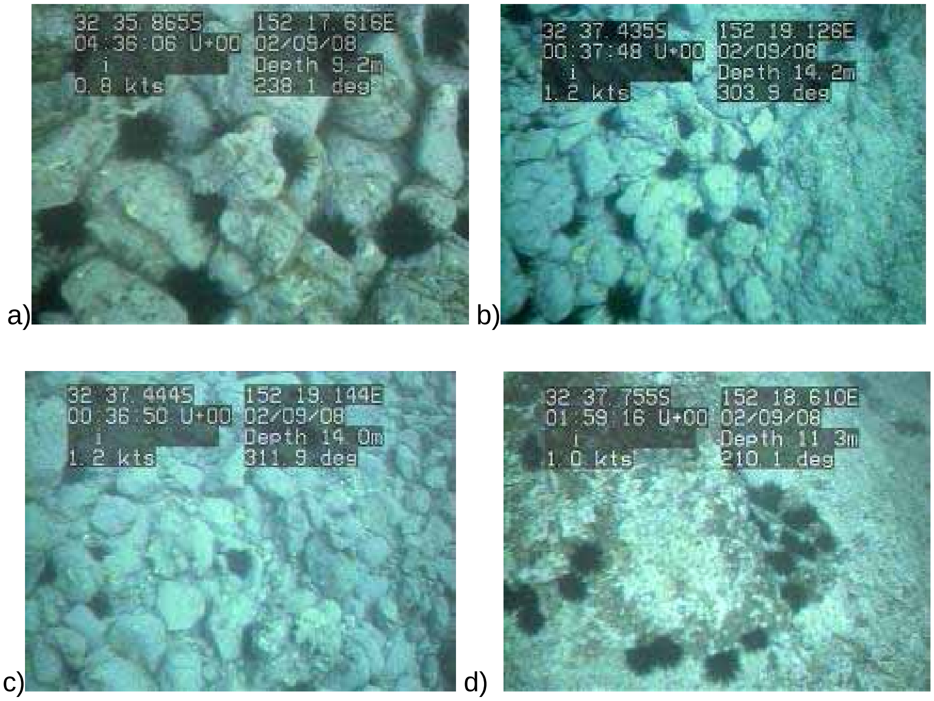


Figure 109. Barrens habitat on boulder-dominated reefs (a–c) and bedrock reef (d) near Broughton Island.

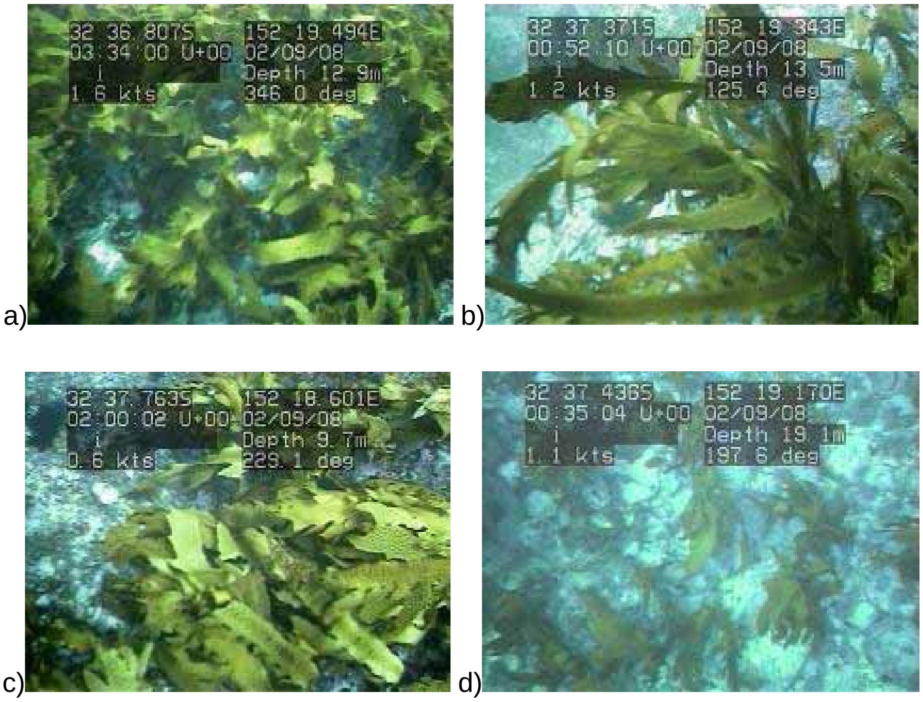


Figure 110. Kelp (*E. radiata*) on bedrock reef (a–c), mixed boulders and sand (d).

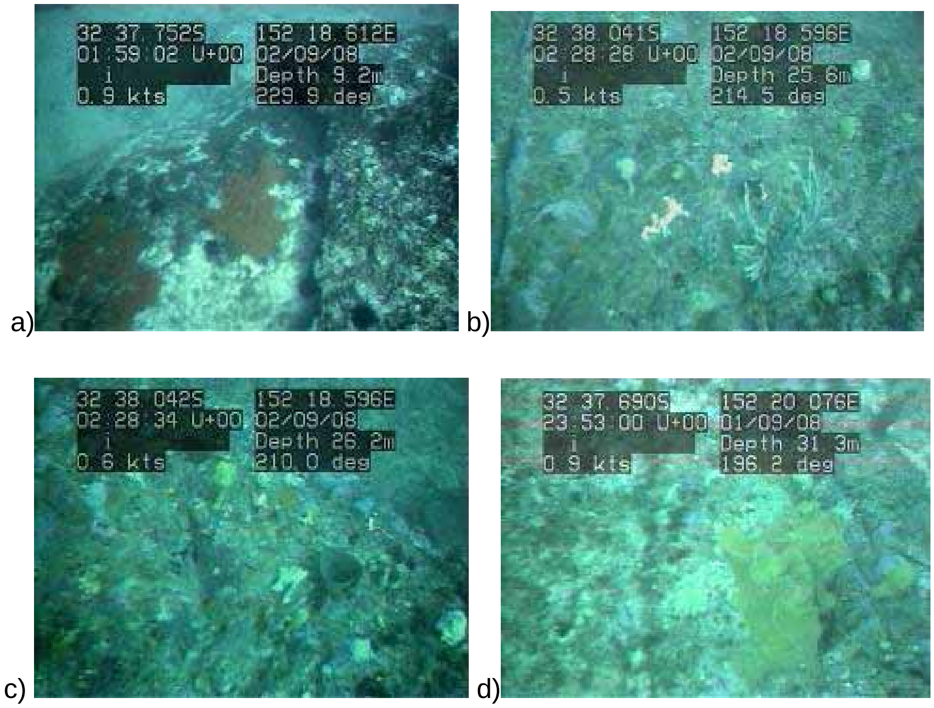


Figure 111. Encrusting sponge amongst sea urchin-dominated barrens habitat (a) and branching (b), cup (c) and elongate (d) sponges at Broughton Island.

4.3.9 Newcastle to Broken Bay

There was evidence of a considerable amount of shallow nearshore reef along the coast between Newcastle and Broken Bay, particularly around the Newcastle, Swansea, Catherine Hill Bay, Norah Head, The Entrance, Wamberal and Terrigal regions (Figure 112). Most of the reef was shallow and continuous to the shore from 200 metres up to about 1.8 kilometres offshore, and it was likely that most of it extended considerably further than currently mapped. Much of the mapping was constrained to the 15–20 depth limit of aerial photography. This was supported by the more extensive recent and historical sidescan sonar mapping conducted south of Wamberal. Along this southern section, the reef was continuous to shore and extended at least 1 kilometre offshore, ranging up to over 4.5 kilometres off the north of Wamberal where patchy reef then extended for another 1.5–2 kilometres. It was likely this reef system was continuous with that of Tuggerah Reef and other reef complexes to the north that formed shallow reefs over 3 kilometres offshore as evidenced in the broadscale bathymetry. Continuous reef was highly prevalent along the section from Avoca Beach to the mouth of Broken Bay. The only discontinuities were unconsolidated sediments evident at Avoca Beach, MacMasters Beach and several smaller beaches further south.

The recent swath mapping conducted between Terrigal and Copacabana, along with the detailed bathymetry and backscatter, revealed the extent of seabed habitats that were consistent with some of the trends occurring more broadly throughout the region. Firstly, the bathymetry revealed that the continuous reef that extended offshore of both headlands sloped steeply, with intermediate reef occurring close to shore (Figure 112, 113). Offshore of Avoca, continuous reef extended about 1.6 kilometres offshore, whereras off Terrigal it extended only about 600 metres, although patchier reef extended almost another 2 kilometres offshore.

Much of the intermediate reef area was comparatively low profile. Shallow reef in the southern part of the survey area increased at depths of 15 metres over a distance of 150 metres, and reef increased again over a further distance of 950 metres depths increasing another 15 metres at intermediate depths (Figure 114). The soft-sediment areas of the seabed in the region between Terrigal and Copacabana were mostly dominated by fine sand to at least 3 kilometres offshore (Figure 115). On the outer edge of the survey area, extending to the north-east of the reef off Avoca, there was an area that had a much higher backscatter signal. It was accompanied by no distinct changes in bathymetry; hence, it was likely to reflect an area of much coarser sediment types than those seen further inshore.

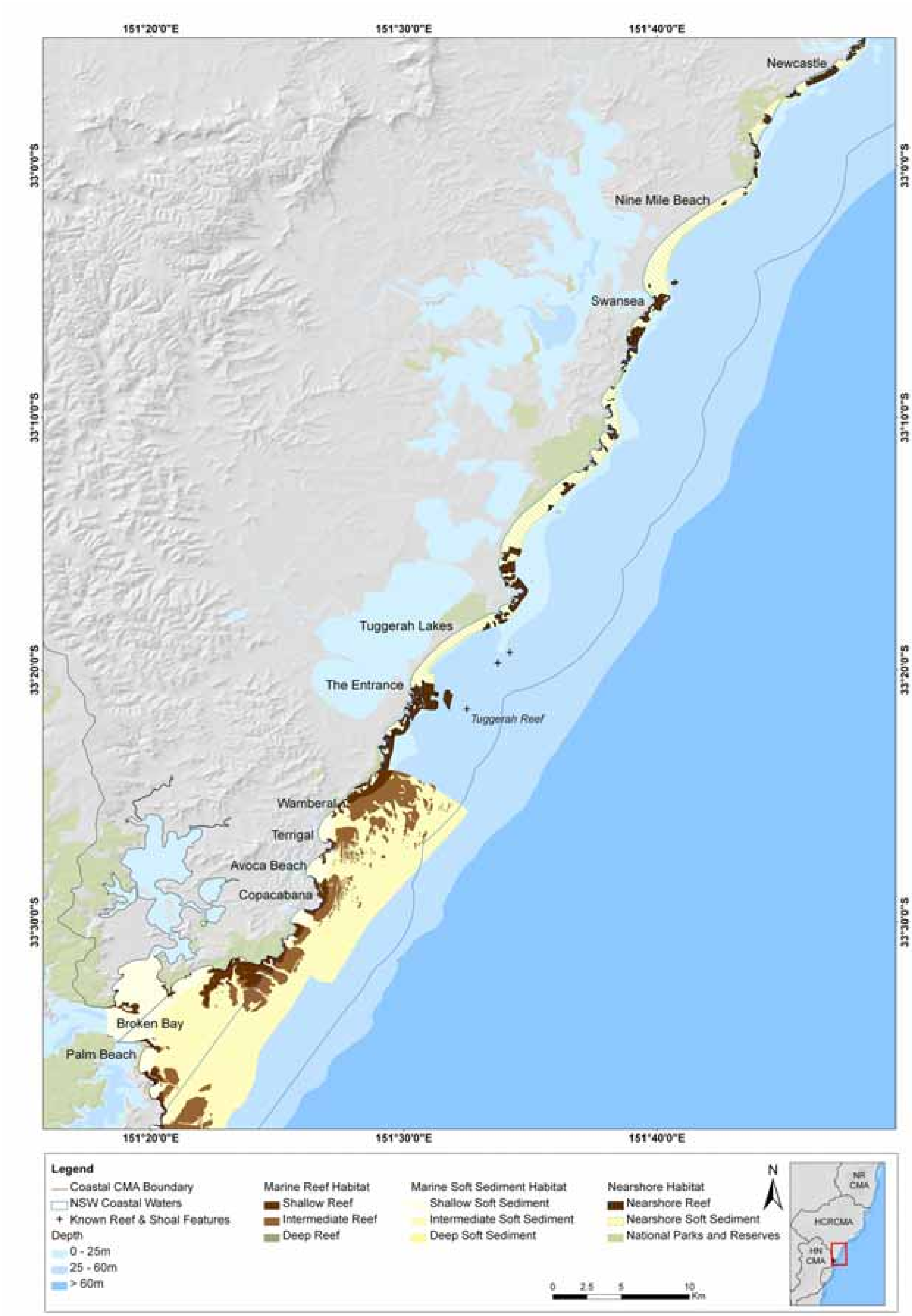


Figure 112. Distribution of known seabed habitats within the Newcastle to Broken Bay region.

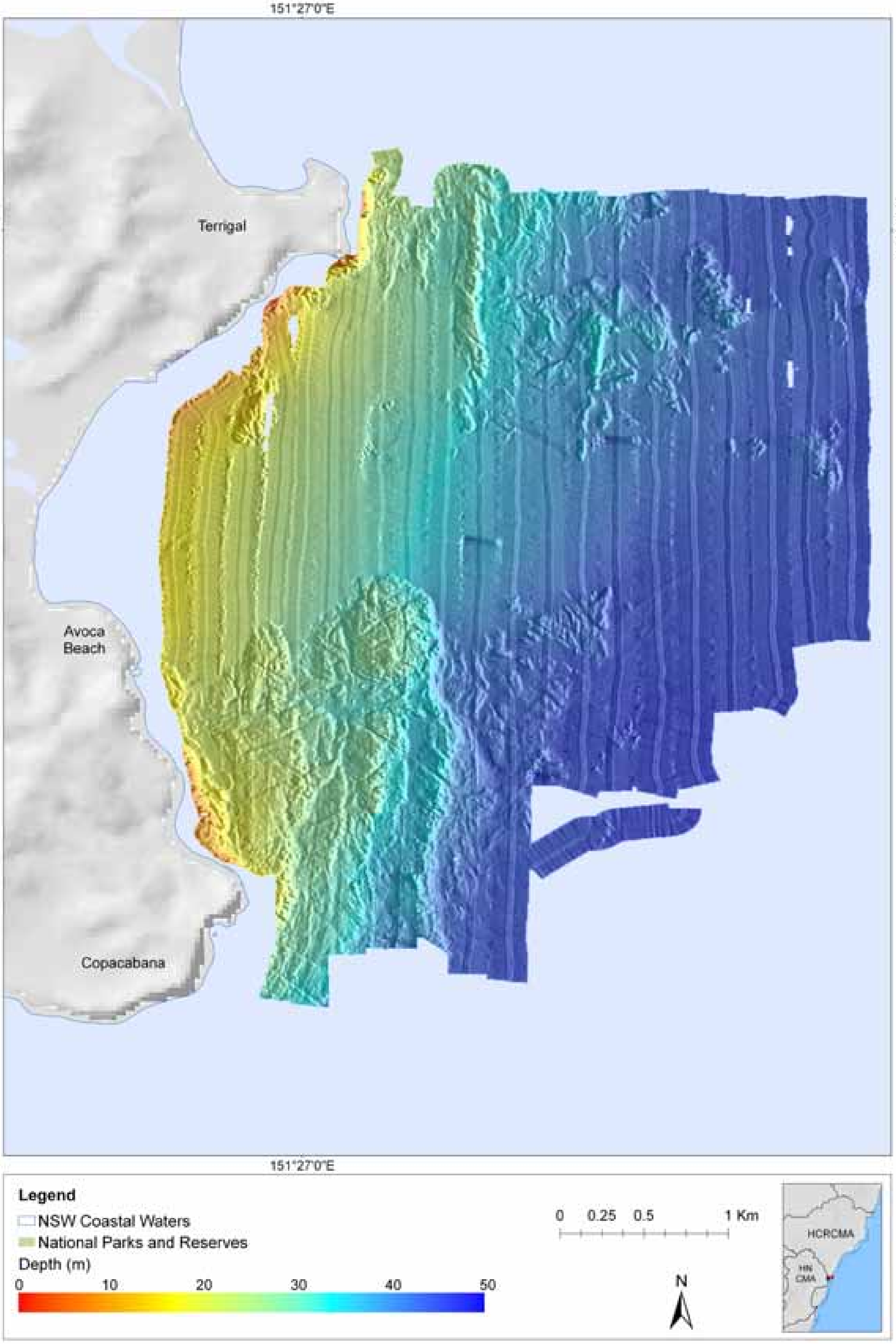


Figure 113. Hill-shaded bathymetric model of the seabed offshore of Terrigal.

Figure 114. Slope model of the seabed adjacent to the Terrigal region.

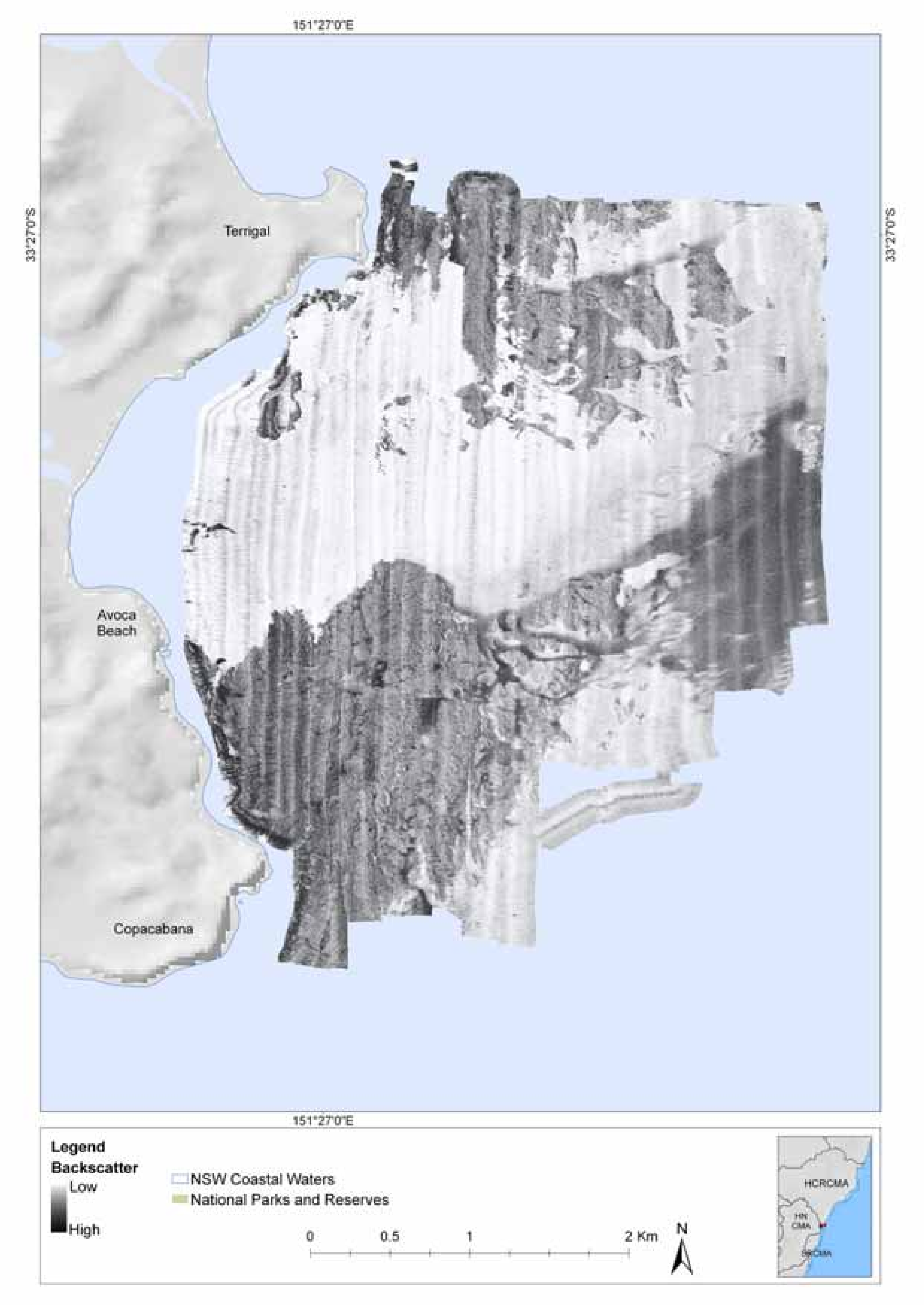


Figure 115. Acoustic backscatter of the seabed offshore of the Terrigal region.

4.3.10 Broken Bay to Stanwell Park

The section of coast between Broken Bay and Stanwell Park has been covered by a considerable amount of historical sidescan sonar mapping as far south as Bundeena (Figure 116) (Gordon and Hoffman 1989). This earlier mapping revealed extensive reef systems adjacent to the Sydney coast, particularly north of the entrance to Sydney Harbour. There was also a regional pattern in the distribution of reefs north of Sydney Harbour where reefs occurred adjacent to headlands that separate ocean beaches, which consisted mostly of soft-sediment habitats. In contrast, south of Sydney Harbour reef was mostly continuous along the entire coastal section apart from the sand-dominated Bondi and Maroubra beaches.

Between Narrabeen and north-east of Avalon a large system of reefs extended up to about 3 kilometres offshore continuous with headlands. These were characterised by large corridors of soft sediments, which split the reefs offshore of the sandy beaches. The majority of these large features were at intermediate depths. Between Long Reef and Sydney Harbour an even larger system of reefs extended over 7 kilometres offshore, with the seabed offshore of Long Reef being the most extensive. The majority of the reef occurred in intermediate depths, which started within several hundred metres from shore, indicating nearshore reefs were steeply sloping. An exception was adjacent to Long Reef, where shallow reef occurred up to 1.5 kilometres from shore. The system contained large blocks of reef separated by irregular corridors of soft sediment, surrounded by smaller patches of reef on the outer edges of the largest of the block features.

South of Sydney Harbour the reef coverage was considerably smaller than that further north, with most reef habitat occurring around 1.4 kilometres from shore. A large nearshore reef system, predominantly at intermediate depths, extended south into shallow depths in Bate Bay at Cronulla. Small areas of deep reef were present throughout the area and occurred about 1.5–2 kilometres offshore, which was much closer to shore than north of Sydney Harbour where areas of deep reef occurred about 3 kilometres from shore.

Narrow areas of shallow nearshore reef were present between Bundeena and Stanwell Park, although it was likely that some of this reef extended further offshore and past the 15–20 metre depth limit of the aerial photography, which was consistent with the reefs systems along the Sydney coast.

4.3.11 Stanwell Park to Crookhaven

No swath acoustic mapping has been conducted on the continental shelf between Stanwell Park and Crookhaven; therefore, all habitats were mapped from aerial photographs. These revealed that a large proportion of this coast contained shallow nearshore reef, particularly adjacent to headlands and areas with continuous rocky coastline (Figure 117). The nearshore habitats between Stanwell Park and Thirroul were dominated by reef, much of which was patchy and occurred consistently across the mapped area regardless of its adjacency to a rock- or a sand-dominated shoreline. The reef was likely to extend further offshore than that mapped using aerial photography, similar to the coast around Sydney Harbour. Between Thirroul and Port Kembla there was a larger extent of sand-dominated beaches bounded by regular reefs extending offshore of all headlands and around the Tom Thumb Islands offshore of Port Kembla. The largest mapped area of reef was offshore of Bellambi, where reef extended at least 1 kilometre from shore, and a shallow section of known reef located around 800 metres south-east of the main headland. Again, it was anticipated that the reef in this area would often extend further than the mapping conducted using aerial photographs.

The section between Port Kembla and Crookhaven was characterised by ocean beaches, varying in length from as little as 300 metres up to over 17 kilometres, and rocky shores with adjacent shallow nearshore reef. The highest proportion of rocky shoreline was adjacent to the Kiama and Gerrigong sections of coast, with fewer sandy beaches interrupting the rocky shores and the largest sand-dominated beach occurring north of Crookhaven. Much of the reef adjacent to shore extended further offshore, although it was deeper than what was visible using aerial photography.

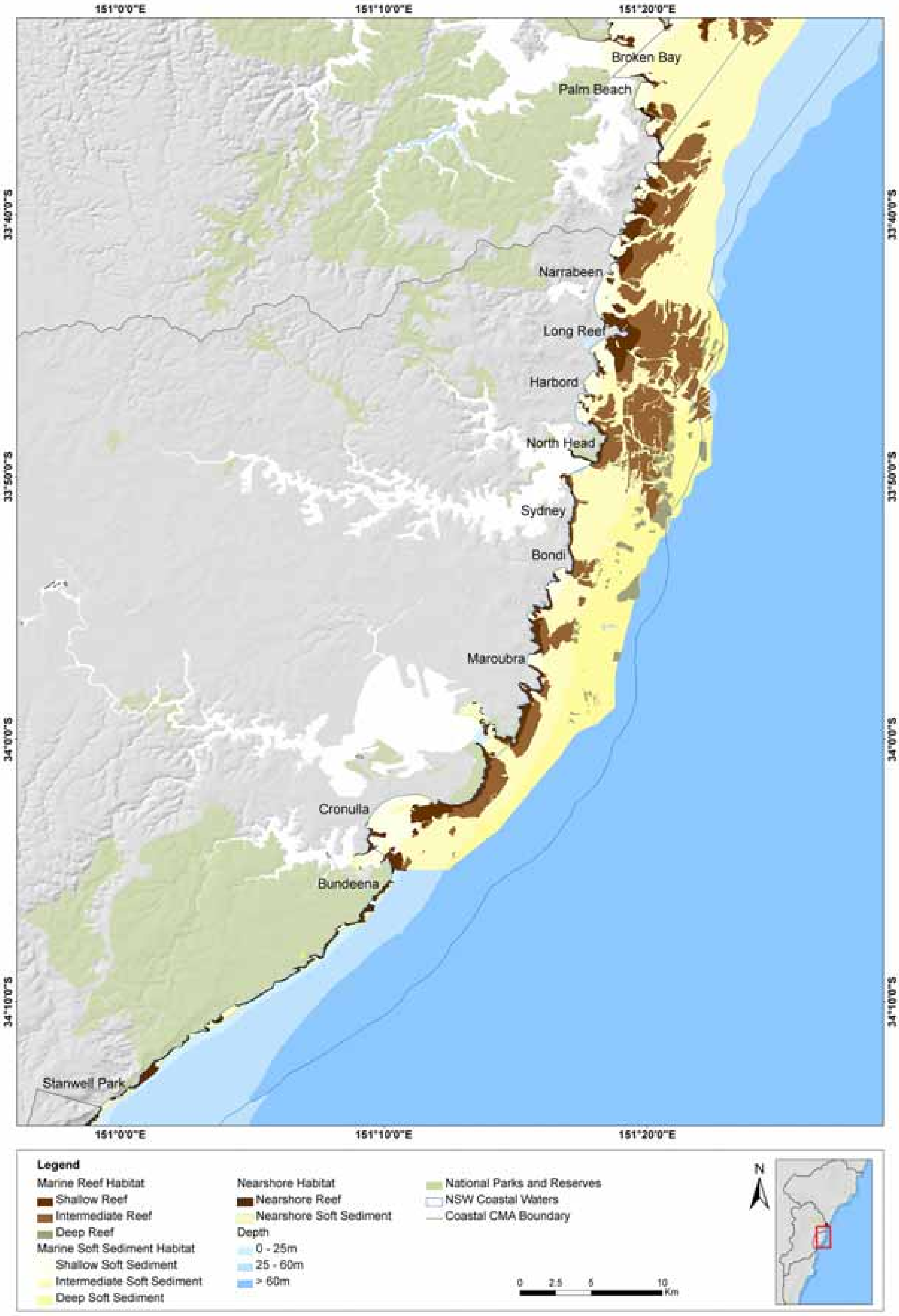


Figure 116. Distribution of known seabed habitats between Broken Bay to Stanwell Park.

