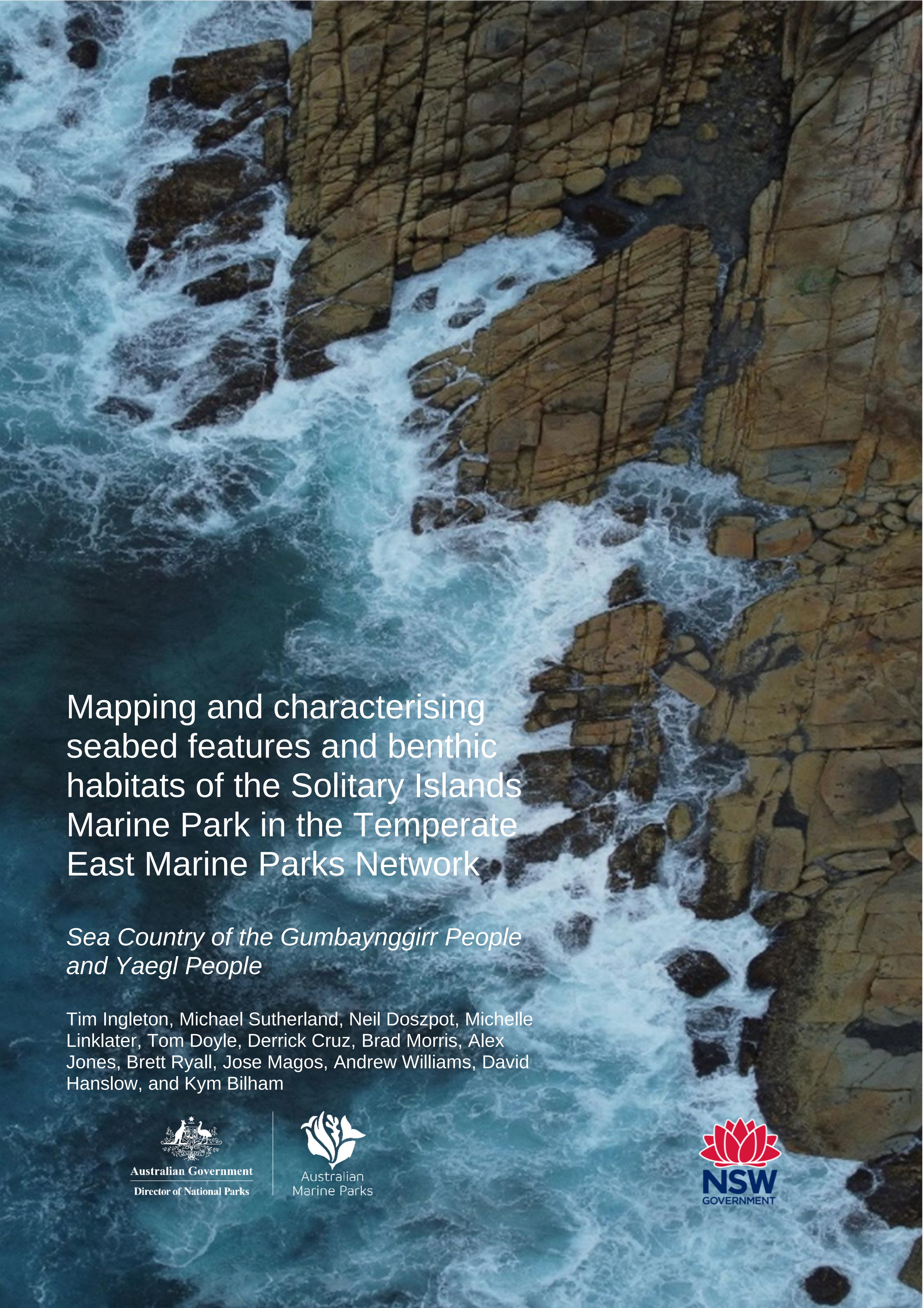

Mapping and characterising seabed features and benthic habitats of the Solitary Islands Marine Park in the Temperate East Marine Parks Network

Sea Country of the Gumbaynggirr People and Yaegl People

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Important Disclaimer

Cover image: drone image of an intertidal rocky shore, Temperate East: Neil Doszpot

Pre-face image: *Chelonia mydas*, Green Sea Turtle: Coffs Harbour, Derrick Cruz

Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

The Solitary Islands Marine Park (Commonwealth waters) surrounds the Solitary Islands Marine Park (NSW state waters) and stretches from Sandon in the north to Coffs Harbour in the south. Occupying the Sea Country of the Gumbaynggirr People and Yaegl People First Nations communities, both marine parks protect submerged landscapes and a range of inherent cultural values. Both parks are located where a unique confluence of warm tropical waters from the East Australian Current and the cooler temperate waters of the Tasman Sea result in a remarkable biodiversity of marine life, including the mixing of many tropical and temperate coral species, many close to the southern extent of their geographical range for Australia's east coast.

The marine park supports a wide range of species of special conservation interest including an aggregation site for the critically endangered east coast population of grey nurse shark (*Carcharias taurus*) at Pimpernel Rock National Park Zone. It also provides habitat for white shark (*Carcharodon carcharias*), black cod (*Epinephelus daemelii*), a migratory pathway for the humpback whale (*Megaptera novaeangliae*), breeding habitat for Indo-Pacific/spotted bottlenose dolphin (*Tursiops aduncus*) and various migratory seabirds. A key management focus for the marine park is the conservation of biological communities associated with the key ecological feature known as 'continental shelf rocky reefs' including such features as Pimpernel Rock.

This project delivered its aim of providing an understanding of previously unmapped deeper areas of the Solitary Islands Marine Park (Commonwealth waters) (SIMP) by high-resolution bathymetric, substrate and habitat mapping. It also provided an unexpected opportunity for First Nations Sea Country Rangers to participate in the research and build their knowledge of their Sea Country and capacity to manage it by enabling them to operate the research vessel and gain sea-time towards their coxswains qualifications.

Until now, more than 70% of SIMP's seabed remained unmapped at high resolution and a baseline picture of the distribution of sediment types, landforms and key reef biota was largely unknown. The data and information from this survey provide, for the first time, a complete (100% mapped) picture of the seabed. Filling this knowledge gap is key to support the development of a long-term monitoring program and effective management of SIMP and its natural assets as part of the Temperate East Network (TE Network) into the future.

Multibeam echosounder (MBES) technology was used to map ~140 km^2 of the Solitary Islands Marine Park (Commonwealth waters) and complete high-resolution coverage for 100% of the park's area. These new surveys increased the total data holdings to 152 km^2 and indicate that of the total park area, 22.6 km^2 can be classified as continental shelf reef. The remaining 85% of the park's seabed is dominated by unconsolidated seabed types. Shallow and mesophotic rocky reefs are most common in the northern section of the park (19.9 km^2) followed by the central section (1.9 km^2) where 'Peaks' and 'Reefs' are the most dominant landform types. While large areas of soft sediment 'Plains' occupy much of the remainder of the park, these are not all flat and featureless. Unconsolidated seafloor to the north of Pimpernel Rock and south-west of both North Solitary and South Solitary islands host an array of complex soft sediment features at both broad and fine spatial scales. These habitats are shaped by the complex oceanography associated with the islands, the displacement of EAC associated water masses and subsequent wakes, in lee of the islands as currents move southward. These impact upon the distribution of sediment types, and different areas of unconsolidated sediments may support their own arrays of mobile as well as infaunal/epifaunal benthic organisms. Mapping indicates that rocky reef features are likely to extend eastward and beyond the current park boundary in the northern and central sections. In the south, long and thin reefs, likely to be relic coastline, are the dominant reef feature for the area, however, only a relatively small proportion is protected within SIMP (NSW waters). MBES surveys over unmapped areas outside the boundary of SIMP from between 60-70 m out to the continental shelf break (200 m water depth) would provide a more complete picture of reefs and habitat types over the continental shelf that lie between the SIMP and Central Eastern Marine Parks.

Towed video imagery and its analysis was effective in characterising both the reef and soft sediment areas and the biological communities for the park. Towed video confirmed that characterisation of the dominant seabed type from MBES and landform analysis was correct 85% of the time (Kappa statistic 0.67, $p<0.001$). Reef was captured in imagery from a total of 26 of the 52 transects from the spatially balanced approach, with scoring of 10% of the reef image set generating 14,708 annotations. Reefs were dominated by sessile epifauna predominantly sponges (Porifera), Black & Octocorals (Cnidaria) and Bryozoans (Bryozoa) and generally diversity and densities of morphospecies appeared to be greater in northern and southern sites compared to the central section of the park. This may be a function of a combination of differences in reef complexity, proximity to reefs beyond the park boundary, proximity to flows from rivers/estuaries, EAC interaction with the islands effecting larval dispersal and/or the nature of the surrounding seabed. For the sponges, massive forms tended to have the highest relative abundances and cups tended to be more common on reefs in the north compared to central and southern sites. Branching 2D and 3D corals dominated the relative abundances for the Cnidaria in the north, with hydroids and 3D branching & stony corals were more common in the central and south. Hard fenestrate or soft foliaceous morphotypes were the most common Bryozoans observed within the imagery. Mobile species over reefs were mainly fishes, sea stars and crinoids. Soft sediments although were not devoid of life, however, and commonly, burrows, crinoids, fishes (including flathead), sea stars and ophiuroids (brittle stars) were observed.

Despite the occurrence of shallow and mesophotic rocky reefs across the SIMP, the smoother seabed between reef platforms and Islands are sedimentary (unconsolidated) plains and were the focus of the sediment sampling campaign. Forty-six sediment samples were collected across the SIMP, and each location of those sample sites were chosen using the varying intensity return signals of the high-resolution MBES backscatter product. Results show that the sedimentary environments within and surrounding the SIMP reflect typical units of the NSW shoreface and inner shelf, those being; pockets of fine sands of the outer nearshore zone (~250 µm; water depths of <40 m); lenses of medium to coarse grain inner shelf sands (or gravels) (900-2050 µm, water depths typically between 40-50 m); to the fine muddy sands of the gently sloping, low energy inner-mid shelf unit (<250 µm, at water depths of > 50 m). Interestingly, carbonate content varied across the samples, but typically increases within the inner-shelf sand unit, and proximity to rocky reef outcrops.

The surveys and analysis approaches applied here had both benefits and limitations. Improvements to motion correction and use of ‘true’ MBES systems have provided a more precise/accurate digital elevation model with higher point cloud counts. The output products are ‘cleaner’ with less artefacts than previous surveys (pre-2012; https:/portal.aodn.org.au) for both bathymetry and backscatter, facilitating a much straight-forward process and automation of the landform classification and sediment interpretation. The quality of the towed video and subsequent utility for annotation of benthic organisms is less than that provided through AUV and stereo survey approaches. A percentage of images acquired using towed video will always be unusable due to lighting, the tethered nature of the fish and/or environmental factors. Towed video, however, remains a rapid and cost-effective approach until size, weight and cost limitations around AUV-type vehicles are overcome. While diversity statistics were calculated from the 2-step annotation approach here, the ability to use and compare it with previous approaches (i.e., Hunter - 50 random images and 25 random points) should be further explored with further annotation and analyses.

The broadscale sediment sampling campaign demonstrated that the sedimentary environments within and surrounding the SIMP reflect typical units of the NSW shoreface and inner shelf and provides greater insight in the key processes acting on or controlling the shoreface response / evolution for this section of the NSW coast. Further development using a combination of backscatter and sediment analyses will provide further output products in the form of substrate maps detailing the sediment distribution in more detail than ever before around the SIMP. This type of data can be used (in conjunction with other products developed in this study) to help inform appropriate application (or derivation) of management actions and protection measures within the SIMP and wider primary sediment compartment. In the future, data on the distribution of benthic invertebrates and microbes would be easily acquired by sub-sampling from the same grab sampler, should this be of interest toward exploring the park’s soft sediment biodiversity.

A series of recommendations toward the development of a monitoring program and future survey work for the Solitary Islands Marine Park are provided at the end of this report.

1. INTRODUCTION

1.1 The Solitary Islands Marine Park (Commonwealth waters)

The Director of National Parks, represented by Parks Australia, is responsible for managing the Solitary Islands Marine Park (Commonwealth waters) under the *Temperate East Marine Parks Network Management Plan 2028 – 2028* (the Management Plan), a legislative instrument under the *Environmental Protection and Biodiversity Conservation Act 1999* (Commonwealth EPBC Act).

The Temperate East Marine Parks Network comprises eight individual Australian Marine Parks (AMPs) which are located in Commonwealth waters which start at the boundary between NSW and Commonwealth waters, 3 nautical miles (nm) from (~5.5 km) from the shore and extend to 200 nm offshore.

The Solitary Islands Marine Park (Commonwealth waters) adjoins the Solitary Islands Marine Park (NSW waters) which is managed by the NSW Department of Primary Industries and Regional Development (NSW DPIRD). SIMP (Commonwealth) was established in 1993, two years after and the SIMP (NSW) was established in 1991. The submerged landscapes and biodiversity within both the SIMP (NSW waters) and the SIMP (Commonwealth waters) are culturally significant to the Gumbaynggirr and Yaegl Peoples First Nations communities.

The park covers an area of 152 km^2 and is currently divided into three management zones (Figure 1.1):

1) Special Purpose Zone (Trawl) (IUCN VI) extending from the state waters boundary to the 50m depth contour. This zone borders a section of the NSW state Solitary Islands Marine Park at the state coastal waters boundary from a point due east of One Tree Headland to Coffs Harbour over the inner continental shelf and represents 114.1 km^2 (75%) of the total park area.

2) Multiple Use Zone (IUCN VI) 36.7 km^2 (24%)

3) National Park Zone (IUCN II) 1.6 km^2 (1%).

Each zone allows different types of activities within them consistent with the zone objectives defined in the *Temperate East Marine Parks Network Management Plan (2018 – 2028)*.

The region is strongly influenced by the East Australian Current (EAC), which influences the ecology of the region and attracts both aquatic and terrestrial marine species of interest such as tuna, whales, terns (i.e. the crested tern *Thalasseus bergii*; Figure 1.3) and albatross. There are also over 50 species of fish endemic to this region (Director of National Parks, 2018). The key ecological features of the Solitary Islands Marine Park are continental shelf rocky reefs and Tasman front and eddy field (Director of National Parks, 2018).

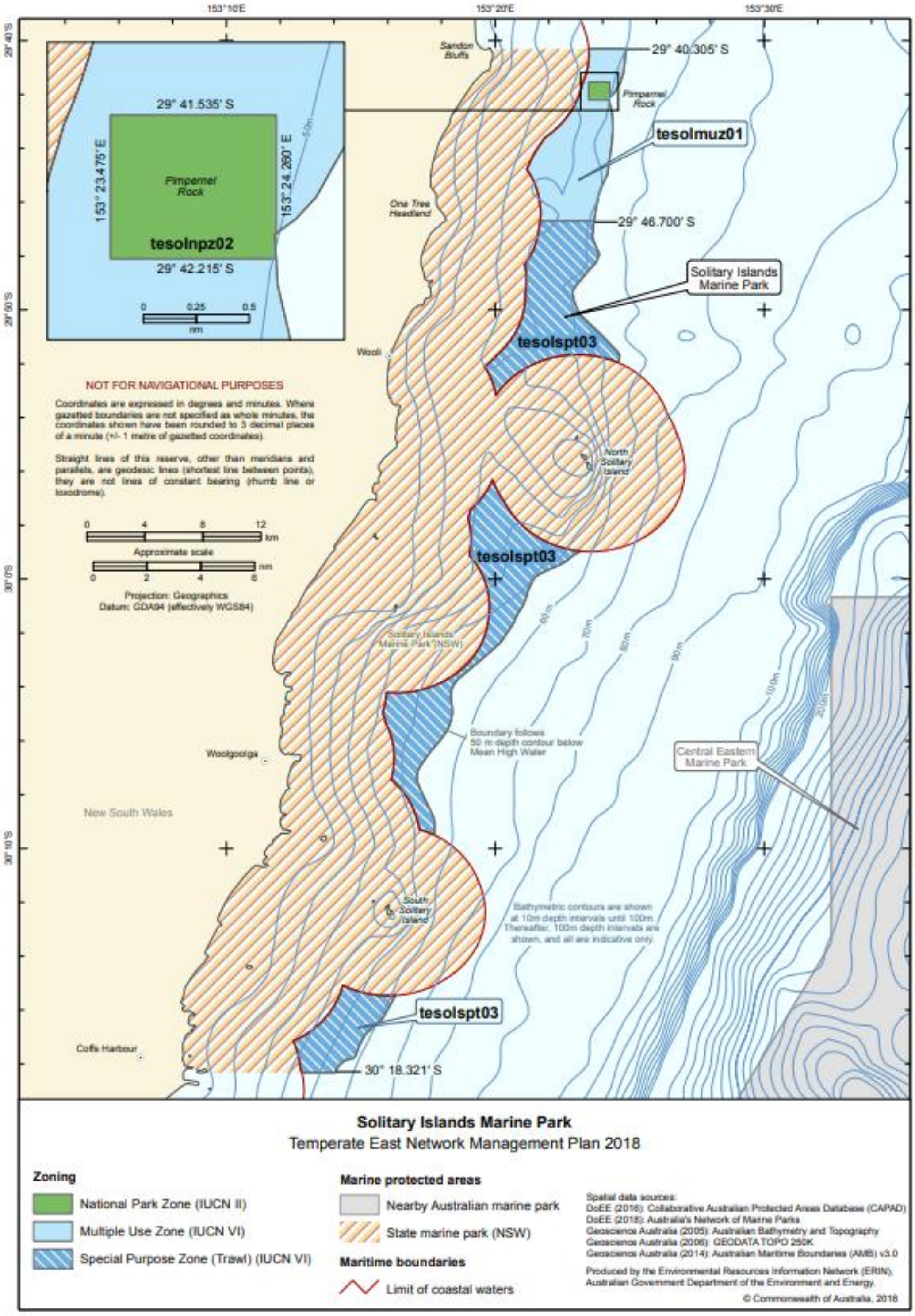


Figure 1.1 Zoning map of the Solitary Islands Marine Park (Commonwealth waters), Temperate East Marine Park Network.

Importantly, the highly protected National Park Zone (NPZ) at Pimpernel Rock in the northern-most section of the SIMP (Commonwealth) protects an aggregation site of Grey Nurse Shark (east coast population; nurse shark; Figure 1.2) (*Charcharias taurus*) a species listed as critically endangered under the EPBC Act. This is one of two aggregation sites in Commonwealth waters listed in the Recovery Plan for the Grey Nurse Shark, with the other being at Cod Grounds Marine Park, (also within the TE Network). Pimpernel Rock is a unique underwater pinnacle with high conservation value rocky reef that also provides sanctuary for an array of both subtropical and temperate coral and fish communities, including the Black cod (*Epinephelus daemeleii*) a species listed as vulnerable under the EPBC Act (Figure 1.3).

Non-First Nations people's understanding of the cultural values of the Solitary Islands Marine Park has improved in recent years with connection of the Yaegl and Gumbaynggirr Peoples' to Sea Country shared in cultural experiences and public displays (i.e. Gumgali Track and Sealy Lookout). The islands and several coastal sites have particular cultural significance such as Split Solitary Island (Wiirriiga), Muttonbird Island (Giidany Miirlarl), South Solitary Island (Bunyun gudi in Morelli 2008) and North Solitary Island (Ngarunda). The Solitary Islands Marine Park also has strong social and economic significance as it supports commercial fishing, recreational fishing and tourism through a range of activities, including diving, whale, dolphin and bird watching.

Figure 1.2 Grey Nurse shark, *Carcharias taurus*, and scuba diver, SIMP (Parks Australia website image).

1.2 Survey Area Location, Oceanographic and Geomorphological Features

In 2022, Parks Australia sought high resolution (5m) bathymetric, substrate and habitat mapping of identified priority seabed areas of the SIMP. Using a combination of multibeam sonar, towed underwater video and sediment sampling, contracted surveys were commissioned to deliver 100% high-resolution mapping coverage across the park's seabed.

Previous mapping campaigns over the continental shelf (<200 m water depth) in NSW and Commonwealth waters have provided new levels of understanding of the distribution of seabed types and benthic habitats for the Temperate East. Surveys have identified areas with relatively high structural complexity, at depth, that were likely to support high levels of biodiversity such as hard substrate reefs, but also a diversity of unconsolidated (soft-sediment, intermediate habitats) across mesophotic (mid-light level) depths over the inner to mid continental shelf (Williams et al; Ingleton et al, Jordan et al).

Five of the TE marine parks that contain and manage continental shelf habitats and seabed. The Hunter Marine Park near Port Stephens currently covers the largest area (~1800 km^2) followed by the Solitary Islands (~150 km^2) and then Jervis Bay (~120 km^2). The smallest park, named the Cod Grounds (4 km^2) is a Grey Nurse Shark aggregation site and situated near Laurieton on the NSW mid-north coast, 30 km south of Port Macquarie. Both the Hunter and Jervis Bay parks on-shelf areas are managed within IUCN Special Purpose Trawl Zones. These zones extend further east and encompass areas of deeper water out onto the continental slope to depths of ~1000-1200 m. While the extensive Central Eastern Park lies close to the Solitary Islands, its western boundary starts at the continental shelf break (~12 NM and 200 m water depth) and is focused over relatively deeper habitats.

1.3 Existing State of Knowledge for the Solitary Islands Marine Park

At the time of writing, a total of ~1000 km2 of the network's seabed was indicated to have been mapped at a resolution of 10 m or finer (https://seamap.australia.org). Other RV *Investigator* surveys may have been completed since the last update, however, they are yet to be made accessible online. Prior to the commencement of these surveys, approximately 51.3 km^2 (~35%) of the SIMP's ~150 km^2 seabed had been mapped to a resolution of 10 m or finer scale, with only 7.9 km^2 mapped as 'Hard Substrata' or reef. SeaMap Australia (https://seamap.australia.org) also indicated that underwater imagery of seabed substrate and biota was limited to a small number of Reef Life Survey (http://www.reeflifesurvey.com) scuba transects at Pimpernel Rock (2016) with a total of 225 annotations. Baited Remote Underwater Stereo-Video surveys (stereo-BRUVs) have been completed more consistently during the period 2010-22 with a total of 10 separate campaigns completed. The site also indicated that only 3 sediment samples had been reported to have been collected or held within the current database. However, a total of 20 sediment samples are registered (2018) as having been collected within the bounds of the marine park according to Geosciences

Australia archives (https://www.ausseabed.gov.au). Details of the location of pre-existing underwater imagery and sediment samples are not provided here.

Figure 1.3 Crested tern *Thalasseus bergii*, Solitary Islands Marine Park. Photo Derrick Cruz

1.3.1 Photic and Mesophotic Reefs

According to earlier surveys (Jordan et al, 2010) areas of <30m of water depth in the SIMP are shallow rocky reef and either associated with the pinnacle reef feature, Pimpernel Rock, or contained within a small area further to the south-west and to the north-northeast of Minnie Water. Totalling an area of ~0.3 km^2, seabed organisms are generally exposed to sunlight at these depths and lie within the photic zone. The remainder of the park's mapped area (Figure 1.4) lies in deeper water (>30 m) that, either soft or hard, is exposed to relatively lower levels of light. Thes are classified as 'mesophotic' habitats. More broadly across the SIMP, reefs vary in nature from small (10's of m), discontinuous and isolated reefs in the south to continuous and relatively extensive (>1-2 km2) areas in the north.

The mesophotic zone, is defined as a 'middle-light' region of the ocean covering depths of ~30-150 m (Figure 1.5) and at these depths, reef organism are often characterised by the presence of light-dependent invertebrate assemblages and low-light tolerant algae.

Figure 1.6). Many of these communities have been described within tropical and subtropical regions of the world (Hinderstein et al. 2010, Kahng et al. 2010, Baker et al. 2016, Loya et al. 2016, Turner et al. 2017; Figure 1.5). A further sub-division can also be considered, where mesophotic ecosystems are split into both an upper (30-60 m) and lower mesophotic (60-150 m), with in-water quality variables such as clarity and temperature as, generally, the defining

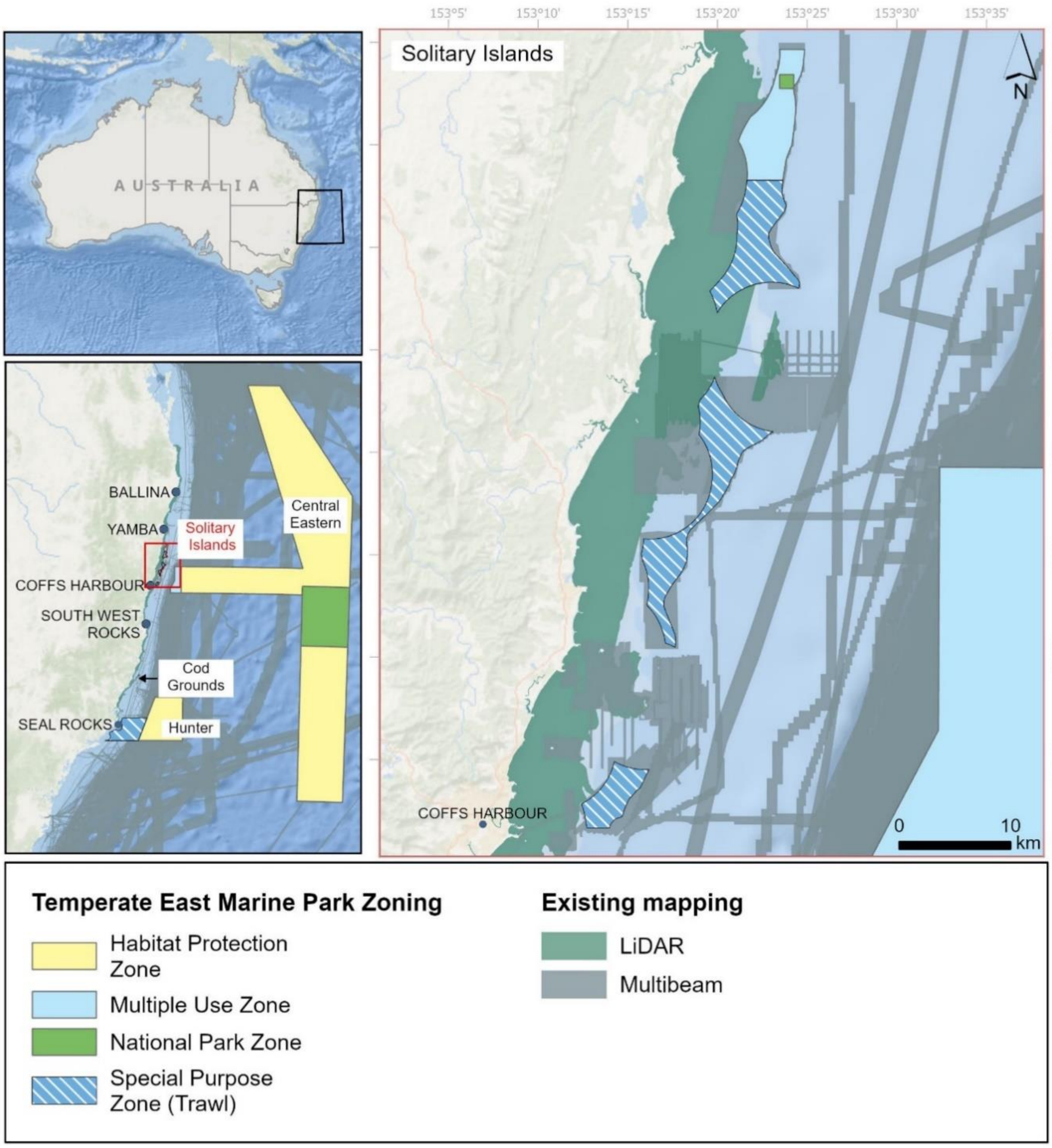


Figure 1.4 Location of the SIMP (Commonwealth) a) along Australia's temperate east offshore of northern NSW; b) marine parks of the Temperate East (with zoning) and multibeam echosounder (MBES) extents (grey); and c) detailed zoning plan within the SIMP; with extents of seabed data coverage (MBES, LADS) (grey) prior to 2022-23. Note: Long, narrow grey lines denote transit surveys by the RV Investigator (Marine National Facility).

factors for the depth of the transition zone (Loya et al. 2016, Tamir et al. 2019; Figure 1.5). How these zones are defined and applied is yet to be reported for temperate areas (Williams et al 2020). With the recent expansion of multibeam acoustics, surveys over continental shelf waters have revealed that mesophotic ecosystems can form extensive areas of seabed habitat (papers in Harris et al, 2020) including that within Australian coastal waters (Jordan et al. 2010, Lucieer et al. 2016, 2019, Nichol et al. 2016) and the Temperate East (Ingleton et al, 2019; Williams et al 2020).

Generally, mesophotic reefs occupy depths below active wave base and sit within secondary sediment compartments (Hazelwood et al 2013; MacPherson et al 2015) below the lower shoreface where active processes such as sediment transport may cover or uncover reefs on interdecadal timescales (Thom 2015; Thom et al., 2018). Mesophotic reefs may range from discontinuous and isolated reef, surrounded or interspersed with areas of unconsolidated sediments (i.e. Gulf of Carpentaria, Australia in Harris et al. 2008, Baker et al. 2016) to broad continuous structures, sometimes connecting to shallower reef systems and providing an unbroken opportunity for biological connectivity across a relatively wide depth gradient (i.e. Great Barrier Reef (Bridge et al. 2011). While the number of studies on mesophotic reefs in recent years has increased (Hill et al. 2014, Loya et al. 2016, Turner et al. 2017, Williams et al. 2019), research has focused on tropical reefs systems and scleractinian corals (Baker et al. 2016, Turner et al. 2017). Relatively lower temperatures in temperate systems sees reefs generally dominated by sponges and octocorals (Jordan et al. 2010, Lucieer et al. 2016, Heyns-Veale et al. 2016, Turner et al. 2019, Williams et al. 2019, Ingleton et al. 2020) except where tropical to subtropical corals also appear, most notably at some seamount islands (Linklater et al. 2016).

The SIMP sits at the transition of tropical and temperate and supports tropical to subtropical coral species close to the southern extent of their range for Australia's east coast.

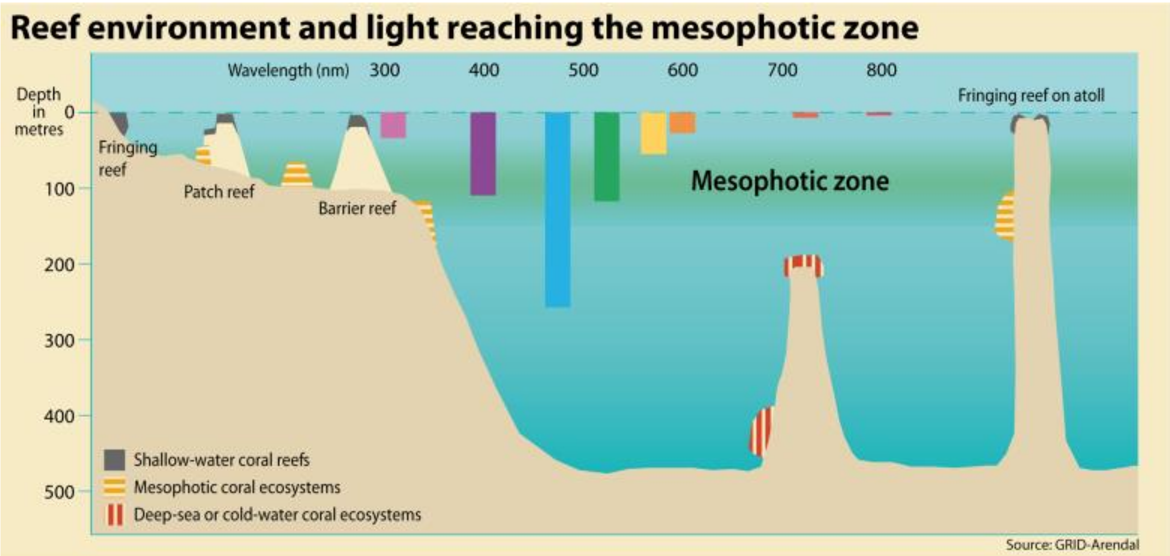


Figure 1.5 An illustration demonstrating the mesophotic zone in relation to depth and how light penetrates through the water column (reproduced in Williams et al, 2020).

The SIMP supports a wide range of species of special conservation interest including foraging habitat for the grey nurse shark (*Carcharias taurus*) and white shark (*Carcharodon carcharias*), black cod (*Epinephelus daemelii*), and a migratory pathway for the humpback whale (*Megaptera novaeangliae*), breeding habitat for Indo-Pacific/spotted bottlenose dolphin (*Tursiops aduncus*) and various migratory seabirds (Director of Parks, 2018). A unique confluence of warm tropical waters from the East Australian Current and the cooler temperate waters of the Tasman Sea results in a remarkable biodiversity of marine life, with a mixing of many tropical and temperate species. Many species found within the Marine Park are at, or close to, either their southern or northern geographical limits and co-exist within the same area.

Routine BRUVs to monitor fisheries species in NSW have focused on reef areas within the state's marine parks across bioregions within the Temperate East (Knott et al 2021) and now span more than a decade. With complimentary funding, surveys have often included sites within adjacent marine parks (i.e. NESP and Hunter Marine Park in Williams et al 2020). In the Solitary Islands Marine Park, BRUVs over reef (Malcolm et al 2018) have been complimented with surveys over soft sediment (Schultz et al, 2015) demonstrating how fish community structure varies between areas of the seabed consisting of different sediment types. These surveys also indicate that certain fish species benefit from 'no-take' zones with increases in the size and abundance of some targeted fisheries species (Malcom et al (2018).

Some of the NSW DPI surveys have included 'drops' at a limited number of sites within the AMP at reef dominated and intermediate habitat (cobble-boulder-gravel) locations including, more recently, Pimpernel Rock (2023). Results of these newest surveys are yet to be published but surveys area accessible via Global Archive (https://globalarchive.org). More recently in NSW, the Marine Estate Management Strategy, has funded towed video surveys to monitor kelp cover and urchin barren extent in shallow water sites along the coast (Davis et al 2021). A total of 36 deployments over 2 campaigns (2019, 220) with 832 annotations have been completed around the Solitary Islands and are accessible via SQUIDLE+ (https//:squidle.org).

While these research activities including seabed mapping, dive, towed and baited video surveys, across the broader Solitary Islands has generally been well supported across shallow water sites in recent years, a broader ecosystem level understanding around links between fish assemblages, habitat structure, and connectivity between mesophotic and their shallower counterparts is required (Bo et al. 2014, Heyns-Veale et al. 2016, Turner et al. 2019).

1.3.2 Seabed and Sediment Surveys

Multibeam echo sounder (MBES) surveys to characterise sections of the seabed around the Solitary Islands were first completed in 2005. The NSW government, at the time, was planning a zoning review for several of the state's established marine parks and the then NSW Department of Environment, Climate Change and Water (DECCW) invested in a MBES survey capability. Initial surveys covered ~60 km^2 focusing on areas around South and North Solitary islands, Sidney Shoals (40-Acres Reef) and a broad area adjacent to the state park's outer boundary in the far north from Wooli to Sandon. This data significantly improved the fundamental baseline knowledge of seabed ecosystems and provided the first high-resolution picture of reef extent within 3 NM of the coast.

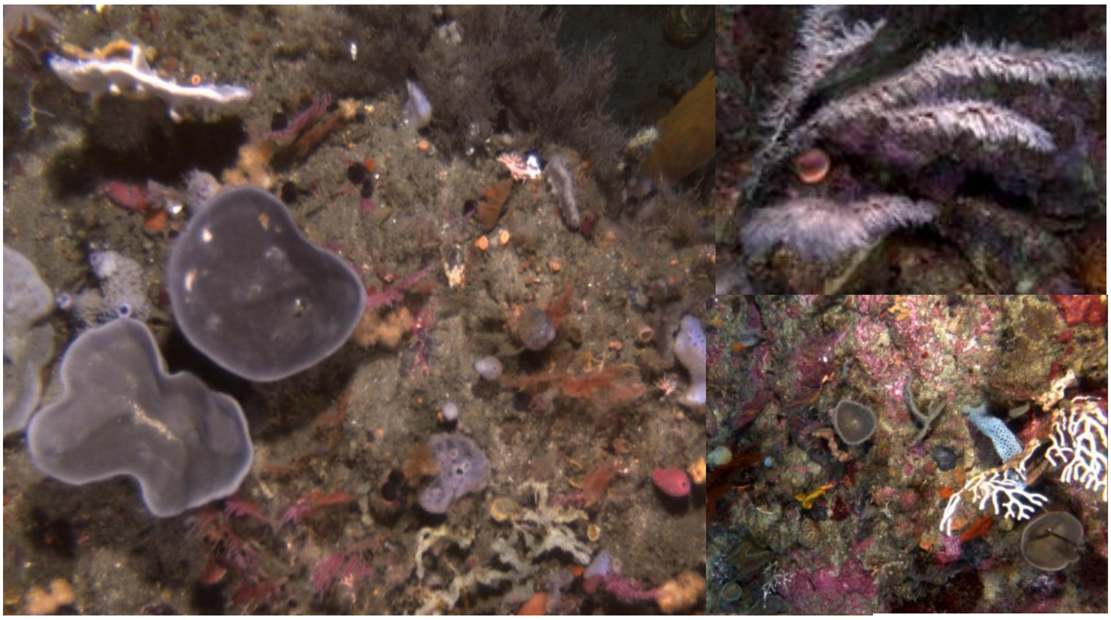
The first MBES surveys within adjacent Commonwealth waters, were completed offshore of Wooli in 2006 and provided the first high-resolution picture of the regionally significant sub-tidal feature, Pimpernel Rock. With funding from the Director of National Parks (Commonwealth Department of the Environment, Water, Heritage, and the Arts) the surveys covered an area of ~12 km^2 and highlighted the extent of reef at the site. The surveys also established the connection of these reefs to larger reef complexes extending to the south-west and into state waters. Completed by the NSW DECCW, a survey report, gridded data (bathymetry, backscatter) and shapefiles ('2-class' habitat: reef, unclassified) detailing the extent of 'consolidated' reef were provided to the department in 2007 (DECCW, 2007).

In 2009, further sections of the Solitary Islands were mapped during state funded surveys to provide complete coverage across an east-west cross-sections of the park (shallow to deep). At this time, areas south and south-west of North Solitary Island were targeted with new mapping capturing bathymetry and backscatter for ~98 km^2 of previously unmapped areas. For the AMP, an area of ~18 km^2 was completed and indicated that the area of interest was dominated by large sediment plains and low-profile features including gravel beds and migrating sand waves. Some limited towed video and sediment surveys were completed during the period 2009-2011 to ground truth MBES survey backscatter and develop a sediment distribution map. These were restricted to within state waters with details of these surveys reported in Jordan et al (2010).

MBES surveys targeting southern sections of the park were first achieved in 2012 with collaborative funding secured under the National Environmental Research Program (NERP) Marine Biodiversity Hub. The focus for this work was to identify areas of continental shelf reef, a key ecological feature for conservation efforts for Australian marine parks including the Temperate East. Mapping of almost all the southern section of the park was completed by NSW DECCW and provided ~45 km^2 of new high-resolution (2 x 2 m gridded) data for both commonwealth and state parks.

These surveys indicated that seabed within the southern section of the AMPs was sand-dominated and planar, and characterised by migrating sand-waves with some small and isolated reefs located close to the southern boundary. More extensive reef features were mapped further offshore and in deeper water (65-70 m) further to the east, beyond the park boundary, but also extending to the north-east and to within state waters. These reefs were long (several km), relatively narrow (<10 m), rising less than 5 m above the seabed. This feature is likely associated with relic coastline from a period when global sea levels were lower than the present day (Nichol et al, 2016).

MBES data from this and previous surveys were further used by NERP researchers to identify sites for Autonomous Underwater Vehicle (AUV) to capture seabed imagery and explore new spatially and statistically balanced sampling approaches of different video-type approaches. Annotations for some of these surveys are accessible via SeaMap Australia and SQUIDLE+ websites. Shapefiles of interpreted seabed habitat types across the NSW inner shelf, including the SIMP, were provided to NERP (University of Tasmania) and made publicly available on the SeaMap Australia website in 2012. By the end of 2012, the NSW



DECCW had completed mapping over ~401 km^2 between Coffs Harbour and Sandon for both the state and commonwealth waters. Through a collaboration with the national Integrated Marine Observing System (IMOS) all surveys were made publicly available through the Australian Oceanographic Data Network (AODN) portal in 2014.

Figure 1.6 Examples of benthic flora and fauna on reefs of the Solitary Islands; i) cup sponges; ii) black corals and iii) mixed assemblages; captured in surveys during National Environmental Research Program, 2012. Images were captured using 'Sirius', an Autonomous Underwater Vehicle (AUV) and extracted from SQUIDLE+; developed by the Australian Centre for Field Robotics, Sydney University, an Integrated Marine Observing System (IMOS) facility funded under NCRIS.

More recently (2018), airborne laser (marine Light Detection And Ranging (LiDAR) is terrestrial LiDAR combined with Laser Assisted Depth Sounding (LADS)) surveys have been completed along the extent of the NSW coast providing nearshore bathymetry and topography at 5 m grid resolution. Funded by the NSW government, the LADs sensors typically map seabed to depths, on average, of 25-30 m and covered 465.3 km^2 of the total area of the state marine park, superseding bathymetry acquired during earlier MBES surveys. Along this section of the NSW coast however, the lasers reached depths of up to ~48 m and provided new data for an area of 22.4 km^2 for the AMP. While the bathymetry data was of improved quality the seabed hardness (reflectance) product is yet to be properly processed.

Historically, the use of seabed topography data for mapping seabed types had relied on hand-digitised interpretations and analyses using GIS. More recently, with improvements in remote sensing technologies, ‘higher’ quality data and digital elevation model outputs, techniques have been able to become more automated. And with this, further application of geomorphometric analysis approaches are being used to classify seabed features and characteristics from local to global scales (Nichol et al; Dove et al 2020; Linklater et al, 2019). For NSW waters, Linklater et al. (2023) developed a classification toolbox to extract seabed features from marine LiDAR and MBES data, termed seabed ‘landforms’ (available for download on SEED and GitHub) that now extends along the length of the NSW coast. Seabed landforms represent areas of the seascape which have distinct morphology, and include reefs, plains, channels and depressions, scarps and peaks. Terms were sourced from international and national nomenclature (IHO 2019, Dove et al. 2020) and adapted to suit the NSW seabed datasets. Classified seabed landforms for the NSW state-wide marine LiDAR dataset and selected MBES surveys (Wollongong, Shellharbour) are available on SEED and SeaMap Australia. Future work could assess the similarities between our approach and other recently published tools for deriving underwater geomorphological features (Zhi et al 2023) with an agreed international terminology and definitions (Dove et al 2020; Nansen et al, 2023) for systematic application across mapped areas of the Australian seabed.

Generally, mapping over the nation's continental shelf has been limited through a general lack of shelf mapping capabilities (Townsend, et al 2022) and less than ~11% of the nation’s shelf is currently mapped at adequate resolution for management (AusSeabed.gov.au). For the Solitary Islands and Temperate East, some other sources of seabed data are available such as that collected by the Marine National Facility (RV *Investigator*). These are, however, limited to a small number of transit surveys (Figure 1.4) and, until now, ~72% of Australia’s SIMP has remained unmapped. This knowledge gap was identified by Parks Australia and NSW government and lodged as a priority for mapping in the national co-ordination mapping tool database in 2021.

Although ~20 samples have been identified as held within national archives, an overall assessment of the sedimentology across both the Solitary Islands state and Commonwealth parks is not evident from the literature. A broad characterisation of the Australian continental margin including surficial sediments of the Temperate East was detailed by Boyd et al (2004; 2006) with an update focused on the continental shelf directly offshore of NSW completed by Jordan et al (2010). Generally, the shelf of the state’s north coast was found to be dominated by inner-shelf muddy sand, mid-shelf muddy sand and inner-shelf coarse sand. In a general sense, finer sediments are characteristic of the seafloor offshore of Wooli and Yamba and areas of coarser sediments situated south of Yamba, through the Solitary Islands and offshore of Cape Byron (Boyd et al, 2006; Jordan et al 2010). Earlier work was completed focusing on the sedimentology, stratigraphy, and geomorphology of the upper and lower shoreface between White Bluff (Sapphire Beach), Split Solitary Island and Sawtell (Roy and Stephens, 1981).

1.3.1 Benthic Imagery

Prior to this survey, imagery of the seabed within the bounds of Australia's SIMP was limited. According to SeaMap Australia (https://seamapaustralia.org/map/ site accessed 25 March 2024) some observations of the seabed made in 2016 (and some more recent in 2023) were still images associated with Reef Life Survey transects at Pimpernel Rock. These types of surveys are, generally, not designed to be used for ground-truthing MBES or understanding seabed typology as the information is spatially limited and may be considered relatively not cost effective. Some earlier towed-video surveys were completed in 2005 as part of the Solitary Islands Marine Reserve Baseline Surveys (The Ecology Lab, 2006) with scoring of some limited biota. The seabed and benthic organisms identified within the tows were classified into broad substrate types and densities of four 'conspicuous' benthic invertebrate groups (sea urchins, sea stars, sea pens and sea whips). Generally, the study identified sea urchins to be in the greatest densities for the four groups observed with urchins at their lowest densities in northern sites and highest densities in central and southern sites for the survey. Sea pens were at their greatest density at sites in the central section of the park. Imagery from these surveys, however, are not currently accessible through SeaMap Australia or SQUIDLE+.

Figure 1.6).

Although the benthic communities at these sites are likely similar, reefs within the SIMP are in deeper water and managed by different zoning approaches, and thus, different assemblages may occupy different sites. Differences in techniques for assessing seabed communities may also contribute to differences in the types of organisms observed, making direct comparisons between earlier and these surveys difficult.

1.3.2 Oceanography and Geomorphology

Tasman Sea and the EAC

The waters surrounding the Solitary Islands Marine Park are influenced by the East Australian Current (EAC), a western boundary current that arises in the Coral Sea and flows poleward along Australia's east coast and into the Tasman Sea. In the north, the EAC forms a 'jet' with strong directional flow with advection of its warm tropical surface waters often encroaching onto the shelf. To the south, characteristically the jet breaks down and separates from the coast anywhere between 30°S and 32°S (Cetina-Heredia, et. Al., 2014) forming a field of clockwise and anti-clockwise rotating ocean eddies (Oke et al., 2019). Both components of this EAC flow influence the nearshore oceanography by either driving surface waters onshore, offshore or creating an inshore northward counter-flow (Li et al 2022). Offshore of the Solitary Islands the EAC tends to commonly form a jet.

A combination of EAC driven effects and seasonality influence the park's ecosystems (Armbrecht et al, 2014; Armbrecht, 2015) including upwelling at times (Schaeffer 2014). The nearshore bathymetry associated with the many islands and subtidal reef make the oceanography complex sometimes driving the development of small-scale eddies (Schaeffer et al 2017) and temperature gradients of up to 11°C (Malcolm et al 2011).

The region is also being exposed to changes over longer-term temporal scales. The Tasman Sea is identified as one of the world's fastest warming regional seas (Hobday and Pecl, 2014) that, along with a strengthening EAC (Cai et al 2005), has seen surface water temperatures in and around the Solitary Islands (~30°S) rise at a rate of 0.23°C/decade over the last 30 years (Malan et al 2020). For biological communities exposed to the influences of the EAC over the shelf and within the Temperate East, the distribution ranges of some species ranges are shifting further south (i.e., *Centrostephanus rodgersii* in Perkins et al 2015) while others are disappearing, including key habitat-forming kelp forests (Vergés et al 2016). The implications for biological communities have been summarised in various review papers (Suthers et al 2011; Wernberg et al. 2011, Gervais et al 2021, Wolfe et al. 2022) and detail changes to chlorophyll-a, some commercial fish species, seaweeds, with little knowledge of implications for larvae, plankton and megafauna.

Although these changes are driven by regional to global-scale pressures, some tools are being provided to assist management of ecosystems in preparation for change across a range of spatial scales by exploring past trends or in development of early warning systems. For example, access to near real-time temperature data for the nations coastal ocean, including SIMP, is accessible through satellite imagery and analysis provided through such groups as the Integrated Marine Observing System's Ocean Current Facility (https://oceancurrent.aodn.org.au/). Multiple daily satellite images are accessible and provide Sea Surface Temperature (SST) and other ocean state parameters in near real-time. These facilities also provide month-to-month analyses of the state of sea surface temperatures

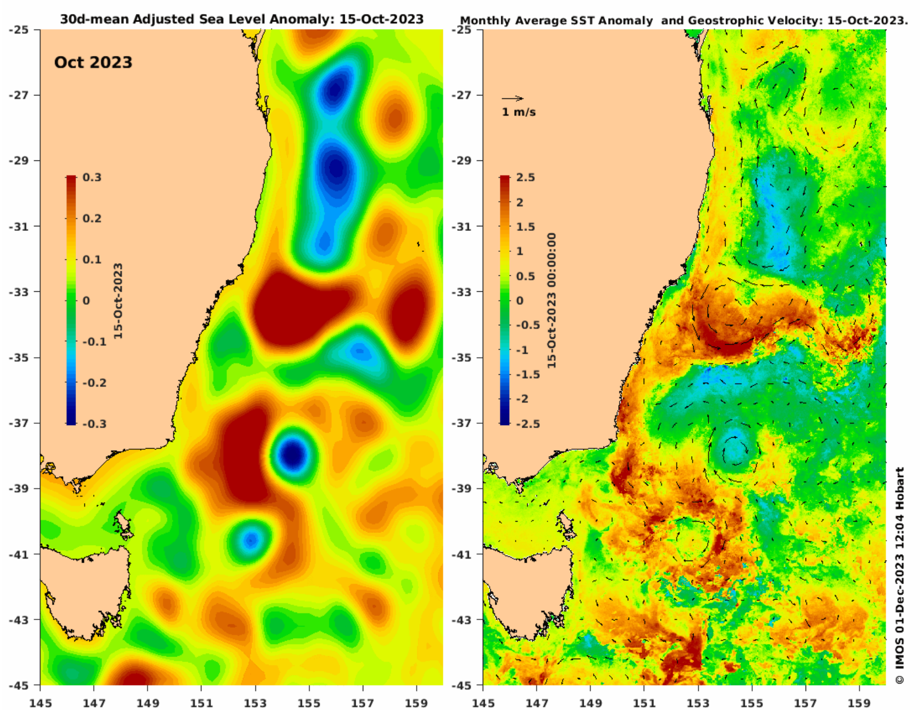
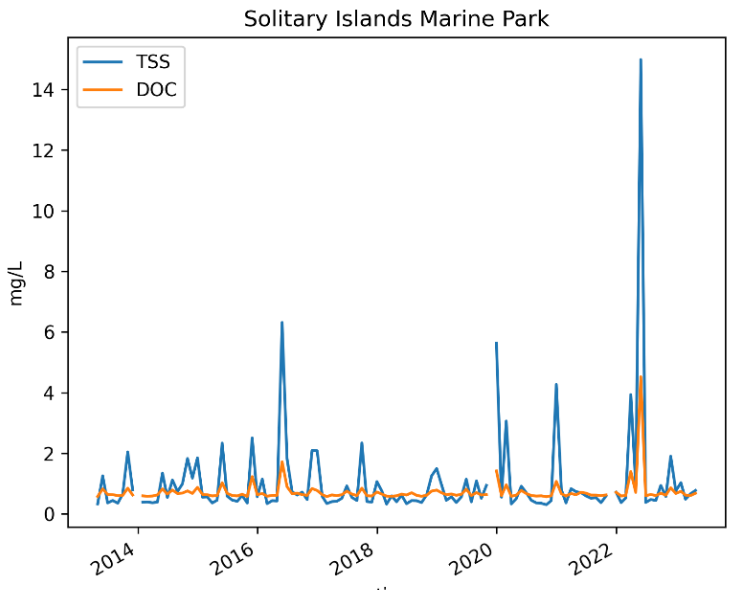


Figure 1.7 Monthly Sea Level and Sea Surface Temperate anomaly maps from the Integrated Marine Observing System (IMOS) using MODIS imagery (NASA) – maps for October 2023 describe ‘above average’ sea surface temperature across the Temperate East (+1.5°C, orange-red).

(Figure 1.7) indicating when SST conditions are outside the expected normal bounds (anomalous) relative to longer-term data. Other new programs such as Aquawatch (CSIRO) and NSW Marine Estate Management Strategy Projects (Coastal Outflows) are developing



water quality analysis and forecasting capabilities using modelling, in-situ sensors and artificial intelligence. These tools would assist natural resource managers in the assessment of changing risk to marine assets and the develop plans on potential responses to pressures such as extreme events (marine heatwaves, flood events; Figure 1.8). The example figure here shows how this AMP has been exposed to estuarine outflows and extreme wet weather (2013-2023), with elevated suspended solids and dissolved carbon observed following the extreme wet weather events in April-May 2022. During this period, NSW received the equivalent of 1-years average rainfall within a single wet weather event (Malan et al, 2024).

Figure 1.8 Timeseries mean for Total Suspended Solids (TSS) and Dissolved Organic Carbon (DOC) across all pixels (30 m resolution) within the AMP Solitary Islands using LandSat8 (USGS) satellite imagery and a Deep Learning Model (NSW DCCEEW and CSIRO Aquawatch).

Coastlines and seabed geomorphology

NSW has an embayed coastline where rocky cliffs and headlands alternate with sandy embayments, infilled to differing degrees with late Pleistocene and Holocene sediments over the past ~6,500 years (Roy et al., 1980). The coastline aligning with the Solitary Island Marine Park (SIMP) is a section of bedrock-controlled coast with extensive offshore rocky reef features (Roy and Stephens, 1980). The bedrock of this region is composed of hard Palaeozoic metamorphic rocks of the New England Fold Belt, that formed perpendicular and relatively close to the modern coastline. This coast, has had less fluvial (river) inputs over geologic timescales, resulting in slower erosion rates than further north or south (Roy and Thom, 1981). This history has helped create relatively small and narrow valleys with smaller coastal embayments (i.e. compartmentalised) and pocket beaches (especially between Iluka River and Coffs Harbour; average beach length is 1.5 km) (Short, 2007). The small beaches are backed by narrow Holocene sand barriers, that are subsequently backed by bedrock. These sand barriers also become submerged and extend offshore, but the marine sand is only a thin layer in this part of the coast and becomes indurated or mud dominated with increased depth and over time (see below) (Roy and Stephens, 1981). Immediately to the south (Coffs Harbour to Port Stephens), fluvial inputs were more dominant across a similar geological setting and more moderate sized rivers have reached the coast. The increased valley erosion aided in the formation of larger and broader valleys and coastal plains. Boambee and Bonville beaches are good examples of this embayment/beach/larger sand barrier type coastline (Figure 1.9) (average beach size increased to 2.4 km from Coffs to Port Stephens) (Short, 2007).

