Marine Biodiversity Hub

National Environmental Science Programme

Beagle Marine Park Post Survey Report: South-east Marine Parks Network

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Project D3 - Implementing monitoring of Australian Marine parks and the status of marine biodiversity assets on the continental shelf

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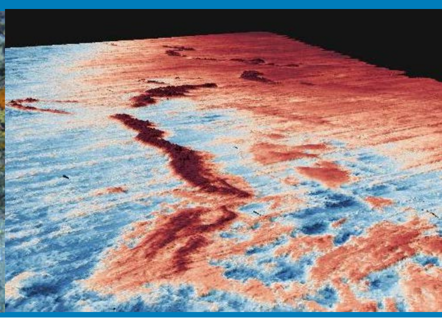


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IMOS Integrated Marine Observing System

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Important Disclaimer

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EXECUTIVE SUMMARY

This report presents preliminary results and observations of a seabed mapping and biodiversity survey of Beagle Marine Park, within the South-East Marine Park network. The survey was undertaken in 2018 by the Institute for Marine and Antarctic Studies (University of Tasmania), Geoscience Australia and the University of Sydney Centre for Field Robotics as part of Marine Biodiversity Hub Project D3—*Implementing monitoring of Australian Marine Parks and the status of marine biodiversity assets on the continental shelf.*

The objective of the survey was to collect field data to build baseline information by characterising benthic habitats in shelf waters of Beagle Marine Park that will support ongoing monitoring of the park, and adjacent Bass Strait habitats. Existing bathymetry mapping and underwater imagery for the park indicated that the seabed is characterised by soft sediments with some low-profile reef. The reefs are recognised as a Key Ecological Feature (KEF), but their true extent was unknown and they had yet to be described from a biodiversity and ecological perspective.

The survey was completed over three stages between June and November 2018, comprising: Stage 1 – Seabed mapping to acquire high resolution bathymetry and backscatter data across 13 survey grids, covering a combined area of 407 km^2; Stage 2 – Deployment of an Autonomous Underwater Vehicle (AUV) to acquire high resolution downward-facing imagery of epibenthic biota and seabed substrate along 15 transects to characterise reef and adjacent soft sediment habitats, plus targeted dredge sampling of reef material and seabed sediments; Stage 3 – Deployment of Baited Remote Underwater Stereo Videos (stereo BRUVs) at 124 sites to acquire footage of demersal fish assemblages. Importantly, all stages of the survey, from mapping to BRUV deployment, were based on a spatially-balanced sampling design to ensure that estimates of proportion of habitat types or abundances of key species, were representative of the park as a whole.

Seabed mapping results show that water depths decrease from 84 m in the west of Beagle Marine Park to 53 m in the east and there are extensive areas of mobile, sedimentary bedforms and limited areas of raised hardground reef. Of the 13 survey grids, the nine grids located in the deeper western part of the marine park are characterised by continuous sediment cover and active bedforms, including 2D (straight crested) and 3D (wavy to sinuous crested) dunes. These bedform fields are generally low profile and broadly oriented in the direction of tidal flow (SW to NE), but with dune heights less than one metre, such that the overall seabed is defined as planar. In contrast, the four survey grids in the shallower eastern area of the marine park are characterised by fields of linear evenly spaced ridges that extend several kilometres along a consistent SW to NE alignment. These features likely represent the seabed expression of the underlying sedimentary rock of the Bass Strait region, with a thin mantle of sand and gravel.

The raised areas of hardground reef mapped during this survey are very limited in spatial extent, covering ~5 km^2 (~1% of the mapped area of Beagle Marine Park) but represent an important geomorphic feature of the marine park. From prior mapping in this region, coupled with a concurrent mapping program in the northern part of the park by the AHO, we believe the reef features described here are the most significant in the park, and represent the vast majority of reef to be found there. Rising up to 5 m above the surrounding seabed in water depths of ~60 m, these reefs form narrow (100-200 m wide) ridges that range from 200 m to ~4 km in length and are comprised of consolidated carbonate sand. In plan view, some of the ridges are broadly u-shaped, a form that is consistent with terrestrial (aeolian) dunes. On the

basis of this shape and the cemented condition of the carbonate sand, these reefs are interpreted as relict coastal dunes that formed on the Bass Strait land bridge that connected Tasmania to the mainland during the last glacial period, ca. 15,000 – 12,000 years ago. As such, they are a rare geological feature preserved within the marine park that fall within the ‘twilight reef’ category of natural values for Australian Marine Parks.

These drowned and lithified ancient dune systems now form a complex reef system running for many kilometers northward from the Kent Group of Islands towards the Hogan Group of islands. During the last glacial period they would have formed a notable high-point in the land bridge between Tasmania and Victoria that the Indigenous people of the region would have used during migration. As a solid 5 m high feature with crevices and ledges, it would have formed a conspicuous shelter from wind and weather amongst what otherwise was a vast sandy plain. It now forms a similar oasis, but this time, a complex reef system surrounded by vast areas of sandy to shelly to pebbly seabed. As it is in the 55–60+ depth range, it is below the influence of strong waves and swells. However, importantly, this reef system is still subject to the large tidal currents that sweep in and out of the eastern and western ends of Bass Strait, providing an abundance of food for the sponges and other sessile (attached) invertebrate species found there, as well as providing shelter for the sharks that reside there in winter and presumably feed on the scallop beds that cover parts of the adjacent sandy seabed.

AUV imagery collected along transects across the relict dunes and adjacent sediment plain revealed four broad habitat categories, including: 1) low profile (2 – 5 m high) hard ground reef supporting moderate to high densities of sessile invertebrates (mixed sponge, bryozoan and hydroids); 2) scallop beds interspersed among unconsolidated coarse sand with shell fragments and extensive fields of sediment bedforms; 3) screw shell beds; and 4) aggregations of shell hash with broken bryozoan skeletons, and disarticulated and live scallops that provide an important substrata for a moderate cover of sessile filter feeding invertebrates.

A highly diverse epifaunal assemblage was recorded from AUV imagery, with 205 biological morphospecies identified and seven substratum types. Sponges were the dominant organism with 159 morphospecies, of which massive forms were most common. Other sponge forms observed included creeping/ramose, encrusting, branching and cup sponges. Representatives from cnidarians, bryozoans and ascidians were also recorded. Similar to other mesophotic reef environments around Tasmania (such as the Flinders Marine Park), matrix classes consisting of turf-like, finely-structured short (<5 cm) sessile invertebrates were observed to have the highest cover (matrix classes) providing an average cover of ~ 2 % in images. For the larger, more identifiable sessile invertebrates, mean cover was generally < 0.1 % overall, but when focussed on reef substrates only, this rose to 6.7% for the hard bryozoan *Adenoma grisea*, the “orange 2D” hydroid morphospecies, and 3.3% for the “soft orange” bryozoan morphospecies. Nearly 34 % of morphospecies were singletons (i.e. only seen once) and nearly half the morphospecies in the assemblage were observed less than twice. This suggests that the benthic assemblage in the Beagle Marine Park consists of morphospecies that are highly diverse and spatially rare. When compared to sessile invertebrates, doughboy scallops and invasive New Zealand Screw shells had considerable coverage, indicating both that scallops are likely an important component of the food-web in this region, and that its preferred habitat (soft sediments) is being increasingly altered by the invasive screwshell. Significant differences were found between morphospecies assemblages across habitats, with the greatest difference being the reef associated assemblage which contained the largest overall cover, diversity and within-habitat variability. Conversely, the screw shell and shelly sand habitats had lower variation (i.e. high similarity within these habitats). Sampling adequacy and power to detect change suggest that current effort was generally sufficient and that 100-200% change in proportion cover could be achieve with <1000 images sampled for most habitats and key morphospecies.

Large aggregations of port Jackson shark (*Heterodontus portjacksoni*) were observed in AUV imagery along the central ridge features in Grid 0, and while not an intended target of AUV-based sampling, indicated that the reef ridges in the Beagle Marine Park may be an important shelter location for this species during winter foraging migrations to Bass Strait, and that adjacent scallop beds may be a significant food source (although this remains to be tested).

Demersal fish were abundant across the Beagle Marine Park, with approximately 3,232 individual fish recorded by stereo BRUV video. This sample was also diverse, comprising 61 species from 33 families across the study area (which included sites outside the marine park), although few commercially or recreationally targeted species were encountered in any numbers. The most speciose family were monacanthids with eight species, followed by labrids and triglids with four species of each recorded. Commonly observed fish were Degens leatherjacket, butterfly, barber and common gurnard perches, Melbourne silverbelly, jackass morwong, rosy wrasse, cosmopolitan leatherjacket, sand flathead and draughtboard shark. Model-based abundance estimates for Beagle Marine Park were developed for selected fish species based on the spatially-balanced sampling design utilised for both BRUV deployments and mapping-based estimation of habitat cover. These estimates varied from a low of 1093 individuals (240-4978 CI) of jackass morwong to the most abundant species in the Marine Park of 61674 individuals (8452-450003 CI) of barber perch, and while based on assumptions around Max N estimation from individual BRUV deployments, provide a first park-wide estimation of individual species abundance from which to monitor future changes. Toothy flathead, blue-throat wrasse, cosmopolitan leatherjacket, draught board shark and orange spotted catshark had significantly larger lengths in the AMP when compared to reference locations. While these differences are most likely to be habitat related rather than protection effects, they both provide a reference for observing and comparing future trajectories in both areas, and a successful test of the power of our sampling effort to describe and detect differences in species size distributions in space and time. At the individual species abundance level, examination of sampling adequacy and power to detect change suggest that current effort was generally sufficient to detect biologically meaningful levels of change in most common species, with at least a 100 % increase in mean abundance being readily detected (with confidence) from a modest sampling effort (nominally 50-150 stereo-BRUV deployments at each sampling event).

In sum, these new data provide detailed insights into the distribution of sediment-dominated and hardground habitat within Beagle Marine Park, providing a sound baseline of the benthic conservation values of this marine protected area. A key highlight of the survey was the confirmed presence of a diverse temperate sponge/bryozoan dominated invertebrate assemblage on isolated reef features. These reefs, in turn, are features of significant geological and Indigenous peoples' heritage value, being rare examples of lithified dune systems that once formed an important part of the land bridge connecting Tasmania to Victoria in recent glacial periods. The valuable shelter that these would have provided to Indigenous people at the time, now provides a similar role in supporting an abundant demersal fish community. With the information from this survey, the ongoing management of Beagle Marine Park now has a baseline against which future changes can be detected and assessed.

1. INTRODUCTION

1.1 Background and Rationale for Survey

Australia has one of the largest marine jurisdictions of any country, covering 13.86 million square kilometres (Commonwealth of Australia, 2015). The oceans and coastline surrounding Australia host a vast array of ecosystems that have biological, cultural, and aesthetic value, as well as providing economic benefit through fisheries, tourism, ports and shipping, offshore oil and gas, and offshore renewable energy (Commonwealth of Australia, 2015). Australia's marine jurisdiction therefore requires careful management of economic, social, and environmental factors.

Australian, state, and territory governments have established marine protected areas around the country to provide for the protection and conservation of biodiversity and other natural, cultural and heritage values while allowing ecologically sustainable use and enjoyment. Within Commonwealth waters, 58 Australian Marine Parks (Commonwealth reserves proclaimed under the Environmental Protection and Biodiversity Conservation [EPBC] Act in 2007 and 2013) are located across six networks that span the continental shelf to the abyss. These marine parks are zoned to ensure balance between protection of the natural environment and sustainable use. Levels of protection vary between and within marine parks, ranging from very high (strictly protected areas where human use, visitation, and impacts are strictly controlled) to zones allowing exploitation of natural resources.

The impact of anthropogenic activities on marine environments is difficult to quantify in settings where natural environments and processes have not been assessed in detail. The establishment and ongoing management of marine parks therefore requires an understanding of their values and monitoring of temporal variability of marine physical and biological characteristics. This in turn will allow a better understanding of the impacts of human activities on the marine environment. Marine protected areas also provide a baseline for assessing the environmental costs of natural resource use outside the parks. Consistent and objective methodological approaches to monitoring marine parks are also required to ensure comparability between temporally offset surveys.

To monitor and understand impacts in the marine environment, the National Environmental Science Program (NESP) Marine Biodiversity Hub is supporting the development of nationally consistent tools and approaches to survey design, condition assessment and trend detection through the research theme 'Biophysical, economic and social assessments'. Within this research theme, Project D3—*Implementing monitoring of Australian Marine Parks and the status of marine biodiversity assets on the continental shelf*—aims to understand the extent and nature of rocky reefs and other seabed habitats on the continental shelf (Lucieer et al., 2016a; Bax and Hedge, 2019).

Rocky reefs are an important habitat on Australia's continental shelf, and are recognised in the Australian Marine Bioregional Plans as 'Key Ecological Features' (KEFs) that support benthic and pelagic marine communities, including migratory species (Commonwealth of Australia 2012, 2015b). However, little is known about the extent and nature of Australian temperate rocky reefs beyond their value to the commercial and recreationally targeted species (Recfish Australia, 2010; Curley et al., 2013; Williams et al., 2019). With the exception of the distribution of inner-shelf reefs within much of the Temperate East, South East and South West networks, the extent of reefs on the continental shelf is poorly delineated, anthropogenic impacts and rates of recovery are virtually unknown, and most reefs remain to be described from a biodiversity and ecological perspective (Lucieer et al., 2016a; Monk et al., 2017). Project D3 therefore supports the mapping of geomorphic and biological values of Australia's continental shelf habitats, development of habitat modelling tools and improvement in methods to identify reefs from spatial data. This work will provide background knowledge essential in monitoring and managing long-term shelf reef ecosystems (Lucieer et al., 2016b). Additionally, this information will contribute to the development of key indicators of ecosystem values and pressures for Australian Marine Parks that is being undertaken by the Marine Biodiversity Hub (Project D7, Project SS2).