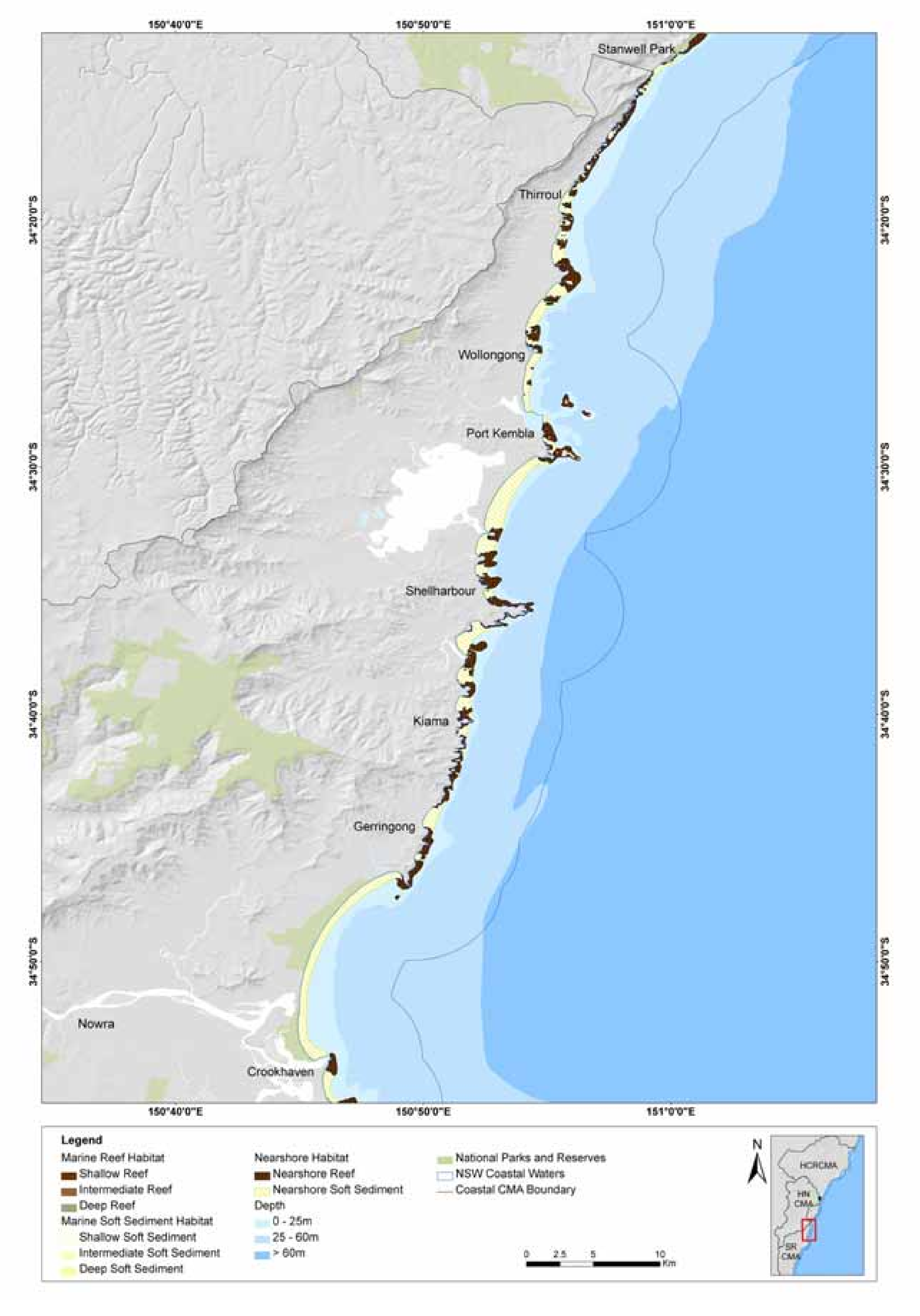


Figure 117. Distribution of known seabed habitats within the Stanwell Park to Crookhaven region.

4.3.12 Crookhaven to Bawley Point

The broadscale distribution of seabed habitats in this region reflects the area’s geomorphology, with the sheltered waters of Jervis Bay dominated by unconsolidated habitat and the open coast dominated by complex rocky reefs extending out from headlands and rocky shorelines (Figure 118). In the north of the region the reefs in Crookhaven Bight and offshore of Beecroft Head covered a large area from nearshore to over 2 kilometres offshore in areas at least 40 metres deep. Shallow and intermediate reefs were found in the two areas and their structure varied considerably (Figure 119). The reefs directly offshore of Beecroft Head consisted of bedrock that is part of the Snapper Point Formation (primarily quartz sandstone and pebbly sandstone), whereas those immediately west extending along Currarong Beach consist of Wandrawandian siltstone. Intermediate reefs north of Beecroft Head, at a broad scale, have a high profile, rising 25 metres over a distance of 700 metres, compared to the inshore reef system which only rises 8 metres over more than 1 kilometre (Figures 119 and 120). Similarly, there was an increased slope within the reef system to the north of Beecroft Head demonstrated by gutters ranging up to 4 metres compared with gutters of about 2 metres in the Currarong Beach system.

The rocky reef in Crookhaven Bight was interspersed with mostly coarser unconsolidated seabed that also surrounded the system in some areas as indicated by darker backscatter (Figure 121). Lighter backscatter occurred outwards from the reef and the surrounding coarser sediments, often across a distinct boundary indicating a change to finer sediments that most likely consisted of well-sorted sand. Surrounding the reefs offshore of Beecroft Head, unconsolidated sediments changed across a gradual scale from the finest sediments to the east of the Crookhaven Bight reefs to coarser sediments closer to these reefs.

Shallow reefs surrounding the Beecroft Peninsula extended an average of 150 metres offshore (Figure 118). Reefs extending along the Peninsula were characterised by steep drop-offs, large boulders, caves and overhangs. Further along the Peninsula to the south-west, a large area of shallow reef extended 900 metres from Longnose Point into the bay mouth and continued as intermediate reef for another 150 metres. To the east of this reef there was a distinct area of unconsolidated sediment patterning with sharp light and dark sections in the backscatter. This feature seemed to be an area of sand ripples about 0.4 metres deep. The darker areas indicated coarser sediment in the troughs between the finer sand that constituted the ripple peaks.

A small number of mainly fringing reefs occur within Jervis Bay, which is dominated by unconsolidated substrate, much of which contains seagrass (Creese et al 2009). The exception is the large reef that extends up to 1.5 kilometres offshore from Plantation Point. There is also reef at the mouth of Moona Moona Creek and Currambene Creek that extends about 1.3 kilometres offshore. Smaller reefs exist adjacent to the headlands that are located around the bay between Vincentia and Bowen Island. In the north of the bay there are reefs around Callala Point, fringing reef to the south of Hare Bay, and around the west of the Beecroft Peninsula, with the exception of one sandy beach area. Many of the subtidal reefs are continuous with intertidal reefs that vary greatly in extent and exposure.

To the south of the bay mouth there was another large rocky reef system around Bowen Island (Figure 118). One continuous reef extended due north from the northern headland of the island for over 1.7 kilometres, peaking at ‘Middle Ground’ and coming to within 900 metres from the reef that extended south from Longnose Point. This reef to the north of Bowen Island was characterised by three main ridges of reef running north-south, surrounded by other reef areas (Figure 122). It rose a maximum of 12 metres from the surrounding seafloor mostly over distances of around 100 metres resulting in a seabed with a moderate slope (Figure 123). The reef extended around the eastern side of the island and between the island and the mainland towards Governors Head. Immediately to the east and extending to the reef north-east of Bowen Island, the seabed was dominated by unconsolidated sediments that had a low backscatter intensity suggesting the presence of fine sands. This contrasted somewhat to the seabed west of the reef and particularly to the north, which was surrounded by areas of higher backscatter indicating the presence of coarser sediments (Figure 124).

Although narrow fringing reef occurred along much of the Bherawerre Peninsula, the majority of the reef in this area existed offshore of Stoney Creek, with the reef extending over 700 metres offshore immediately north of this area (Figures 118 and 125). Most of this reef was at intermediate depths, with the eastern edge of the main reef dropping onto sand over a very steep slope (over 30 degrees in some places) to an average depth of around 55 metres (Figure 126). A smaller amount of reef existed to the south adjacent to Steamers Head and although it only extended an average of 120 metres offshore, it had areas of steep slopes and dropped very quickly to depths of up to 40 metres (Figure 125). An area of patchy reef also existed offshore of St Georges Head, almost all of which was in intermediate depths. Much of this reef system was characterised by drop-offs and gutters up to 2 metres deep.

The unconsolidated sediments adjacent to the reef off Stoney Creek appeared to be mostly homogenous with moderate backscatter (Figure 127). Lower backscatter occurred to the north and south of the major headlands. This low backscatter was interrupted by linear darker features off the northern reef that comprised sand ripples of around 0.3 metres deep which tended to collect coarser sediments in the trough between the finer sand peaks. South-east of the thin reef system running south to the reef at Steamers Head there were bands of higher backscatter in depressions on the seabed, which were likely to be associated with sand waves made up of finer sediments.

South of the Bherawerre Peninsula, shallow nearshore reefs in Wreck Bay stretched over 1.3 kilometres offshore in some places and were likely to extend further than what was mapped from aerial photos. Although the swath-mapping revealed much more rocky reef throughout the region than was defined in previous surveys, it is likely that even more reef extended offshore adjacent to reefs identified off Beecroft Head, immediately south of Governor Head and between the Drum and Drumsticks. This was indicated from bathymetric, aerial and swath-mapping evidence to date.

Between Sussex Inlet and Bawley Point large areas of shallow nearshore reef were identified offshore of almost all rocky headlands, particularly along the Ulladulla section of coast. There were also some small reef areas offshore of several ocean beaches. Most of the reef areas were likely to extend further offshore than the 15–20 metre depth limit than was mapped from the aerial photos.

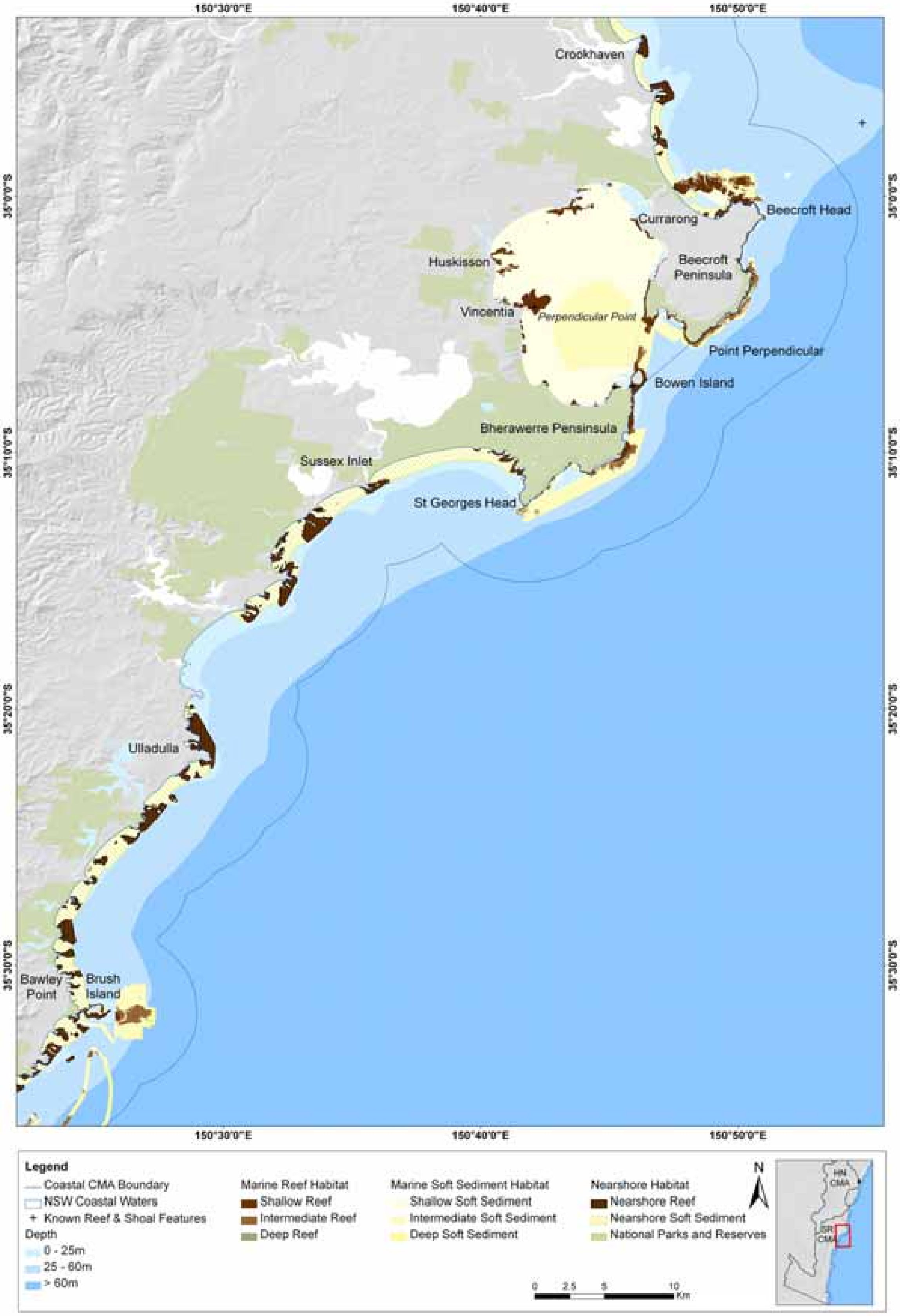


Figure 118. Distribution of known seabed habitats in the region between Crookhaven and Bawley Point.

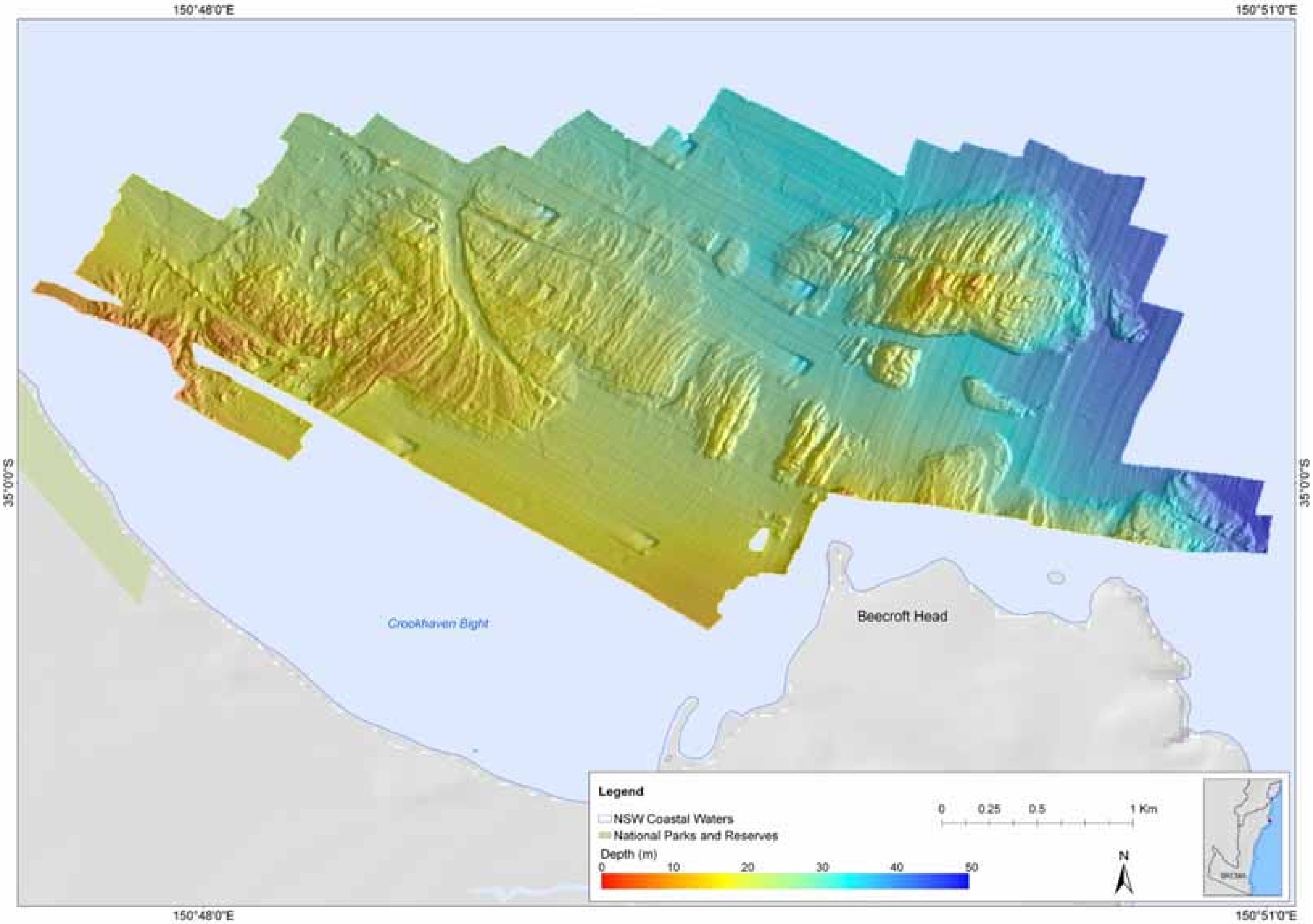


Figure 119. Hill-shaded bathymetric model of the seabed within Crookhaven Bight.

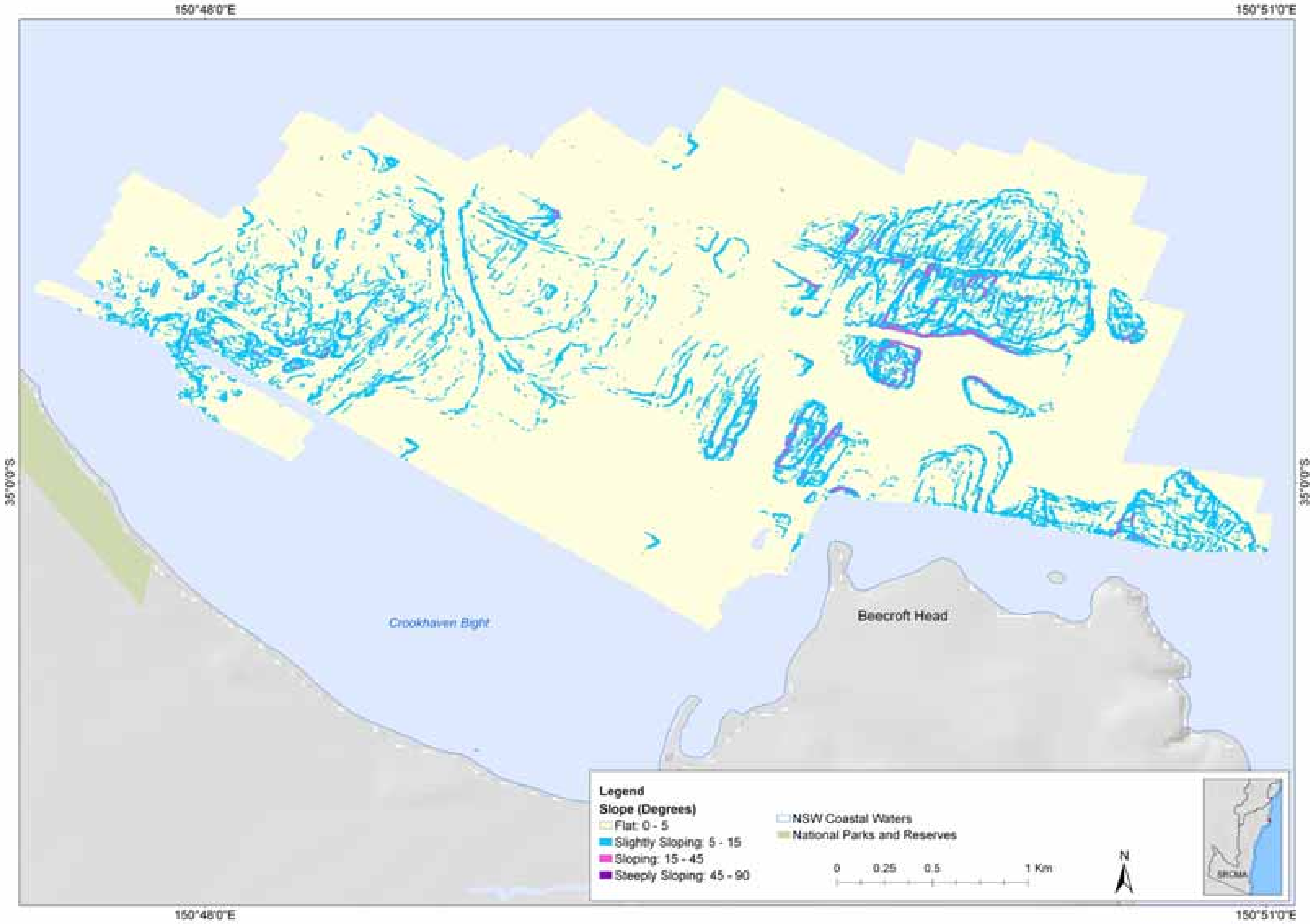


Figure 120. Slope model of the seabed within Crookhaven Bight.

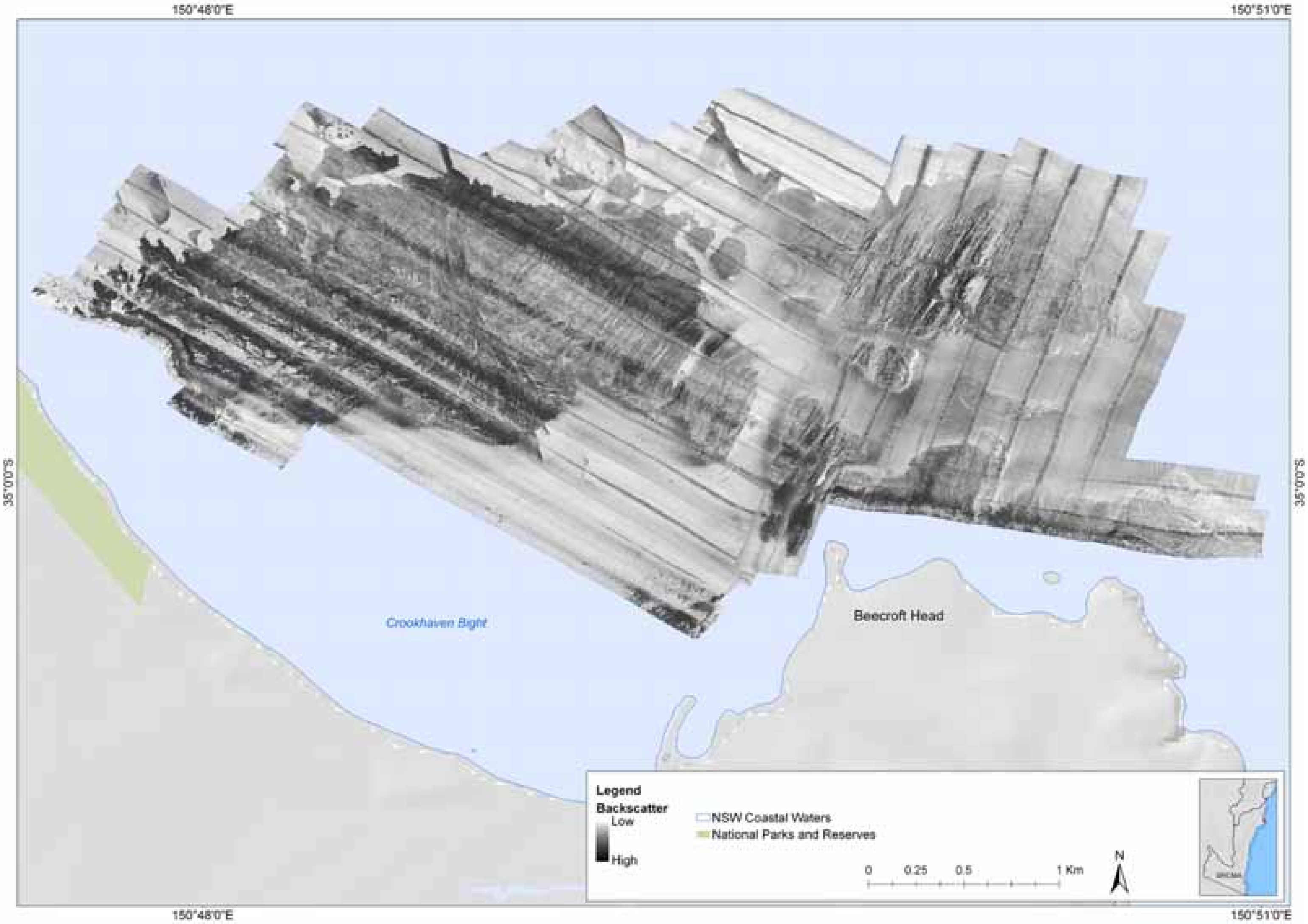


Figure 121. Acoustic backscatter of the seabed within Crookhaven Bight.

Figure 122. Hill-shaded bathymetric model of the seabed adjacent to Bowen Island.

Figure 123. Slope model of the seabed adjacent to Bowen Island.

Figure 124. Acoustic backscatter of the seabed adjacent to Bowen Island.

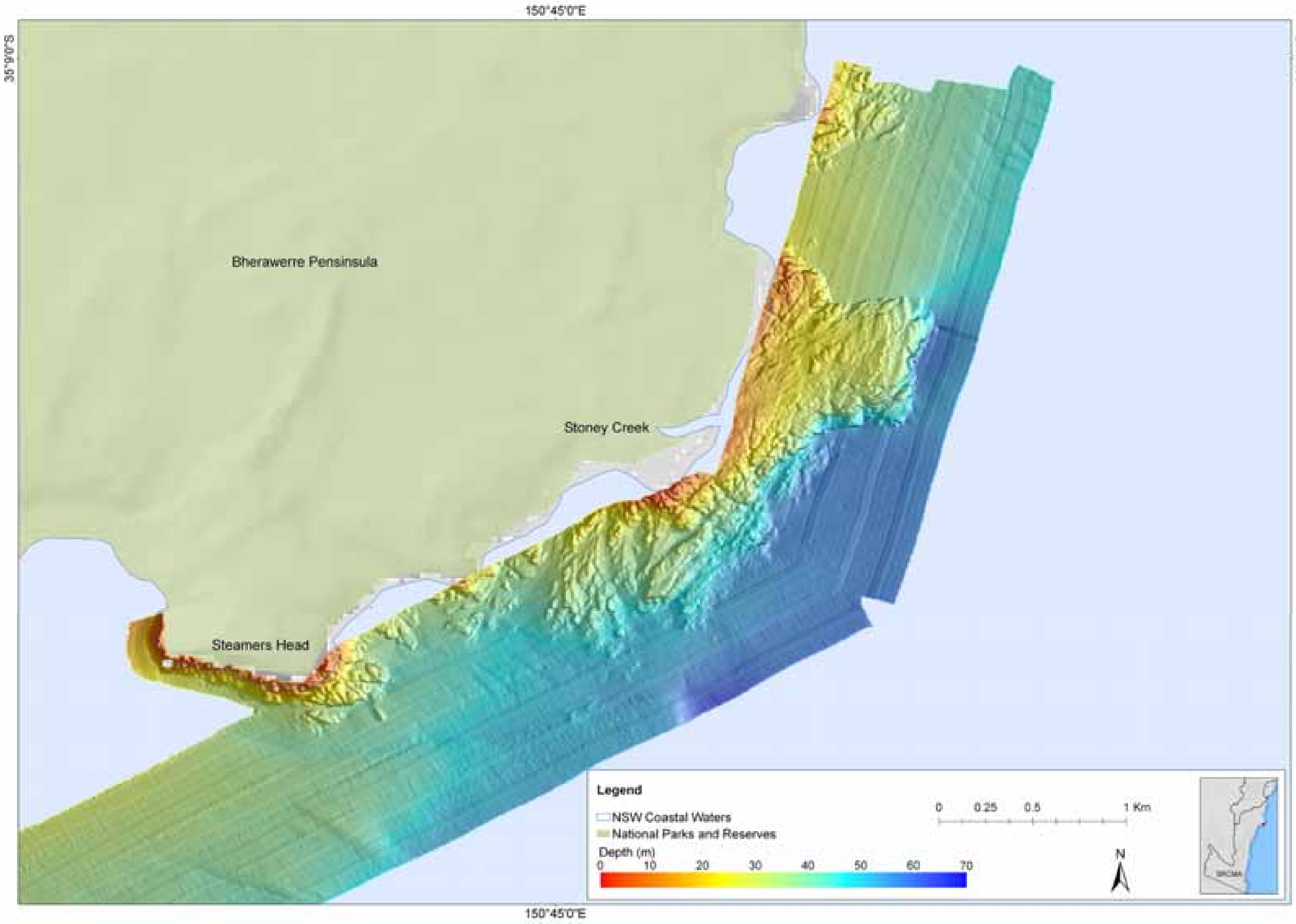


Figure 125. Hill-shaded bathymetric model of the seabed adjacent to the Bherwerre Peninsula between Steamers Head and the southern section of Governors Head.