The current approach to classifying the Australian coastline uses the concept of a coastal sediment compartment and has recently been adopted at a national scale to better understand sediment and shoreline dynamics and to underpin coastal management (Thom et al., 2018; Woodroffe et al., 2022). This approach was first applied to coastal management and planning in Western Australia (Eliot et al., 2011), and more recently, in NSW, with the

Coastal Management Act (2016) recommending coastal management programs to use this approach when setting the program boundary/ focus. The geologic provinces comprising the SIMP (shown in Figure 1.9) also contain distinct sediment compartments. These compartments comprise a hierarchical sequence within which similar processes and sediment budgets operate, and they are generally bounded by broad-scale structural features (e.g., rocky headlands, coastline orientation, geology or topography) that often impede (northward) alongshore transport of sand (Davies, 1974; Thom et al., 2018). In this region of NSW, the larger primary compartments are defined by prominent landforms such as river mouths or prominent headlands. Secondary compartments are characterised by sand movement on the shoreface, as well as within and between beaches. The smallest level are tertiary compartments, which are often individual beaches (Thom et al., 2018). Figure 1.9 delineates the primary (red line) and secondary (blue line) compartments aligning, or forming part of the SIMP, as these spatial extents are most suitable for regional-scale strategic planning and management (Thom, 2015; data layers extracted from the national mapping products, see Hazelwood et al., 2013; McPherson et al., 2015), and these include (from larger to smaller):

The Northern Rivers Primary sediment compartment (which spans from Yamba Point/ Clarence River to Laggers Point, near South West Rocks).

- Yuraygir Secondary sediment compartment (which spans from Yamba Point/ Clarence River to the southern end of Wooli Beach) and includes North Solitary Island.
- Woolgoolga (Wooli-Emerald) Secondary Sediment Compartment (which spans from south end of Wooli Beach to Bare Bluff) and includes North-West Solitary Island.

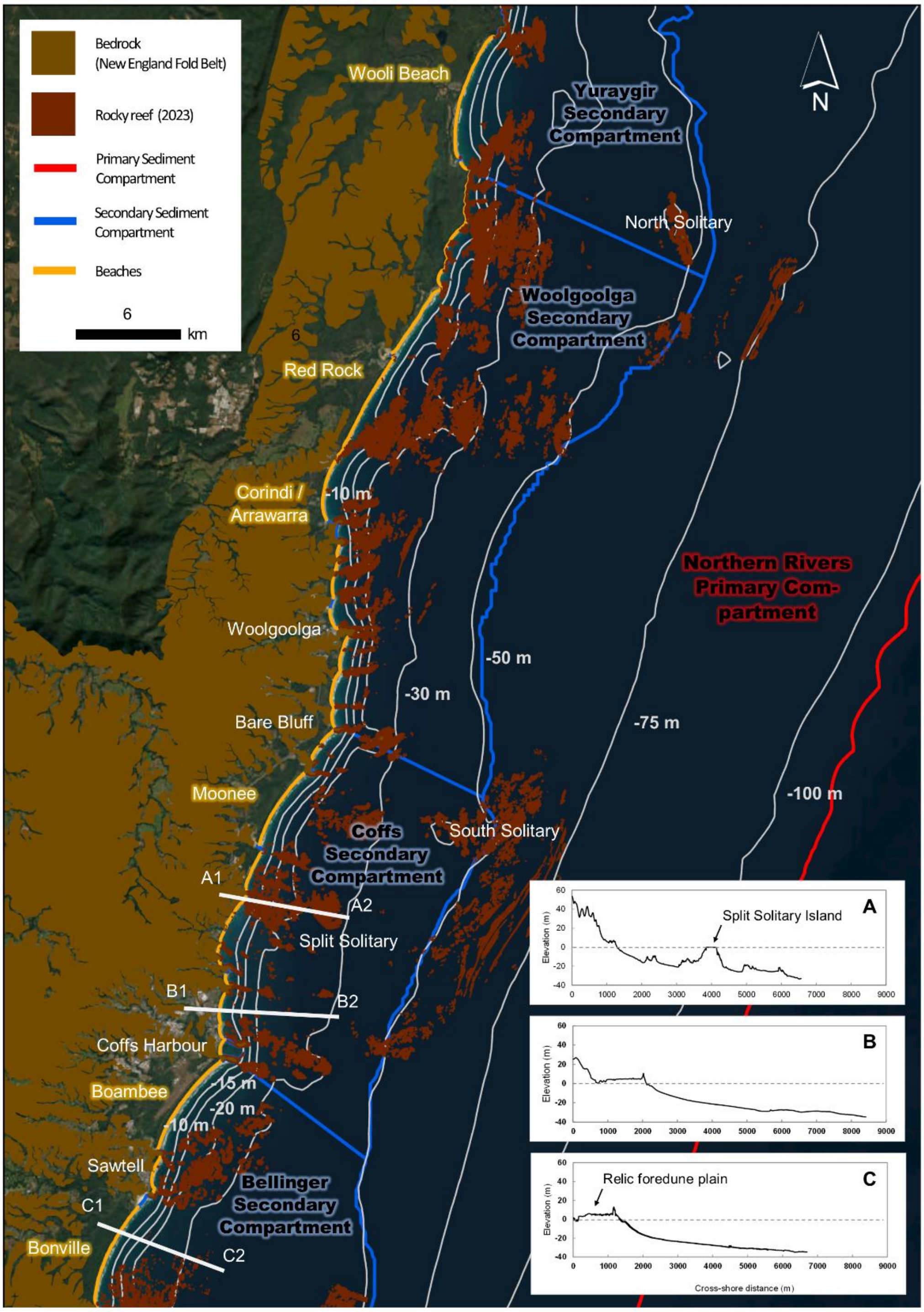


Figure 1.9 Location map showing the Coffs Harbour and SIMP region, including the primary and secondary sediment compartment boundaries (red and blue respectively), navigation bathymetry contours (grey), mapped rocky reef (2023), and bedrock (New England Fold Belt). Inset panels show shore-perpendicular elevation profiles at key embayments and shorefaces, demonstrating the different geomorphological characteristics of the region.

- o Coffs Harbour Coast Secondary sediment compartment (which spans from Bare Bluff to Coffs Harbour township) and includes Split, and South Solitary Island.

It is important to map and classify the seabed within the SIMP, and understand the sedimentology and geomorphology of the park, especially at the primary sediment compartment scale, as it will help managers understand the larger scale processes impacting the region. High resolution and characterised mapping of the shoreface is also a fundamental step towards developing and formalising conceptual frameworks of coastal evolution that can be used to help guide appropriate application of predictive models and management actions within the SIMP and wider primary sediment compartment (Kinsela et al., 2022).

The shoreface is the term used to describe the nearshore seabed extending from the low-tide shoreline (or lower beach), offshore to a supposed break in slope (where seaward is distinctly less steep) (Cowell et al., 1999). The NSW shoreface is characteristically know as a segmented shoreface, which can be broken up into distinct zones, which are illustrated in Figure 1.10 and based on sediment characteristics and depth, they include:

1. Upper shoreface (or inner nearshore), which extends from the beach and dunes to approx. 12 m water depth, and is characterised by coarser grained sands;
2. Lower shoreface (or outer nearshore, which extends to approx. 30-40 m water depth), characterised by finer grained sands, and
3. Inner Shelf (>30-50 m water depth); characterised by coarse sand initially, then finer muddy sand further offshore (>50 m). It is this part of the shoreface we are expecting to see as forming many parts of the SIMP.

The relative difference in the shape of this coastline and shoreface, between north and south, is illustrated in Figure 1.9 Figure 1.9 with several shore-perpendicular cross-sectional profiles. For the southern coastline, the seabed generally is steep and concave, compared to the north, where the underlying geology exerts a much stronger control on the seabed configuration (Roy and Stephens, 1980).

Nearshore and inner shelf unvegetated sediments of the SIMP and Coffs coast generally form a thin layer over bedrock or Pleistocene clays. Maximum shoreface sediment thickness occurs south of Coffs Harbour (within the larger embayments), while nearshore sediment to the north are commonly less than 2 m thick (Roy and Stephens, 1980). The extents of the inner nearshore sands are also interrupted by Coffs Harbour itself, and a number of headlands to the north, by a connection to adjacent subtidal reefs (Figure 1.9). The sediment unit is typically wider and extents to greater depths (~12 m) in the larger, southern embayments, especially compared to those aligned with the SIMP which extend to ~ 5-8 m water depth.

Beach and inner nearshore sands adjacent to the SIMP are generally coarse (some with river pebbles, indicative of relic river channels), resulting in steeply sloping beaches that are predominantly reflective (or low energy intermediate) morphodynamic beach types (Short, 2007). Previous investigations of the area describe outer nearshore sands extending alongshore as a thin lens of sediment that is frequently interrupted by shallow rocky reefs,

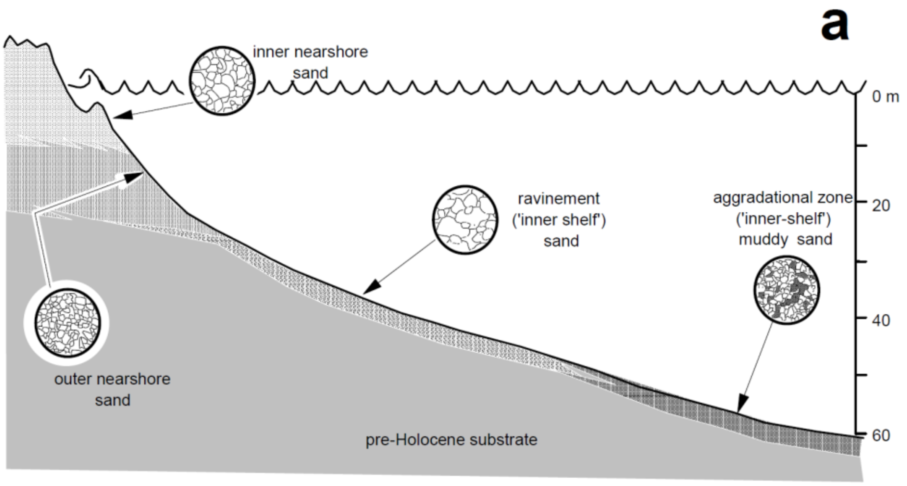


Figure 1.10 Schematic illustration of the Shoreface zones, and the arrangement of segmented sediment units of SE Australia (from Cowell et al., 1999).

and exposure to more coarse inner shelf sand and gravel that form the underlying substrate (Roy and Stephens, 1980). More recently, these gravel lens have been documented for the southern section of the SIMP, with Schultz et al. (2015) linking them to higher intensity backscatter areas mapped and sampled by DCCEEW MBES (Jordan et al, 2020). These outer nearshore sands have been reported to occur in depths of 12-25 m in the south and 5-20 m in the north of Coffs Harbour, and as inferred above, form a thin “mobile carpet” that can be mobilised under just moderate storm conditions (Roy and Stephens, 1980).

Generally, in terms of sediment movement and pathways within and between the secondary compartments of this region, a northward longshore movement and headland bypassing dominates (Thom et al., 2018). With the construction of Coffs Harbour (in 1915) however, northward transport was interrupted, and sand has now become trapped within the southern embayment, though studies suggests that episodic headland (or harbour) bypassing occurs (Lord and VanKerkvoort, 1981; BMT WBM, 2010). Over the past 75 years, areas such as that around northern sections of Boambee Beach have largely prograded with the foredunes, beach and inner nearshore zones accumulating large sums of sediment (Roy and Stephens, 1980; Doyle et al., 2019). Over the same period, large volumes of the finer, outer nearshore sand have also accumulated within the Harbour and its entrance. This sedimentation has resulted in a significant navigational hazard surrounding the harbour’s boat ramp and has been the subject of recent major sand management plans, including the installation of the Gallows sand pipeline, that pumps sand from the harbour to the northern corner of Gallows Beach (Jayewardene et al., 2021; Transport for NSW, 2022). To the north, the cessation (or decrease) of the longshore sand supply has been strongly influenced by the shallow substrate with potential for coastal retreat alleviated by both the backing bedrock hinterland as well as the character of the offshore seabed. Subsurface dating and sampling of the outer nearshore sediments shows that the underlying coarser inner shelf unvegetated sediments are reworked onshore during large storm activity. This periodic exposure has allowed for the coarser sands and fine gravels to migrate landwards, and help form the steeper, coarser sand beaches present today (Roy and Stephens, 1981).

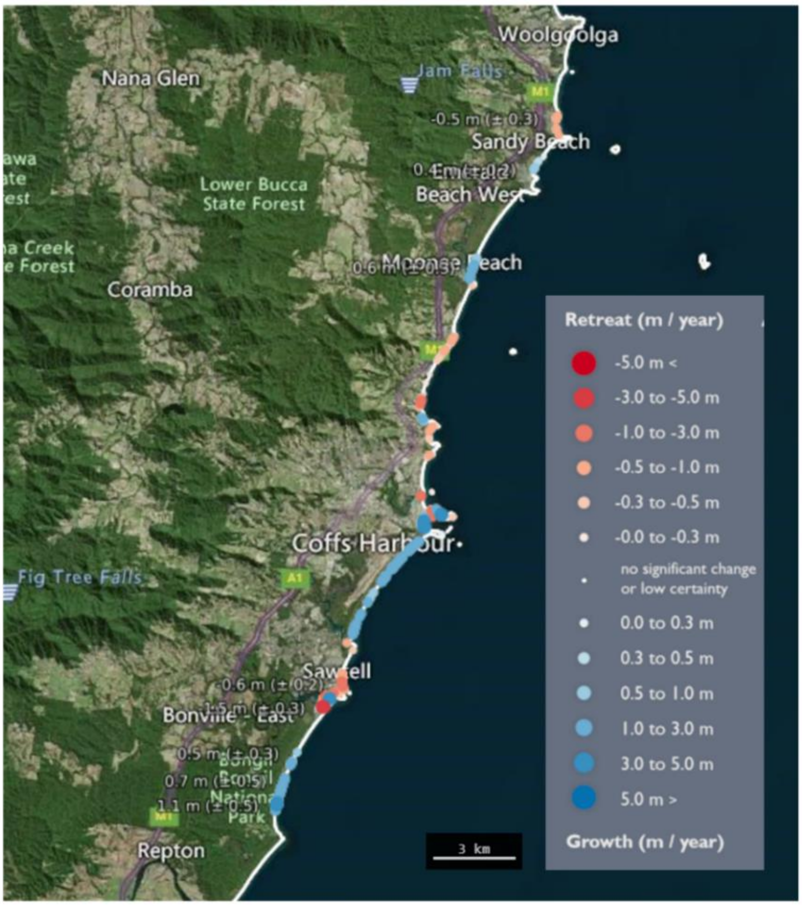


Figure 1.11 Coastline change rates extracted from the DEA Coastline database (https://maps.dea.ga.gov.au/story/DEACoastlines), demonstrating the historic recession/stability in the northern region, and coastline progradation south of Coffs Harbour. Red circles indicate erosion, white indicates no significant change, while blue represents coastline growth (or progradation).

More recent work has shown that these geomorphologic traits, are not as effective, and that the harbour is acting as a major obstacle to longshore transport and sand bypassing (Carley et al., 2006; BMT WBM, 2010). Over more historic (decadal) timescales, it has been shown beaches from Corambirra Point to Moonee Beach have receded, while those north of Moonee becoming more stable. Digitised foredune volume changes in the area, presented by Doyle and others (Doyle et al., 2019), as well as Geoscience Australia’s DEA Coastline dataset (illustrated in Figure 1.11) also show similar patterns in this stretch of coast, as well as the progradation experienced in embayments south of the harbour (Doyle et al., 2019; Bishop-Taylor et al., 2021).

Investigating and mapping further offshore (i.e., within and around the SIMP), is now necessary, as these environments are all connected, especially considering the Northern Rivers primary sediment compartment. By discerning the sedimentology and derived geomorphological features of the SIMP will help broaden our understanding of the greater processes acting on or controlling the shoreface response / evolution of this section of the NSW coast. Knowledge that can be used to help guide appropriate application (or derivation) of management actions and protection measures within the SIMP and wider primary sediment compartment.

2. SURVEY AIMS AND METHODS

2.1 Aims/objectives and management questions being addressed

The focus for the Solitary Islands Mapping Project 2022-23 was to survey previously unmapped areas within commonwealth waters. The survey would complete high-resolution mapping coverage across all 152 km^2 of the marine park. Coupled with sediment sampling and towed video, the data would be used to:

1) ground-truth the MBES data

2) map extent and characterise the diversity of unconsolidated seabed types; and

3) map extent of rocky reefs and characterise sessile invertebrate diversity within these reef-dominated areas.

2.2 Fieldwork dates, locations, sample collection

During the planning phase, unmapped areas of seabed were identified by accessing NSW DCCEEW (AODN) archives and other sources including Marine National Facility (RV *Southern Surveyor*; RV *Investigator*); the Australian Hydrographic Office and AusSeabed (Geosciences Australia). A shapefile denoting the unmapped area of the park had been previously submitted (2021) to the AusSeabed survey portal (Parks Australia, NSW DCCEEW) identifying the area as a priority for national mapping effort.

Unmapped areas to target for mapping under this project were identified within all 3 separate sections of the park (Figure 2.1);

A) the northern section; with large data gaps both north and south of Pimpernel Rock and areas immediately adjacent to those surveyed in 2009,

B) central section; with data gaps across large areas east of North-West Solitary Island to north of South Solitary Island, and

C) the southern section: a small unmapped area east of Split Solitary Island and north-west of a MBES survey completed in 2012 (NERP).

Generally, the unmapped areas were expected to lie within depths of ~35-60 m (Figure 2.1) and across <140 km^2 of the park. At these depths the completion of MBES surveys was expected to require ~16 full survey days (8-9 survey hours) with 2-3 days sediment sampling (~40-50 samples) and 3-4 days of towed video capture (~48 x 200 m transects).

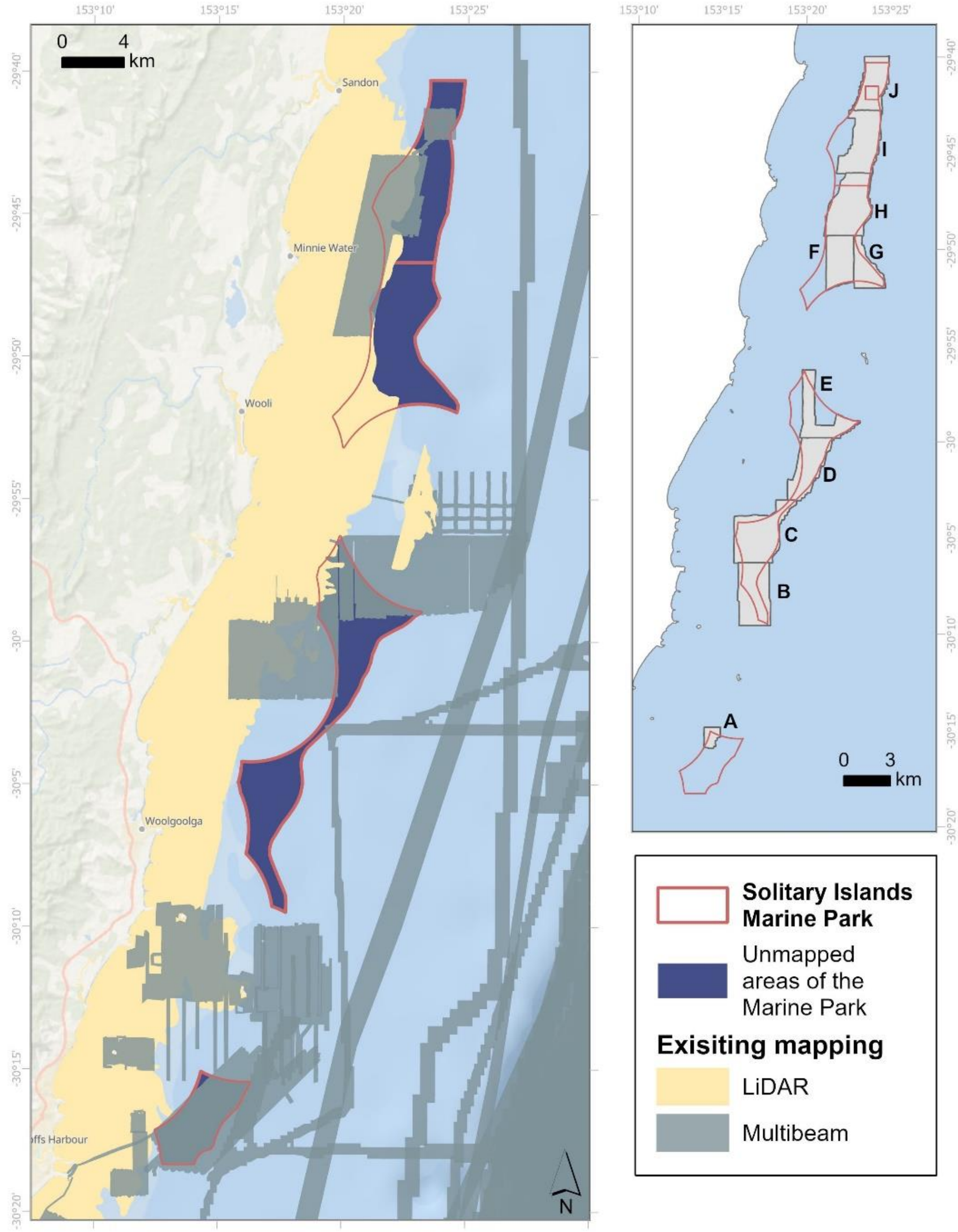


Figure 2.1 i) Map of high-resolution seabed mapping data holdings (AusSeabed) in and around the Solitary Islands, Temperate East Network with the boundary of the Australian Marine Park is denoted in red - an area of ~78 km^2 (blue) remaining unmapped prior to this survey. and ii) a breakdown of survey blocks A-J for focused MBES surveys 2022-23.

Initial plans to commence and complete fieldwork during June- September 2022 were delayed due to two issues: 1) installation of new engines for the survey vessel, RV *Bombora* and 2) a contract variation and additional requirement by Parks Australia's Threatened Species Unit. This new requirement was for field staff to be trained and undertake Marine Mammal Observer (MMO) duties while undertaking surveys in Commonwealth waters. DCCEEW were trained and a Cetacean Permit was obtained in August 2022. The permit required one dedicated MMO with a minimum of 1 additional MMO trained crew member as support onboard when surveys were underway. The permit also restricted vessel operating speed to a maximum of 15 kn.

MBES surveys were able to commence in September 2022. Sediment and towed video surveys were only designed and planned once newly acquired MBES data was processed and quality controlled as data from across all surveys was then combined to assist in the selection of sites. A compilation of bathymetry datasets was used to identify areas of reef and provide a base map for informing the selection of towed video locations. Similarly, the backscatter, was mosaiced to provide a map of unconsolidated, soft sediment features across mapped areas of the park, and provide a base for the selection of sites for sediment sample collection.

2.3 Methods – design, data collection, processing, and analysis

2.3.1 MBES and bathymetry

Detailed methods around mobilisation, acquisition and processing are described in *Seabed NSW: Standardised operating procedures for multibeam surveying* (Ingleton et al. 2019).

For these surveys, the research vessel RV *Bombora* was mobilised from Newcastle and transited to Coffs Harbour in late August 2022. Survey planning was completed using Hypack (Hypack, USA) with the park's unmapped areas divided into survey blocks (south to north: A-J; ~10-15 km^2 areas) to efficiently manage data acquisition, storage, and processing. A hard-stand survey to check the 3-D frame of reference (Table 2.1) and a calibration patch-test (Table 2.2) were both completed in the lead-up to arrival of the vessel at Coffs Harbour. Subsequent patch tests mid and post-survey as quality control checks were completed to quantify any changes in offset values. Both survey checks confirmed that the angle offsets of the MBES transducer heads relative to the vessel's centre line (roll, pitch) were within acceptable tolerances and after a day of sea trials (31/8/2022) MBES surveys commenced. Patch tests were also conducted mid and post-survey as quality control checks and to quantify changes in offset values (Table 2.2).

MBES data for this survey was collected using an R2Sonic 2022 (Austin, USA) system and Hypack with coupled global positioning and 3-D motion correction provided by a POS MV Wavemaster (Applanix, Canada) and logged using POSView (Applanix, Canada). MBES surveys were completed in the manner of a 'baseline' survey as described in the Australian Multibeam Guidelines and NESP MBH manual '*Seafloor Mapping Field Manual for Multibeam Sonar'* (Picard et al. 2018). To account for changes in water column sound speed during MBES surveys, surface sound velocity was logged $1s^{-1}$ at the sonar head and vertical casts obtained >$1.day^{-1}$ when surface sound velocity varied by more than $2m.s^{-1}$. A summary of water column profiles for the entire MBES survey are provided in Figure 2.2. The density of soundings was checked daily following acquisition using the tool QA4MB (AusSeabed) and ensure a minimum sounding density of 10 points/m^2 (Table 2.3).

Table 2.1 Summary of patch tests completed for confirming vessel and MBES 3-D frame of reference. Geoswath and R2Sonic have both been used for surveying from RV *Bombora* in the Solitary Islands Marine Park.

3D Frame of Reference	Location	Date	Surveyor & Method	XYZ resolution	Offset sonic centre to waterline
1	Nelson Bay	Mar 2012	S Holtznagel; laser scanner and smart-station	<0.005 m	-0.619 (Geoswath)
2	Newcastle	Dec 2018	S Holtznagel	<0.005 m	-0.908 (R2S)
3	Marmong Point	Jul 2022	S Holtznagel	<0.005 m	-0.908 (R2S)

Table 2.2 Patch Test Table indicating recent roll, pitch and yaw offset values derived from system calibration surveys in the field.

Patch Tests	Location	Date	Roll °	Pitch °	Yaw °
1	Port Hacking	Dec 2021	0.30	-0.50	1.00
2	Forster	Aug 2022	0.35	-0.50	2.50
3	Woolgoolga	Oct 2023	0.35	-0.50	2.00
4	Woolgoolga	Nov 2023	0.30	-0.50	1.00

MBES survey data collected during this project were acquired between the period of 1 September 2022 and 13 September 2023 and provide a total of 145.5 km^2 of new mapping data (

Table 2.4). Field survey quality control checks (Table 2.3) using QA4MB indicated that 98% of nodes satisfied required specifications regarding sounding density and uncertainty for IHO Order 1b survey.

Marine Mammal Observation was conducted during all operations carried out by DCCEEW for Parks Australia within the Solitary Islands Marine Park, with 1 dedicated MMO and at least one other trained MMO onboard as secondary and relieving observer. Observations were recorded as required per Cetacean Permits 2022-005, 2023-003 and training provided by Blue Water Research to NSW DCCEEW. A total of 270 observations were logged during the survey campaign and annual reports lodged with the Australian Antarctic Division’s Migratory Species Section for 2022 and 2023. Copies of reports are provided in Appendix D and E.

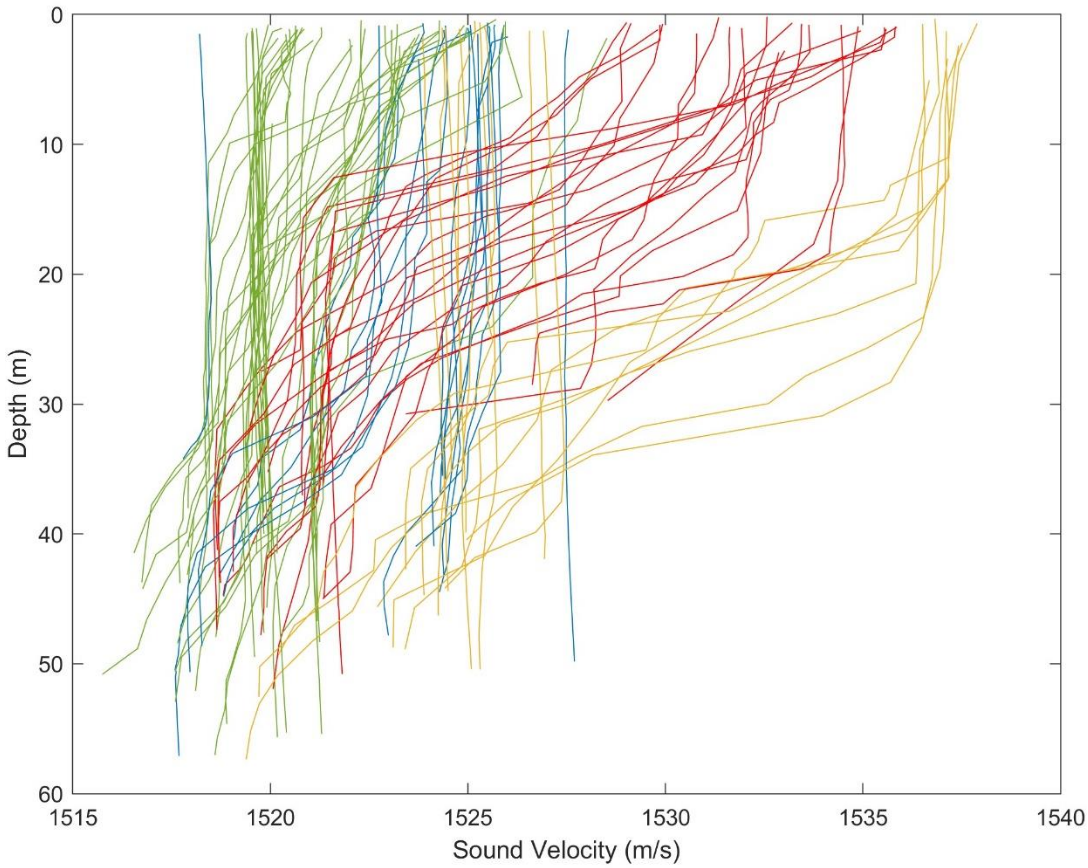


Figure 2.2 A summary of sound velocity profiles across the Solitary Islands Marine Park MBES survey days grouped for spring (green); summer (red); autumn (yellow) and winter (blue) demonstrating the seasonal variability associated with water column density.

Post processing of 3-D motion reference and positioning data (POS MV) indicated that XYZ errors at the vessel centreline were less than 0.015 m for XY and 0.025 m for Z vectors, respectively. Total propagated uncertainties were calculated with Qimera (QPS, Netherlands) with Total Horizontal Uncertainties (THU) at <1.6m and Total Vertical Uncertainty of <0.14 m.

Further details are provided in the survey report issued with the gridded datasets on the AusSeabed portal and in Appendix A

Table 2.3 Summary of QAX MBESGC (AusSeabed, Australia) and line x-check results per Survey Block (A – J) for quality assurance of 2023 'R2Sonic 2022' MBES data.

Survey Block	**QAX MBESGC**			**X-Check Surface Difference**		
	Survey Area (km^2)	Passed Density (% 1 point/m2)	Passed Uncertainty (% IHO 1b)	$\bar{x}$ (m)	median (m)	σ (m)
A	2.6	99.1	99.7	NA	NA	NA
B	18.1	97.8	100.0	0.08	0	0.07
C	21.8	98.6	99.4	0.06	0.01	0.07
D	14.9	92.8	99.8	0.07	0.02	0.06
E	10.0	93.5	100.0	0.08	0.03	0.06
F	12.6	97.8	99.9	0.09	0.06	0.08
G	9.5	94.3	99.8	0.17	0.14	0.12
H	21.4	98.1	96.8	0.11	0.09	0.08
I	18.0	98.5	95.9	0.11	0.01	0.1
J	13.4	97.4	96.5	0.13	0.09	0.15
Total	**142.8**	**96.8**	**98.7**	**0.1**	**0.05**	**0.08**

Previous NSW DCCEEW surveys were then combined with these new data to provide a 100% high-resolution bathymetric model. Details on differences in data quality between the survey-types and equipment used are presented here (Table 2.5).

Surveys during 2006-2012 were acquired using an interferometric Geoswath 125 kHz (GeoAcoustics, UK) swath bathymetry system. While the system generally achieved equal or greater sounding densities to the R2Sonic, surveys prior to 2011 also relied on Differential GPS (DGPS) positioning, pressure-sensor deployment for tidal corrections and stand-alone heading and inertial sensors. XYZ accuracies for data obtained during this period were in the order of <5 m (horizontal) and <1 m (vertical and included surveys at Pimpernel Rock (2006) and south-west of North Solitary Island (2009). 2012 surveys south of South Solitary Island also utilised the Geoswath but inertial data, GPS positioning and tides (Real-Time Kinematic RTK) were provided using the POS MV system.

The total mapping effort across all MBES and marine LiDAR surveys contributing to a final combined high-resolution (5 m gridded) Digital Elevation Model for the 152 km^2 of the Solitary Islands Marine Park is summarised in Table 2.2. Although marine LiDAR also provided seabed return intensity data as 'reflectance', its utility in delineating soft seabed types here is limited. Thus, only MBES echosounder backscatter is to be used here to provide a mosaic of seabed hardness across the entire park.

Table 2.4 A summary of field survey campaign statistics for the Solitary Islands Marine Park surveys 2022-23. A detailed day-by-day summary is provided in Appendix C

	Survey Days	Date Range	Quantity	Type
MBES	27	31 Aug 22 -31 Jul 23	1403 145.5	lineal km area km2
Sediments	4	24 Aug- 1 Nov 23	48	samples
Imagery	6	7- 26 Nov 23	51 14043	transects images

Table 2.5

Bathymetry surveys within the Solitary Islands Marine Park contributing to the digital elevation model and backscatter mosaic for a 100% mapped seabed. Note: LiDAR reflectance did not contribute to the park-wide mosaic of seabed hardness here.

Year	Location	Mapped Area (km^2)	System	Nominal Precision
2006	Pimpernel Rock	11	Geoswath; DMS05; DGPS	XY< 2 m; Z< 0.75
2009	North Solitary	18	Geoswath; DMS05; DGPS	XY< 2 m; Z< 0.75
2012	South Solitary	45	Geoswath; POS MV	XY < 1 m; Z< 0.015 m
2018	North, Central	22	Marine LiDAR; Riegl ALB system*	XY < 0.2 m; Z< 0.15 m
2022-23	All sections, this project	108	R2Sonic; POS MV; G4	XY <0.2 m; Z< 0.011

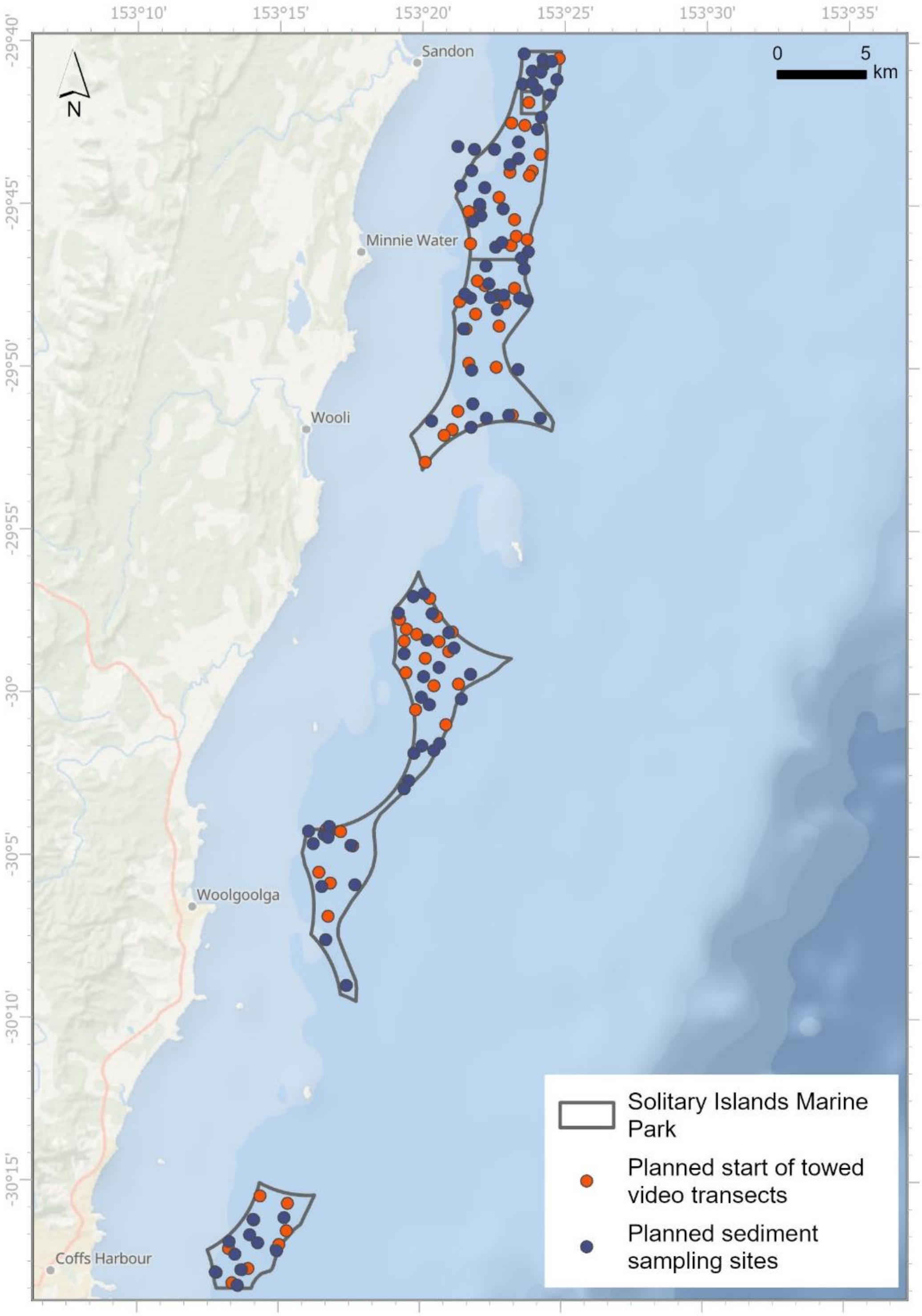


Figure 2.3 Planned sediment grab sites (blue) and towed underwater video 'start' locations (orange) for the Solitary Islands Marine Park surveys 2022-23.

Raw sonar data were post-processed using first with coarse filtering in Hypack (Hypack, USA) and, subsequently using a cube-modelling approach in Qimera (QPS, Netherlands) using International Hydrographic Office Order 1B filters. Final cleaned soundings were then gridded (5 x 5 m) into a digital elevation model and quality checked in Fledermaus (QPS, Netherlands) before being exported to other software packages (ESRI; QGIS) for further investigation. Gridded data is made available on the Geosciences Australia website AusSeabed. A copy of the Survey Report is provided in Appendix A.

Digital bathymetric models were imported in Arc and used to generate rasters and derive a suite of additional layers including hill-shades, contours, rugosity and slope. To derive underwater landform features, DEMs from this survey was combined with those from previous surveys. Once completed, landform layers were then clipped to the Australian Solitary Islands Marine Park boundary. To map the parks geomorphometry, a semi-automated classification approach was applied to the combined DEM in Arc using the Seabed Landforms Classification Toolset as described in Linklater et al (2023), with features labelled using the terminology outlined in Dove et al. (2016) and IHO (2019). The Seabed Landforms Classification Toolset classifies prominent seabed features into seabed 'landforms' which represent areas of the seascape with distinct morphology, including 'reefs', 'peaks', 'scarps', 'channels and depressions' and 'plains'. Plain areas are subsequently classified into areas representing broad- and fine-scale sedimentary structures.

The classification approach utilises terrain derivatives including slope (ESRI Spatial Analyst), ruggedness (Benthic Terrain Modeler, Walbridge et al. 2018) and broad- and fine-scale bathymetric position index (BPI, Evans et al. 2014). The input DEMs were smoothed three times to reduce noise artefacts, and the landform and plain classifications were performed as outlined in Linklater et al (2023). The plain classification was performed on a DEM extracted from classified plain areas. Output polygons were manually reviewed and edited to achieve the final classification, and polygons smaller than 100 m^2 were eliminated. Landform layers are made publicly available on SeaMap Australia and the NSW Sharing and Enabling Environmental Data portal SEED.

2.3.2 Underwater Imagery

Towed video setup, acquisition and field survey design, generally adhere to national protocols detailed in Przeslawski et al (2018). To inform the selection of sites for towed video transects, the slope layer was partitioned into a 2-class shape file and then used to run the R-script based MBH Design as detailed in NESP MBH manual: 'Statistical Consideration for Monitoring and Sampling' (Foster et al. 2020). The tool was used to randomly select the starting location for a maximum of ~90 potential towed video transects (Figure 2.3).

The equipment used for imagery acquisition and further details around data acquisition and handling are covered in the ground truthing section of SeaBedNSW: Standardised operating procedures for multibeam surveying (Ingleton et al. 2019).

Once in the field, RV *Bombora* was navigated to each site, the towed video camera (Figure 2.4) deployed and winched to within 1-2 m of the seabed. Downward looking still images (2s intervals) and forward-looking video were then captured while the vessel drifted (at a speed of <1 kn) in the direction of the ambient current and/or prevailing wind for a minimum distance of 200 m (Canon 450D and Canon EOSR10, EF 20 mm f2.8 lens, EF-EOSR adaptor). The position of the tow-fish was determined using an Evologics S2C 18/34 (Berlin, Germany) Ultra-Short Base Length (USBL) modem providing a GPS position of the video sled (tow-fish) through a range-angle calculation relative to the position of the vessel. Nominally the USBL provides a calculated tow-fish GPS position accurate to reported slant range accuracy of 0.01 m and bearing within 0.1° within a horizontal distance ±0.16% of the vessel's water depth at the time of collection.

Forward looking video was recorded continuously and overlain with ship position, depth and site information. All vessel and camera information (roll, pitch, yaw, fish position, depth etc) was also logged using the acquisition software.

Raw still imagery collected for each transect was examined and sub-set to retain images between the first and last images of the seafloor. Still imagery and towed video time stamping was cross checked for synchronicity before renaming stills using a script in MATLAB®© and using the NSW DCCEEW towed video imagery naming convention using platform, site, transect number, image date and time (UTC). Details of positioning offsets and camera system setup specific to these surveys are provided in the metadata statement.

Downward looking still imagery is made accessible on the benthic imagery annotation site SQUIDLE+ (https://squidlle.org) through DCCEEW's SEED portal and an S3 Amazon Web Service data point and can also be explored through SeaMap Australia (www.seamapaustralia.org).

To analyse the seabed typology and benthic organisms observed within these towed-video surveys, a multi-step annotation approach was used (Figure 2.5). Images and annotations were managed online using SQUIDLE+ (Understanding Marine Image Facility, IMOS) by digitally assigning points to features within images. Points were tagged or annotated based on the libraries held within the Australian Morphospecies Catalogue (AMC), an extension of the CATAMI 1.4 label scheme (CATAMI Technical Working Group, 2023). To target our analyses on areas of reef, all 14,000+ images were firstly examined and assigned a single whole frame annotation based on the dominant (> 50%) observable seabed type ('rock or 'sand/mud (< 2 mm)). To target our analyses on areas of reef, all 14,000+ images were firstly examined and assigned a single whole frame annotation based on the dominant (> 50%) observable seabed type ('rock or 'sand/mud (< 2 mm)). Only a relatively small proportion of loaded images (< 1%) were considered 'unscorable', i.e. when the image quality and the seabed could not be readily characterised as either type, and were excluded from further analyses.

Figure 2.4 Image on the left shows the NSW DCCEEW Towed Underwater Video (tow-fish) with centre-forward looking video camera, live fish-to-surface fibre optic cable, lights, rear deck of RV *Bombora* (the digital stills camera sits toward the back of the tow-frame with dual green lasers). Image on the right shows the downward facing lasers that project two parallel beams and appear as green dots in still images and estimate relative size of underwater objects.

In an effort to further target reef imagery, maximise the number of morphospecies observed (full annotation), and provide a subset of secondary annotations focused on the most conspicuous organisms, each transect was first partitioned using the QAQC function in SQUIDLE+ by assigning every 10^{th} scorable 'Rock' (> 50% reef) image with a 2nd whole frame annotation - 'Image Assessed'- label. For this step, when the benthic organisms within an image were considered 'unscorable' due to poor lighting or image quality, the next image of suitable quality either side, was selected and assigned as 'Image Assessed'. This resulted in a subset of 283 images for subsequent biological annotation.

Images selected for biological assessment were then treated to a two-step process:

1) Up to ten (Top-10) of the most prominent and obvious non-mobile (sessile, epibenthic) organisms (invertebrates and macroalgae) identified and annotated to the highest possible taxonomic (morphospecies) resolution

2) All observable organisms annotated to a mid-tier taxonomic (morphospecies) classification (see Figure 3.16) and Appendix G. (Nb: species which were assigned a Top-10 classification were also included as their corresponding mid-tier classification in this assessment)

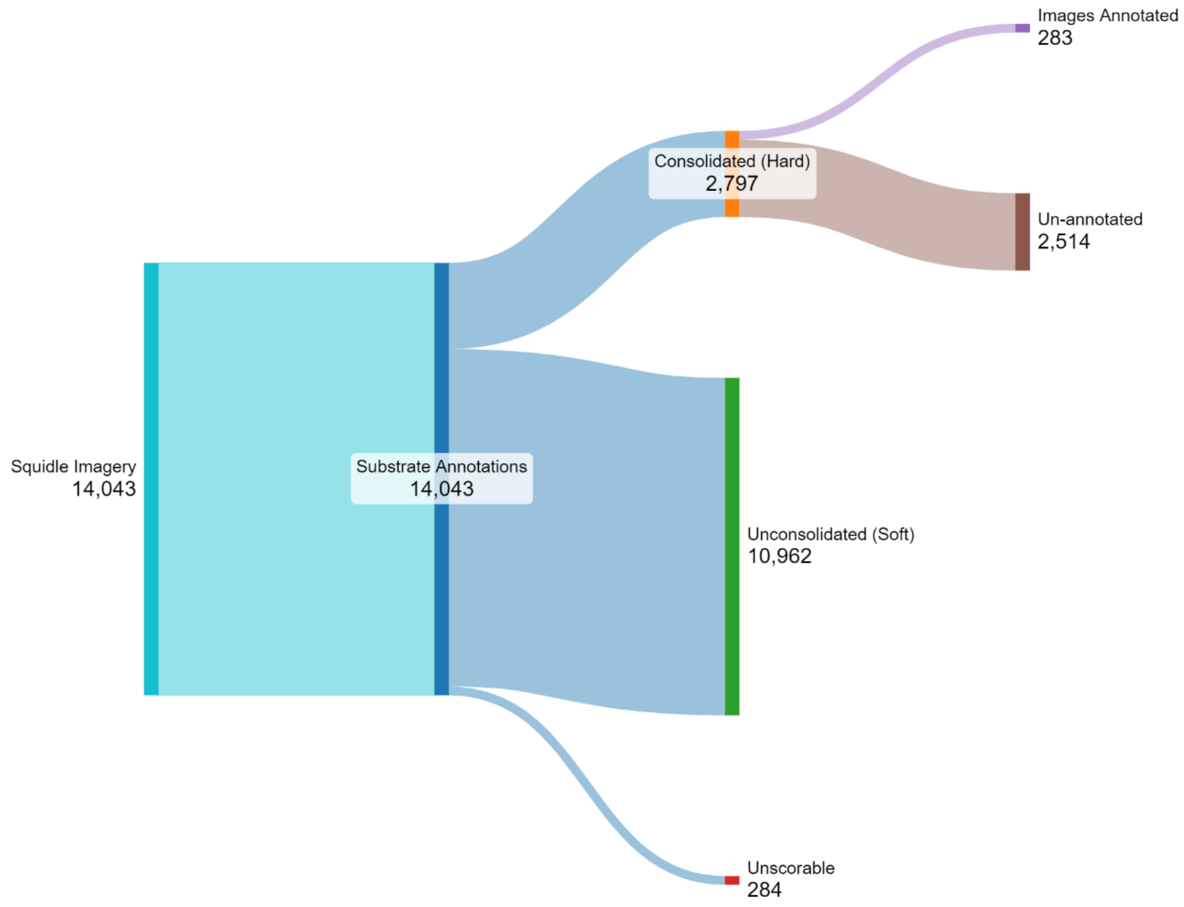


Figure 2.5 Division of whole frame annotations of towed digital stills annotated on SQUIDLE+

Quality control over the identification of morphospecies and annotation was completed through i) matching observed organisms with ‘exemplar’ species held within the AMC, ii) creation of a SIMP 2023 image catalogue of observed morphospecies for this survey; iii) cross-validation of annotation sets between DCCEEW operators, through group QC sessions; and iv) group validation session with University of Tasmania Understanding Marine Imagery (UMI) Hub staff and SQUIDLE+ catalogue custodian. Where new benthic organisms were observed, UMI were consulted before a new original tag could be provided within the AMC. Exemplar images of key species are provided in a SIMP 2023 Morphospecies Catalogue in Appendix H.

Annotation statistics for each transect was exported from SQUIDLE+ and combined for statistical analyses. An indication of diversity and evenness was calculated using equations for the Shannon Diversity Index and Shannon Equitability Index and applied to both the top-tier/‘Top-10’ morphospecies dataset as well as the mid-tier morphospecies classifications.

The indices are calculated using the equations:

$H = -\sum p_i * \ln(p_i)$, where p_i is the proportion of the community made up of species i.

$E_H = H/ln(S)$, where S is the total number of species sampled

To ensure even sampling of scored images, transects with less than 50 scorable images were removed, and 5 randomly selected images from the remaining transects (n = 19) and their annotations (n = 8-50 for Top10; n = 29-535 per transect for mid-tier) were used in the calculations. The maximum number of different morphospecies observed in any given transect was n = 38 (Top10) and n = 21 (mid-tier) (nb: this compares to a total of n = 209 (Top10) and n = 30 (mid-tier) morphospecies across all transects for the random five subsampled images). To calculate a density value for morphospecies, an R-script (R Core Team, 2020) was used to identify the location of the dual green laser points of known scale (100 mm apart) at the seabed and calculate the field of view area 'observed' within each image of the randomly selected subset. The 'mid-tier' annotation dataset was then used the calculate average density of sponge, coral and bryozoan morphospecies over reef within each transect. The density of all annotated biota was also calculated.

To compare the remote sensed (MBES) derived seabed classification with the ground-truthing imagery of the towed video, a simplistic pair-wise comparison was completed in GIS. This approach is called Cohen's Kappa statistic (Cohen, 1960) and quantifies the level of agreement between categorical variables derived using two different approaches for characterising the seabed, in this case for deriving reef and sand (unconsolidated) seabed types (Table 2.6; n = 500 random points).

The formula is as follows: $k = \frac{p_o - p_e}{1 - p_e}$, where p_o is the probability of agreement observed, and p_e is the probability of agreement by chance.

Imagery agreed with and confirmed the landform classification derived from MBES 85% of the time. The approach is also spatially coarse in that towed video is an image covering an area of ~1-3 m^2 of seabed, classified as reef dominated or sand dominated (> 50% dominants seabed type) assigned to a GPS point at the centre or corner of an image, and even though the GPS horizontal accuracy is likely in the order of ~1 m, the USBL precision is only to within between 3-9 m (20-60 m water depth). That image is then being used to compared to a category derived from a 5 x 5 m grid cell of the bathymetry (averaged over 10-20 cloud point soundings that are horizontally and vertically precise (10s of cm)) but is then used to calculate surface statistics across a neighbourhood (9 x 9) of cells to characterise reef or unconsolidated seabed based on its level of roughness. In addition, often more than one image falls within the bounds of any individual 5 x 5 m grid cell. Areas of intermediate habitats (i.e., boulder habitat) will appear flat according to the bathymetry DEM but will be 'hard' and act as reef and support benthic assemblages.

2.3.1 Sediments

Backscatter time-series files were imported into Fledermaus Geocoder (FMGT; QPS, Canada) with DEM, time-varied gain and angle corrections applied to render mosaics of

Table 2.6 A summary of Cohen's Kappa Statistics comparing the classified seabed derived from MBES data geomorphometric analysis with that of scored towed video imagery. k = 0.607 (p<0.001)

	Video imagery **Reef (> 50%)**	**Imagery** **Sediment (>50%)**	**TOTAL**
MBES Landform **Reef**	89 (18%)	59 (12%)	148
MBES Landform **Unconsolidated**	16 (3%)	336 (67%)	352
TOTAL	105	395	500

seabed hardness (dB). Mosaics were then imported into GIS, merged as geotiff and stretched to display the range of seabed textures in greyscale (0-255). The mosaic was combined with previous survey (2006, 2009, 2012) backscatter mosaics and then used to select ~70 sites for potential grab sampling across the park's fully mapped seabed (Figure 2.3). Sites were selected through consideration of the following factors:

1) Sampling of different backscatter 'textures': small scale (10s -100s of metre scale) soft sediment features characterised by either a heterogeneity or homogeneity in greyscale values that delineates a feature within the seascape.

2) distribution of samples across the northern, central and southern park areas

3) distribution of samples across depth gradient/ distance from shore.

Generally, sediment grab sampling was completed following the principle and protocols detailed in Carroll et al (2020). In the field, RV *Bombora* was navigated to a proposed sampling site before arming and deploying a Smith-MacIntyre grab sampler (Figure 2.6). Equipped with a USBL positioning system and Go-Pro Hero 10 (USA) camera with external Keldan (Switzerland) lighting, the grab was lowered to the seabed and triggered by contact with the substrate, and a sample captured. The grab was winched to the surface and once onboard was checked for integrity and sample volume and overlying excess water allowed to drain away before the contents of the grab were emptied into a sampling tray. The sample was then photographed, and sediment properties qualitatively described before being sub-sampled in duplicate labelled 1 L snap-lock bags. Samples were stored in eskies onboard and then refrigerated at ~2-4°C back on shore.

Once sediment sampling was completed, a sample inventory was prepared, and samples transported to the University of Newcastle for processing and analysis within the Earth Sciences Sediment laboratory. Marine sediment samples were washed to remove salt content by soaking in purified water in 2 L beakers three times, removing the water by siphon between rinses after all sediment had settled. Samples were then dried in a dehydrating oven at 60°C. Once dry, the full samples were split into subsamples for analysis, description and archive using a riffle splitter. Samples were weighed using a precision balance at all stages to measure the wet weight, dry weight and water content. The samples were photographed, described by microscope observation, and assigned Munsell colour codes.

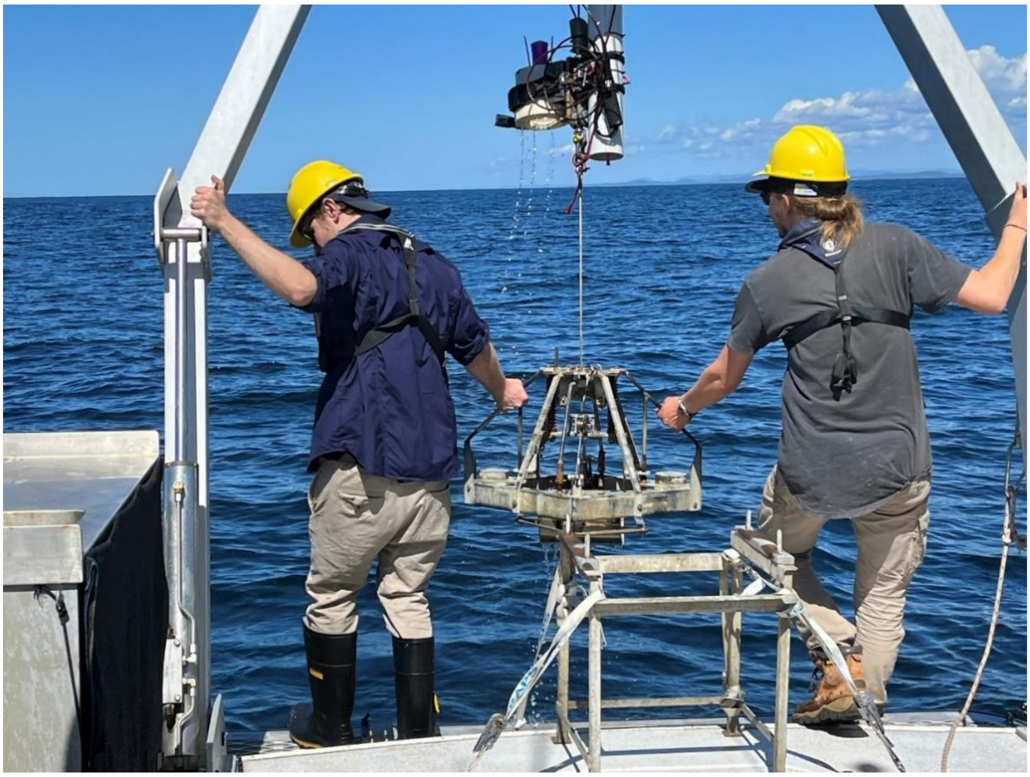


Figure 2.6 Smith-MacIntyre grab (near stand) with USBL and GoPro (top of picture) armed and ready for deployment, RV Bombora; credit Tom Doyle.