Beagle Marine Park is located in north-eastern Bass Strait within the South-east Marine Park Network (Figure 1). The park sits entirely on the continental shelf, encompassing a shallow-water area surrounding the Hogan, Curtis and Kent island groups that lie within the 3 Nm coastal waters limit. The north-western edge of the park abuts Victorian waters south-east of Wilsons Promontory. Prior to this project, existing low-resolution bathymetry data indicated that the seabed in the park was characterised mostly by soft sediment with some low-profile reef.

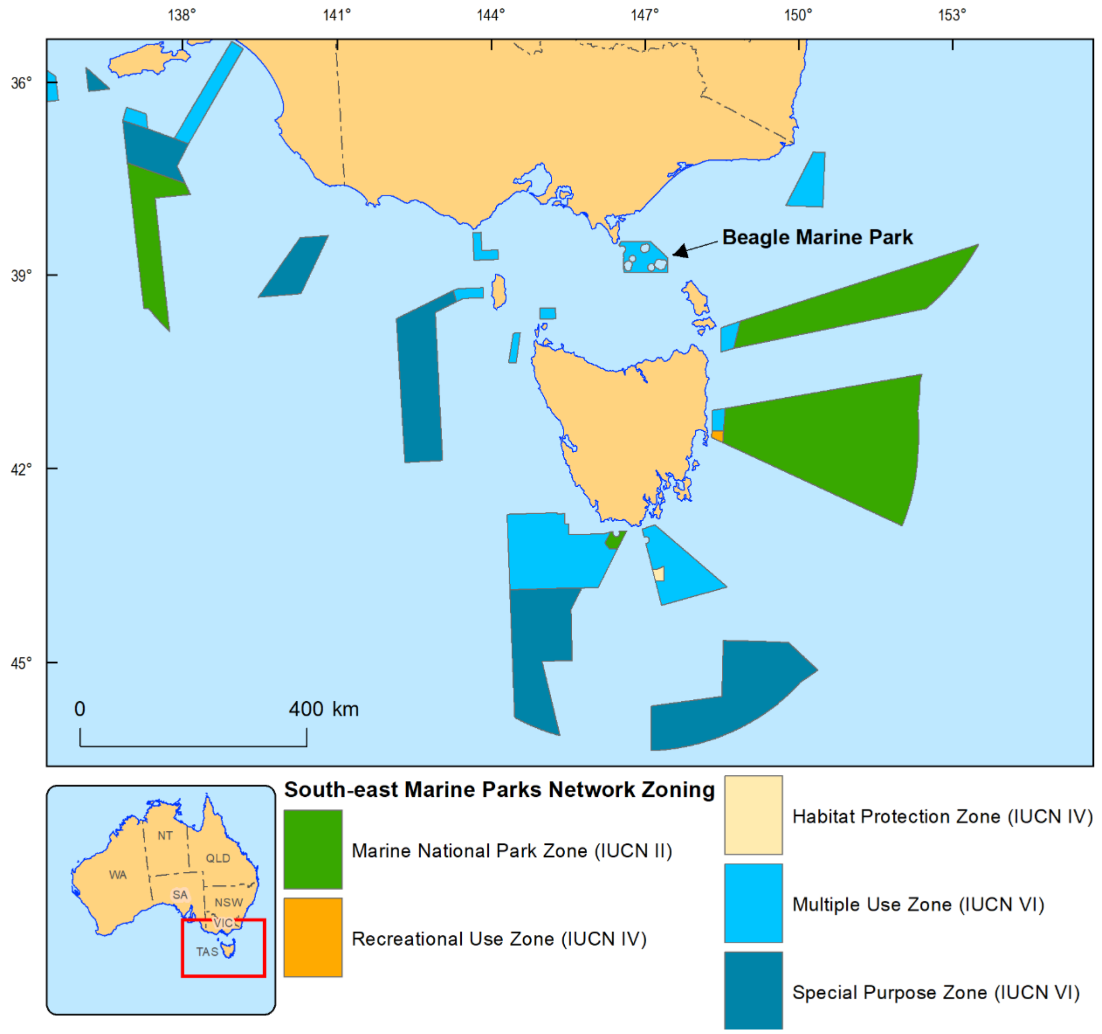


Figure 1. Location of Beagle Marine Park, in the context of the South-east Marine Parks Network.

This existing data was of too low resolution to clearly identify rocky reef features, but awareness of their presence made the park an ideal candidate to develop and test methods for identifying and characterising shelf reef environments (Monk et al., 2017). This survey therefore was designed to provide baseline information for benthic habitats in the shelf waters of the Beagle Marine Park, obtained from interpretation of new high-resolution seabed acoustic data, supported by underwater imagery and seabed sampling. This information will support ongoing monitoring of reef and other habitats in Bass Strait through use of objective and repeatable mapping methods summarised in this report. A key objective of this survey was to plan and demonstrate these methods, so that they can be employed to map and monitor other Australian Marine Parks. Participating agencies and institutions for this survey included: Geoscience Australia, the University of Tasmania (Institute for Marine and Antarctic Studies), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the University of Sydney (Australian Centre for Field Robotics), via their involvement with the Integrated Marine Observing System (IMOS).

1.2 Australian Marine Park Context

The Beagle Marine Park is one of 14 Australian Marine Parks within the South-east Marine Parks Network, located within the South-east Marine Region (Director of National Parks, 2013; Commonwealth of Australia, 2015b) (Figure 1). The South-east Marine Parks Network (formerly known as the South-east Commonwealth Marine Reserves Network) covers 388,464 km^2 off the coasts of Victoria, South Australia and Tasmania, and includes a diverse range of temperate marine environments. These environments support important ecosystems and species, some of which are found nowhere else in the world (Director of National Parks, 2013). The South-east Commonwealth Marine Reserves Network Management Plan covers the period between 2013 and 2023 and is the primary tool for conservation and management of marine parks in the south-east region (Director of National Parks, 2013). The management plan assigns an International Union for Conservation and Nature (IUCN) category to each marine park in the network, in accordance with the requirements of section 367(1)(a) of the EPBC Act. The Beagle Marine Park is designated IUCN category VI—Multiple Use Zone, which allows for general sustainable use and activities that do not significantly affect benthic habitats.

1.2.1 Marine park summary

The Beagle Marine Park covers an area of 2928 km^2, and encompasses shallow continental shelf habitats and ecosystems in water depths of about 50–90 m. The park protects fauna and flora characteristic of the central Bass Strait, including rocky reef habitats supporting beds of encrusting, erect, and branching sponges, rhodolith beds, sediment composed of shell grit with patches of large sponges, and other sparse sponge habitats (Sherwood et al., 2016; Harvey et al., 2017; Monk et al., 2017). The marine park surrounds the Kent Group Marine Park (Tasmania) that extends from the shore to 3 Nm limit of State waters that is characterised by fringing rock reefs and extensive sand dominated areas (Jordan et al., 2005). These islands and others that are also enclosed by Beagle Marine Park (Hogan Island and Curtis Island groups) support important breeding colonies for many Australian seabirds, as well as Australian fur seals (Commonwealth of Australia, 2015a). The waters of the park provide an important foraging area for marine fauna, including apex predators such as white sharks (*Carcharodon carcharias*). The park also encompasses two historic shipwreck sites: the wrecks of the steamship *SS Cambridge* and the ketch *Eliza Davies* (Commonwealth of Australia, 2019).

1.2.2 Key ecological features

'Key ecological features' (KEFs) are elements or features of a marine area that are regionally important for either biodiversity or ecosystem function and integrity. Eight key ecological features have been identified in the South-east Marine Region, and one of these occurs within the Beagle Marine Park: *shelf rocky reefs and hard substrates* (Commonwealth of Australia, 2015b). Rocky reefs and hard grounds provide habitat and shelter for fish, as well as attachment sites for macroalgae and sessile invertebrates (Commonwealth of Australia, 2015b). Despite the importance of these features, reefs have not yet been mapped or sampled in detail within the park. This limits opportunities for monitoring and protection of these features.

1.2.3 Biologically important areas

'Biologically important areas' are spatially defined areas where aggregations of individuals of a regionally significant species display biologically important behaviours such as breeding, foraging, resting, and/or migration. Many biologically important areas overlap the Beagle Marine Park (Commonwealth of Australia, 2015a). Dominant bird species that forage within the park include albatrosses (Black-browed, Buller's, Campbell, Indian yellow-nosed, Shy and Wandering) and white-faced storm petrels (AMP Science Atlas). Common diving petrels breed on islands adjacent to the park from July to January, and forage in the park year-round. Short-tailed shearwaters breed on islands within Bass Strait from October to May, but are generally present from September to May.

The park intersects a pygmy blue whale (*Balaenoptera musculus brevicauda*) migratory corridor, and therefore hosts seasonally high numbers of pygmy blue whales. The park is also part of the core range of the southern right whale (*Eubalaena australis*); the area of the park closest to Wilsons Promontory in particular is a known migration pathway for southern right whales. White sharks (*Carcharodon carcharias*) occur in low densities in coastal/shelf waters out to 1000 m, but most commonly between the 60 and 120 m depth contours. The sharks occur in low densities during autumn, winter, and spring, offshore from coastal pinniped colonies that provide a food source. White sharks may also feed opportunistically within the park as they move between nursery areas.

1.2.4 Pressures on conservation values

Sources of pressure on the conservation values of the park are the same as those affecting the broader South-east Marine Reserves Network; i.e. anthropogenic activities (Director of National Parks, 2013). Anthropogenic events and activities can be classed as either those directly associated with human activities (Cafe, 2001), or those that are related to the effects of climate change (e.g. Li et al., 2007). Regarding the former, activities that may detrimentally affect the park include:

- All types of fishing;
- Noise, oil and light pollution associated with shipping, other vessels, acoustic surveys, offshore mining operations, and offshore construction; and,
- Invasive species and diseases translocated by shipping, fishing and other vessels, and tourism.

In the case of climate change, specific large-scale effects on temperate mid-latitude marine environments are unpredictable, but may include changes in ocean currents, sea level, ocean pH, and changes in the variability and extremes of weather and climate features such as sea temperature, winds, and storms (Li et al., 2007). The vulnerability of a range of key fish species in this region has previously been assessed by Pecl et al. (2010) as part of an FRDC-funded fisheries risk-assessment, however, empirical data is required to determine which of these species are present in the Beagle Marine Park, and to monitor their trajectory over time.

The rocky reef habitats of the Beagle Marine Park are of specific interest, as they are targets for recreational and commercial fishing, which may affect local fish populations. Determining the nature of the seabed and monitoring change through repeat surveys will provide important baseline information for understanding the impact of these anthropogenic pressures.

1.3 Survey Area

1.3.1 Location

The surveyed area is entirely within the Beagle Marine Park in north-eastern Bass Strait (Figure 1). Bass Strait is a shallow sea separating south-east mainland Australia and Tasmania, comprising a broad shallow shelf region, which descends abruptly to very deep water either side of the strait (Whiteway, 2009). The mean distance between Tasmania and the mainland is ~250 km, and the median width of the modern strait (distance between the 200 m depth contours on the east and west sides) is ~550 km (Wijeratne et al., 2012). Water depths in Bass Strait range from 55 to >85 m, with the deepest point near the geographic centre of the strait (James et al., 2008). The Beagle Marine Park is bounded by the coordinates 39.2°S to 39.6°S (latitude) and 146.5°SE to 147.5°SW (longitude), and encloses areas of Tasmanian State Waters that surround the Hogan Group, Kent Group, Devils Tower and Curtis islands.

1.3.2 Climate and oceanography

Winds over Bass Strait are dominated by the mid-latitude westerlies, particularly in autumn and winter (Sturman and Tapper, 1996). The main meteorological features are cold fronts, and strong winds associated with these fronts result in a moderate- to high-energy wave dominated environment on the shelf (Li et al., 2007). Tides in Bass Strait are mainly semidiurnal, with tidal range increasing from ~0.2 m in the west of Bass Strait to a maximum of ~1.1 m near the northern Tasmanian coast (Fandry et al., 1985; Wijeratne et al. 2012). Tidal flows reach up to 2.5 m/s, resulting in locally strong currents (Sandery and Kampf, 2005) that are amongst the highest speed and power for tidal currents in southern Australia (Griffin and Hemer, 2010). This is particularly the case in the north-east of the strait, where flow is concentrated between islands (Baines et al., 1991; Wijeratne et al., 2012).

The waters of Bass Strait are generally well-mixed in winter and spring, but the central region stratifies in summer when winds are weaker (Baines and Fandry, 1983; Sandery and Kampf, 2005). The combination of shallow water with the passage of mid-latitude cold fronts also makes the region susceptible to storm surges, particularly during autumn and winter (McInnes and Hubbert, 2003). Water flux through Bass Strait is highly correlated to the local wind stress, and is therefore characterised by a dominant east-ward fluid transport during winter (Baines et al., 1991; Jones, 1980); wind-driven currents through the strait are generally weaker during summer.

1.3.3 Seabed sediments

The seabed sediments in north-eastern Bass Strait are generally coarse, comprising a mix of sand and gravel, with mud occurring only in water depths greater than 60 m closer to the centre of the strait (Jenkins, 2000; James et al., 2008; Harris and Heap, 2009). The sediments are dominantly composed of carbonate, and are a mixture of the skeletal fragments of marine organisms, carbonate grains of Holocene age (<10,000 years), older relict carbonate grains from previous sea level high stands (120,000 – 30,000 years), and a small amount of terrigenous (mainly quartz) sediment (James et al., 1992; James et al., 2008; Harris and Heap, 2009).

Of all the sediment types, bryozoan fragments form the highest proportion of the bulk sediment (Amini et al., 2004); additional biogenic components include the skeletal remains of molluscs, benthic and pelagic foraminifera, echinoids, and corals, as well as sponge spicules and calcareous worm tubes (James et al., 2008). Near the coast of Victoria, sediments are generally both coarser and richer in molluscs than further offshore (James et al., 2008). The area of seabed within the Kent Group Marine Park is also dominated by coarse sand, with a high proportion of deal shells and shell grit (Jordan et al., 2005). In the region of the Beagle Marine Park, sediment transport is dominantly via tidal currents, with some contribution from wave processes (Harris, 1995; Porter-Smith et al., 2004). The direction of net bedload flux is approximately eastward (Harris and Heap, 2009).