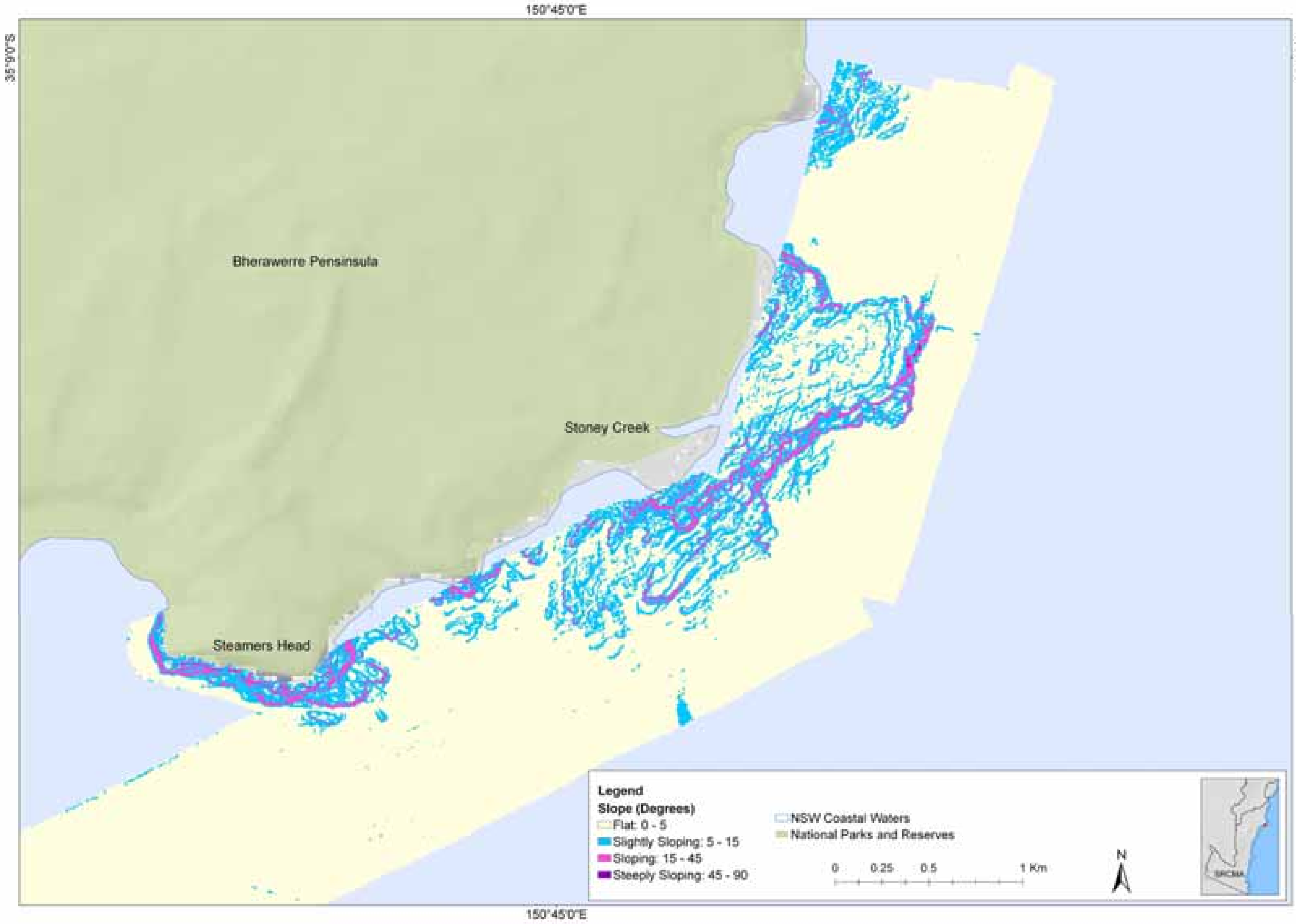


Figure 126. Slope model of the seabed adjacent to the Bherwerre Peninsula between Steamers Head and the southern section of Governors Head.

Figure 127. Acoustic backscatter of the seabed adjacent to the Bherwerre Peninsula between Steamers Head and the southern section of Governors Head.

4.3.13 Bawley Point to Bermagui

The distribution of seabed habitats in this region was characterised by extensive nearshore reefs that dominated the coast, reflecting the high proportion of rocky shoreline and numerous ocean beaches (Figure 128). There were also large areas of consolidated habitat on the inner- and mid-shelves, with several islands that had adjacent reefs. Rocky reefs were continuous to the coastline along the vast majority of the coastal section between Bawley Point and Batemans Bay. Exceptions to this were areas adjacent to some small sand-dominated beaches, the largest of which was along the Durras section of coast where the beach extended for almost 5 kilometres. A prominent reef system was present offshore of Brush Island, which occurred up to about 2.9 kilometres east of the island (Figures 128 and 129). The majority of this reef system was in intermediate water depths, although an area of shallow reef between the extent of the aerial photo analysis and swath mapping was not mapped. The area contained shallow reef that surrounded the island extending as far as 400 metres to the south, and, assuming the unmapped area was reef, up to about 1.1 kilometres to the east. There were also two sections of intermediate reef separated by an area of soft sediments that was 20–170 metres wide. The majority of the reef system was continuous, with some patchy areas in places to the south and east. Much of the reef east of Brush Island was characterised by steep slopes associated with reef walls and deep gutters (Figure 130). To the south of the shallow reef in this section, the reef fell in a steep slope at angles up to 24 degrees. In the larger block of intermediate reef the steep gutters between the tallest peaks reached angles over 28 degrees. Other areas of reef were characterised by more moderate features such as the uniform gentle slope of the eastern block of reef that sloped to the east and fell 25 metres to depths over 450 metres. Similarly, the eastern side of the larger reef block dropped to 16 metres in depth over a distance of 500 metres.

Immediately to the north and south of the reefs offshore of Brush Island there were large areas of unconsolidated sediments that had low backscatter and were relatively homogenous, indicating they were large areas of sand (Figure 131). Areas of higher backscatter primarily occurred adjacent to the reefs indicating that they were most likely to consist of coarse sand.

There were extensive nearshore reefs along the coast south of Brush Island, with many extending from the intertidal zone to depths of at least 20 metres (the extent of the aerial photography coverage), and most likely considerably deeper. This assumption was supported by the presence of large areas of intermediate reef on the mid-shelf up to about 4.3 kilometres offshore, which were highlighted in swath survey data along the coast between Brush Island and the north of Batemans Bay. There was also some evidence of deep reef between 4 and 6 kilometres offshore, particularly off the south of Durras Beach. Further evidence of the presence of reef across this inner shelf region was supported by the extensive areas of reef to the south within the Batemans Bay region offshore of the Tollgate Islands (Figure 132). In this area, reef appeared to be continuous to at least 6.5 kilometres offshore of the coast, with intermediate reef commencing at an average distance of around 800 metres east of the Tollgate Islands and deep reef at around 4.5–5 kilometres. To the north and south of the Tollgate Islands the reef sloped steeply, the sharpest section of the slope was over 30 degrees to the south (Figure 133). To the east, more gradual changes in bathymetry and a gentle fall of the entire system of less than 1 degree created a less complex reef structure than the more prominent features to the north and south.

Between the Tollgate Islands and reefs close to the shore on the south of Batemans Bay, there was a distinct large area of seabed with low backscatter that reflected an area of finer sand compared to that within the reef complex (Figure 134). This area was distinguishable from surrounding coarser sediments to the north and south that were immediately adjacent to the reefs and extended west into Batemans Bay. The reefs in this area generally contained a matrix of gutters of varying extent containing coarse sand, cobbles and boulders (Figure 135).

An extensive nearshore system of reefs also occurred along the southern shore of Batemans Bay. This system was almost continuous to several kilometres south of Burrewarra Point, apart from a few small sand-dominated beaches, the longest of which was only about 900 metres wide. The swath acoustic data revealed large areas of intermediate reef offshore of some of the nearshore reefs in the Malua Bay area. It was likely that such reef also occurred offshore of the nearshore reefs adjacent to Burrewarra Point. South of this area to Narooma, the coast had a much higher proportion of sand-dominated beaches that were interspersed with nearshore reef primarily adjacent to prominent headlands such as Broulee and Moruya Heads. The large headland reefs were likely to extend further offshore than the limit of what was mapped from aerial photos, although many of the smaller reefs along this stretch of coastline, such as off Tuross Head and north of Narooma, only extended offshore to a maximum of around 100 and 300 metres, respectively.

The small amount of swath acoustic coverage along the southern section of this region indicated that intermediate reef was present on the inner- and mid-shelves, although its entire extent is unknown. Given the extent of such reef habitat offshore of Potato Point it is likely that intermediate reef is extensive along this section of coast. Interestingly, none of the reef in this area was directly continuous to shore. This suggested there may be other reef systems, dominated by intermediate-depth reefs, which start some distance from shore. Some of the shallow reefs, such as those off Tuross Head and Narooma, although not continuous to shore, could be the shallow reaches of such intermediate-depth-dominated systems. The reef at Potato Point extended at least 2.7 kilometres offshore, the eastern limit of the swath coverage (Figure 136), and was likely to continue further offshore. The reef was increasingly patchy with increasing distance offshore and, as a system, had a relatively low slope falling 35 metres over 2.2 kilometres at its widest point (Figure 137). Backscatter from the Potato Point area indicated that fine sand dominated the seabed to the north and south of the main reef complex, with coarser sediments present within the main reef system (Figure 138).

South of Narooma, patchy nearshore reef was adjacent to the rocky shorelines; however, in contrast to areas to the north, it was not predominantly fringing subtidal reef that occurred adjacent to intertidal reef. Much of the reef was not continuous to shore or widened with increasing distance from shore. The largest coastal nearshore reef occurred adjacent to the Mystery Bay region where the reef extended over 700 metres offshore and it was likely to extend further than the depths mapped from the aerial photos. The largest mapped reef system on this section of coast was adjacent to Montague Island. Large shallow reef areas extended to the west and south of the island, with the southern reef (known as Aughinish Rock) separated by an area of soft sediment about 200–300 metres wide. A further series of small reefs were located about another 800 metres to the south (Figure 139). These reefs were mostly in shallow depths and extended into intermediate depths on the very edges of the reefs within an average of 100 metres from the reef/sand boundary. The reef system to the north-east of the island extended as intermediate reef to a maximum of 1 kilometre offshore and as deep reef for a further 500 metres offshore.

Reefs around Montague Island were characterised as complex with large gutters predominantly running in an east-west direction. The slope of the reef was variable, with the highest slope occurring to the north and east of the island when the reef dropped to sand at an average slope of 20 degrees (Figure 140). Large areas of unconsolidated sediments that appeared relatively homogenous in the acoustic backscatter surrounded the island (Figure 141). These were dominated by fine sand that appeared lighter in the backscatter image. Smaller areas of darker backscatter occurred throughout the area primarily adjacent to the reefs, with video footage indicating that this was most likely to consist of coarse sand (often with ripples) (Figure 142). To the north and west of the reef systems the gradual darkening of the backscatter indicated a gradual increase in the grain size of the sediments. In contrast, the defined boundaries between lighter and darker areas to the south were indicative of distinct edges between sediment types.

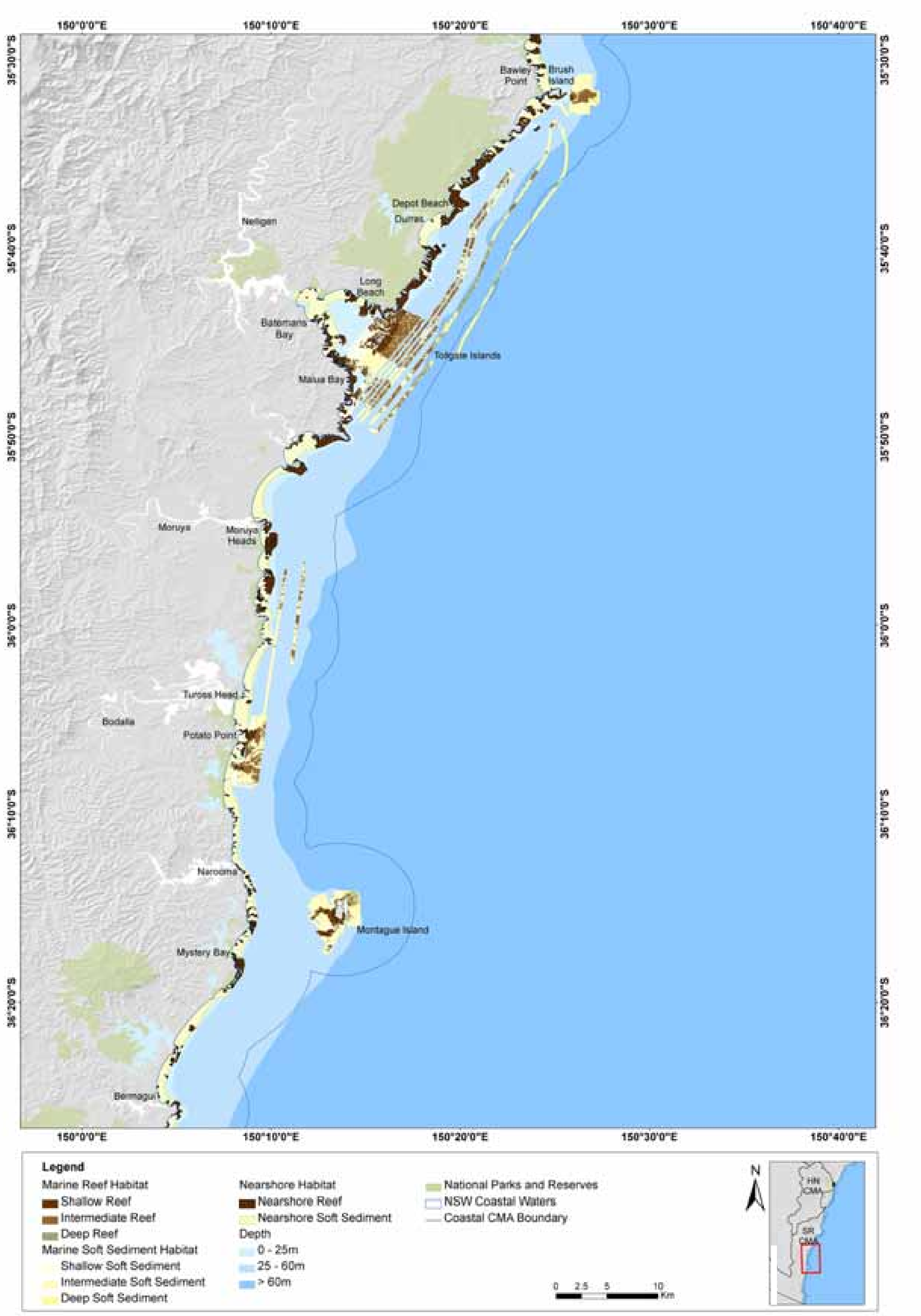


Figure 128. Distribution of known seabed habitats within the region between Bawley Point and Bermagui.

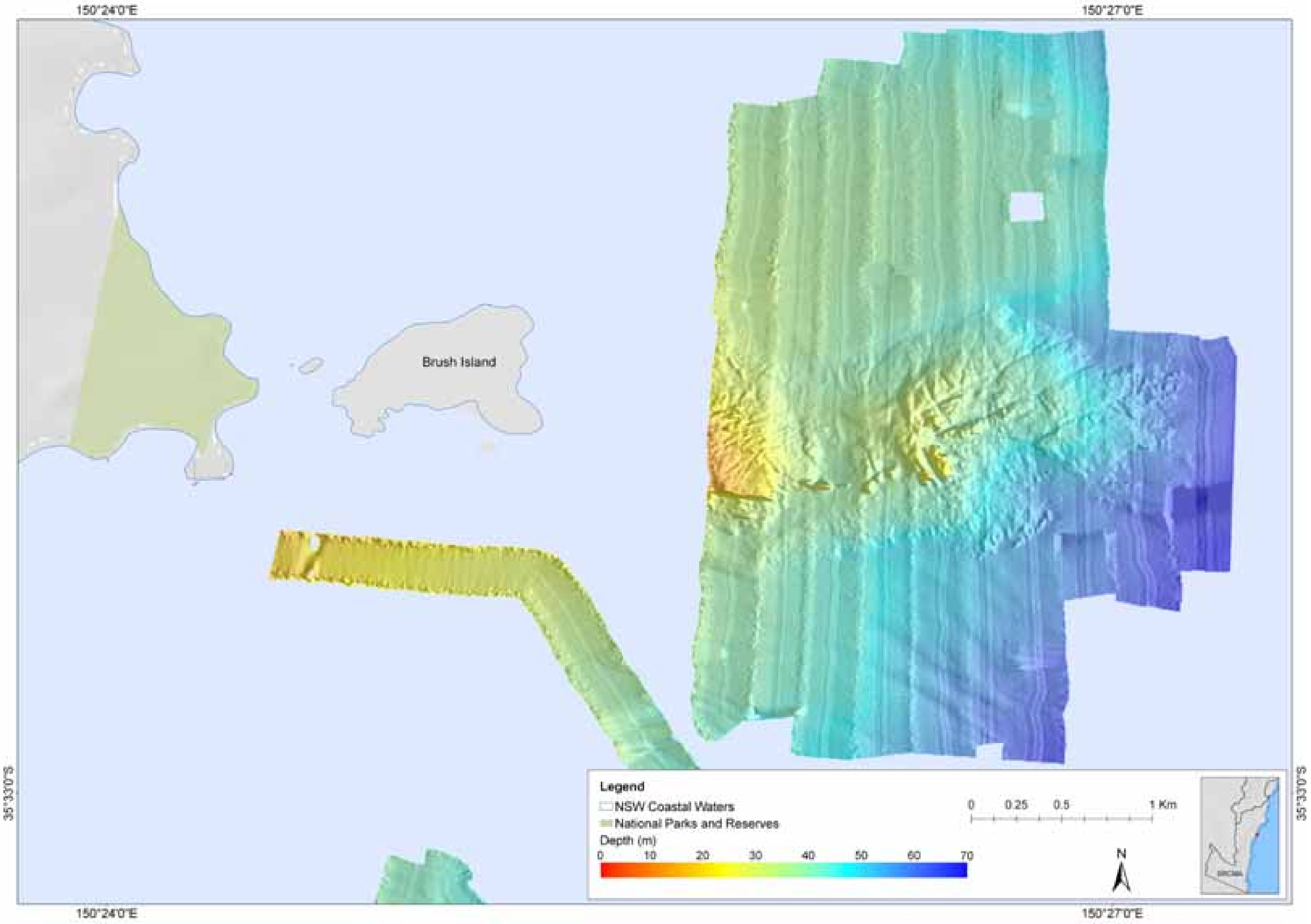


Figure 129. Hill-shaded bathymetric model of the seabed offshore of Brush Island.

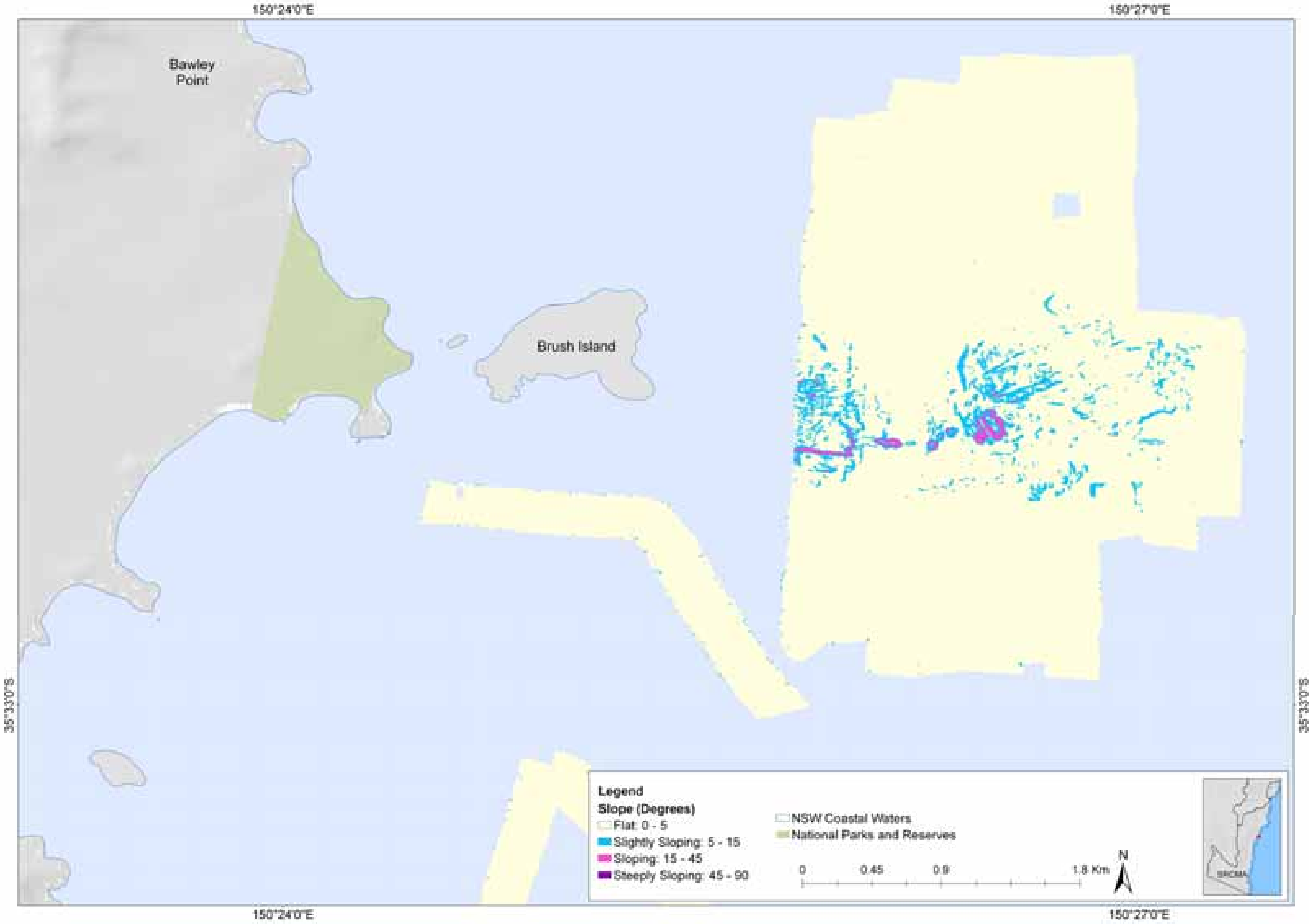


Figure 130. Slope model of the seabed adjacent to the Brush Island region.

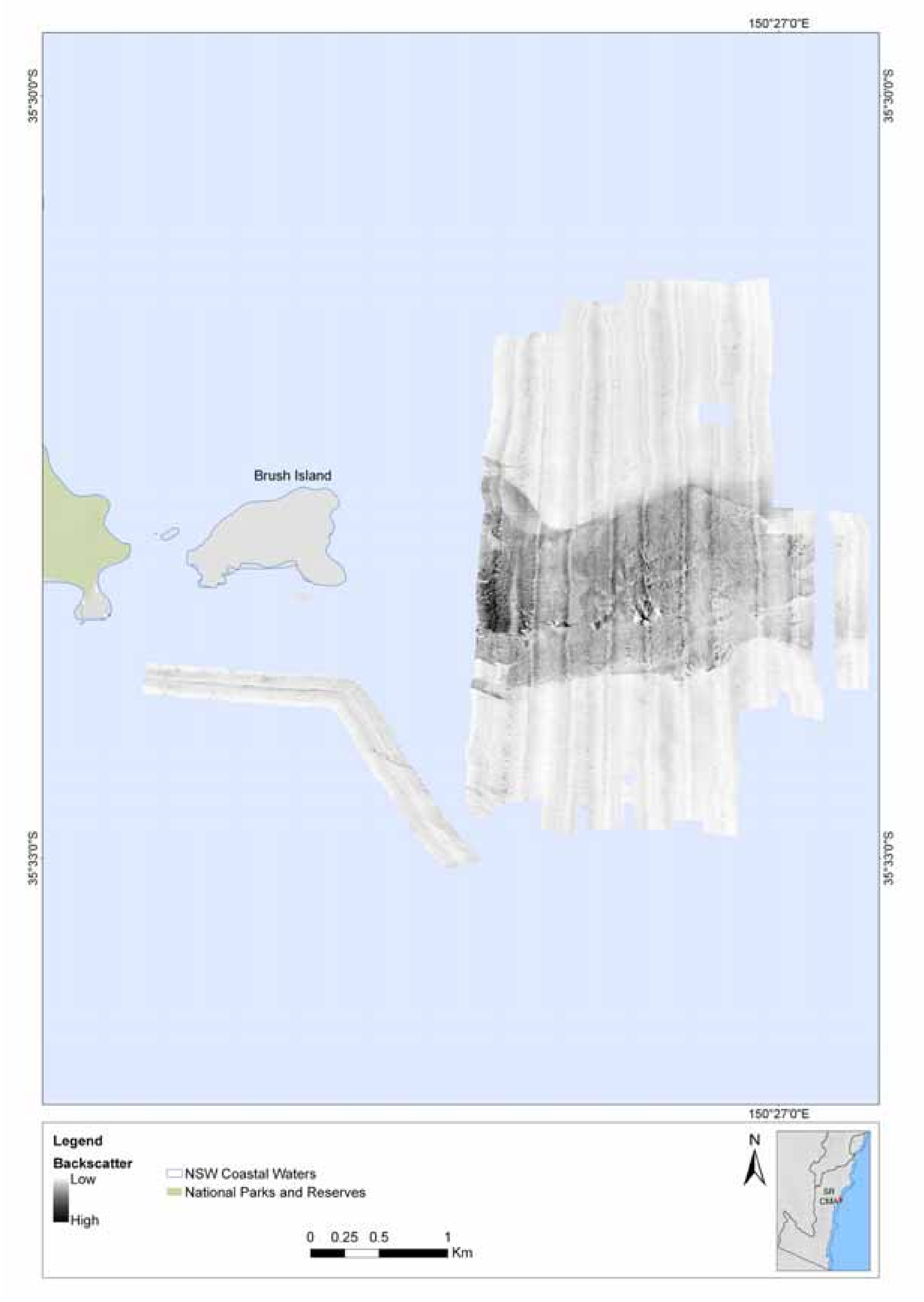


Figure 131. Acoustic backscatter of the seabed surrounding the Brush Island region.

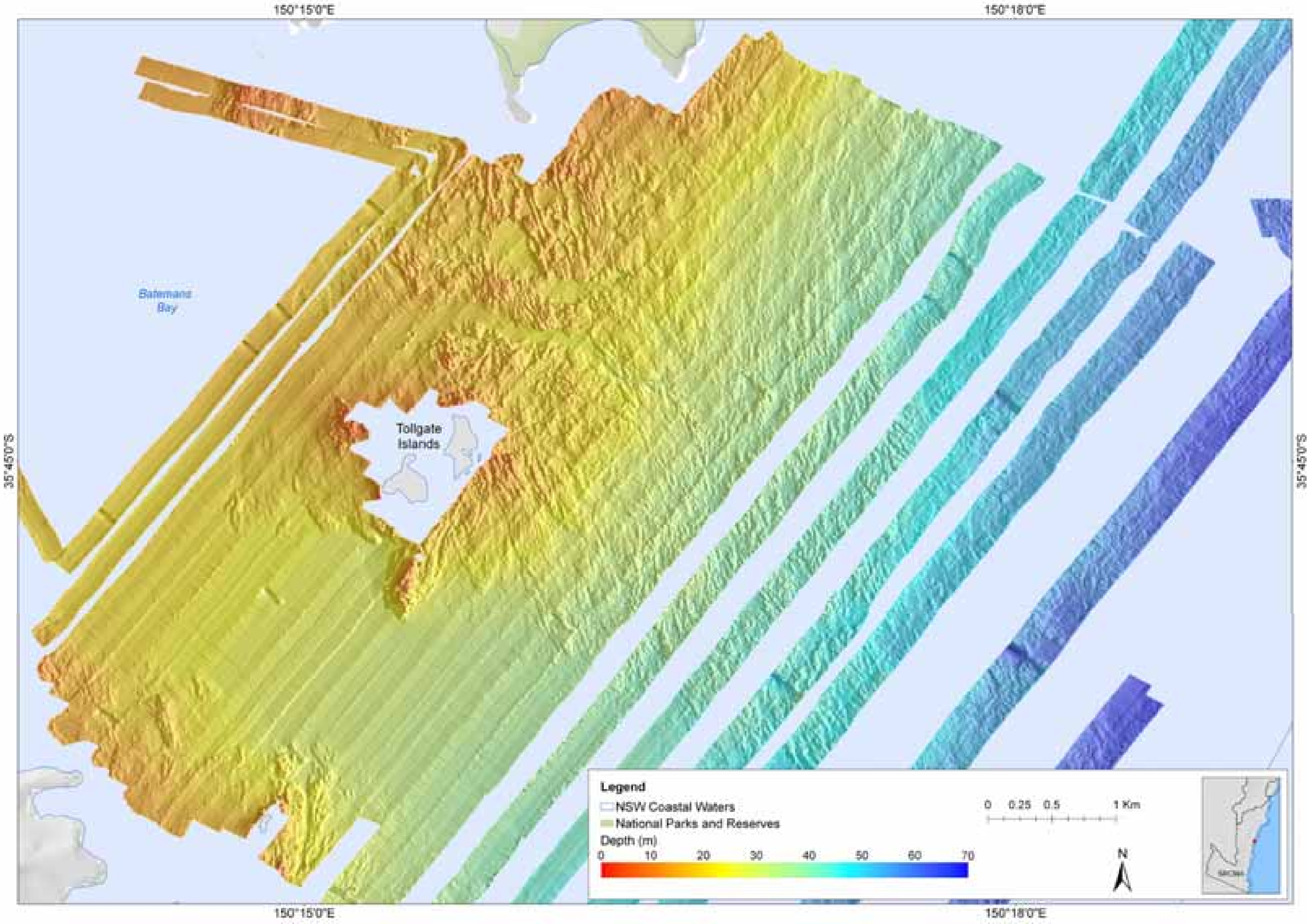


Figure 132. Hill-shaded bathymetric model of the seabed surrounding the Tollgate Islands region.