Grain size analysis was carried out using a combination of dry sieving and laser particle sizer techniques. The coarser fractions (> 1 mm) of each sediment sample were sieved through standard half-phi aperture screens using an Endecotts Minor sieve shaker and screens. Sediment finer than 1 mm that remained after dry sieving of the coarse fractions was analysed using a Malvern Mastersizer 2000 laser particle sizer. For some samples featuring predominantly complex grain shapes, due to a high abundance of bioclastic grains, dry sieving of all fractions through half-phi aperture screens was also completed to build robust grain-size distributions from the sieving and laser particle sizer methods. The sediment grain size distributions and statistics were derived using GRADISTAT (Blott & Pye, 2001) following the method of Folk & Ward (1957).

The organic matter and carbonate ($CaCO_3$) content of samples were also analysed using the sequential loss-on-ignition (LOI) technique (Dean, 1974; Heiri et al., 2001). Small subsamples (3-4 g) were crushed to break up carbonate matter and dried in an oven overnight to derive the starting weight. The samples were then heated in a furnace at 550°C for 2 h to oxidise organic matter and the weight difference measured. They were then heated in a furnace at 950°C for 2 h to oxidise the remaining carbonate matter and the weight difference measured. The $CaCO_3$ content was calculated as a percentage of the subsample starting weight following the method of Dean (1974).

Sediment sample reports are provided in Appendix I and methods in Appendix J. Data were then collated and made available on AusSeabed and can be accessed via the following link https://portal.ausseabed.au.

3. RESULTS

Surveys were completed over 37 separate field days during the period 31 August 2022 to 26 November 2023. For the purposes of this report, the results of the remote sensing and landforms are described in section 3.1. Seabed geomorphological features, with the nature of the unconsolidated sediments, reefs and associated benthic ecology are described in Section 3.2 Benthic Habitats and Sedimentology.

3.1 Seabed features

With the completion of MBES survey, 100% of the area of seabed within Australia's Solitary Islands Marine Park (152 km^2) has been mapped at 5 m gridded scale resolution. During the 27 individual days over which MBES surveying was completed, a total of 145.5 km^2 of seabed was mapped inside and around the edges of the park's boundaries with a total of ~110 km^2 of new data has been provided over areas of previously unmapped seafloor. Prior to this survey it was reported that the park covered a depth range of between 15-70 m with a mean of 44 m, however, the new bathymetric model (CUBE) indicates a slightly more restricted and accurate depth range of 7.8 – 63.6 m with an average of 48.1 m relative to Australian Height Datum (AHD) (Figure 3.1).

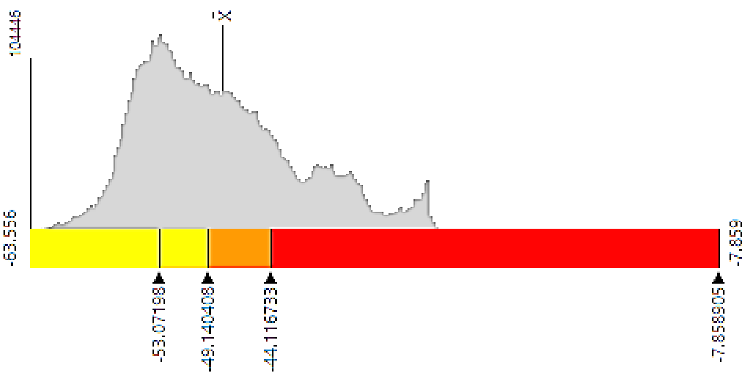


Figure 3.1 Histogram and quartiles of all depth values for the park's combined 5x5 m gridded bathymetric model, a compilation of MBES and marine LiDAR survey datasets (2006-2023). Increasing depth is displayed along the x-axis and the number of grid cells (population statistic) for each depth on the y-axis. X denotes the median depth value for the data set.

Summaries of the extent of different landforms interpreted from the park's digital elevation model derived from the bathymetry data are provided in Tables 3.1 and 3.2. 'Plain' areas dominate the overall composition of seabed landforms classified within the park, comprising 84% (128 km^2). Landform categories which represent inferred hard-substrate outcrops, including 'reefs', 'peaks', 'channels and depressions – rugose' and 'scarps', collectively represent 15% (22.6 km^2). ‘Depressions and channels – smooth’, which are lows within the reef outcrop inferred to be soft substrate, comprise 0.3% (0.5 km^2).

Plain areas were further classified using the plain classification toolset indicate the majority is flat plain (82%, 104.4 km^2), with fine scale sedimentary features representing 10% of the seascape (13.3 km^2) and broadscale features representing 8% (10.3 km^2).

Table 3.1 Classified landform features for the northern, central and southern mapped areas of SIMP. Landform classes which are inferred as reef outcrops or unconsolidated substrates are identified in the ‘Reef landform' column

Section	Landform	Reef landform	Area (km^2)	Area (% of section)
Northern	Depressions and channels Rugose	Reef	1.5	1.9
	Depressions and channels Smooth	Unconsolidated	1.5	1.8
	Peaks	Reef	7.4	9.3
	Plains	Unconsolidated	58.3	73.1
	Reefs	Reef	10.5	13.2
	Scarps	Reef	0.5	0.6
	Total area (Northern)		**79.7**	
Central	Depressions and channels Rugose	Reef	0.1	0.2
	Depressions and channels Smooth	Unconsolidated	0.1	0.2
	Peaks	Reef	0.6	1.1
	Plains	Unconsolidated	52.3	96.3
	Reefs	Reef	1.2	2.2
	Scarps	Reef	0.0	0.0
	Total area (Central)		**54.4**	
Southern	Depressions and channels Rugose	Reef	0.0	0.0
	Depressions and channels Smooth	Unconsolidated	0.0	0.1
	Peaks	Reef	0.1	0.7
	Plains	Unconsolidated	17.3	95.8
	Reefs	Reef	0.6	3.3
	Scarps	Reef	0.0	0.0
	Total area (Southern)		**18.1**	
Total	**Total mapped area**		**152.2**	

Table 3.2 Sub-classified plain landform features for the northern, central and southern areas of SIMP

Section	Plain landform	Area (km^2)	Area (% of section)
Northern	Broadscale sedimentary features	4.3	7.4
	Fine scale sedimentary features	5.0	8.6
	Flat plain	49.0	84.0
	Total area (Northern)	**58.3**	
Central	Broadscale sedimentary features	4.0	7.7
	Fine scale sedimentary features	4.9	9.3
	Flat plain	43.4	83.0
	Total mapped area (Central)	**52.3**	
Southern	Broadscale sedimentary features	1.9	11.1
	Fine scale sedimentary features	3.4	19.8
	Flat plain	12.0	69.1
	Total area (Southern)	**17.3**	
Total	**Total mapped area**	**127.9**	100.0

3.1.1 North to South

Northern Section

The shallowest sections of the SIMP are in the park's north and associated with reefs around the regionally significant feature, Pimpernel Rock (Block J) (Figure 3.2). Surveys identified two relatively smaller rocky pinnacles lying at ~1.1 and 1.3 km north-east of Pimpernel Rock that had not been previously mapped (collectively named Banana Rock in Kline et al (2020)). Less than 100 m across, each feature shallows to depths of 34.4 m and 30.8 m, respectively, with relief of 15-20 m compared to the surrounding seafloor (49-50 m). While reefs and other hard substrates were identified as dominant features within this section of the park in earlier surveys (DECCW, 2009), this survey demonstrates that reef is even more extensive (Blocks H-J) (Figure 3.3 - Figure 3.4). New data south and south-east of the 2009 surveys and across the middle of the northern park areas indicate significant consolidated and near-continuous reef complexes (Figure 3.5 -Figure 3.6). These areas are generally lower profile than in the north but extend east and west beyond the park boundary into deeper and shallower water, respectively, at several locations.

Classified reef landforms (reefs, peaks, scarps, depressions and channels – rugose) comprise 25% (19.2 km^2) of the mapped northern section (Figure 3.7), which is the highest proportion of reef across the three areas. Of these reef landforms, which are inferred hard-substrate categories, 'reefs' and 'peaks' were the most common at 13% (10.5 km^2) and 9% (7.4 km^2) of the northern area, respectively. Scarps (1%, 0.5 km^2) and 'depressions and channels - rugose' (2%, 1.5 km^2) represented a smaller proportion, though had the greatest occurrence of these landforms across the three sections mapped. Similarly, 'depressions and channels – smooth', which are the inferred unconsolidated areas within a reef outcrop, comprise 2% (1.5 km^2) of the mapped area, which is the highest proportion of the landform observed across the park. While the 'plain' area was the overall dominant feature observed at 73% (58.3 km^2), it has the lowest proportion of mapped area across the three sections mapped.

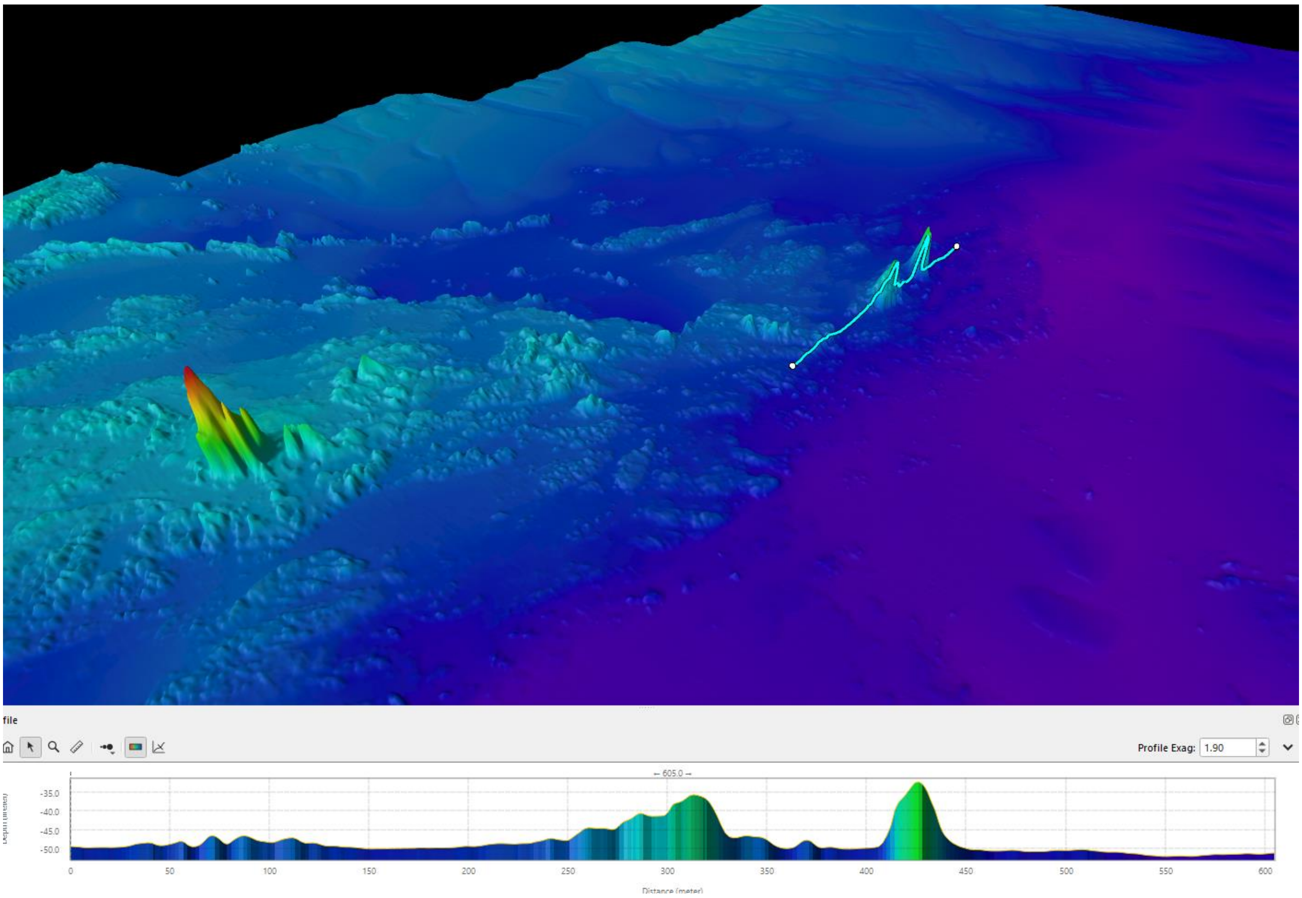


Figure 3.2 A north-west oriented view of false-colour shaded bathymetry in and around Pimpernel Rock in the park's northern section. Recently mapped additional 'pinnacle' features lie to the north-east with detailed cross-section showing the height of the features relative to the surrounding seafloor.

To the north of Pimpernel Rock, reefs dimmish in size and become patchier and more interspersed with sediments. This area abuts the park's northern boundary and, generally, is relatively planar in nature and sediment dominated. Backscatter, however, indicates the area is not completely homogeneous. For this section of the park, generally, the unconsolidated seabed is dominated by two distinct backscatter signatures;

1) relatively dark ‘harder’ coarse material (highly reflective; high backscatter (dB) returns at the sonic receiver) forming long irregular dendritic shapes (Figure 3.4; example feature A) ; and

2) broader, variably sized (10-100s of m) and round-edged areas of ‘lighter-softer’ backscatter, low-return-intensity material (Figure 3.4; example feature B) likely to be finer sands.

The asymmetric cross-sectional profile of these areas indicate that the soft sediment features are 10-100 m wide and likely to be migrating sand ridges.

These sedimentary features are common on the much flatter lower shoreface and inner-shelf regions of the NSW coast (Kinsela et al., 2023). The sand ridge plain in the north of this section are all orientated transverse to oblique relative to the shoreline and bathymetry contours. They are strongly asymmetric with N-NW faces rising gradually to the S-SE to crests that lie around 1-3 m above the surrounding seabed. The S-SE faces fall steeply into troughs, and the wavelength of the ridges are hard to determine. Complex currents are likely here, owing to abundant rocky reef, causing complex soft sediment morphologies (Figure 3.3).

The profile also indicates that darker material situated at slightly greater depth relative to the finer sands indicating that it underlies them. Areas of the greatest variability in backscatter returns are at scales of 10s of meters, and generally lie across areas dominated by reef. Areas of relatively homogenous strong backscatter returns can be observed at scales of 10s-100s of meters and lie in broad planar areas of unconsolidated seabed between mesophotic rocky reefs. These are likely associated with harder, coarser or more compacted unconsolidated sediments.

The southern portion of this section transitions from rocky reef dominated to unconsolidated (sediment dominated) sandy plains (i.e., adjacent to Wooli coast) (Figure 3.5 – 3.7). The backscatter in Figure 3.6 clearly shows a large, and relatively homogenous sandy plain with a lobe like morphology, most likely forming a shelf sand body further inshore (Figure 3.5).

Plain landforms classified within the northern section are dominated by flat plain (84%, 49.0 km^2), with broad- and fine-scale sedimentary features comprising 9% (5.0 km^2) and 7% (4.3 km^2), respectively (e.g., the sand ridges as discussed above).

Central Section

Depths across the central section of the park range from ~35-59 m with the shallowest sections to the north-west (2009 surveys) and the deepest areas due south of North Solitary Island (both in Block E). The bathymetry and backscatter (Figure 3.8-3.11) delineate three main areas of reef, each relatively small and more isolated (non-continuous) than those in the northern park. In total, reef landforms (reefs, peaks, scarps, depressions and channels – rugose) comprise 3.5% (1.9 km^2) of the mapped central section (Figure 3.12). The shallowest reef lies in ~39-45 m of water due east of Arrawarra (30° 04’S) and close to the park's western boundary (Block C). This reef has the greatest relief with a 4-5 m ridge and gutter along its western edge. This reef also crosses the 3 NM immediately to the north and

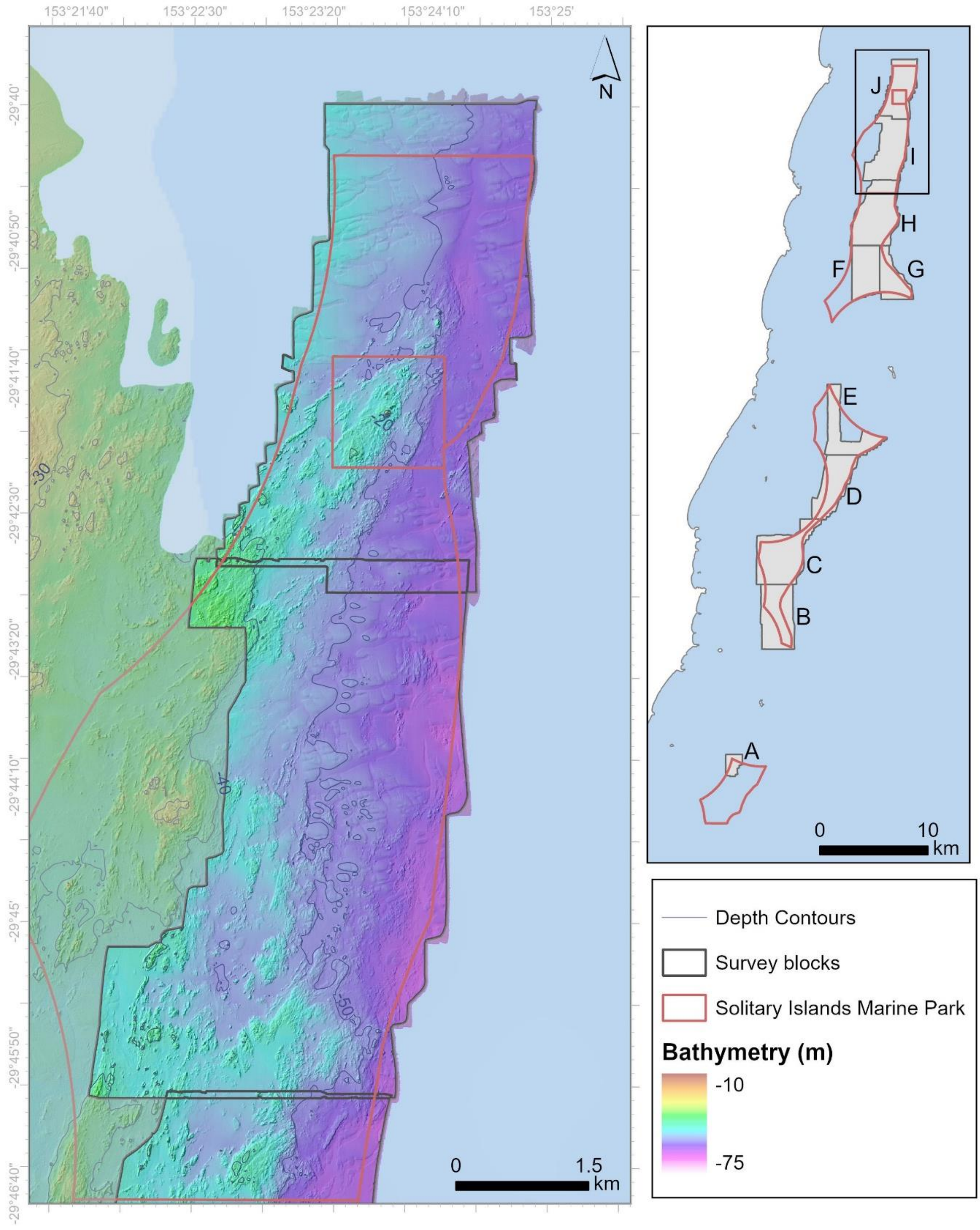


Figure 3.3 False-colour digital elevation model (5 m grid) and extents of new MBES bathymetry data acquired during this survey across blocks I-J, northern section, Solitary Islands Marine Park (Commonwealth waters).

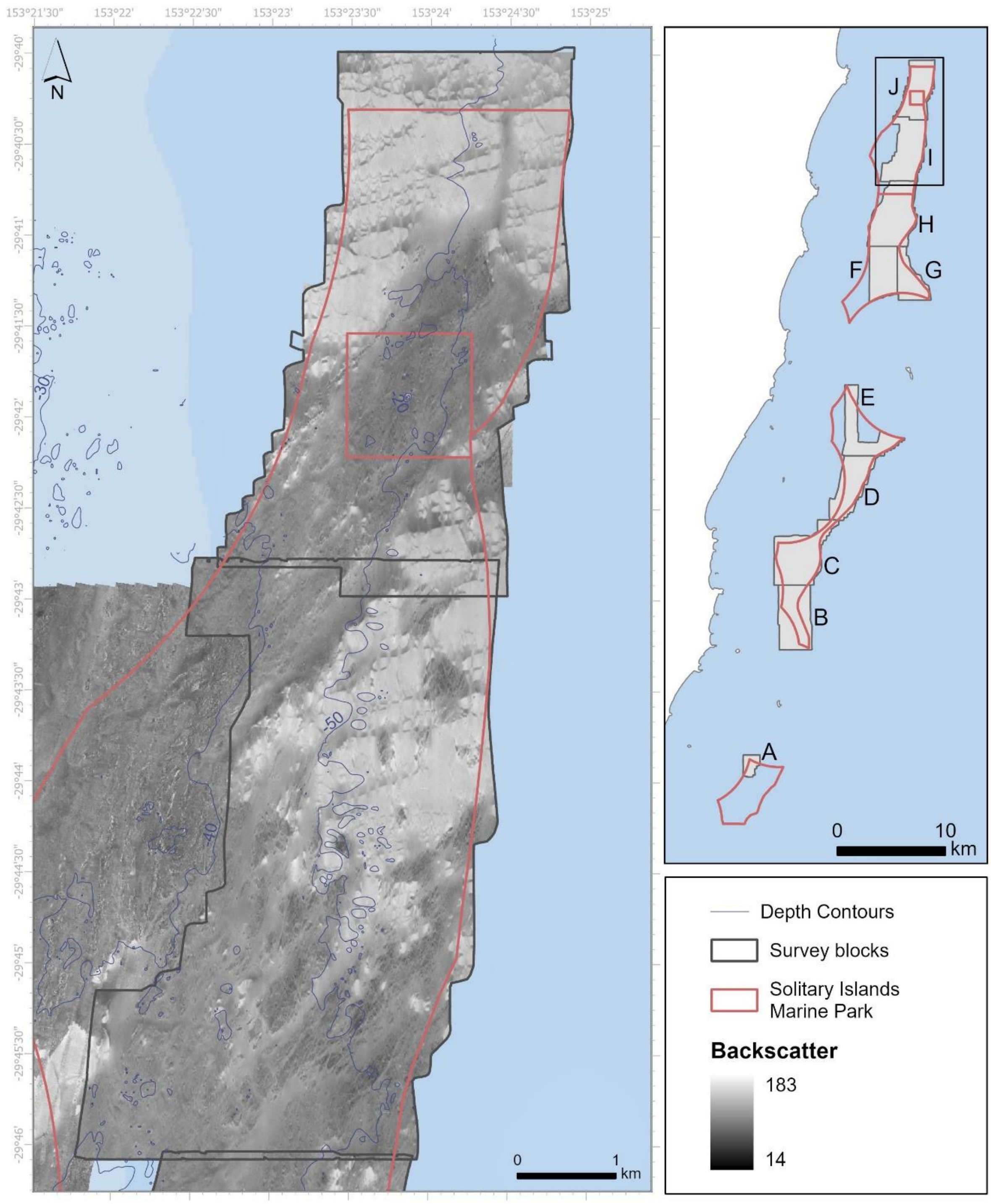


Figure 3.4 Greyscale backscatter mosaic (5 m grid) and extents of new MBES backscatter data acquired during this survey across blocks I-J, northern section, Solitary Islands Marine Park (Commonwealth waters).

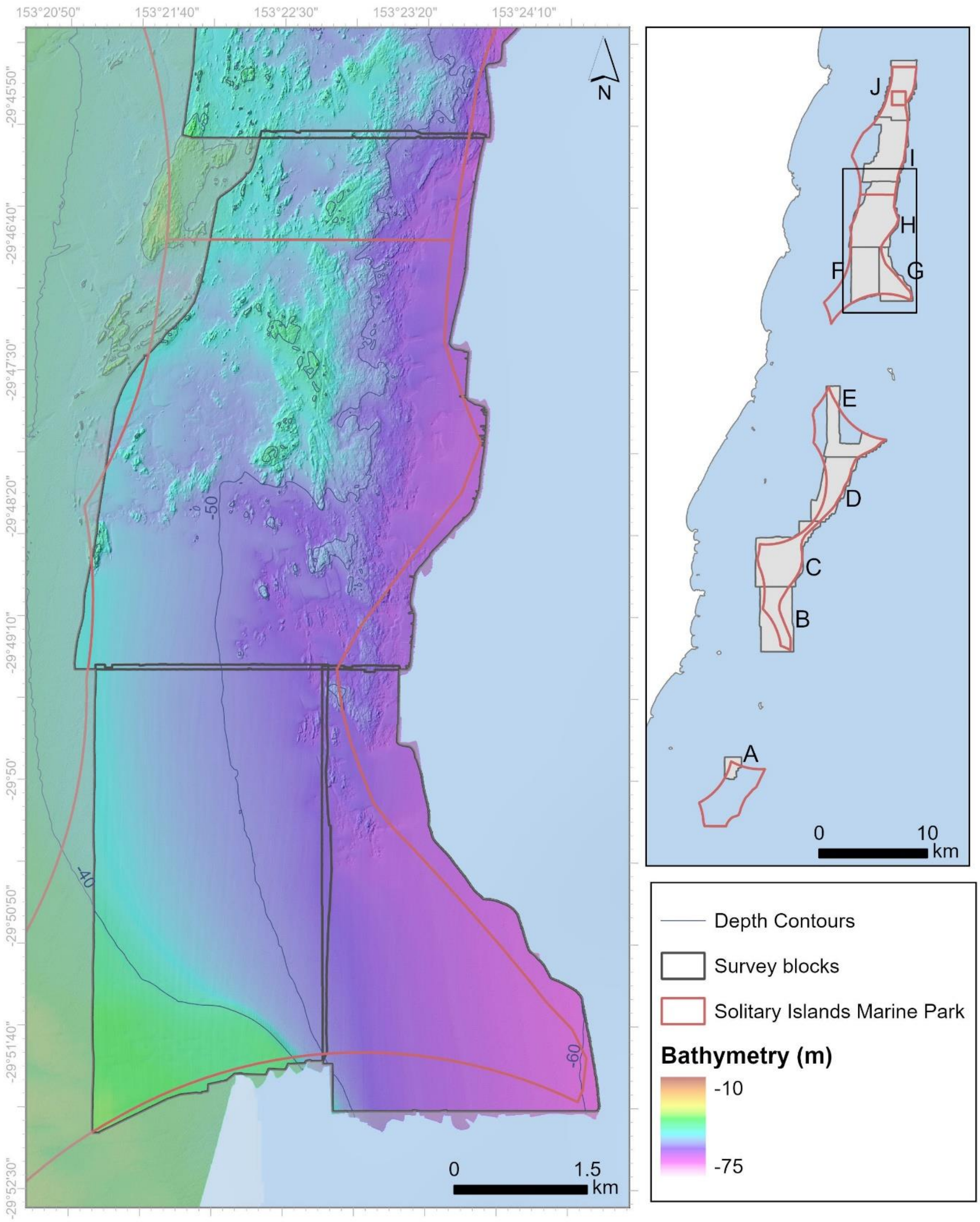


Figure 3.5 False-colour digital elevation model (5 m grid) & extents of new MBES bathymetry data acquired during this survey, blocks F-H, northern section, Solitary Islands Marine Park (Commonwealth waters).

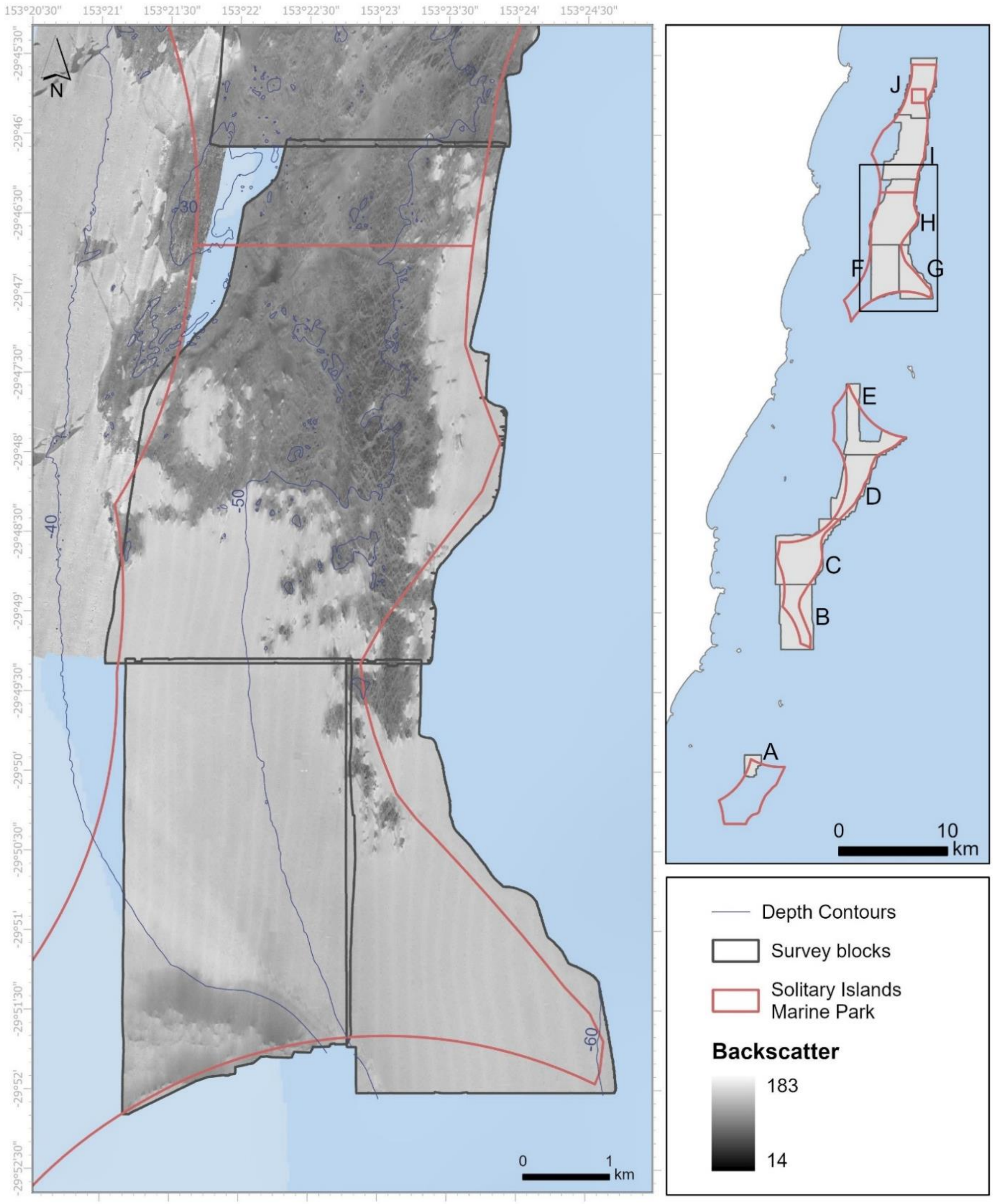


Figure 3.6 Greyscale backscatter mosaic (5 m grid) and extents of new MBES backscatter data acquired during this survey, blocks F-H, northern section, Solitary Islands Marine Park (Commonwealth waters).

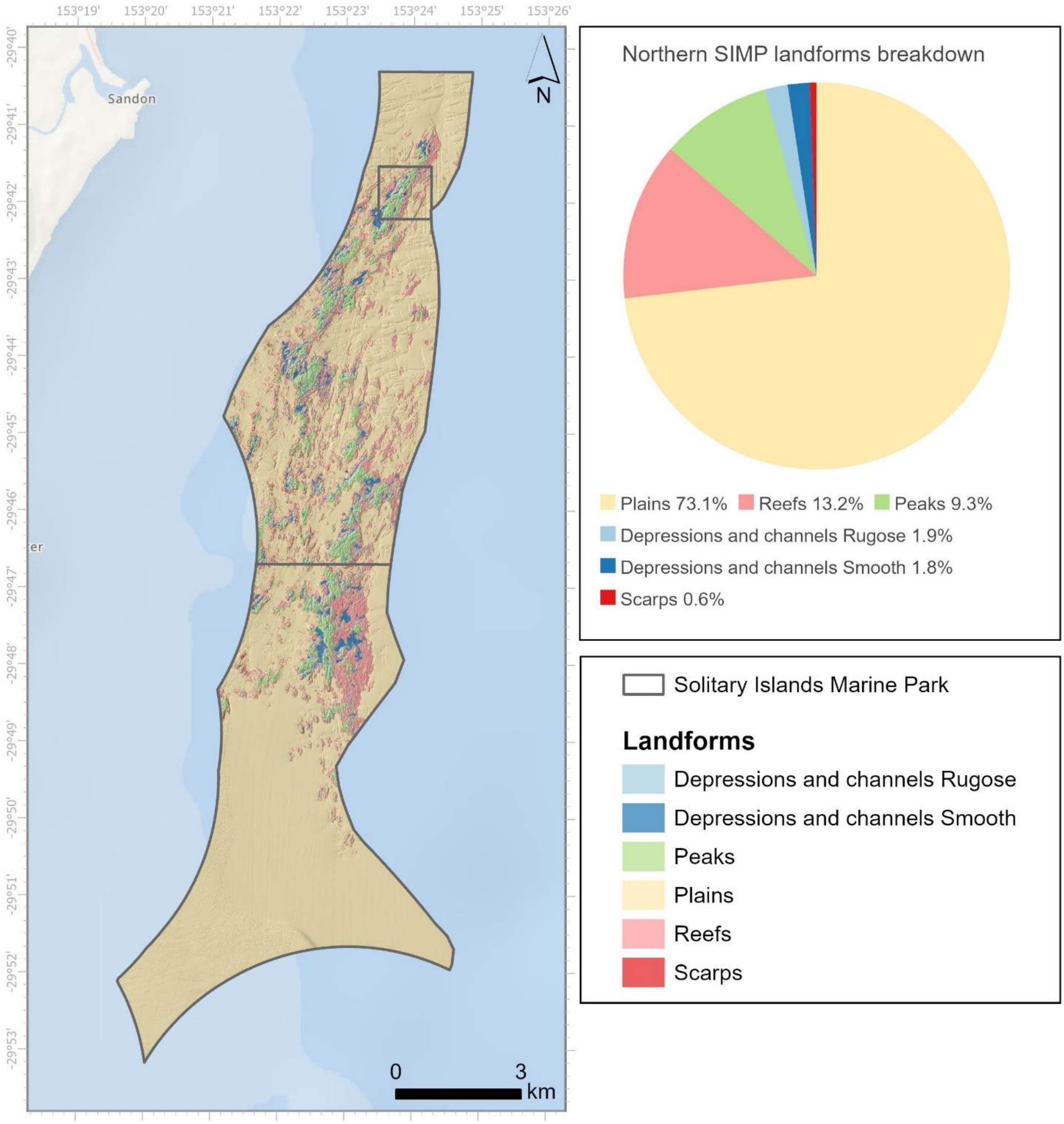


Figure 3.7 Landform classifications across the northern section of Solitary Islands Marine Park (Commonwealth waters) using Linklater et al (2023) and derived from a compilation of bathymetry surveys 2006-2023

contributes to a larger and more prominent reef feature lying predominantly within state-waters.

Other deeper reefs, identified in this section of the park, lie to the north, cover a depth range of 42-56 m, are patchy and surrounded by areas of unconsolidated seabed with mobile sand ridges (of various sizes, decreasing from north to south) (Blocks D and E). Similar to the very northern section of the park, the sand ridges are large features (esp. in block E: 1- 1.5 km in length), transverse relative to the shoreline and asymmetric in shape, but with a more N-NE and S-SW orientation (Figure 3.8). There also appears to be some topographic scouring

occurring within this region, owing to the diversion of currents around the prominent surrounding islands and rocky reef outcrops. This can be seen, for example, as scour (deeper by 10s of cm) and coarser sediments (darker areas of backscatter; higher intensity returns) running NE-SW along the 50m depth contour. Block D also has a sand ridge plain, but with much smaller wavelengths, and orientating N-NW to S-SW. The ridge plain seems to be divided by a sinuous N-S paleo-drainage channel (Figure 3.8).

Classified plain areas represent 96% (52.3 km^2) of the central section, with broadscale and fine scale sedimentary features comprising 8% (4.0 km^2) and 9% (4.9 km^2) of the mapped plain, respectively. These sand features and highly variable backscatter are characteristic for this area of seabed to the south, south-west and in the lee of North Solitary Island. A small additional area of patchy and low-profile reef in the south-east was also surveyed. Lying in 54-57 m of water the reef lies outside the park’s eastern boundary. The southern areas of this section of the park (Blocks B and C) are dominated by relatively uniform backscatter and planar seabed, that are largely featureless (Figure 3.10, Figure 3.11).

Southern Section

In the southern-most section of the park, depths ranged from 35-64 m shallowing from east to west (Figure 3.13, Figure 3.14). The deepest areas of seabed for the entire park lie in this southern section and due south of South Solitary Island. This section of the park, at a broad spatial scale, is dominated by plains (96%, 17.3 km^2), indicating that they are unconsolidated sediments. At a smaller scale, these sediments present as large mobile sand features (i.e., sand ridges), each in the order of 10s-100s of meters across. Broad- and fine-scale sedimentary features are represented in greatest proportion in this southern section, with broadscale high and low features comprising 11% and fine scale, localised low and high features comprising 20% of the mapped plain area. In the east and the north of the mapped southern section, the leading edges of these sand ridge features appear V-shaped. This appears to be two intersecting mobile sand units, suggesting that transport may be driven by currents from two dominant directions, NW and ENE, owing to the topographic steering of currents around the islands and reefs further north (i.e., South Solitary Island and 40-Acres Reef). Further to the west, the longer edges of the sand features are predominantly oriented NE to SW suggesting a dominant current from the north-west. Moving south, the sand ridges progressively develop from small to larger wavelengths and are more shore-transverse (and

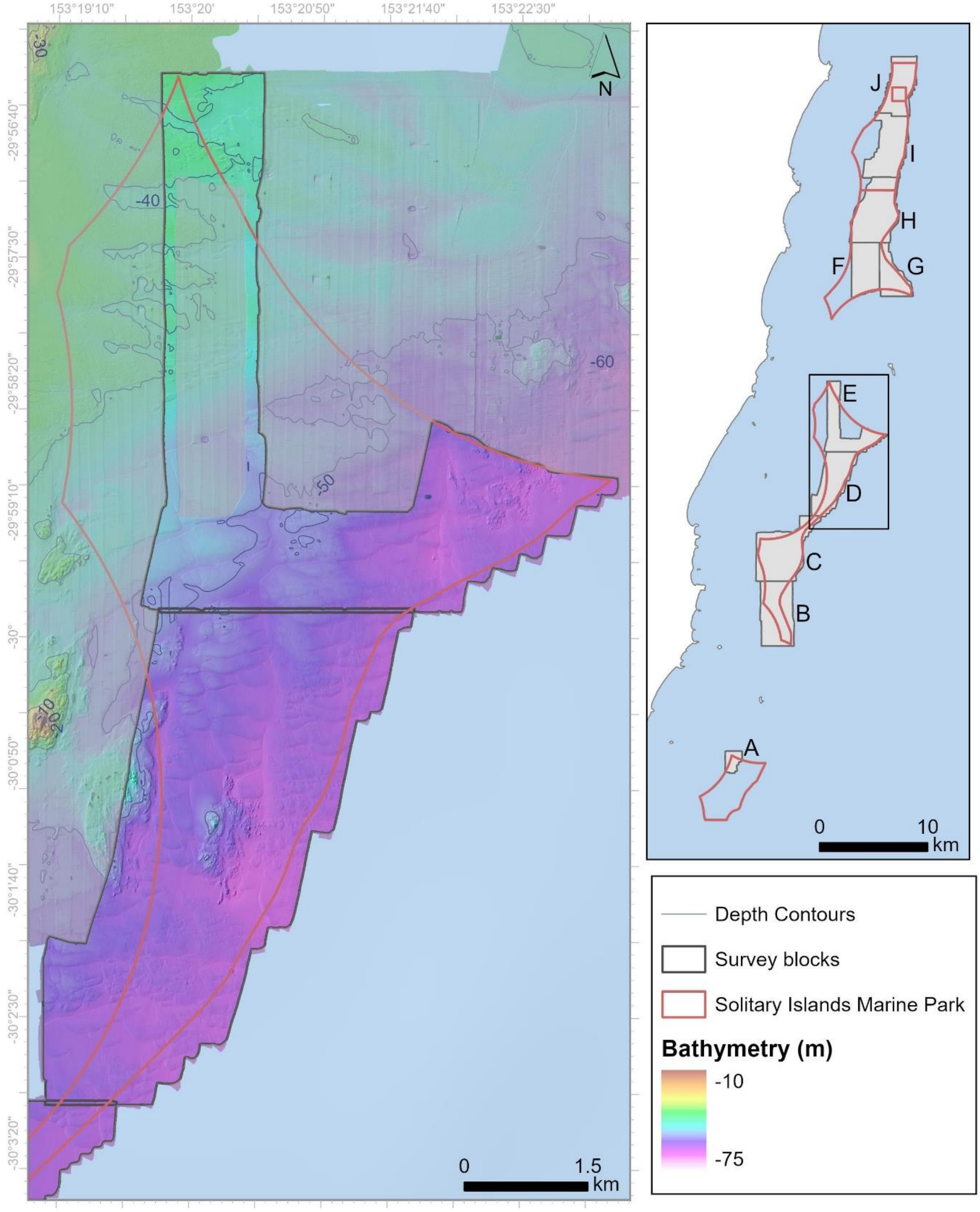


Figure 3.8 False-colour digital elevation model (5 m grid) and extents of new MBES bathymetry data acquired during this survey across blocks E-D, central section, Solitary Islands Marine Park (Commonwealth waters).

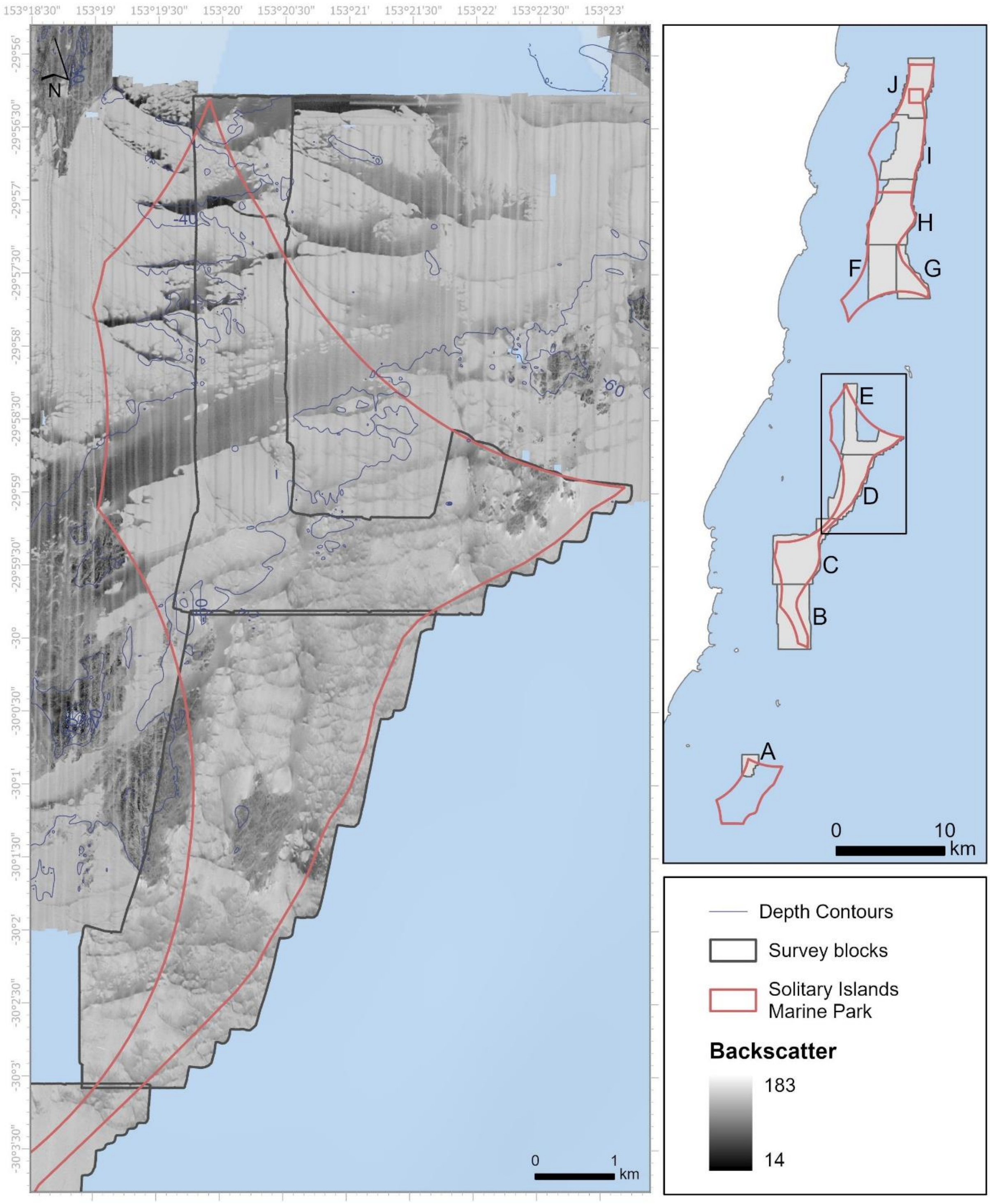


Figure 3.9 Greyscale backscatter mosaic (5 m grid) and extents of new MBES backscatter data acquired during this survey, blocks D-E, central section, Solitary Islands Marine Park (Commonwealth waters).

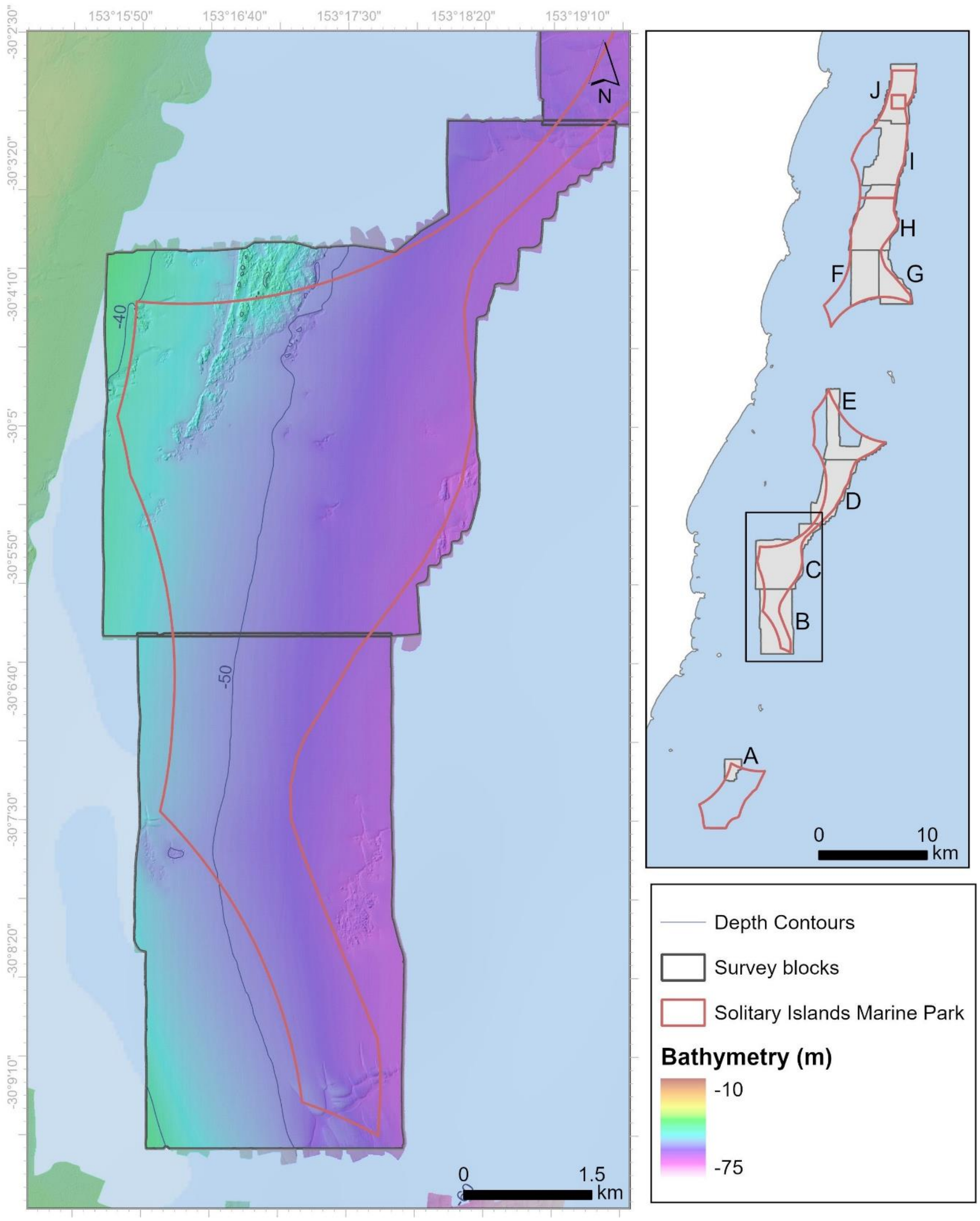


Figure 3.10 False-colour digital elevation model (5 m grid) & extents of new MBES bathymetry data acquired during this survey, blocks B-C, central section, Solitary Islands Marine Park (Commonwealth waters).

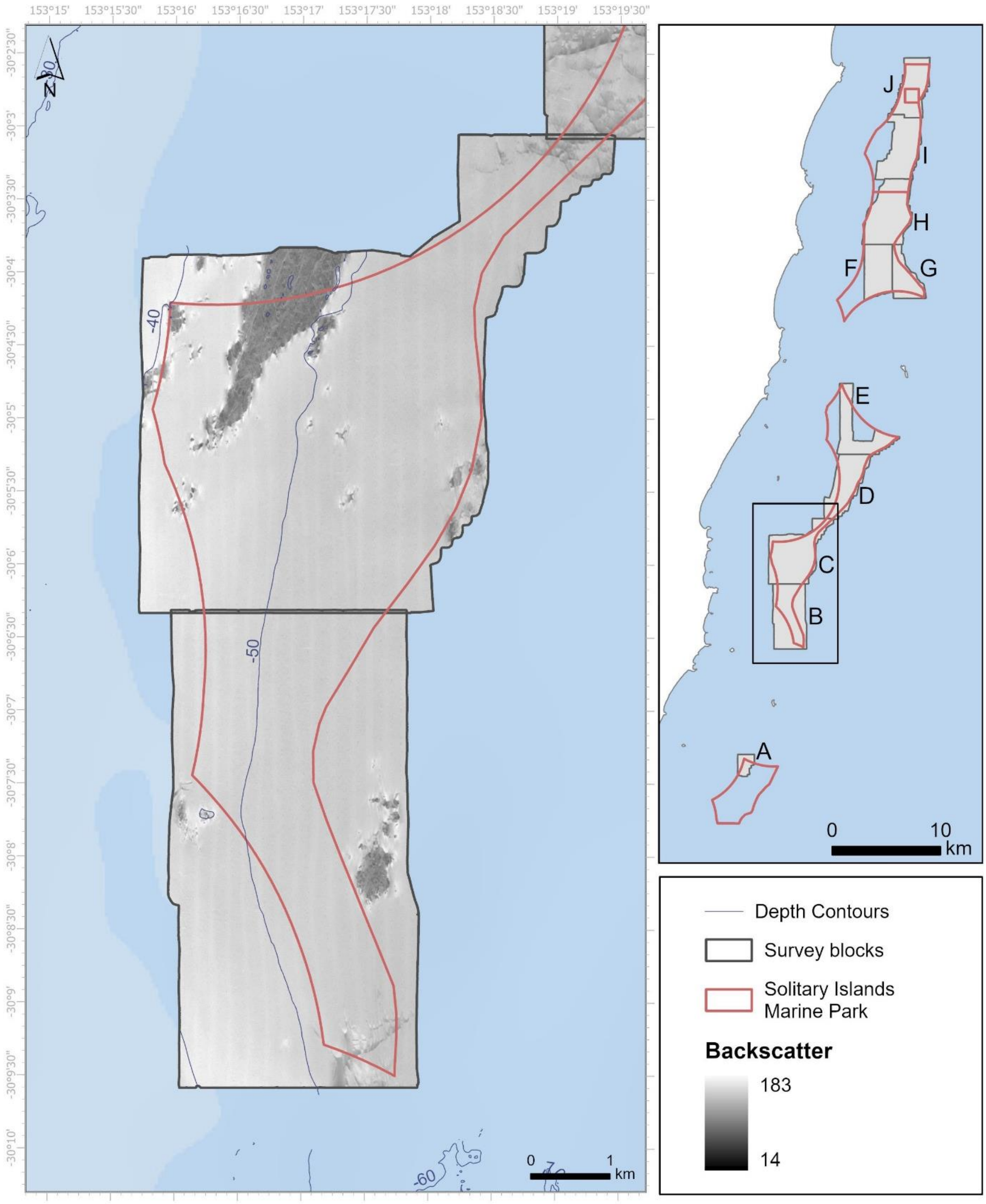


Figure 3.11 Greyscale backscatter mosaic (5 m grid) and extents of new MBES backscatter data acquired during this survey, blocks B-C, central section, Solitary Islands Marine Park (Commonwealth waters).