1.3.4 Geomorphology

There has been little detailed investigation of the seabed geomorphology of Bass Strait, probably a result of the lack of high-resolution bathymetry data. Generally, the seabed has been inferred to be soft, flat, and mostly featureless. Modern subaqueous dunes occur in discrete areas of the strait where tidal flow is constricted between two land masses i.e. islands, however these areas of inferred modern dune activity do not overlap the Beagle Marine Park (Harris and Heap, 2009). Large, flow-transverse bedforms (’sandwaves’)—which frequently occur in tidally-dominated shelf environments—have previously been identified in the shallower water immediately to the south-east of the park, in water depths of approximately 20–50 m (Malikides et al., 1988). Along a 61 km survey line, Malikides et al. (1988) identified 77 sandwaves, with an average height of six metres. Detailed analysis of these sandwaves revealed asymmetrical geometry, with steeper lee sides to the east. Large sand waves have also been mapped in 60 m water depth to the west of Erith and Deal Islands, close to the eastern boundary of Beagle Marine Park (Jordan et al., 2005). Smaller ripples are also present in troughs between sandwaves, and on sandwave crests. These features were interpreted to be mobile bedforms, based on their orientation approximately perpendicular to the prevailing ebb tidal flow. Low-resolution (40 m) bathymetry data acquired within the centre of Beagle Marine Park showed a mostly flat seabed with discrete low ridges, however these features have not been formally interpreted.

1.3.5 Quaternary history

Changing sea levels during Quaternary glacial-interglacial cycles resulted in periodic exposure of the seafloor in Bass Strait. The first sustained connection of Tasmania with mainland Australia probably occurred around 43,000 years ago, with the exposure of the ‘Bassian Rise’ connecting Wilsons Promontory with north-eastern Tasmania; this would have included the location of what is now the Beagle Marine Park (Blom, 1988; Lambeck and Chappell, 2001). The most recent exposure of the entire strait (the ‘Bassian Plain’) occurred at the peak of the last glaciation, ca. 21,000 years ago (Lambeck and Chappell, 2001). At this time, the Bassian Plain was most likely a dry, grassy plain with few trees, some low hills (the modern Bass Strait islands), and a wide shallow lake to the south-west of the marine park (Hope, 1978; D'Costa et al., 1993). During the subsequent postglacial sea-level rise, the Bassian Plain was flooded initially across the lower sea floor in the west of Bass Strait, leaving only the eastern land bridge (including the park) exposed (Lambeck and Chappell, 2001; Worth et al., 2017). Tasmania was completely separated from mainland Australia by around 14,000 years ago (Lambeck and Chappell, 2001).

The timing of the exposure and flooding of Bass Strait provides important insights into human movement, particularly concerning the first arrival of humans in Tasmania. Archaeological evidence suggests that people were present in Tasmania from at least 35,000 years ago (Bowdler, 2015), contrasting known human occupation of Australia for at least the past 50,000 years (O'Connell et al., 2018). Although Aboriginal people migrated rapidly down the east coast of Australia (Tobler et al., 2017), they were prevented from reaching Tasmania until sea level was sufficiently low to create a connection to the mainland. Whilst exposed, the Bassian Plain provided a route to Tasmania, as well as habitable terrain (Bowdler, 2015). Additionally, the intermittent seaway served as a biological filter for the dispersal of seeds between Victoria and Tasmania, which may provide insight into how seed dispersal may be affected with future sea-level rise (Worth et al., 2017).

1.3.6 Existing biological data

There has been little investigation of seabed habitats in the Beagle Marine Park, with current knowledge generated from four Baited Underwater Videos, two Autonomous Underwater Vehicle deployments and a limited number of animal-borne cameras (Volpov et al. 2015), the latter representing a non-traditional form of surveying fishes (Monk et al., 2017). The geo-located animal-borne cameras were used to record the foraging event locations of Australian fur seal. The footage revealed that foraging events occurred in seawater depths between 43 and 78 m, on low-profile sand-inundated reef covered in sparse to medium densities of sessile invertebrates, including branching, cup and massive sponges, as well as the commonly observed CATAMI class, bryozoan/cnidarian/hydroid matrix (Monk et al., 2017). In 2017, NESP researchers from the Institute of Marine and Antarctic Studies undertook a more targeted pilot study of the Beagle Marine Park using an AUV and stereo BRUVs. Imagery from that study confirmed the presence of a low-profile reef feature (Monk et al., 2017), but sessile seabed biota and benthic and demersal fish assemblages were not fully quantified.

1.3.7 Existing seabed data

Prior to this survey, the bathymetry product with the best coverage across the Beagle Marine Park was the national 250 m resolution bathymetry grid (Figure 2; Whiteway, 2009). However, for the marine park area this is largely an interpolated grid and is of insufficient resolution to identify and describe seabed features—such as rocky reefs—in the park. In 2003, the Australian Government Department of Defence (Australian Hydrographic Office; AHO) acquired MBES data at 40 m resolution (survey 'Bass Strait HI378' aboard the HMAS *Leeuwin*), for use in creating navigational charts. This data covers approximately 34% of the park and revealed the presence of low relief reefs, however the data has not been published. The AHO also acquired high-resolution data in the north and north-east of the park in 2017 (acquired aboard the RV *Investigator*, gridded to five- and two-metre resolution, respectively) and 2018 (acquired aboard the RV *Investigator*, gridded to two-metre resolution) (Figure 2). However, these data are further north than the inferred location of rocky reefs in the park and also remain unpublished. Low resolution bathymetry data is also available within the area of the Kent Group Marine Park, out to the 3 Nm limit, derived from interpolated single beam acoustic data gridded to 10 m bathymetric intervals (Jordan et al., 2005).

New high-resolution bathymetry maps will allow identification and description of seabed features that may provide important habitats in the region, and acoustic backscatter data will permit interpretation of the nature of the identified morphological features. This improved knowledge of the nature of the sea floor will inform targeted seabed sampling and acquisition of underwater imagery to identify flora, fauna, and seabed composition associated with various seabed geomorphological features.

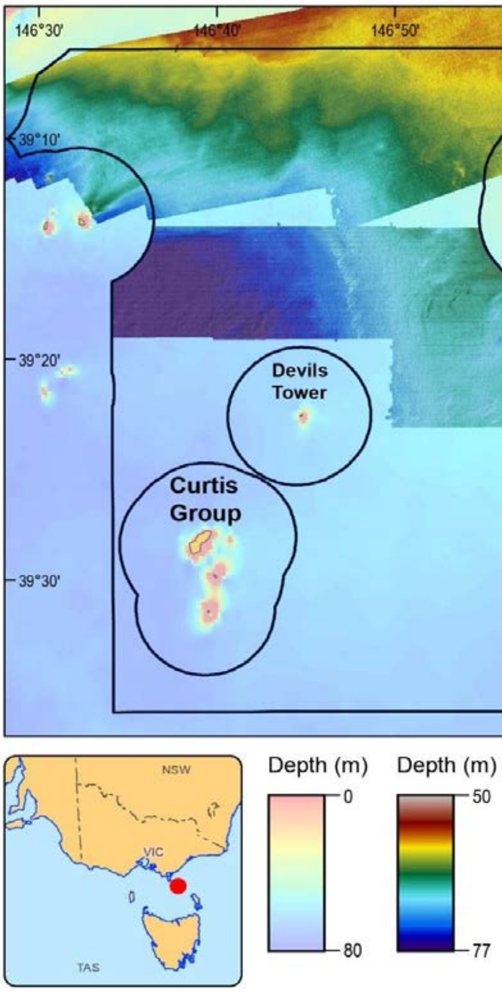


Figure 2. Existing bathymetry data in Beagle Marine Park, prior to this NESP project. The data that covers the entire area is gridded at 250 m resolution and is taken from the Australian Bathymetry and Topography Grid 2009 (Whiteway, 2009). Continuous data covering approximately 35% of the park is gridded at 40 m resolution, and was acquired by the AHO in 2003 (data not publicly available). Data to the north-west of the Hogan Group was acquired by the AHO in 2017, and data in the far north-western corner of the park was acquired by the AHO in 2018 (data not publicly available).

2. SURVEY OVERVIEW

2.1 Aims

This survey was designed to collect field data to build baseline information by characterising benthic habitats in shelf waters of the Beagle Marine Park that will also support ongoing monitoring of Bass Strait habitats. Existing bathymetry mapping and underwater imagery for the park indicates the seabed is characterised by soft sediments with some low-profile reef. The reefs are recognised as a Key Ecological Feature (KEF), but their true extent is unknown and they remain to be described from a biodiversity and ecological perspective.

2.2 Survey stages

The Beagle Marine Park survey was undertaken in three stages:

- Stage 1: High resolution acoustic mapping of seabed features and morphology (multibeam echo sounder [MBES] bathymetry, acoustic backscatter, sub-bottom profiles);
- Stage 2: Characterisation of sessile epifaunal communities (Autonomous Underwater Video [AUV] deployment) and sediment sampling;
- Stage 3: Quantification of demersal fish communities (Baited Remote Underwater Stereo Videos [Stereo BRUVs]).

Survey data collected during Stage 1 was used to characterise the geomorphology and potential seabed habitats within Beagle Marine Park. Stage 1 data also informed the selection of sites for Stage 2 – AUV deployment and sediment sampling. The stereo BRUV data acquired in the third and final Stage 3 of the survey facilitated the identification of epibenthic and demersal fish communities associated with particular seabed features (e.g. sand-inundated reefs), as well as quantitative estimates of the distribution of various benthic and demersal species assemblages within the park.

3. DATA ACQUISITION AND PROCESSING

3.1 Data acquisition

3.1.1 Seabed features and morphology

Data characterising seabed features and morphology was collected during Stage 1 and 2 of the survey from TV *Bluefin,* operated by AMC Search (training and consulting division of the Australian Maritime College, Launceston). For Stage 1 the vessel was fitted with a Kongsberg EM2040C multibeam sonar system in single head configuration and linked to an Applanix POS-MV V5 motion referencing system, with positioning data acquired on a C-Nav system.

To efficiently characterise the seabed environments across Beagle Marine Park, a spatially balanced randomised method was used in conjunction with continuous mapping within one targeted survey area where low reef features are visible in the AHO 40 m bathymetry data (Figure 2). The targeted area of reef was designated ‘grid 0’ and covered 10 km x 20 km of seabed (Figure 3). To identify the supplementary areas for bathymetry mapping the R package MBHdesign, was used to create twenty 5x5 km spatially balanced patches (Foster et al., 2017). In this design, Grid 7 overlapped grid 0, and the two were therefore amalgamated (Figure 3). This method ensures representative coverage across the park, as well as being repeatable and objective. Coverage by existing bathymetry data (Figure 2) was not taken into account when calculating the location of the 20 sites.

Bathymetry data acquisition was planned to provide sufficient horizontal resolution (1 m) to reveal detailed features of the sea floor, with this new information to then inform seabed sampling and imagery acquisition. This suite of data (seabed acoustic data, sediment samples, underwater imagery) was planned to provide the greatest possible insight into the nature of the sea floor in terms of seabed geomorphology and the habitats associated with various substrates (e.g. rocky reef). MBES bathymetry and acoustic backscatter data were collected in a total of 13 grid areas, over two separate voyages (Figure 3 & Figure 6, Appendix A).

Data were acquired in grids 0, 1, 2, 3, 4, 5, 6, 8, 9, 10, and 12 during the scheduled project voyage (survey GA0364) aboard MTV *Bluefin* in June 2018. Grid 11 overlapped the area mapped by the AHO in 2018 and was not re-surveyed (Figure 3). Grids 16, 17, 18 and 20 were not mapped due to time constraints. This did not impact the sampling design as grids were mapped in sequence to maintain the spatial balance of sampling sites. Two sub-bottom profiles were also collected, intersecting grids 2 and 4. Additional bathymetry and backscatter data were acquired in grid 13 and grid 15 during the 2019 RV *Investigator* voyage ‘RAN Hydrographic and Maritime Heritage Surveys’ (IN2019_V07). This supplementary data was acquired opportunistically when time became available during that voyage. Similar to grid 11, grid 14 was passed over in favour of mapping an area not yet covered by high-resolution data. Following the seabed mapping, sediment grab and dredge sample locations were chosen to represent geomorphic features within grid 0, including ridge and soft sediment (bedform) features.