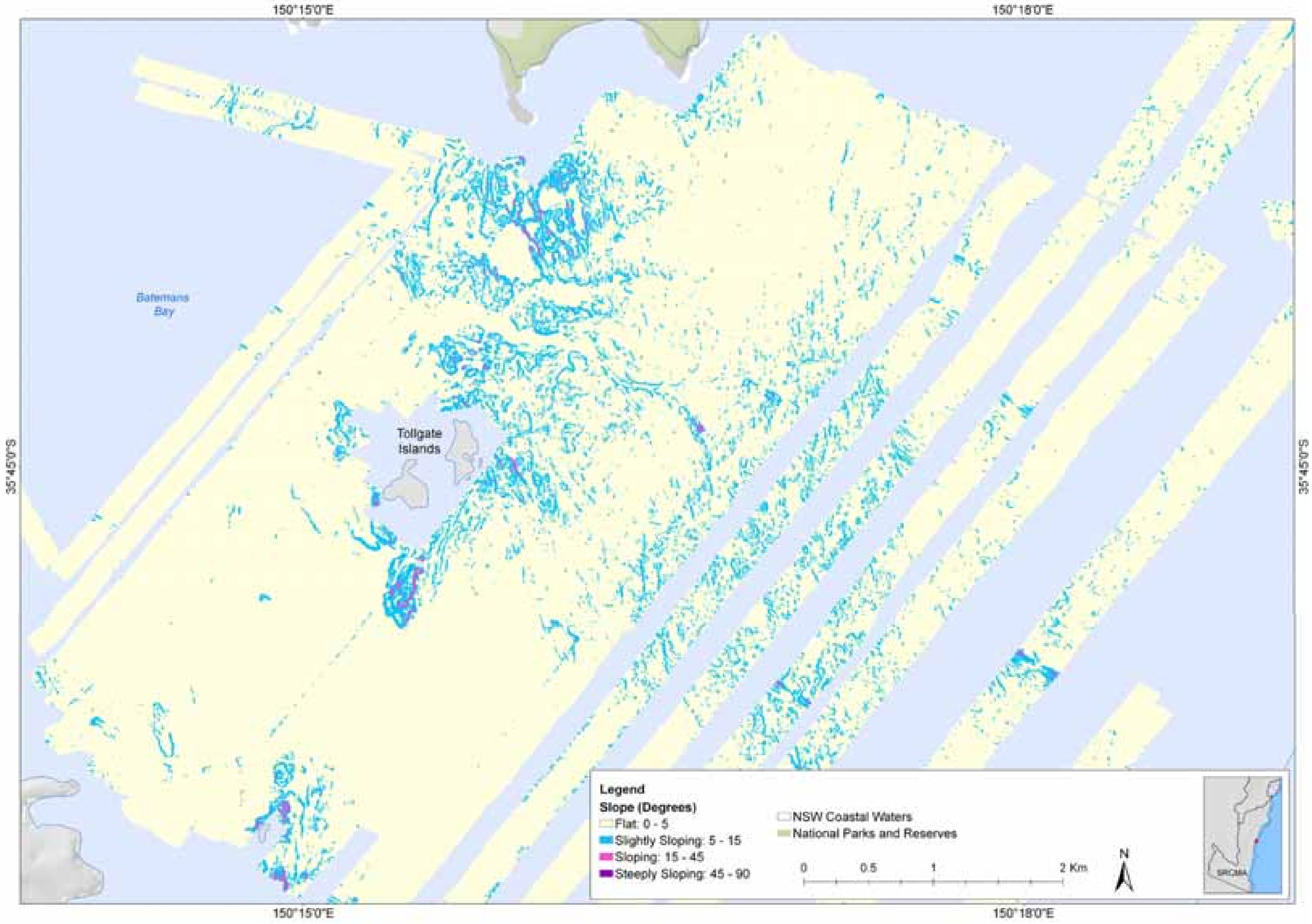


Figure 133. Slope model of the seabed adjacent to the Tollgate Islands region.

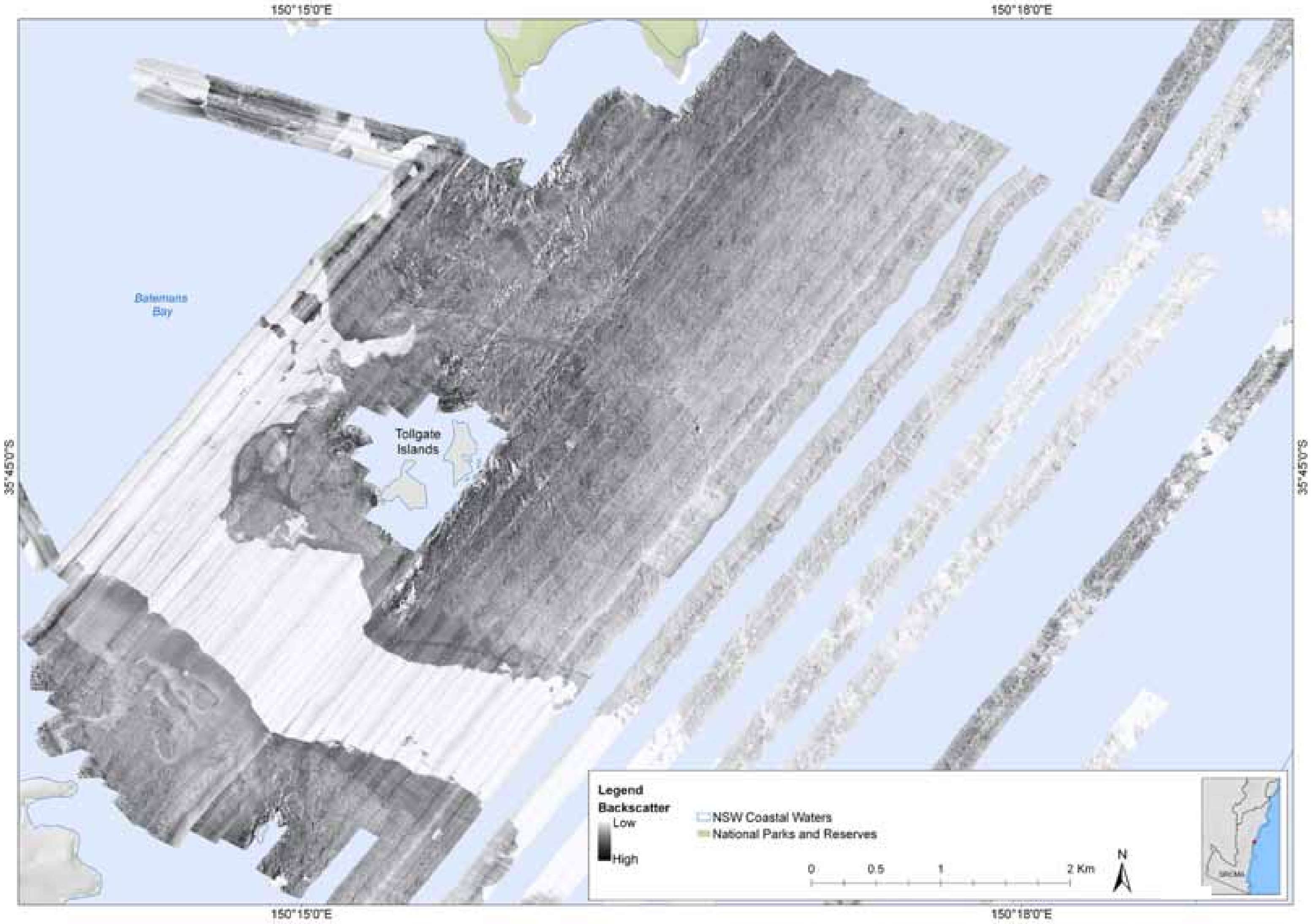


Figure 134. Acoustic backscatter of the seabed surrounding the Tollgate Islands region.

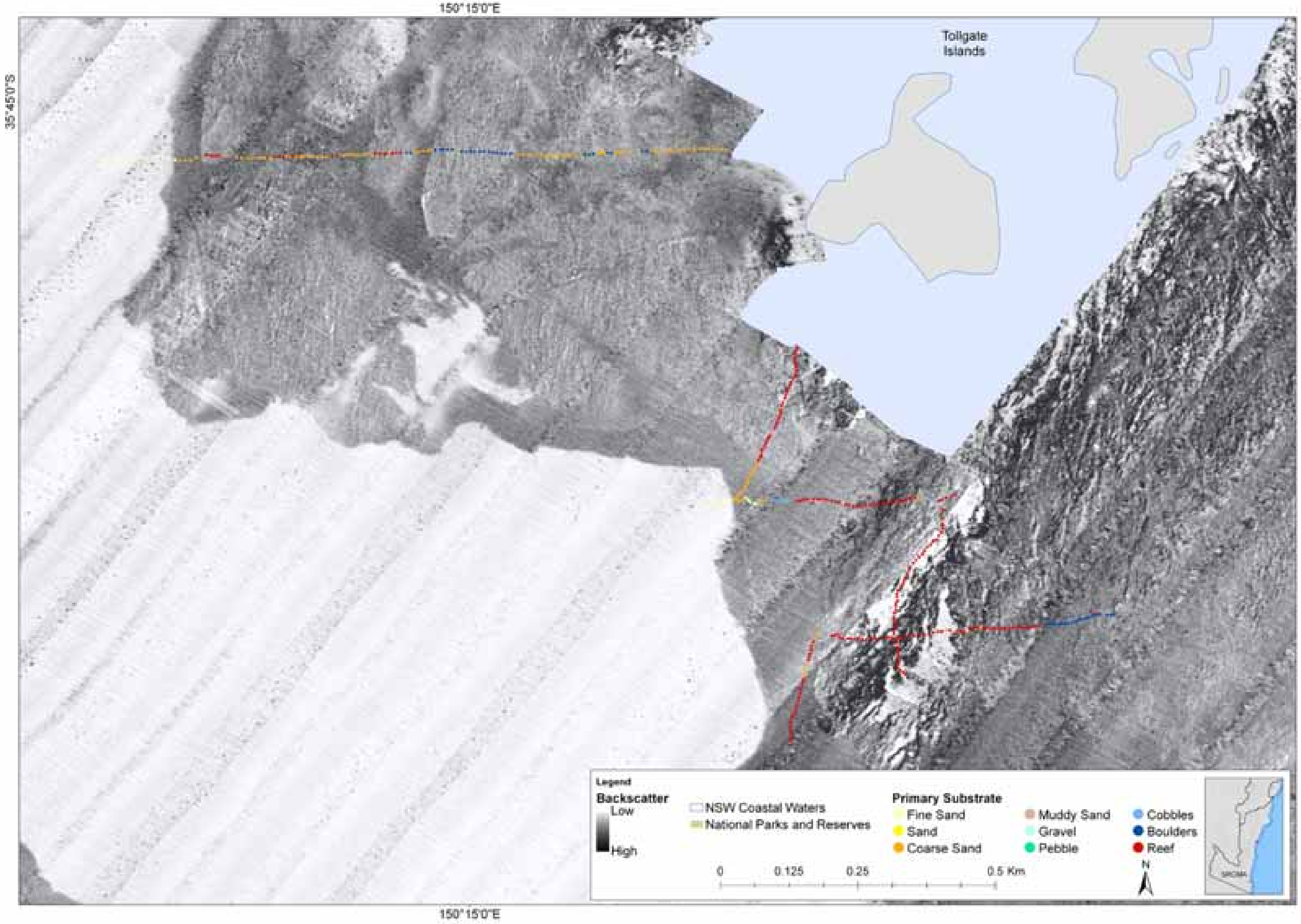


Figure 135. Acoustic backscatter of the seabed south of the Tollgate Islands region.

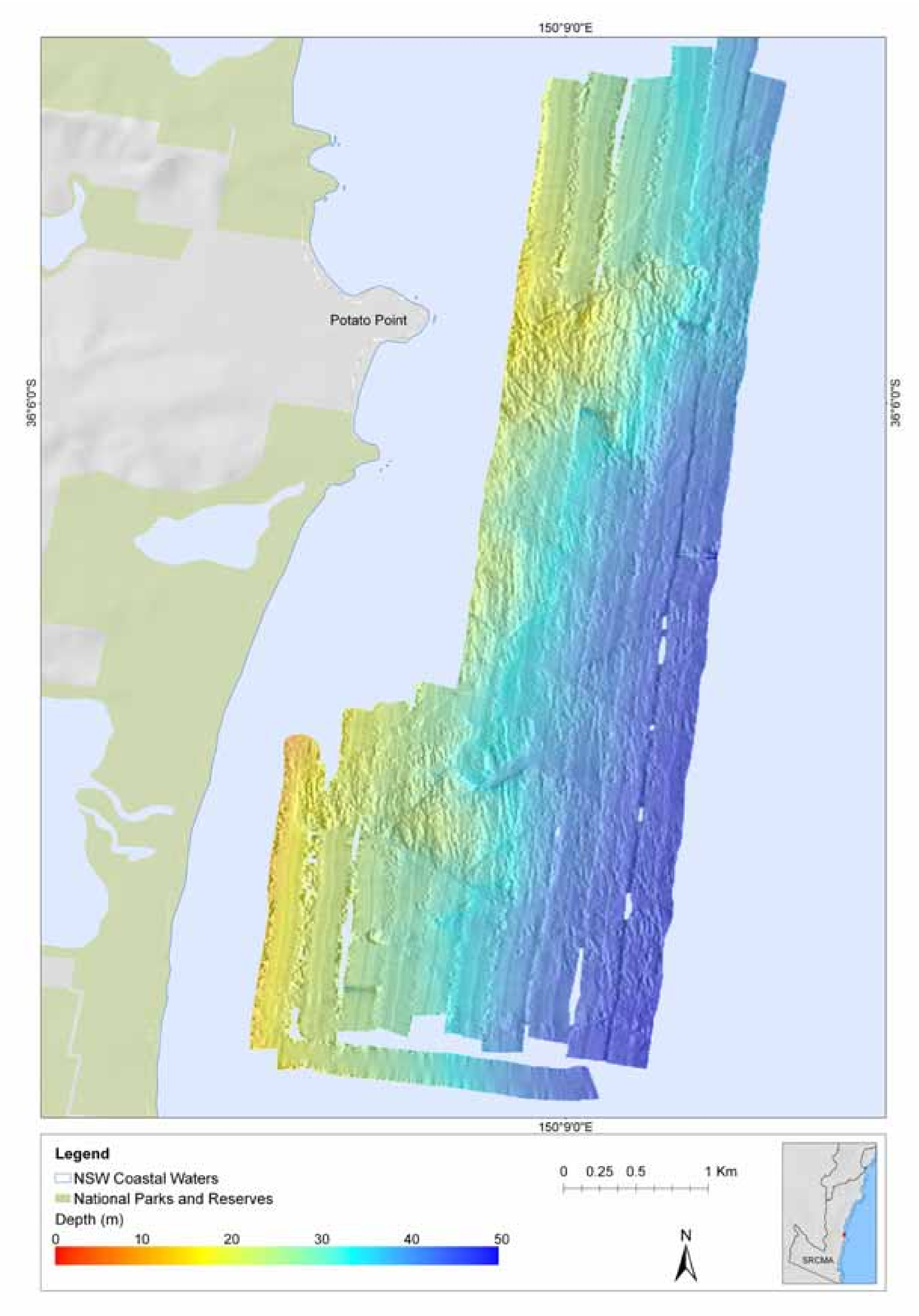


Figure 136. Hill-shaded bathymetric model of the seabed offshore of the Potato Point region.

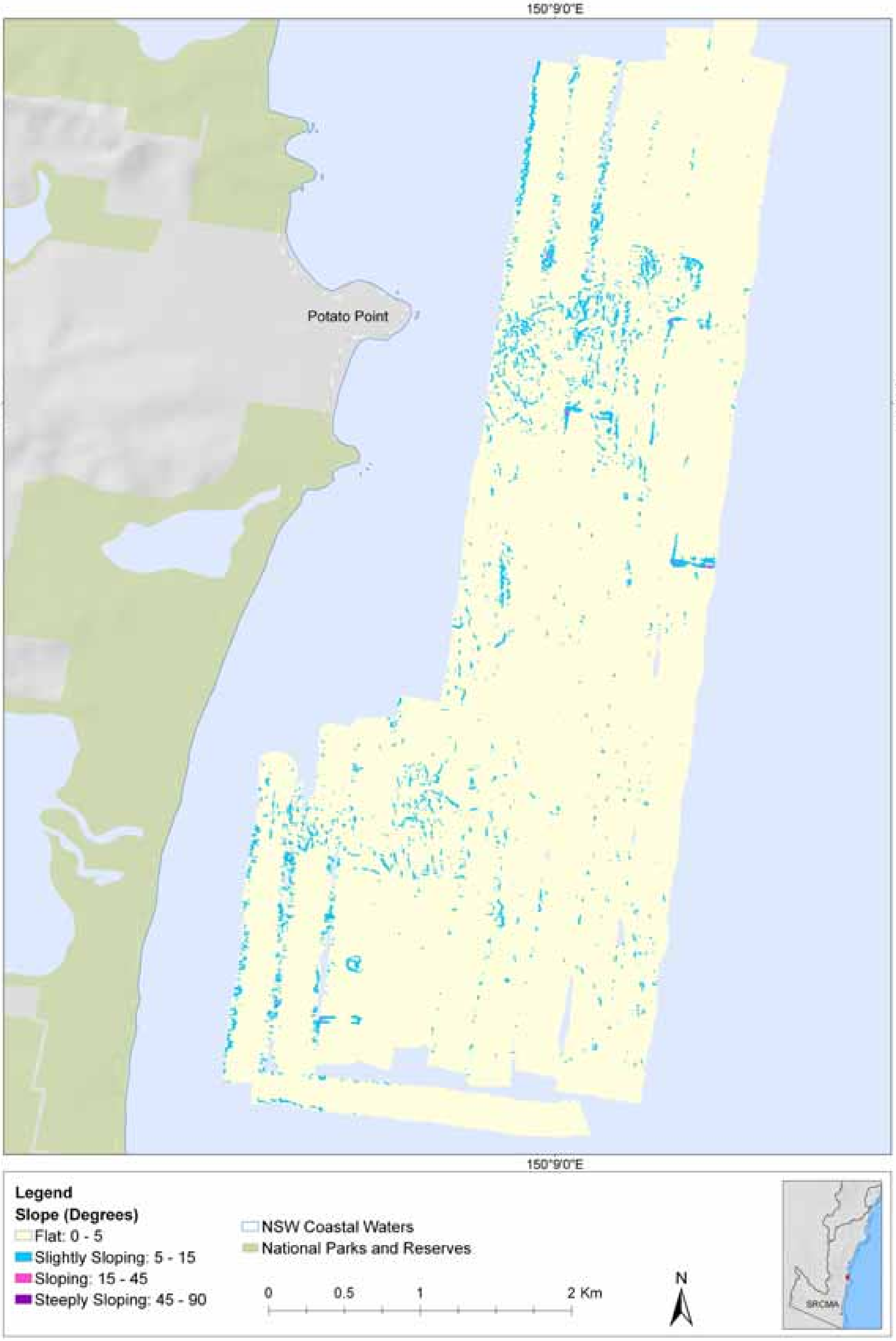


Figure 137. Slope model of the seabed offshore of the Potato Point region.

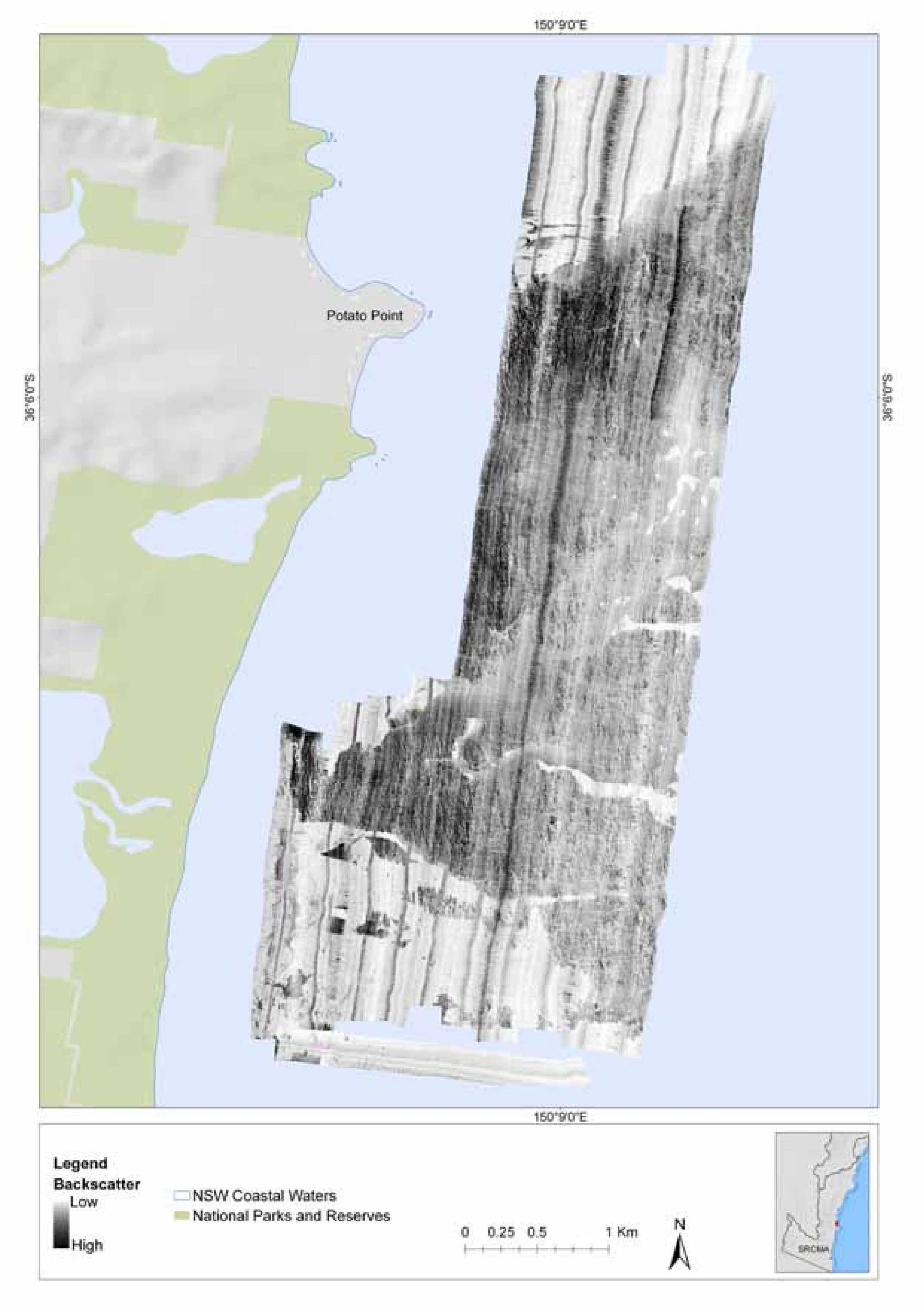


Figure 138. Acoustic backscatter of the seabed offshore of Potato Point.

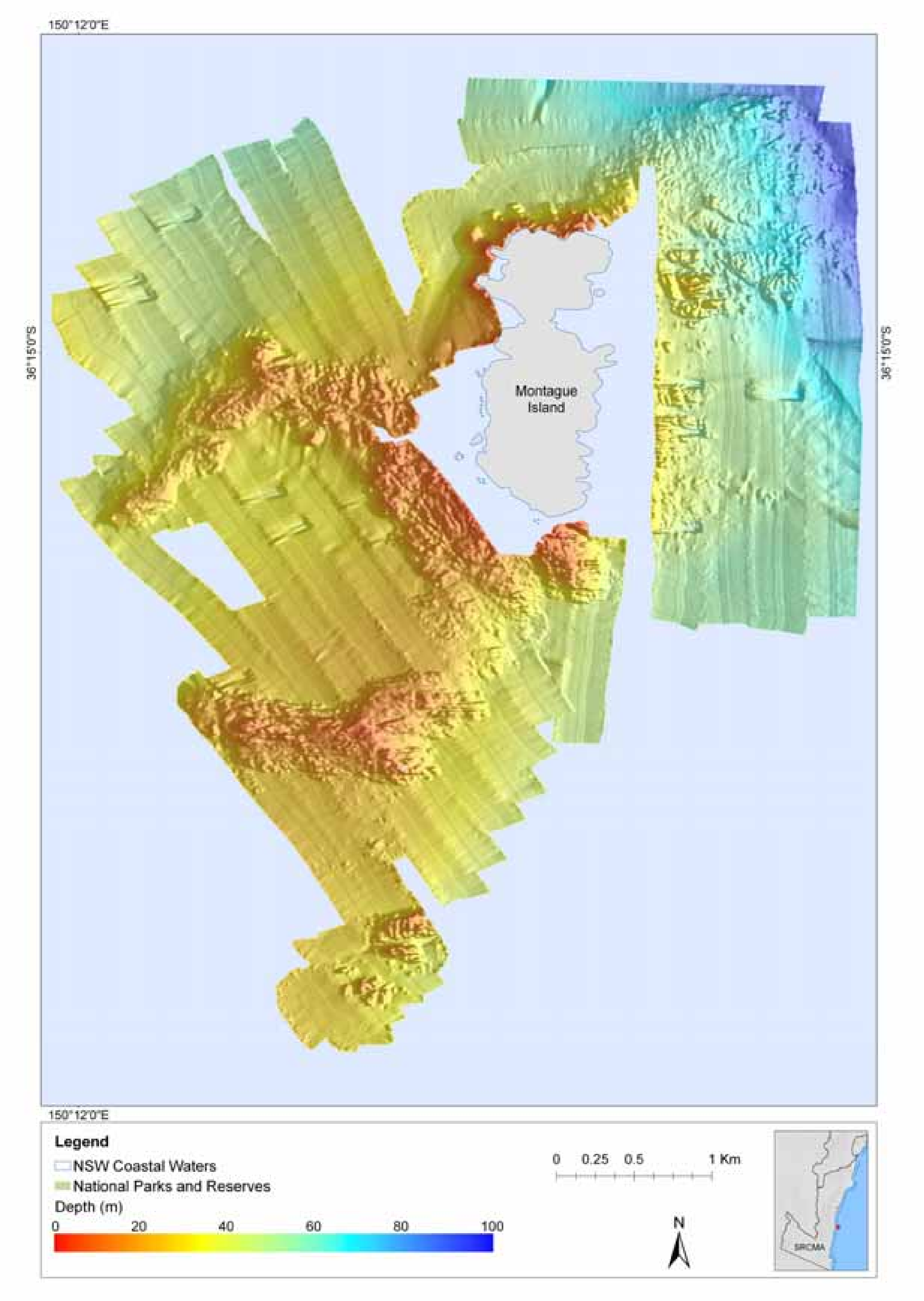


Figure 139. Hill-shaded bathymetric model of the seabed surrounding Montague Island.