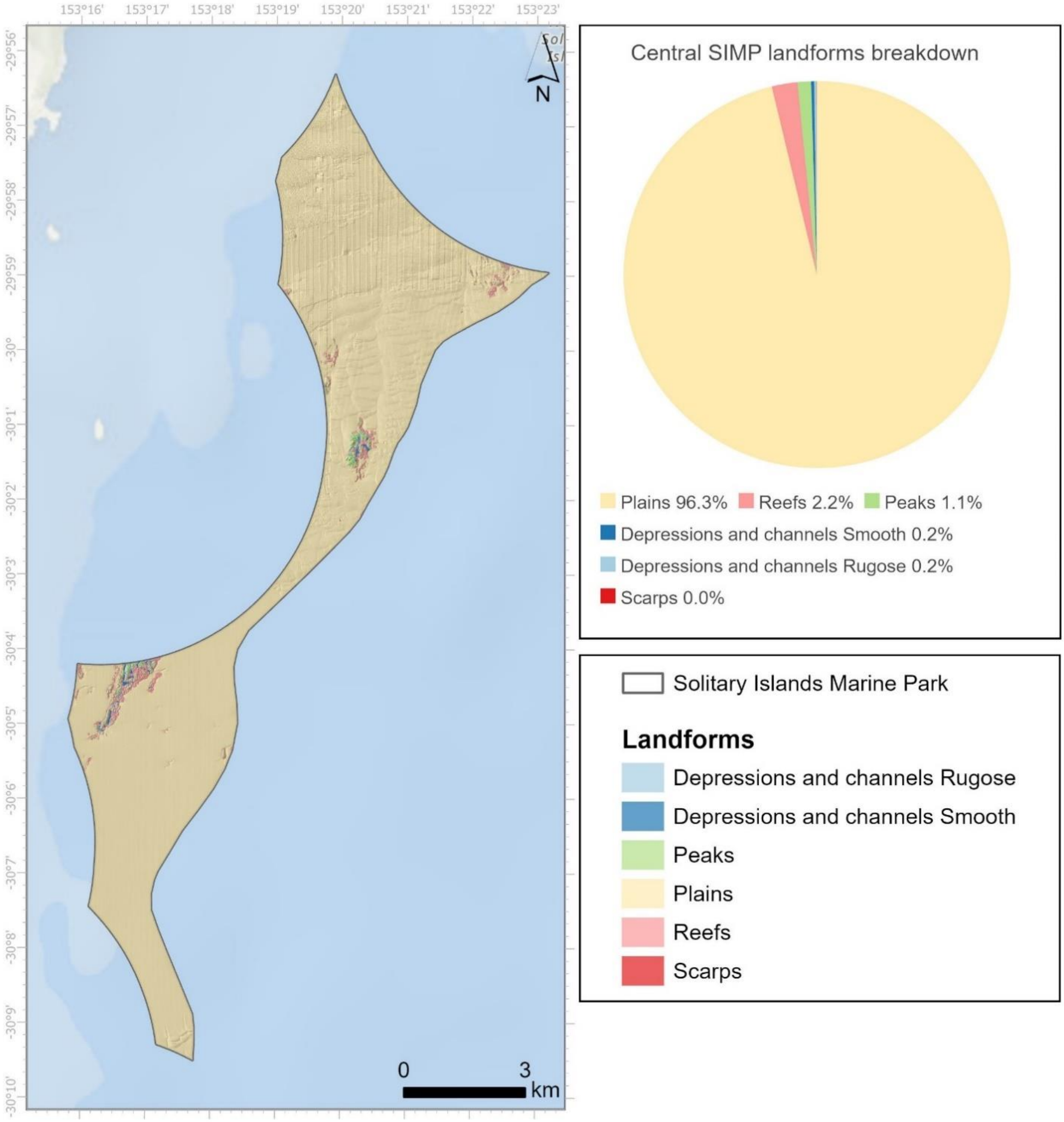


Figure 3.12 Landform classifications across the central section of Solitary Islands Marine Park (Commonwealth waters) using Linklater et al (2023) derived from a compilation of bathymetry surveys 2006-2023.

almost N-S crest orientation; see Figure 3.13). Many of the ridge wavelengths in the southern section are superimposed with finer secondary ridges (50-200 m), all oriented in a similar direction.

While the seabed appears less active in some planar areas to the north-west in Block A, both depositional and erosional features are present. Areas of low backscatter return signals (light coloured – soft sediment) are bisected by long (500-900 m) thin (25-60 m) sections of harder (darker) material. Sand ridges typically signal a bimodal grain size distribution (Kinsela et al., 2023), which seems to be observed in the backscatter, with the darker (coarser) sediment layers indicating coarser inner shelf sands, and the lower signal (lighter colour) indicating the finer inner-shelf muddy sands. This, however, needs to be confirmed with the sediment grab samples (see Section 3.2).

Reef is not a common feature in this section of the park and generally occurs as patchy outcrops. Reef landforms, including reefs, peaks, scarps and channels and depressions – rugose, collectively comprise only 4% of the mapped area (0.74 km^2). The patchy reef and surrounds are low profile and interspersed with unconsolidated material with relatively strong backscatter returns. These darker areas likely indicate seabed habitat types intermediate between unconsolidated ‘sands’ and consolidated ‘reef’ often characterised by boulders, cobbles, pebbles and/or gravel sized material. The size of these materials is smaller than the grid cell size of the DEM and backscatter mosaics, and so, as a feature, they are not as easy to delineate from one another using the remotely sensed MBES datasets. The most significant reef features in the south, were identified in earlier MBES surveys for the National Environmental Research Program in 2012 are a series of parallel ridge features that lie in a north-east to south-west orientation. The ridges lie across a range of depths from ~60 to 75 m, are 100s of m to 3-4 km in length, 10-100 m wide and between 1 and 5 m in height may represent relic coastline. These features lie outside the park’s current eastern boundary (Figure 3.13).

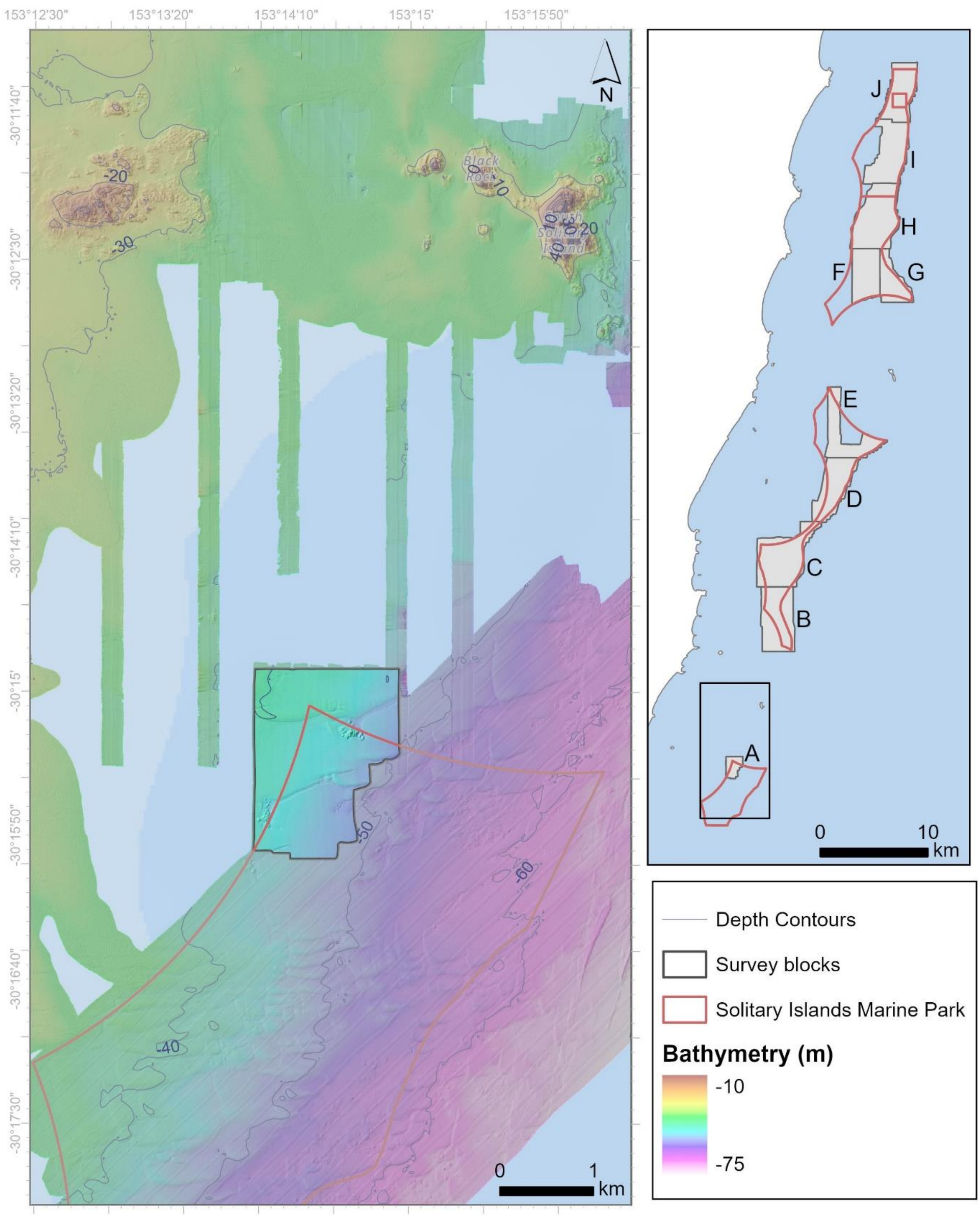


Figure 3.13 False-colour digital elevation model (5 m grid) and extents of new MBES bathymetry data acquired during this survey block A and earlier 2012 survey area, southern section, Solitary Islands Marine Park (Commonwealth waters).

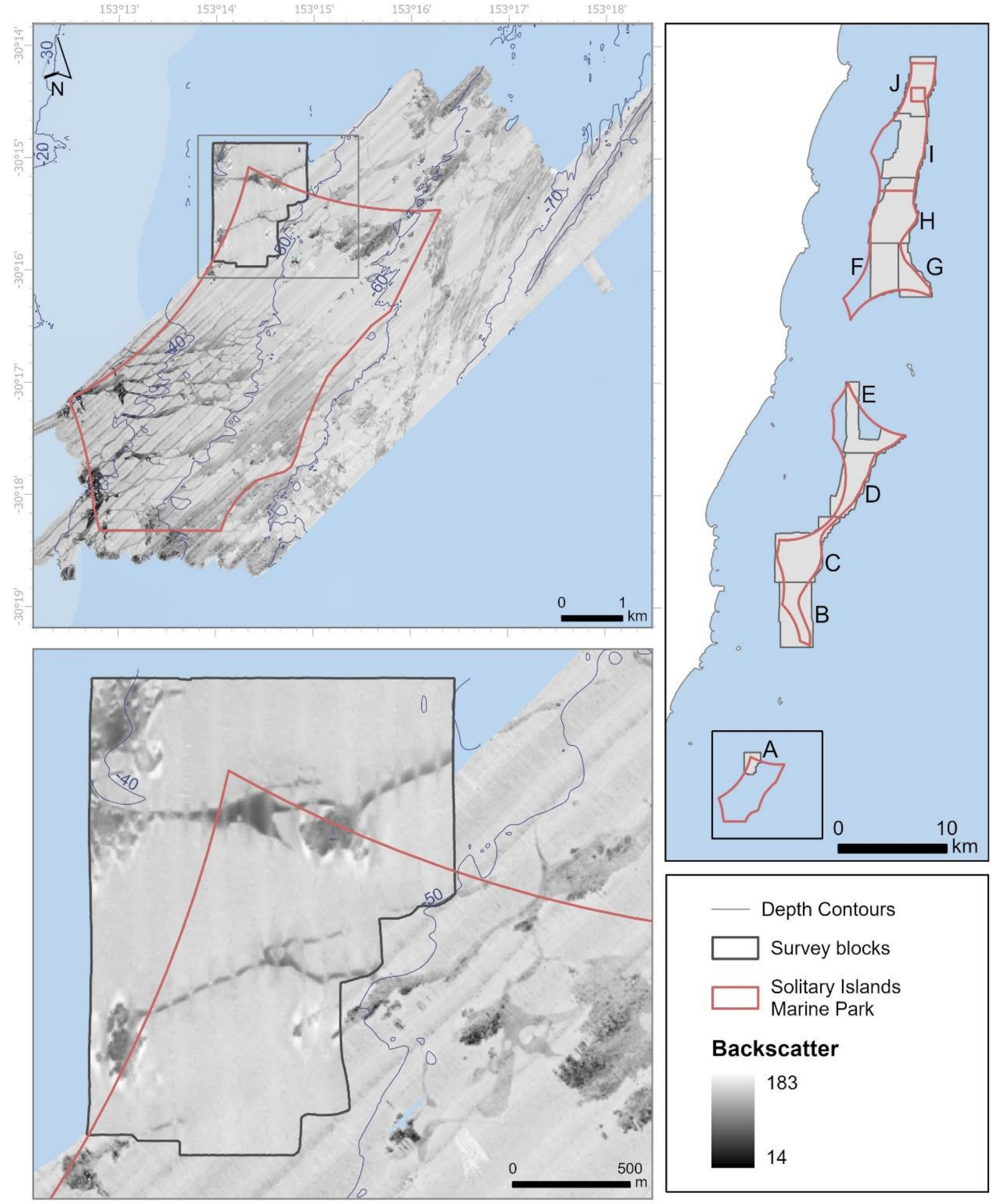


Figure 3.14 Greyscale backscatter mosaic (5 m grid) and extents of new MBES backscatter data acquired during this survey block A and earlier 2012 survey area, southern section, Solitary Islands Marine Park (Commonwealth waters).

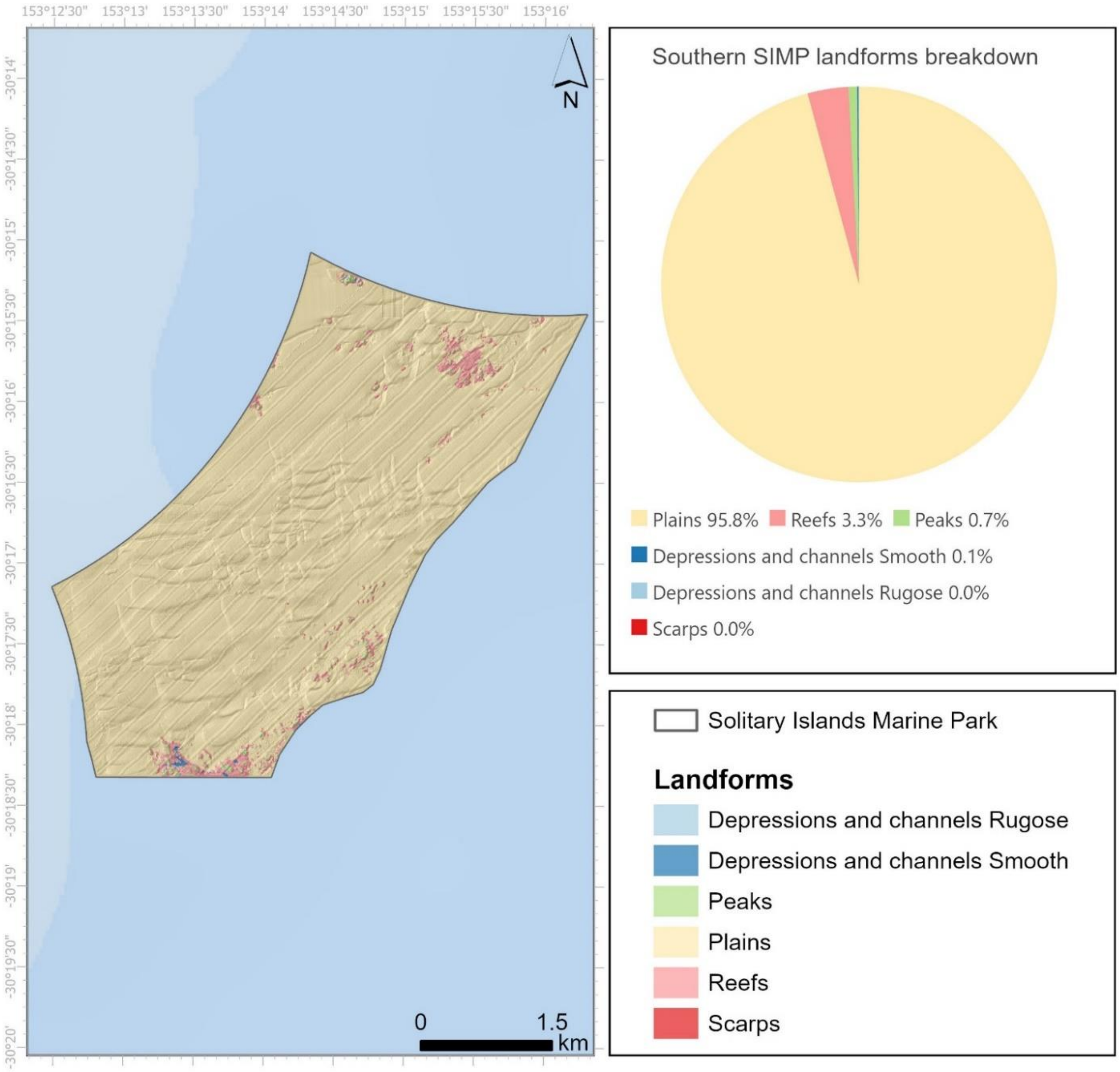


Figure 3.15 Landform classifications across the southern section of Solitary Islands Marine Park (Commonwealth waters) using Linklater et al (2023) derived from a compilation of bathymetry surveys 2006-2023

3.2 Benthic Habitats and Sedimentology

Descriptions of the general characteristics of the seabed, sediment and any biological features are described in this section. For sedimentary features, any measurements provided are relative to the dual laser points of known scale (100 mm apart), where possible, otherwise they are descriptive and general in nature only. Apart from annotations for some limited organisms in sediment dominated areas, statistical analyses were not performed on these images.

A total of 24 transects contained images with reef-dominated substrate suitable for reef-targeted annotations; 17 in the north, 4 in the central and 3 in the southern sections of the park. Targeted point counts for the Top-10 organisms combined with all visible and scorable mid-tier morphospecies for the 283 reef dominated images (~10% of all reef images available) across all transects generated a total of ~14,720 annotations for statistical analyses. The greatest number of reef images within any single transect was T009 (20241124UTC) located within the central section of the park with 481 images of which 335 were reef dominated.

The total number of different morphospecies identified across all Top10 annotated imagery was 321 which was reduced to 36 morphospecies when collating annotations from the mid-tier taxonomic approach. A summary of the number of images analysed and annotations assigned are summarised in Figure 3.16. Of the 19 transects used to calculate diversity and density, all but 6 were located within the northern section of the park between Pimpernel Rock and a line due east of Diggers Camp north of Wooli.

The relative abundances of the key morphospecies of Porifera, Cnidaria and Broyzoa (mid-tier classification across all transects are presented in Figure 3.17-3.22. The number of morphospecies, numbers of annotated individuals and H-index values were, on average, higher with equitability indices closer to 1.0 (most equitable) for transects in the northern and southern sections compared to transects in the central section of the park (Table 3.3). While this general trend between 'sections' was consistent for both approaches, the transects with the highest H-index values for Top-10 were not consistently the highest values for those calculated using the mid-tier classification data. Note: both the Top-10 and mid-tier approaches used data from a random selection of 5 annotated images.

The greatest diversity according to Top-10 were T005 and T007 (20231126) in the northern and T009 (20231124) in the central section. Based on mid-tier annotations, the highest H-index values were T007 (20231126) in the north and T007 (20231107), T022 (20231126) and T023 (20231126). The greatest range in H and E_H values between transects within a park area also occurred in the central section which only contained 3 transects. A map of the Shannon Diversity Index is provided in Figure 3.23.

Density values were generally comparable when calculated using either method for all morphospecies grouped by phyla. The greatest differences between the two values appeared to occur for the lower density phylum Bryozoa (Table 3.4). Across all transects

Porifera (sponges) were observed at the greatest densities followed by Cnidaria and then Bryozoa. Generally, some transects displayed high densities across the 3 phyla, most notably T005, T013 and T015 (20231126) in the northern and T022 and T023 (20231126) in the southern section of the park. Northern and southern transects generally had higher density values compared to transects of the central section.

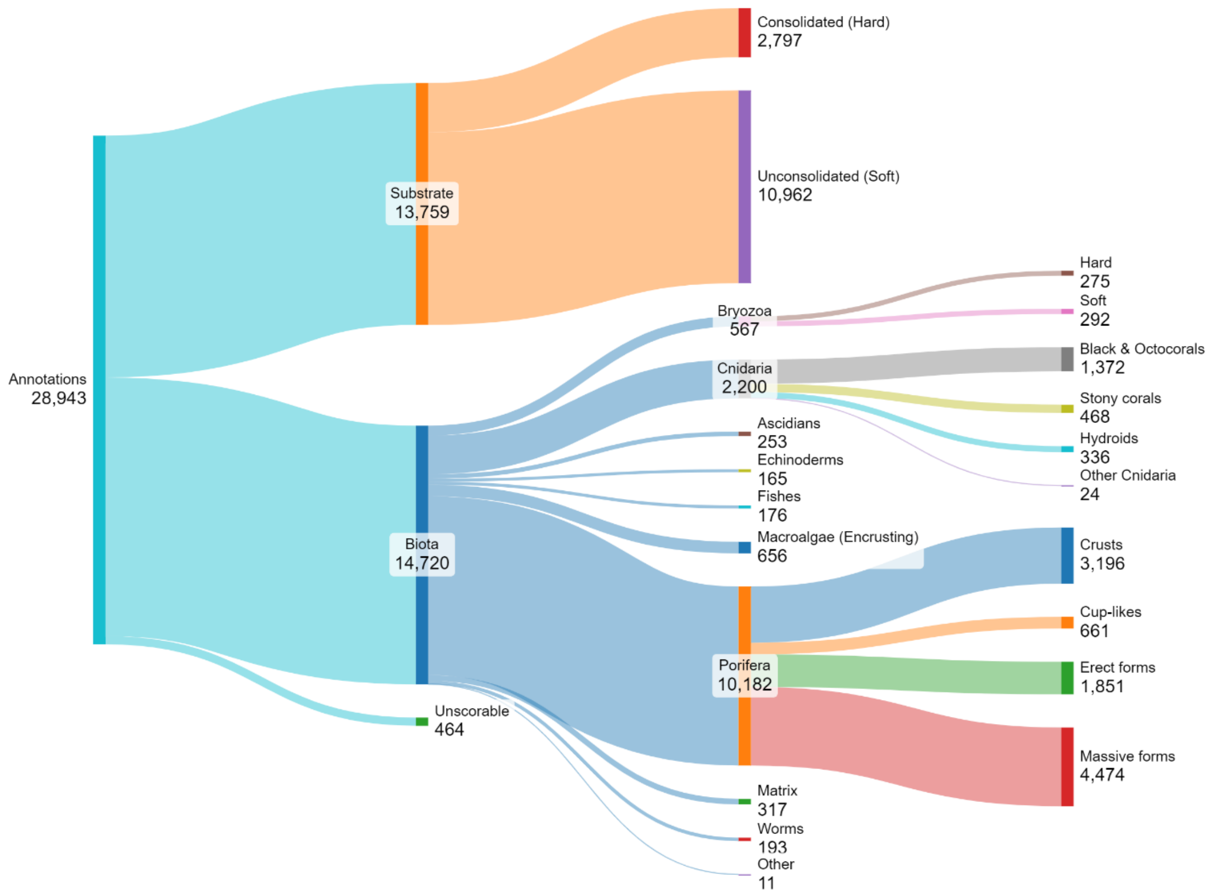


Figure 3.16 Proportionate breakdown of all annotations with increased detail for the three key phyla

Table 3.3 Shannon Diversity (H) and Equitability (E_H) indices based on the 'Top-10' and 'mid-tier' annotation sets from 5 randomly selected images per transect (transects with >50 reef images only; n=19). Transects are north to south with park zone denoted (NP = National Park, MU = Multi Use, SP = Special Purpose). Nb: Total number of morphospecies parkwide: n=320 (Top 10), n = 36 (Mid-tier). Highly mobile organisms (i.e. fish) were not used

	Zone	Section	Top10				Mid-tier			
Transect			#morp	Ind. count	**Index H**	**Equitability E_H**	#morp	Ind. count	**Index H**	**Equitability E_H**
20231126_T015	NPZ	North	29	50	**3.13**	**0.93**	14	166	**1.95**	**0.74**
20231126_T016	MUZ		18	50	**2.59**	**0.90**	13	304	**1.96**	**0.76**
20231126_T017			26	41	**3.07**	**0.94**	18	380	**1.80**	**0.62**
20231126_T018			24	38	**2.93**	**0.92**	16	280	**1.92**	**0.69**
20231126_T003			22	44	**2.75**	**0.89**	14	207	**1.77**	**0.67**
20231126_T004			3	8	**0.74**	**0.67**	7	29	**1.14**	**0.59**
20231126_T007			29	50	**3.23**	**0.96**	14	199	**2.17**	**0.82**
20231126_T005			36	53	**3.49**	**0.97**	15	339	**1.53**	**0.56**
20231126_T006			23	40	**2.96**	**0.94**	12	105	**2.07**	**0.83**
20231126_T008	SPZ		24	49	**2.94**	**0.93**	17	535	**1.88**	**0.67**
20231126_T009			27	50	**3.08**	**0.94**	16	261	**1.96**	**0.71**
20231126_T011			28	49	**3.03**	**0.91**	15	272	**1.99**	**0.74**
20231126_T013			28	49	**3.17**	**0.95**	12	282	**1.63**	**0.66**
Average North			**24**	**44**	**2.85**	**0.91**	**14**	**258**	**1.83**	**0.70**
20231124_T007	SPZ	Central	3	8	**0.74**	**0.67**	7	29	**1.14**	**0.59**
20231124_T009			36	53	**3.49**	**0.97**	15	339	**1.53**	**0.56**
20231123_T003			22	44	**2.75**	**0.89**	14	207	**1.77**	**0.67**
Average Central			**20**	**35**	**2.33**	**0.84**	**12**	**192**	**1.48**	**0.61**
20231107_T007	SPZ	South	21	37	**2.84**	**0.93**	14	122	**2.13**	**0.81**
20231126_T023			21	44	**2.81**	**0.92**	19	322	**2.47**	**0.84**
20231126_T022			26	43	**3.07**	**0.94**	21	295	**2.17**	**0.71**
Average South			**23**	**41**	**2.91**	**0.93**	**18**	**246**	**2.26**	**0.79**
Average (all reef sites)			**29**	**50**	**3.13**	**0.93**	**14**	**166**	**1.95**	**0.74**
All Annotated reef images			209	822	4.78	0.90	30	4954	2.21	0.65

Table 3.4 Summed image area 'assessed' (annotated) and mean density values calculated for the 3 key phyla based on total annotation counts available for i) for all available annotated images per transect (i.e., 10% of reef images) and ii) limited to 5 random images. Nb: for summed area as '10% reef', calculation is based on average images area multiplied by number of available assessed/annotated reef images. Transects are north to south and park zone denoted (NP = National Park, MU = Multi Use, SP = Special Purpose)

	Zone	Section	Sum of Area Assessed (m²)		Bryozoa		Cnidaria		Porifera (Sponges)		Total (All Biota)	
Transect			10% Reef	Random 5	**10% Reef**	**Random**	10% Reef	Random	**10% Reef**	**Random**	10% Reef	Random
20231126_T015	NP	North	18.5	8.4	**1.7**	**2.2**	3.1	3.5	**22.2**	**24.6**	30.3	33.4
20231126_T016	MUZ	North	28.6	11.9	**0.7**	**1.2**	1.5	1.3	**12.4**	**11.8**	17.3	16.7
20231126_T017	MUZ	North	13.1	9.4	**1.5**	**0.9**	10.7	5.6	**20.0**	**18.4**	38.2	31.0
20231126_T018	MUZ	North	19.1	13.7	**2.1**	**1.0**	5.7	2.9	**28.0**	**20.6**	38.5	26.9
20231126_T003	MUZ	North	**19.0**	**9.5**	**0.5**	**0.3**	**1.8**	**1.3**	**8.6**	**8.0**	**12.7**	**11.1**
20231126_T004	MUZ	North	27.0	7.9	**1.1**	**1.1**	6.4	6.8	**18.7**	**15.0**	28.7	25.1
20231126_T007	MUZ	North	35.4	8.9	**1.1**	**0.9**	7.0	5.3	**20.9**	**21.9**	32.1	30.7
20231126_T005	MUZ	North	20.4	11.3	**0.9**	**1.5**	6.8	8.0	**32.7**	**34.7**	43.6	47.3
20231126_T006	MUZ	North	32.2	8.5	**0.6**	**0.5**	4.7	5.8	**18.7**	**21.2**	26.5	30.8
20231126_T008	SPZ	North	26.1	10.9	**0.3**	**0.5**	2.2	1.6	**24.7**	**23.1**	28.7	26.0
20231126_T009	SPZ	North	12.4	8.9	**0.1**	**0.1**	2.9	3.2	**9.0**	**10.3**	18.7	18.8
20231126_T011	SPZ	North	25.8	11.7	**0.6**	**1.1**	2.3	3.2	**17.0**	**17.2**	23.6	25.9
20231126_T013	SPZ	North	10.7	6.7	**1.6**	**1.2**	10.0	9.1	**61.0**	**44.2**	75.0	56.8
Average North		North	22.17	9.81	**0.98**	**0.95**	5.01	4.4	**22.61**	**20.85**	31.84	29.25
20231124_T007	SPZ	Central	24.8	9.5	**0.0**	**0.0**	7.2	2.2	**0.9**	**0.4**	10.1	3.1
20231124_T009	SPZ	Central	56.8	8.4	**1.7**	**1.8**	1.4	2.4	**24.3**	**36.0**	28.4	40.6
20231123_T003	SPZ	Central	32.0	8.0	**1.1**	**0.6**	1.8	1.3	**24.2**	**20.2**	33.8	25.9
Average Central		Central	37.86	8.63	**0.92**	**0.8**	3.49	1.95	**16.47**	**18.89**	24.09	23.16
20231107_T007	SPZ	South	11.9	5.0	**1.7**	**0.8**	7.4	6.8	**15.3**	**14.5**	26.2	24.5
20231126_T023	SPZ	South	29.6	6.4	**3.2**	**4.5**	6.5	9.2	**24.0**	**24.8**	44.0	50.0
20231126_T022	SPZ	South	14.4	4.5	**2.4**	**3.8**	10.7	9.6	**33.4**	**42.2**	56.3	65.5
Average South		South	18.7	5.3	**2.4**	**3.0**	8.2	8.5	**24.3**	**27.2**	42.2	46.7
Average (all reef sites)			**24.1**	24.1	**8.9**	**1.2**	1.3	5.3	**4.7**	**21.9**	21.5	32.2

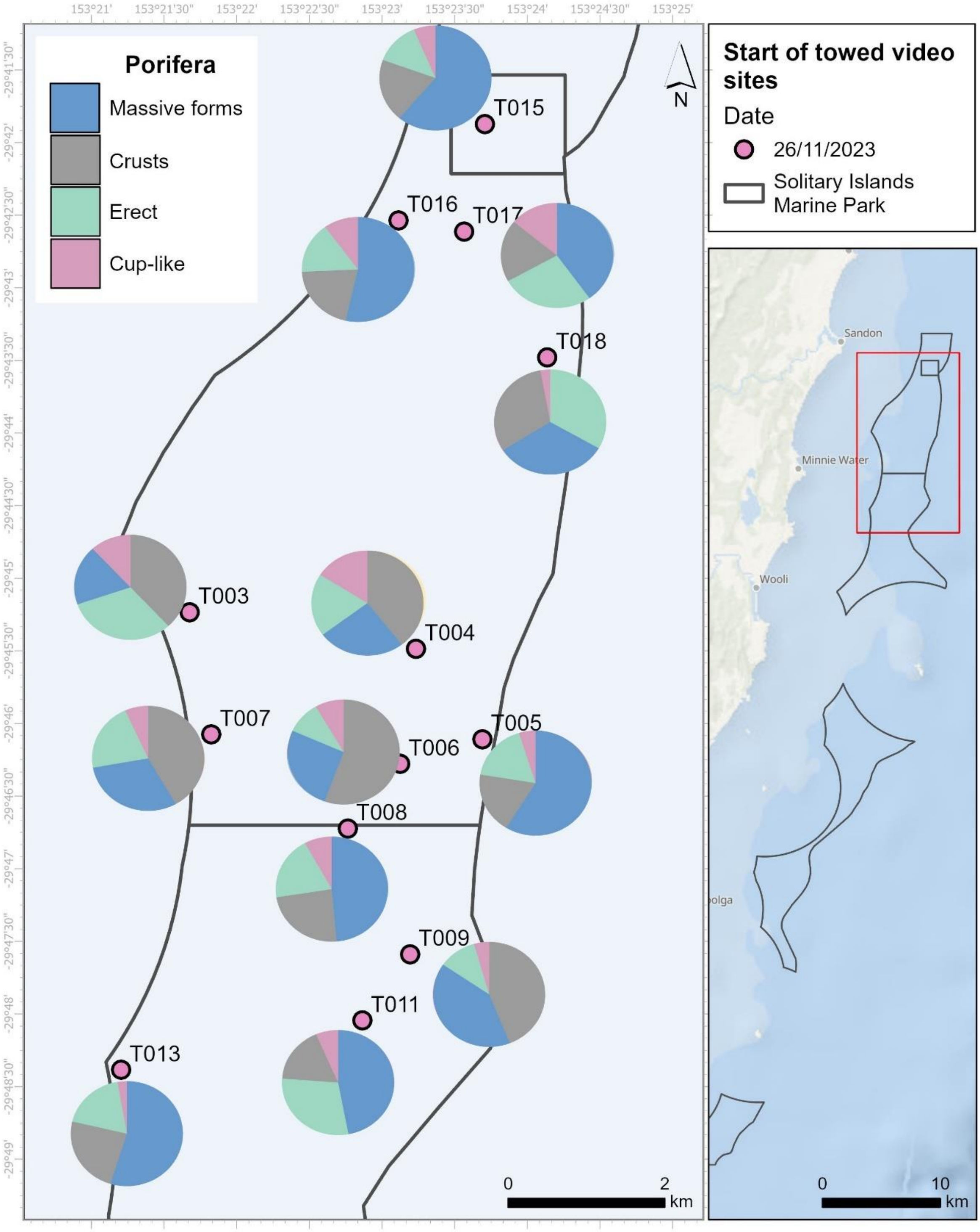


Figure 3.17 Map of the relative abundances of the 4 most common sponge (Porifera) morphospecies, northern section

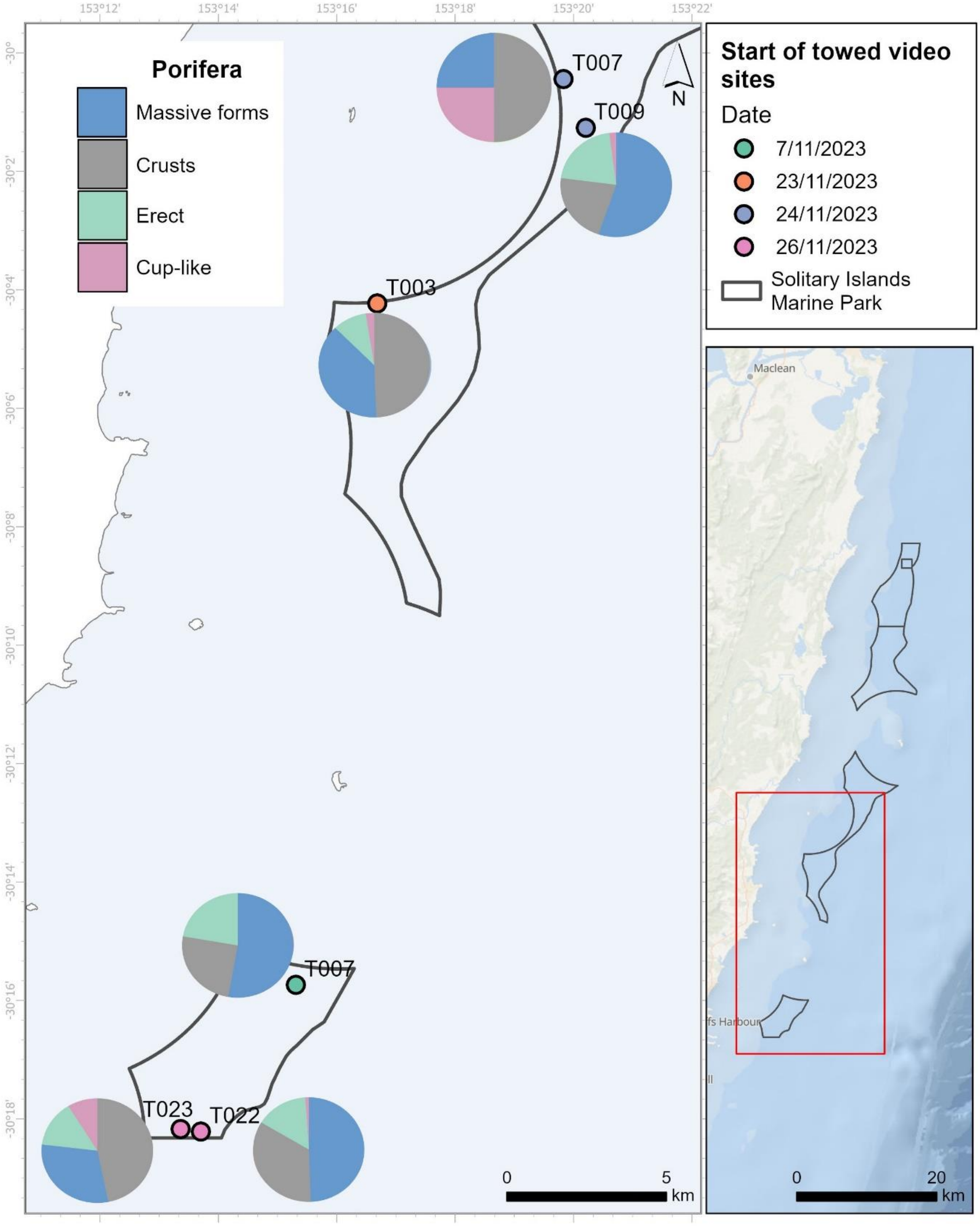


Figure 3.18 Map of the relative abundances of the 4 most common sponge (Porifera) morphospecies, central and southern section

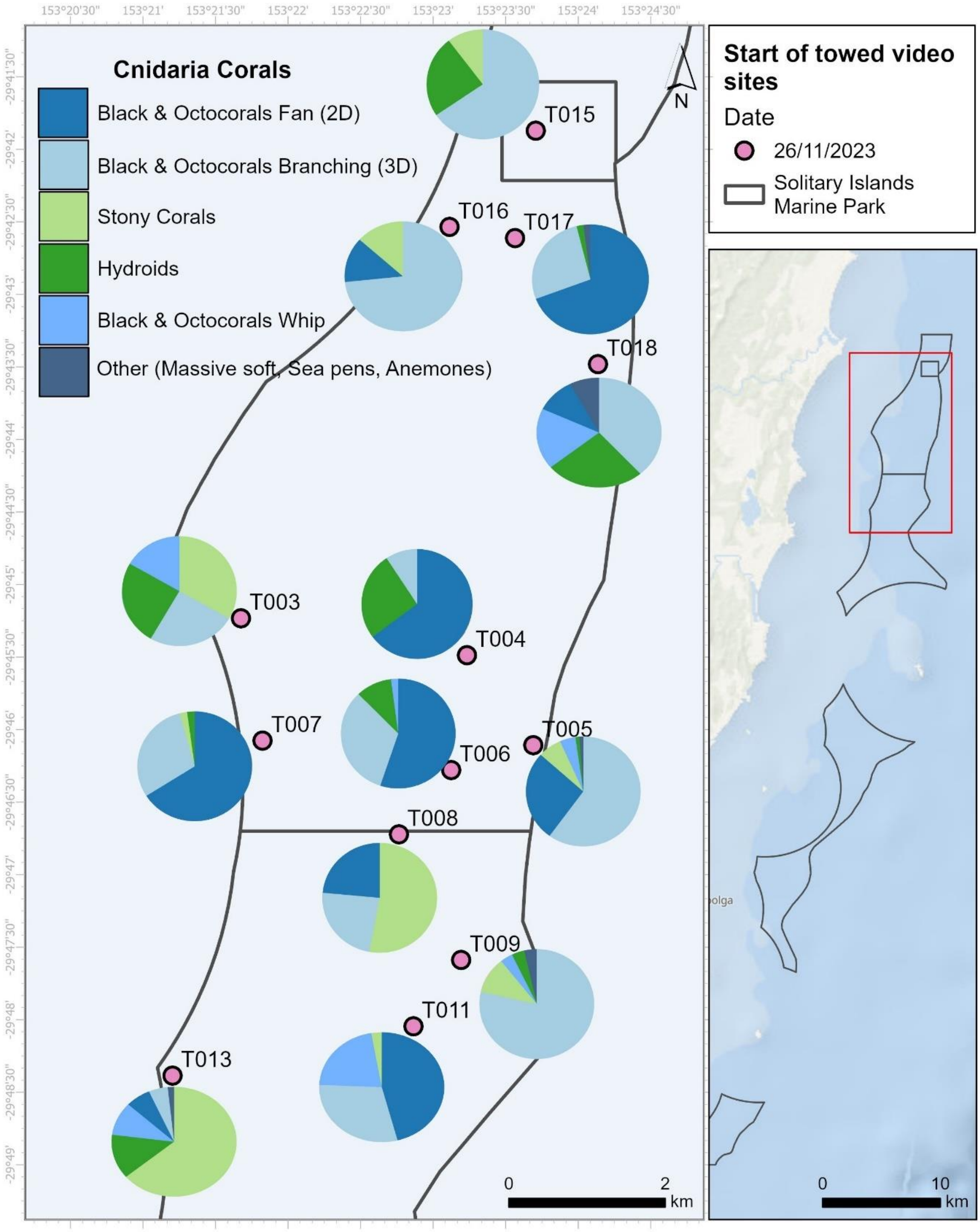


Figure 3.19 Map of the relative abundances of the 5 most common Cnidarian morphospecies, northern section

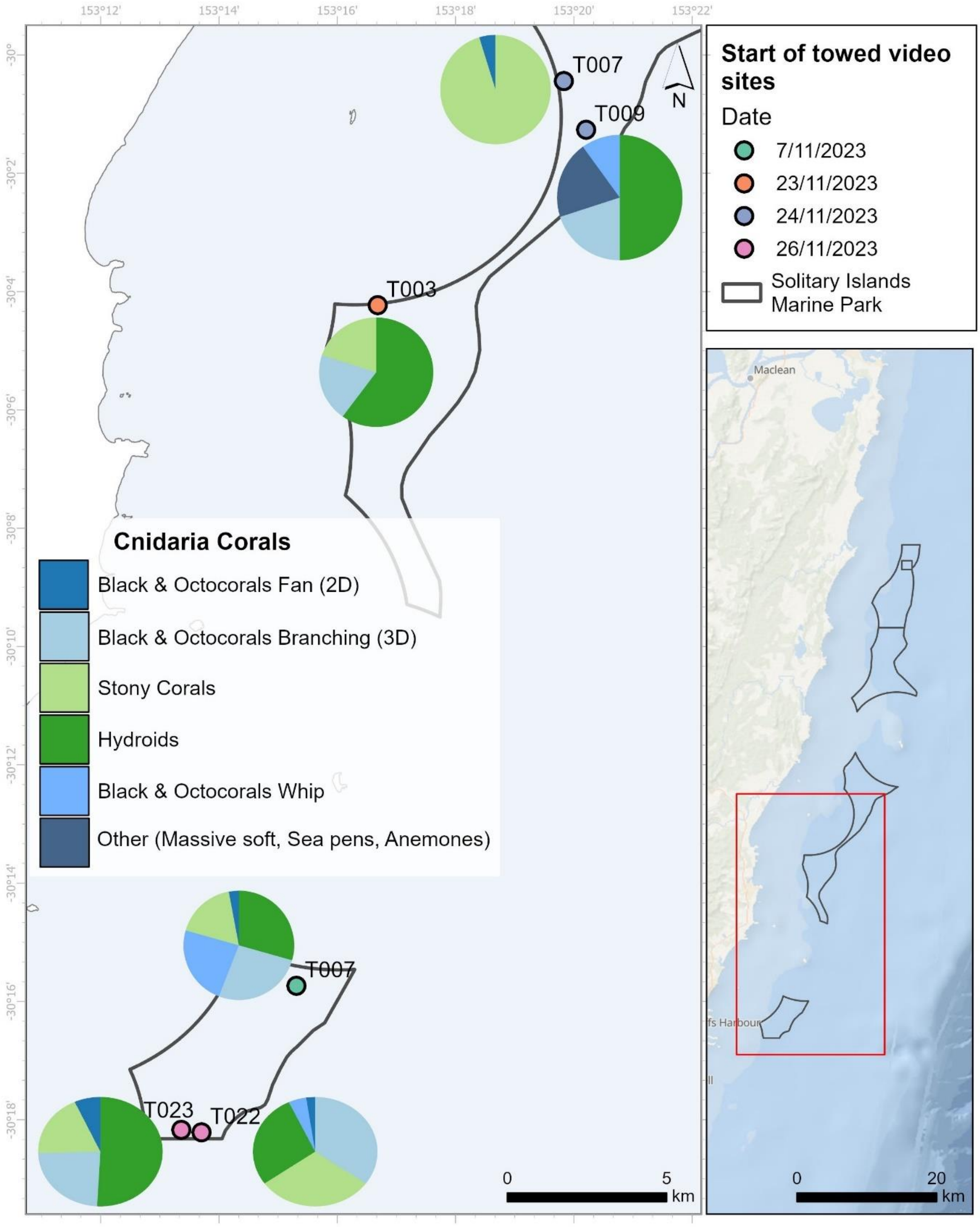


Figure 3.20 Map of the relative abundances of the 5 most common Cnidarian morphospecies, central and southern section

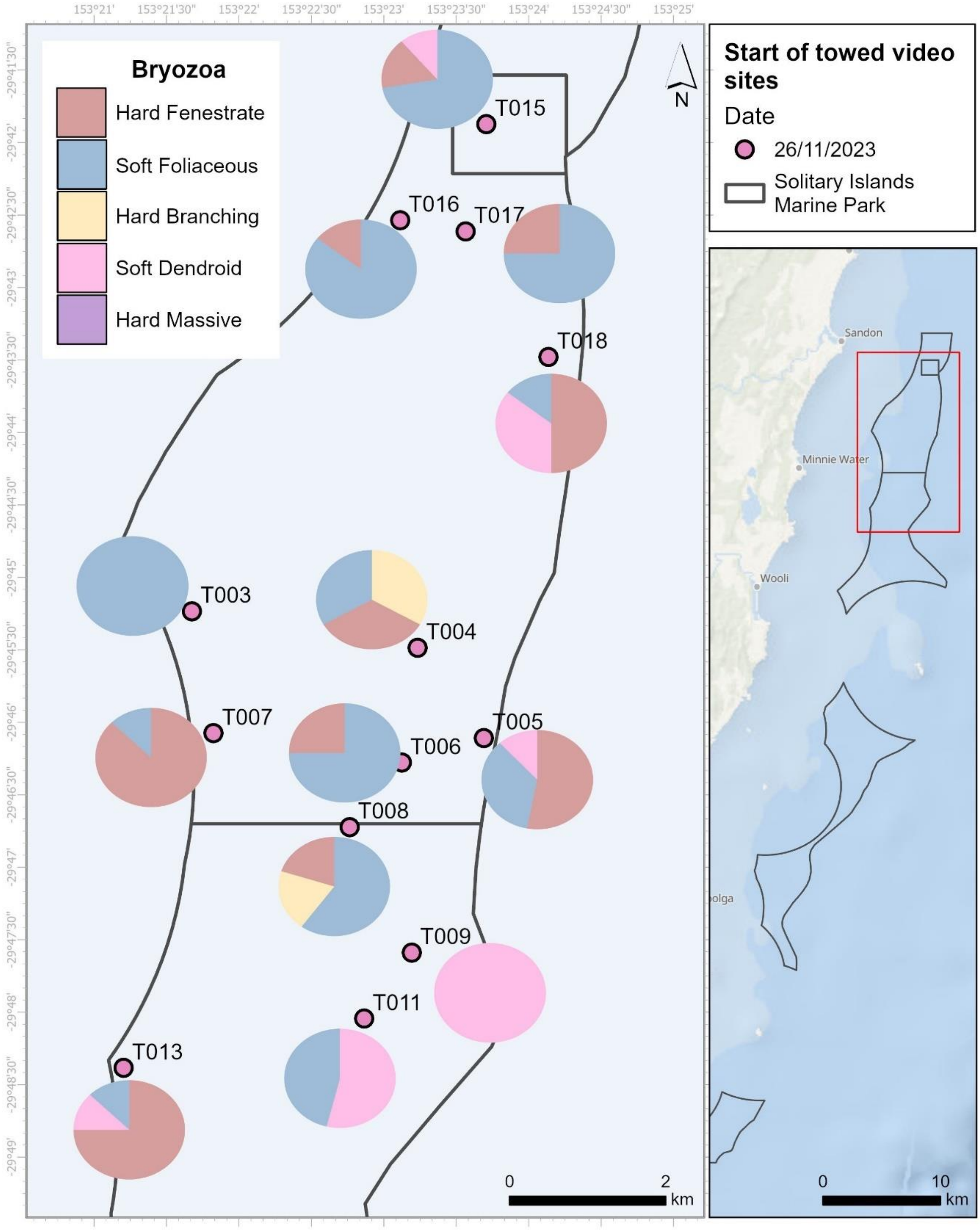


Figure 3.21 Map of the relative abundances of the 5 most common Bryozoa morphospecies, northern section

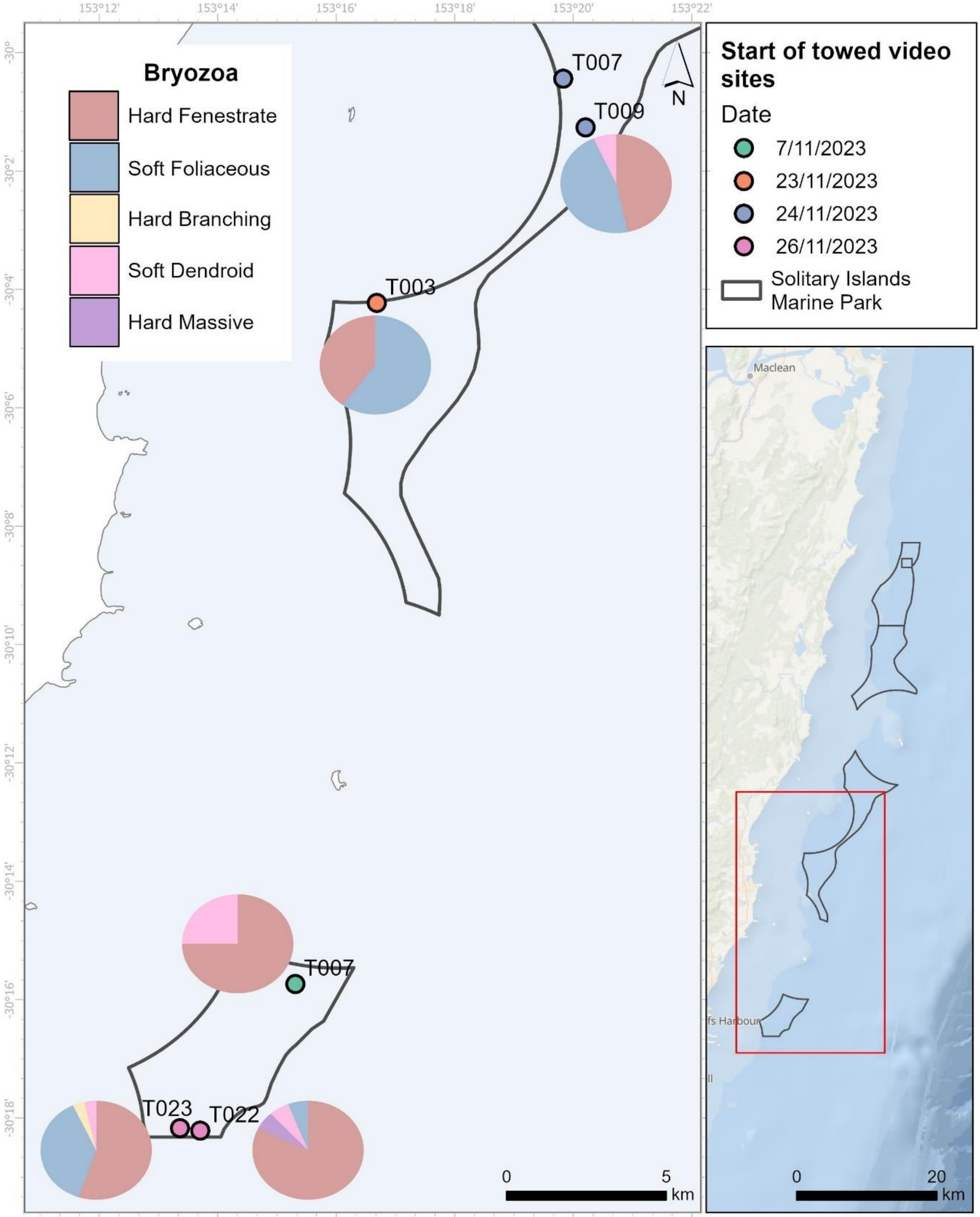


Figure 3.22 Map of the relative abundances of the 5 most common Bryozoa morphospecies, central and southern section

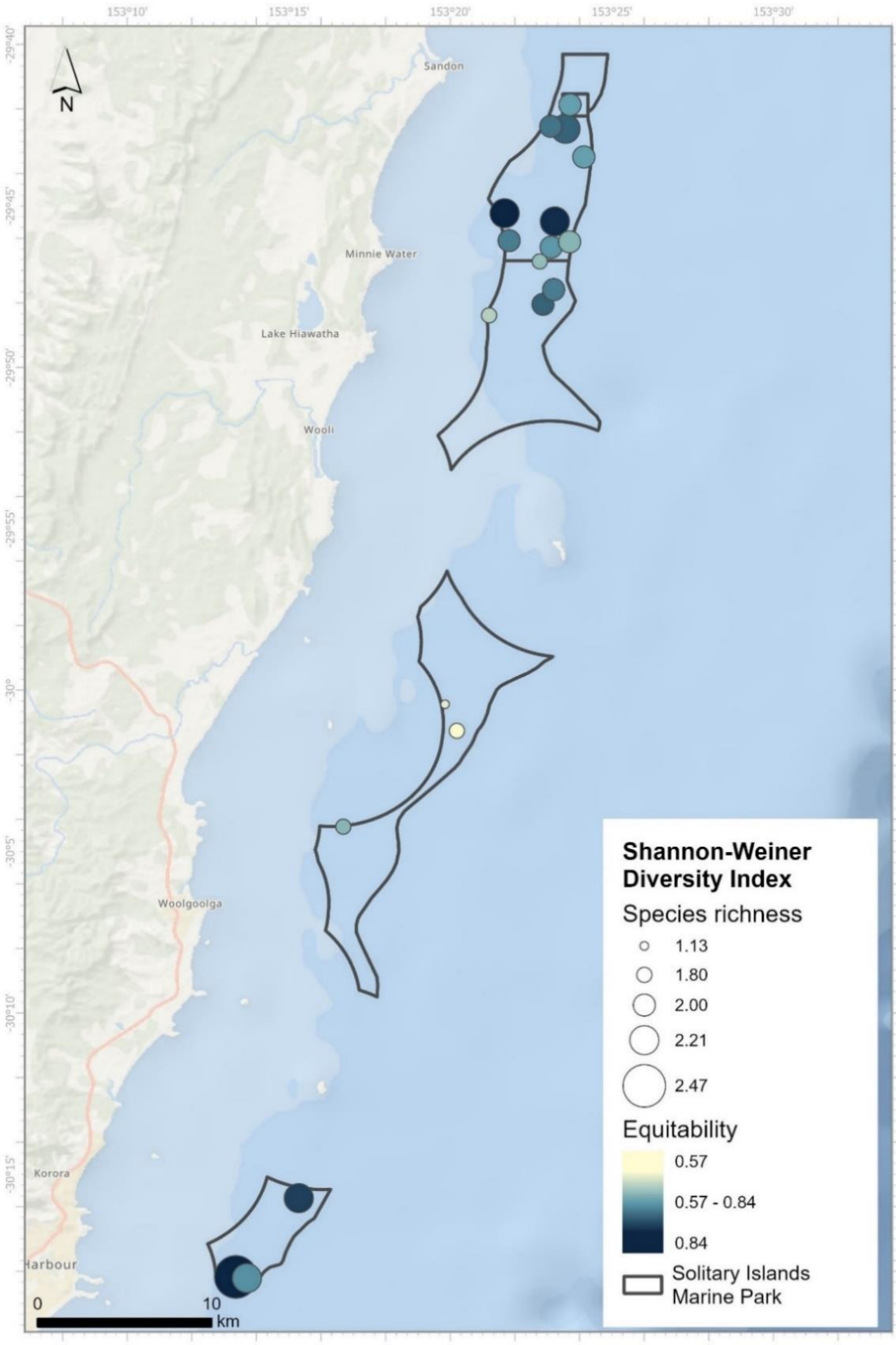


Figure 3.23 Map of Shannon Diversity Index based on mid-tier annotations for the Solitary Islands Marine Park towed-video surveys 2023

A range of mobile species were observed in imagery across the park during this survey and were annotated to the highest resolution available from within the AMC listings. All but the morphotype label 'fish' were included in the diversity for mid-tier classification but were excluded from the Top-10 (sessile benthic only). Mobile species included fish (bony fishes, elasmobranchs – rays and skates), echinoderms (feather stars/crinoids, sea stars, sand dollars, ophiuroids – brittle & basket stars, pencil urchins) and molluscs (nudibranchs). A summary of fish genus and/or species identified surveys are presented in Table 3.5.