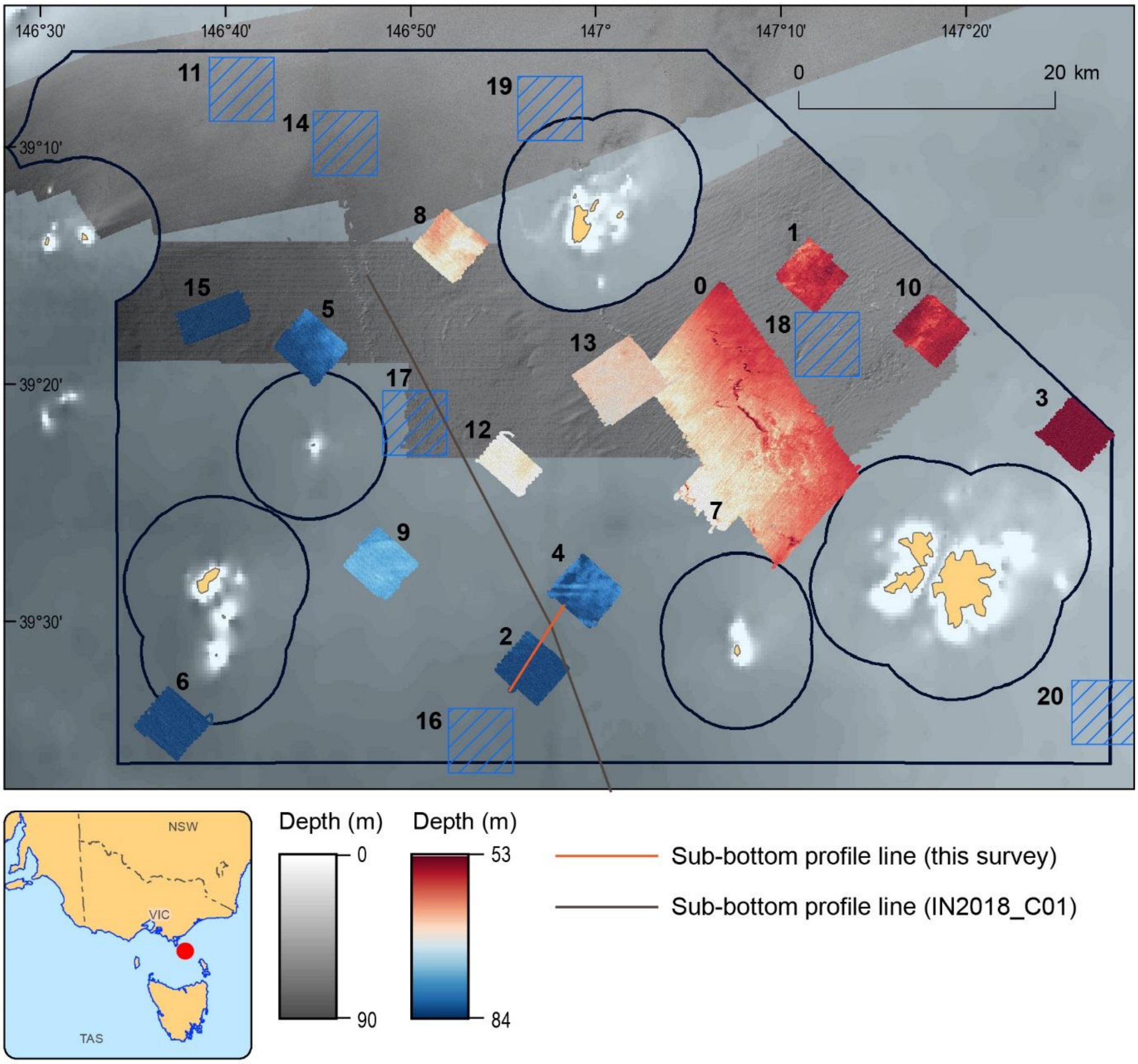


Figure 3. Location of survey areas within Beagle Marine Park mapped for this survey, with water depth indicated (red-blue gradient) and pre-existing data shown in shades of grey. Numbers alongside the grids correspond to the survey area designations used throughout the text. Note that grid 7 was combined with grid 0. The black lines denote the boundaries of the Beagle Marine Park, and the red dot on the inset map denotes the location of the park. Blue hatched squares show the location of survey areas that were identified by the spatially balanced randomised method. Note: grids 11, 14 and 19 have been previously mapped by the Australian Hydrographic Office (data can be accessed via the AusSeabed Marine Data Portal). Remaining blue hatched squares have not yet been mapped.

3.1.2 Seabed sediments

A sediment grab was deployed to collect seabed sediment samples at sites close to AUV transects within grid 0 (Figure 4). Samples were described in the field following the standard operating procedure set out in Przeslawski et al. (2020). Samples were retained for lab analysis of grain size and carbonate content.

3.1.3 Sub bottom profiles

An applied acoustics CSP-D "Sparker" system was used during Stage 1 to map the stratigraphy of the upper 50–100 m of the sub-seabed sediments. Sub-bottom profile data was acquired along one 7.7 km profile with a vessel speed of ~4 knots. The ping rate and frequency range (secondary: 0.5-6 kHz and primary: 15-21 kHz) was optimised for water depths.

3.1.4 Sessile epifaunal communities

Sessile epifaunal communities data were acquired during Stage 2 using the AUV *Sirius*, operated by the Australian Centre for Field Robotics, University of Sydney. The AUV *Sirius* (~200 kg) is a modified version of Seabed class AUV and is equipped with a variety of navigational sensors including GPS, Ultra Short Baseline Acoustic Positioning System (USBL) and forward looking obstacle avoidance sonar, to enable precise tracking of the vehicle and high-precision geo-referenced image acquisition. Seabed images were collected with a synchronized pair of high sensitivity 12-bit, 1.4-megapixel cameras (AVT Prosilica GC1380 and GC1380C; one monochrome and one colour). Illumination was achieved by two 4-J strobes mounted in the fore and aft-sections of the vehicle and synchronised with the cameras (see Williams et al. 2012 for full specifications). Each AUV transect was pre-programmed so that the AUV tracked the seabed at an altitude of 2 m at a cruising speed of 0.5 m per second. All deployments were conducted during daylight hours over 4 days in August 2018 (Campaign Tasmania 201808) in seawater depths ranging from 54–71 m. Deployments followed protocols outlined in Monk et al. (2020).

The AUV transects were predominantly done in Grid 0, with targeted census being used to cover all mapped reef within this region. A total of 15 AUV transects were completed inside Grid 0 as well as including an additional exploratory transect conducted in 2017 in the west of the marine park (Figure 4). Logistical constraints prevented deployment of the AUV in other survey grids within the marine park.

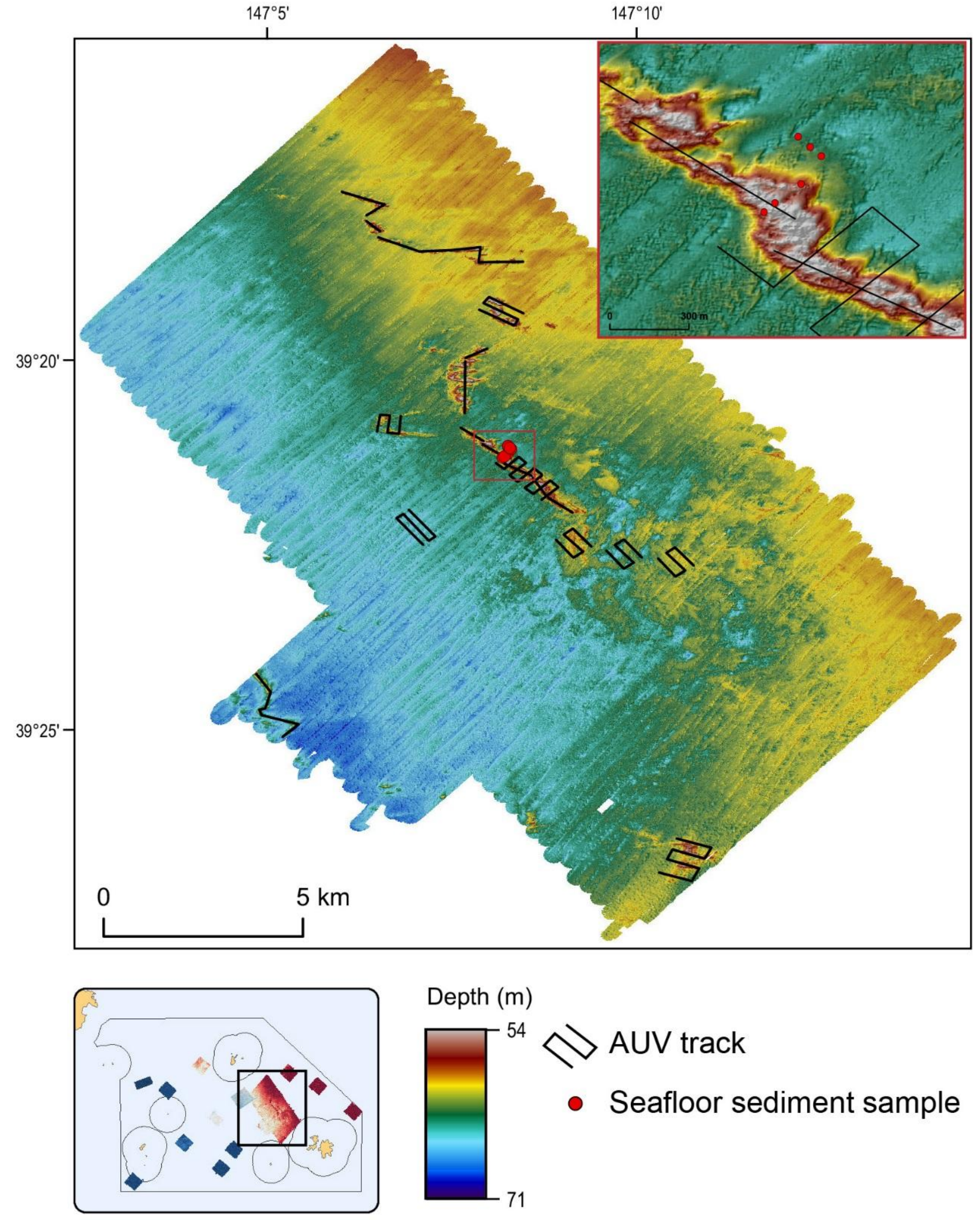


Figure 4. Location of 15 AUV transects and seabed samples within grid 0. The locations are overlain on the 1 m resolution hill shaded bathymetry. Inset map shows location of sediment samples.

3.1.5 Demersal fish communities

Demersal fish communities were quantified during Stage 3 of the survey using baited remote underwater stereo videos (stereo-BRUVs) to facilitate robust surveys of epibenthic and demersal fish assemblages. Each stereo-BRUV comprised a pair of high-definition video cameras inwardly converged at 7º to provide an overlapping field of view. To maximise calibration stability, the systems used a purpose-built, dual housing mounted on a base-bar designed to minimise camera movement within the housing, and between the cameras. These stereo pairs were fixed to a galvanised steel bar within a trapezium-shaped frame, which was weighted to ensure stability on the seafloor. Each stereo-BRUV was baited with approximately ~1 kg of oily pilchards (*Sardinops* spp.) contained within a plastic-coated wire mesh basket, attached to a conduit rod and positioned ~1.2 m in front of the cameras. Bait was crushed to promote dispersal of the flesh and fish oil. Each system was illuminated with a royal blue LED light (RayTech) and left to film remotely for at least 60 minutes on the seafloor before being retrieved and re-deployed. Concurrent deployments were separated by at least 250 m to reduce the likelihood of fish swimming between neighbouring stereo-BRUV deployments. Deployments followed the standard operating procedures outlined in Langlois et al. (2020a, b).

A spatially-balanced design of 150 deployments was achieved using the R package MBHdesign (Foster et al., 2017). The centroids of the 20 MBES grids were treated as legacy sites with an addition 80 sites allocated within the AMP (total 100). Two adjacent reference locations were chosen based on their likely comparable seabed habitats, with 25 stereo-BRUV site allocated in each (total of 50; Figure 5). These reference sites provide an initial understanding of fish assemblages in habitats similar to those in the nearby Beagle Marine Park, but are fully open to fishing. Hence, they allow a contrast between areas open to benthic trawling and the park where trawling is not allowed. While these sites may differ naturally at the time of this initial study, they provide an important contrast for future monitoring, as any increasing difference between these areas is then likely to be attributable to differences in management prescriptions.

3.1.6 Operations during marine mammal sightings

Survey personnel maintained a watch for marine mammals during daylight operations. This was achieved through visual observations from the bridge and other areas with good visibility. No marine mammals were sighted during the survey.

3.1.7 Licences and permits

Prior to the survey, UTAS and Geoscience Australia obtained a permit from the Director of National Parks to conduct research activities within the Beagle Marine Park (Permit No: CMR-18-000577). This permit allowed for the operation of multibeam sonar, sub-bottom profiler, AUV, BRUVs, and seabed samples from 13 June 2018, and expired on 13 June 2019.

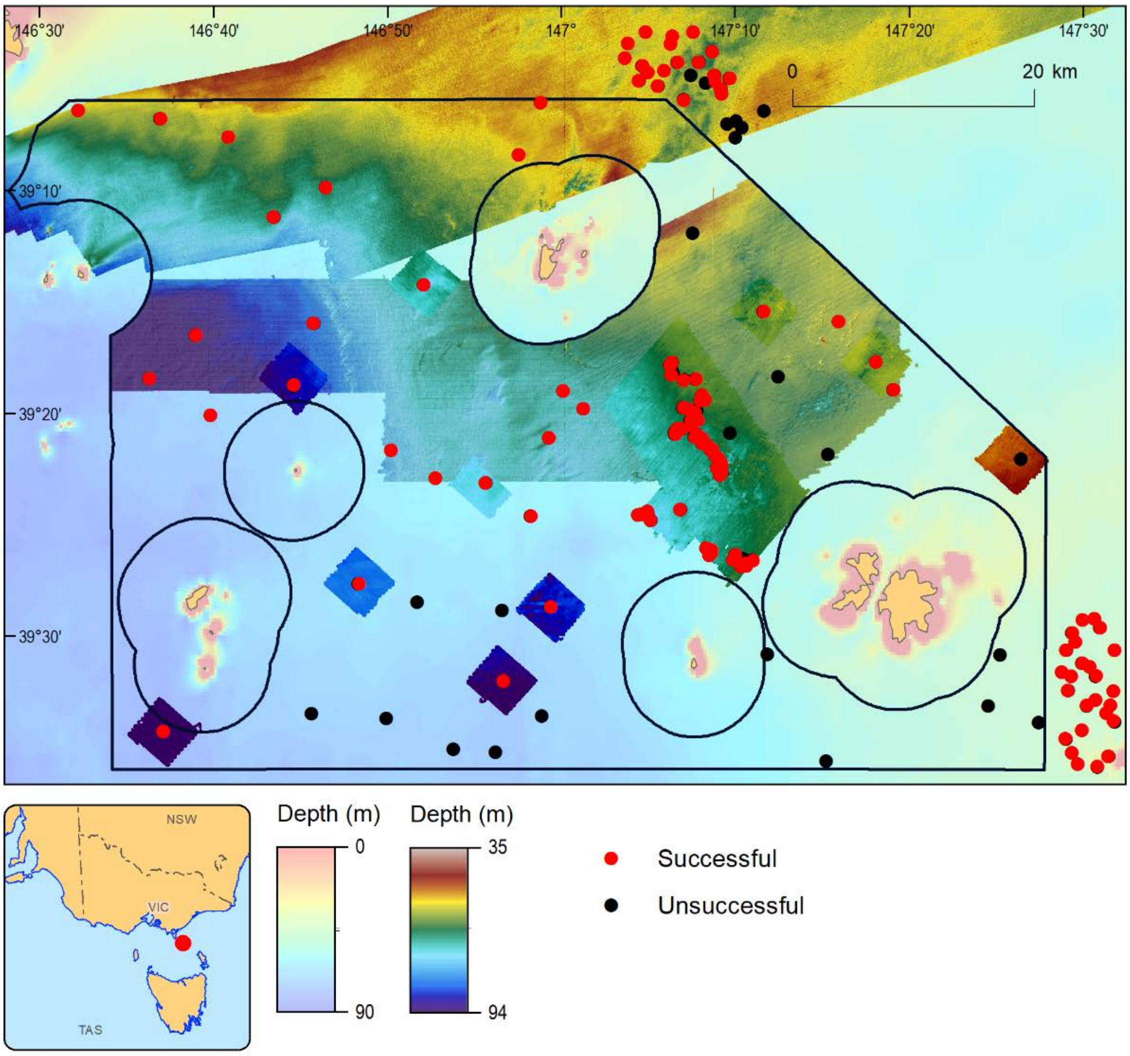


Figure 5. Location of successful (124) and unsuccessful (26) stereo-BRUV deployments based on a spatially-balanced design.