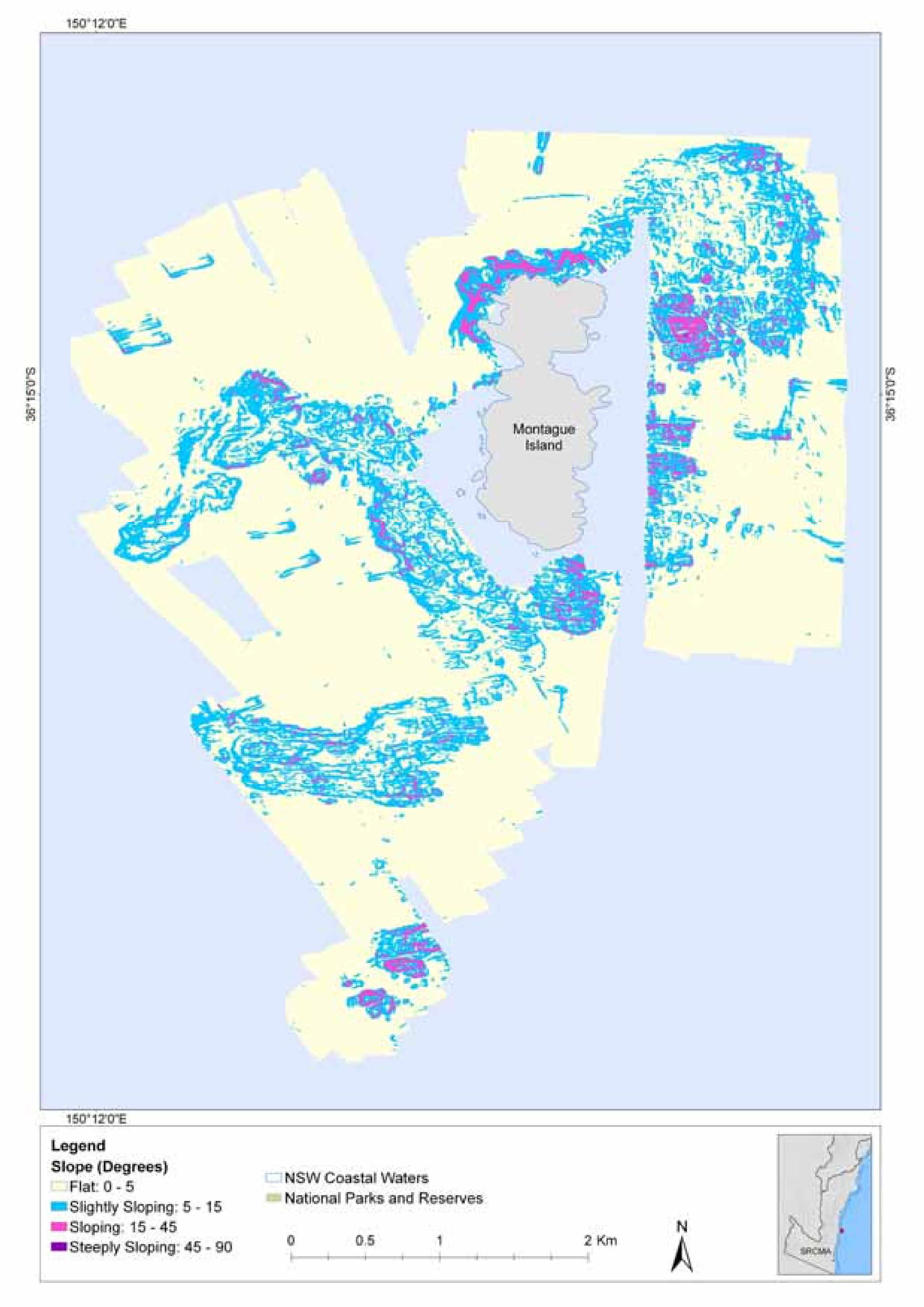


Figure 140. Slope model of the seabed surrounding Montague Island.

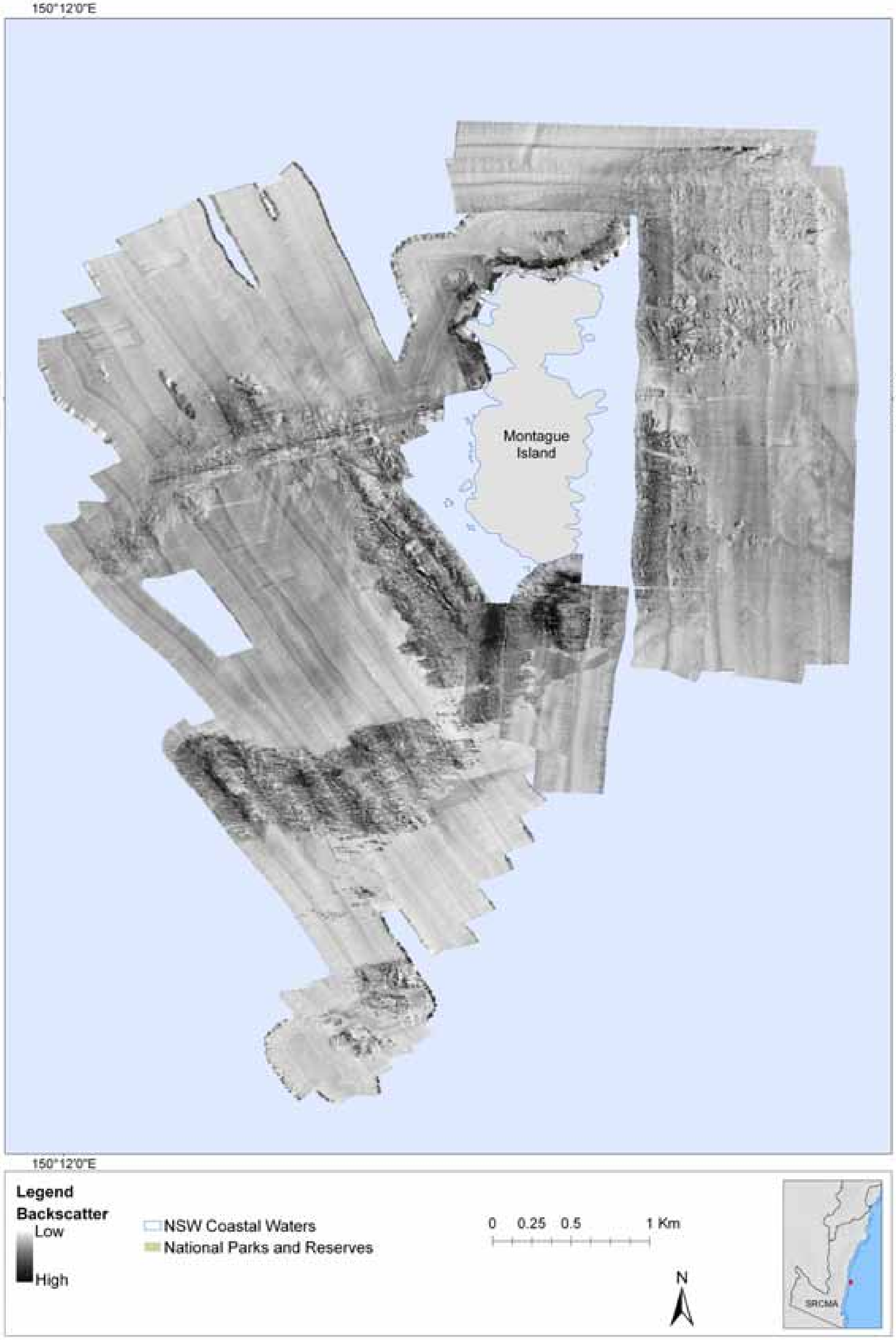


Figure 141. Acoustic backscatter of the seabed adjacent to Montague Island.

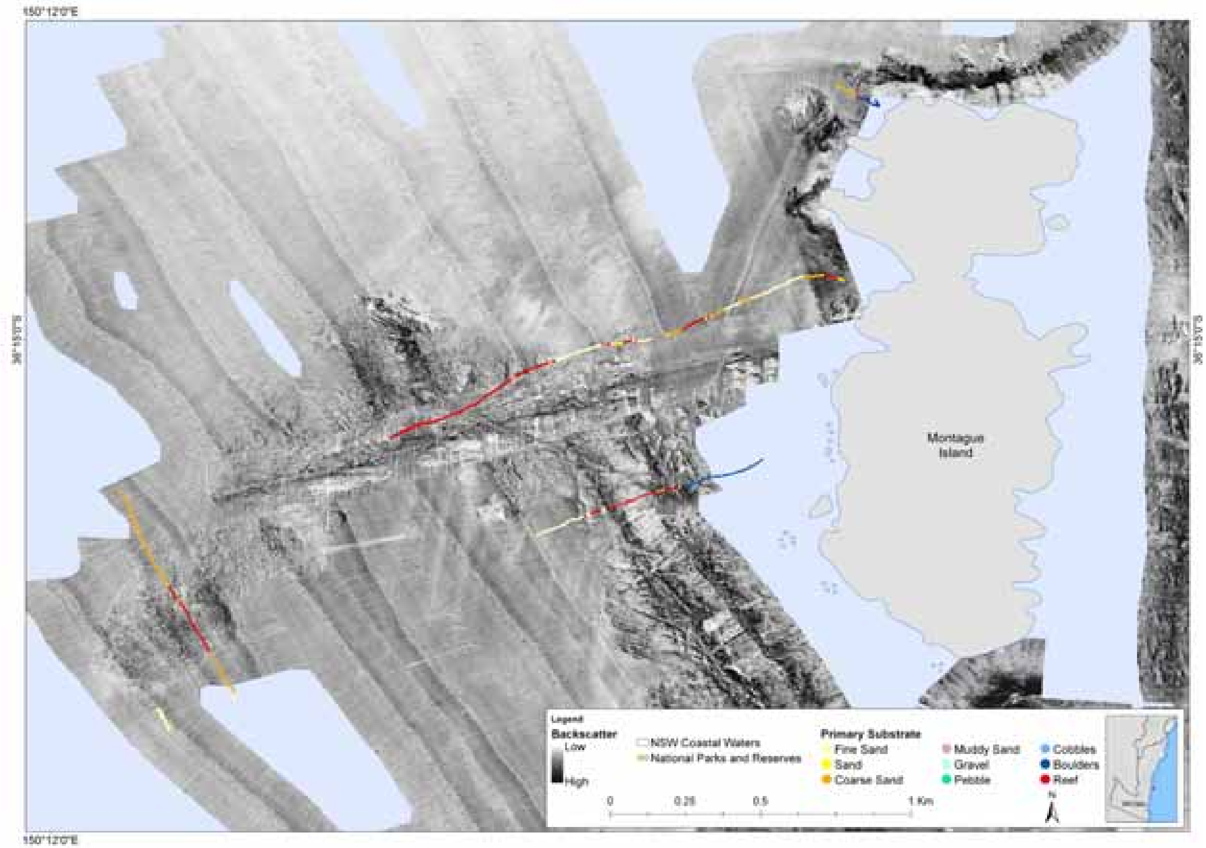


Figure 142. Acoustic backscatter of the seabed east of Montague Island.

A total of 6.3 linear kilometres of video footage was taken over 12 transects near Montague Island and the Tollgate Islands. Reef in these areas supported a mosaic of urchin barrens habitat, *E. radiata*, sponges and mixed algal assemblages (Figure 143). Reef at depths less than 15 metres, particularly complex high-profile and boulder reef, was dominated by the sea urchin, *C. rodgersii* (Figure 144). *E. radiata* was common on reef and areas of mixed reef/sand (Figure 145) at depths of 10–30 metres, which contained a high cover in most areas (Figure 143). Sponges were observed over similar depth strata, with encrusting and massive sponges found alongside sea urchin barrens habitat, and branching, cup, and elongate sponges forming distinct sponge gardens at depths of 20–30 metres (Figure 146). Ascidians, particularly *P. spinifera*, were common alongside sponges in the 20–30 metre depth range. Stands of unidentified green algae (Chlorophyta) were common as an understory to *E. radiata* in the 12–18 metre depth range. Dense stands of green algae, possibly *Caulerpa flexilis* (Figure 147), were observed at Montague Island and were small (estimated to be less than 10 metres across), patchy, and seemingly unrelated to depth.

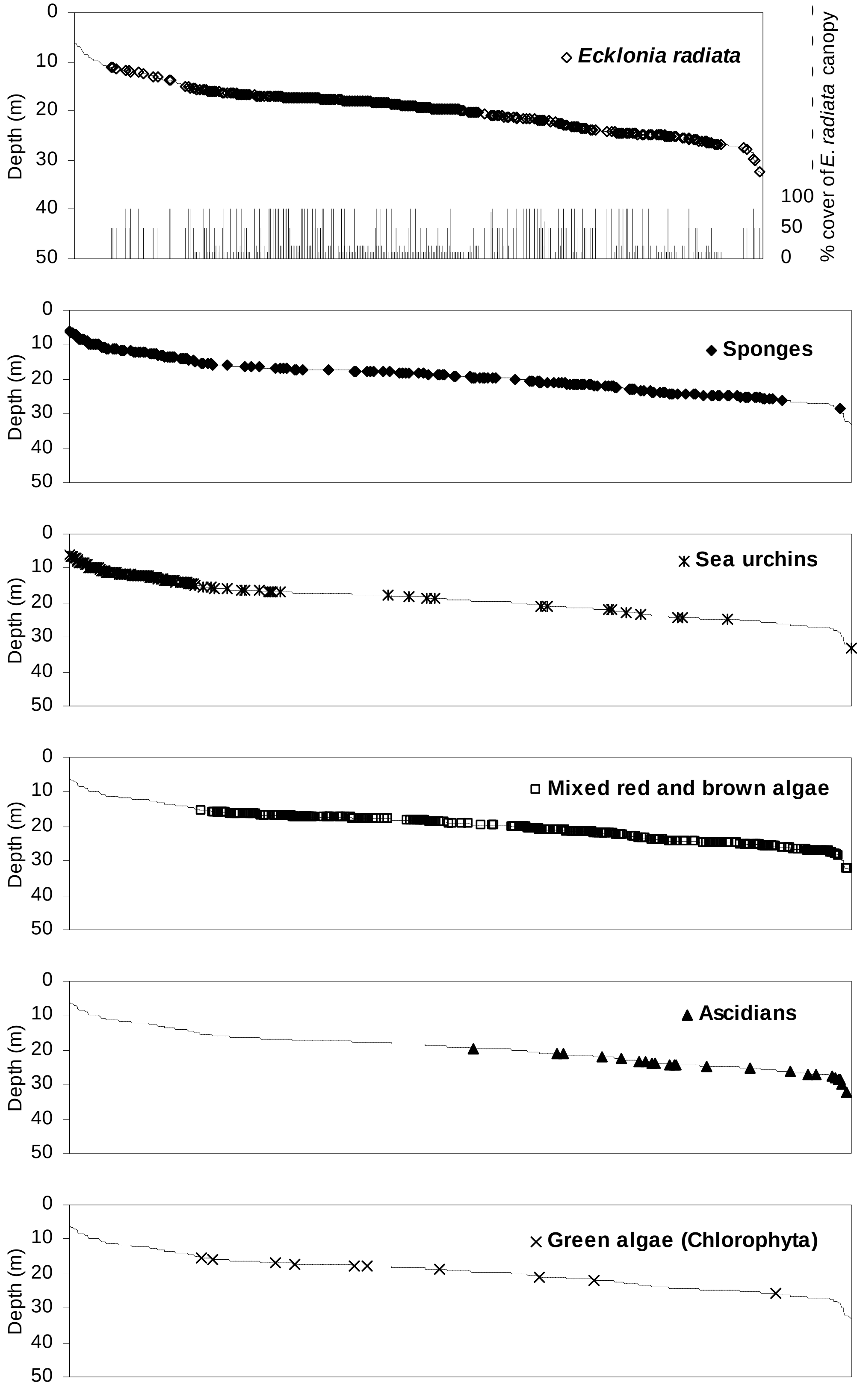


Figure 143. Presence of biota along video transects near the Tollgate Islands and Montague Island.

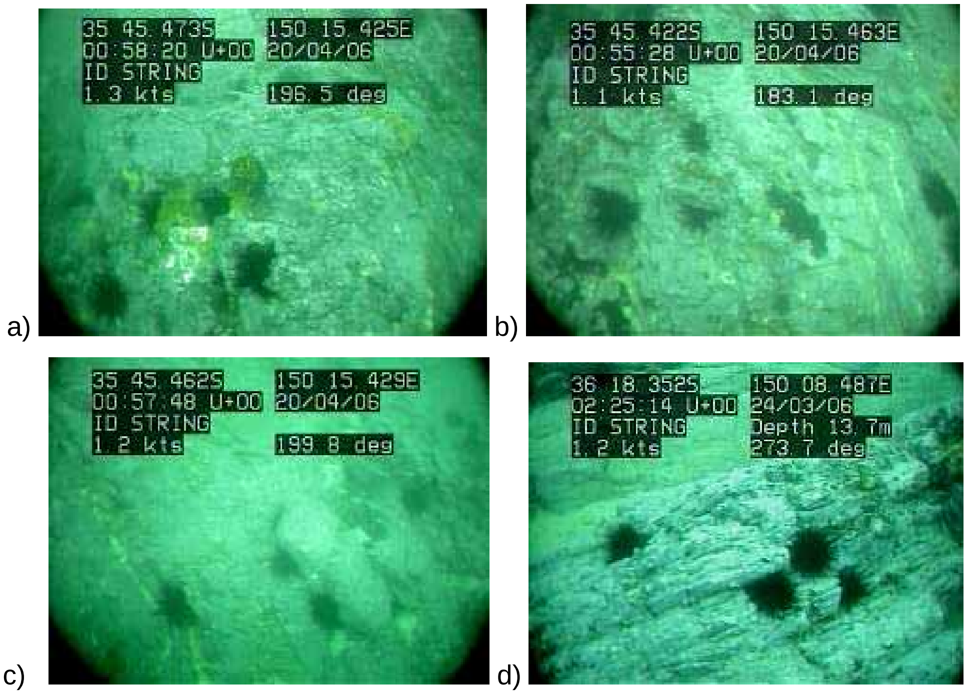


Figure 144. Barrens habitat near the Tollgate Islands (a–c) and Montague Island (d).

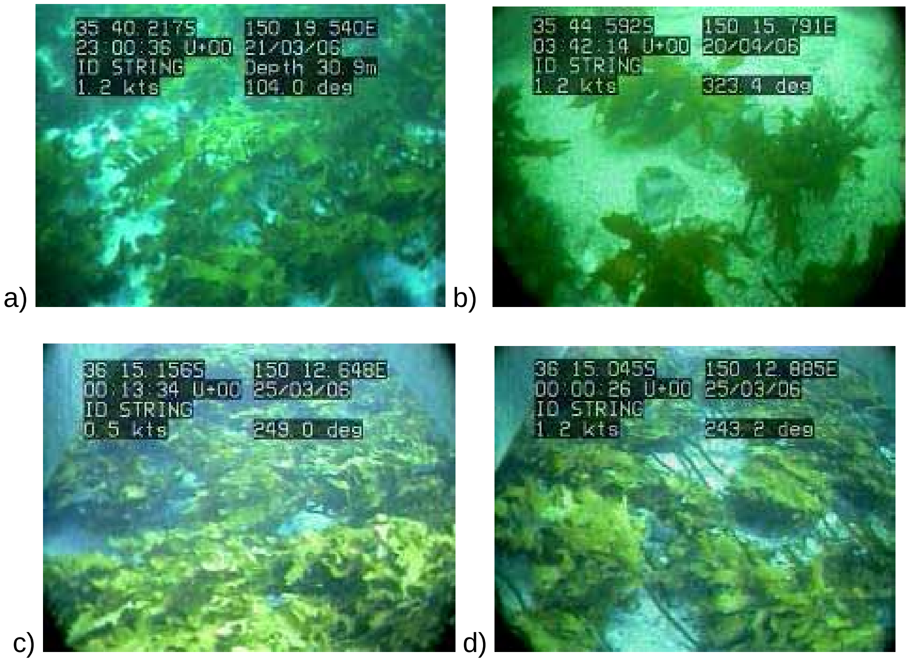


Figure 145. Kelp (*E. radiata*) stands at the Tollgate Islands (a–b), and Montague Island (c–d).

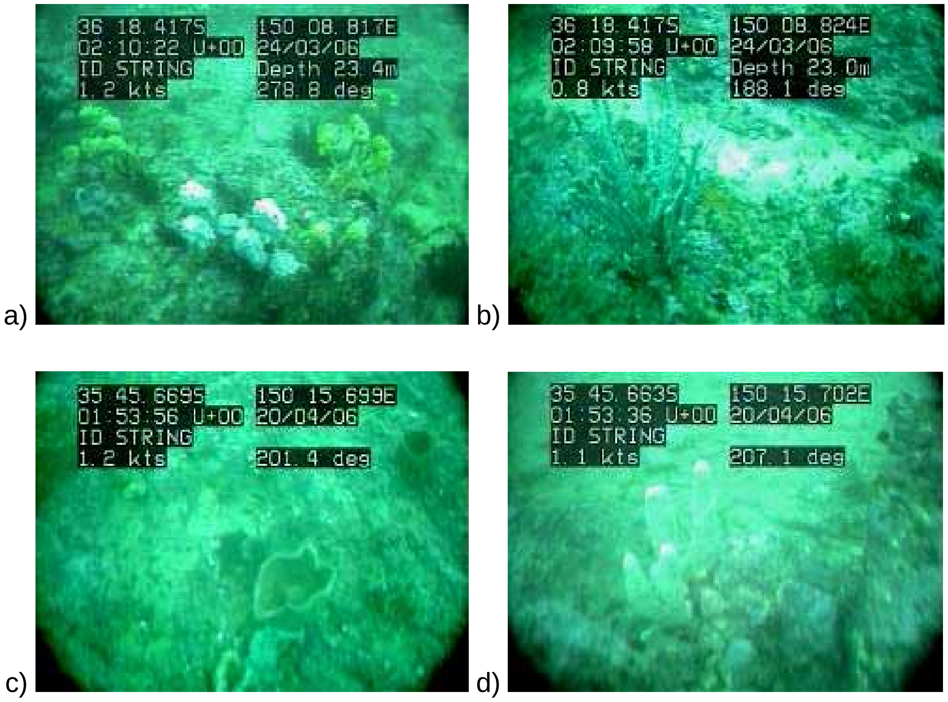


Figure 146. Sponges on reef at Montague Island (a–b), and the Tollgate Islands (c–d). Note the presence of the ascidian *P. spinifera* in (a).

Figure 147. Green algae (possibly *Caulerpa flexilis*) on shallow reef habitat at Montague Island.

4.3.14 Bermagui to Cape Howe

The distribution of seabed habitats in the region between Bermagui and Cape Howe was characterised by nearshore reefs occurring adjacent to rocky shoreline interspersed between a number of sand-dominated beaches that varied from about 300 metres to more than 7 kilometres in length (Figure 148). The largest areas of nearshore reef occurred along the sections of coast north and south of Mimosa Rocks, Tathra Head, and between Twofold Bay and Disaster Bay. The majority of this reef system extended further offshore than could be mapped from the aerial photos. This was supported by the swath acoustic data from the Twofold Bay region, which mapped the extent of reef for a distance up to 2 kilometres offshore along 15 kilometres of coastline (Figure 149). The majority of the reef in this area was in intermediate water depths and extended to depths up to 57 metres.

The swath survey revealed the reef systems off the northern headland of Twofold Bay were continuous along the entire shore and extended around 1.7 kilometres offshore. The reef system was somewhat complex with semi-regular gutters running in a predominantly north-south direction that were predominantly 1 metre or less deep (Figure 150). A distinct large reef system was also present off the southern headland of Twofold Bay that extended around 2 kilometres offshore and was characterised by a large number of ridges and gutters that ran mostly north-south. The eastern edge of the reef extended to a depth of about 50 metres. A further 2 kilometres to the south there was a complex reef system extending to the edge of the swath coverage and, presumably, beyond this limit. It had distinct patchy reef features that were predominantly long, thin curvilinear or folding features, with some interspersing larger blocks of reef, separated by unconsolidated sediments.

The shallow nearshore reef directly off Eden ranged further offshore than what could be determined from aerial photos, with the western edge of the system just reaching into the intermediate-depth range. Some very small and patchy intermediate reef occurred as distinct peaks in the bathymetry in the middle of the entrance to Twofold Bay.

Overall, the main reef systems were divided into three main areas by stretches of unconsolidated sediments that were about 100 metres wide (Figure 151). There was clear evidence of distinct boundaries between the areas of fine and coarse sand, particularly on the northern and southern areas of Twofold Bay. The main reef systems within this swathed area were mostly surrounded by intermediate to dark homogenous backscatter, indicating coarser unconsolidated substrate.

South from Twofold Bay continuous nearshore reef was almost consistent to Disaster Bay and was interrupted by a number of small sandy beaches. Consistent with other areas, it was likely that the reef extended deeper than the 15–20 metre depth-limit of the aerial photos. Small and very patchy nearshore reef was present to the south of Disaster Bay, in an otherwise very sandy-substrate-dominated section of the coast that continued to the north of Nadgee Lake. South from Nadgee Lake to Cape Howe, shallow reef extended from peninsulas interspersed with sandy seabed offshore of beaches.

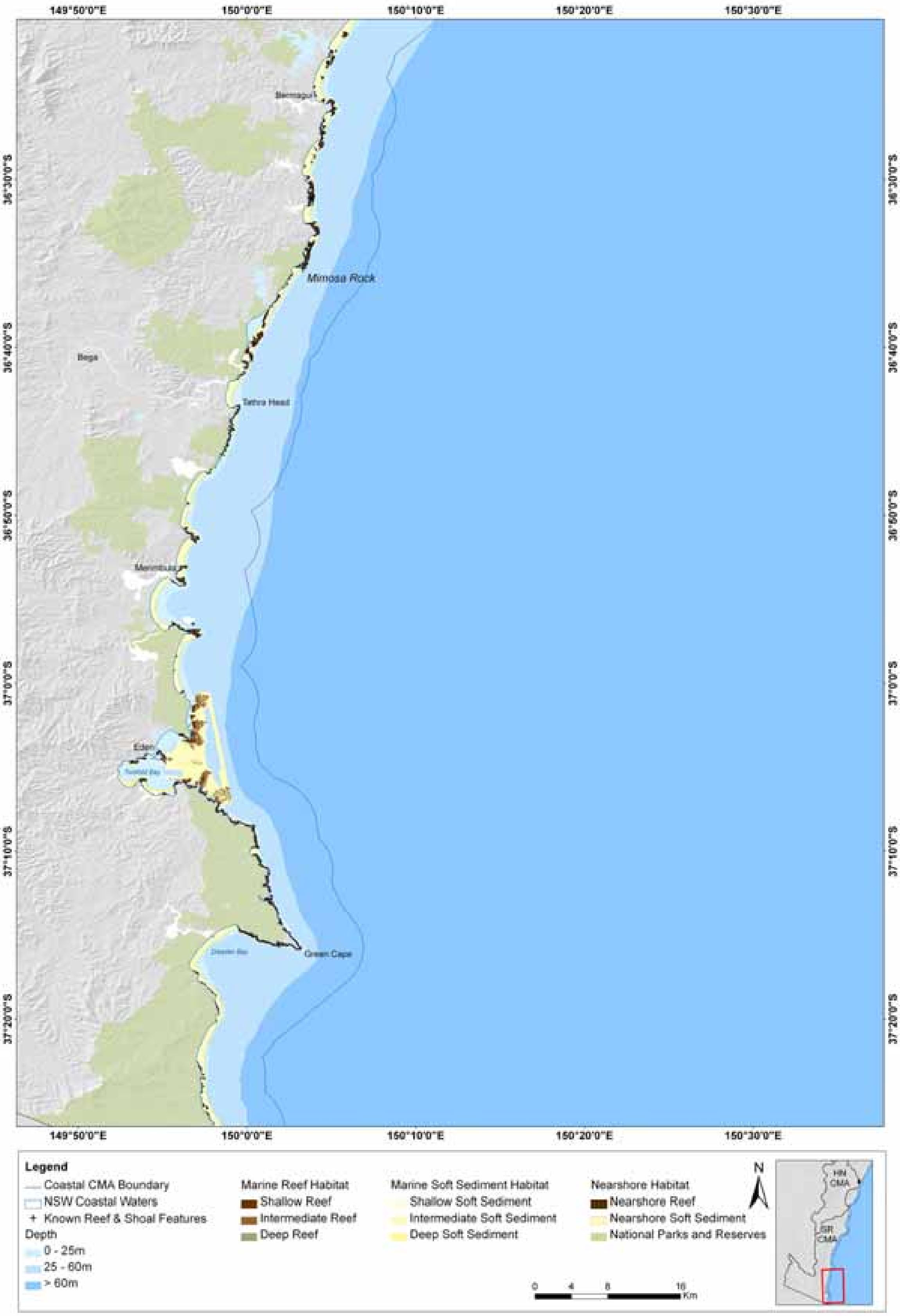


Figure 148. Distribution of known seabed habitats within the region between Bermagui and Cape Howe.