Table 3.5 Genus and/or species and common names for fish observed and annotated within still imagery over reef and soft sediment areas from the Solitary Islands Marine Park 2023

Scientific name	Common name
Atypichthys strigatus	Australian Mado
Anoplocapros inermis	Eastern Smooth Boxfish
Chelmonops truncatus	Eastern Talma
Enoplosus armatus	Old Wife
Eubalichthys bucephalus	Black Reef Leatherjacket
Gymnothorax prasinus	Green Moray
Hypoplectrodes maccullochi	Halfbanded Seaperch
Mecaenichthys immaculatus	Immaculate Damselfish
Parapercis sp.	Grubfish sp.
Parma microlepis	White-ear
Parupeneus spilurus	Blacksaddle Goatfish
Playtcephalus sp.	Flathead sp.
Pleuronectiformes sp.	Flounder sp.
Scorpaena jacksoniensis	Eastern Red Scorpionfish
Synodus sp.	Lizardfish sp.
Trachurus novaezelandiae	Yellowtail Scad
Triglidae sp.	Gurnard sp.
Trygonoptera testacea	Common Stingaree
Upeneichthys lineatus	Blue-lined Goatfish

Despite the occurrence of mesophotic rocky reefs across the park, the smoother seabed between reef platforms and islands are sedimentary plains and were the focus of the sediment sampling campaign (see Figure 3.25; Figure 3.28; Figure 3.31). A total of 46 sediment samples were collected and 52 towed video transects with 13,759 images of the seabed obtained and available for analysis for this study.

For the sediments, samples ranged from coarse and poorly sorted fine gravel dominated sediments (grainsize of ~2200 µm), to coarse shelly sands (~1150-520 µm) to fine-grained sands (<200 µm fraction). Carbonates ranged from 8.5% within the medium to fine grained samples (often forming part of sedimentary plains, or depositional landforms), to 80% in samples that were taken from rocky reefs, or those near a reef feature. Organic matter content did not appear to vary with any clear relationship or variable, however, and similar to carbonate content, it tended to be higher in samples closer to rocky reef features.

The sediment samples collected as part of this study reflect typical units of the NSW shoreface; primarily:

a) Outer nearshore (<30 to 40 m): thin layers of finer sands (outer edges of this unit).

b) Inner Shelf: coarse ravinement sands (in many places with high carbonate content).

c) Inner to mid Shelf (>50 m): muddy sands (often dark grey in colour), and abundant in fauna of foraminifera, polychaetes and bivalves.

Northern Section

The largest number of transects (n= 13), reef-dominated images and reef-focused annotations occurred in the northern section of the park. Diversity values were variable and both the highest and lowest values were observed across ‘northern’ transects. For density, three northern transects (20231126 T005, T013, T015), captured some of the highest values for Porifera, Cnidaria and/or Bryzoa in the whole park. These were spread across the north and not clustered to one sub-area. Morphospecies for these transects were generally dominated by massive, encrusting (creeping fat white) and erect sponges, branching 3D (orange bushy; gorgonian pink – *Pteronisis* like) black/octocorals and a solitary coral (Orange *Caryophyllia*-like).

Generally, for sediment dominated transects in the south here (T019-021: 20241126), the absence of mobile sand features confirmed the planar nature of the area. Occasionally, purple banded crinoids and sparse medium sized burrows (2-5 cm diameter) were present. The sediment appeared to be consistently fine sands with some minor shell fragments (<10%). T006 and T007 (both 20231114) east of the main reefs in the north were similar but also showed evidence of a matrix of epifauna/infauna with burrows and tracks from mobile fauna also common. Between reefs at T008 (20231114) sediments were coarse sands but regularly pockmarked with >10-20 burrows (~1 cm) within many images. Imagery from a single transect (T001: 20231114) north of Pimpernel Rock indicated a seabed of coarse sand with greater percentage of shelly material and flathead (*Playtcephalus sp.*) were observed across 20-30 images. Mobile sediment features were not observed within the field of view.

The backscatter intensity signal had abrupt changes within the sedimentary plains of the northern section of the SIMP, which is also reflected in the results of the sediment samples (Figure 3.25). Table 3.6 summarises key variations in surficial grab samples, particularly what depth they were taken at, and key sedimentological characteristics. The most northern portion of this section has clear sand ridge landforms, that alternate with high (i.e., dark colour in Figure 3.25 mosaic) and low (i.e., lighter colours) backscatter intensity returns (Figure 3.26). The sand ridges have shorter wavelengths than others found in the park, and the low intensity returns correlate with much finer muddy sands of the inner-mid shelf unit (~187-223 µm, often occurring in water depths of >50 m). They comprise a dark grey, fine to very fine sand plus muds (e.g. SAN001, 015, 016, 018, 019), that is non-iron stained, and the carbonate (shell) content ($CaCO_3$) is typically lower in this unit than other sediment of the inner shelf (see Section 1.1.4) (Table 3.6; Fig. 3.26). The coarser material (with higher intensity returns; ~ 2159 µm) that appears, to overlie it, is likely inner shelf sand. This sand unit occupies the gently sloping inner shelf (as the name suggests), are orange-brown in colour, composed of quartzose material, and are medium to coarse grained reaching gravel-sized in some places (e.g. SAN005). This unit is also generally poorly sorted, and carbonate content is variable in this part of the SIMP, but tends to increase with proximity to rocky reef outcrops (Figure 3.25 and Figure 3.26).

The central part of this northern section of the SIMP is dominated by a rocky reef outcrop, and sediment samples taken around this landform all seems to be coarse grained sands of the inner shelf (~743-1149 µm, e.g., SAN007; 008; 010; 014) and have a high carbonate content (Table 3.6., Figure 3.26).

The southern part of this section is relatively featureless, and is dominated by lower intensity sonar returns, representing the fine muddy sands of the gently sloping inner-mid shelf unit (e.g. SAN018), or a shelf sand body (SAN019?). The abundance of these fine sands, and lack of sedimentary features also indicates a lower energy depositional environment.

Table 3.6 Summary of sediment grain-size and carbonate content (loss of ignition; LOI) analysis results for (selected) grab samples retrieved from the Northern section of the SIMP (Figure 3-25). Note. **Bold** ID labels are pictured in Figure 3.25

ID	Elevation (m)	Mean (µm)	Sorting	Skewness	Kurtosis	Organic (%)	CaCO3 (%)
SAN001	**-44.2**	**Fine sand (223.0)**	**Mod. sorted (1.746)**	**Symmetrical (0.087)**	**Mesokurtic (0.957)**	**2.81**	**34.41**
SAN005	**-47.6**	**V. fine gravel (2158.7)**	**Poorly sorted (2.463)**	**Fine skew (-0.201)**	**V. Leptokurtic (1.590)**	**6.71**	**73.80**
SAN006	-44.7	Fine sand (186.6)	Mod. well sort (1.551)	Symmetrical (0.041)	Mesokurtic (0.959)	2.28	27.11
SAN007	-51.3	V. coarse sand (1066.6)	Poorly sorted (2.073)	Symmetrical (-0.065)	Leptokurtic (1.334)	6.41	68.11
SAN008	-47.2	Coarse sand (742.7)	Mod. sorted (1.958)	Coarse skew (0.107)	Leptokurtic (1.164)	3.87	66.43
SAN010	-36.9	Coarse sand (887.6)	Mod. sorted (1.643)	Symmetrical (0.065)	V. Leptokurtic (1.637)	2.58	45.13
SAN011	-36.6	V. coarse sand (1149.3)	Poorly sorted (2.936)	Symmetrical (0.043)	Mesokurtic (1.033)	2.96	67.90
SAN013	-40.9	Fine sand (192.3)	Mod. well sorted (1.456)	Symmetrical (0.028)	Mesokurtic (0.951)	1.43	21.71
SAN014	**-46.1**	**V. coarse sand (1107.1)**	**Mod. sorted (1.841)**	**Symmetrical (-0.098)**	**Leptokurtic (1.112)**	**4.92**	**70.35**
SAN015	-53.3	Fine sand (195.8)	Mod. sorted (1.794)	Coarse skew (0.108)	Mesokurtic (1.036)	2.10	22.87
SAN016	-54.5	Fine sand (173.2)	Mod. sorted (1.806)	Coarse skew (0.101)	Mesokurtic (1.038)	2.24	25.20
SAN018	-45.0	Fine sand (173.2)	Mod. well sorted (1.539)	Symmetrical (0.041)	Mesokurtic (0.972)	1.53	14.21
SAN019	-42.7	Medium sand (279.3)	Well sorted (1.382)	Symmetrical (0.006)	Mesokurtic (0.959)	0.45	8.47

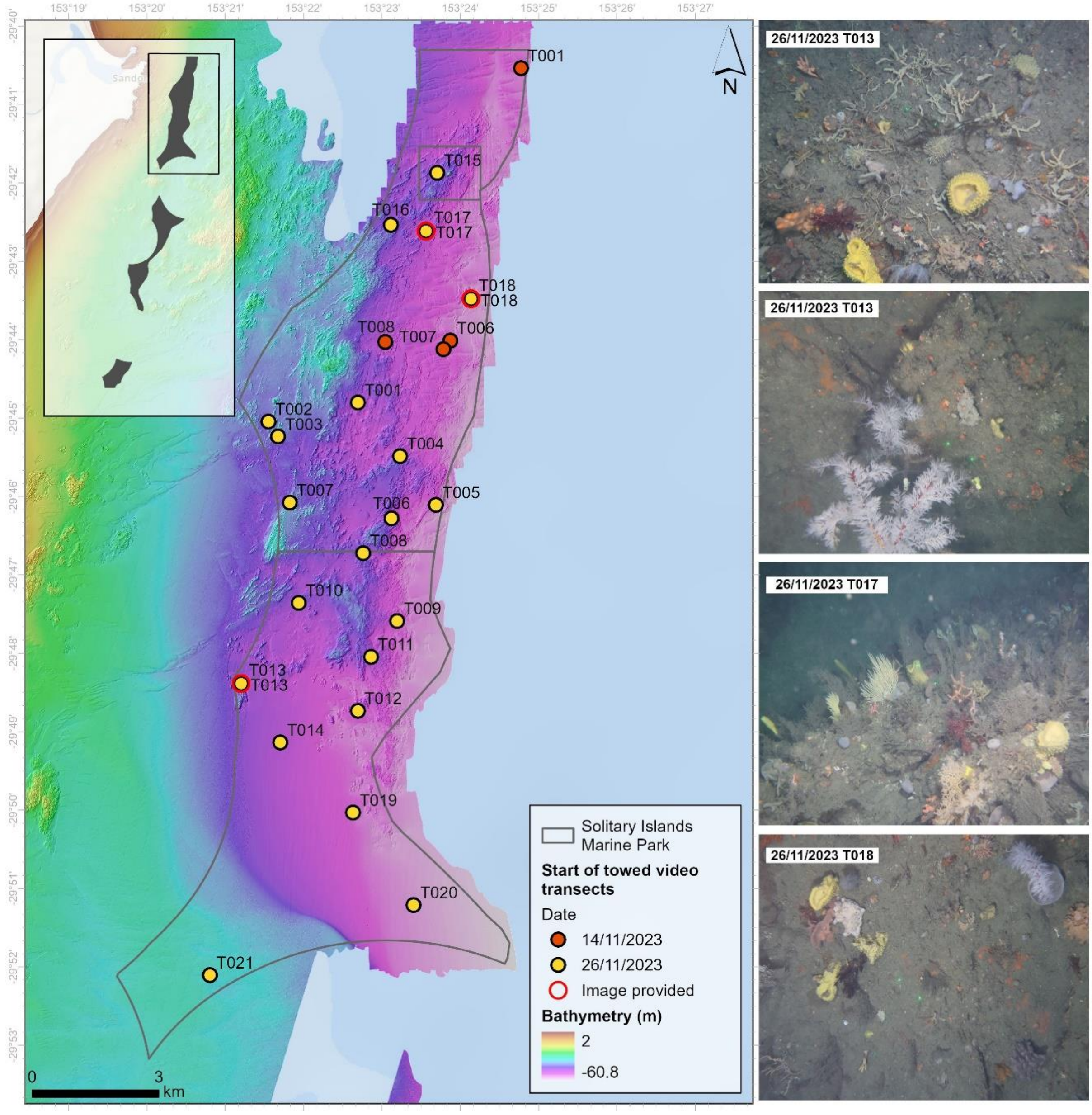


Figure 3.24 Bathymetry with towed video sites (start points) and examples of benthic organisms captured in towed video imagery across the northern section, Solitary Islands Marine Park (Commonwealth waters).

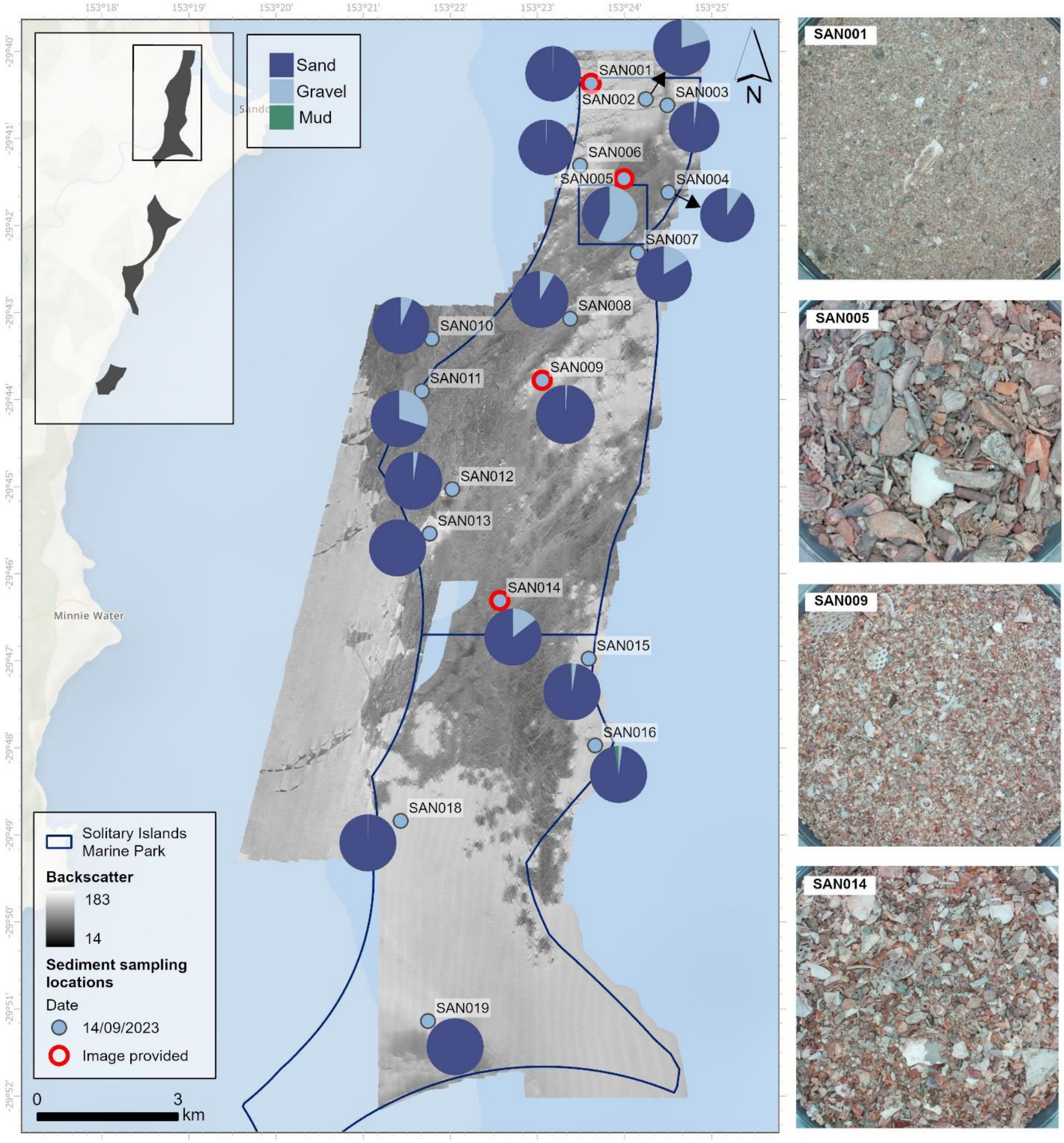


Figure 3.25 Backscatter mosaic, sediment sample locations and images of collected across the northern section, Solitary Islands Marine Park (Commonwealth waters).

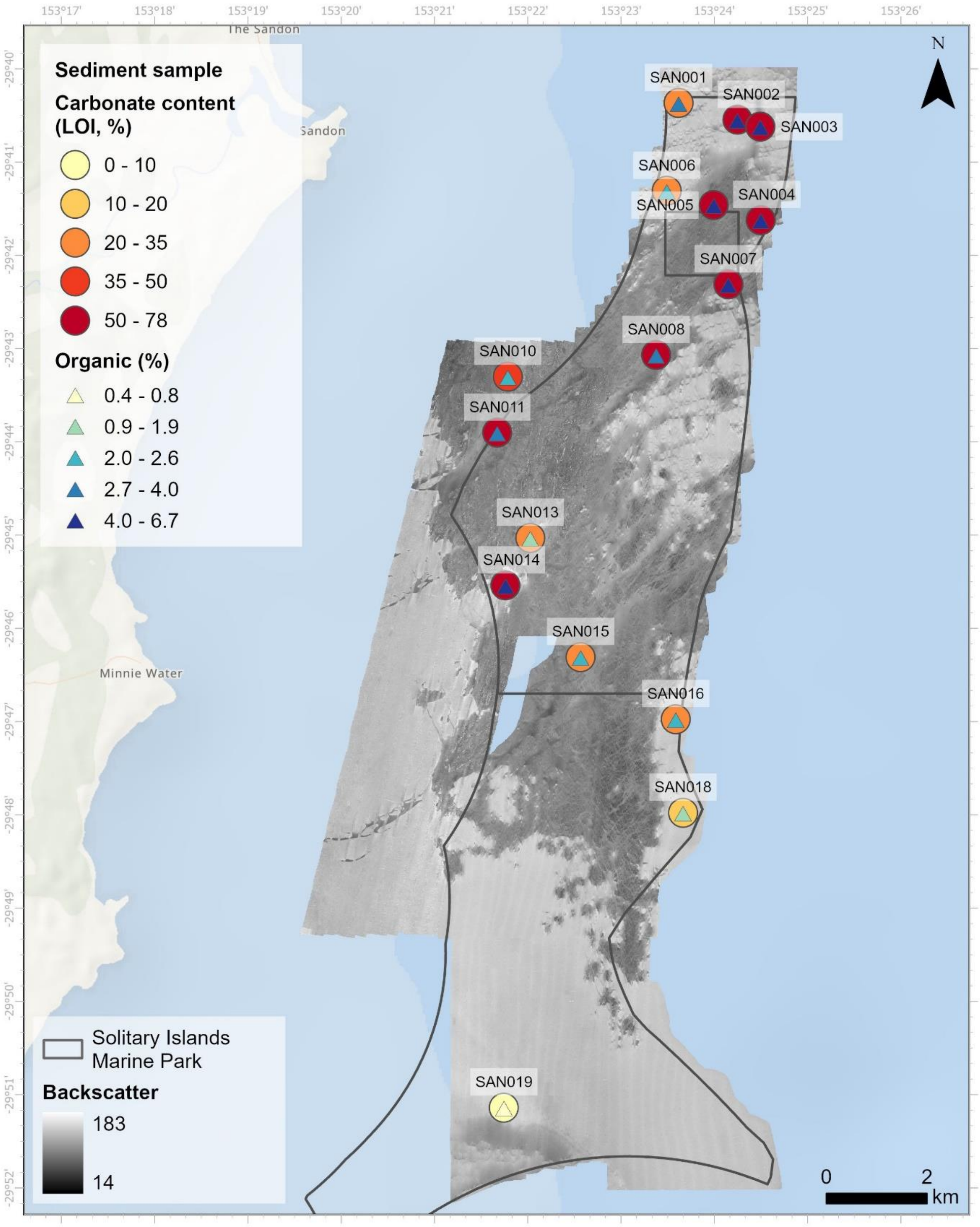


Figure 3.26 Backscatter mosaic with sediment sample relative percentage of sample carbonate and organic matter content (dry weight) for the northern section, Solitary Islands Marine Park (Commonwealth waters).

Central Section

Average diversity and density values derived for the 3 transects T003 (20231123), T007 and T009 (20231124) from reef-dominated images were generally in the low end of values for the park). Dominant morphospecies identified in images for these transects included crusts (Encrusting Dark Red, Encrusting Purple Lumpy), massive and erect sponges, a bryozoan (Soft Dark Red) and calcareous red algae. A solitary coral (*Caryophyllia*-like) dominated counts for transect 007 (20231124).

Towed video imagery for 13 of the 17 available transects captured were predominantly over areas of unconsolidated sediments for the central section of the park. In the north the transects captured images across several of the mobile sediment features characteristic in this area. At T004 (20231116) the start of the transect (north) indicates very coarse sands with whole and fragmented shells concentrated in the troughs of sand waves (~2D) with wavelengths in the order of 10s of cm to a metre. The southern end of the transect gives way to more uniform and medium to coarse sands with minor shell fragments sand waves (3D) with wavelengths of less than 10-15 cm. The occasional flathead, crinoids and sand dollars were observed in the imagery. Variation in sediment characteristics were also observed for other transects and consistent with transects of generally dark (T002: 20231124) and softer/lighter (T001-002: 20231116) backscatter.

The variability in the unconsolidated seabed around T006, T008 and 010 (20231124), however, differed from those to the north according to the backscatter textures and the imagery. Generally, sediments here appear to be coarse sands with poorly sorted fragmented shells with no sand waves were observable within the field of view. Crinoids and pencil urchins were present in several images. In the uniform planar areas further south (T001: 20231123; T001: 20231124; T007; 20231116) sand waves are absent. Burrows are relatively common, are irregular in frequency, shape and size (2-3 cm to 10 x 40 cm) and vary from rounded holes to deep scars and furrows from larger mobile animals (i.e. rays, skates, fish). Crinoids and brittle stars (ophiuroid) occurred rarely, but a single species of sea star (genus?) reoccurred observed across ~15-20 images across these 3 transects. The sediments themselves appear reasonably consistently poorly sorted (variable grain size) fine to medium grained sand with minor (< 10%) variably sized shell fragments. A matrix of epifauna/infauna is observable in some images captured in closer proximity to the seabed.

The backscatter intensity signal, varied both gradually (southern) and abruptly (northern half) within the sedimentary plains of the central section of the SIMP, which is also reflected in the results of the sediment grab samples (Figure 3.28 and Figure 3.29). Table 3.7 summarises key variations in surficial grab samples, particularly what depth they were taken at, and key sedimentological characteristics. In the northern half of this section, median grain size alternates from very fine gravel (2067 µm) to fine sand (245.7 µm), which the latter, appears to be sand from the lower shoreface (outer nearshore, see Figure 1.10). These sands are olive grey, fine grained and well sorted (e.g., WLI008, 009), with shell content like those sediments found on the upper shoreface (i.e. surf zone, closer to shore). Despite winnowing wave turbulence at these depths, grain size usually shows little variation with increasing depth (i.e., WLI008, 009 in Figure 3.28). The coarser materials underlying the finer sands are most likely inner shelf sediments, that are coarse to fine gravel in grain size. This unit is generally poorly sorted, and carbonate (shell) content is again variable in this part of the SIMP (Figure 3.29). Sand ridges are typical bedforms of lower shoreface sands (Roy and Stephens, 1980), and dominate the northern half of this section. A large dark band bisects the NW part of this park section within the backscatter mosaic (Figure 3.28), which grades in high intensity seaward. The sediment grab samples reveal that this band is composed of course to very coarse sands (927-1040 µm) (i.e., WLI010, 011; Table 3.7), that are quite high in carbonate content (Figure 3.29), and also seem to identify as the coarse inner shelf sediments.

Moving to deeper water depths (i.e. central areas) of this section, (Figure 3.27), the sand ridges decrease in wavelength, and the lower (lighter) intensity backscatter returns correlate with much finer muddy sands of the inner-mid shelf unit (occurring in water depths of >50 m). Like in the northern section, this unit is dark grey in colour, fine to very fine sand plus muds (e.g., WLI014, 015, 016), that is non-iron stained. The coarser material (with higher backscatter intensity), overlying this fine muddy sand, is most likely inner shelf sands, as described above. The southern half of this section is featureless, and dominated by lower backscatter intensity returns, again representing the finer muddy sands of the gently sloping inner-mid shelf unit.

Table 3.7 Summary of sediment grain-size and carbonate content (loss of ignition; LOI) analysis results for (selected) grab samples retrieved from the Central section of the SIMP. Note. **Bold** ID labels are pictured in Figure 3.27

ID	**Elevation** (m)	**Mean** (µm)	**Sorting**	**Skewness**	**Kurtosis**	**Organic (%)**	**CaCO3 (%)**
WLI007	**-39.2**	**V. fine gravel (2066.5)**	**Poorly sorted (2.878)**	**Symmetrical (-0.081)**	**Leptokurtic (1.204)**	**3.19**	**40.52**
WLI008	-35.2	Medium sand (256.4)	Well sorted (1.387)	Symmetrical (0.012)	Mesokurtic (0.968)	0.38	8.60
WLI009	-40.6	Fine sand (245.7)	Well sorted (1.387)	Symmetrical (0.013)	Mesokurtic (0.959)	0.52	10.10
WLI010	**-45.3**	**Coarse sand (927.0)**	**Poorly sorted (2.399)**	**Coarse skew (0.171)**	**Leptokurtic (1.230)**	**2.96**	**51.03**
WLI011	-41.3	V. coarse sand (1039.6)	Poorly sorted (2.142)	Coarse skew (0.239)	Leptokurtic (1.122)	2.80	42.20
WLI013	-50.8	V. coarse sand (1039.6)	Poorly sorted (2.813)	Fine skew (-0.110)	Mesokurtic (0.946)	3.45	53.25
WLI015	**-58.0**	**Fine sand (249.7)**	**Poorly sorted (3.499)**	**Fine skew (-0.107)**	**Leptokurtic (1.406)**	**1.86**	**17.68**
WLI016	-57.4	Fine sand (211.5)	Mod. sorted (1.900)	Symmetrical (-0.070)	Mesokurtic (1.060)	2.96	20.12
WLI017	-52.4	Medium sand (414.9)	Mod. sorted (1.680)	Coarse skew (0.152)	Leptokurtic (1.406)	1.13	20.18
WLI018	-54.8	Fine sand (213.0)	Mod. sorted (1.883)	Symmetrical (-0.027)	Mesokurtic (1.032)	1.72	16.58
WLI019	-54.1	Coarse sand (517.4)	Mod. sorted (1.632)	Coarse skew (0.112)	Leptokurtic (1.201)	1.69	25.29
WLI020	**-47.1**	**Coarse sand (963.1)**	**Poorly sorted (3.108)**	**Coarse skew (0.247)**	**Leptokurtic (1.401)**	**3.95**	**65.07**
WLI001	**-47.4**	**Fine sand (187.7)**	**Mod. well sorted (1.544)**	**Symmetrical (0.071)**	**Mesokurtic (1.000)**	**2.09**	**15.94**
WLI002	-53.5	Fine sand (174.2)	Mod. sorted (1.955)	Coarse skew (0.208)	V. Leptokurtic (1.546)	2.25	22.97

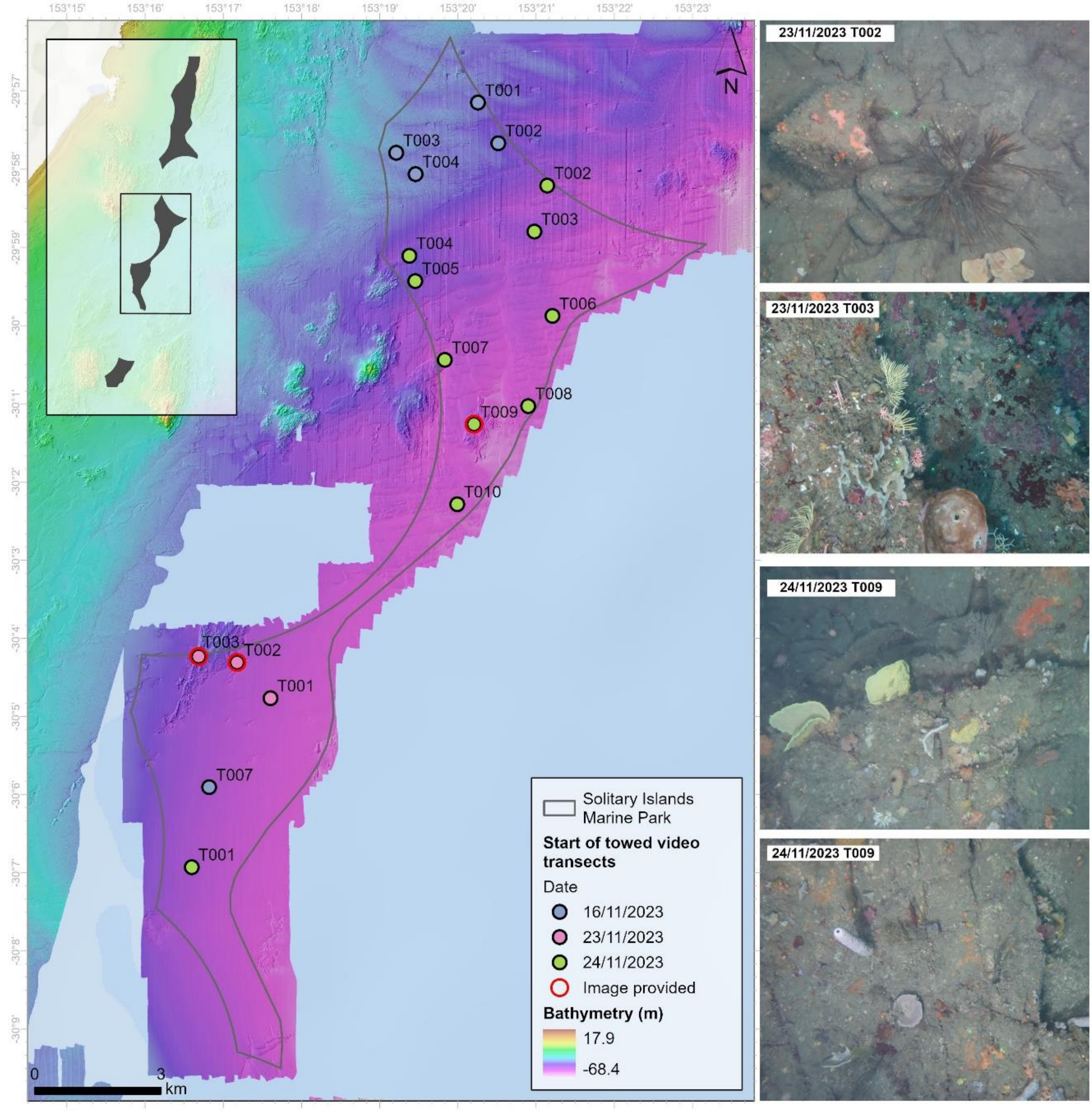


Figure 3.27 Bathymetry and towed video sites (start points) and examples of benthic organisms captured in towed video imagery, central section, Solitary Islands Marine Park (Commonwealth waters).

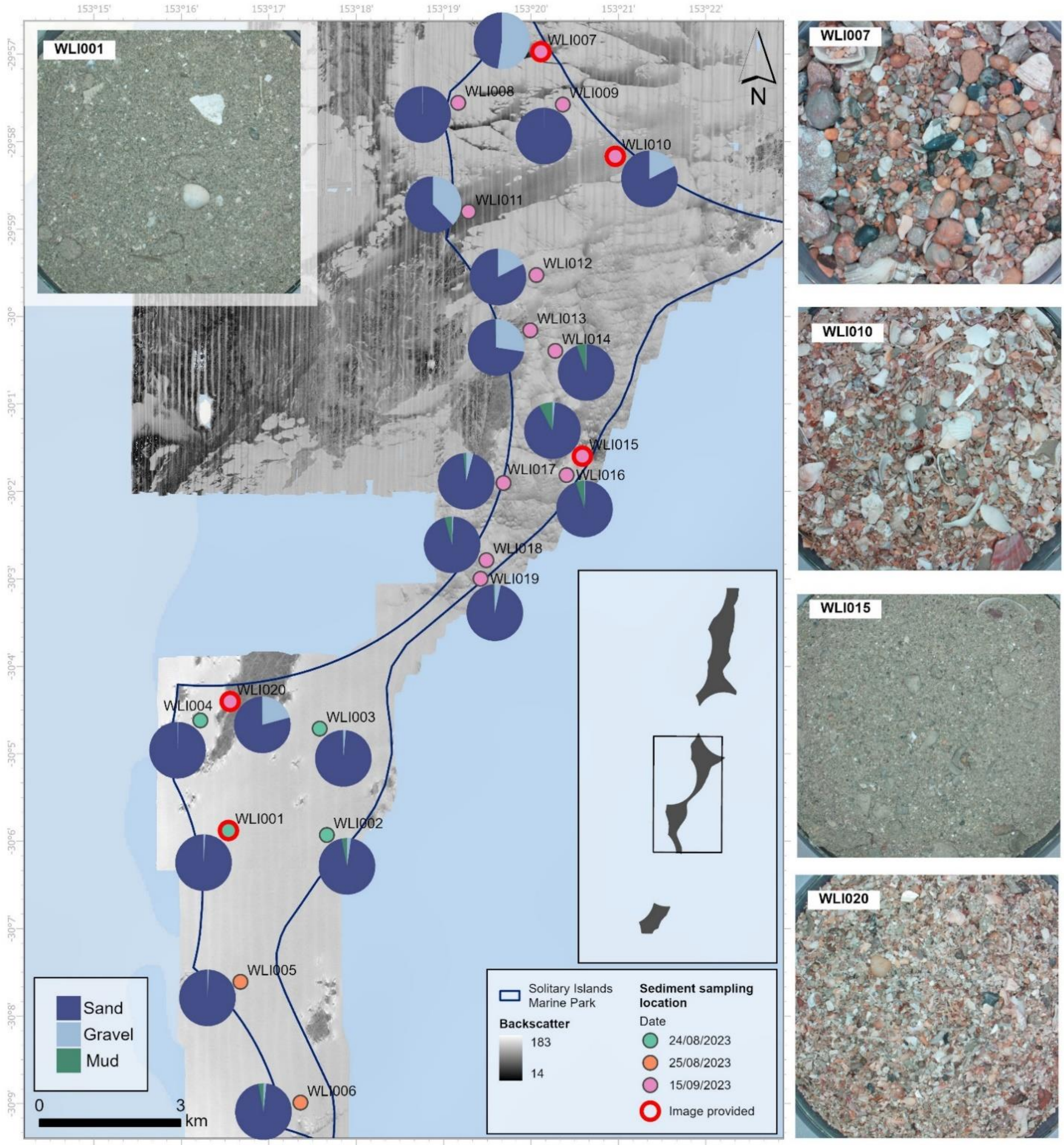


Figure 3.28 Backscatter mosaic, sediment sampling sites and images of samples collected across the central section, Solitary Islands Marine Park (Commonwealth waters).

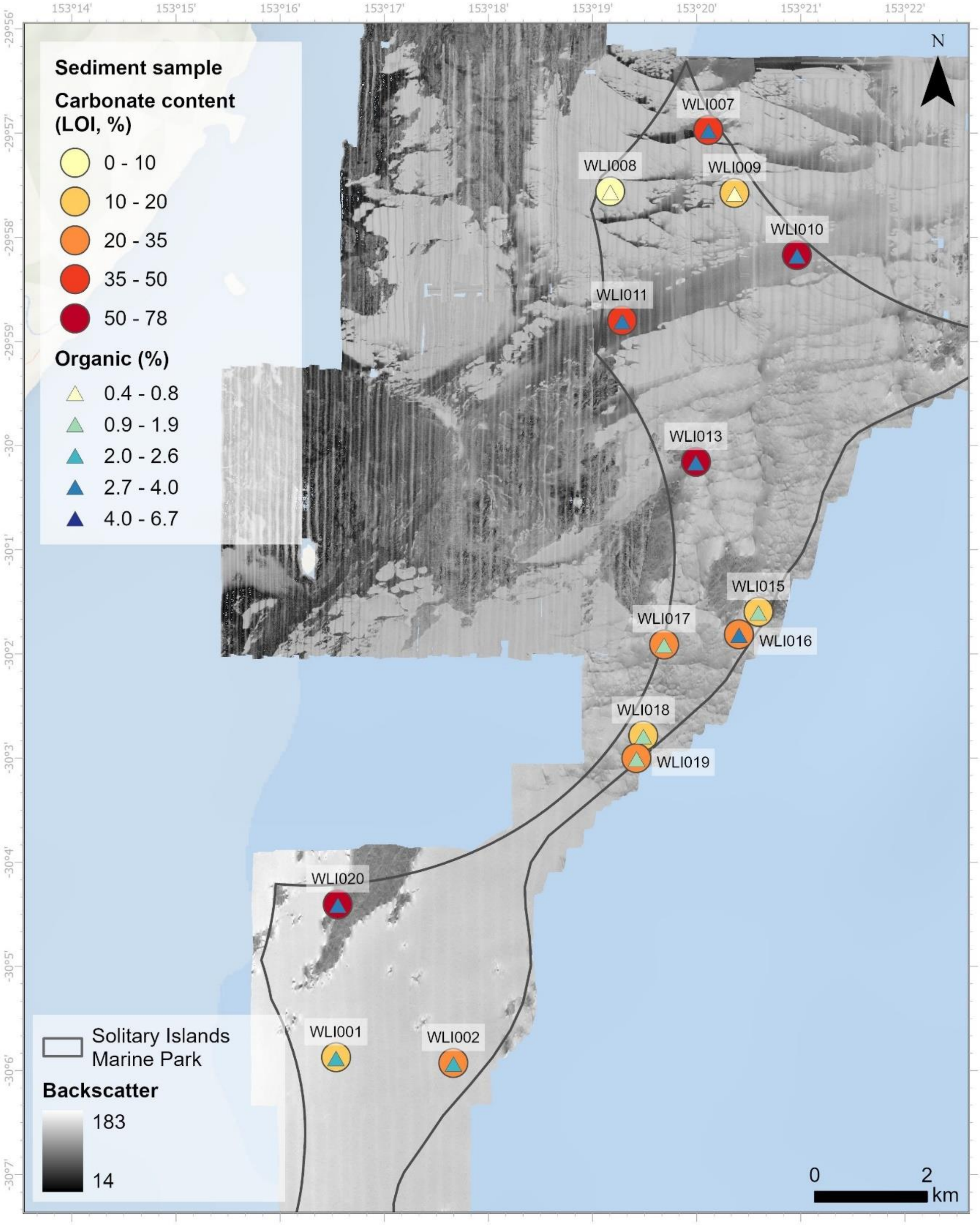


Figure 3.29 Backscatter mosaic with sediment sample relative percentage of sample carbonate and organic matter content (dry weight) for the central section, Solitary Islands Marine Park (Commonwealth waters).

Southern Section

A total of 3 transects T007, T022 and T023 captured 127, 159 and 228 reef dominated images, respectively. Reef appeared as relatively low-profile and patchy with massive, encrusting, encrusting orange an erect form sponges, hydroids, calcareous red algae and branching 3D black/octocorals the most common morphospecies observed. Diversity ranged from 2.8-3.1 for Top-10 and 2.1-2.5 for mid-tier which was in-line with the higher end of values for the entire park. Density was also generally high when compared to values for the rest of the park.

Towed video transects over soft sediment in the south of the park (n= 9; 3219 images) were predominantly distributed over planar areas some of which captured the variability between relatively lighter (weaker signal returns) and darker (stronger returns) backscatter indicated within the mosaics (Figure 3.31). Images from T002, T005 and T006 (20231107) over low return backscatter indicate generally medium sized sand habitats with no obvious sand wave features. The sediment appears to contain minor to rare levels of fragmented shells, commonly with either regular sized rounded burrows (<1 cm) or aggregations/matrix of surficial epifauna/infauna. The sediment in T002 (20231107) is of coarser material with a relatively higher fraction of shelly materials. Small and rounded burrows (<1 cm) are reasonably common. Some ripples or sand waves are present in these areas indicated by linear aggregations of whole and fragmented shells. The wavelengths of these ripples are in the order of 50-60 cm.

Table 3.8 Summary of sediment grain-size and carbonate content (loss of ignition; LOI) analysis results for (selected) grab samples retrieved from the northern section of the SIMP (Figure 3-22)

ID	Elevation (m)	Mean (µm)	Sorting	Skewness	Kurtosis	Organic (%)	CaCO3 (%)
COF001	-53.1	Fine sand (186.5)	Mod. well sorted (1.55)	Symmetrical (-0.041)	Mesokurtic (1.085)	2.26	19.92
COF002	**-44.9**	**Fine sand (222.6)**	**Mod. well sorted (1.433)**	**Symmetrical (0.032)**	**Mesokurtic (0.972)**	**0.81**	**12.12**
COF003	**-44.1**	**Coarse sand (836.8)**	**Poorly sorted (2.724)**	**V. coarse skew (0.353)**	**V. Leptokurtic (1.841)**	**1.64**	**35.67**
COF004	-47.2	Coarse sand (631.5)	Mod. sorted (2.000)	Symmetrical (-0.024)	Leptokurtic (1.230)	1.82	38.32
COF005	**-55.8**	**Coarse sand (698.5)**	**Mod. sorted (2.000)**	**Fine skew (-0.224)**	**V. Leptokurtic (1.577)**	**5.27**	**57.68**
COF006	-48.1	Fine sand (221.1)	Mod. well sorted (1.601)	Symmetrical (-0.011)	Mesokurtic (1.026)	2.08	18.88
COF007	-51.6	V. coarse sand (1082.5)	Poorly sorted (2.521)	Fine skew (-0.206)	Mesokurtic (1.085)	4.99	68.49
COF008	**-39.0**	**V. coarse sand (1602.8)**	**Poorly sorted (3.953)**	**Fine skew (-0.146)**	**Mesokurtic (1.044)**	**1.37**	**25.87**

The backscatter (intensity signal) also varied both gradually and abruptly within the sedimentary plains of the southern section of the SIMP, and this correlated well with changes in sediment texture and composition, as revealed by the grab samples (Figure 3.31). Table 3.8 summarises the variations in surficial grab samples, particularly what depth they were taken at, and key sedimentological characteristics.

Median grain size alternates from very coarse/ coarse (1603-632 µm) to fine sand (223-187 µm), moving NE through the sand ridge plain. It is clear in Figure 3.31, that the higher (i.e., darker grey colour in mosaic) intensity backscatter return layers are slightly deeper than the lower intensity (lighter) material suggesting that the coarser fractions overly it. For example, course inner shelf sands are overlaying the finer inner-mid shelf muddy sands, allowing the sand ridge landforms to develop. Similar to the Northern, and Central sections of the park, the inner shelf sands are orange-brown in colour, composed of quartzose, and are coarse to very coarse grained and in places, gravel size (Table 3.8). This unit is poorly (to moderately) sorted, and carbonate (shell) content is variable, but typically increases within the inner-shelf sand unit, and proximity to rocky reef outcrops (Figure 3.32). The NE portion of this part of the park, and the lower intensity backscatter returns correlate with much finer muddy sands of the inner-mid shelf unit and are occurring in water depths of 45 to >50 m (e.g. COF001, 002, 006). Like other areas of the SIMP, this unit is non-iron stained, and carbonate content is slight lower than other sediments on the inner shelf. The abundance of fine sand in this unit also indicates a lower energy depositional environment.

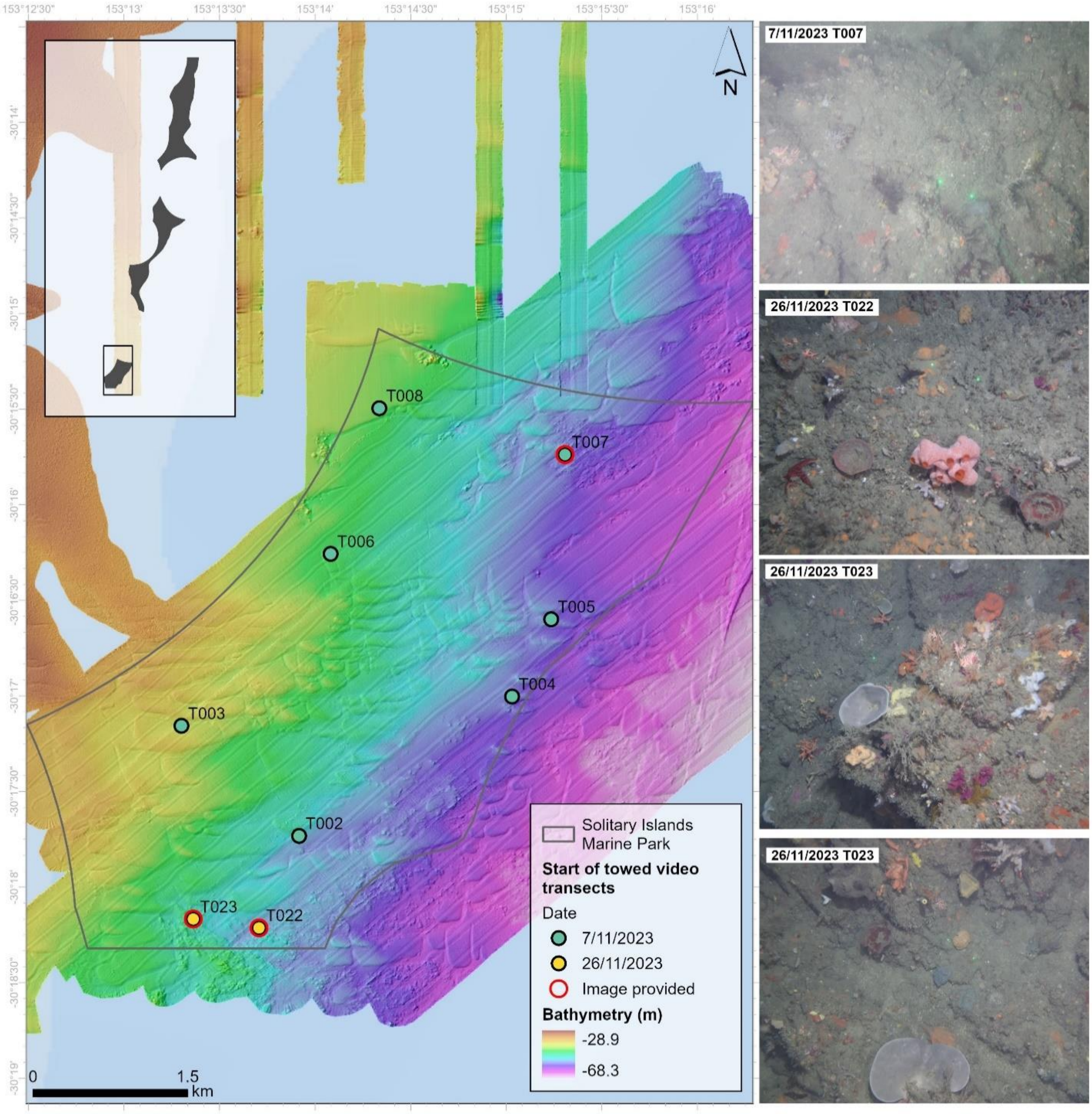


Figure 3.30 Examples of seabed imagery and benthic organisms from towed video transects across block A and earlier 2012 survey area, southern section, Solitary Islands Marine Park (Commonwealth waters).

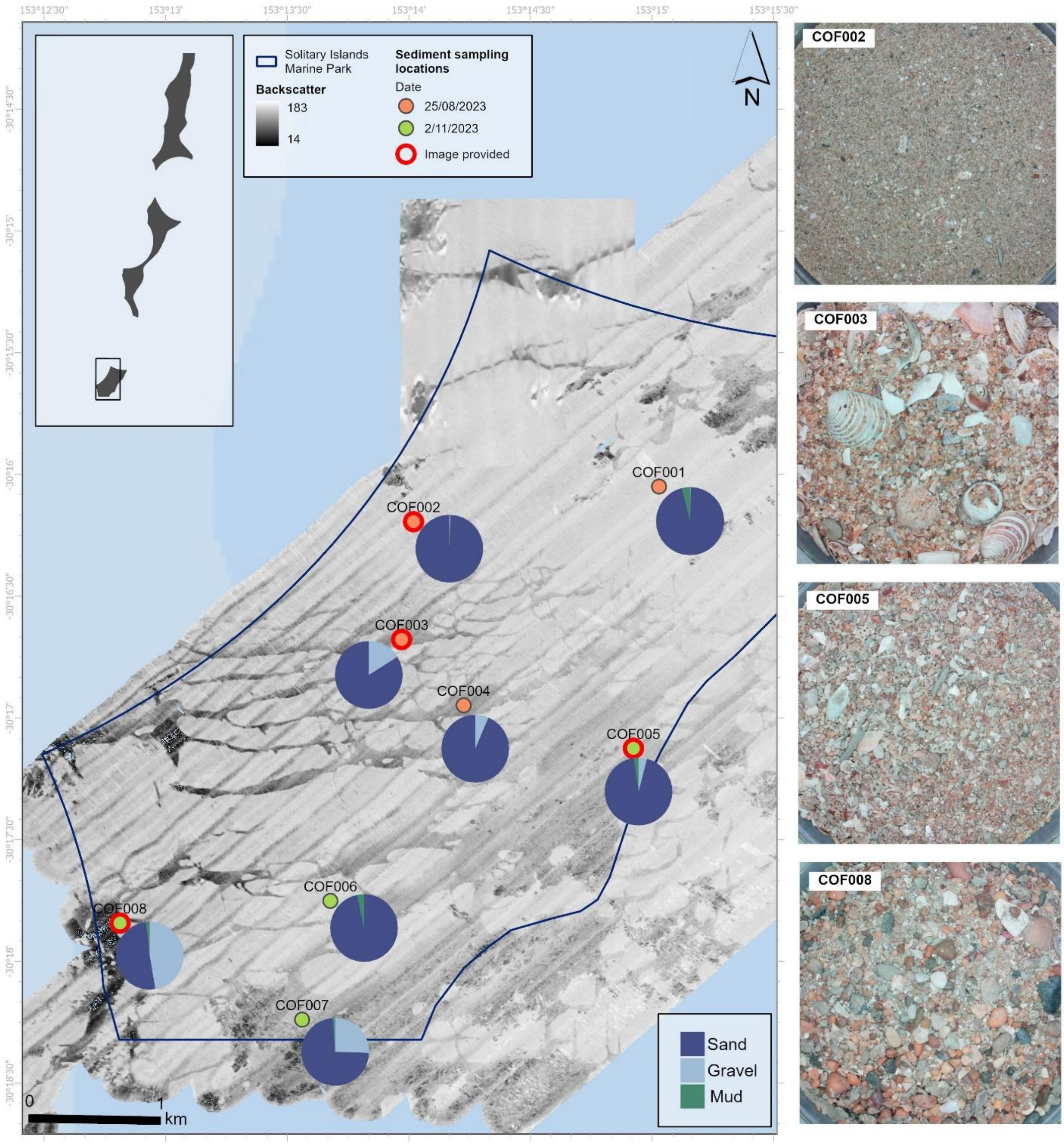


Figure 3.31 Backscatter mosaic, sediment sample locations and images from across block A and earlier 2012 survey areas for the southern section, Solitary Islands Marine Park (Commonwealth waters).

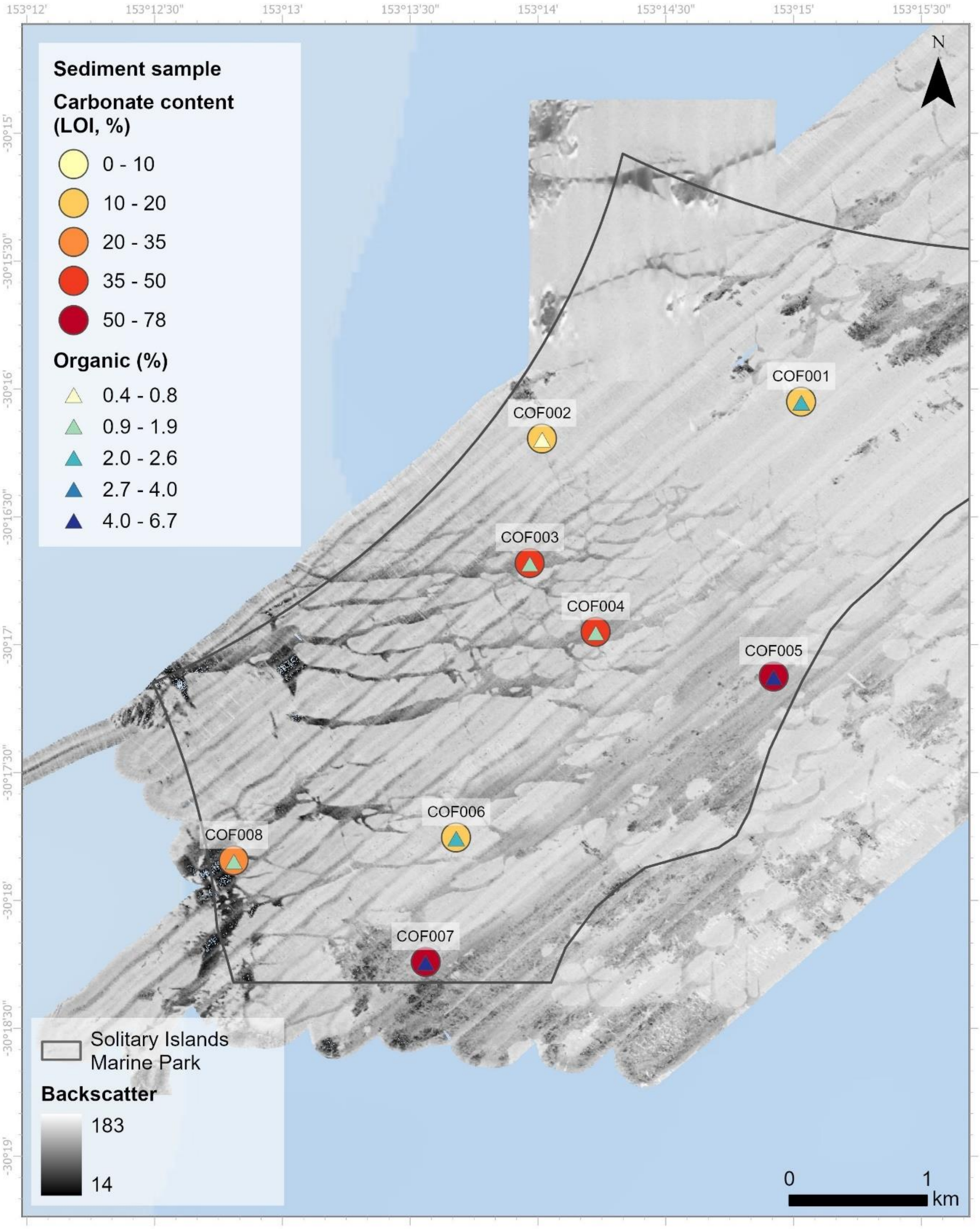


Figure 3.32 Backscatter mosaic with sediment sample relative percentage of sample carbonate and organic matter content (dry weight) for the southern section, Solitary Islands Marine Park (Commonwealth waters).