3.2 Data processing

3.2.1 Seabed features and morphology

Bathymetry

The MBES bathymetry data from GA0364 survey was processed using CARIS HIPS & SIPS v10.4.13 software. Processing steps included: i) application of algorithms that corrected for tide and vessel pitch, roll and heave; ii) the use of software filters and a visual inspection of each swath line to remove any remaining artefacts and noisy data (e.g. nadir noise and data outliers); iii) application of GPS tide to minimise tidal bursts. To provide more accurate motion-compensated data for all surveys—including GPS tide—positioning data were acquired separately by an Applanix POS MV motion reference unit and post-processed using POSPac software. The GPS tide was used to reduce the bathymetry to the ellipsoid height. Final bathymetric surfaces at 1 m horizontal resolution were created using CARIS and exported as a gridded surface for further analysis.

Seabed backscatter

Along with bathymetric data, the MBES generated co-registered seabed backscatter data. Backscatter data provides a measure of the intensity of the sound (measured in decibels, dB) reflected by the seabed, with higher intensity indicating harder seabed (e.g. rock, gravel). These data were processed using the CMST-GA MB Process v15.04.04.0 (·64) toolbox software co-developed by the Centre for Marine Science and Technology (CMST) at Curtin University and GA (described in Gavrilov *et al*., 2005; Parnum and Gavrilov, 2011). The process involved: removal of the system transmission loss; removal of the system model; calculation of the incidence angle; correction of the beam pattern; calculation of the angular backscatter response within a sliding window of 100 pings with a 50 % overlap in a 1° bin; removal of the angular dependence, and; restoration to the backscatter intensity at an incidence angle of 40° (Siwabessy *et al*., 2015, 2016, 2017, 2018). The final processed data were gridded to 1 m horizontal resolution, then exported as a gridded surface for further analysis.

In the process of removing the angular dependence from the backscatter response to produce a consistent backscatter intensity across the swath at various incidence angles (for a homogeneous seabed), the angular backscatter response was calculated in a 1° bin of incidence angle and averaged within the sliding window to produce an angular backscatter response curve. The angular backscatter response illustrates that the backscatter intensity changes as a function of the angle of incidence and is dependent on substrate type. Therefore, considering that it is an intrinsic property of the seabed, the response was reserved for further use in the future, as necessary.

Semi-automated mapping of seabed features and morphology

As a preliminary mapping exercise, a semi-automated approach was used to create morphological maps of the seafloor. The mapping approach used here follows the first step of Geoscience Australia's draft 'National Seafloor Geomorphology' (NSGM) classification scheme (Nanson and Nichol, 2018). The scheme is designed to facilitate seabed mapping at multiple spatial scales and builds on an existing two-part scheme, which distinguishes between seabed *morphology* and *geomorphology* (Dove et al., 2016). Morphology is mapped only using bathymetry data and derivatives (e.g. slope). The geomorphology is subsequently interpreted using a combination of user expertise and additional data types (e.g. backscatter, sub-bottom profiles, sediment samples). The latter is beyond the scope of this report and will be addressed in future publications.

The morphology component of the NSGM scheme assigns defined names to features that describe the shape of the sea floor; these features may overlap. For example, an entire survey area may be classified according solely to its *slope*, with all pixels classified as 'plane', 'slope', or 'escarpment' surfaces. Additional features further describe the shape of the sea floor, and are broadly divided into high, low, and plane features; these may overlap the surface polygons.

For this report, each bathymetry grid has been classified to the morphology surface level and defined as polygons, using ArcMap v10.5 software. For each survey grid, the Spatial Analyst toolbox was used to calculate slope from the relevant bathymetry dataset. The slope grids were initially classified into plane (0-2°), slope (2-10°), or escarpment (>10°) categories. 'Majority filter' and 'boundary clean' operations (both in the Spatial Analyst toolbox) were performed twice each on each slope grid, before the raster data were converted to polygon shapefiles. The total area covered by each surface category was calculated using the

‘Summarize’ function in ArcMap, which creates a table containing summary statistics for each unique value of a field. In this case, the field was surface type (i.e. plane, slope, or escarpment) and the summary statistic was the sum total polygon area.

In addition, ridge features (relict sub-aerial dunes) were classified in grid 0 using a combination of semi-automated and manual methods. Raised seabed features were identified using a modified version of the method described by Erdey-Heydorn (2008), based on Bathymetry Position Index (BPI) grids. BPI grids are derived from bathymetry data and measure the elevation of each pixel in a bathymetry grid relative to the surroundings, within a user-defined area. Here, a user-defined classification dictionary was used to translate BPI values into discrete features, based on their BPI at both fine and broad scales. This classification was undertaken using the Benthic Terrain Modeler (BTM) toolbox (Walbridge et al., 2018). High-relief features identified using the BTM toolbox were then filtered to keep only those with elongate morphology. The Data Management Tools toolbox was used to create Minimum Bounding Rectangles (MBR) (by width) for each feature polygon, and then all polygons with an MBR of L/W<2 were deleted. Manual checks were then applied to the remaining elongate, elevated features, including removal of artefact polygons around the edges of the grid. Final manual editing was based on user discretion, where only polygons covering the larger ridge features were retained.

3.2.2 Seabed sediment samples

Five seabed sediment samples were collected from within grid 0, from depths between 56 and 62 m. Sediment recovery was variable, ranging from 50 g to 500 g wet weight. In addition, one dredge sample was collected using a rock dredge at 59 m water depth. This sample consists of a number of clasts of cemented carbonate sand. Sediment samples were analysed for grain size using a combination of manual sieving and laser particle sizing, with the latter performed on a Malvern Mastersizer 2000. Percentages of mud, sand, and gravel were recorded as dry weights. Calcium carbonate content was determined using the acid digestion method (Muller and Gastner, 1971). Sediment samples are lodged at Geoscience Australia (Appendix B).

3.2.3 Sub-seabed profiles

Visualisation and data interpretation of sub-bottom profiles was undertaken using SonarWiz V5.0.

3.2.4 Sessile epifaunal communities

AUV imagery

Post-processing of AUV imagery included image colour-balancing and simultaneous localisation and mapping (SLAM) processing of the stereo imagery to improve geo-referencing. The optical imagery was provided as individual colour-corrected images (geotiffs) and as mosaics. Over 127 000 geo-referenced stereo image pairs were collected (15 AUV deployments) within grid 0. Stereo image pairs were stitched together to generate composite geo-rectified 3D “meshes” of seabed. These meshes were imported into ArcGIS to visually assess broad-scale ecological structure and the distribution and abundance of benthic fauna (see Figures 16-20).

A random sub-sample of 876 AUV images were selected for annotation. Visual inspection of selected images was undertaken to ensure no overlap between sequential images occurred. The proportion cover of the taxon in the selected images was obtained by scoring 25 random points superimposed on each image using the online annotation platform Squidle + (https://squidle.org/) – A tool for managing, exploring and annotating images, video and large-scale mosaics. For each superimposed point, the underlying substrata (e.g. unconsolidated sand) or biota was identified using the Australian Morphospecies Catalogue – An extension of the Collaborative and Annotation Tools for Analysis of Marine Imagery (CATAMI) classification scheme (Althaus et al., 2015). Observer error testing was conducted prior to, and after AUV image annotations to account for observer bias and assess the reproducibility of scoring among three annotators. In addition to the individual points, four ‘whole of image’ tags were assigned to the image classifying the overall relief, bedform, proportion of hard substrata and proportion of soft substrata following CATAMI classes for physical substrata. These four whole of image tags were then used to assign each image into dominant habitat types for subsequent statistical analyses. Habitats included: “low profile reef”, “shell hash”, “screw shell bed” and “fine sandy sediment”.

Analyses of patterns in epibenthic communities

Multivariate analyses were performed using the PRIMER v6 and PERMANOVA add-on package (Anderson et al. 2008; Clarke and Gorley 2006). A Bray–Curtis similarity matrix, based on proportion cover data, was used for multivariate analyses. No further data transformation was required after visual inspection of Shepard diagrams. The non-metric multi-dimensional scaling (nMDS) were used to visualize the patterns in morphospecies assemblages across habitat categories. The nMDS plot is a way to condense information from multidimensional data (multiple variables/species) into a 2D plot. In this ordination, the closer two points are, the more similar the corresponding samples are with respect to the variables that went into making the nMDS plot. Vector overlays (calculated from Pearson’s ranked correlation coefficients) of the habitat categories that contributed to the multivariate structure within the nMDS.

A permutational analysis of covariance (PERMANCOVA) routine, and associated pairwise comparisons, were used to compare the variation in morphospecies proportion cover and composition across habitat categories accounting for depth. A single-factor PERMANCOVA with habitat as a fixed effect, and associated pairwise comparisons, were run with 9999 permutations of residuals under an unrestricted model. As part of the PERMANCOVA, we quantified variance components, the proportion of the multivariate variation accounted for by each variable (Anderson et al., 2008). Using the Bray–Curtis similarity matrix, a distance-based test for homogeneity of multivariate dispersions (PERMDISP) routine was run to assess the dispersion assumption for PERMANCOVA, with no strong dispersion differences between habitat categories being detected.

The major morphospecies responsible for between habitat categories were determined using the similarity percentages routine (SIMPER; Clarke and Warwick 2001). A 90% threshold of the community structure between each of the four habitats was set. These major morphospecies identified by SIMPER were also superimposed on the nMDS ordinations using the bubble plots to visually depict their proportion cover associated with the habitat categories. These were also mapped to show the spatial changes in proportion cover.

Sampling adequacy and power to detect change

We also applied a multiple lines of evidence approach to assessing the sampling effort required to characterise the epibenthic sessile assemblages sampled using the AUV. Firstly, to ensure the current subsampling of imagery were sufficient to detect the majority of morphospecies present based on species accumulation rates. Species accumulation curves were created using the “vegan” R package and *specaccum* function set to random with 9999 permutations.

Secondly, we applied a *MultSE* as proposed by Anderson and Santana-Garcon (2014) who proposed a method that provides a novel approach to assess adequacy in sample sizes. The *MultSE* is perfectly suitable as a measure of the variability in the position of the sample centroid for a given group in the space of the chosen dissimilarity measure (in our case Bray-Curtis) and within a given study. It is important to note, however, that it produces a value which is not standardised in any way – it will be in the units of the resemblance measure chosen – hence can only be used within the context of a given study, and cannot be compared among studies.

The third approach applied was a power analysis to estimate the level of sampling needed to detect changes in these major morphospecies as candidate indicators were also undertaken. Since we only have one sampling event, we conducted power analyses with simplistic assumptions to gain a coarse estimate of feasibility. We expect that the proportion cover of the morphospecies would increase under the removal of fishing pressure. Therefore, we determined the approximate number of images required at each sampling event to detect a 50, 100 and 200 percent increase in mean cover between two sampling events within the Marine Park for scenarios where; (1) the same sites are revisited (i.e. a paired t-test), and (2) new sites are sampled (i.e. an un-paired t-test). The significance level for detecting a difference between the sampling events was set at 0.05, and the power to detect an effect set at 0.8. The effect sizes corresponding to a 50, 100 and 200 % increase in proportion cover were calculated using Cohens-D formula (which is essentially the standardised mean difference between proportion cover at the two sampling times (Cohen, 1988)) for each morphospecies and an appropriate multiplier for sampling event 2 (i.e. 1.5 for 50 % increase and so on). The same variance was used for both sampling events as no other information was available to estimate temporal variance. Since we are interested in detecting an increase in proportion cover, tests were one-tailed. Separate power calculations were run for each morphospecies and for each habitat (i.e. all habitats combined, reef, shell hash, screw shell bed and fine shelly sand substrata). Power analyses were carried out using the R statistical package “pwr” (Champely, 2007).

3.2.5 Demersal fish observation

Stereo BRUV annotation

All individual fishes were identified to their lowest taxonomic level, with their relative abundance estimated using maximum number of fish occurring in any one frame for each species (MaxN; Ellis and Demartini, 1995). Only fish within a standardized 4 m field of view of the bait bag were annotated and measured. The length of all fish species was recorded for as many individuals as possible occurring within frames adjacent to MaxN as some individuals were obscured by other fish. Calibrations, annotations and measurements were done using methods outlined in Langlois et al., (2020a, b) with calibrations completed in software Cal (www.seagis.com.au), and annotations and measurements done in the software EventMeasure (www.seagis.com.au). The seabed habitat in deployment was annotated using whole of image tags to assign each image into dominant habitat types for subsequent statistical analyses. Habitats included “low profile reef”, “shell hash”, “screw shell bed” and “fine sandy sediment”.