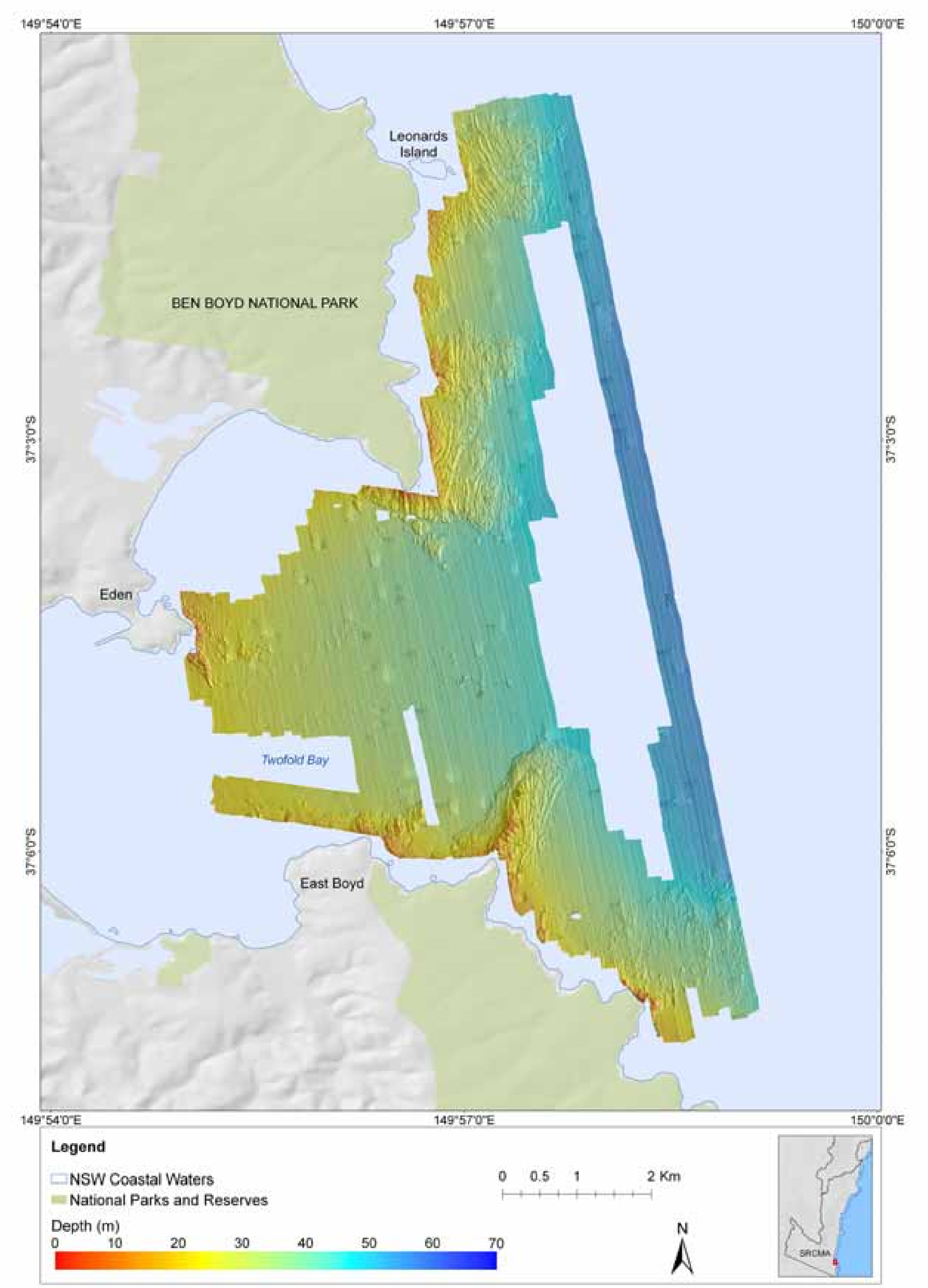


Figure 149. Hill-shaded bathymetric model of the seabed within the Twofold Bay region.

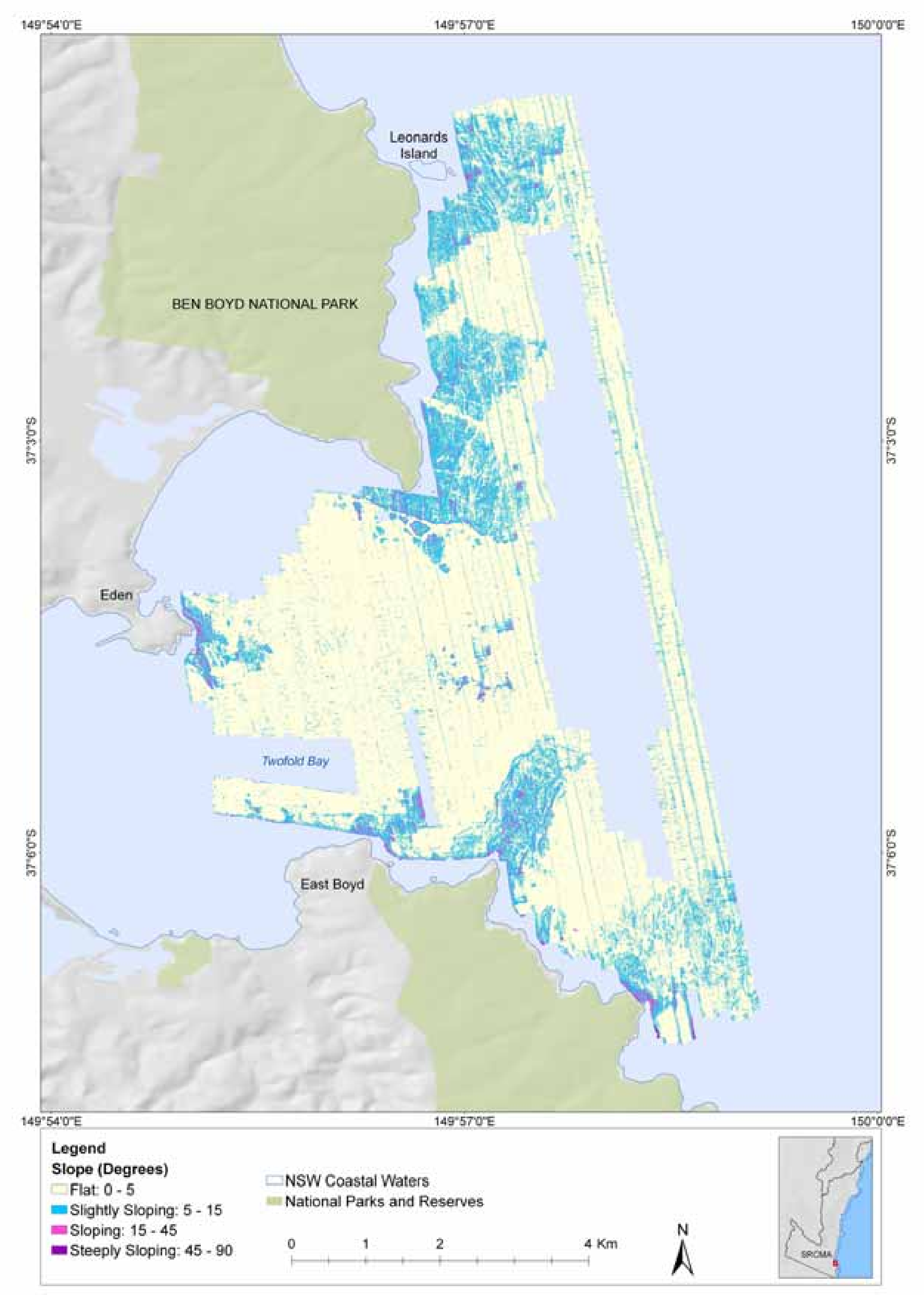


Figure 150. Slope model of the seabed within the Twofold Bay region.

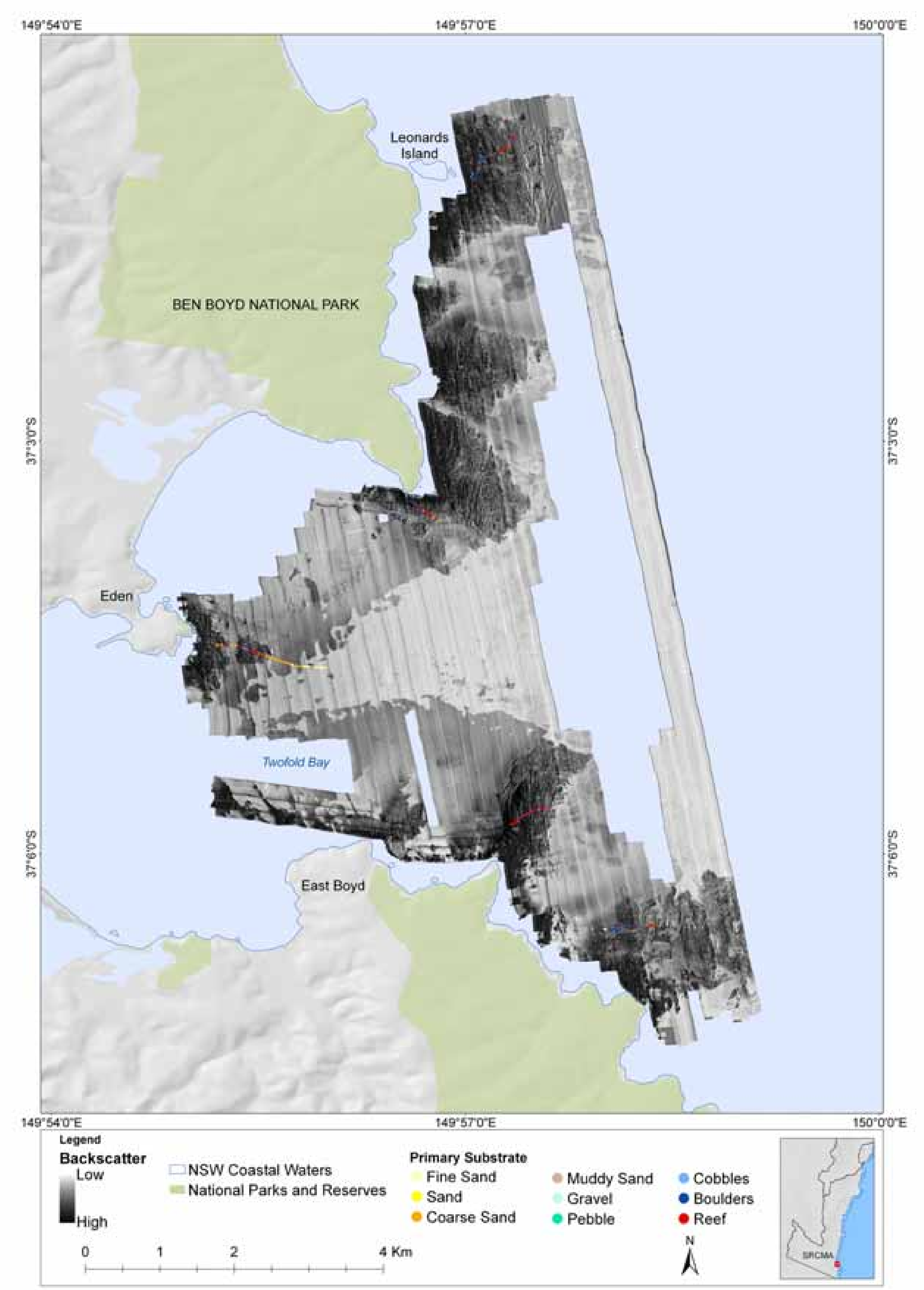


Figure 151. Acoustic backscatter of the seabed offshore within the Twofold Bay region.

Approximately 5 linear kilometres of video footage was collected across five transects near Twofold Bay, Eden. Barrens habitat, dominated by the long-spined sea urchin, *C. rodgersii*, was relatively common on boulder and bedrock reefs, particularly those reefs with complex gutters and crevices (Figure 154). Kelp (*E. radiata*) was relatively rare and was only observed at depths between 16 and 25 metres (Figure 152). Kelp was fixed to reef and areas of patchy reef and sand (Figure 156), and was usually found nearshore with canopy cover rarely exceeding 40%.

Barrens habitat was observed at depths of 7–27 metres, although it was most apparent in the 7–15-metre depth range (Figure 152), and was widespread on reefs on the southern side of Twofold Bay. The introduced encrusting bryozoans, *Watersipora sp.*, were observed at depths of 10–27 metres. Many areas of high-relief reef, particularly boulder reef, were covered by *Watersipora* (Figures 153 and 155). Several reefs exhibited a pattern of barrens habitat in shallower areas that gradually gave way to *Watersipora*-dominated reef at increasing depths. Encrusting pink coralline algae was common on boulder reefs at depths of 25–38 metres. Much of the reef between 15 and 35 metres supported a rich mosaic of sponges and mixed algal assemblages (Figures 153 and 157). Sea whips (most likely *Primnoella australasiae*) were observed in areas of patchy reef and sand at depths between 25 and 35 metres. Soft sediments along video transects in Twofold Bay were a mosaic of fine- and coarse-grained sand. The coarser-grained sand usually had well-defined waves with shellgrit in the troughs, whereas the finer-grained sand appeared to have less well-defined ripples and a more uniform grain size without shellgrit (Figure 158).

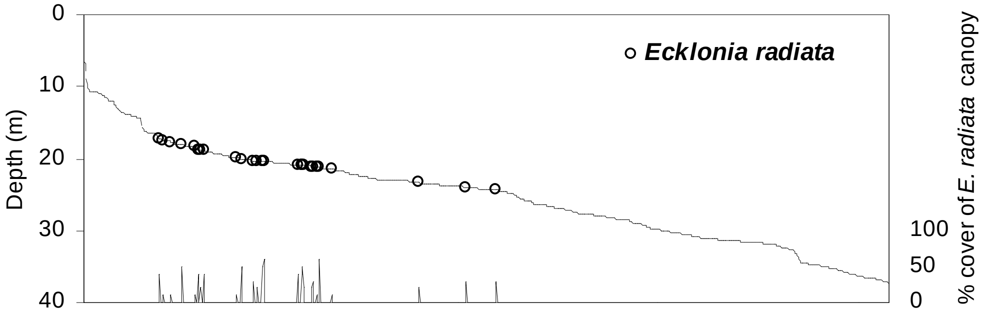


Figure 152. Presence of kelp (*E. radiata*) along video transects near Twofold Bay.

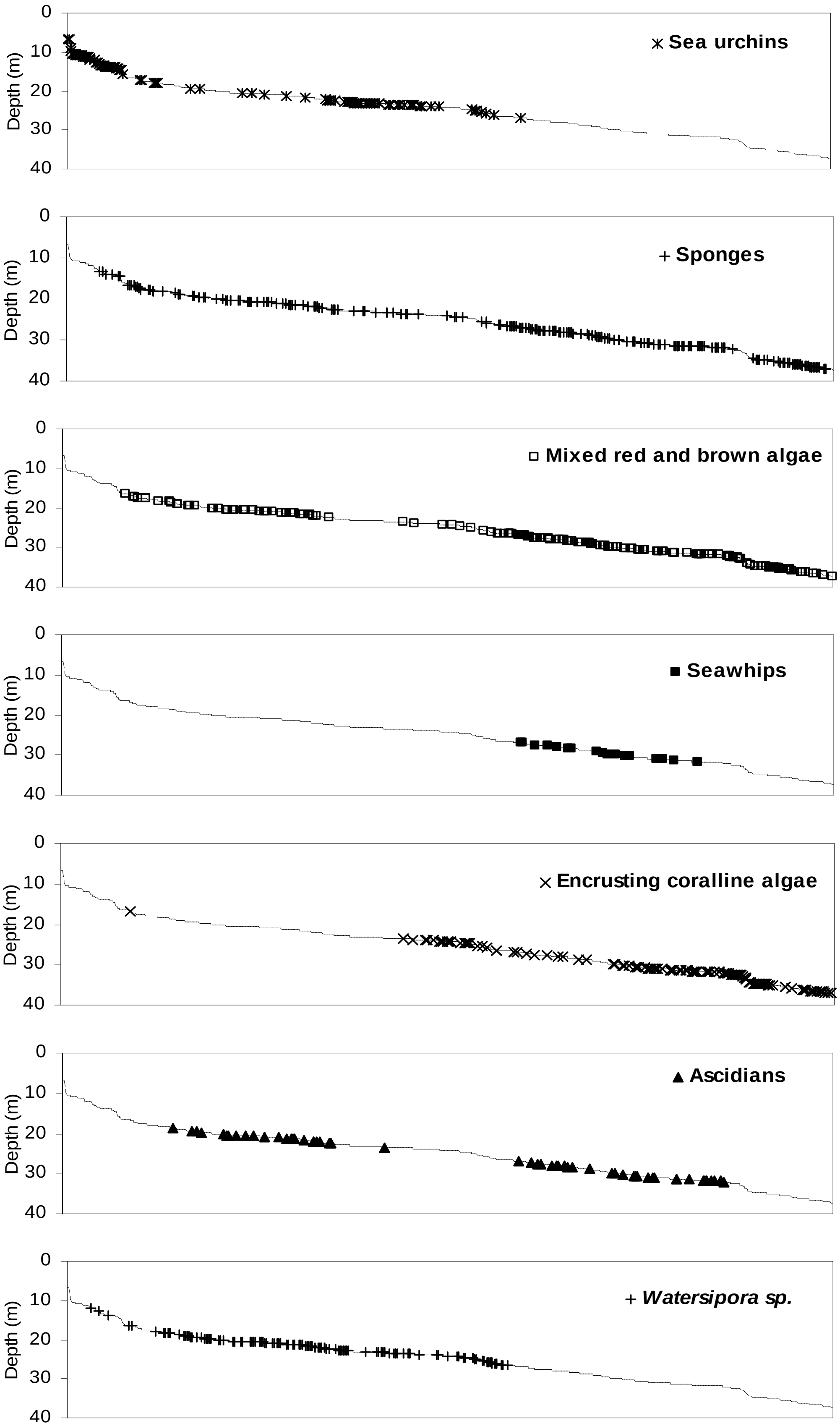


Figure 153. Presence of biota along video transects near Twofold Bay.

Figure 154. Sea urchin-dominated barrens habitat on reef near Twofold Bay.

Figure 155. Encrusting bryozoans, *Watersipora* sp.

Figure 156. Kelp (*E. radiata*) on bedrock reef and patchy boulder reef near Twofold Bay.

Figure 157. Sponges on reef near Twofold Bay; note the ascidian, *P. spinifera*, in (b).

Figure 158. Coarse sand with waves and shellgrit (a–b), and fine sand with ripples (c) in Twofold Bay.

5. Discussion

The primary aim of this report is to document the information currently available on bathymetry, surficial sediments and seabed habitats within continental shelf waters of NSW. Existing datatsets for broadscale bathymetry, sediments and seabed habitats defined from single-beam and swath acoustic surveys as well as aerial photography were collated from a wide range of sources. These datasets were supplemented with high-resolution bathymetry and acoustic backscatter information from targeted swath acoustic surveys conducted at a number of continental shelf locations along the NSW coast that primarily focussed on the inner- and mid-continental shelf regions. These data layers were used to map the fine-scale distribution and extent of biophysical seabed habitats within this region. The swath bathymetric data was combined with the existing broadscale bathymetric data to calculate bathymetric grids and depth contours throughout the survey region, and to calculate the slope of the seabed to assist in the description of rocky reef structure. The acoustic backscatter allowed an assessment of the spatial extent and distribution of rocky reef and unconsolidated habitats. Video footage was used to describe the dominant benthic assemblages from a number of rocky reef and unconsolidated habitats along the NSW coast as well as the broad distribution of a number of habitat modifiers. Approximately 1500 square kilometres of swath-acoustic coverage from NSW continental shelf waters has been collated from various sources allowing a significant improvement in the information available on the distribution, extent and structure of seabed habitats throughout the region. This area, combined with the mapping coverage of nearshore reef and sand habitats mapped using aerial photographs (about 825 square kilometres), has resulted in habitat mapping coverage of approximately 28% of NSW state coastal waters outside of estuaries.

Firstly, the broadscale bathymetry revealed considerable variations in the overall width- and depth-structuring of the continental shelf. This results in regional variations in the distance to the shelf break and the depth in which the shelf break occurs; the narrowest sections occur offshore of Montague Island, Jervis Bay and Smokey Cape, and the widest sections occur off Newcastle and Eden (Boyd et al 2004). Due to differences in the angle of the coast, the location of prominent headlands and slope of the seabed, the distance to the shelf break does not directly relate to the depth at which the shelf break occurs, which gradually decreases in areas north of Sugarloaf Point (Davies 1979, Boyd et al 2004). A recent analysis of the geomorphology of the NSW shelf and slope region is detailed in Keene et al 2008, which is based mostly on earlier analyses (e.g. Jones et al 1975, Davies 1979, Marshall 1980, Colwell 1982, Von Stackelberg 1982, Walsh and Roy 1983, Ferland and Roy 1997, Roy 1998, Boyd et al 2004, Roberts and Boyd 2004). Much of this recent analysis has focussed areas outside NSW state coastal waters.

The key feature of the shelf within state coastal waters is the regional and local variation in the slope of the seabed of the inner- and mid-shelf regions, which results in considerable spatial differences in the extent of shallow (0–25 metres), intermediate (25–60 metres) and deep (60–200 metres) seabed habitats. This is further influenced by the longitudinal position of the state coastal waters boundary, which varies from 5.6–18.4 kilometres off the coast. Overall, the inner-shelf is steeper along much of the coast south of Newcastle than regions further north, except in some areas where large reef systems are present such as in the southern part of Shoalhaven Bight. Steep subtidal gradients are prominent offshore of much of the Sydney coast and Jervis Bay where the 60 metre depth contour is located less than 1 kilometre from shore.

In general, the continental shelf of NSW is characterised by an inner zone (shoreward from water depths of about 60 metres) that contains considerable bedrock, outcropping or close to the surface, and an outer zone (greater than depths of about 60 metres) that forms the surface of a sediment wedge up to 700 metres 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, which has varying geomorphic attributes (e.g. hardness, grainsize, jointing) and resistance to weathering. Along most of the NSW coast there are prominent rocky reef outcrops seaward of most headlands, although the present surveys have also identified significant rocky reef systems in areas on the continental shelf that are not continuous to shore or are continuous to shore associated with offshore islands. There are also a number of significant reef systems that occur offshore of ocean beaches in all regions. In most areas that were swath mapped, the area of rocky reef habitat is significantly greater than what has been interpreted from existing hydrographic charts, which mostly present only locations for significant shoal areas of larger reef systems. Historically, there has been little fine-scale mapping of rocky reef habitats throughout continental shelf waters of NSW, apart from that conducted on shallow nearshore reefs using aerial photography (Avery 2004) and targeted surveys using sidescan sonar in the Cape Byron (Bickers 2004) and Sydney regions (Gordon and Hoffman 1989). Further broadscale mapping of reefs has been conducted primarily using single-beam acoustic sounders within the Solitary Islands region (Mau 1997, Mau et al 1998), and sections of the mid- and outer-shelf on the far south coast (Bax and Williams 2001).

In contrast, the continental shelf sediments of south-east Australia have been documented in a number of studies over the past several decades (e.g. Boyd 1974 and 1980, Davies 1979, Marshall 1980, Colwell 1982, Von Stackelberg 1982, Walsh and Roy 1983, Ferland and Roy 1997, Roy 1998, Boyd et al 2004). A number of local studies of surficial sediments have also been conducted at specific locations on the NSW coast (e.g. Gordon et al 1978, Browne 1994, Bickers 2004). The broadscale patterns of surficial sediments along much of the north and central coast of NSW using a collation of historical data is detailed in Boyd et al (2004). This analysis confirmed that there are basically several main classes of sediments on the shelf, which relate to depth and distance from shore. These are defined as:

- Inner-shelf sands – comprises nearshore sands (generally found between depths of 0–30 metres and shows a decreasing grain size with increasing water depth)
- Inner-shelf gravels – comprises nearshore gravels (these are quartz–lithic in composition and are patchily distributed between depths of 20 to 60 metres)
- Mid-shelf muddy sand – comprises poorly sorted sand with variable mud content (10–80%); the inner boundary of the muddy band is usually clearly defined at depths of 50–70 metres in the south and occurs in much shallower depths in the north; this sediment type is most common offshore of the major rivers such as the Hunter River
- Outer-shelf carbonate sand – comprises sands that have a high carbonate content because they are composed primarily of a range of bivalves, bryozoa and foraminifera with localised occurrences of carbonate gravels and minor components of terrigenous sand and mud; this sediment type usually occurs in a band on the outer shelf below depths of 120 metres in southern NSW, decreasing to depths of 60 metres in northern NSW.

Based on detailed analysis of geometry and slope, Boyd et al (2004) also defined a number of distinct seabed morphological units that occur in parts of the continental shelf north of the NSW central coast, with the broad distribution of the units reflecting a number of processes that are common to the entire margin of the shelf. These units are defined as the shoreface, inner plain, inner- and outer-mid-slope and outer plain, with these being shore parallel zones. There are also 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). The innermost zone at the shoreface reflects the influence of wave sediment transport out to a depth of about 30 metres and is well developed off sandy barriers and absent off most sections of rocky coast. The inner plain is a relatively flat zone occurring at depths of around 25–75 metres and varies greatly in width along the coast (Boyd et al 2004). This zone is thought to represent a number of seaward-prograding shoreface and barrier sediments that were deposited under the stable to slowly falling sea-level about 30,000–60,000 years ago and have remained relatively unmodified (Roy and Boyd 1996, Roy et al 1997). The wide distribution of coarse sediment throughout the inner continental shelf of the region reflects the small input of finer coastal sediments, strong tidal currents and oceanic swells (Boyd et al 2004).

The mid-slope region is steeper and occurs seaward of the inner plain in depths around 60 metres at 2–20 kilometres offshore. Because of the shallower outer-shelf in northern NSW, these inner-shelf zones are wider and of lower gradient in the north. The extent of these broad zones within state coastal waters is determined by along-shelf variability of zone distribution and by variation in the offshore distance of the state coastal waters limit (i.e. this can vary from 5.6 to 18.3 kilometres and to depths of 32–132 metres). Periods of sea level change have strongly influenced the current geomorphology of the NSW coast, with sea levels during the last glacial period up to about 20–15,000 years ago at least 120 metres lower than the present sea level, resulting in the shoreline being located many kilometres offshore. Different erosional and depositional forces acted on the rocks and sediments during that time, with fluvial processes playing an important role in forming many of the present features.

Overall, the delineation of broadscale seabed morphological units provides a useful framework with which to examine the fine-scale distribution of seabed habitats along the inner- and mid-shelf regions of the NSW 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); however, it also includes the outer mid-slope and locally defined units in specific locations, particularly seaward of offshore islands such as Broughton and Montague Islands.

Many hierarchical levels represented on seabed habitat maps are usually 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 (Allee et al 2000). Such classification schemes reflect the strong influence of the physical factors of depth and seabed hardness on the resulting benthic communities. It also important to recognise that the provision of habitat maps representing broad classes over large areas of the continental shelf is only possible using acoustic remote-sensing tools. The primary habitats defined for the NSW continental shelf are rocky reef and unconsolidated habitats. This is because the boundaries of these habitat types are optically or acoustically distinct and can be accurately mapped using aerial photography and sidescan sonar, as well as 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.

The use of an interferometric sidescan sonar allows the use of 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 significant increase in our understanding of the distribution, extent and structure of reef habitats at a number of spatial scales. The results of the accuracy assessment indicate that digitising bathymetry and backscatter data to map areas of reef/non reef polygons is effective at defining areas of reef, with acceptable accuracy of 81.6% (Appendix 2). This is comparable to recent habitat-mapping done in Victoria, where map accuracies of 72% and 83% were reported (Ierodiaconou et al 2007). Inspection of incorrectly classified points revealed that many of the digitising errors occurred at or near the reef/sand interface. These errors may be inherent in this type of mapping data where substrates do not have a distinct boundary but present as a gradual change from reef to mixed reef/sand to sand, which can result in some positional error of a habitat boundary. Digitised polygons are slightly more accurate at defining areas of reef compared to areas of non-reef, although both categories are acceptable. The Tau coefficient of 0.69 indicates that 69% more points were classified correctly than would be expected by chance alone (Appendix 2). This indicates that the techniques used to interpret the swath acoustic data are, for the purposes of this study, suitable for defining reef and non-reef areas.

The recent swath acoustic data revealed considerable fine-scale structuring of unconsolidated habitats, influenced primarily by the presence of sand ripples, waves, and variations in sediment particle size and shell content. There was often a rapid transition between fine and coarse sediments that were commonly associated with a small change in bathymetry. In addition, varying amounts of boulders, cobbles, pebbles and gravel, particularly adjacent to areas of rocky reef, generally resulted in complex patterns of backscatter that precluded the digitising of the unconsolidated class into additional secondary classes than those based on the broad depths of shallow, intermediate and deep, consistent with those used for rocky reefs.

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 benthic assemblages defined in the study restricted the area of habitats that could be described, with descriptions only available over relatively small areas of the seabed through video assessment. In most locations video assessment was restricted for logistical reasons to depths greater than 10–15 metres; therefore, several macroalgal-dominated habitats were not surveyed and information on assemblage composition was sourced from earlier SCUBA surveys that targeted reefs in depths of around 5-15 metres (e.g. Barrett et al 2007, Smith et al 2008).

The distinct shallow-reef habitats of the NSW coast, defined by their dominant sessile biota, include:

- Fringe habitat –This habitat occurs just below low-tide level to depths of around 3 metres and contains a diverse range of algae, usually dominated by the brown algae *Phyllospora comosa* in the south and *E. radiata* in the north of the state. This habitat also includes turfing algae such as the *Sargassum* species, several species of red algae including *Corallina officinalis* and *Amphiroa* sp., the brown alga *Lobophora variegata* and smaller amounts of coralline algae (Underwood et al 1991). However, the algal species composition of the fringe habitat can vary, with some shallow reefs dominated by the phaeophyte *Dictyopteris muelleri,* with other macroalgae including *Ulva*, *Sargassum* and *Padina* also important components of the benthic cover (Bucher and Hartley 2004).