4. DISCUSSION AND RECOMMENDATIONS

4.1 Regional to national context

This project has completed the benthic mapping of the SIMP (Commonwealth waters) to 100% through MBES, imagery and sediment sampling surveys. Although the shelf along the eastern seaboard is relatively narrow (~35-50 km) and the area contained within the park is small, the nation's largest population lies along this section of coast and there is the potential for significant anthropogenic pressures (pollution, shipping, development, fishing) to be placed upon the ecological communities that live here. In addition, the marine environment is also exposed to the effects of a strengthening and warming EAC, driving ecosystem changes, the disappearance of some species and the shifts of others further south. These new datasets provide a baseline for the SIMP that can now be used manage the parks assets more effectively and monitor changes into the future.

4.1.1 Seabed mapping and inner continental shelf habitats

With the completion of these current surveys, baseline benthic habitat, substrate and community data are now available across the full 152 km^2 of the SIMP (Commonwealth waters). Surveys identified new seabed features from small pinnacles (or peaks) and previously unmapped reefs to sand ridges and large sandy plains. This work has also delivered an expanded number of classes through sub-division of hard and soft substrates to detail the distribution of a wider range of seabed habitat types. The MBES data certainly identified reef and soft sediment features that extend across park boundaries to the west and east in the northern section of the park.

Previous mapping in the southern section in 2012 identified features that may not yet be captured within marine protected areas at local or regional scales, i.e., relic coastlines, and currently have limited protection under a marine reserve management approach. For example, in the regions approximately 5 km southeast of North Solitary Island, and 11 km due east of Split Solitary Island (or 4.5 km southeast of South Solitary Island), a series of narrow (20-80 m each) elongated reefs form a single near-continuous feature ~ 6 km (off the northern section), and ~ 11 km long and between 2-3 m high off the southern section of the SIMP (Figure 3.13; Figure 3.30). These reefs are of a consistent depth (~65-75 m), lie parallel to the general orientation of the coast, and likely to also be relic coastline. These features are more prominent and conspicuous when observing in the hill-shaded bathymetry, backscatter (high relative reflectivity), derived slope and terrain ruggedness layers. These relic coastline features are expected to have been formed thousands of years ago when sea level was much lower than today (Nichol et al. 2016).

Additional pinnacle reef features and/or other relatively high-profile reefs in the northern section and adjacent to Pimpernel Rock were mapped in high-resolution by these new surveys. Kline et al (2020) who used passive acoustics to understand vessel activity around Pimpernel Rock identified this feature as a popular fishing location collectively known as Banana Rock. None of the imagery captured as part of this study, or previously captured imagery available on SeaMap Australia has been collected over these newly mapped features. Only one transect T015 (20231126) was situated in close proximity and to the west of Pimpernel Rock and within the National Park Zone. A video tow obtained by the Ecology Lab (2006) along transect L4DPT1 would potentially provide imagery at the closest proximity to Banana Rock. The reported biota (Appendix 3 in Ecology Lab, 2006) was limited to sea pens, sea whips, sea stars and sea pens and drift algae.

Further assessment of the diversity of biota at these pinnacles and how they differ from Pimpernel Rock may be warranted to ascertain their unique nature. The features themselves are narrow with between 15-40 m of relief. The three dominant pinnacles in this northern section are unique in the underwater landscape of this park as well as more broadly across parks on the shelf in the Temperate East.

Mapped features such as The Pinnacle off Forster and other isolated pinnacle reef features near Seal Rocks, lie within state marine parks. These types of features have the potential to be culturally significant as they would likely have been prominent features on the landscape when sea levels were lower than the present day. These features impact upon localised oceanography in the immediate vicinity and attract megafauna, other mobile species and recreational divers. The large depth gradient means the sites are ‘rare’ within the park. Understanding connectivity between the ecosystems on photic and mesophotic reef system, is a noted knowledge gap within the literature and this site could be the focus for future studies with its near continuous reef.

Although soft sediment habitats are not currently a Key Ecological Feature targeted for mapping over the Australian continental shelf, they are significant contributors to the biodiversity of the park. Soft sediments are variable across the park, and each may support a unique sets of mobile and sessile species. At the Solitary Islands, earlier work in the adjacent state park by Schultz et al (2015) identified the significance of sediment type as a driver of fish community structure. The wide variety of seabed textures is also reflected in the adjacent in SIMP, as identified by these surveys, and conversely the variability of soft sediment types as a driver of fish community structure might be expected to be similar.

It is unknown if assessments of benthic biodiversity using methods such as benthic infauna have been completed for the park or region. Areas of the seabed around this section of coast certainly contain relatively finer sediment fractions (Jordan et al, 2010) that support benthic infauna. Burrows were observed in the imagery and consistently within the sediment samples during these surveys. Burrows were often observed in planar areas with significant proportions of finer sands and muds. Muddier sediments at nearshore locations were also observed immediately north of SIMP (Jordan et al, 2010) from Yamba to Angourie and coincides with a notable prawn fishery adjacent to NSW largest estuary, the Clarence River (Glastier 1978 in Taylor et al 2022). The movements of the Eastern King Prawn (*Melicertus plebejus*) are heavily influenced by rainfall with flows stimulating migration from estuarine nurseries to adjacent inshore waters (Ruello et al 1973 in Taylor et al 2022).

Areas of boulder, cobble and/or gravel habitats or even veneered reefs (sand covered) can also provide other unique habitat types that can cover broad areas. For this survey, these areas are likely seabed that were mis-classified by the MBES (i.e. were identified as reef in the imagery). These can often look relatively flat and be classed as planar and then mis-classified as ‘unconsolidated’ planar seabed through the automated morphometric (landform) analysis. These habitats, however, are intermediate between sand and reefs, and act as hard substrates, supporting a range of sessile and mobile invertebrates that provide a suite of other habitat types.

An area of seabed offshore of Seal Rocks in the Hunter demonstrates this (Williams et al 2020). At the site, imagery indicated a seabed of coarse sand to gravel, with high intensity sonar returns as dark backscatter over a largely planar area, a diverse range of erect sponges and corals including gorgonians was observed. The sites here lie in 90-110 m of water and are exposed to strong southward flowing EAC. The seabed was likely providing a hard return, due to either compacted/winnowed seabed or a veneer of coarse sandy material over low-profile reef.

4.1.2 Patterns in sessile benthic invertebrates

Certainly, comparisons of the diversity and density or organisms from the SIMP to other Temperate East parks is not achievable at this point in time, as no other parks have had comprehensive surveys across a 100% mapped continental shelf area. Only towed-video surveys in the Hunter (Williams et al, 2020) completed relatively recently might be used, however, annotation of the surveys (50 random images x 25 random points) is incomplete. The Hunter surveys covered across depths from 10-110 m, applied a similar approach to sampling design but the area of available reef is only 5.5 km^2 (< 1%) of the mapped shelf area. Currently, only 30% of the Hunter’s seabed has been mapped at high resolution. Williams et al (2020) completed only a coarse qualitative analysis of the captured seabed imagery in the Hunter and indicated that reefs in <70 m, and at similar depths in this SIMP survey, were upper mesophotic to photic and dominated by branching (*Ecklonia radiata*) and turfing algae with branching sponges, ascidians, sea starts and whips (corals). Unsurprisingly, soft sediment burrows were also common to planar soft sediment areas in imagery from both parks and absent from areas where features and seabed types indicated the seabed was more mobile (depths of <60 m for Hunter).

Analysis of AUV (IMOS) imagery from isolated and island-attached reefs (2020) within the Hunter (Outer Gibber) and adjacent Port Stephens – Great Lakes Marine Park (Seal Rocks, The Pinnacle, Broughton Island) was completed in 2023 (Tan Rui Zen et al, unpublished thesis). These surveys used the 50 images x 25 annotations approach with sites focused on a depth range of <45 m. Generally, deeper sections of reef for these surveys were sponge and coral dominated with kelp dominating communities at shallower sites. While the results are currently unpublished, annotations are accessible upon request (via SQUIDLE+) and could be used for a full quantitative comparison between regions. A single towed video transect was also conducted during 2019 at the Cod Grounds (Jordan et al, 2010), which lies midway between the Hunter and SIMP parks (Cod Grounds ~31° 45.5’S). Here the seabed lies at depths of 21-46 m, and this may provide another AMP site for mesophotic reefs. Scoring was by estimating % cover of coarse habitat forming groups (CATAMI) in still frames from forward looking video and generally, the site was dominated by sponges, particularly encrusting, massive and branching forms, ascidians and mixed brown algae. Unfortunately, imagery from the Cod Grounds is not publicly accessible although sourcing of earlier video with further annotation may then provide the appropriate data to compare the 3 sites and provide some understanding of the latitudinal variability across this section of the Temperate East.

The validity of using data from the 5 randomly annotated images to calculate diversity here, using either method should be treated with caution. With the Top-10, the number of different morphospecies is limited to a maximum of 10 and the identification of conspicuous species is somewhat subjective with a bias toward the larger and more charismatic invertebrates. The use of 5 randomly selected images reduced the potential for auto-correlation, although the image sample size was limited. With annotations grouped to a mid-tier morphospecies level, however, the number of individuals per image (count) is significantly greater. One alternative approach would be to combine all image annotations across all sites to compare. This approach, however, may be considered to suffer a weighted bias (uneven numbers of images) and/or autocorrelation. A comparison between the different approaches using annotations from both '5 random images only' and 'all available images' per transect to calculate the diversity metric indicates that the general patterns are consistent (Figure 4.1). This may provide some level of confidence around the patterns described here but further exploration of the data to understand consistency across approaches for calculating diversity using these annotation sets is warranted. The greatest difference in derived diversity values lies between choosing 5 or all images for Top-10 annotation set, then between Top-10 and mid-tier annotation approaches. This may be unsurprising as the number of values (n annotations) per morphospecies from which to calculate the diversity is much greater for the latter (mid-tier) approach.

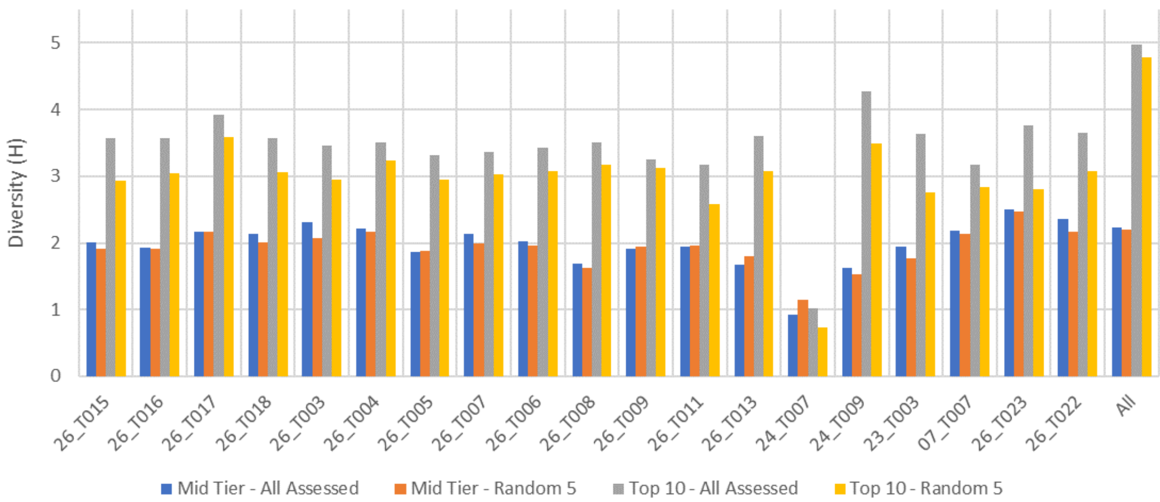


Figure 4.1 Bar chart of diversity index values (H) calculated using both mid-tier and Top-10 annotation approaches for all available scored images, per transect. Transects ordered latitudinally from North to South

The use of the laser-pointers to calculate the area of the seabed captured within each image was reliable and consistent, except where points were unobservable, or visibility was poor.

In these cases, images were excluded from detailed, morphospecies analysis and only provided a substrate annotation (consolidated/unconsolidated) where possible. The technique allowed for the area to be effectively calculated ‘per image’, or when not possible, a substituted ‘transect average’ or neighbourhood value could be substituted. Calculating densities on Top-10 annotations was unlikely to yield useful results as counts for individuals for the majority of the 320 morphospecies would relegate them to a classification of ‘rare’ (i.e., <5-10 individuals; or <1-2% relative abundance) for the majority of images and transects. While it must also be noted that the exclusion of highly mobile or non-sessile morphospecies from some calculations may have introduced other biases, the counts for these were relatively low compared to the major groups.

Density for the 3 most common phyla was provided here just to provide a broad first-pass look at the differences between sites (transects) and sections of the park. Generally, the density approaches were consistent, and densities of the 3 phyla were greatest in the north and south. Reef-type, in extent or nature as either relatively continuous and rugose as opposed to patchy and low-profile, may not be a determinant for density. Further exploration of the data using multivariate approaches is warranted. Additionally, density values based on data at the mid-tier annotation level could be calculated and maps generated. The number of mid-tier (non-rare) morphospecies available would be limited to 4 sponge classes (Massive, Erect, Cups, Encrusting) and 4 classes of Cnidaria (Black & Octocorals 3D Branching, Black & Octocorals Fan 2D, Hydroids, Solitary Stony Coral) and 2 Bryozoa (Hard, Soft). These data are contained within the annotations sets available and maps of distribution and density could be provided.

4.1.3 Geomorphology and sediment distribution

The sedimentary features and landforms mapped, identified, sampled, and described within this study represent the depositional evidence of fluid motions and sediment transport on the dynamic shoreface-inner shelf surrounding the SIMP. The presence, size, shape, distribution, and complexity of the landforms (esp. rocky reef outcrops) and features were largely unknown prior to the recent mapping of the coastal seabed with a combination of airborne LiDAR (with dual topography-bathymetry sensors), vessel-based multibeam echosounding, sediment grabs and towed underwater video (see Kinsela et al., 2022 for further details on datasets and methods). Preliminary interpretations of the shoreface and inner shelf geomorphology and morphodynamics is described in the following section, which are based on the feature morphology, and spatial distributions, put within the context of past work competed in the area, as well as international research.

The sediment types and their distributions within the SIMP reflect existing depth-based shelf sedimentation models for this coast (Roy and Stephens 1980; Roy and Thom 1981; Roy 2006), however, the expanse of rocky reef outcrops in this area will impart additional complexity to the processes occurring there (Kinsela et al., 2022). The depths occurring in the northern section of the park do not include many (if any) shoreface sediments and displays a clear transition from the coarse inner-shelf sand to the finer, muddy inner shelf sand. The coarser material is consistent with the inner shelf sand sheet described by Roy (2006), which is a sand deposit (generally) extending from 20-35 m water depth to around 60 m water depth, which was abandoned by landward migrating coastlines (or barriers) during the Holocene post-glacial sea level rise (~7,000 years ago). Inner shelf sands also do not fine seaward (as other units do closer to the shoreline) but are relict deposits that are presently being reworked (Roy and Stephens, 1980).

The finer, muddy inner shelf sands (i.e., water depths of 45-70 m) occur on the more gently sloping part of the shelf, extending to mid shelf muds (further offshore). In places of this unit, like in the southern sections of the park, coarser modes are apparent (e.g., SAN005, WOLI 013,019), and they are thought to be related to underlying relict substrate, intermixing presumably via bioturbation (Roy and Stephens, 1980). The transition to mid-shelf fine sands or muds marks the extent of shelf sediment that is relevant to the beach-shoreface sediment budgets at millennia timescales (Kinsela et al., 2022).

There appears to be inner shelf sand ridges in all three sections of the SIMP, and they have been studied in detail elsewhere (Schwab et al., 2017; Duran et al., 2020). They typically occur in areas of the SIMP beyond the influence of the coastline geology (i.e., headlands and embayments), but highly influenced by the rocky reef outcrops and islands found commonly all over the park (Kinsela et al., 2023). These features form where coarser sand or gravels occur (i.e., inner shelf sands), have various sizes (from small to large wavelengths) and their landform orientation is generally transverse to oblique (relative to the shoreline), have steep S-SW crests, and flat/ broad N-NE faces. That strong asymmetric morphology indicates a north-south sediment transport and bedform migration (Schwab et al., 2017; Kinsela et al., 2023), opposing the dominant wave direction (SE), indicating currents as a key transport mechanism. This may be further impacted by the complex hydrodynamics enhanced by the dominant shallow and mesophotic rocky reefs across the park.

The MBES mapping at the southern portion of the northern section of the SIMP (just outside of the park boundary), shows the presence of shelf sand body siting just landward of the 45 m depth contour (directly seaward of Wooli), and displaying a typical flatter lobe morphology for the northern coast of NSW (Kinsela et al., 2023), also shown in Figure 4.2. Shelf sand bodies are thought to be reworked remains of transgressive barriers, similar landscapes to Stockton or the Myall Lakes open coast region in the present day. It is thought that these sand units became stuck on steeper sections of the inner shelf (usually off headlands, coastal cliffs or in this case, rocky outcrops), as sea level flooded coastlines that were much further offshore (and remnants we can see in the mapping – see Figure 3.13), towards the end of the Holocene (post-glacial transgression; ~7,000 years ago) (Ferland, 1990; Roy et al., 1994; Roy, 2006).

Sediment samples were not collected directly at this feature, as it was outside park boundaries (SAN019 could be a sample of the sand body?), but future work should sample this unit to properly determine if it provides a pathway for sand bypassing in the area, be a supply of sand onshore, or be an avenue for offshore losses of sediment (via downwelling bottom currents)? The latter has been observed by others, on other shelf sand bodies off the Sydney and (southern) Illawarra coast (Field and Roy, 1984; Kinsela et al., 2022).

The central and southern sections of the park seem to have lower shoreface (or outer nearshore) sands present (Figure 1.10). Lower shoreface sediments in this region of NSW typically form a very thin veneer above bedrock or a Pleistocene clay substrate (Roy and Stephens, 1980), and are occurring at water depths of 35-40 m within the SIMP (Table 3-6). These finer lower shoreface sands are overlaying the coarser inner shelf sands, forming large (~2 km) sand ridges, for example features along the dotted black arrow in Figure 4.2 (also, Figure 3.27 – 3.29). Their steep SW crests (and broader N-NE faces) and asymmetric orientation indicate a north-south sediment transport and bedform migration (like others in the park).

In addition, the lower shoreface sands found in this region have similar characteristics to those sediments occurring on the beach face (comparing beach sediment characteristics within Andy Short's Beach sediment database). Table 4-1 presents samples of the two sand units; and its clear they are quite similar, indicating that some of the lower shoreface sand (even sand from the shelf body as a potential source; i.e. SAN019) could be making its way onshore, especially in the central areas of the park, and during higher wave conditions, like during storms (as explained in Section 1.1.2). Presumably the upper shoreface (surf zone) will have similar sediments to both these units, but this unit was not sampled as part of this study but could be considered in future work. Figure 4.2 illustrates and identifies a lot of these sedimentary features using the high-resolution mapping for the entire secondary sediment compartments of Yuraygir and Woolgoolga, as well as indicating potential interconnected processes occurring within and between the SIMP.

Table 4.1 Comparison of sediment characteristics (i.e., grain-size and carbonate content results) for (selected) grab samples of the SIMP lower shoreface (blue shading), and beach sand samples (white shading). Note: beach samples are from Andy Short's Beach sediment database

ID	**Elevation** (m)	**Mean** (µm)	**Sorting**	**Skewness**	**Kurtosis**	**LOI (%)**
SAN019	-42.7	Medium sand (279.3)	Well sorted (1.382)	Symmetrical (0.006)	Mesokurtic (0.959)	8.5
WLI008	-35.2	Medium sand (256.4)	Well sorted (1.387)	Symmetrical (0.012)	Mesokurtic (0.968)	8.6
WLI009	-40.6	Fine sand (245.7)	Well sorted (1.387)	Symmetrical (0.013)	Mesokurtic (0.959)	10.1
Station	0	Fine sand (142.5)	Well sorted (0.302)	Coarse skew (0.306)	Mesokurtic (0.937)	12.5
Red rock	0	Fine sand (177.9)	Well sorted (0.336)	Coarse skew (0.360)	Leptokurtic (1.16)	10.6
Red rock (sth)	0	Medium sand (316.0)	Mod. sorted (1.007)	Symmetrical (0.000)	Mesokurtic (0.816)	17.0

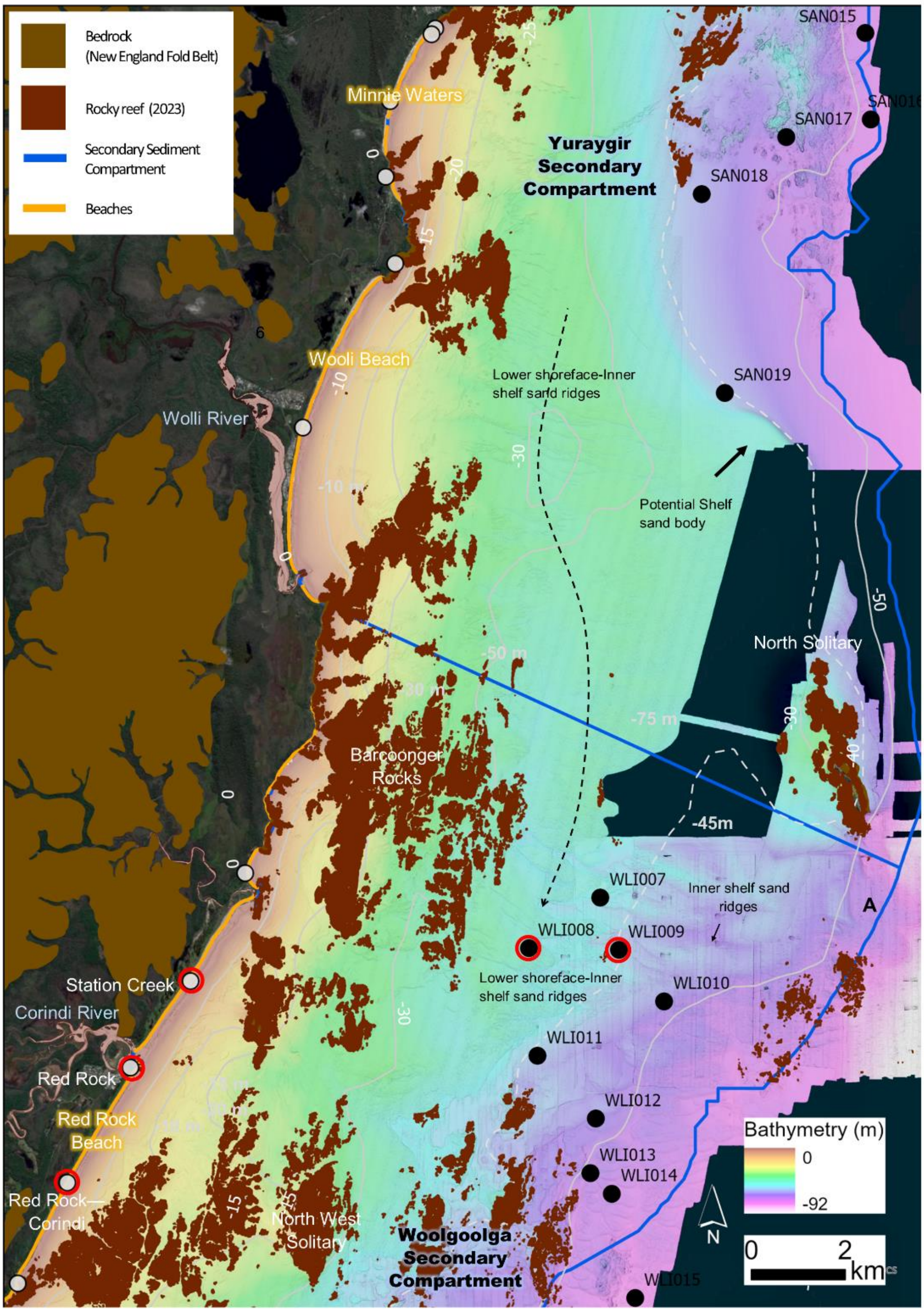


Figure 4.2 Map of the Woolgoolga and Yuraygir secondary sediment compartments, showing the mapped bathymetry (derived from both the MBES and marine LiDAR), secondary sediment compartment boundaries (blue outline), navigation bathymetry contours (grey), mapped rocky reef (2023), bedrock (New England Fold Belt), beaches (orange line), location of sediment samples for both the beach and seabed (red outline are those in Table 4-1), as well as key sedimentary features and pathways mentioned in-text.

4.2 Implications for Marine Park Management

4.2.1 Seabed mapping for marine conservation and coastal management

The additional data for SIMP provided here combined with previous survey efforts, provides unprecedented full coverage across an entire continental shelf park. With full coverage, these data provide the first full picture of the range of habitats and seafloor types to be managed within the bounds of the park. The depth range observed here now differs to that published previously 15-70m and detailed in policy documents (Director of Parks, 2018). Certainly, original depths used to define the boundary (50m depth contour) were relatively inaccurate (navigational faring sheets) and outdated with more recent information.

The new data indicates a slightly narrower and shallower depth range that may or may not have any implications for the ultimate definition of the boundary and management of the park area. Certainly, the surveys indicate that the seabed is mobile in some areas of the park more than others, and depths are likely to change over time. Combined with fish (BRUV), benthic communities (imagery), sedimentology and oceanographic knowledge, a picture of several of the components of the park's ecosystem is taking shape. From the 'physics to fish' these data sets help build a spatial and temporal picture that can ultimately be used to develop hydrodynamic, biogeochemical and ecological models required for a holistic approach to future management.

Knowledge across the complete range of habitat types over the shelf, more broadly is far from complete. Less than 11% of Australia's shelf has been mapped at the resolution required for effective management (Townsend et al, 2023). Without a complete picture across the whole shelf for this part of the coast we are unable to ensure that what is contained within reserves is comprehensive, adequate and representative of all continental shelf habitats. While there is a national effort striving to map all of Australia's EEZ by 2030 (AusSeabed.gov.au) the current resourcing available to achieve that ideal is not sufficient. Parks Australia and stakeholders should, however, continue to advocate for high resolution mapping over marine park areas and lodge priority unmapped areas for funded mapping through MNF or the Hydroscheme Industry Partnership Program (HIPP) using the national Areas of Interest tool on AusSeabed.

In the interim, for the Temperate East, NSW DCCEEW continues to map secondary sediment compartment scale sections of the coast (<60 m depth) for coastal management purposes (NSW State-wide Science Program: SeabedNSW) that directly benefits marine conservation efforts and providing increased knowledge of the distribution of seabed habitats over the shelf. Data around the periphery of the parks captured during this and previous surveys also builds on the seabed archive and provides data over deeper, adjacent, non-park areas. Where new significant features are identified, i.e., relic coastlines, representative areas of these new types of habitats should be investigated and if deemed as unique (culturally, ecologically, economically), could be considered for future protection.

In particular, it is the connection across boundaries and understanding that the science and knowledge we need must stretch beyond just the area of any individual park itself. By understanding what lies outside the park, we can identify what is unique and those biological communities captured in the park are being represented and managed adequately. Many marine organisms and/or their propagules are highly mobile and do not observe jurisdictional boundaries. But their success and/or survival is reliant on parks and fisheries management approaches, such as zoning or restrictions on development or fishing activities more broadly. Certainly, what happens over reefs and other habitats outside the park, but nearby, can also have implications for biological communities within the park.

We must consider surrounding environments and have an understanding the relationship of park assets to activities in adjacent areas. A more recent example of this, for example, is the current development proposal for offshore wind farms further south within the Temperate East where floating wind turbines are anchored to the seabed in areas directly adjacent to an existing AMP.

A complete picture and park-wide knowledge of the distribution of underwater landforms from the bathymetry and seabed typology from the sediment surveys, is also novel for AMPs of the Temperate East. Knowledge of the distribution of landforms, sediment types and reefs is important from a coastal management perspective. The volumes, types and locations of sediments and associated geomorphology are indicative of the sediment transport and hydrodynamic processes operating at the seabed in these areas of the shelf. While the depths mapped in the SIMP are predominantly below effective wave base (30-40 m), what happens at these depths is connected across the different compartments although at various time-scales.

While beach erosion or accretion today may not appear to be impacted by development or management activities, however, further offshore, changes in the seabed and transport processes at depth may impact on shallow areas at scales of decades to millennia. For example, the construction of Coffs Harbour in 1915, interrupted the northward longshore transport of sand, and the subsequent re-adjustment of embayments north and south have taken decades to occur (and still are changing) (see Section 1.1.2). Over a decade, the movement of sediments or the blocking nature of reefs within one part of the inner shelf may effect how sands are being transported along the coast (or cross-shore) and controlling sand available to be deposited or removed from a nearby beach or may drive the smothering of kelps, sponges and corals living on nearby reefs when inundated with sand.

It is also important to map and analyse the spatial variations in sediment characteristics as it can give land managers and scientist a good idea of what processes are impacting those depositional environments. For example, the types of landforms present, as well as larger (coarser) mean grain sizes that are in a leptokurtic and positive distribution, can indicate higher energy transport processes such as waves (typically only during high energy events, i.e., storms), or strong longshore currents. Conversely, abundance of finer sands in the deeper outer inner shelf indicates a low energy "window" between the wave-dominated inner shelf, and current dominated outer shelf, allowing the abundant fauna to occur within this sediment unit (Roy and Stephens, 1980).

Investigating the sedimentology and geomorphology of the park, especially at the primary sediment compartment scale, will help coastal managers and scientists understand more holistically the larger scale processes occurring in, and impacting the region. High resolution and characterised mapping of the shoreface is also a fundamental step towards developing and formalising conceptual frameworks of coastal evolution that can be used to further help guide appropriate application of predictive models and management actions within the SIMP and wider primary sediment compartment (see Kinsela et al., 2022 for good example).

4.3 Recommendations for Future Research and Monitoring

The following are a list of recommendations that might be considered for future work to either make full use of the existing data or acquire additional data through new surveys and monitoring. Future work to be considered might include:

- Sediment analyses (and backscatter) used to develop a full surficial substrate map for the SIMP. The map would detail the full spatial diversity of sediment types and unconsolidated habitats across 100% of the park, something not currently available for any other Temperate East marine reserves. This information is important for coastal, marine conservation and natural resource management perspectives.
- Complete MBES and targeted sediment sampling for entire secondary sediment compartments in the area around the Solitary Islands, to more accurately define sediment connectivity and dynamics using a compartment framework. This is a critical step towards developing quantitative sediment budgets that can underpin more targeted management, and enhance locally meaningful predictions of future shoreline change under projected climate change scenarios (for example see Kinsela et al., 2022).
- Further mapping over larger expanses of the shelf between SIMP and the Central East further offshore to the shelf break. This is needed to gain a full picture of the range of seabed habitats present in this sub-tropical to temperate section of the Temperate East. The area could be identified as a priority within the national Areas of Interest tool on AusSeabed.
- Assess the similarities between the geomorphic approach used here with other recently published tools for deriving underwater geomorphological features, specifically the recently developed and agreed international terminology and definitions (Dove et al 2020; Nansen et al, 2023) toward systematic application across mapped areas of the Australian seabed.
- Sub-bottom profiling, coring and dating of different sedimentary environments of the shoreface and inner shelf to better understand past changes/ evolution of the region, to better define and predict future shoreline and shoreface changes.
- Assessments of diversity of unconsolidated habitats should be explored through BRUVs, benthic infauna and/or genomics type approaches as they constitute the majority (85%) of the park’s seabed area
- Establish the significance of the newly mapped pinnacle reef features and/or other relatively high-profile reefs in the northern section and assess if increased level zoning or protections if warranted. Further assessment of the diversity of biota at these pinnacles and how they differ from Pimpernel Rock would better inform such a consideration. Pimpernel rocks and its ‘sister’ peaks, may benefit from mapping using high-resolution (cm) stereo-imaging techniques and support communications of the unique features of the park and its values.
- Consideration of the seaward extension of the park boundaries in southern areas to include some sections of the significant regional relic coastline. These features currently

receiving some protection (IUCN VI: General Use Zone) of limited spatial extent within state-waters, only. These long (kms) linear features are extensive and morphologically distinct from other lower profile and shallower reefs in the area with some limited mapping also indicating the presence of similar features offshore of North Solitary. Techniques such as ultra high-resolution mapping (cm) using stereo-imaging techniques could be used to showcase these underwater landscapes.

- Incorporate exemplar images for observed morphospecies observed to boost SQUIDLE+ library and support/tune AI detection algorithms with examples of SIMP species specific to make greater utility of existing and future imagery.
- Imagery and associated annotations of sessile benthic invertebrates across mesophotic areas outside the AMP and elsewhere within the Solitary Islands are limited. Additional surveys annotations in park and non-park areas to assess the variability between reefs but potentially and with suitable statistical power, test the effect of different zoning approaches.
- Different field designs and annotation approaches will yield different results. Revisit some previous annotation work and revise to ensure a consistent approach and facilitate comparisons between parks and surveys.
- Use the results to design a monitoring program to track changes within benthic communities especially with potential for exposure to extreme events like marine heatwaves and freshwater outflows. Temperature loggers and surveys in and around the reefs in different sections of the park would be beneficial to assess exposure of mesophotic reefs to marine heatwaves and other extreme events, at depth.
- While spatial and temporal understanding of the oceanography at the surface is reasonable (i.e., satellite), for the sub-surface it is reasonably limited. Sea glider and moorings (South Solitary Island 70 m and 100 m) data are providing some sub-surface information under national programs (IMOS). However, data density at depth over the shelf is relatively poor and our knowledge of the exposure of mesophotic reefs to elevated temperatures and low salinity is not well understood. Additional sub-surface data collection to drive hydrodynamic models that can then be used for management and predictive capability through operational biogeochemistry and ecological models.

5. CONCLUSIONS

- A total of 22.6 km^2 (~15%) of the Solitary Islands Marine Park (Commonwealth waters) seabed was identified as shallow rocky reef or mesophotic rocky reef. This brings the total mapped area of the park to 100%.
- The majority of mapped reef occupies the northern two-thirds of the northern section of the park, which is reasonably continuous and hosts the greatest geomorphic diversity, with significantly smaller and more isolated or patchier reefs in the central and then southern sections of the park.
- Soft sediment habitats cover around 85% of the seabed area. Soft sediment features are wide and varied from large flat planar areas of fine sands, coarse sand to gravel filled areas between reefs to fields of mobile sands traversing (covering/exposing) across overlying beds of coarse sand to gravel and pebble sized shells. Large planar areas lie north of North and South Solitary Island, while areas of mobile features occupy the seabed to the north of these same islands as well as the reef complex in the north surrounding Pimpernel Rock.
- Imagery from soft sediment areas were not scored but a range of mobile species were observed in the imagery including elasmobranchs, crinoids, and echinoderms. Burrows in fine sandy planar areas or the presence of an infauna/epifauna matrix (ophiuroids, polychaetes) in muddier areas indicated that organisms varied with sediment type.
- Porifera, then Cnidaria, followed by Bryozoa were the dominant phyla for reefs across the park, the majority of which lie in depths 30-60 m, in the upper mesophotic zone. Diversity and density varied from site-to-site but generally were greater for reefs in the northern and southern zones.
- Massive, erect and encrusting sponges were most common 'mid-tier' morphotypes, with 3D and 2D branching corals, hydroids, solitary corals, and hard and soft bryozoans. While 34 different morphospecies were identified across all imagery at this mid-tier taxonomic level; 320 different morphospecies were identified by annotating the Top-10 most conspicuous sessile benthic species in the imagery.
- The sedimentary environments within and surrounding the SIMP reflect typical units of the NSW shoreface and inner shelf, those being; pockets of fine sands of the outer nearshore zone (~250 µm; water depths of <40 m); lenses of medium to coarse grain inner shelf sands (or gravels) (900-2050 µm, water depths typically between 40-50 m); to the fine muddy sands of the gently sloping, low energy inner-mid shelf unit (<250 µm, at water depths of > 50 m). Interestingly, carbonate content varied across the samples, but typically increases within the inner-shelf sand unit, and proximity to rocky reef outcrops.
- The sedimentary features and landforms mapped, identified, sampled, and described within this study represent the depositional evidence of hydrodynamic processes and sediment transport on the unique shoreface-inner shelf surrounding the SIMP. The

presence, size, shape, distribution, and complexity of the landforms (esp. rocky reef outcrops) and features (i.e., sand ridges; and potential shelf sand body) were largely unknown prior to the recent mapping done as part of this project.

- Morphometric analyses, sediment sampling for the mapping of landforms and sediment typologies are an important part of the story on the formation and of the seabed and its features within the area of the park. Understanding the geomorphological features helps us understand the processes operating within the park and the adjacent coast and supports management of the coastal landscape for the years and decades to come.

METADATA AND DATA STORAGE

Data has been made publicly accessible via the following;

1) as data packages (5 x 5 m gridded geotifs; survey report) on AusSeabed and backed up on NSW DCCEEWs Internal Assets Register; metadata on NSW Sharing and Enabling Environmental Data (SEED).

2) Towed video imagery: metadata on NSW SEED and DCCEEWs Internal Assets Register (IAR); imagery supported on DCCEEWs IAR Amazon Web Service and accessible for annotation via SQUIDLE+ (NSW ENV Towed Video Surveys). Both MBES and towed video imagery are backed up on DCCEEWs IAR NSW Department of Planning Industry and Environment Internal Assets Register with full metadata statements. Towed video metadata stored on the AODN metadata catalogue.

3) Sediment sample data provided to AusSeabed with data backup on DCCEEWs IAR and metadata on NSW SEED.

MBES:

https://iar.environment.nsw.gov.au/dataset/nsw-environment-multibeam-survey-gridded-bathymetry-and-backscatter-datasets

https://portal.ga.gov.au/persona/marine

Towed Video Imagery:

https://iar.environment.nsw.gov.au/dataset/nsw-marine-estate-towed-video-imagery/metaexport/iso19115_html

Further information about imagery with IMOS Understanding Marine Imagery facility at https://catalogue-imos.aodn.org.au/geonetwork/srv/eng/catalog.search#/metadata/5a94a2cf-0810-44ea-a28d-cc8a5c30fbd7

Sediment samples

http://dbforms.ga.gov.au/pls/www/npm.mars.search

https://iar.environment.nsw.gov.au/dataset/nsw-marine-estate-sediment-grab-sampling

Landforms

https://datasets.seed.nsw.gov.au/dataset/solitary-islands-marine-park-commonwealth-marine-ecosystems-substrates-and-geomorphology

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APPENDIX A – AUSSEABED SURVEY REPORT

Introduction

Survey Title and ID	Locality
Solitary Islands Gumbaynggirr Yaegl MP	**New South Wales Coffs Harbour Coast**
Survey Authority	**Survey Sponsor/Custodian**
New South Wales Government (Department of Planning and Environment)	**Parks Australia**
Surveyor in Charge and qualification	**Date this Survey Summary was completed**
Stephen Holtznagel Hydro Surveyor, Dr Tim Ingleton Mapping Scientist/Senior Scientist	**12 November 2023**
Start Date of Survey	**End Date of Survey**
31-08-2022	**31-07-2023**
Survey Platform/Vessel Name	**Survey Platform/Vessel Name**
RV *Bombora* (12 m monohull) over-the-side Pole Mounted R2Sonic 2022	**RV *Bombora* (12 m monohull) over-the-side Pole Mounted R2Sonic 2022**
Purpose of the Survey	
Collection of high-resolution near-coastal bathymetric data to inform Australian Commonwealth Marine Park management	

Horizontal Control

Soundings are on the following datum (WGS84 preferred but not essential)	
Datum	**WGS84**
Spheroid	**GRS80**
Projection and Zone	**UTM Zone 56**
Was the positioning system validated?	**No**
Were laybacks applied?	**Not required**
Estimated horizontal accuracy of soundings at 2 Sigma (95%) confidence level (Calculations can be included as an attachment. Don't know? Enter "Not Known")	**Rinex 48-hour Singe-Station Solution horizontal and vertical uncertainties of <0.015 m and <0.025 m respectively.** **POS MV RMS <0.1m in XYZ**

	5 x 5m CUBE surface of survey area has THU mean, median and standard deviation of 1.69 m, 1.65 m and 0.13 m respectively.

Vertical Control

Tides Applied	**Yes**
Soundings Datum	**Australian Height Datum**
Tide Station 1 Details	**Coffs Harbour (COFF) Base Station**
Benchmark (BM) used and Datum connection	**CorsNet RTCM ID 0064, Marker 50146M001v**
Geoid details if using GPS tides	**AUSGEOID20**
Tide Station 2 Details	**Yamba (WMBA) Base Station**
Benchmark (BM) used and Datum connection	**CorsNet RTCM ID 0107, Marker AUM000273**
Geoid details if using GPS tides	
Tide Station 3 Details	
Benchmark (BM) used and Datum connection	
Geoid details if using GPS tides	
Tide Model comments (if applicable)	
Were soundings corrected for draught?	**Not required**
Were the soundings corrected for sound velocity?	**Yes**
Estimated vertical accuracy of soundings at 1.96 Sigma (95%) confidence level (Calculations can be included as an attachment. Don't know? Enter "Not Known")	**5 x 5m CUBE surface of survey area has TVU mean, median and standard deviation of 0.14 m, 0.10 m and 0.11 m respectively.**

Details of Survey Execution

The following positioning systems were used:

Positioning System 1	**POSMV with G2 Satellite RTK-equivalent post-processed in POSPac v.8.4 as a single-base or multi-base solution with 48-hour Rinex base-station data**	
Positioning System 2		
Base station (If applicable)		
The following sounding systems were used:		
Model / System Details	Frequency (kHz)	
Echosounder 1	R2Sonic2022 210-250 KHZ	
Echosounder 2		
Logging and Processing Systems used, and Versions:		
Logging	**Hypack 2020**	
Processing	**Qimera v2.6.0**	
Was the survey systematically controlled with planned survey lines or methods?	**Yes**	
Was full feature detection achieved as defined in IHO publication S-44, Edition 5, February 2008?	**N/A**	
If feature detection was achieved, what Order of features is applicable?	**N/A**	
Feature detection comments (if applicable)		
Were all shoal depths systematically investigated and their least depths determined?	**No**	
Has data been thinned from that collected?	**Yes**	
If thinned, what thinning method and bin size was used?	**Very weak spline filter, Cube 5 m bin size to IHO1B; SV corrections, TUD speed of sound inversion**	

Remarks (If applicable):
further metadata can be accessed on the NSW SEED website at **https://iar.environment.nsw.gov.au/dataset/nsw-environment-multibeam-survey-gridded-bathymetry-and-backscatter-datasets**

Shoals and Dangers

This section seeks comments on any features that may be dangerous to surface navigation. (Comments as required. General location and depth references, pictures, screen dumps, etc. will assist. Has a Hydrographic Note or Danger to Navigation Report been submitted?)
None observed

Wrecks

This section seeks comments on any wrecks detected during the course of survey. (Comments as required. General location and depth references, pictures, screen dumps, etc. will assist.)
None observed

APPENDIX B – GPS POSITIONS OF SEDIMENT SAMPLES AND TOWED VIDEO TRANSECTS

Sediment Sampling Sites

Site Name	Time (UTC)	Latitude	Longitude	Depth (m)
SAN001	14/09/2023 0:20	-29.6728	153.3936	44.15
SAN002	14/09/2023 0:40	-29.6758	153.4041	49.85
SAN003	14/09/2023 1:11	-29.677	153.4082	52.21
SAN004	14/09/2023 1:45	-29.6937	153.4083	51.56
SAN005	14/09/2023 2:02	-29.691	153.3999	47.55
SAN006	14/09/2023 2:20	-29.6885	153.3915	44.69
SAN007	14/09/2023 2:46	-29.7052	153.4025	51.34
SAN008	14/09/2023 3:07	-29.7178	153.3896	47.16
SAN009	14/09/2023 3:22	-29.7296	153.3842	45.81
SAN010	14/09/2023 3:39	-29.7217	153.3631	36.91
SAN011	14/09/2023 4:05	-29.7317	153.3612	36.62
SAN012	14/09/2023 4:30	-29.7505	153.3671	39.62
SAN013	14/09/2023 4:44	-29.759	153.3627	40.9
SAN014	14/09/2023 5:04	-29.7718	153.3761	46.09
SAN015	14/09/2023 5:23	-29.7829	153.3931	53.29
SAN016	14/09/2023 5:50	-29.7996	153.3944	54.5
SAN018	14/09/2023 6:32	-29.814	153.3572	45.02
SAN019	14/09/2023 6:52	-29.8523	153.3624	42.72
WLI001	24/08/2023 22:32	-30.0979	153.2756	47.36
WLI002	24/08/2023 23:01	-30.0988	153.2944	53.5
WLI003	24/08/2023 23:27	-30.0786	153.293	51.62
WLI004	24/08/2023 23:57	-30.077	153.2703	42.85
WLI005	25/08/2023 0:31	-30.1268	153.278	49.97
WLI006	25/08/2023 0:59	-30.1498	153.2894	51.64
WLI007	15/09/2023 1:46	-29.9495	153.3352	39.21
WLI008	15/09/2023 2:04	-29.9593	153.3195	35.17
WLI009	15/09/2023 2:22	-29.9596	153.3394	40.62
WLI010	15/09/2023 2:40	-29.9695	153.3494	45.31
WLI011	15/09/2023 3:25	-29.98	153.3214	41.33
WLI012	15/09/2023 4:07	-29.9921	153.3343	48.56
WLI013	15/09/2023 4:19	-30.0026	153.3332	50.82
WLI014	15/09/2023 4:36	-30.0065	153.3379	52.43
WLI015	15/09/2023 5:21	-30.0266	153.3432	57.96
WLI016	15/09/2023 5:34	-30.0302	153.3401	57.4
WLI017	15/09/2023 5:51	-30.0318	153.3281	52.43

WLI018	15/09/2023 6:10	-30.0464	153.3248	54.77
WLI019	15/09/2023 7:04	-30.05	153.3237	54.07
WLI020	15/09/2023 7:29	-30.0734	153.2759	47.12
COF001	25/08/2023 2:23	-30.2675	153.2505	53.05
COF002	25/08/2023 2:55	-30.2699	153.2336	44.93
COF003	25/08/2023 3:19	-30.278	153.2328	44.06
COF004	25/08/2023 3:35	-30.2825	153.2371	47.24
COF005	2/11/2023 1:26	-30.2854	153.2487	55.75
COF006	2/11/2023 1:51	-30.2959	153.228	48.05
COF007	2/11/2023 2:22	-30.304	153.226	51.63
COF008	2/11/2023 3:31	-30.2974	153.2135	39.04

Towed Video Transects

		Start of transect		**End of transect**	
Date	**Transect**	**Latitude**	**Longitude**	**Latitude**	**Longitude**
20231107_T002	T002	-30.2955	153.2319	-30.2967	153.2295
20231107_T003	T003	-30.286	153.2217	-30.2871	153.2192
20231107_T004	T004	-30.2834	153.2505	-30.2853	153.2485
20231107_T005	T005	-30.2766	153.2539	-30.2783	153.2517
20231107_T006	T006	-30.271	153.2347	-30.2727	153.2319
20231107_T007	T007	-30.2623	153.2551	-30.2638	153.253
20231107_T008	T008	-30.2582	153.2389	-30.2606	153.2354
20231114_T001	T001	-29.6756	153.4129	-29.677	153.4113
20231114_T006	T006	-29.7335	153.3979	-29.7352	153.3965
20231114_T007	T007	-29.7354	153.3964	-29.7374	153.3949
20231114_T008	T008	-29.7338	153.3841	-29.7358	153.3827
20231116_T001	T001	-29.9525	153.3376	-29.9533	153.3354
20231116_T002	T002	-29.9611	153.342	-29.9623	153.3403
20231116_T003	T003	-29.9632	153.3202	-29.963	153.3182
20231116_T004	T004	-29.9677	153.3243	-29.9688	153.3227
20231116_T007	T007	-30.0984	153.2803	-30.0976	153.279
20231123_T001	T001	-30.0795	153.2934	-30.081	153.2916
20231123_T002	T002	-30.0718	153.2863	-30.0734	153.2848
20231123_T003	T003	-30.0705	153.2781	-30.0718	153.277
20231124_T001	T001	-30.1154	153.2766	-30.1173	153.2759
20231124_T002	T002	-29.9701	153.3524	-29.9724	153.3515
20231124_T003	T003	-29.98	153.3496	-29.982	153.349
20231124_T004	T004	-29.9851	153.323	-29.9866	153.322
20231124_T005	T005	-29.9905	153.3242	-29.9921	153.323

20231124_T006	T006	-29.998	153.3535	-30.0002	153.3532
20231124_T007	T007	-30.0073	153.3306	-30.0095	153.3295
20231124_T008	T008	-30.0172	153.3483	-30.0193	153.3474
20231124_T009	T009	-30.021	153.3367	-30.025	153.3355
20231124_T010	T010	-30.0381	153.3332	-30.0391	153.3323
20231126_T001	T001	-29.7467	153.3782	-29.7485	153.3772
20231126_T002	T002	-29.7507	153.3592	-29.7526	153.3582
20231126_T003	T003	-29.7539	153.3613	-29.7556	153.3603
20231126_T004	T004	-29.7581	153.3872	-29.76	153.3864
20231126_T005	T005	-29.7685	153.3948	-29.7703	153.394
20231126_T006	T006	-29.7713	153.3854	-29.7732	153.3844
20231126_T007	T007	-29.7679	153.3637	-29.7701	153.3625
20231126_T008	T008	-29.7787	153.3794	-29.7804	153.3783
20231126_T009	T009	-29.7931	153.3866	-29.7949	153.3855
20231126_T010	T010	-29.7893	153.3657	-29.791	153.3645
20231126_T011	T011	-29.8008	153.3811	-29.8027	153.3798
20231126_T012	T012	-29.8122	153.3782	-29.8139	153.3771
20231126_T013	T013	-29.8064	153.3534	-29.8081	153.3521
20231126_T014	T014	-29.819	153.3617	-29.8207	153.3605
20231126_T015	T015	-29.6979	153.3951	-29.6996	153.3939
20231126_T016	T016	-29.7089	153.3852	-29.7107	153.3841
20231126_T017	T017	-29.7102	153.3927	-29.7119	153.3915
20231126_T018	T018	-29.7247	153.4023	-29.7264	153.4013
20231126_T019	T019	-29.8339	153.3772	-29.8358	153.3767
20231126_T020	T020	-29.8535	153.3901	-29.8546	153.3898
20231126_T021	T021	-29.8684	153.3467	-29.8702	153.3463
20231126_T022	T022	-30.3036	153.2284	-30.3056	153.2275
20231126_T023	T023	-30.3028	153.2227	-30.3046	153.2218

APPENDIX C – FIELD DATES AND SUMMARY STATISTICS

Date (UTC)	Survey Block/Area	Type	Lineal km/ number of sites or samples
31/8/2022	B	MBES	70.1 km
1/9/2022	B		65.3
16/9/2022	B + C		58.2
17/9/2022	C		60.2
18/9/2022	C		48.8
26/10/2022	C		70.1
27/10/2022	C + D		71.3
28/10/2022	D		44.0
6/11/2022	D + E		58.7
7/11/2022	D + E		66.9
30/01/2023	F		37.7
31/01/2023	F		74.1
6/2/2023	J		0.0
7/2/2023	J		65.9
20/2/2023	F + G		45.6
15/03/2023	G		62.3
17/03/2023	G + H		61.4
23/05/2023	H		43.4
24/05/2023	H		50.2
29/05/2023	H		48.8
30/05/2023	H + I		42.5
31/05/2023	I		43.1
16/06/2023	J		23.4
17/06/2023	I		35.4
18/06/2023	A		29.5
30/07/2023	I		55.3
31/07/2023	I + J		30.4
24/8/2023	WOOLI + COFFS	Sediments	10 Grab Samples
13/9/2023	SANDON		14 Grab Samples
14/9/2023	WOOLI		20 Grab Samples
1/11/2023	COFFS		4 Grab Samples
7/11/2023	South Solitary	Imagery	7 transects; 2366 images
14/11/2023	North Solitary		4 transects; 1054 images
16/11/2023	Central Solitary		5 transects; 1549 images
23/11/2023	Central Solitary		3 transects; 819 images
24/11/2023	Central Solitary		10 transects; 3211 images
26/11/2023	North, Central, South		23 transects; 5044 images
TOTAL			Lineal km: 1,403; Sediment Grabs: 48; Images:

APPENDIX D – MARINE MAMMAL ENCOUNTER REPORT 2022

Solitary Island Marine Park Multibeam Survey – Marine Mammal Encounter Report – Permit 2022-0005

This report has been completed to satisfy the requirements of **Cetacean Permit 2022-0005**.

Background

New South Wales Department of Planning and Environment (NSW DPE) in early 2022 was contracted by Director of Parks at Parks Australia (PA) to undertake surveys within the Australian Solitary Islands Marine Park SIMP on the New South Wales north coast. These surveys were to provide 100% coverage of the seabed using multibeam, towed video and sediment sampling surveys. DPE were requested to acquire a Cetaceans Permit from the Migratory Species Section for the contract period 04 July 2022 – 14 April 2023 and manage risks to cetaceans from these activities appropriately.

Marine Mammal Observer training was provided to DPE staff in June 2022 by Blue Water Research. Under advice from Australian Antarctic Division, DPE were requested to record all cetacean encounters using the CSA_Data_v7.1 spreadsheet as the online version was inoperable. AAD Advised that only sections of the *Observer*, *SurveyOperation*, *SurveyLine*, *ObserverEffort* and *CetaceanSighting* pages of the CSA were applicable to DPE during the activities involved in the agreement.

Summary

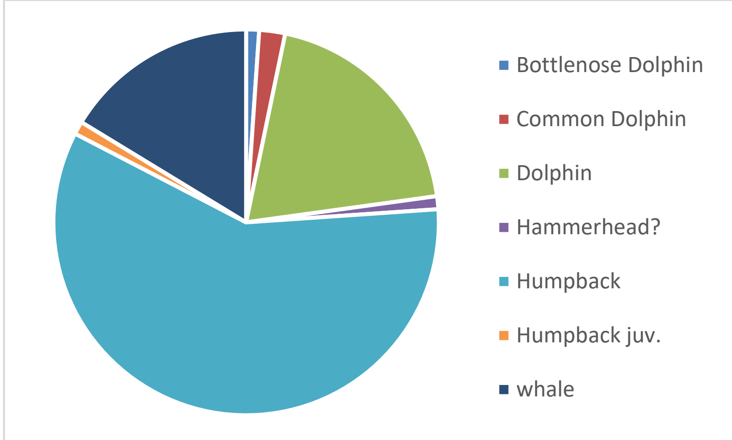
As of the completion of this report, 11 days of MBES survey have been completed by DPE in the Solitary Islands Marine Park (Table 1). DPE has not yet completed any of the other types of survey work covered in the permit, namely towed video, and sediment grabs; these will be completed in 2023. There are no plans to undertake any additional survey work before 31 December 2022.