Analyses of patterns in demersal fish communities

Multivariate analyses were performed using the PRIMER v6 and PERMANOVA add-on package (Anderson et al. 2008; Clarke and Gorley 2006). A Bray–Curtis similarity matrix, based on abundance data, was used for multivariate analyses. All highly mobile pelagic species, such as scad (*Trachurus* spp), were dropped from all analyses. No further data transformation was required after visual inspection of Shepard diagrams. The non-metric multi-dimensional scaling (nMDS) were used to visualize the patterns in abundance structure of the fish assemblages across habitat categories. Vector overlays (calculated from Pearson's ranked correlation coefficients) of the habitat categories that contributed to the multivariate structure within the nMDS.

A permutational analysis of covariance (PERMANCOVA) routine, and associated pairwise comparisons, were used to compare the variation in fish species abundance and composition across habitat categories and status (i.e. Marine Park v reference locations) accounting for depth differences. A two-factor PERMANCOVA with habitat and status as fixed effects, and associated pairwise comparisons, were run with 9999 permutations of residuals under a reduced model based on type three sum of squares. As part of the PERMANCOVA, we quantified variance components, the proportion of the multivariate variation accounted for by each variable (Anderson et al., 2008). Using the Bray–Curtis similarity matrix, a distance-based test for homogeneity of multivariate dispersions (PERMDISP) routine was run to assess the dispersion assumption for PERMANCOVA, with no strong dispersion differences between habitat categories and status being detected.

The major fish species responsible for between habitat categories and status were determined using the similarity percentages routine (SIMPER; Clarke and Warwick 2001). A 90% threshold of the community structure between each of the four habitats and two status categories were set. These major fish species identified by SIMPER were also superimposed on the nMDS ordinations using the bubble plots to visually depict their relative abundance associated with the habitat categories and status. These were also mapped to show the spatial changes in relative abundance.

The patterns in length-frequency between Marine Park and reference locations were graphically and statistically compared using kernel-density estimates based on the approach by Langlois et al., (2012). This approach was chosen as it provides a data-driven method for representing length-frequency compositions, instead of using histograms with length classes chosen arbitrarily or via bootstrapping from very large independent samples. Analysis was done in R using scripts provided in Langlois et al. (2012). Estimates of abundance for the whole of the Beagle Marine Park were achieved using a distance sampling approach using R packages "Distance" and "dsm". This model-based approach to estimating abundance was selected to account for potential differences in detection rates between species, depths and habitats. Model structure using a tweedie distribution was:

count ~ s(lat, lon, k=10)+s(depth, k=3, bs= "cr")+s(vrm, k=3,bs= "cr")+"distance offset"

The course 250m bathymetry and vrm (rugosity) was used to create a spatial prediction of the target fish species as it covered the entire Marine Park.

Sampling adequacy and power to detect change

As with the AUV analysis we also applied a multiple lines of evidence approach to assessing the sampling effort required to characterise the demersal fish assemblages sampled using stereo-BRUVs. Firstly, species accumulation rates was used to ensure the current sampling effort was sufficient to detect the majority of fish species present. Species accumulation curves were created using the “vegan” R package and *specaccum* function set to random with 9999 permutations. Secondly, we applied the *MultSE* as proposed by Anderson and Santana-Garcon (2014) and explained above in Section 3.2.6

The third approach applied was a power analysis to estimate the level of sampling needed to detect changes in these major demersal fish as candidate indicators were also undertaken. As with the AUV imagery, we only have one sampling event, so power analyses with simplistic assumptions were used to gain a coarse estimate of feasibility. We determined the approximate number of deployments required at each sampling event to detect a 50, 100 and 200 percent increase in mean abundance between two sampling events within the Marine Park for scenarios where; (1) the same sites are revisited (i.e. a paired t-test), and (2) new sites are sampled (i.e. an un-paired t-test). The sample multipliers, significance and power levels as for the AUV imagery was applied here. Again, separate power calculations were run for each demersal fish and for each habitat (i.e. all habitats combined, reef, shell hash, screw shell bed and fine shelly sand substrata). Power analyses were carried out using the R statistical package “pwr” (Champely, 2007).

4. PRELIMINARY INTERPRETATIONS

4.1 Seabed features and morphology

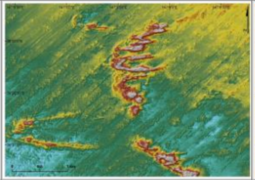
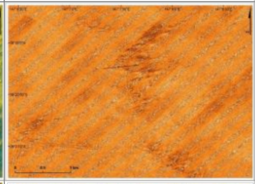
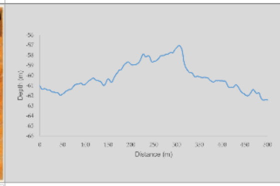
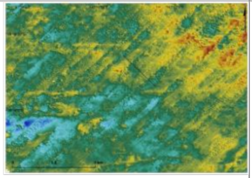
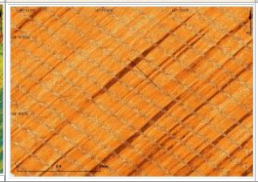
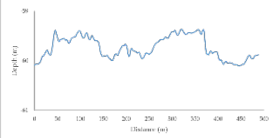
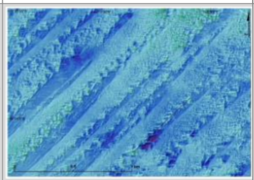
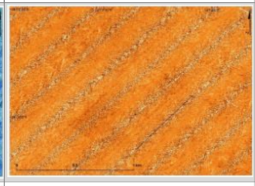
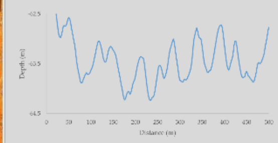
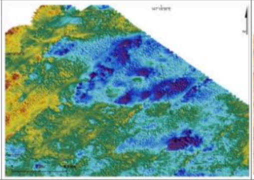
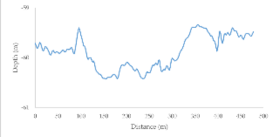
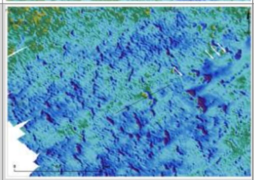
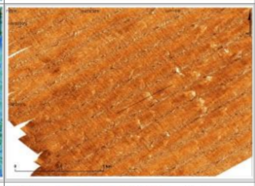
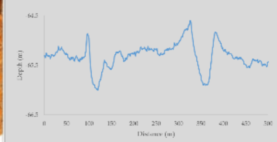
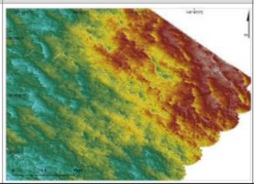
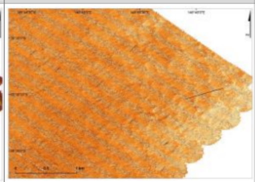
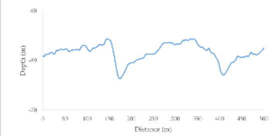
High-resolution seabed mapping in the Beagle Marine Park revealed a shallow shelf environment, with water depths ranging from 53 m in the east of the park to 84 m in the west (Table 1, Figure 8-Figure 11 and Appendix A, Figs. S1-S10). Representative geomorphic features identified within the Marine Park are summarised in Table 2. These include continuous fields of low-relief sedimentary bedforms with localised higher relief ridges and mounds, as shown by the morphological surface map for grid 0 (Figure 13 and described below). Most linear features (ridges and depressions) are broadly aligned between SE to NW and SSE to NNW. This is particularly the case in the western-most deeper water survey areas (grids 8, 12, 4, 2, 15, 5, 9, and 6), where each survey area is covered by rippled sand sheets with maximum relief of approximately one metre, but more commonly 20-40 cm (Table 2, rows 6, 7, & 10). In all of these survey areas, bedform crests are consistently aligned SSE to NNW, which is broadly perpendicular to the direction of the principal tidal current within Bass Strait (Baines et al., 1991; Jones, 1980; Malikides et al., 1988). Tidal current influence on unconsolidated sediment is therefore a major influence on seabed geomorphology in the Marine Park.

As a proxy of the relative hardness of the seabed within Beagle Marine Park, acoustic backscatter data revealed a distinct transition from harder, more heterogeneous substrate in the shallower east of the park (grids 3, 10, 1, 0, and 13), to relatively soft sediment bedform fields in the deeper water to the west (Figure 6 & Figure 7). Within individual survey areas that are planar in morphology with bedform fields, variability in backscatter intensity is generally low, indicating uniform seabed hardness (i.e. sand) (Table 2). In contrast, the higher relief features that occur in the shallower eastern-most survey areas (grids 3, 10, 1, 0, and 13), show a generally higher backscatter intensity, indicative of harder (reef) substrate (Figure 6 & Figure 7). Two feature types are particularly notable in this regard: the linear SW to NE oriented ridges which record a distinct backscatter intensity contrast between crest and swale (grids 3, 10, 1, 0, and 13) (Table 2, row 2), and the 2-5 m high ridges that form the main areas of raised reef, with a subtly lower backscatter intensity than their surroundings (Table 2, row 1). These backscatter contrasts indicate local variability of sediment grade and/or cover, with higher intensity interpreted as gravel/rock substrate (e.g. in swales between ridges) and lower intensity interpreted as sand substrate.

Table 1. Summary of bathymetry and backscatter data for individual survey areas.

Survey area	Longitude	Latitude	Area	Bathymetry			Backscatter			
				Minimum depth	Maximum depth	Mean depth	Minimum (weak) acoustic return	Maximum (strong) acoustic return	Mean acoustic return	SD
	centre	centre	km^2	m	m	m	db	db	db	db
Grid 0	147.14	-39.37	190	53.8	71.1	61.8	-55.5	-0.1	-17.1	1.8
Grid 1	147.19	-39.26	17	54.4	62.9	59.9	-38.7	-2.1	-17.1	2.0
Grid 2	146.94	-39.53	18	69.0	74.1	71.4	-47.4	-1.5	-19.6	2.0
Grid 3	147.44	-39.37	18	53.0	60.0	55.3	-36.0	-1.0	-16.8	1.7
Grid 4	146.99	-39.48	18	61.6	73.9	69.6	-38.7	-0.7	-17.9	1.8
Grid 5	146.74	-39.31	18	66.4	74.1	70.0	-55.3	0.0	-19.4	1.9
Grid 6	146.62	-39.57	18	75.3	84.0	77.5	-48.0	-6.4	-21.8	1.9
Grid 8	146.87	-39.24	18	60.8	70.2	62.9	-38.0	-0.1	-16.7	1.8
Grid 9	146.80	-39.46	18	66.4	73.4	67.6	-52.5	-2.0	-19.1	2.0
Grid 10	147.31	-39.30	18	57.4	67.5	59.4	-33.7	-1.5	-16.4	1.9
Grid 12	146.92	-39.39	13	62.7	70.3	64.3	-38.1	-6.2	-18.5	1.8
Grid 13	147.02	-39.33	29	61.6	66.7	64.9	-69.7	-4.8	-28.0	2.2
Grid 15	146.65	-39.29	14	71.1	75.7	73.4	-53.0	-8.3	-28.4	2.1

Table 2. (overleaf). Representative examples of seabed features (bathymetry and backscatter) from high-resolution mapping.

Row	Feature (morphology)	Feature (geomorphology)	Representative bathymetry	Representative backscatter	Profile	Vertical exaggeration	Bathymetry description	Backscatter description	Occurs in grid squares (*denotes location of image)
1	Ridge	Relict sub-aerial (aeolian) dune				25	2 to 5 m elevation. Discrete ridges vary in length from around 350 m to 3 km. Ridges are arranged approximately N-S. Sometimes approximately parabolic in shape but not always, arms of parabola generally point approximately east to south-east. Ridges are steep-sided and approximately symmetric in profile, with smaller ripples in the main ridges. No obvious relationship with direction of dominant bottom current. Not obviously related to linear features; possibly overlie these.	Subtle decrease in backscatter intensity on ridges, although not in all cases. Indicates softer seabed or higher rugosity.	Grid 0*, block 13, grid 1. Location of representative profile shown in Figure S4 (Attachment 5).
2	Ridge	Bedform field (linear ridges)				125	Very straight ridges delineated by alternating troughs and crests in 55 - 60 m water depth. Approximately 40-80 cm average relief, with troughs 100-200 m in width. Linear features strike SW-NE in all cases and appear to underlie parabolic ridges. Ripple fields superimposed on ridge crests, oriented ~perpendicular to strike of linear ridges. This feature is immobile, as demonstrated in the overlapping surveys.	In shallowest survey grids, backscatter intensity is distinctly higher in troughs between ridge crests. Less of a distinction in deeper water areas (grid 0 and block 13). Backscatter minima (indicating likely thicker sand cover) are generally on ridge crest and 30-60 m in width.	Grid 0, block 13, grid 1*, grid 3, grid 10. Location of representative profile shown in Figure S3 (Attachment 5).
3	Ridge	Patchy bedform field: 3-D dunes (subtle parabolic form)				125	Sedimentary bedforms 80-100 cm high and 30-60 m in wavelength; poorly developed as 3D forms. Oriented NE to SW along linear ridges.	No backscatter intensity change	Grid 0*, block 13. Location of representative profile shown in Figure S4 (Attachment 5).
4	Depression	Elongate depression (broad)				125	Elongate (almond-shaped) depression, 200-700 m long and 90-150 m wide, with pinched ends. Approximately 1 m deep, with local bedform fields (sand ripples). Water depth ~60 m	No intensity variation across this feature.	Grid 10. Location of representative profile shown in Figure S2 (Attachment 5).
5	Depression	Swale in bedform field				125	Isolated depression 30-200 m long and generally 50-80 cm deep, but up to one metre. Elongate and aligned with strike of sandwave crestlines i.e. approximately NW/SW to NNW/SSE.	Depressions have higher backscatter intensity than surrounding bedforms. Combined with the flat morphology of the base of the swales, this may suggest limited sediment availability, with a thin veneer of soft-sediment bedforms over sporadically exposed bedrock.	Grid 0, block 13*, grid 3, grid 8, grid 9, grid 12 (no change in backscatter intensity). Location of representative profile shown in Figure S5 (Attachment 5).
6	Ridge (bedform field)	Bedform crestline (2D to 3D transitional dunes)				125	Generally very low gradient, with crestlines approximately 200 m apart. The sandwaves have distinct stoss and lee sides, with relief around 50 cm, and form in ~70 m water depth. Similar morphology and wavelength to sandwaves of Malikides et al. (1998), but an order of magnitude less in height.	No backscatter intensity change	Grid 5*, block 15, grid 2, grid 4. Location of representative profile shown in Figure S11 (Attachment 5).