- Turf habitat – This habitat is dominated by turfing coralline and filamentous algal species such as *Corallina* spp. and *Zonaria* spp.; however, it often contains smaller amounts of other larger species such as *Sargassum*. There are also areas where species of the genus *Caulerpa* dominate, often in monospecific stands. This habitat is also characterised by the absence of sea urchins.

- Phyllospora habitat – This habitat is dominated by the brown alga *Phyllospora comosa* and is mostly restricted to a narrow band adjacent to the intertidal zone (Underwood et al 1991). A range of filamentous, turfing and crustose coralline algae are often present beneath the canopy, with the habitat present in waters south of Port Stephens.

- *Ecklonia* habitat – This habitat usually occurs at depths of more than 2 metres, and is characterised by a canopy of the brown macroalgae, *E. radiata*, although some reefs contain species of *Cystophora* and *Sargassum* (Kennelly 1995, Underwood et al 1991). An understory of algae consists mostly of *Lobophora variegata*, crustose coralline algae and a diverse range of foliose algae, including species of *Zonaria, Rhodymenia* and *Ulva* (Kennelly 1995, Edgar 1997). There are also sponges, ascidians (such as the pyurids *Herdmania momus* and *P. stolonifera)* and other sessile invertebrates within kelp habitats, but these usually not the dominant assemblages.

- Barrens habitat – This habitat usually occurs at depths greater than 2 metres. It is devoid of macroalgae but is often covered with encrusting coralline algae, small numbers of sessile invertebrates and numerous limpets and snails which graze on the algae. There is a strong correlation between the types and amount of algal cover and the abundance of the long-spine urchin, *C. rodgersii*. The overall abundance of urchins at barrens habitats strongly influences the assemblage of algal species found there (Andrew and O'Neill 2000). Such barrens have been estimated to cover around 50% of shallow rocky reefs along the central and southern NSW coast (Andrew and O'Neill 2000).

- *Pyura* habitat – This habitat is dominated by the large solitary ascidians *P. gibbosa* and *P. stolonifera*, with a small amount of filamentous and turfing algae.

- Sponge habitat – Sponge-dominated assemblages often replace macroalgae as the dominant sessile assemblage in the deeper sections of shallow reefs. This is particularly evident in areas where walls, overhangs and caves provide suitable habitat, or as part of the understorey beneath the macroalgae. Sponge habitats are the dominant habitat type on intermediate and deep reefs. The distribution, ecology and taxonomic knowledge of sponges in NSW waters have been reviewed by Davis et al (2010).

In addition, corals occur as a small component of the assemblage on shallow reefs in northern NSW, although coral cover and species richness increases in an offshore direction throughout the Solitary Islands region due to the presence of offshore islands (Harriott et al 1994). There are also small areas of habitat dominated by the large brown alga, *Durvillaea potatum*, which occurs in a narrow band in the immediate subtidal zone on the far south coast of NSW (Andrew and O'Neill 2000).

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

Less is known about the distribution and composition of sessile macrofauna that occur on unconsolidated habitats on the inner continental shelf of south-eastern Australia, although they are known to be dominated by sponges, ascidians, bryozoans and sea whips, which increases the diversity and complexity of this habitat type (Bax and Williams 2001, Beaman et al 2005). However, variations in sediment composition and structure seen in the swath-mapping data are likely to influence the patterns of sessile faunal assemblages that exist in this habitat.

The extent, distribution and structure of seabed habitats along with identifiable macrofauna and flora for the northern, central and southern NSW continental shelf regions are provided in the following sections.

5.1 North coast region

5.1.1 Seabed habitats

The broad distribution of consolidated and unconsolidated habitats within the northern region reflects the patterns of bedrock geology, geological history and coastal inputs. A broad description of the geology and morphology of the continental shelf in the northern NSW region is provided in Boyd et al (2004), Roberts and Boyd (2004) and Kenna and Kirkwood (2008). The morphological zones in the region (shoreface, inner plain and mid-slope) are broadly similar to the remainder of the NSW inner continental shelf, although there are a number of distinct sand bodies and lobes specific to this region (Gordon et al 1978, Boyd et al 2004). There is considerable along-shore and cross-shelf variation in morphological zones on the continental shelf of northern NSW reflecting sediment processes that occurred at previous sea levels and recent transport by currents (Boyd et al 2004). There is also fine-scale structuring of ocean beaches that are strongly influenced by wave exposure, resulting in sand bars, troughs and gutters, and rip channels that are frequently changing (Short 2003).

Overall, the sediments on the shelf of the northern region are mostly dominated by inner-shelf sand, mid-shelf muddy sand and outer-shelf carbonate sand, although there are localised variations to this broad pattern (Roberts and Boyd 2004, Boyd et al 2004). The most significant sediment variations on the inner-shelf are the patchy occurrence of finer sediments offshore of the Yamba and Wooli regions, and the presence of coarser sand offshore of Tweed Heads, south of Yamba and throughout the Solitary Islands region. The wide distribution of coarse sediment throughout the inner continental shelf of the region reflects the small input of finer coastal sediments, strong tidal currents and oceanic swells (Boyd et al 2004).

Inner-shelf sediments have been examined in detail in a number of areas within the northern region. In the Byron Bay area, Gordon et al (1978), Colwell (1982) and Bickers (2004) investigated marine sediments and found surficial sediments composed of quartzose sand with variable amounts of shell and gravelly sand around reefs, but little mud. Sand covered the inner nearshore zone in the Byron Bay area to depths of 5–10 metres, with an inner-shelf sand body to depths of 11–22 metres. Elsewhere, outer nearshore sand occurs seaward to depths of 23–29 metres. Overall, sediments in depths less than 50 metres comprised fine and well-sorted sand, whereas sediments at depths greater than 50 metres were much coarser. A clear transition occurs between these two sediment types at depths of 50 metres in areas south of Cape Byron; however, a less clear transition occurs in areas to the north (Bickers 2004). At a fine scale, distinct areas of coarse sediment occur in the troughs of sand waves located seaward of exposed beaches between Lennox Head and Cape Byron, and also within a large area around Julian Rocks.

Offshore of the Clarence River there are a number of types and size ranges of sediments found on the inner-shelf, identified as nearshore sand and inner-shelf sand (Walsh and Roy 1983). Overall, grain size in the nearshore sands becomes finer as distance offshore increases. A blanket of fine-grained muddy sands occurs off the mouth of the Clarence River and extends to the south, and a belt of coarser inner-shelf sand exists seaward of the nearshore sands and muddy sediments. There is also evidence of a mound of sand around 8 kilometres long and up to 5 kilometres wide located about 4 kilometres seaward of the Iluka Bluff to Woody Head coastline, which is defined as an inner-shelf sand body (Davies et al 2007). Previous interpretations of the area (Walsh and Roy 1983) suggest that sediment may be actively supplied to this sand body at the present time. Further to the south-east a field of parabolic sand dunes occur at depths of about 60 metres. The shape of the dunes indicates they are migrating toward the south and are around 150–250 metres in length, 100–300 metres wide and less than 2 metres high. The steep leading edge of the dunes appears to be composed of coarser material. It is likely that the dunes are produced by the passage of strong currents across the seafloor.

Nested within the broad morphological zones, recent swath-mapping revealed significant fine-scale structuring of unconsolidated habitats on the inner- and mid-shelves, influenced primarily by the presence of sand ripples, waves, and variations in particle size and shell content (Bickers 2004, Davies et al 2007, Ku 2007). There are also areas that contain varying amounts of boulders, cobbles and pebbles, particularly adjacent to areas of rocky reef. A detailed examination of sediments around a large inner-shelf reef complex north-east of Coffs Harbour found distinct areas of gravel, coarse sand and fine sand; however, there were no overall trends between grain size and proximity to the nearest reef edge (Ku 2007). The majority of the areas with coarse/gravely sediment contained large sand ripples (greater than 60 centimetres wide) and those with fine sand contained small ripples (less than 60 centimetres wide). There were also many areas that had sharp transitions between fine and gravely substrates, with the coarse sediments generally occurring in depressions up to 1 metre deeper than the surrounding fine sediments.

More broadly, fine-scale variations in sediment type and seabed morphology are evident in all areas mapped during the present study. Much of the sediment within the reef complexes contains a high proportion of boulders, cobbles and pebbles, and variability in backscatter intensity at a range of spatial scales is a key feature of most areas of unconsolidated habitat. An example of this is evident in the large area of unconsolidated sediment south-west of North Solitary Island.

Overall, there is considerable variability in bedrock geology along the northern coast, which is reflected in the spatial variations in the extent of bedrock on the inner shelf. In general, volcanic rocks such as granites and basalts, and coarser-grained sedimentary rocks such as conglomerates and massive sandstones tend to occur as outcrops on the inner shelf because they are more resistant to erosion (Rule et al 2007). Consistent with the pattern along most of the NSW coast, there are prominent rocky reef outcrops seaward of most headlands in this region that are made up of erosion-resistant rocks, although the present surveys have also identified significant rocky reef systems in inner- and mid-shelf regions, often associated with offshore islands. There are also a number of significant reef features that occur offshore of ocean beaches in the region.

Firstly, the geology of the area from Tweed Heads to Lennox Head is dominated by the Beenleigh Block and overlying volcanics, which vary in composition along the coast but are mostly basalts and basalt with assorted acid volcanics. In a number of places these outcrop to form large reef systems, which are particularly prominent offshore of Fingal Head, north of Brunswick Heads and at Cape Byron. Within the Cape Byron region the two prominent reef systems (Julian Rocks and Cape Pinnacle) are formed by outcropping extensions of the onshore bedrock whereas the low relief deep reef system in the area is likely to result from earlier resistant bedrock that has been exposed. Further swath acoustic surveys are likely to reveal further reef on the shelf in this area.

The area along the coast from Shelley Beach Head to Evans Head contains sedimentary rocks of the Clarence Moreton Basin, whereas south from near Shelley Beach Head and north from Evans Head metamorphic rocks of the Coramba Beds are found. Because the rocky reef outcrop near the Clarence mouth east from Shelley Beach Head is contiguous with headland, it is likely to be made up of resistant Ripley Road Sandstone and the offshore extension of the reef to the north-east represents the southern boundary of the Clarence Moreton Basin and the contact between Ripley Road Sandstone/Red Cliff Coal Measures and Coramba Beds. The Coramba Beds are a succession of strongly folded and faulted greywacke, slate and siliceous argillite that forms part of the Coffs Harbour Block. The Red Cliff Coal Measures consist of sandstone, siltstone, conglomerate and coal that in general form a lower relief than the more erosion-resistant Ripley Road Sandstones, which is a quartz-rich fine- to coarse-grained sandstone that is quite resistant and forms prominent cliffs in the coastal range from Wooli to Brooms Head and also at Evans Head. The remainder of this section of the coast contains Quaternary beach and dune sands which cover the bedrock geology.

South of Brooms Head throughout the Solitary Islands region the geological formations are mostly derived from marine sediments of the Coffs Harbour Sequence, the largest being the Coffs Harbour

Block where hard metamorphosed slates crop out over a large area of the seabed, forming reefs that extend as far south as Sawtell. These slates form numerous submerged reefs, washes and emergent islands, islets and rocks, including the five main islands in the Solitary Islands group and at least 10 smaller islets and rocks (e.g. North West Rock). These outcrops are a seaward extension of the adjacent coastal range, which has a strong influence on the coastline of the area. North Solitary Island, which is situated in the Coramba Bed zone, is atypical of other islands because sandstone is virtually absent on this island (Copeland et al 1993).

Variations in sea level have also influenced the geomorphology of the region, with the sea level being considerably lower during the last glacial period around 20,000–15,000 years ago. Different erosional and depositional forces acted on the rocks and sediments of this area during that time. A linear reef, paralleling the coastline in places, occurs at a depth of about 60–70 metres and may be a previous coastline. The overall morphology of sandstone outcrops (elongate, low-relief and parallel to the present-day coastline) suggests that the rocks were formed in sand bodies along palaeo-coastlines similar to that noted in other sections of the east coast (Beaman et al 2005).

Between Sawtell and Nambucca Heads the metamorphic rocks of the Nambucca Basin slates dominate the coastal region, and there is clear evidence of a significant offshore extension of this bedrock to form the large reef system mapped along this section of coast. Volcanic rocks crop out extensively around Smoky Cape and the adjacent seafloor (Boyd et al 1998), which is one of the most prominent and significant headlands on the east coast of Australia. The geology of the Cape is dominated by granite known as Smokey Cape adamellite. The acoustic data revealed that Fish Rock and Black Rock are steep outcrops which rise above the surface of the sea from the sandy seafloor 30 metres deep at Fish Rock and 20 metres deep at Black Rock. Dramatic scour features can be seen around these outcrops, which provide evidence of the strong currents of the East Australian Current that frequently contacts this part of the shelf.

Between Point Plomer and Crescent Head, and at Crowdy Head, the Byabbara Beds (part of the Hastings Block), which are composed of lithic sandstone, siltstone, tuff, shale and limestone, crop out along the coast. The reef offshore of Point Plomer is generally of low relief; however, it is spatially complex and contains many reef features which form a series of shallow gutters. The reef here is the surface expression of deeply folded and eroded beds of the same rocks evident on the shore at Point Plomer as deeply folded beds forming dramatic synclines and anticlines. Within this section of coast, erosion-resistant metamorphic rocks of the Port Macquarie Block also occupy parts of the coast and inner shelf from the Hastings River to Tacking Point.

The Triassic Camden Haven Beds of conglomerate, sandstone and shale crop out along the coast between Point Perpendicular and Bonny Hills. Mapping between Crowdy Head and Perpendicular Point revealed an abundance of rocky outcrops that form a chain of reefs from Crowdy Head to the Cod Grounds, which lie in Commonwealth waters. Only Mermaid Reef breaks the surface. The remaining reefs are about 2 kilometres in diameter and typically rise 10–20 metres from the seabed.

The central peaks of the Cod Grounds area consist of a series of steep, jagged and blocky outcrops and appear to be made up of a different material than the surrounding cobble fields. The more resistant material that constitutes the peaks may consist of Tertiary volcanics of the Comboyne Beds. These beds consist of tuffs and shales that overlie a series of conglomerates, sandstones and shales. This rock type outcrops at the nearby headland of Point Perpendicular that lies to the north-west of the Cod Grounds. Contact between the two observed rock types within the area appears to occur at depths of around 27 metres. The reef outcrops in the Cod Grounds area are surrounded by a mixture of cobbles and larger boulders. This seabed type interlaces with the surrounding sand areas and is likely to be progressively covered and uncovered by sand movement. The sand fields are rippled, filled with coarser shell material and are oriented east-west indicating sediment is moving in a southerly direction in response to the south flowing East Australian Current.

Overall, the swath-mapping revealed considerably more rocky reef throughout the northern region than previously defined from broadscale bathymetry. The location and extent of all subtidal reefs has not yet been mapped, particularly those in depths greater than 60 metres. A number of known reef and shoal areas are yet to be mapped, including those offshore of Fingal Head, the Evans Head region and Sawtell.

It is likely that much of the shallow nearshore reef along the north coast mapped using aerial photography extends further offshore than currently defined (which occurs mostly at around depths of 15–20 metres). There is also evidence of this extension of reef in several of the areas swath mapped, including Shelley Beach Head, along the Nambucca coast and Black Head. Similarly, extensive areas of reef were mapped in the inner- and mid-shelf areas within state coastal waters, with clear evidence of many reefs continuing into Commonwealth waters, for example within the Solitary Islands and Crowdy Head regions.

The reefs varied considerably in extent of patchiness, although there was no particular latitudinal or cross-shelf trend in reef structure. The high resolution of the swath bathymetric data also revealed considerable variations in the geomorphic structure of reefs (e.g. boulders, gutters, walls, pinnacles), often within the same continuous reef system. This variability in reef complexity is likely to influence the diversity of biota within the region because reef complexity significantly influences the diversity and assemblages present (Harman et al 2003). The detailed bathymetry is important because many rock types produce a range of structural complexity and this range determines the structure of the biotic community, not the type of rock itself.

5.1.2 Benthic communities

Overall, benthic communities on rocky reefs throughout much of the northern region of NSW contain a mix of tropical, subtropical and temperate species, reflecting latitudinal and cross-shelf gradients of water temperatures and ocean currents (Zann 2000). Shallow inshore reefs in northern NSW are characterised by abundant macroalgae (Millar 1990 and 1998), dominated by the kelp, *E. radiata*, and various species of *Sargassum* and *Caulerpa* (Smith and Simpson 1991, Harriott et al 1994, Mau et al 1998). However, this is not consistent over all shallow reefs within this area as considerable broadscale variability in assemblages can occur (Smith and Edgar 1999, Bickers 2004, Smith et al 2006, Smith et al 2008). Most significantly, many shallow reefs on the mid-shelf have a dominant benthic cover of coral, particularly throughout the Solitary Islands area. Surveys of shallow reefs at South West Rocks also found assemblages to be significantly different between Fish Rock, Bait Reef, Black Rock and Green Island, despite these reefs only being separated by several kilometres (Smith et al 2006). Black Rock was characterised by a high coral cover, Bait Reef by a high diversity of algal species and Fish Rock by urchin barrens. In many locations surveyed in the present study, coral was present as a minor understory of *E. radiata* and as a distinct habitat type. Similarly, shallow reefs immediately north of Brunswick Heads are dominated by *E. radiata,* whereas several reefs only about 15 kilometres south at Cape Byron contained no *E. radiata* and were dominated by a cover of *Lobophora* and *Zonaria* (Harriott et al 1999, Bucher and Hartley 2004, Bickers 2004). Other small reefs in the Cape Byron area contain *E. radiata*, but usually at low abundance (Bickers 2004).

Because video analysis in the present study was restricted mainly to depths greater than 10 metres, the ‘fringe habitats’ that occur to depths of around 3 metres were not surveyed. This habitat is dominated by foliose algae (mostly *Phyllospora comosa*, *Sargassum* spp. and *Zonaria* spp.) and smaller amounts of coralline algae (Underwood et al 1991). It is likely that such a habitat occurs widely throughout this region, but may also include coral in many sheltered locations.

Assemblages of mixed brown algae were also common on shallow reefs, but generally associated with *E. radiata*, which was abundant in most areas of reef or mixed reef/sand, although the abundance, and often the morphology, of *E. radiata* plants varied across depths and between areas surveyed. For example, *E. radiata* at Nambucca had a distinctly elongate stalk and fine fronds compared to the short stalk and broad fronds observed at nearby Sidney Shoals. Smith et al (2008) also report a similar localised dominance of kelp habitat at study sites at Wenonah and Valla reefs at depths between 8 and 10 metres.

The pattern of habitats are generally different on shallow reefs around the mid-shelf islands, some of which have been mapped at a fine scale, including those at Split Solitary, South West Solitary and North West Solitary Islands (Smith and Edgar 1999). These islands are fringed by a range of different reef habitats, including those dominated by coral, kelp, boulders, gravel, algae and urchin barrens (Smith and Edgar 1999). Despite fine-scale differences in the distribution of the main habitat types such as kelp and coral, most habitats are generally present around each island. Overall, corals tend to be a dominant component on reefs more than about 1.5 kilometres from the coast and at depths less than 25 metres, with reasonably high hard-coral cover occurring on an average of 37% of mid-shelf reefs (Malcolm unpubl. data). The number of reef habitat types is greatest around North West Solitary Island and coral cover is highest round Split Solitary Island and South West Solitary Island. These patterns are most likely due to variability in natural processes such as growth, recruitment, competition and predation. Other influences include mortality due to bleaching and disease, storm removal of coral, and possibly localised competition with spreading corallimorphs (species that resemble coral but do not have a skeleton and have tentacles, often in radiating rows) at some sites.

Benthic assemblages are also strongly influenced by exposure to waves, currents and water column characteristics, with the more sheltered western and north-western sides of the islands generally having greater densities of corals and other fragile assemblages (NSW MPA 2000). However, due to most of the islands being small, no area is fully sheltered and the same aspect at two different islands can contain very different dominant sessile assemblages (Smith and Edgar 1999). The denser anemone assemblages commonly located on the western and northern sides of the islands include aggregations of host anemones at Anemone Bay on the northern end of North Solitary Island, which has the highest density of host anemones recorded in the southern hemisphere (Richardson 1996, Richardson et al 1997). On the more exposed eastern sides of these islands and reefs, coral diversity and cover is often reduced and communities are dominated by filamentous turfing algae and large solitary ascidians such as *Herdmania momus* and *P. stolonifera* (Smith and Edgar 1999). Shallow benthic assemblages around North and South Solitary Islands differ greatly. South Solitary Island has a higher cover of foliose coral and compound ascidians, and a lower cover of large anemones, zoanthids, algae and soft coral (Smith and Edgar 1999). The mobile benthic invertebrates that occur around these islands also differ (Rule and Smith 2005).

In general, the richness of coral species increases in an offshore direction, and the northern islands generally support a higher cover of coral and a lower cover of turfing and calcareous algae than the southern islands (Veron et al 1974, Smith and Simpson 1991, Veron 1993, Harriott et al 1994). There is a trend towards tropical coral species in offshore areas and subtropical to temperate species on inshore sites (Wilson 1998). The greatest diversity occurs at North Solitary Island where 43 species have been recorded, although some of these are ephemeral (Harriott et al 1994). Compared to tropical areas, soft corals are less abundant here, being replaced by a mixed invertebrate assemblage of solitary ascidians, barnacles and other sessile, suspension-feeding species. The transport of tropical and sub-tropical coral species via the East Australian Current is a major factor in the dynamic variation in coral species found along the north coast (Harriott et al 1994). Over the latitudinal range of the northern region the coral community composition is highly variable, although overall coral cover decreases in the southern part of the north coast region (Harriott et al 1999, Smith et al 2008). There are also strong cross-shelf differences in fishes associated with shallow reefs in the Solitary Islands region (Malcolm et al 2010a). Three distinct assemblages occur on inshore (1.5 kilometres), mid-shelf (1.5–6 kilometres) and offshore (greater than 6 kilometres) reefs, with the cross-shelf pattern persistent over the scale of years (Malcolm et al 2010b).

A gradual transition generally occurs at around 25–30 metres where kelp and coral often decrease in abundance and become sparse within a mosaic of algae species and sponge-dominated assemblages. The mapped area of intermediate reef in the northern region indicates that this is an extensive habitat type that covers a considerably larger area than that of shallow reef. The habitat often contains a range of sessile invertebrate species including sponges, ascidians, octocorals, soft corals, anemones and bryozoans (Mau et al 1998, Fitzpatrick 2003, Bickers 2004). Erect, vase, elongate, tubular and branching sponges are common, whereas black corals (*Antipathes* sp.), sea pens, sea whips and branching soft corals are also present, although sparsely distributed. In general, sessile invertebrate abundance and diversity is lowest in sections of intermediate reef consisting of cobble and boulders, with the more continuous reef with a high profile supporting greater densities.

The high diversity in growth forms of sponges on much of the reef indicates a high species diversity, and sponge morphological diversity can provide a qualitative estimate of sponge species diversity (Bell and Barnes 2001), although the large plasticity in growth forms for some species (Ponder et al 2002) is likely to be a problem when examining spatial diversity. Further classification of specific taxa was not possible primarily due to limitations in video resolution, and paucity in available taxonomic information on many groups of sessile invertebrates and turfing algae (Ponder et al 2002, Davis et al 2010). For example, up to 588 species of macroalgae have been identified within the northern NSW region (see Rule et al 2007), although less than 5% of species can be consistently identified using video techniques.

On the deep reefs (i.e. greater than 60 metres) benthic assemblages are dominated by sponges and a mixed assemblage of sessile invertebrates. These include stalked ascidians, sea whips, gorgonians, hydrozoans and black coral. Little deep reef was videoed during the present study. Although a variety of sponges and other sessile invertebrates also occur on shallow reefs, they are not generally the dominant assemblage. This is consistent with the findings of Mau et al (1998), Fitzpatrick (2003) and Bickers (2004).

Given the small area sampled through the use of towed video there are also operational limitations (in time and costs) which result in benthic habitats mostly being mapped as reef and unconsolidated classes, with the dominant floral or faunal sessile assemblages (e.g. kelp, corals, sponges, etc.) described as general patterns defined by depth and distance offshore. It is difficult to map the exact extent of these specific habitats that define lower hierarchical classification levels as they can only be defined using video techniques, and often video transect spacings are greater than the spatial patches of the habitats.

In addition, because variation in the dominant species composition can occur at spatial scales of tens of metres to kilometres in the reef habitats, it is difficult to predict the exact dominant assemblage based on knowledge of physical factors such as geomorphology, depth, distance offshore and exposure. This is particularly the case within the Solitary Island region that is strongly influenced by tropical and temperate oceanic conditions and benthic assemblages. However, there are some broad depth-related trends in the distribution of habitats defined at a certain level of classification (e.g. fringe*, Ecklonia,* sponge), and trends related to distance offshore (e.g. macroalgal cover, coral richness) (Harriott et al 1994, Mau et al 1998). Further details on patterns of reef biodiversity within the northern NSW region are presented in Rule et al (2007) and NSW MPA (2008a).

The variations in sediment type evident in the acoustic backscatter, in combination with depth, are also likely to result in considerable differences in macrofaunal composition (Coleman et al 1997, Edgar et al 1999, Beaman et al 2005). As many as 241 species of infauna have been identified from soft-sediment habitats in the Solitary Islands area (which excludes potentially diverse groups such as polychaete worms and isopods) (Smith and Rowland 1999). Approximately 85% of the species identified in the soft-sediment samples to date have not previously been listed for the Solitary Islands region, and there was increasing species diversity and composition from shallow sites (20 metres) to intermediate sites (50 metres) (Smith and Rowland 1999). Differences in species composition were also found between samples taken from coarser-grained gravely substrates, sand and mud areas. Most of the animals within these habitats occur as infauna, although the habitat also commonly contains larger sessile macrofauna (e.g. sponges, ascidians, bryozoans, sea whips) that increase the diversity and complexity of the habitat (Bax and Williams 2001, Bickers 2004). These are particularly prevalent in areas of higher current flows adjacent to offshore islands and pinnacles. Although there is currently little information regarding the distribution and diversity of soft-sediment assemblages in this region, it is likely that the considerable structural complexity seen in the swath-mapping data will influence the patterns of faunal assemblages within this habitat.

More detailed studies will require sampling at a number of spatial and temporal scales, improved taxonomic resolution and expertise, combined with continued high-resolution swath mapping. Further surveys with video and digital still photography will allow reef habitats to be defined at a lower hierarchical level, improving our understanding of the spatial distribution of benthic reef diversity on the continental shelf of this region.

5.2 Central region

5.2.1 Seabed habitats

Consistent with the northern region, the extent, distribution and structure of reef and unconsolidated habitats within the central 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 the Port Stephens region in Davies (1979). The unconsolidated morphological zones in the region of shoreface, inner plain and mid-slope are broadly similar to the rest of the NSW inner continental shelf, although there are a number of distinct zones specific to this region. These include the composite regions which are areas of merged shoreface, inner plain and inner mid-slope adjacent to the rocky headlands of Port Stephens and Cape Hawke (Boyd et al 2004). There is considerable along-shore and cross-shelf variation in morphological zones on the continental shelf of central NSW that reflect sediment processes at previous sea levels and recent transport by currents (Boyd et al 2004).

Overall, much of the shelf of the central region is dominated by clastic sediments on the inner-shelf to depths of about 100–110 metres and carbonate-dominated sediments on the outer-shelf (Davies 1979, Boyd et al 2004). The distribution of grain sizes indicates that the region is characterised by fine sand along much of the inner-shelf and a broad area of finer sediments on the mid-shelf, particularly south of Port Stephens and offshore of the Hawkesbury River, Port Jackson and Botany Bay. The distinct areas of coarser sediment on the inner-shelf immediately north of Port Jackson and throughout the Port Stephens region are usually associated with areas of bedrock that outcrop in these areas. This is particularly evident around areas such as Broughton Island and Seal Rocks, which have been shown to have extensive reef systems on the inner-shelf. Historical sidescan sonar maps from the Central Coast and Sydney regions also indicate some variability in sediment composition, with medium- to coarse-grained sand dominant on the mid-shelf north of Port Jackson and fine-grained sand dominant south to Botany Bay (Gordon and Hoffman 1989).

Swath mapping in the central region has revealed significant 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. This fine-scale data indicates that in many places the broadscale sediment point-data is a poor representation of the actual fine-scale spatial variability in sediment types on the inner shelf. There are also areas that contain varying amounts of boulders, cobbles and pebbles, particularly adjacent to areas of rocky reef that are likely to be poorly sampled by sediment grabs and corers. The majority of the areas swath-mapped 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 the seaward transport of nearshore sands to overlay parts of the coarser inner-shelf gravels during storm conditions that produce down-welling currents (Niedoroda et al 1985).