Of the ~106 hours of total sea time, ~74 hours were spent actively recording MBES data. A total of 95 cetacean observations events were recorded, the majority of those during survey time (59%). During survey, only 7% of encounters were within the agreed shutdown range, and the majority of these were constituted by dolphins (~70%). Sightings within the "Shutdown Zone" triggered shutdown procedures, on every occasion; survey was ended, and action taken to safely increase distance between the animal and the vessel. Following a shutdown event, a prewatch was conducted until no cetaceans were seen within the observation area for 15 minutes. There were no near misses or collisions (Table 1).

Humpback whales (*Megaptera novaeangliae*) were the most common sighting (~56%) and the only large cetacean observed with confidence. There were 15 other large cetaceans observed with no identification however these were generally at a great distance outside the observation zone and in most cases were likely also humpbacks based on their blow patterns and body shape. Dolphins made up ~30% of cetacean observations (Figure 1). No pinnipeds or other mammals were observed. A general decline in the number of whale sightings has been observed approaching the end of the 2022; coinciding with the end of the southern migration period. Dolphin sightings have remained generally consistent across the survey period (Figure 2).

Table 1: Cetacean sightings for each survey day broken into zones as per Cetacean Permit and Blue Water Research training guidelines (Long distance: >500 m; Observation: <500 m; Caution:300 m-whale/150 m-dolphin; Shutdown: 100 m-whale/50 m-dolphin)

Date	MBES hours (hh:mm)	Total sea time (hh:mm)	Total sightings	Long distance Sightings	Observation zone	Caution zone	Shutdown zone	Near misses
1/09/2022	8:25	10:50	6	3	1	1	1	0
2/09/2022	7:20	9:20	1	0	0	1	0	0
17/09/2022	6:05	10:00	16	3	6	3	4	0
18/09/2022	8:01	10:50	12	3	2	5	2	0
19/09/2022	5:38	8:03	34	9	11	9	5	0
4/10/2022	4:15	6:20	5	1	1	2	1	0
27/10/2022	8:30	11:37	8	4	2	2	0	0
28/10/2022	8:59	11:20	3	0	3	0	0	0
29/10/2022	4:40	7:10	4	0	0	4	0	0
7/11/2022	7:35	10:59	4	0	4	0	0	0
8/11/2022	5:55	10:14	2	0	1	1	0	0
Total	74:23	106:42	**95**	**23**	**31**	**28**	**13**	0



Animal	Count
Bottlenose Dolphin	1
Common Dolphin	4
Dolphin	21
Hammerhead?	1
Humpback	53
Humpback (sub-adult)	1
whale	15
Total	96

Note: One humpback was deemed to be a sub-adult based on smaller than average size. The individual was not calf size nor did it appear to be travelling with an adult. A distance > 300 m was kept from this individual at all times.

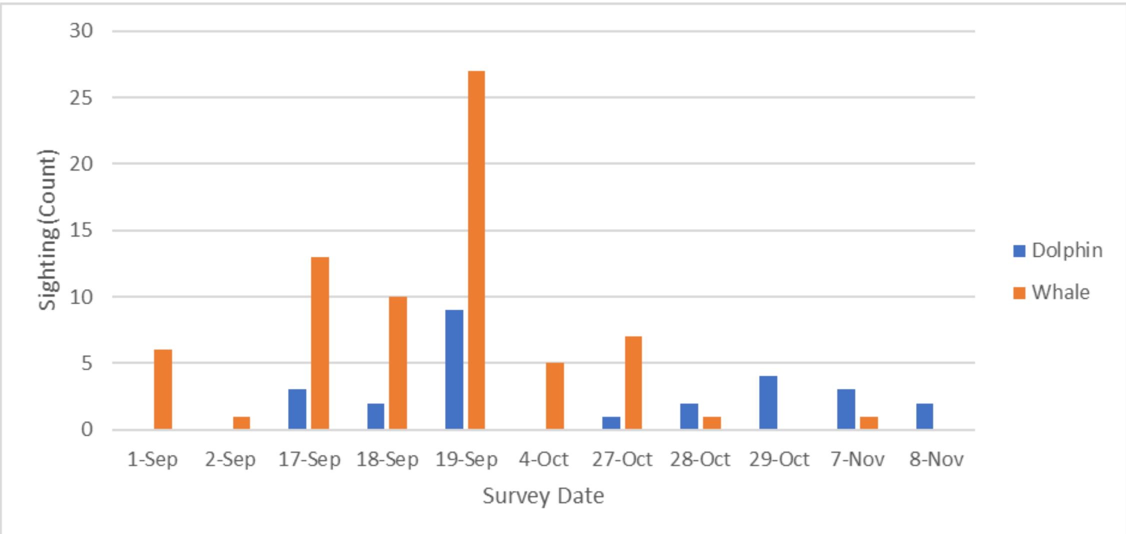


Figure 1: Species composition of the 95 recorded cetacean sightings, and one shark sighting for work conducted in 2022

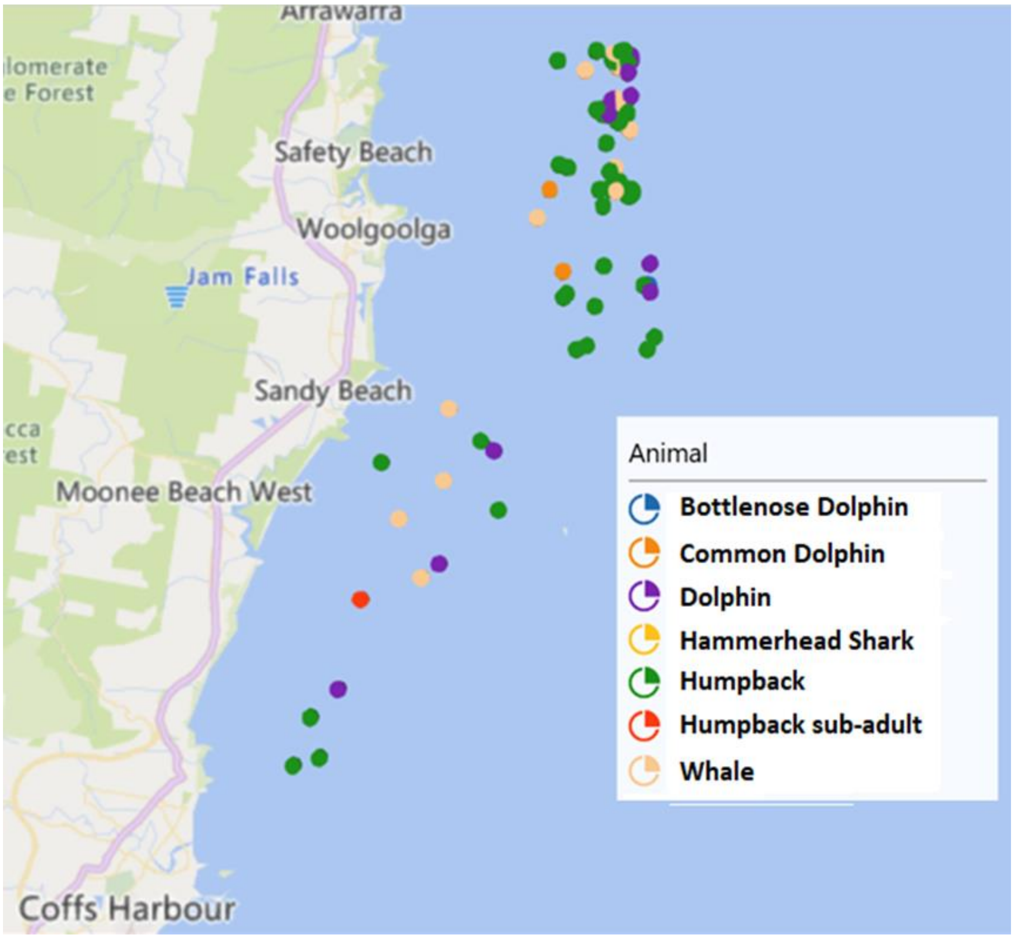


Figure 2: Cetacean sightings per trip displayed in course categories of dolphin and whale.

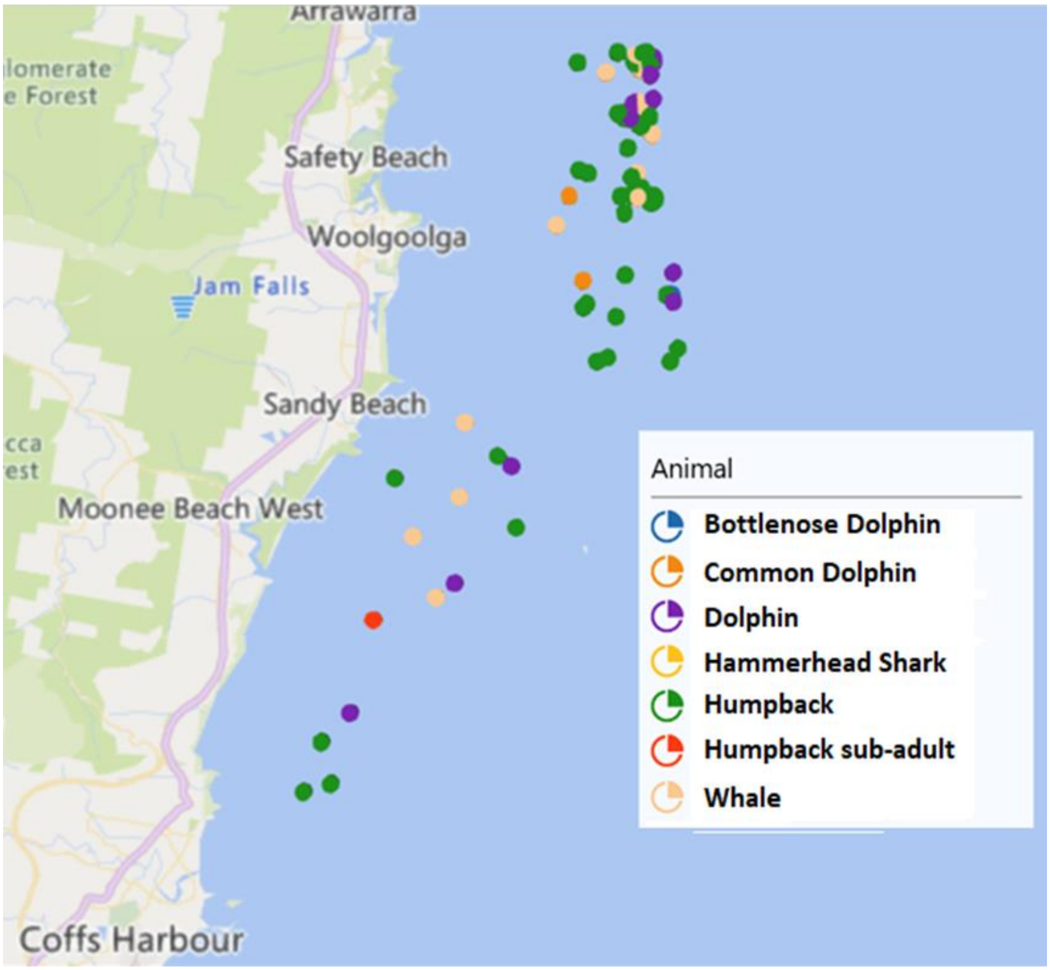


Figure 3: Distribution of sightings during transit and survey work during 2022

Concluding Statement

It is evident from the data provided here that DPE's approach to managing risk to cetaceans under this permit is appropriate. No incidences of adverse effects, behavioural change, or impact (collision) had been observed during the survey, to date. NSW DPE will continue to operate surveys in this manner for the remaining period of the contract.

Authorisations		
Name	Neil Doszpot	Dr Tim Ingleton
	Environmental Technician **Report preparation**	**Senior Scientist** **Permit Holder**
Signature	[signature]	[signature]
Date checked	20/12/2022	20/12/2022

APPENDIX E – MARINE MAMMAL ENCOUNTER REPORT 2023

Solitary Island Marine Park Multibeam Survey – Marine Mammal Encounter Report – Permit 2023-0003

This report has been completed to satisfy the requirements of **Cetacean Permit 2023-0003**.

Background

In early 2022, New South Wales Department of Planning and Environment (NSW DPE) was contracted by Director of Parks at Parks Australia (PA) to undertake surveys within the Australian Solitary Island Marine Park (SIMP) on the NSW North Coast. These surveys were to provide 100% coverage of the seabed using multibeam echo sounding (MBES), with towed video and sediment sampling as a means of ground truthing. In late 2022, the project timeline was extended with a final completed date scheduled for April 2024. DPE were requested to acquire a Cetaceans Permit from the Migratory Species Section for the contract period and manage risks to cetaceans from survey activities appropriately. In December 2022 DPE delivered the requisite data and report for Cetacean Permit 2022-0005 and was granted a new permit 2023-0003 to cover work conducted in 2023.

Marine Mammal Observer training was provided to DPE staff in June 2022 by Blue Water Research. Under advice from Australian Antarctic Division, DPE were requested to record all cetacean encounters using the CSA_Data_v7.1 spreadsheet as the online version was inoperable. AAD Advised that only sections of the *Observer*, *SurveyOperation*, *SurveyLine*, *ObserverEffort* and *CetaceanSighting* pages of the CSA were applicable to DPE during the activities involved in the agreement.

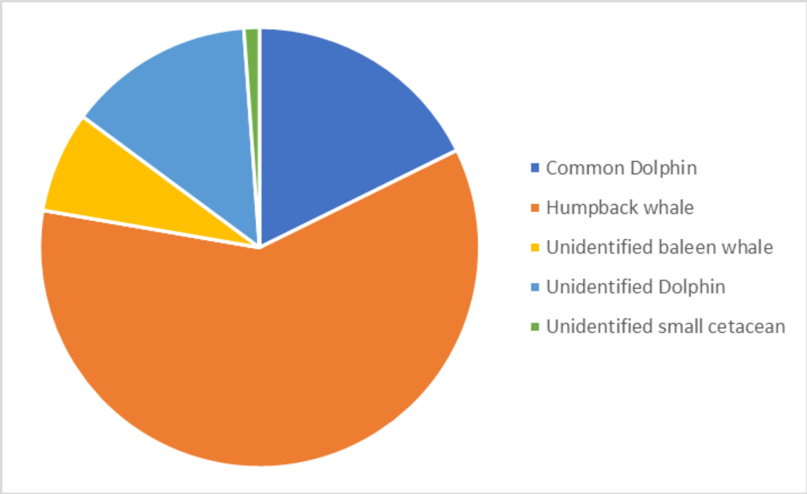
Summary

DPE finalised field work for the project on 27 November 2023 with a total of 28 days gathering data in the marine park in 2023. Of those days, 17.5 were spent on MBES, 4.5 sediment sampling, and 6 gathering towed video data. No further field work is required for the completion of the project.

During the 28 field days, 174 cetaceans were observed in 97 events. Humpback whales (*Megaptera novaeangliae*) were the most common sighting (~60%) and the only large cetacean observed with confidence. There were 13 other large cetaceans observed with no identification however these were generally at a great distance outside the observation zone and in most cases were likely also humpbacks based on their blow patterns and body shape. The rate of whale observations peaked in July with the greatest frequency from July-September.

Mixed delphinids contributed ~31% to observations, with the common dolphin (*Delphinus delphis*) being the most common group. Two instances of unidentified small cetaceans were observed at a distance outside the observation zone. No pinnipeds or other mammals were observed.

During field work, ~9% encounters were within the agreed shutdown zone, with a relatively even split between events triggered by dolphins (~55%), and events triggered by whales (~45%). Sightings within the shutdown zone triggered shutdown procedures, on every occasion; survey was ended, and action taken to safely increase distance between the animal and the vessel, if appropriate. Following a shutdown event, a pre-watch was conducted until no cetaceans were seen within the observation area for 15 minutes. There were no near misses or collisions.



Animal	Count
Common Dolphin	31
Humpback whale	105
Unidentified baleen whale	13
Unidentified Dolphin	24
Unidentified small cetacean	2

Figure 1: Species composition of the 175 recorded cetaceans from work conducted in 2023

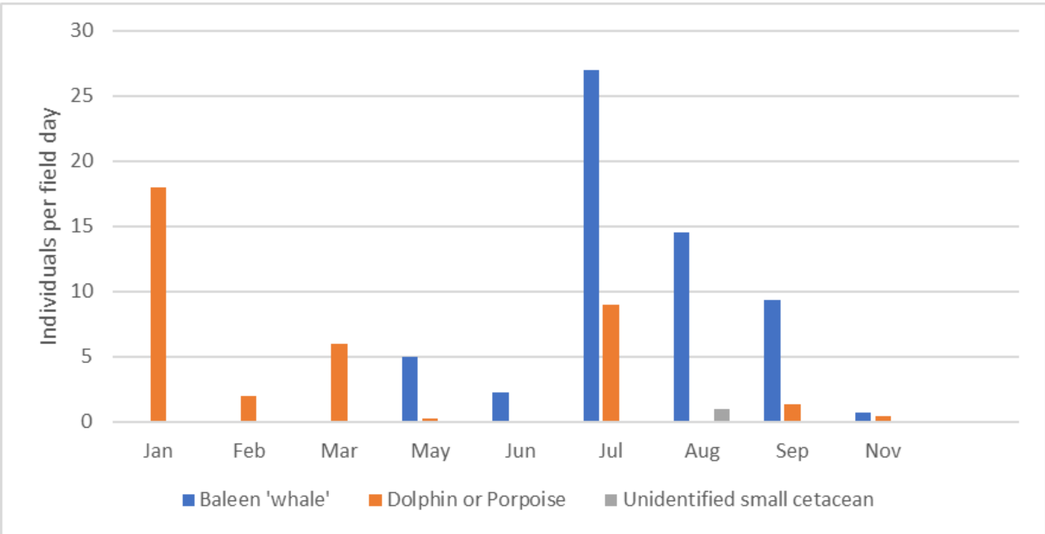


Figure 2: Average daily cetacean sightings for each month field work was undertaken.

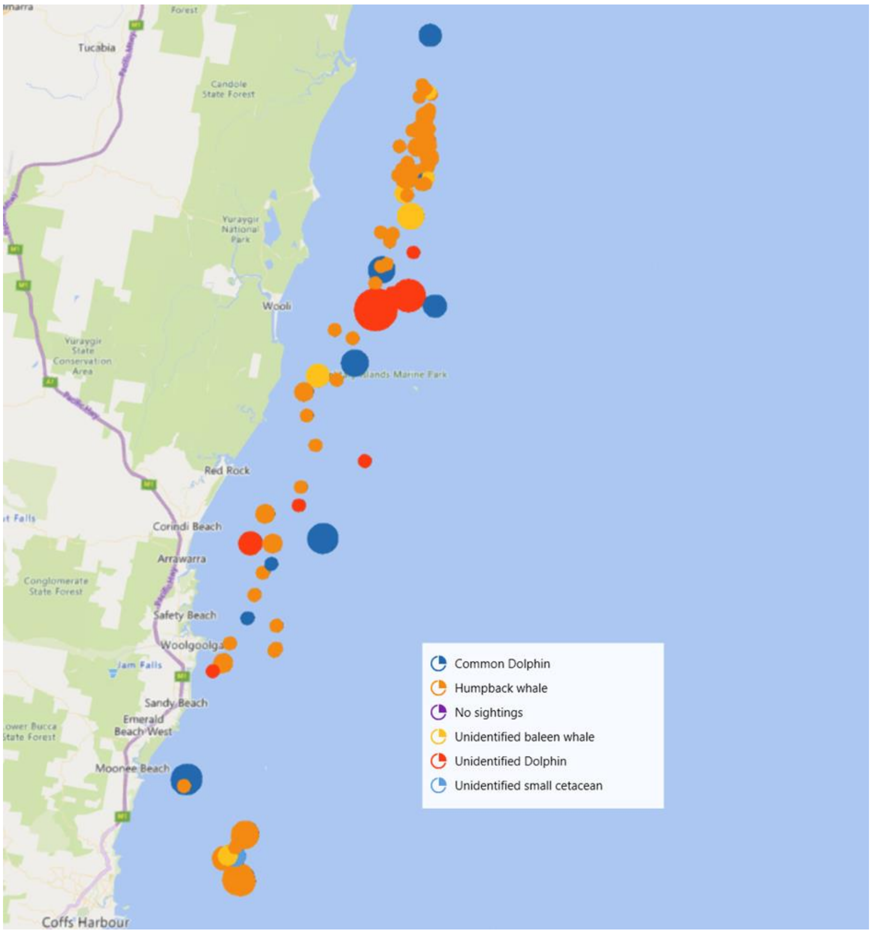


Figure 3: Distribution of sightings during transit and survey work during 2023

Concluding Statement

NSW DPE has now completed field work for this project in the Solitary Islands Marine Park. It is evident from the data provided here that DPE's approach to managing risk to cetaceans under this permit is appropriate. No incidences of adverse effects, behavioural change, or impact (collision) have been observed during the life of the project.

Authorisations		
Name	Neil Doszpot	Dr Tim Ingleton
	Environmental Technician **Report preparation**	**Senior Scientist** **Permit Holder**
Signature		
Date checked	15/12/2023	20/12/2023

APPENDIX F – LANDFORM ANALYSIS SETTINGS

Input variables and threshold settings for the seabed landform and plain classification, performed using the Seabed Landforms Classification Toolset.

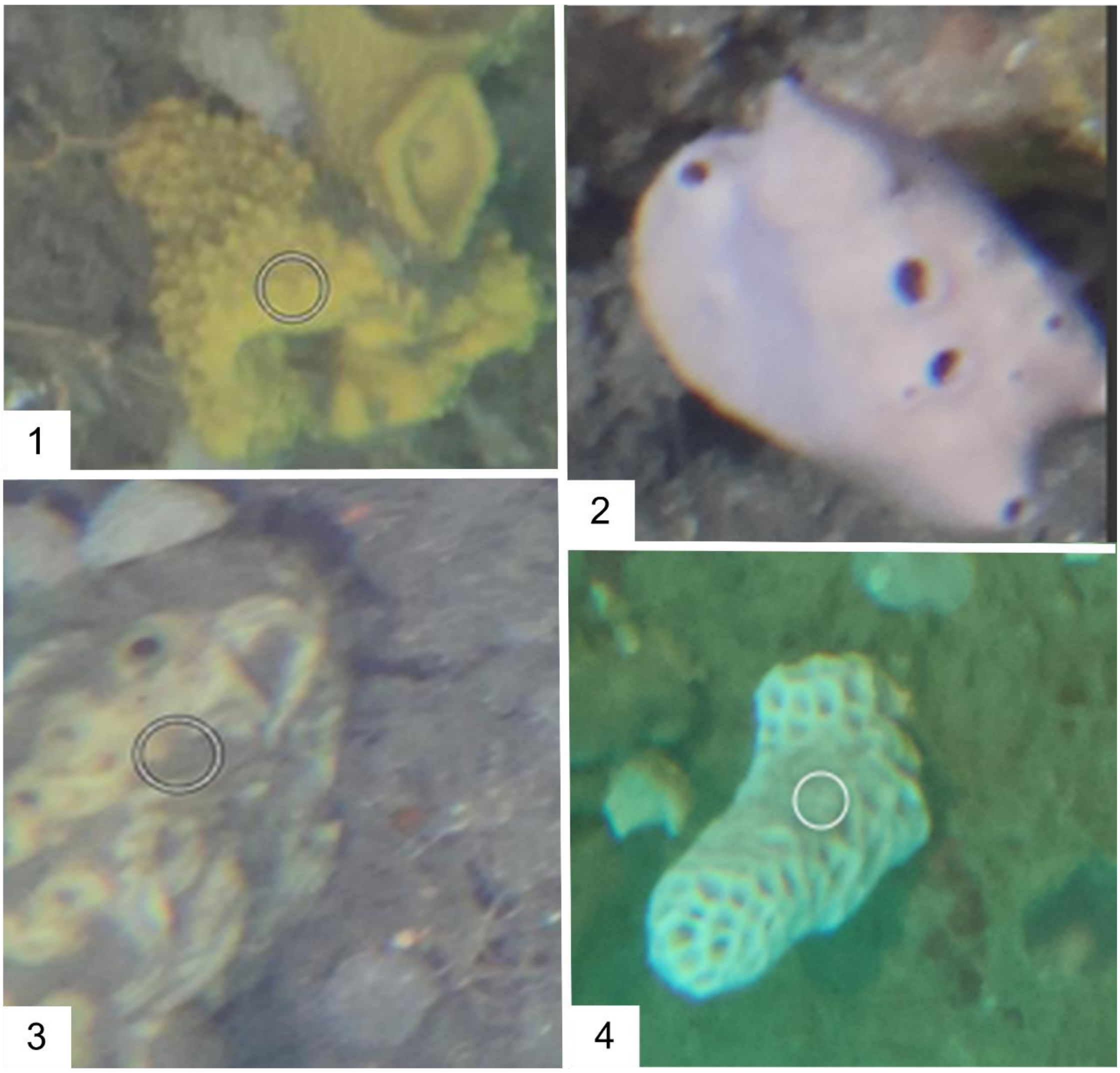
Landform classification		Plain classification	
Input variable	**Threshold**	**Input variable**	**Threshold**
Broadscale BPI	150 window size; -100, 100	Broadscale BPI	150 window size; -150, 150
Finescale BPI	27 window size; -100, 100	Finescale BPI	27 window size; -150, 150
Slope	10		
Ruggedness	0.00005		
Ruggedness (Noise)	0.0003		

APPENDIX G – MID-TIER ANNOTATION SET: MORPHOSPECIES

Hierarchy & final list of morphospecies (Morphotype Label) according to Australian Morphospecies Catalogue

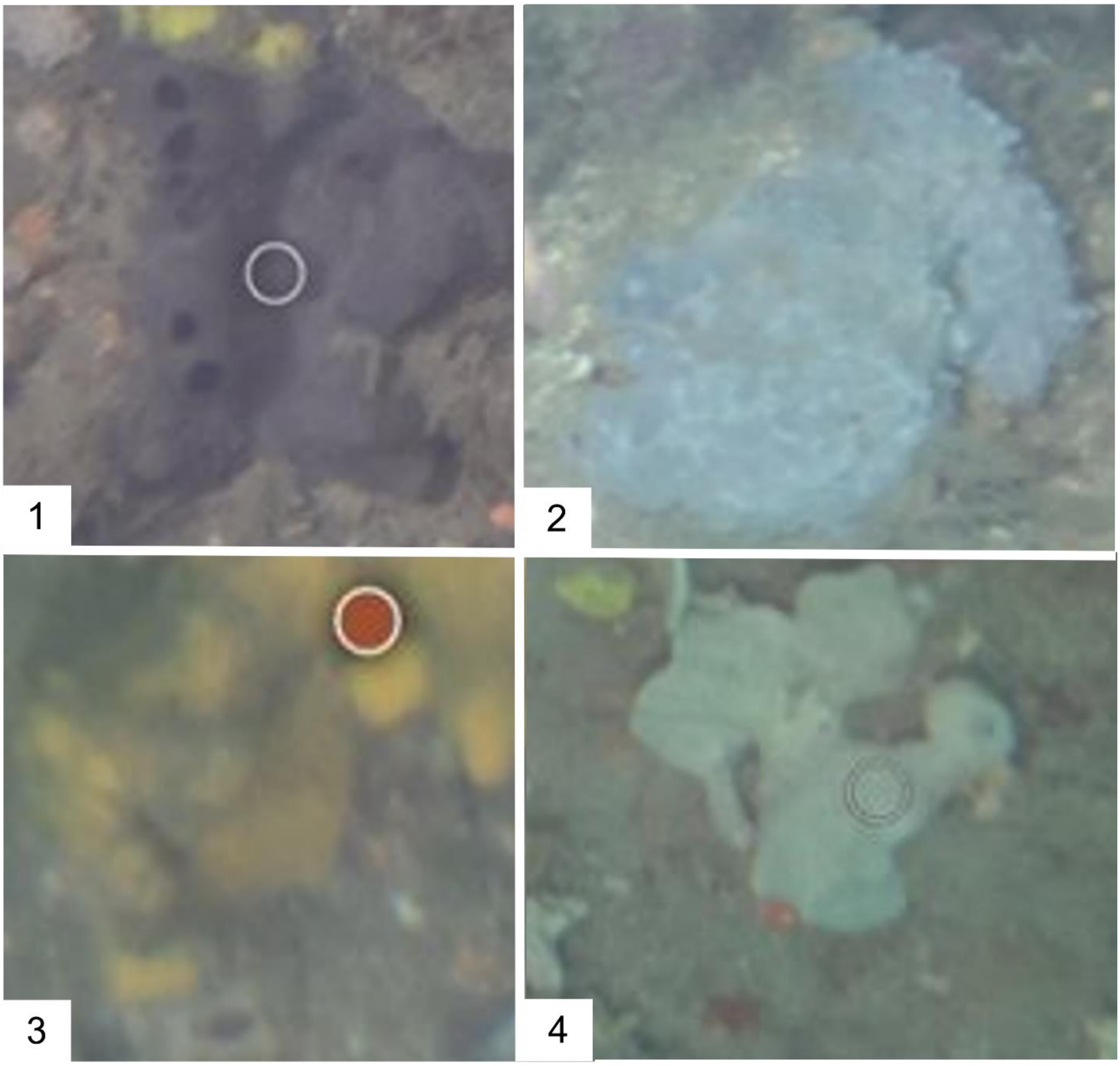
Phylum	Tier2	Tier3	Tier4	Tier5	Morphotype Label
Chordata	Ascidians	Stalked	Solitary		Ascidians Stalked Solitary
Chordata	Ascidians	Stalked	Colonial		Ascidians Stalked Colonial
Chordata	Ascidians	Unstalked	Solitary		Ascidians Unstalked Solitary
Chordata	Ascidians	Unstalked	Colonial		Ascidians Unstalked Colonial
Bryozoa	Bryozoa	Hard	Branching		Bryozoa Hard Branching
Bryozoa	Bryozoa	Hard	Fenestrate		Bryozoa Hard Fenestrate
Bryozoa	Bryozoa	Soft	Dendroid		Bryozoa Soft Dendroid
Bryozoa	Bryozoa	Soft	Foliaceous		Bryozoa Soft Foliaceous
Cnidaria	Cnidaria	Colonial anemones			Cnidaria Colonial anemones
Cnidaria	Cnidaria	Corals	Black & Octocorals	Branching (3D)	Cnidaria Corals Black & Octocorals Branching (3D)
Cnidaria	Cnidaria	Corals	Black & Octocorals	Encrusting	Cnidaria Corals Black & Octocorals Fan (2D)
Cnidaria	Cnidaria	Corals	Black & Octocorals	Fan (2D)	Cnidaria Corals Black & Octocorals Massive soft coral
Cnidaria	Cnidaria	Corals	Black & Octocorals	Massive soft coral	Cnidaria Corals Black & Octocorals Massive soft coral
Cnidaria	Cnidaria	Corals	Black & Octocorals	Quill (Seapen)	Cnidaria Corals Black & Octocorals Quill (Seapen)
Cnidaria	Cnidaria	Corals	Black & Octocorals	Whip	Cnidaria Corals Black & Octocorals Whip
Cnidaria	Cnidaria	Corals	Stony Corals		Cnidaria Corals Stony Corals
Cnidaria	Cnidaria	Hydroids			Cnidaria Hydroids
Cnidaria	Cnidaria	True anemones			Cnidaria True anemones
Cnidaria	Cnidaria	Tube anemones			Cnidaria Tube anemones
Echinoderms	Echinoderms	Sea urchins			Echinoderms Sea urchins
Echinoderms	Echinoderms	Sea stars			Echinoderms Sea stars
Echinoderms	Echinoderms	Sand Dollar			Echinoderms Sand Dollar
Echinoderms	Echinoderms	Ophiuroids			Echinoderms Ophiuroids
Echinoderms	Echinoderms	Feather stars			Echinoderms Feather stars
Chordata	Fishes	Bony Fishes			Fish
	General Unknown Biology				General Unknown Biology
Macroalgae	Macroalgae	Encrusting	Red	Calcareous	Macroalgae Encrusting Red Calcareous
Macroalgae	Macroalgae	Large Canopy Froming	Brown	Eklonia	Macroalgae Large Canopy Froming Brown Eklonia
	Matrix				Matrix
Mollusca	Molluscs	Nudibranchia			Molluscs Nudibranchia
Porifera	Sponges	Crusts			Sponges Crusts
Porifera	Sponges	Cup-likes			Sponges Cup-likes
Porifera	Sponges	Erect forms			Sponges Erect forms
Porifera	Sponges	Massive forms			Sponges Massive forms
Annelida	Worms				Worms

APPENDIX H – MORPHOSPECIES CATALOGUE



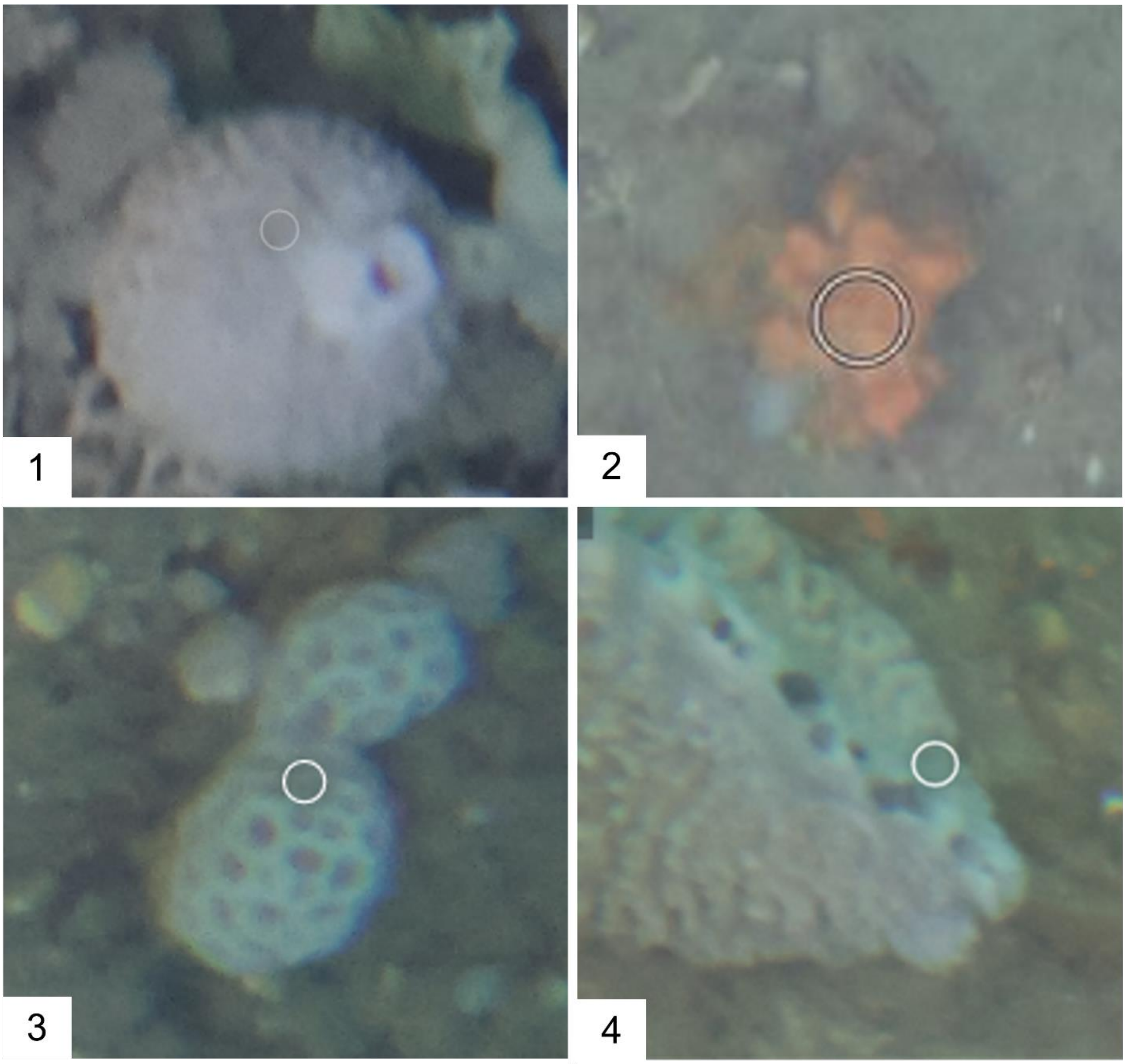
Porifera > Massive > Simple

1: Lumpy Yellow
2: Massive White Holey
3: Massive Yellow holey
4: Massive White Brain



Porifera > Massive > Simple (cont.)

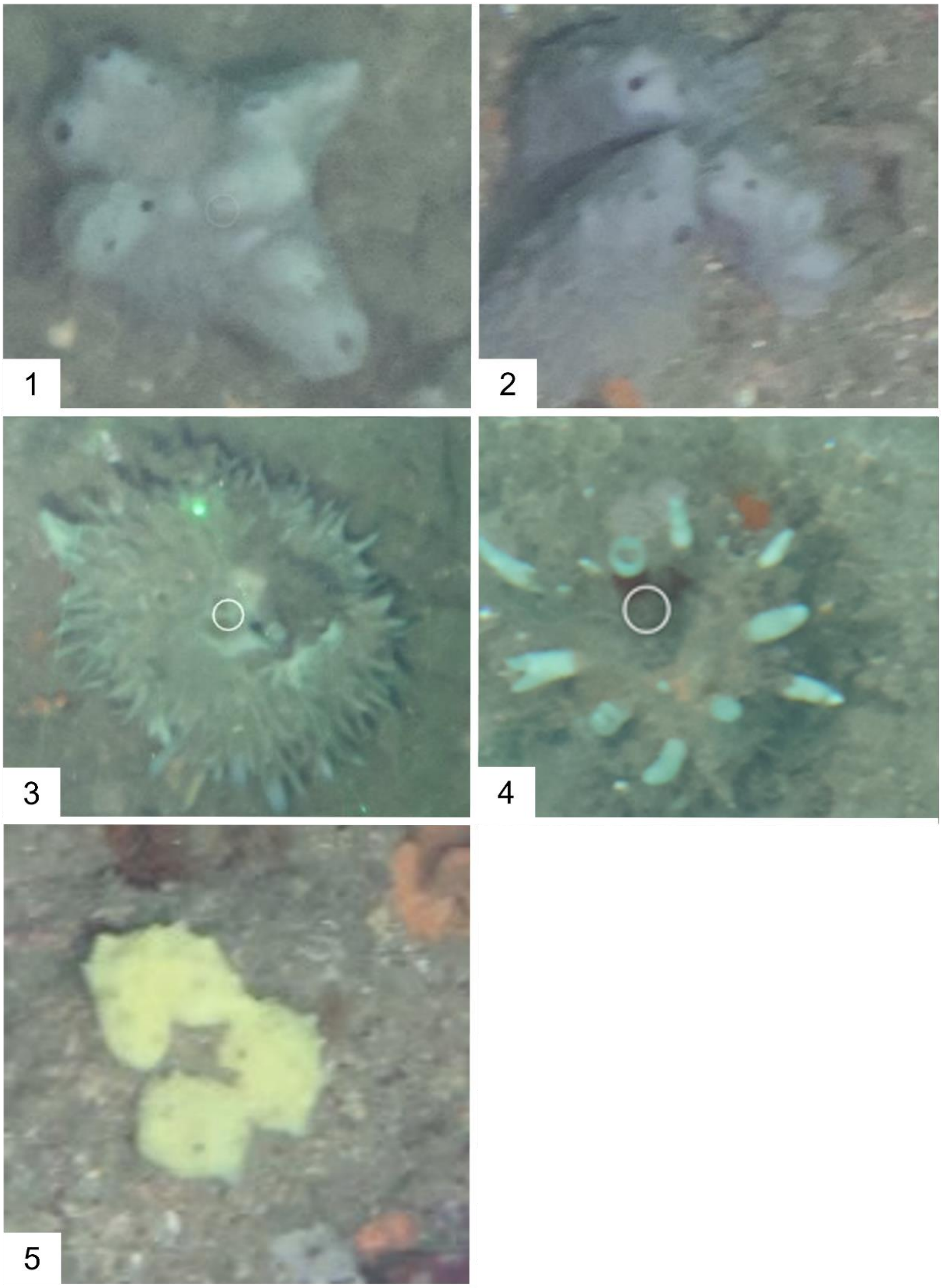
1: Massive Black Oscula Papillate
2: Massive Blue
3: Simple Yellow Lumpy
4: Massive White Shapeless



Porifera > Massive > Simple (cont.)

1: Ball White
2: Simple Orange Globes
3: Simple Grey Brain
4: Simple Blue Laminar-like Oscular*

* Requires addition to Australian Morphospecies Catalogue



Porifera > Massive > Simple (cont.)

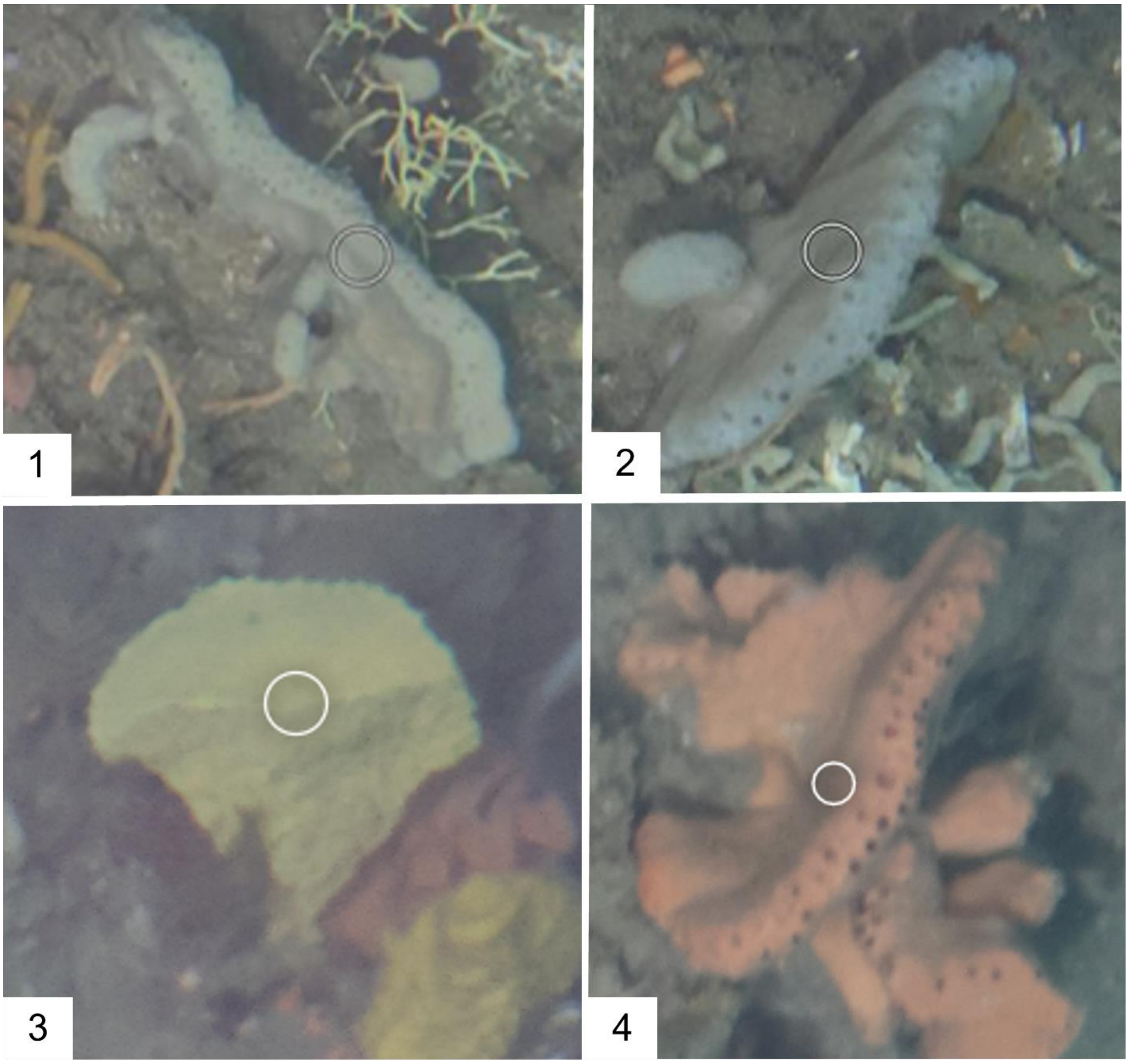
1: Blue Simple Shapeless Oscular

2: Simple Purple Shapeless

3: Massive Blue Spikey*

4: Massive Simple (*Oceanapia* sp.*)

5: Massive Yellow irregular Ball

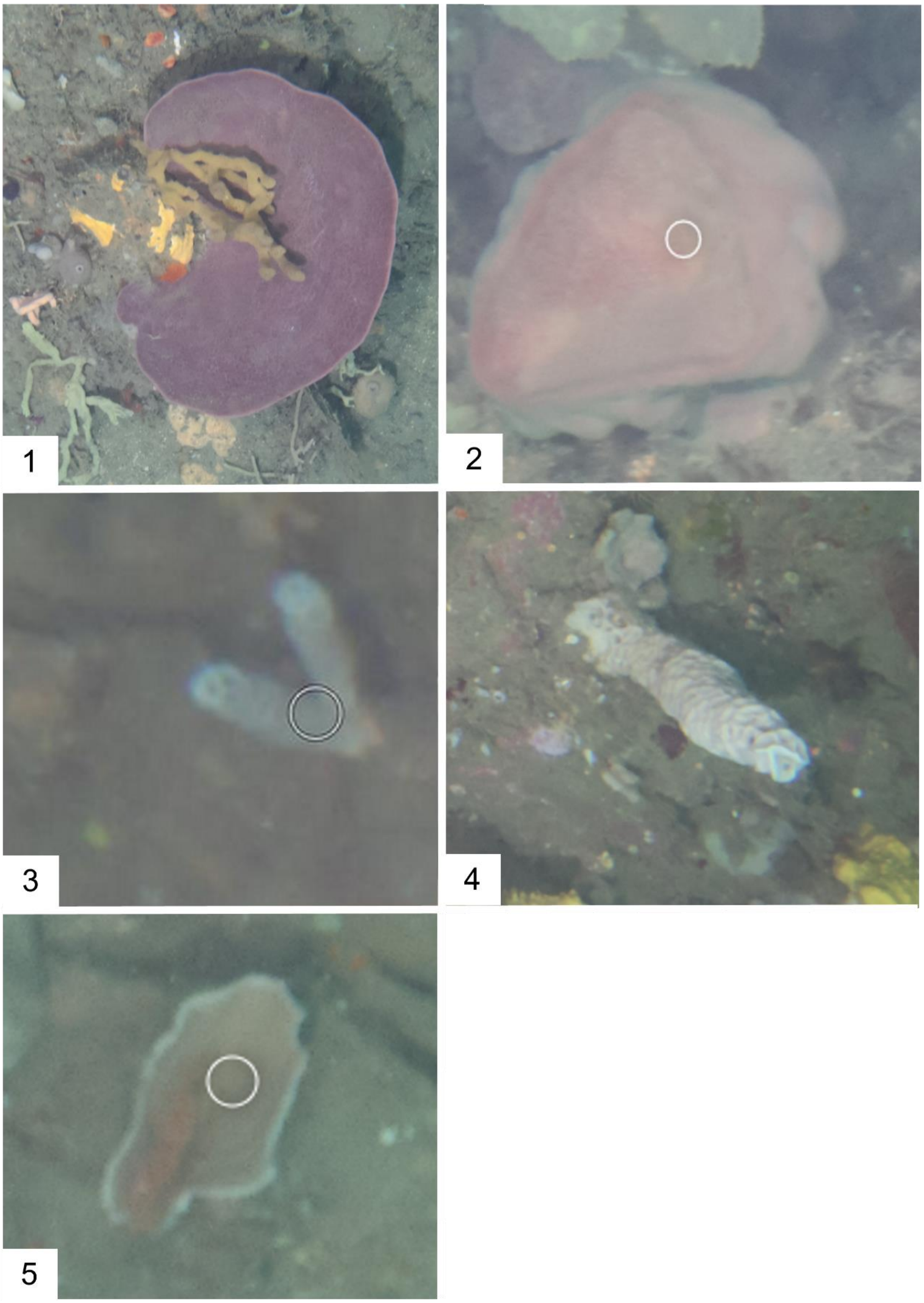


Porifera > Erect > Laminar

1: Laminar White Irregular
2: Fan White Thick
3: Yellow Fan
4: Laminar Orange Oscular

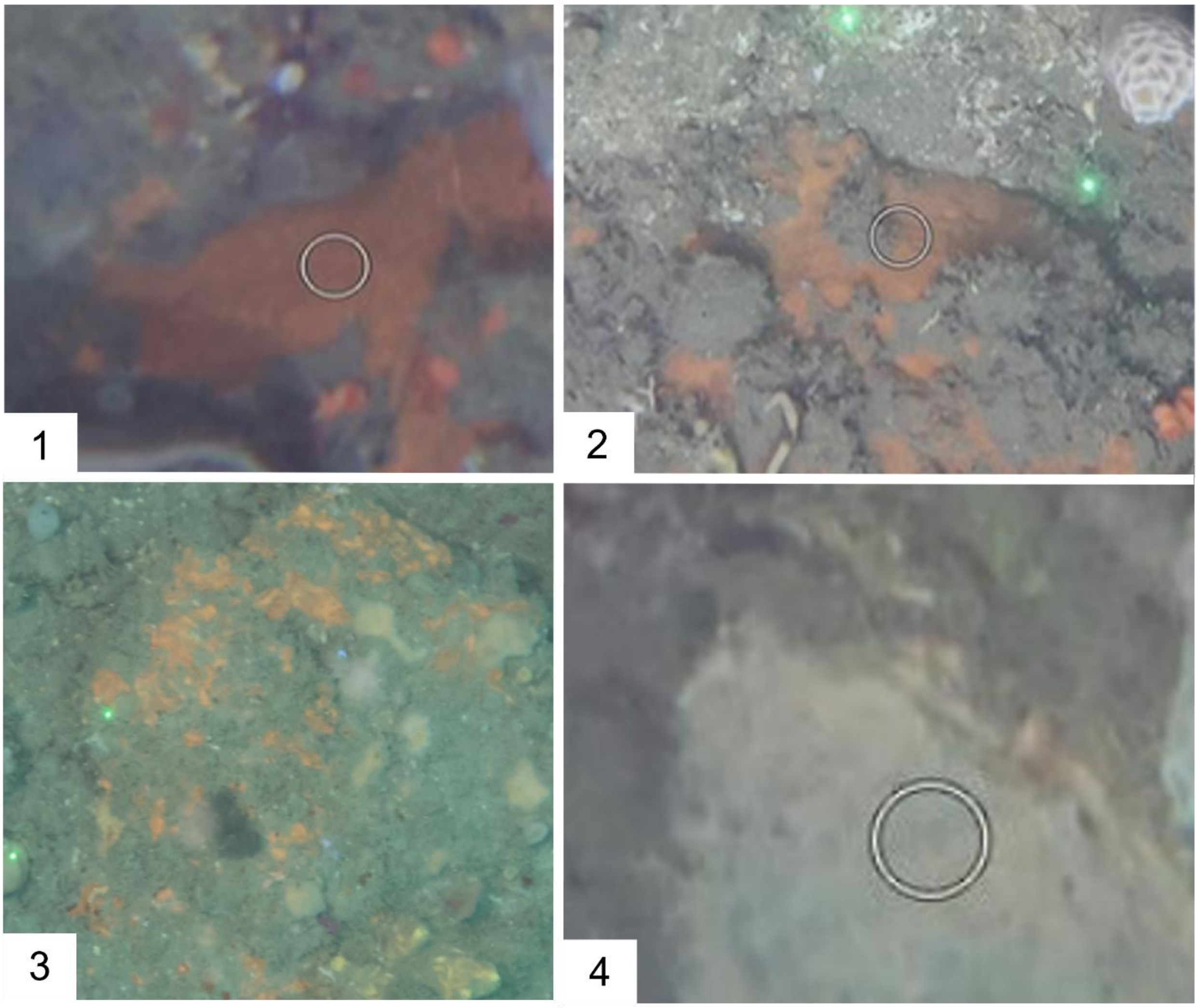
Erect > Cup-likes

1: Incomplete Cup / Curled fan > Fan Pink
2: Cup Pink Thin
3: Cup Pink Thick
4: Red Smooth



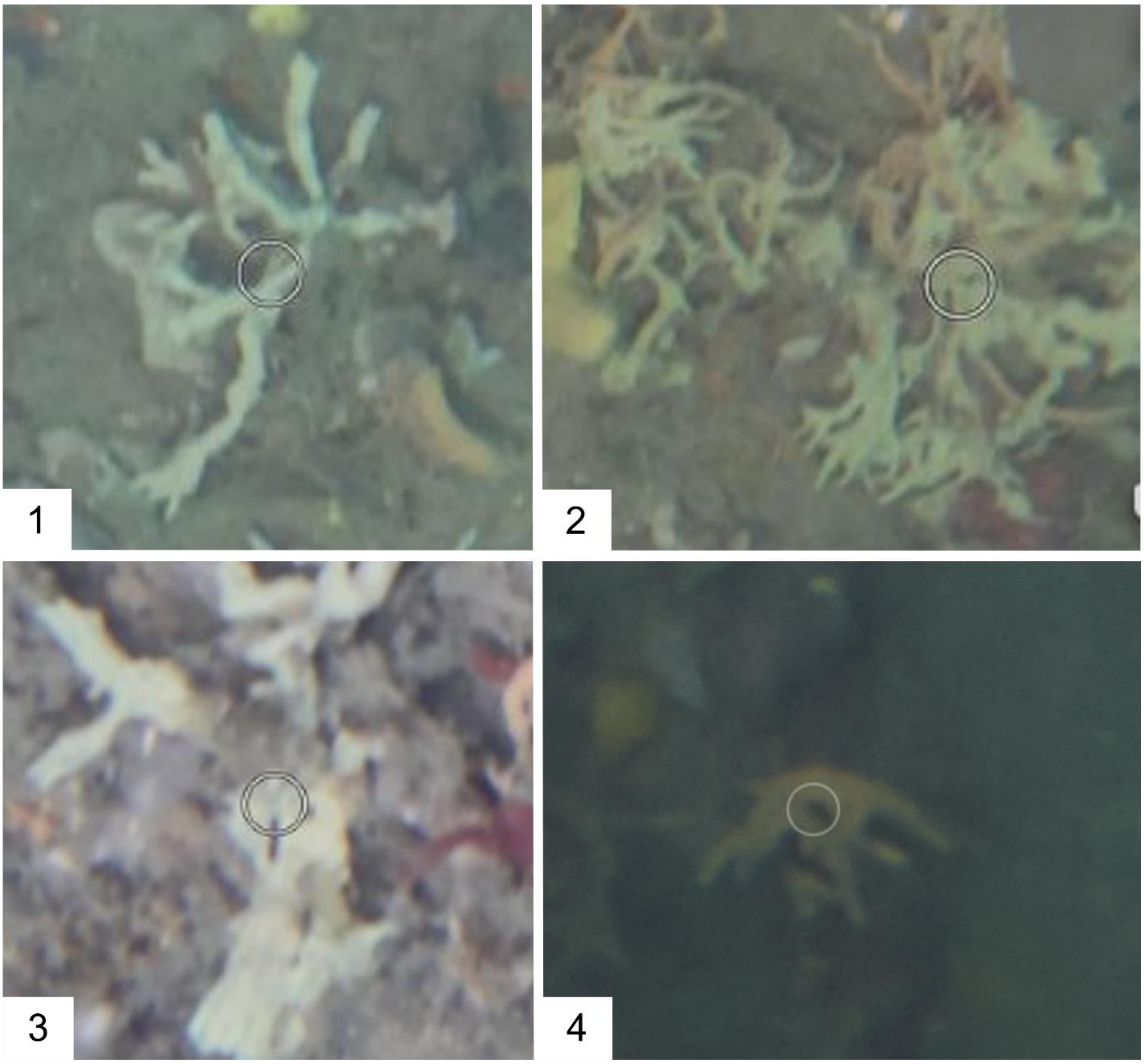
Porifera > Cup-likes

1: Cup Pink Thin Smooth
2: Pink thick
3: Tubular Blue
4: Tubes and Chimneys
5: Cup Orange