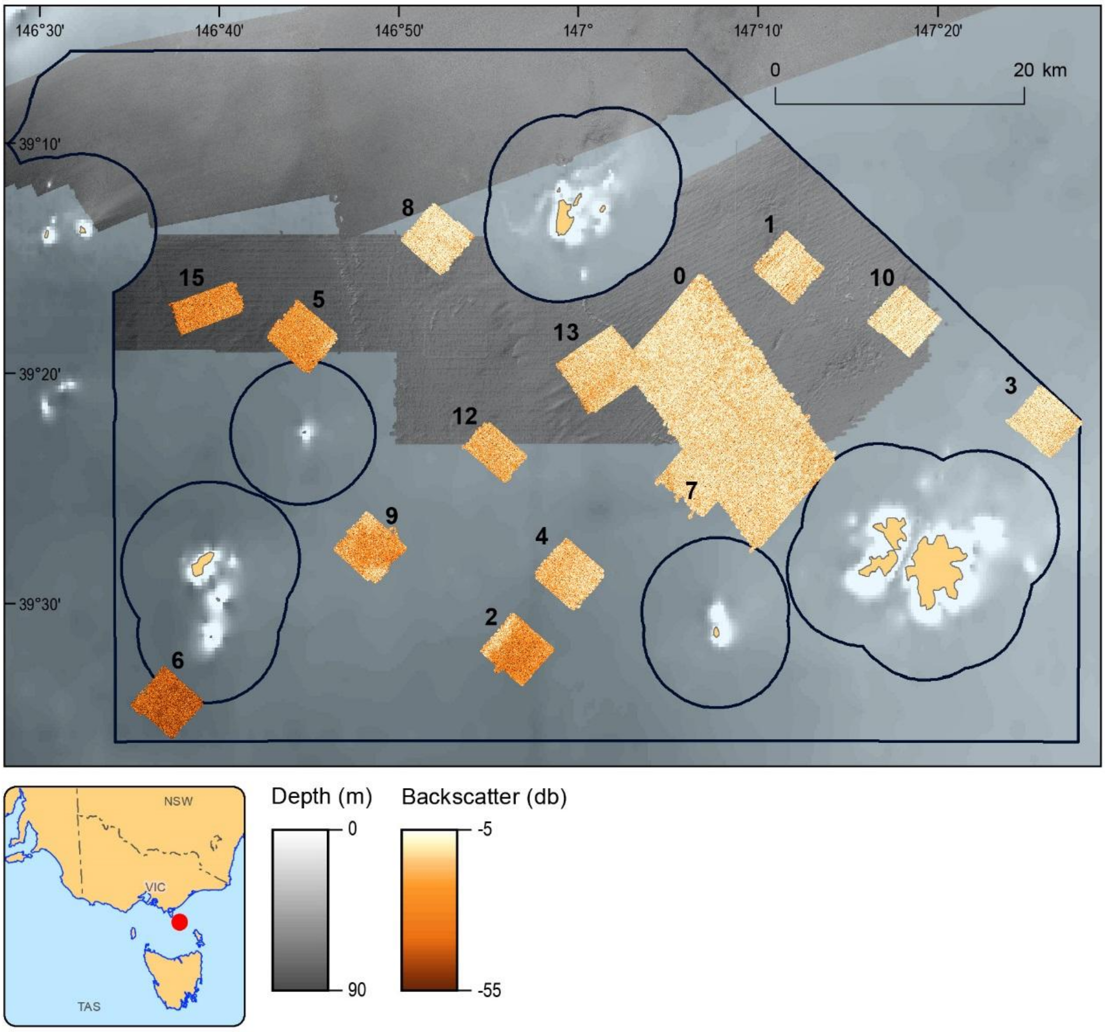


Figure 6. Acoustic backscatter maps for each survey grid across Beagle Marine Park, showing stronger intensity (harder seabed) toward the shallower northeast.

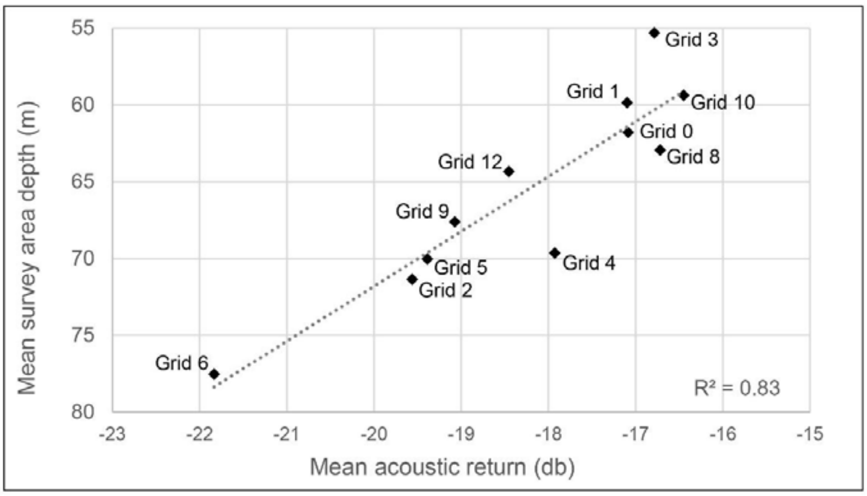


Figure 7. Plot of water depth versus acoustic backscatter intensity calculated as the mean for each survey grid across Beagle Marine Park, showing stronger intensity (harder seabed) in shallower depths.

4.1.1 Seabed features within map grids

This section describes in more detail features of the seabed environment in three of the thirteen survey grids as representative examples; data for the remaining ten are shown in Appendix A; Figures S1-S10.

Grid 1

Grid 1 is in the north-east of Beagle Marine Park and is representative of the three grids in this part of the park (grids 1, 3, 10; Figure 8). The sea floor across most of the grid is characterised by continuous linear ridges that extend several kilometres and are visible both in the bathymetry and acoustic backscatter; bathymetric highs coincide with lower backscatter intensity (i.e. softer seabed). The ridges have approximately 40-80 cm of relief, and the troughs between ridge crests are generally 100-200 m wide. The ridges strike NE/SW and have superimposed smaller 2D sand ripples that are approximately perpendicular to the ridge orientation.

The southern half of the grid 1 contains two narrow, relatively discontinuous linear ridges that strike W/E and extend the width of the grid but are not associated with a change in backscatter intensity. The eastern part of grid 1 also contains raised seabed features that do not have an obvious relationship with the strike direction of the linear ridges and are not associated with a strong change in backscatter intensity. These are 1-3 m in height, 150-250 m long, and approximately parabolic in shape (northern corner of the survey area) or more rounded (eastern corner of the survey area). These features appear to overlie the linear ridges.

Grid 0

Grid 0 covers 190 km^2 is immediately to the west and south of grid 1 (Figure 9; Figure 10), and has similar sea floor characteristics to grid 1 with NE/SW-striking linear ridges, although the backscatter intensity response is not as strong, indicating a more uniform seabed hardness across the grid (Figure 10). A key feature of this grid is raised hardground reefs that rise 2 –5 m above the adjacent seabed and up to 4 km in length. The ridges in grid 0 also have a slightly more distinct change in backscatter intensity; the ridges are associated with lower intensity (i.e. softer, sand covered seabed). The bathymetry mapping also identified the Basslink Interconnector cable in the north-west corner of the survey area (Figure 10).

Grid 12

Grid 12 is slightly to the west of the centre of the park, to the west of grid 0 (Figure 9). The sea floor is dominated by irregular 2D to 3D transitional dunes. The strike of the dune crestlines is approximately NW to SE, and individual crestlines generally continue for 200-1000 metres. Swales between the dunes have slightly flattened bases, are approximately 80-100 cm deep and 20-30 m across. The swales also have higher backscatter intensity than the surrounding dunes, indicating harder seabed (gravel/rock). The dunes are slightly asymmetrical, with steeper lee than stoss sides, which indicates flow direction (stoss side downcurrent).

Newly discovered isolated reefs

Midway along the northern boundary of the Marine Park are three small isolated ridges (Figure 12). These ridges are 80–500 m with vertical relief of 3–7m above the surrounding sediments. They may support high abundances of reef fish and sessile invertebrate cover. However, no biological sampling was undertaken on these reefs and are worthy of further exploration.

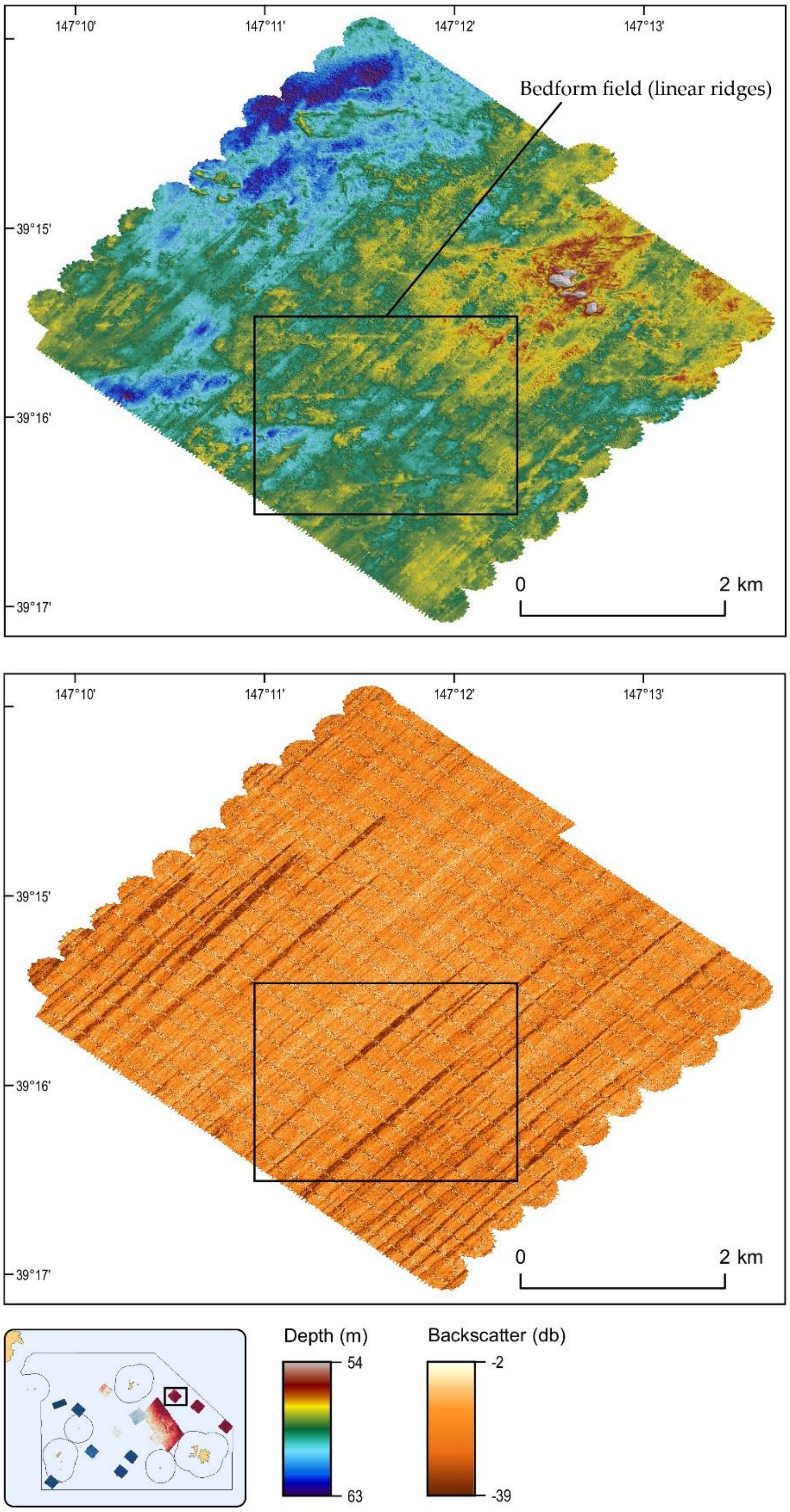


Figure 8. Bathymetry (upper panel) and acoustic backscatter (lower panel) data for grid 1 (dark areas indicate weaker intensity and softer seabed). Inset map shows the location of grid 1 within the Beagle Marine Park.