Within and immediately adjacent to the numerous rocky reef complexes, the unconsolidated habitats consist mostly of 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, although this is not the 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 and gravely substrates, with the coarse sediments generally occurring in depressions up to 1 metre deeper than the surrounding fine sediments. Such distributional patterns are evident around Broughton Island where significant fine-scale variability in sediment type is present, particularly on the southern and eastern sides of the island. A more consistent pattern in soft sediments is evident offshore of Terrigal, which is mostly dominated by a larger area of sand that extends about 3 kilometres offshore. Here, an area with much higher backscatter is present, which is likely to reflect a much coarser sediment type. This very coarse-grained gravely sand is also evident in the historical sidescan sonar maps from the Central Coast region (Gordon and Hoffman 1989).

Within the central region, as in the northern region, swath-mapping revealed considerably more rocky reef than previously defined from broadscale bathymetry. Again it must be noted that the location and extent of all subtidal reefs has not been mapped, particularly those in depths greater than 60 metres. A number of known reef and shoal areas are yet to be mapped, including those offshore of Old Bar, Lake Macquarie and Tuggerah Lakes. North of Newcastle, rocky reef areas include nearshore reefs that extend several kilometres offshore into intermediate depths (e.g. Black Head), discrete intermediate-depth reefs (e.g. The Pinnacles), island-associated reef that extends into intermediate depths (e.g. Broughton Island), and nearshore reefs that are mostly restricted to shallow depths (e.g. Birubi Point). From Newcastle south, the majority of the coastline contains subtidal reef which is broken up by small areas of ocean beaches such as Nine Mile Beach. Overall, it is likely there are large areas of reef yet to be mapped within the central region.

This distribution of reef habitat is primarily determined by the patterns of bedrock geology of the region that varies considerably from north to south. Firstly, in the Black Head region the large reef area is likely to be subtidal outcropping of mudstones and sandstones of the Manning Group and other undifferentiated mixed sediments. Similar outcroppings of bedrock between Sugarloaf Point and Forster are dominated by sandstone, conglomerate and siltstone that form many subtidal reefs along this section of coast. Further south towards Port Stephens the bedrock is dominated by rocks of the Nerong Volcanics that form the islands of Boondelbah and Cabbage Tree, Broughton Island and the prominent headlands of Port Stephens, Yacaaba and Tomaree Heads (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. These rocky reefs have a complex structure consistent with the complexity seen within rocky areas along the shore. They consist of continuous rock, boulder, cobbles, or patches of reef surrounded by sand that also contains many gutters of varying sizes and depths that create vertical walls and overhangs in places.

From Newcastle south to Swansea the nearshore region is dominated by rocks of the Newcastle Coal Measures, which are likely to form the extensive nearshore reefs that extend some distances offshore in places. The large areas of reef evident along the coast south of Swansea reflects the dominance of the Triassic sandstones along the entire Central and Sydney coast, and reduced extent of Quaternary sediments forming large 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 reefs that extend up to 8 kilometres offshore and to depths up to 90 metres within state coastal waters. Another key feature of the region is a large sandstone bedrock outcrop that is present on the outer shelf south of Swansea about 20 kilometres offshore in depths of about 100–150 metres (Boyd et al 2004). There is evidence in the broadscale bathymetry that this reef system may extend as far south as the area offshore of Broken Bay. Recent swath mapping of the shelf break and slope region off the Newcastle region has identified a series of seven canyons that begin in around 200 metres of water and continue to depths of 1500 to 2000 metres (Keene et al 2008).

The extensive reef systems adjacent to the Sydney coast indicate there is a mostly continuous reef on the inner- and mid-shelf regions, particularly south of Sydney Harbour, with some large reefs system extending up to about 7 kilometres offshore continuous with headlands and separated by sandy beaches. The majority of the reef occurs in intermediate depths, which starts within several hundred metres from shore in many places indicating steeply sloping nearshore reefs. The seabed is characterised by large blocks of reef separated by irregular corridors of soft sediment, surrounded by smaller patches of reef on the outer edges in many places. Reef is less extensive south of Sydney Harbour, with most reef habitat occurring within 1.4 kilometres from shore. The seabed is dominated by intermediate reef that is at its greatest extent off North Head and Long Reef. Reflecting the steeper overall slope of the inner-shelf off Sydney Harbour, deep reef is present about 1.5–3 kilometres offshore, which is much closer than similar depths in most other regions. The lack of high resolution swath bathymetry for the reefs in the Sydney region precludes an assessment of the reef structure, although it is likely that it is patchier and more complex than represented.

The southern part of the central region from Sydney to Stanwell Park is composed of Triassic sandstones that form the coastline and high cliffs characteristic of the area. Given the consistent geology of the area with that of the Sydney coast, and the majority of the coastline contains nearshore reef, it is likely that there are extensive areas of reef on the shelf.

5.2.2 Benthic communities

Overall, video surveys indicate that the broad distribution of benthic communities reflects the distribution of shallow, intermediate and deep reefs in the central region, as well as a broadly similar range of dominant reef habitats to the central region. Shallow continuous reef habitats were dominated by *E. radiata*, urchin barrens, turf and ascidian habitat, although the patch size and distribution of these varied considerably. A diverse range of sponges and other sessile invertebrates were also common on the shallow reefs, particularly in depths greater than 15 metres, with some areas of low profile reef dominated by encrusting sponges. As discussed earlier, shallow reefs in NSW are characterised by the abundance and diversity of large algae that are dominated by *Phyllospora comosa* and *E. radiata* and various species of *Cystophora, Sargassum* and *Caulerpa* (Underwood et al 1991). There is also commonly an understory of algae dominated by coralline algae (e.g. *Corallina officinalis*) and a diverse range of foliose algae, including species of *Zonaria*, *Rhodymenia* and *Ulva* (Kennelly 1995, Edgar 1997). Consistent with shallow reefs in other NSW regions, the distribution of these habitats in the central region showed variability at large and fine spatial scales. Intermediate reef generally contained a mosaic of erect, massive, branching and encrusting sponges, and other sessile filter feeders such as bryozoans and gorgonians. Shallow rocky reefs usually also contain a wide diversity of less conspicuous marine animals including nudibranchs, many types of molluscs (e.g. cowries), bryozoans, feather-duster worms, basket-stars, sea whips and seastars, hydroids, corals, anemones, crabs, shrimps, and octopuses (see Edgar 1997).

At a large scale, the extent of shallow and intermediate reefs varies considerably along the coast, with some areas such as Black Head and Broughton Island containing large areas of shallow reef, and therefore large areas of benthic communities that dominate reefs at these depths. In contrast, some areas around Seal Rocks, Forster and south of Newcastle are dominated by intermediate reefs and their associated sessile invertebrate-dominated communities. For example, the intermediate reef habitat at The Pinnacle contains of mixture of sponges, gorgonians, ascidians (mainly *P. spinifera*), sea whips, mixed red and brown algae, and encrusting coralline algae. At depths greater than about 40 metres, the reef primarily contained sponge-dominated assemblages.

At a fine scale, the large variations in reef patchiness and slope reflecting the presence of unconsolidated areas and rocks and gutters of varying size is also an important determinant of the distribution of benthic assemblages. For example, shallow boulder reefs are often associated with barrens habitat, dominated by the long-spined sea urchin *C. rodgersii* and characterised by encrusting coralline algae and an enhanced presence of planktivorous fish (Curley et al 2002). Those reefs that have complex structures that include large gutters, overhangs and small caves contain considerably more sessile invertebrates than areas of flat seabed. This variability in reef complexity is likely to influence the diversity of biota within the region because reef complexity can significantly influence the diversity and assemblages present (Harman et al 2003).

Although there was limited video coverage in depths less than 10 metres, there is commonly a ‘fringe habitat’ that occurs to a depth of around 3 metres, dominated by foliose algae and smaller amounts of coralline algae (Underwood et al 1991). It is likely that such a habitat occurs widely throughout this region. Urchin barrens are an increasingly dominant habitat type on shallow reefs in the central region, with an estimated cover of around 50% (Andrew and O’Neill, 2000). Many reefs in the central region contain large barren areas, with those adjacent to Point Stephens extending from close to the shoreline to depths of around 30 metres. Fine-scale video mapping of reef habitats in the Port Stephens region revealed that barrens habitat covered between 13% and 69% of shallow reef sites, with the greatest percentage of barren areas present between 10 and 15 metres depth (Gladstone and Masens 2009).

`The large extent of these areas in NSW indicates a considerable loss of overall productivity and has important implications for many species of algae, fishes and invertebrates. In addition, although much of the productivity from reef algae is used directly or indirectly by the animals on the reef, considerable amounts are washed off the reef and become part of the detrital food chain that plays an important role in coastal productivity. Therefore, the loss of macroalgal-dominated habitat can have wider effects on marine ecosystems.

At least 100 species of sponge are likely to occur along the central coast of NSW, with a large variety of morphologies ranging from encrusting to massive erect structures. In a study of reefs of intermediate depths off Sydney, over 50 species of sponge were identified, with the number of sponge species increasing with depth, particularly for the erect or massive species (Roberts and Davis 1996). The cover of encrusting sponges decreases with depth and small-scale spatial variation in sponge distribution and abundance is a feature of the habitat.

Only a small amount of deep rocky reef (greater than 60 metres) has been mapped within the marine park, primarily east of Sugarloaf Point and north-east of Pacific Palms (Figure 8). Little is known about these deep reefs, but benthic assemblages are likely to be dominated by sponges and ascidians and some species may be unique to these depths. Further swath mapping is likely to reveal additional intermediate and deep reef habitat offshore of areas such as Sugarloaf Point, Broughton Island and Point Stephens, as fish landings and fishing marks indicate that such reef exists.

5.3 Southern region

5.3.1 Seabed habitats

Consistent with the other regions, the broad distribution of consolidated and unconsolidated habitats within the southern region of NSW reflects patterns of bedrock geology, geological history and coastal inputs. Based on unconsolidated morphological zones defined in the other regions (shoreface, inner plain and mid-slope) (Boyd et al 2004), those on the south coast are likely to be broadly similar to the rest of the NSW inner- and mid-continental shelves, with a number of distinct areas specific to this region and considerable along-shore and cross-shelf variation in sediment composition that reflect sediment processes at previous sea levels and transport by currents.

Periods of sea level change have strongly influenced the current geomorphology of the region. Sea level during the last glacial period up to about 20–15,000 years ago was at least 120 metres lower than the present sea level, with the shoreline located many kilometres offshore. Different erosional and depositional forces acted on the rocks and sediments during that time, with fluvial processes important in forming features such as Currambene Creek in Jervis Bay, which extended well beyond the current bay entrance (Taylor et al 1995). By around 6000 years ago, the marine environment associated with the present interglacial period resulted in the formation of much of the current shoreline. There was considerable shoreward and northerly long-shore reworking of sand that resulted in several coastal sand barriers being formed and sand being deposited on the seabed.

Overall, much of the shelf of the southern region is dominated by clastic sediments on the inner-shelf grading to coarse-dominated sediments on the outer shelf (Davies 1979), although this is less consistent than in the central and northern region. A key feature of the region is the greater cross-shelf and along-shelf variations in sediment composition north of Jervis Bay compared to areas further south. Much of the mid-shelf in the north consists of very fine sands and mud-dominated sediments. It is likely that the distinct areas of coarser sediment on the inner-shelf throughout the region are generally associated with areas of bedrock that outcrop in these areas. The coarse-sediment areas on the outer-shelf east and north-east of Jervis Bay and east and south-east of Narooma consist of coarse sand and gravel (Davies 1979).

Like other regions, swath mapping in the southern region has revealed significant fine-scale structuring of unconsolidated habitats on the inner shelf, most clearly evident through variations in particle size and shell content, and in the presence of sand ripples and waves. Again, the swath-acoustic data indicates that in many places the broadscale sediment point-data is a poor representation of the actual fine-scale spatial variability in sediment types on the inner shelf. Also, given the limitations of acoustic discrimination it should be noted that areas containing varying amounts of boulders, cobbles and pebbles, particularly adjacent to areas of rocky reef, are likely to have higher levels of mapping uncertainty and be poorly represented in sediment grabs and corers. The majority of the areas swath-mapped 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. This is evident in all the areas with swath acoustic coverage, often with distinct boundaries evident between areas of coarse and fine sand. A good example of this is south of the Tollgate Islands and in Twofold Bay where large areas of fine sand occur between two reef systems that have coarser sand on the edges and within the reef matrix.

Another example of this occurs in the region around the entrance to Jervis Bay, which contains a higher proportion of coarser-grained sediments due to the stronger currents. Up to 80% of the sediment is made up of carbonate debris that may consist of fragments of bivalves, gastropods, echinoids and foraminifera (Taylor 1972, Albani et al 1973). Further outside the bay, the sediment type changes from fine to medium, through to muddy sand at depths of around 60 metres. In this region there are also areas of unconsolidated seabed with a very high carbonate content, which is particularly evident immediately offshore of Governor Head to Cape St George and north-east of Little Beecroft Head. In contrast, beach sediments in Jervis Bay are mainly composed of fine grain quartz sand (Taylor et al 1995).

Swath mapping has also revealed that the unconsolidated habitats often contain areas of sand ripples and waves that leads to a higher acoustic backscatter compared to a flat seabed of similar particle-size composition. Video assessment conducted outside the mouth of Jervis Bay identified that the seabed was mostly rippled sand with little evidence of animals or plants above the sediments (CSIRO 1994). Swath-mapping data identified areas of much coarser sediment adjacent to the reefs, due to higher current speeds near the entrance to the bay.

Again, the swath mapping revealed considerably more rocky reef throughout the southern region than had been previously defined, with a large proportion of subtidal reefs of this region not yet mapped, particularly those in depths greater than 60 metres. A number of known reef and shoal areas are yet to be mapped, including areas such as the Sir John Young Banks located offshore of Beecroft Head. The broad distribution of rocky reef habitats within the region reflect the patterns of bedrock geology, which vary in their geomorphic attributes resulting in variations in reef structure. A large proportion of this coast contains shallow nearshore reef, particularly adjacent to the headlands and areas with continuous rocky coastline. At a regional scale the geology of the south coast is composed of the Sydney Basin north of Batemans Bay and the Lachlan Fold Belt further south.

Firstly, the geology of the section from Stanwell Park to Wollongong consists predominantly of shales and sandstone of the Illawarra Coal measures in the north, Quaternary sediments and Gerringong Volcanics in the south. Between Thirroul and Port Kembla there is a larger extent of sand-dominated beaches, although reef extends offshore of all headlands and around the Tom Thumb Islands offshore of Port Kembla. These are likely to be offshore extensions of the Gerringong Volcanics. The largest reef is offshore of Bellambi where reef extends at least 1 kilometre from shore due to a shallow section of reef located around 600 metres south-east of the main headland. The section between Port Kembla and Crookhaven is characterised by ocean beaches of various lengths and rocky shores with adjacent shallow nearshore reef. The highest proportion of rocky shoreline is adjacent to Kiama and Gerrigong sections of coast, and the largest sand-dominated beach occurs north of Crookhaven.

Jervis Bay is within the southern part of the Sydney Basin where three major Permian rock types are found. Firstly, the Snapper Point Formation covers most of Bherwerre and Beecroft Peninsulas (Taylor et al 1995), with this rock-type forming extensive subtidal reefs, particularly adjacent to northern and southern peninsulas. These reefs are characterised by steep drop-offs, large boulders, caves and overhangs. Wandrawandian Siltstone is exposed around the northern and western shores of Jervis Bay and forms the subtidal reefs that extend north-east from Currarong Beach. Currambene Dolerite is found in places around St. Georges Head, Green Point and Montague Point in the form of igneous dykes and sills.

Further south rocky reefs extend along almost the entire coastal section, apart from adjacent to the few small sand-dominated beaches. Prominent reef systems in the region are present offshore of Brush, Tollgate and Montague Islands and there are several distinct areas of these reefs that are characterised by moderate slopes and rapid increases in depth associated with near vertical walls. There is also evidence of large areas of intermediate and deep reef at considerable distances offshore, particularly offshore of the Tollgate Islands. Their structure varies considerably as do the reefs directly north and south of the Tollgate Islands, which drop considerably more rapidly to the surrounding seabed than those to the east. The reefs in this region usually contain a matrix of sand gutters of varying extent which mostly contain well-sorted sand and gravel. The small amount of swath acoustic coverage along this section of coast indicates that intermediate reef is present on the inner- and mid-shelves, although its extent is unknown.

An extensive nearshore reef system also occurs along the shoreline of this region, although south near Narooma the coast has a much higher proportion of sand-dominated beaches that are interspersed with nearshore reef primarily adjacent to prominent headlands such as Broulee and in the Moruya Heads region. Although these large headland reefs appear to extend further offshore, many of the smaller reefs such as off Tuross Head and north of Narooma only extend around 100 metres from the shore. South of Narooma patchy nearshore reef occurs adjacent to the rocky shorelines, but this is not as consistent as fringing subtidal reef that occurs adjacent to intertidal reef. Much of the reef is not continuous to shore or becomes greater in extent with increasing distance from shore. This is evident in the Twofold Bay region where there are large areas of intermediate reef. Areas of complex limestone reef occur in the south of the region at depths of about 80–100 metres, although much of the reef is relatively low relief (Bax and Williams 2001).

5.3.2 Benthic communities

The distribution of shallow reefs in the southern region indicates that there are extensive areas of habitat fringe, Phyllospora- and *Ecklonia*-dominated areas. These have been extensively studied in the Jervis Bay region (Underwood and Atkinson 1995, Barrett et al 2007), although less is known about the habitats of shallow reefs along the open coast. The reefs often also contain many ascidians, predominantly *Pyura* spp. Although there appears to be some depth-related pattern to these 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 (Underwood and Atkinson 1995, Barrett et al 2007). There are also patterns determined by exposure to swell, and patterns of recruitment and grazing that result in considerable variations in algal composition. Limited video footage was taken in the southern region during the course of this study, although it was mostly consistent with that in other studies. Urchin barrens are extensive throughout the region, although patchy in their distribution (Andrew and O'Neill 2000).

Very little is known about the benthic assemblages on intermediate depth reefs in the region because few surveys have been conducted. However, consistent with reefs at these depths in other temperate regions, assemblages are likely to include a diverse range of sessile species dominated by sponges with elongate, encrusting and branching morphologies. Invertebrates probably include stalked ascidians, black corals, hydrozoans, gorgonians, anemones, soft corals and bryozoans (Butler 1995). Variations in invertebrate assemblage composition will often reflect patterns in the physical environment.

The significant variations in composition and structure of unconsolidated habitats seen in the southern region are likely to influence the structure of the associated communities. There is evidence that the various sediment types, in combination with depth, can result in considerable differences in macrofaunal composition (Coleman et al 1997, Edgar et al 1999, Beaman et al 2005). The increased structural complexity of the unconsolidated habitat can also influence the faunal assemblage, with various species using features such as shells, burrows and depressions (Auster et al 1995). Overall, there is often a strong relationship between habitat structure and macrofaunal diversity in coastal soft-sediment habitats (Thrush et al 2001). Most of the animals in this benthic habitat are infaunal species, with over 500 species of macrobenthic infauna identified in Jervis Bay, consisting mainly of polychaetes, molluscs and crustaceans (CSIRO 1994, Jacoby et al 1995). The crustaceans are dominated by amphipods, whereas the molluscs are predominantly gastropods and bivalves.

Video assessment of the macrofauna and flora living above the sediment in this habitat revealed a much lower diversity of species. Previous surveys commonly identified 22 categories of benthic fauna and flora from video surveys, dominated by several species of sea pens, fish, sharks, stingarees, drift algae, bivalves and polychaetes (CSIRO 1994). Five benthic assemblages were identified based on their most distinctive features – bivalve clumps, drift algae, polychaete hummocks, bioturbated sand and rippled sand. These benthic assemblages were situated in distinct locations around the bay (CSIRO 1994). For example, drift algae occurred regularly at the western and southern side of the bay and bivalve clumps occurred predominantly on the northern side of the bay. This pattern of distribution could occur due to depth, the flow of currents, sediment quality, exposure to wave action and past disturbance such as dredging (Jacoby et al 1995). These patterns were generally consistent in the present study.

The bivalve clumps were aggregates of sessile invertebrates and algae dominated by hairy mussels (*Trychomya hirsuta*), and less commonly by mud oysters (*Ostrea angasi*) and several species of scallop (*Chlamys asperrima* and *Chlamys bifrons*) (CSIRO 1994). A number of species of ascidians, sponges, algae and crustaceans occurred at some sites. The polychaete hummock habitat was characterised by mounds of sediment surrounding dense aggregations of the polychaete, *Mesochaetopterus* sp., that form sand-encrusted tubes. Drift algal habitat consisted primarily of unattached banks of the red algae, *Gracilaria edulis* or *Acrosorium venulosum* (CSIRO 1994). Several other species of red algae, such as *Rhodymenia australis* and *Ceramium lentiforme*, can also bloom within the bay (Millar 1995). Further details on patterns of reef and soft-sediment biodiversity within the Jervis Bay region is presented in NSW MPA (2008b).

The reefs in the Twofold Bay region contained large areas of barrens habitat, with kelp (*E. radiata*) relatively rare and only observed at depths between 16 and 25 metres. Barrens habitat extend up to around 70% of some individual reefs in the region, although this is highly variable between reefs (Andrew and O'Neill 2000). In the present study, several reefs exhibited a pattern of barrens habitat in shallower areas that gradually gave way to *Watersipora*-dominated reef at increasing depths, with encrusting pink coralline algae common on boulder reefs at depths of 25–38 metres. Reef at depths greater than around 20 metres supported a mosaic of sessile invertebrates (mainly sponges) and mixed algal assemblages, which is consistent with that found along the much of the NSW coast.

On the far south coast an area defined as the Big Gutter is located in a central section of the Howe Reef at depths of about 80–100 metres, where the reef is broadly subdivided by many channels (Bax and Williams 2001). Disaster Bay is dominated by soft sediments, and offshore of a large reef system that includes the Big Gutter, a large sediment flat extends to the shelf-break. The soft-sediment habitat is an area of unrippled, well-sorted, semi-consolidated, thick (greater than 5 centimetres) mud and organic debris offshore of the reef in depths of about 125 metres (Bax and Williams 2001). Occasional individual solitary ascidians, sea whips (*Primnoella australasiae*) and sponge communities are evident. Fossiliferous limestone-slab reef is complex in places, particularly at the reef margins, with vertical slope and overhangs in patches of high-relief substratum (greater than 3 metres) with pinnacles, some of which support a dense cover of sponges and sea whips. Other areas have less distinct margins and a steep slope (30–45 degrees). The reef platform has a thin (less than 5 centimetre) mud cover with sparse epibenthos and some evidence of bioturbation (Bax and Williams 2001).

5.4 Conclusion

Overall, this study details the distribution, extent and structure of rocky reef and unconsolidated (soft-sediment) habitats on the inner- and mid-continental shelves of NSW, and collates and analyses existing broadscale bathymetric and marine sediment datasets covering the entire NSW continental shelf. The distribution of seabed habitats reflects the regional patterns of geology, geological history, coastal inputs and transport of sediments. The broad distribution of rocky reef habitats reflects the patterns of bedrock geology which varies in its geomorphic and textural attributes and resistance to weathering. Along most of the NSW coast there are prominent rocky reef outcrops seaward of most headlands, although the present surveys have also identified significant reef systems in areas on the continental shelf that are not continuous to shore, or are continuous to shore associated with offshore islands. There are also a number of significant reef features that occur offshore of ocean beaches in the region. The high resolution of the swath bathymetry revealed the reefs show considerable variability in terms of geomorphic structure (e.g. boulders, gutters, walls, pinnacles) and extent of patchiness, although there was no obvious latitudinal or cross-shelf trend in reef structure as such variations were often present within the same continuous reef system.

Unconsolidated habitats were often complex, with the sediments on the shelf mostly dominated by inner-shelf sand, mid-shelf muddy sand and outer-shelf coarse sand, although localised variations to this broad pattern are evident. The most significant sediment variations on the inner-shelf are the patchy occurrence of finer sediments in areas offshore of Yamba, Wooli, Batemans Bay and offshore of the Newcastle, Sydney and Wollongong regions, as well as the presence of coarser sand on the mid- or outer-shelves. Similar areas of coarse sediment are evident on the inner-shelf throughout the Solitary Islands, Port Stephens, Sydney and Wollongong regions. Nested within these broad areas, swath-mapping revealed significant fine-scale structuring of soft-sediments on the inner- and mid-shelves, influenced primarily by the presence of sand ripples, sand waves and variations in particle size and shell content. There are also areas that contain varying amounts of boulders, cobbles and pebbles, particularly adjacent to areas of rocky reef.

The dominant benthic assemblages from shallow, intermediate and deep reef habitats were broadly consistent with previous surveys of these habitats on the continental shelf of NSW, with the distribution of habitats patchy and outwardly related to depth. Shallow reefs in the northern NSW region were a mosaic of corals, sea urchins, kelp and mixed algal assemblages. Intermediate reefs were dominated by sponges and other sessile invertebrates, and supported a lower abundance of kelp and other algae. Deep reefs were dominated by a range of sponges with varying morphologies (e.g. massive, branching, elongate), and sessile invertebrates such as ascidians, gorgonians, and sea whips. Reefs in central and southern NSW supported a similar composition of sessile macrofauna and flora, except that coral habitat was replaced with a mosaic of macroalgal beds and urchin barrens.

Overall, the marine mapping conducted within this project has significantly improved our knowledge about the distribution, extent and structure of seabed habitats and bathymetry on the NSW continental shelf. This data has been combined with the recent mapping of estuarine aquatic macrophytes (Creese et al 2009) resulting in a statewide 1:25,000 seabed habitat maps series. This provides important information available for improving sustainable marine and estuarine natural resource management by focusing regional investment on activities such as coastal catchment initiatives, habitat protection and community education. The information is particularly important for the process of improving the likelihood that marine parks and their zones contain a comprehensive, adequate and representative selection of marine biodiversity. Baseline habitat information is also essential for monitoring, evaluation and reporting, which measures performance towards natural-resource management targets and improves sustainable natural-resource management and biodiversity conservation within marine waters of NSW.

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7. Appendices

Appendix 1. Physical and habitat classes attributed to classified points

	Class	**Description**
Physical class	**Sand**	Sand substrate consisting of fine/coarse/muddy sand; shellgrit and sand waves/ripples may be present.
	Mixed sediments	Any mixture of sand/cobbles/pebbles/gravel/boulders/reef where reef that is present is smaller than the minimum mapping unit.
	Reef	Continuous bedrock or boulder reef.
Habitat Class	**Bare**	No visually obvious biota.
	Ecklonia	Common kelp, *E. radiata*, is visually dominant, with plants fixed to substrate; sea urchins may be present in low numbers (<1 per linear metre) and are generally confined to crevices; sponges, sessile invertebrates, and mixed red/green/brown algae may be present as an understory; may occur on reef or mixed sediments; usually found between depths of 5 and 35 metres.
	Mixed algae	Mixture of large red/green/brown algal species with no obvious visual dominance of one taxa; sea urchins may be present in low numbers (<1 per linear metre) and usually confined to crevices; sponges and other sessile filterfeeders as secondary community; common in areas of mixed sediments; often found as a narrow band at reef/sand interface.
	Coral	Reef visually dominated by hard and/or soft corals; coral cover exceeds 10%; crustose coralline algae, mixed red/green/brown algae and encrusting sponges/ascidians/bryozoans may be present as secondary communities; sea urchins, typically *Centrostephanus* and *Phyllacanthus*, may be present underneath corals and in crevices.
	Urchin barrens	Sea urchins abundant, particularly *Centrostephanus*; reef generally devoid of large brown algae although small stands of *E. radiata* and other macroalgae may be present on flat sections of reef; crustose coralline algae and encrusting/massive sponges may be present; usually found on complex relief reef at depths shallower than 20 metres.
	Sessile filter feeders	Sponges abundant; other sessile filterfeeders such as ascidians, cnidarians, bryozoans, and hydroids may be common; macroalgae may be present in low densities; may occur on reef or mixed sediments; usually found at depths exceeding 25 metres.

Appendix 2. Error assessment of seabed habitat classes

Overall map accuracy was calculated to be 81.56%. User accuracy for reef areas was slightly higher, at 84.05%, whereas accuracy for non-reef areas was 79.36%. The Tau coefficient (T) was 0.69.

Error matrix showing number of video data-points classified correctly (bold) and incorrectly (italics) as reef and non-reef when compared to digitised polygons.

		Digitised polygons				
Video		Reef	Non-reef	Row total	Producers accuracy	Errors of omission
	Reef	**3809**	*1058*	4867	78.26%	21.74%
	Non-reef	*723*	**4068**	4791	84.91%	15.09%
	Column total	4532	5126	9658		
	User accuracy	84.05%	79.36%			
	Errors of omission	15.95%	20.64%			
	Overall accuracy	81.56%				