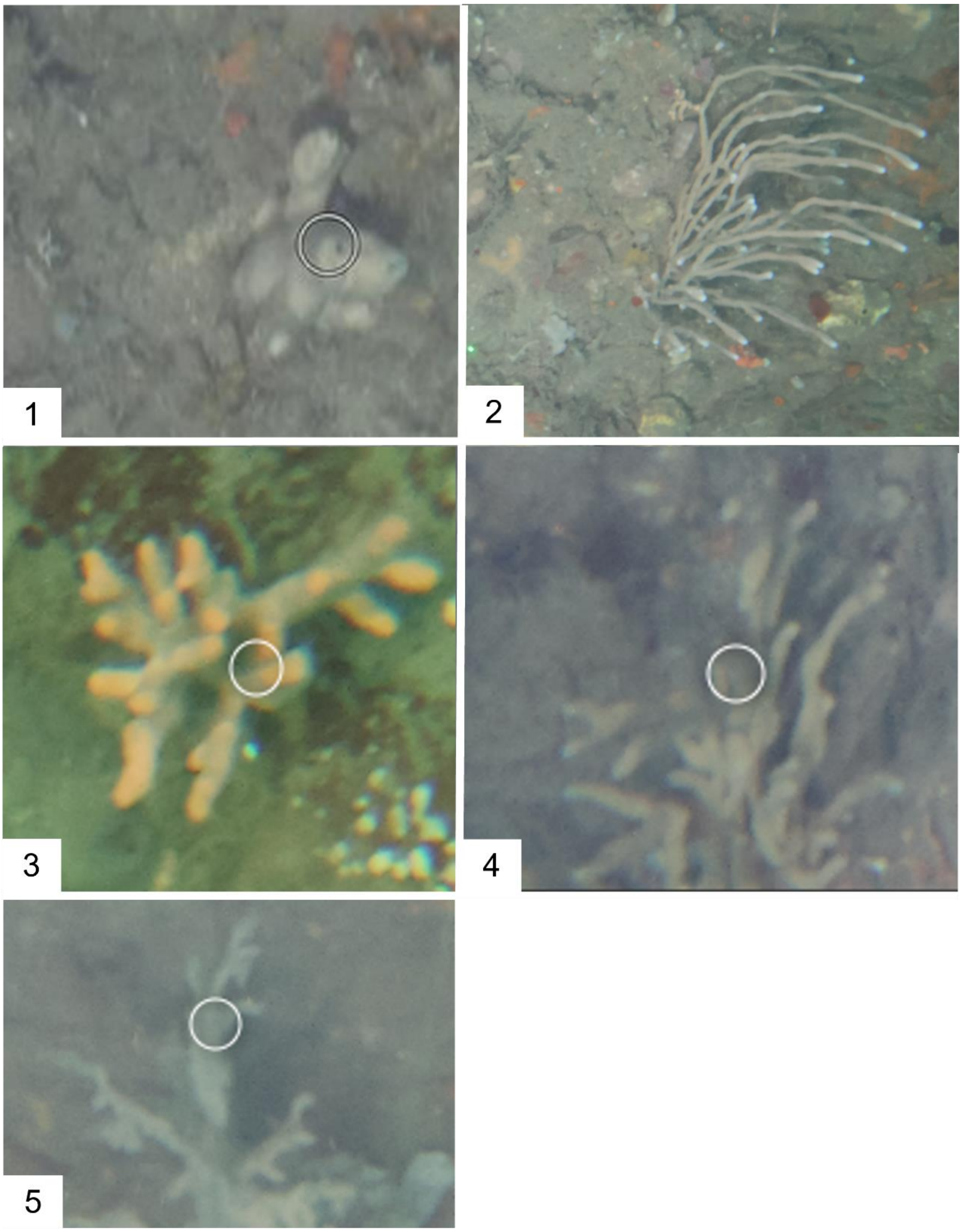
Porifera > Crusts > Encrusting

1: Encrusting Orange
2: Encrusting Orange Fluffy
3: Encrusting Light Orange
4: Encrusting White



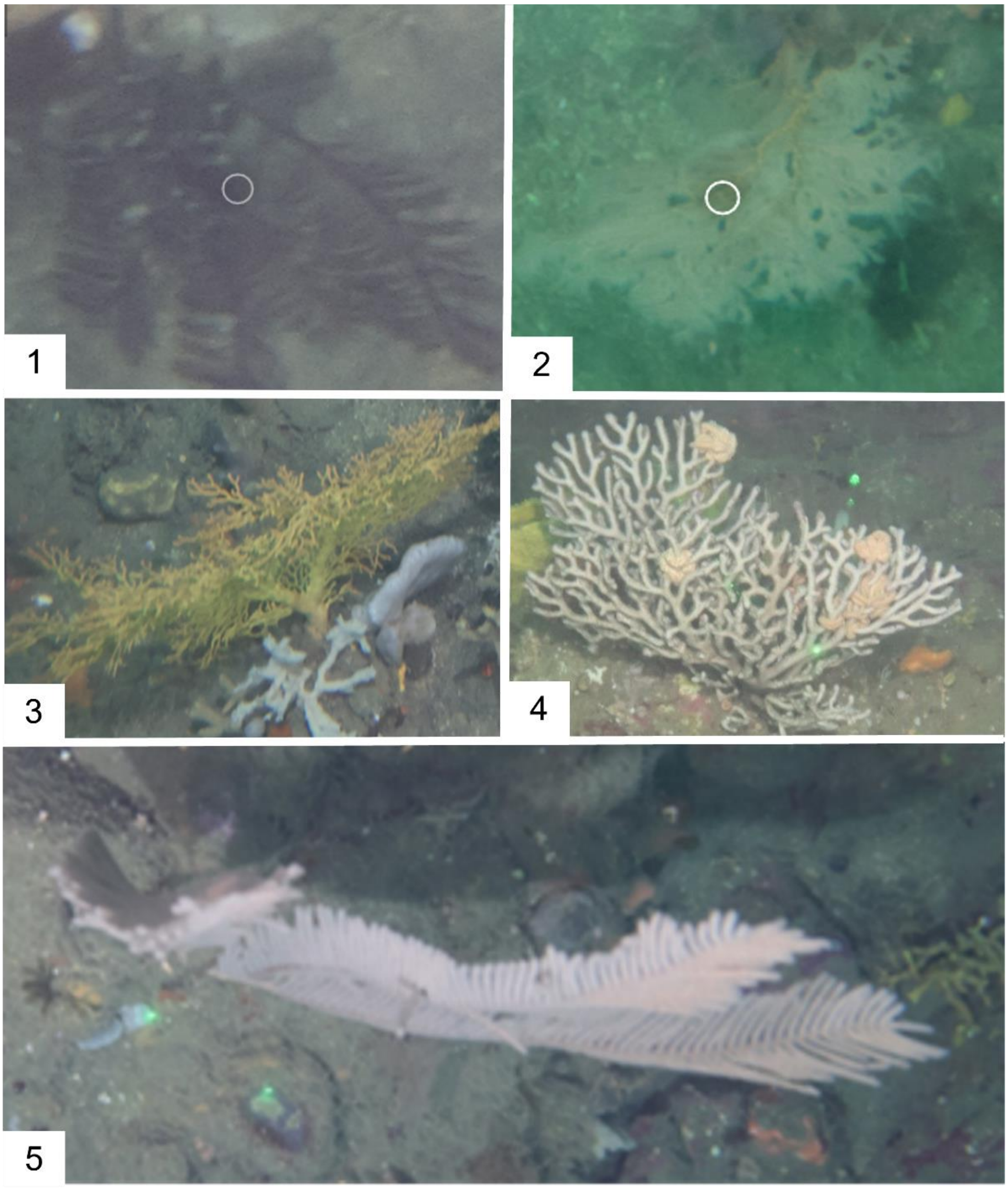
Porifera > Crusts > Creeping/Ramose

1: Creeping Fat White
2: Repent Yellow
3: White Tempura
4: Repent Orange



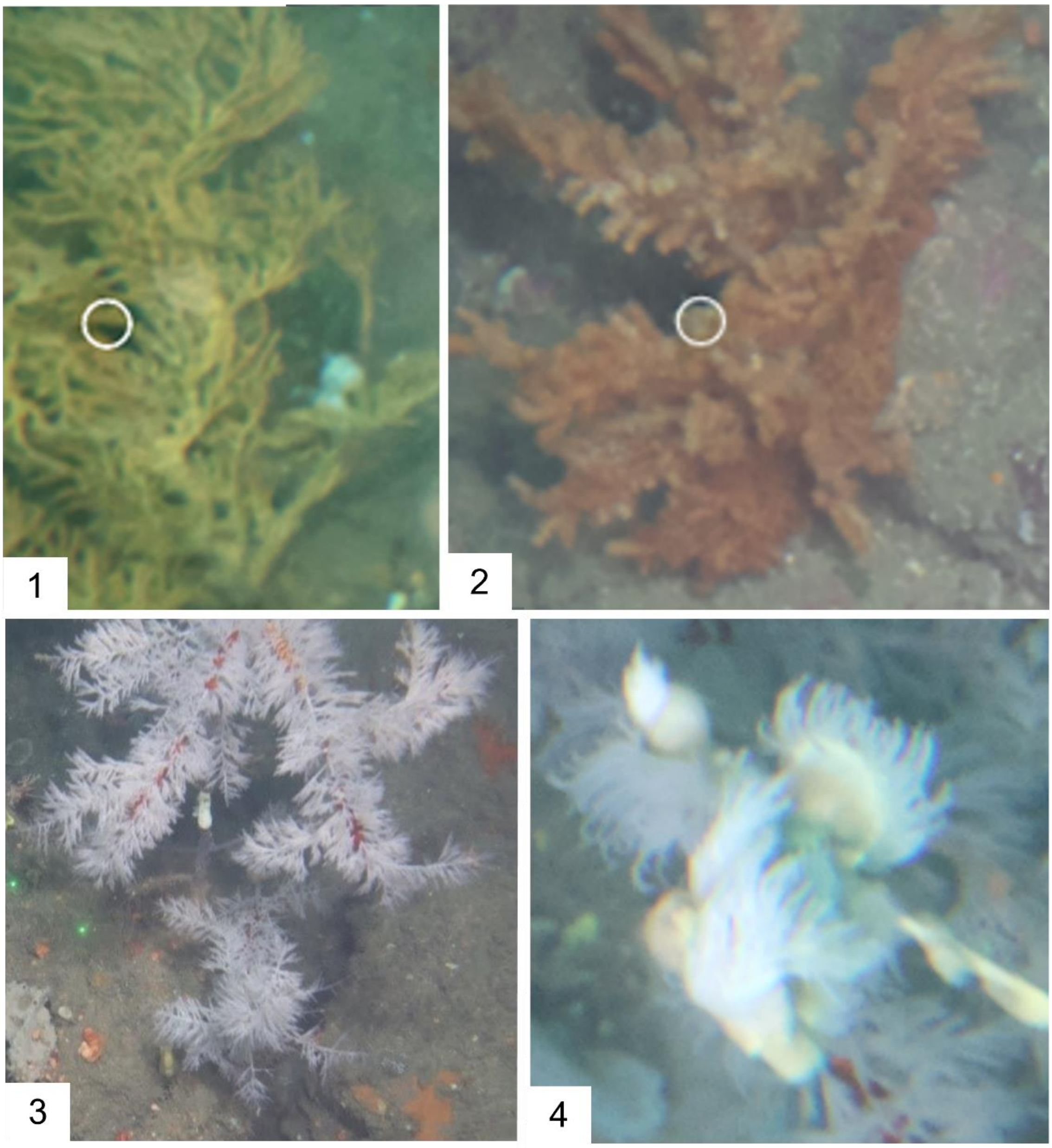
Porifera > Erect forms > Branching

1: Branching White Stubby 2: Branching Arborescent Blue Tip*
3: Branching Orange Fingers 4: Arborescent Yellow Thin
5: Arborescent White Short
* Requires addition to Australian Morphospecies Catalogue



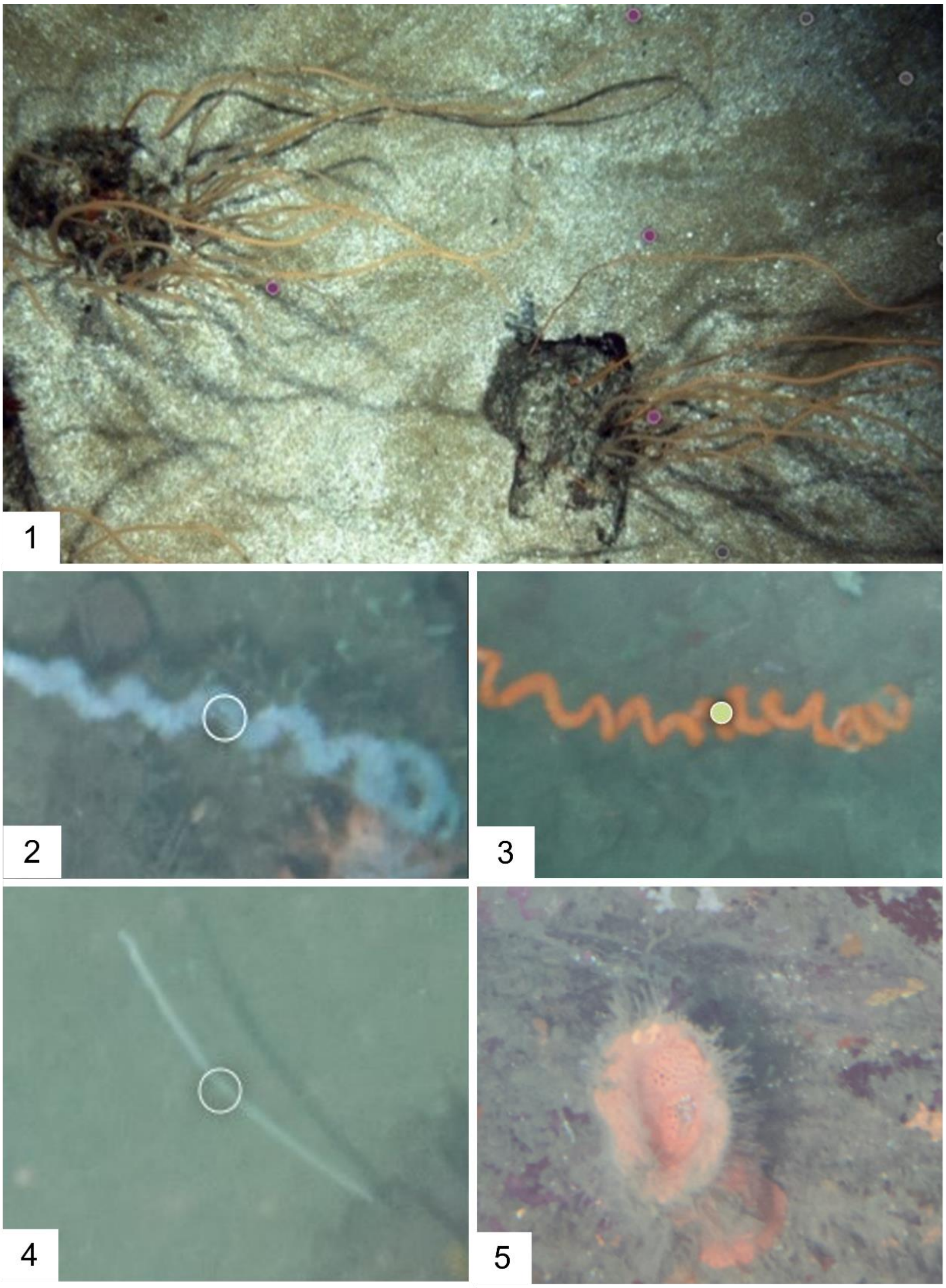
Cnidaria > Black & Octocorals > Fan 2D

1: Blackish Red Complex Fern   2: Fan 2D Complex
3: Gorgonian Red *Mopsella* like   4: Fan 2D simple
5: Gorgonian Pink *Pteronisis* like



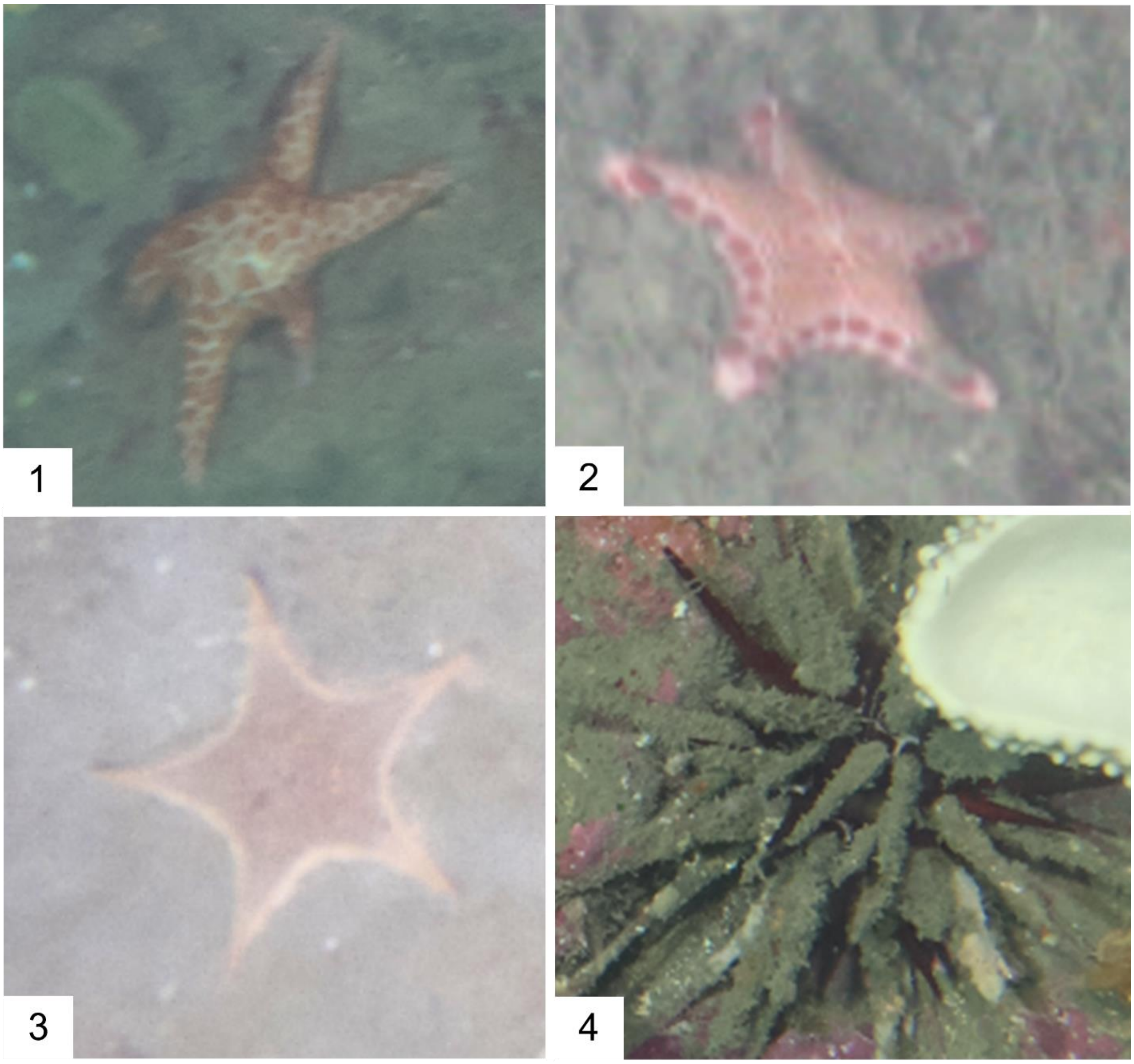
Cnidaria > Corals > Black & Octocorals > 3D Branching
1: Arborescent 2: Orange thick branching
3: Large Black Coral White Feathers

Cnidaria > True Anemones
4: True Anemones



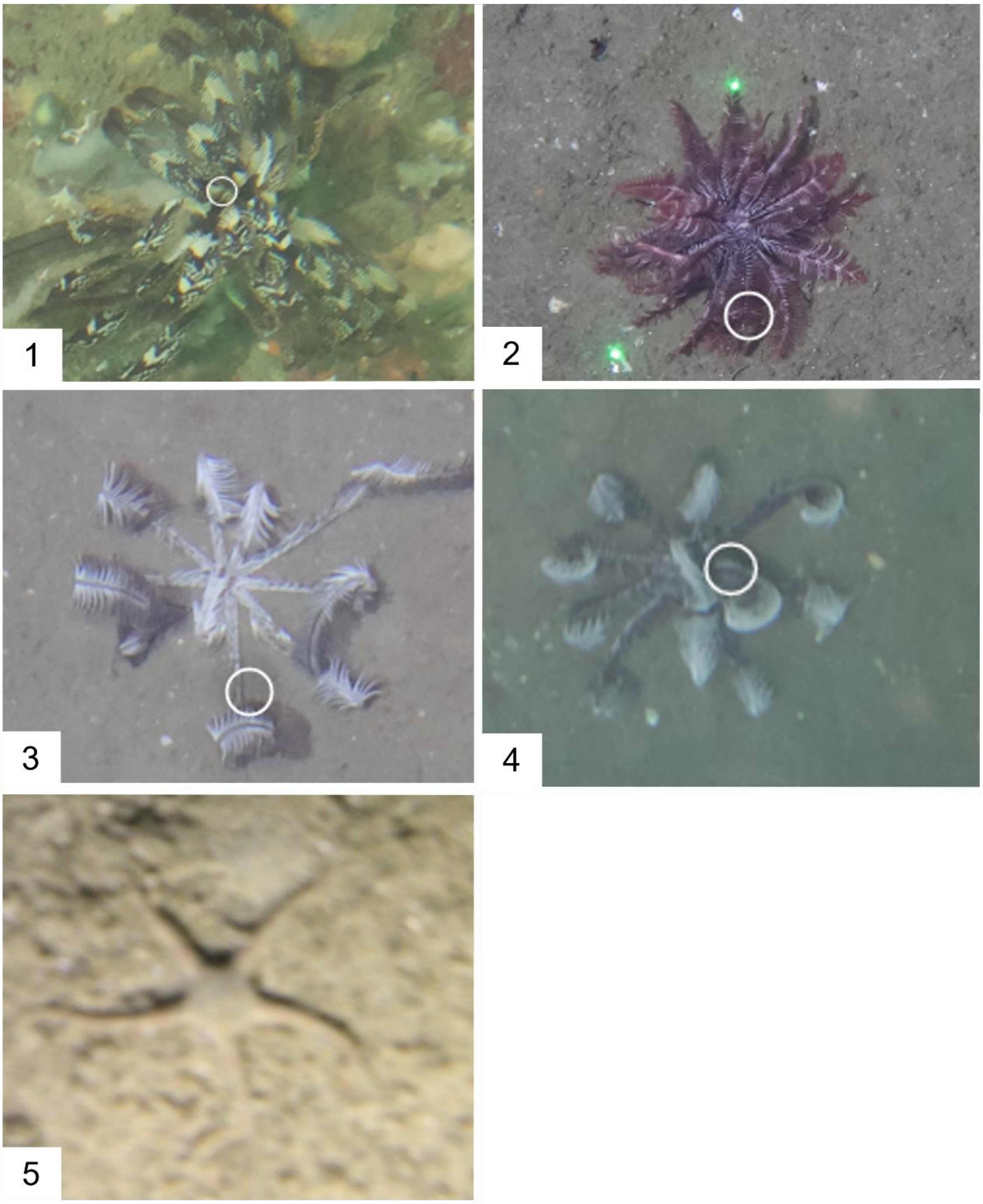
Cnidaria > Corals > Black & Octocorals > Whip
1: *Primnoella australasiae* 2,3: Small Spiral Whip
4: Seawhip

Cnidaria > Corals > Stony Corals > Solitary
5: Coral Orange Solitary (Caryophyllia like)



Echinodermata > Sea Stars
1: *Plectaster decanus* 2: *Pentagonaster dubeni* *
3: *Stellaster* sp. *

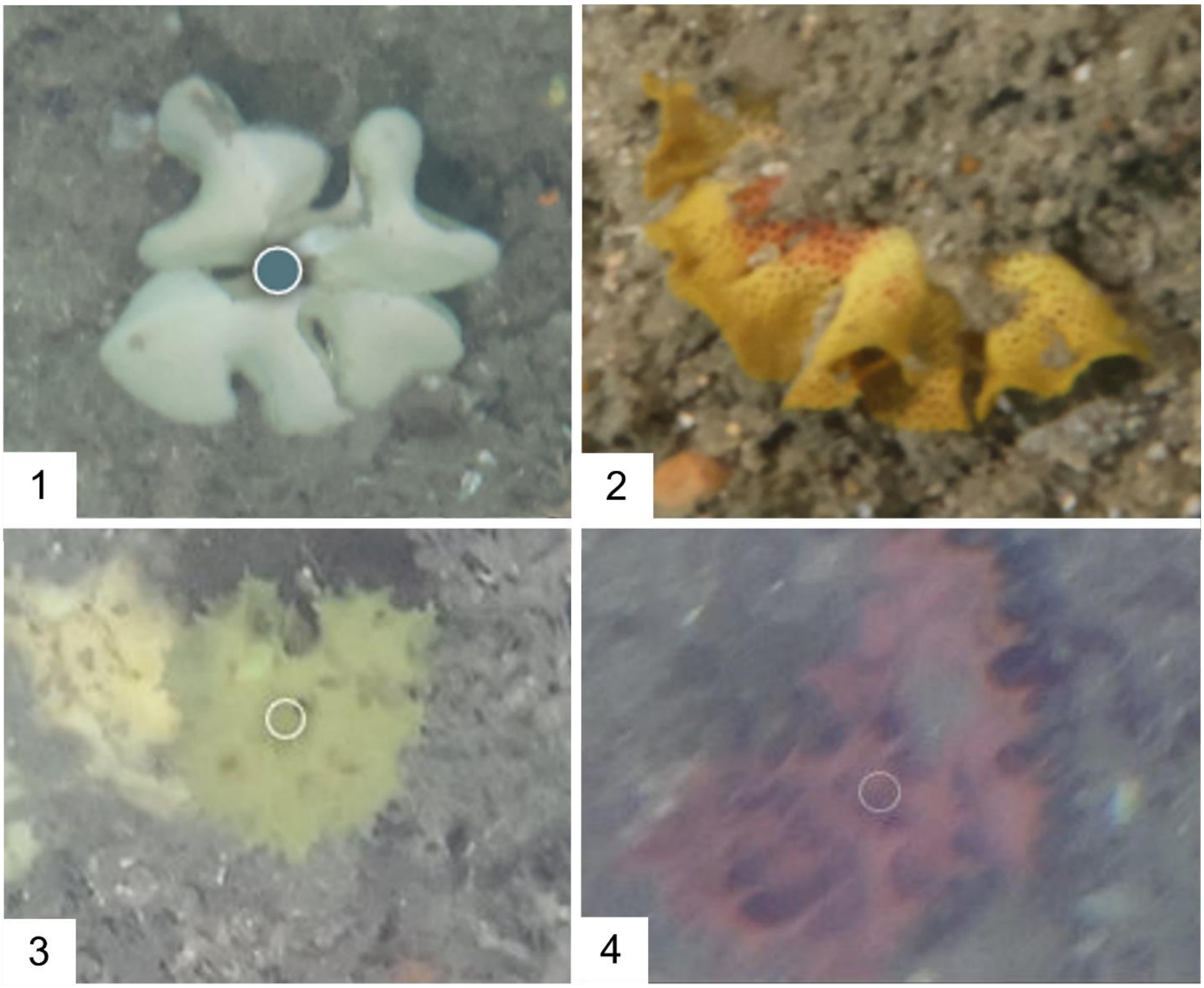
Echinodermata > Sea Urchins > Regular urchin > Pencil Urchin
4: *Prionocidaris callista* *



Echinoderms > Feather Stars
1,2: *Mariametridae* sp.* Possibly *Dichrometra palmata*)
3,4: Possibly *Oligometra serripinna* *, as characterised by 10 arms.

Echinoderms > Ophiuroids
5: Brittle Star

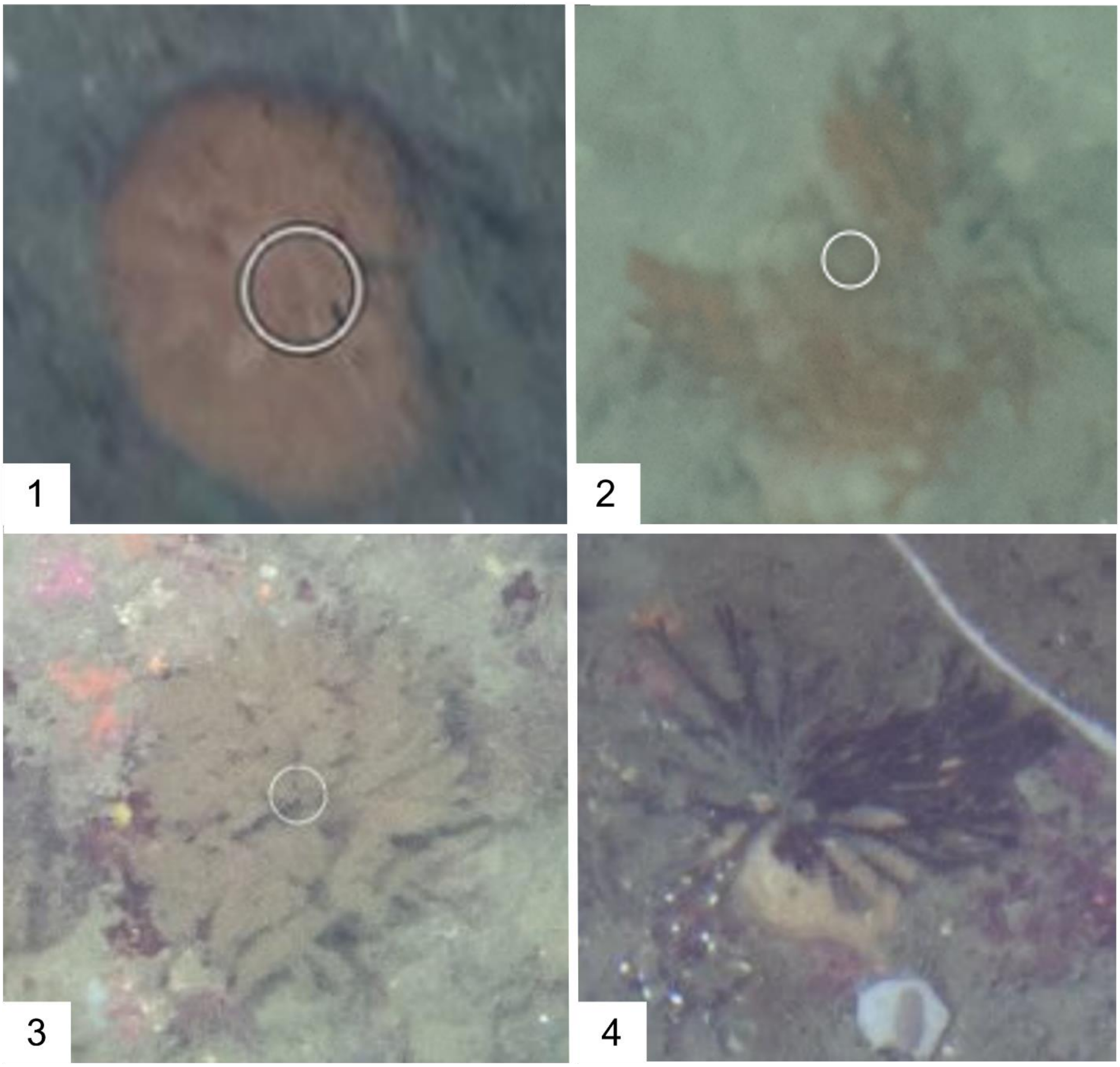
*Requires addition to Australian Morphospecies Catalogue



Bryozoa > Hard

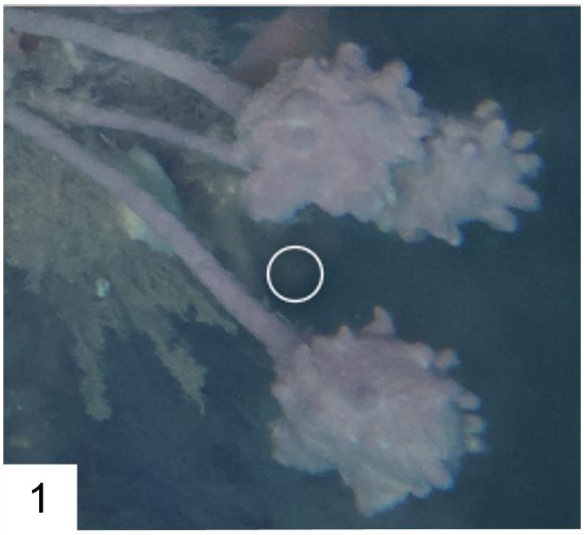
1: Fenestrate
2: Lace
3: Bryozoa Yellow Spikey*
4: Bryozoa Red Spikey

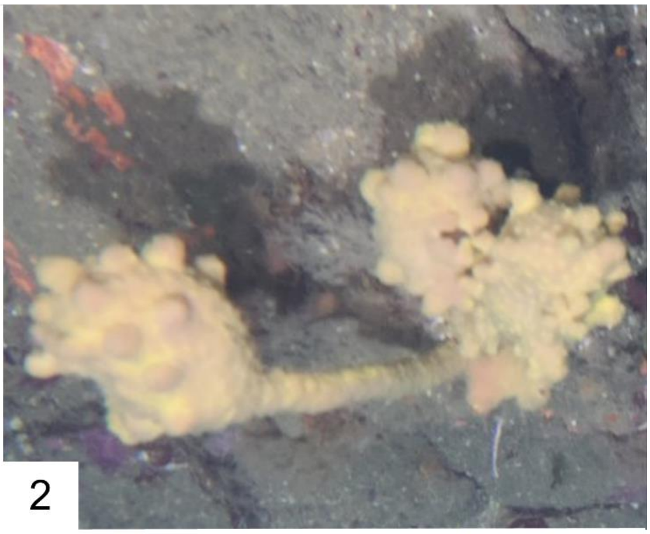
* Requires addition to Australian Morphospecies Catalogue



Bryozoa > Soft > Foliaceous
1, 2: Bryozoa Soft Orange 3: Bryozoa Soft Beige Fluffy

Bryozoa > Soft > Dendroid
4: Bryozoa Soft Dendroid Red-Brown





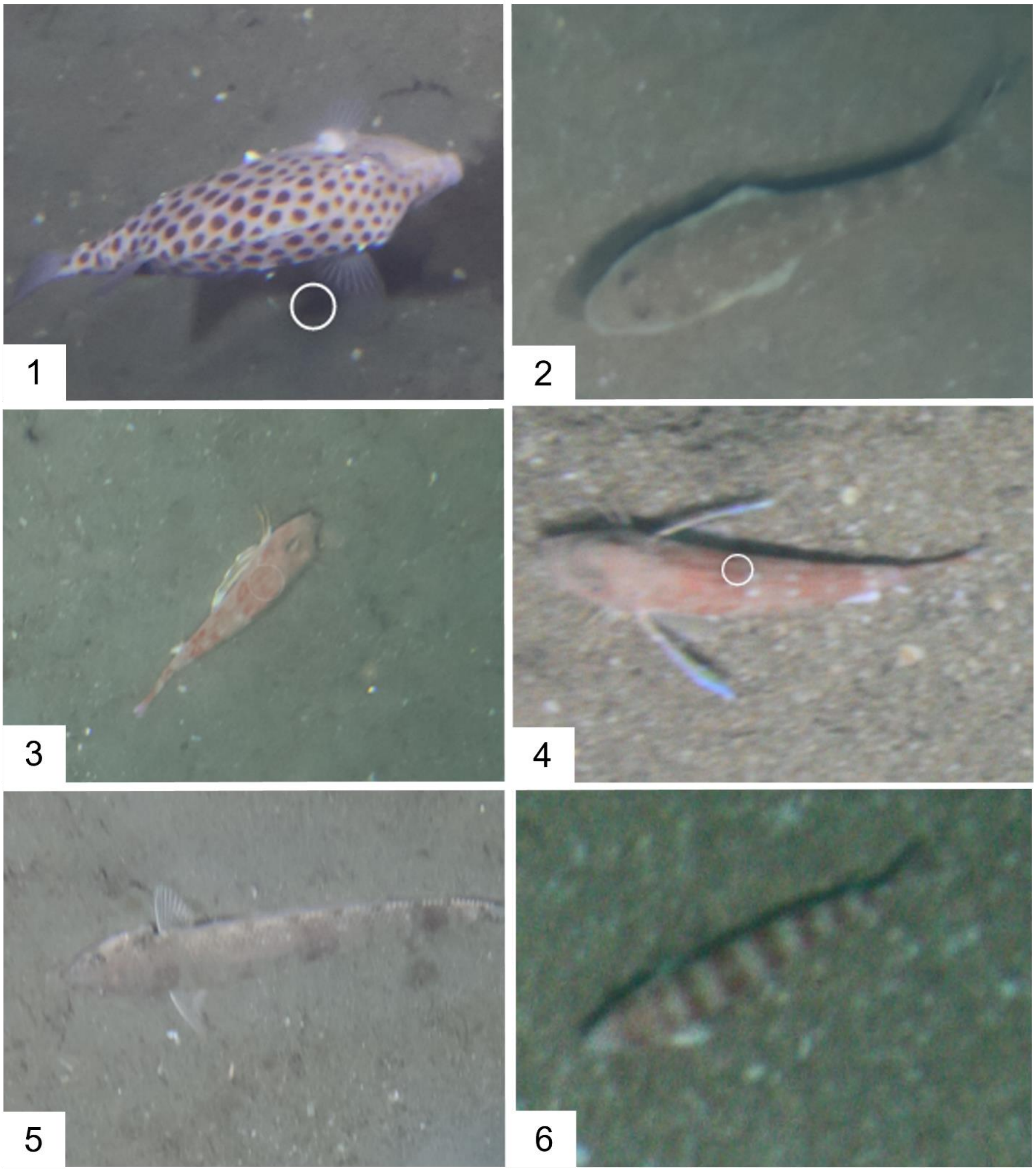
Ascidian > Solitary > Stalked

1: Purple Pyura Like

2: Yellow thorny Pyura Like

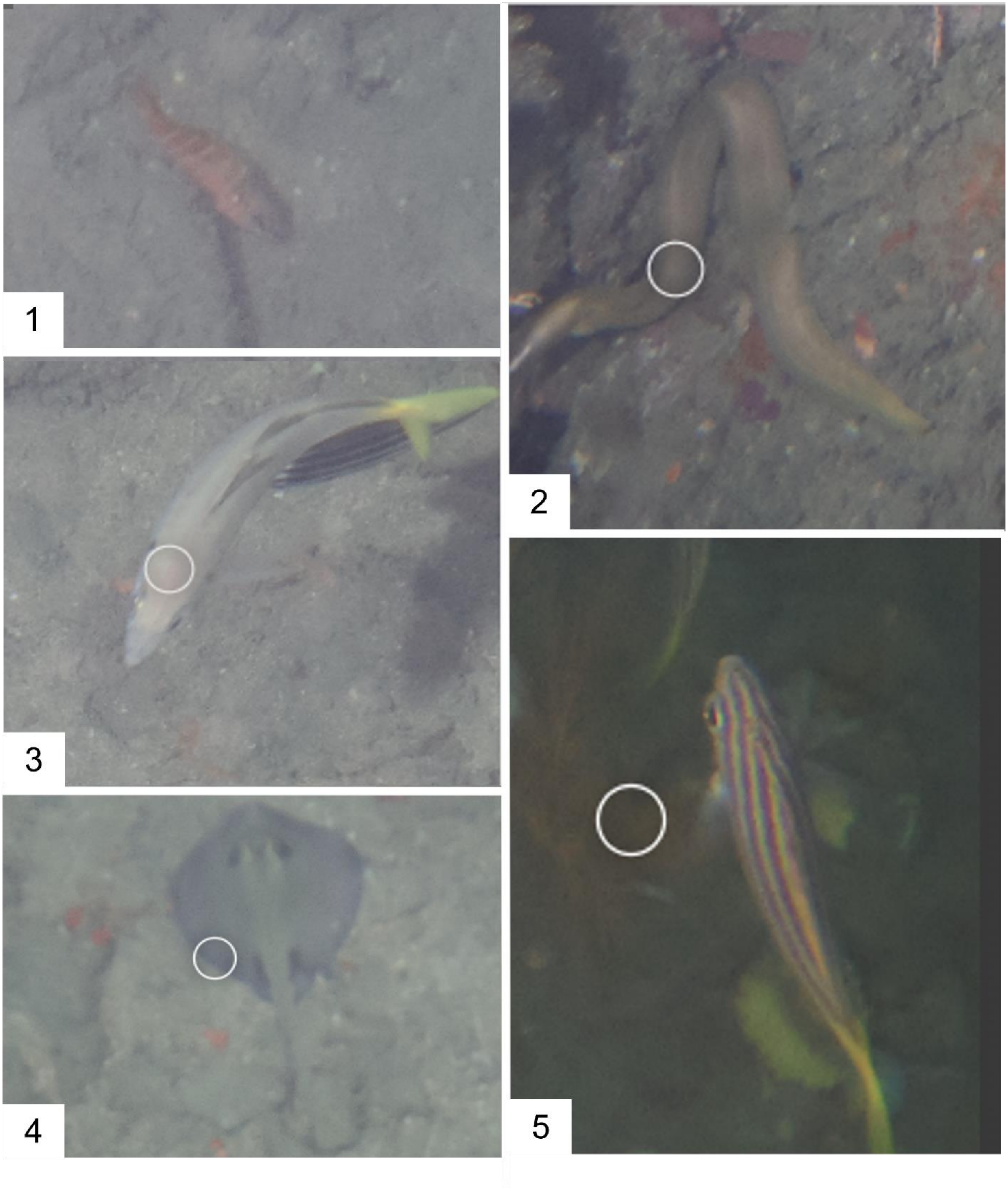
Ascidian > Solitary > Unstalked

3: Ascidian Solitary Grey



Fish

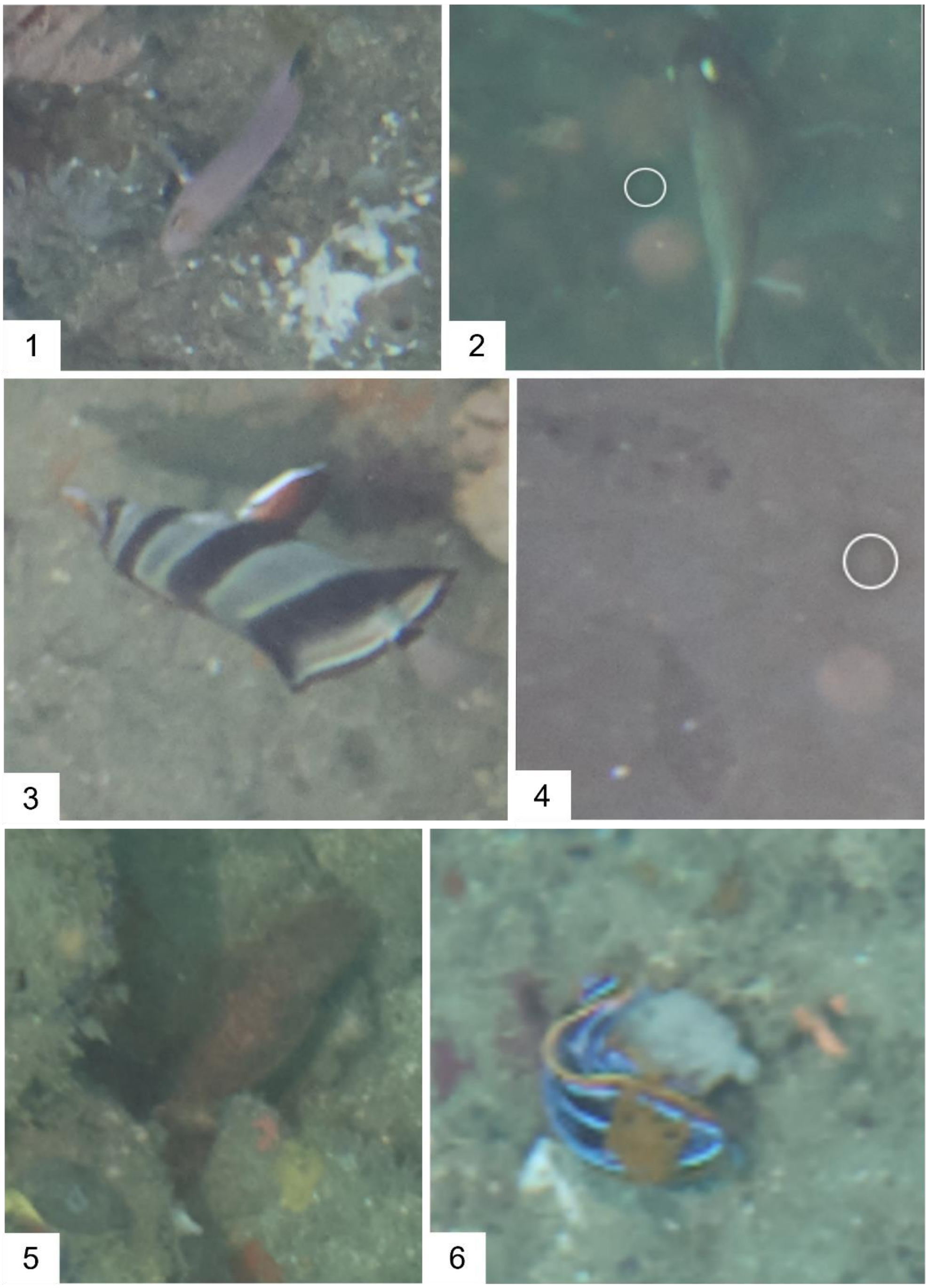
1: *Anoplocapros inermis*
2: *Playtcephalus* sp.
3: *Triglidae* sp.
4: *Triglidae* sp.
5: *Synodus* sp.
6: *Synodus* sp.



Fish (cont.)
1: *Hypoplectrodes maccullochi*
2: *Gymnothorax prasinus*
3: *Trachurus novaezelandiae*
4: *Trygonoptera testacea*
5: *Atypichthys strigatus*

Fish (cont.)

1: *Enoplosus armatus*
2: *Upeneichthys lineatus*
3: *Parupeneus spilurus*
4: *Parma microlepis*
5: *Scorpaena jacksoniensis*
6: *Parapercis* sp.



Fish (cont.)
1: *Mecaenichthys immaculatus* 2: *Eubalichthys Bucephalus*
3: *Chelmonops truncates* 4: *Pleuronectiformes* sp.

Molluscs
5: Cephalopods > Cuttlefish
6: Gastropods > Nudibranchia

APPENDIX I – SEDIMENTOLOGY RESULTS

Summary of sediment grain-size and carbonate content (loss of ignition; LOI) analysis results for (selected) grab samples retrieved from the SIMP (Figures 3-17; 3-19; 3-21).

ID	Elevation (m)	Mean (µm)	Sorting	Skewness	Kurtosis	D_{10} (µm)	D_{50} (µm)	D_{90} (µm)	LOI (%)
SAN001	-44.2	223.0	1.746	0.087	0.957	112.4	217.1	472.9	34.4
SAN002	-49.9	1107.8	2.215	0.042	1.175	413.6	1071.4	3090.7	77.9
SAN003	-52.2	618.3	1.884	-0.172	1.170	264.1	651.6	1275.4	67.4
SAN004	-51.6	767.9	1.958	0.151	1.207	356.3	716.2	1935.0	58.4
SAN005	-47.6	2158.7	2.463	-0.201	1.590	517.6	2233.4	5387.8	73.8
SAN006	-44.7	186.6	1.551	0.041	0.959	107.0	184.6	333.2	27.1
SAN007	-51.3	1066.6	2.073	-0.065	1.334	424.9	1066.7	2548.0	68.1
SAN008	-47.2	742.7	1.958	0.107	1.164	344.1	719.0	1844.3	66.4
SAN009	-45.8	491.7	1.732	-0.024	1.279	258.2	491.9	951.0	65.1
SAN010	-36.9	887.6	1.643	0.065	1.637	507.6	883.7	1665.8	45.1
SAN011	-36.6	1149.3	2.936	0.043	1.033	302.9	1102.4	4657.0	67.9
SAN012	-39.6	582.1	1.649	-0.014	1.130	299.8	584.3	1075.0	62.0
SAN013	-40.9	192.3	1.456	0.028	0.951	119.8	191.3	314.9	21.7
SAN014	-46.1	1107.1	1.841	-0.098	1.112	480.9	1154.7	2373.4	70.3
SAN015	-53.3	195.8	1.794	0.108	1.036	97.47	191.2	423.9	22.9
SAN016	-54.5	173.2	1.806	0.101	1.038	85.22	169.3	380.7	25.2
SAN018	-45.0	190.1	1.539	0.041	0.972	110.3	188.5	336.0	14.2
SAN019	-42.7	279.3	1.382	0.006	0.959	184.8	278.8	423.2	8.5
WLI001	-47.4	187.7	1.544	0.071	1.000	109.7	185.1	335.2	15.9
WLI002	-53.5	174.2	1.955	0.208	1.546	89.64	171.1	357.8	23.0
WLI003	-51.6	182.4	1.626	0.077	1.007	100.6	179.5	348.0	19.9
WLI004	-42.8	178.4	1.470	0.036	0.982	109.4	177.2	296.2	12.7
WLI005	-50.0	193.6	1.546	0.057	0.987	112.4	191.5	345.7	18.3
WLI006	-51.6	216.7	1.623	0.025	1.064	118.8	215.5	402.2	13.5
WLI007	-39.2	2066.5	2.878	-0.081	1.204	544.0	2115.5	6804.0	40.5
WLI008	-35.2	256.4	1.387	0.012	0.968	167.9	255.9	393.4	8.6
WLI009	-40.6	245.7	1.387	0.013	0.959	161.9	245.0	376.3	10.1
WLI010	-45.3	927.0	2.399	0.171	1.230	350.0	847.9	3188.5	51.0
WLI011	-41.3	1775.7	2.142	0.239	1.122	774.6	1599.3	5811.2	42.2
WLI012	-48.6	1010.7	2.219	-0.061	1.168	337.4	1031.3	2674.6	63.3
WLI013	-50.8	1039.6	2.813	-0.110	0.946	273.4	1135.9	3791.3	53.3
WLI014	-52.4	207.4	1.823	-0.163	1.178	96.14	212.2	404.6	12.6
WLI015	-58.0	249.7	2.499	-0.107	1.220	77.74	260.0	687.4	17.7
WLI016	-57.4	211.5	1.900	-0.070	1.060	92.26	213.9	460.4	20.1
WLI017	-52.4	414.9	1.680	0.152	1.406	239.6	412.4	749.3	20.2
WLI018	-54.8	213.0	1.883	-0.027	1.032	94.47	213.4	469.3	16.6
WLI019	-54.1	517.4	1.632	0.112	1.201	294.2	512.3	958.1	25.3
WLI020	-47.1	963.1	3.108	0.247	1.401	261.9	789.7	5799.5	65.1
COF001	-53.1	186.5	1.555	-0.041	1.085	106.3	186.7	320.9	19.9

COF002	-44.9	222.6	1.433	0.032	0.972	141.3	221.5	357.1	12.1
COF003	-44.1	836.8	2.724	0.353	1.841	331.7	738.6	5248.6	35.7
COF004	-47.2	631.5	2.000	-0.024	1.230	262.2	653.6	1540.1	38.3
COF005	-55.8	698.5	2.000	-0.224	1.577	252.4	737.6	1411.6	57.7
COF006	-48.1	221.1	1.601	-0.011	1.026	121.4	220.3	402.3	18.9
COF007	-51.6	1082.5	2.521	-0.206	1.085	275.6	1205.7	3123.2	68.5
COF008	-39.0	1602.8	3.953	-0.146	1.044	231.4	1855.6	9231.8	25.9

APPENDIX J – SEDIMENT ANALYSIS METHODS

LABORATORY SEDIMENT ANALYSIS

METHOD STATEMENT (BRIEF)

Client: NSW Department of Climate Change, Energy, the Environment & Water (Coastal & Marine Science)

Marine sediment samples were washed to remove salt content by soaking in purified water in 2L beakers three times, removing the water by siphon between rinses after all sediment had settled. Samples were then dried in a dehydrating oven at 60°C. Once dry, the full samples were split into subsamples for analysis, description and archive using a riffle splitter. Samples were weighed using a precision balance at all stages to measure the wet weight, dry weight and water content. The samples were photographed, described by microscope observation, and assigned Munsell colour codes.

Grain size analysis was carried out using a combination of dry sieving and laser particle sizer techniques. The coarser fractions (> 1 mm) of each sediment sample were sieved through standard half-phi aperture screens using an Endecotts Minor sieve shaker and screens. Sediment finer than 1 mm that remained after dry sieving of the coarse fractions was analysed using a Malvern Mastersizer 2000 laser particle sizer. For some samples featuring predominantly complex grain shapes, due to a high abundance of bioclastic grains, dry sieving of all fractions through half-phi aperture screens was also completed to build robust grain-size distributions from the sieving and laser particle sizer methods. The sediment grain size distributions and statistics were derived using GRADISTAT (Blott & Pye, 2001) following the method of Folk & Ward (1957).

The organic matter and carbonate ($CaCO_3$) content of samples were also analysed using the sequential loss-on-ignition (LOI) technique (Dean, 1974; Heiri et al., 2001). Small subsamples (3-4 g) were crushed to break up carbonate matter and dried in an oven overnight to derive the starting weight. The samples were then heated in a furnace at 550°C for 2 hours to oxidise organic matter and the weight difference measured. They were then heated in a furnace at 950°C for 2 hours to oxidise the remaining carbonate matter and the weight difference measured. The $CaCO_3$ content was calculated as a percentage of the subsample starting weight following the method of Dean (1974).

Blott, S.J. & Pye, K. (2001) GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surf. Process. Landf.*, 26: 1237-1248.

Dean, W.E. (1974) Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. *J. Sed. Petrol.*, 44: 242-248.

Folk, R.L. & Ward, W.C. (1957) Brazos River bar. A study in the significance of grain size parameters. *J. Sed. Petrol.*, 27: 3-26.

Heiri, O., Lotter, A.F. & Lemcke, G. (2001) Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *J. Paleolim.*, 25: 101-110.