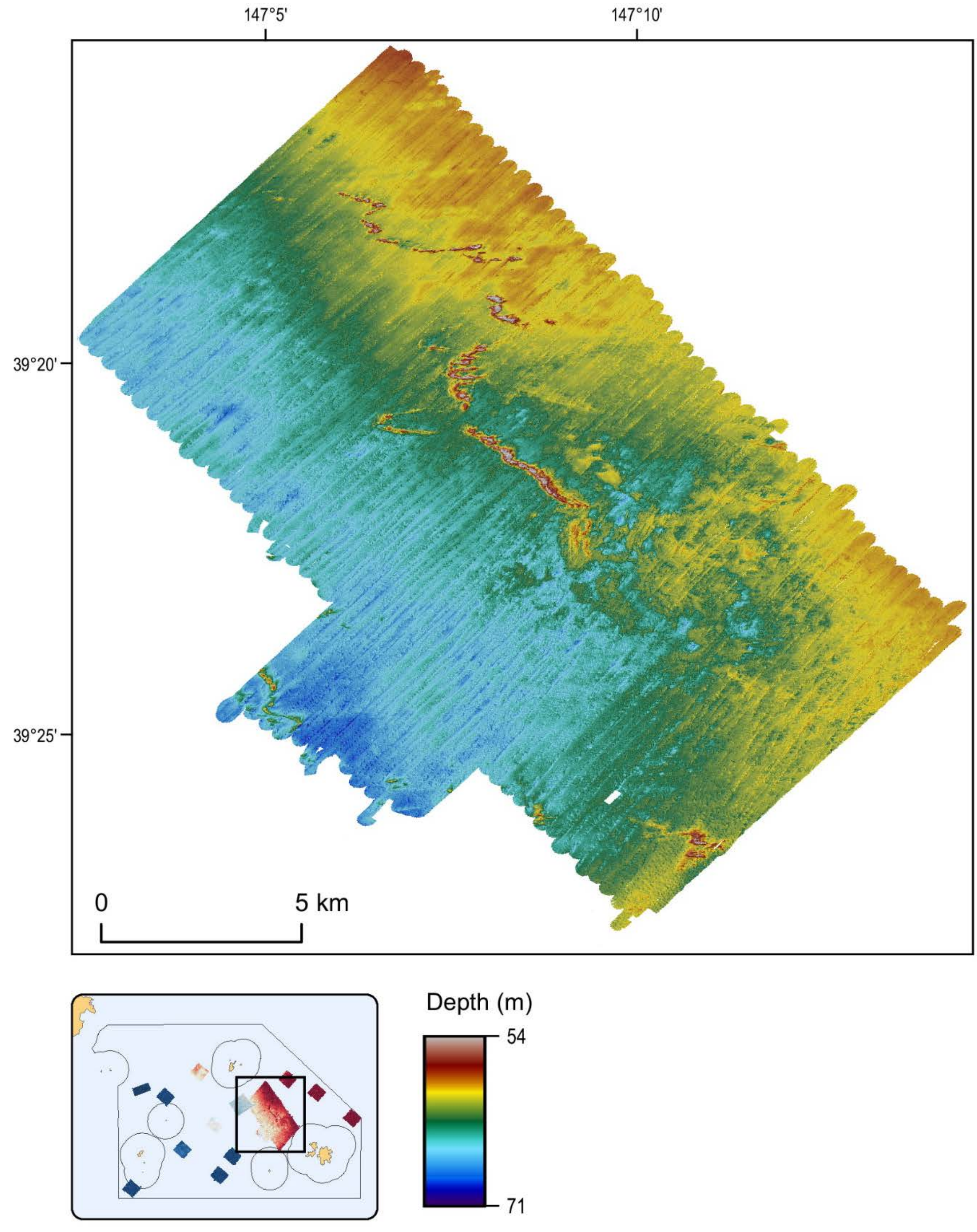


Figure 9. High-resolution bathymetry data for grid 0. Inset map shows the location of grid 0 within the Beagle Marine Park.

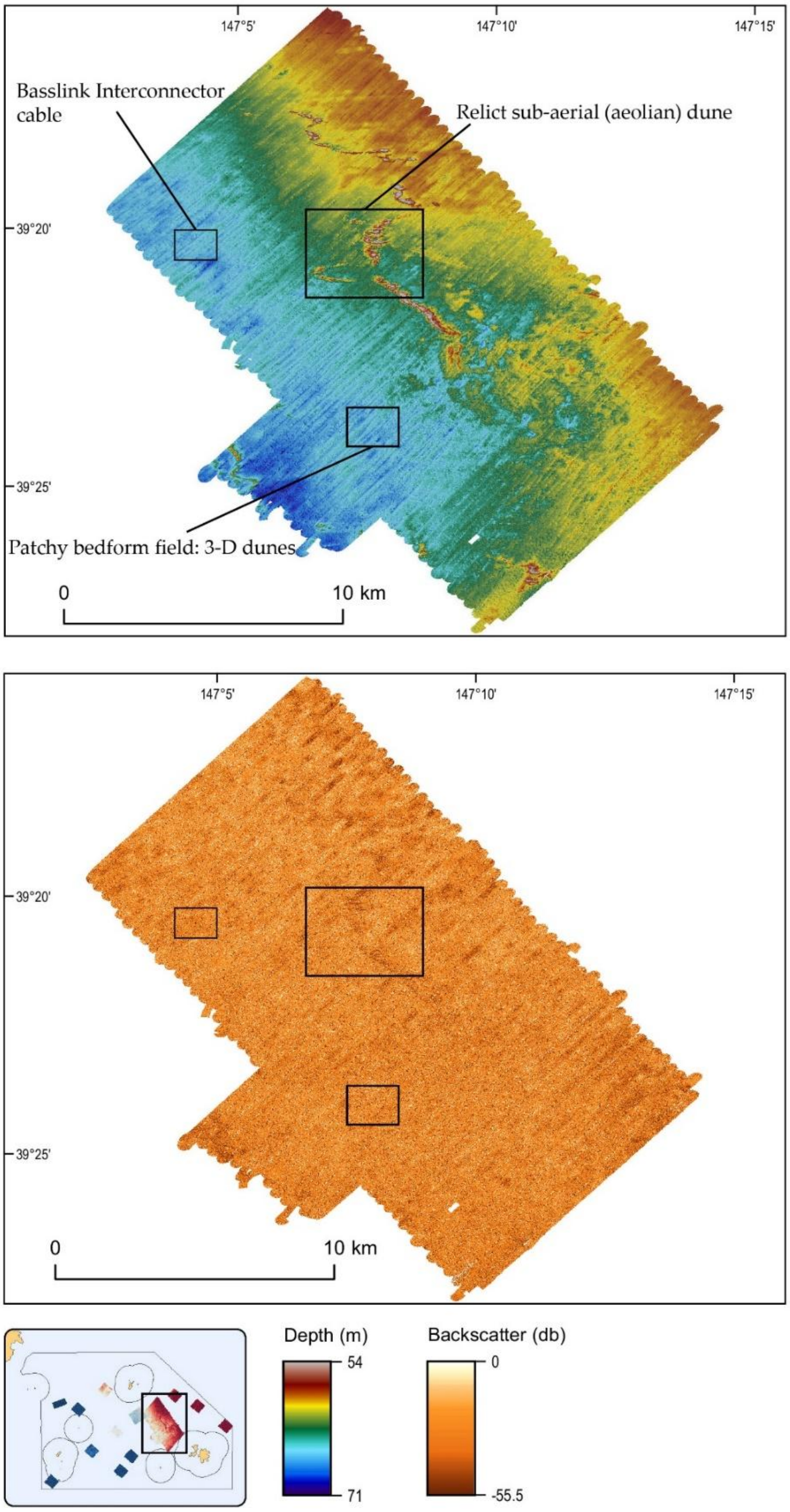


Figure 10. Bathymetry (upper panel) and acoustic backscatter (lower panel) data for grid 0 (dark areas indicate weaker intensity and softer seabed). Inset map shows the location of grid 0 within the Beagle Marine Park.

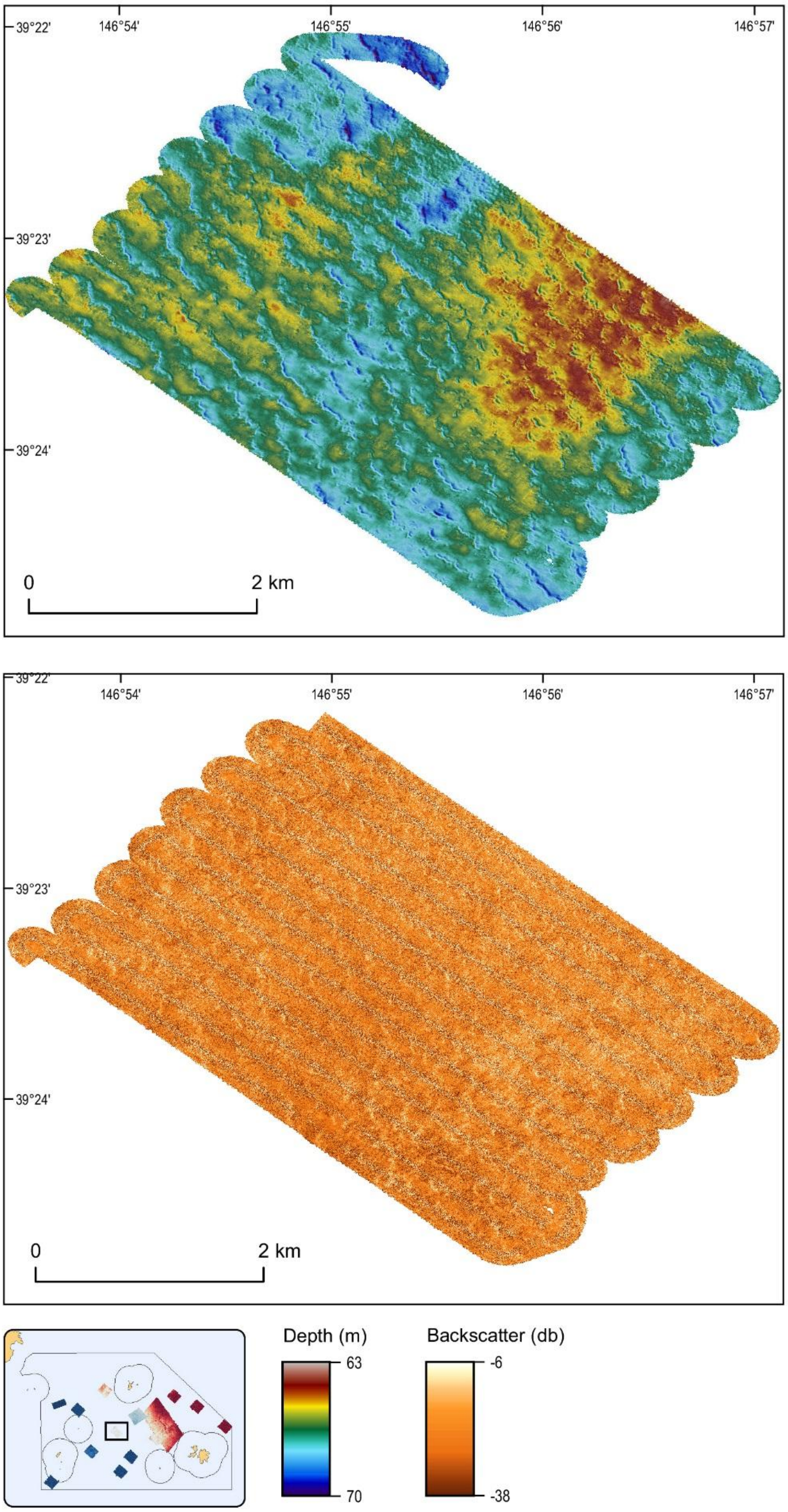


Figure 11. Bathymetry (upper panel) and acoustic backscatter (lower panel) data for grid 12 (dark areas indicate weaker intensity and softer seabed). Inset map shows the location of grid 12 within the Beagle Marine Park.

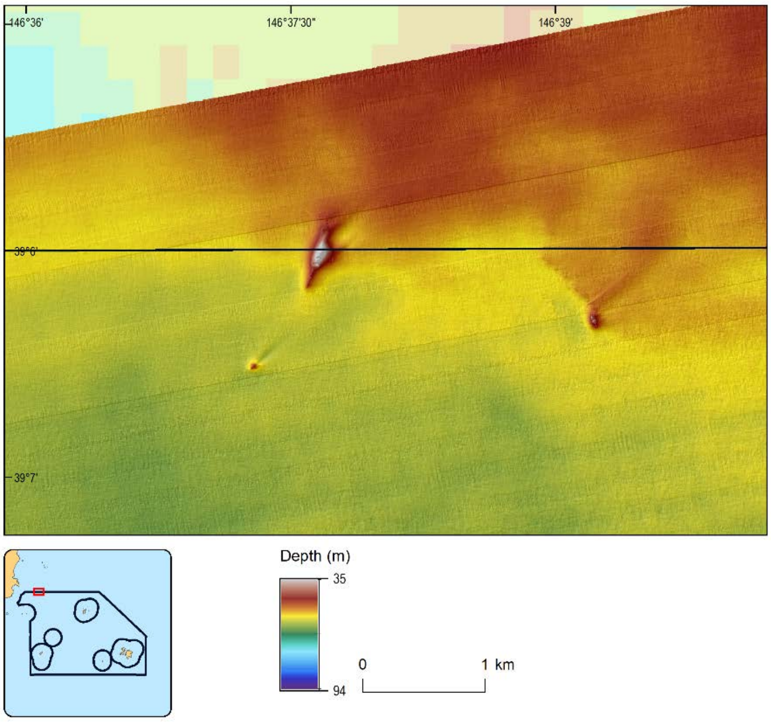


Figure 12. Location of isolated emergent reefs located along the northern boundary of the Beagle Marine Park.

4.1.2 Seabed morphology

The percentage coverage of each morphological surface feature category is summarised in Table 3 and surface morphology maps for each survey grid square are provided in Appendix A, Figure S11. One example is also provided in Figure 13 (surface coverage for Grid 0). The seabed surface maps for the Beagle Marine Park are dominated by 'plane' (terrain with gradient of 0-2°; Figure 14), with coverage ranging from 74-100% of each grid area. 'Slope' surfaces (2-10°) cover between 0-26% of any mapped area, and escarpments (>10°) less than one percent (Table 3). The grid square areal percentage coverage of flat terrain increases with water depth, to a maximum of 100% plane from 70 m (Table 3; Figure S11 in Appendix A).

Table 3. Summary of morphological surface coverage for individual survey areas.

Survey area	Mean depth of grid	Plane		Slope		Escarpment	
		Area	%	Area	%	Area	%
	m	km²		km²		km²	
Grid 0	61.8	145.0	76	45.1	24	0.00137	0
Grid 1	59.9	14.4	82	3.2	18	0.00051	0
Grid 2	71.4	18.3	100	0.0	0	0.00000	0
Grid 3	55.3	13.6	74	4.8	26	0.00012	0
Grid 4	69.6	17.9	98	0.3	2	0.00003	0
Grid 5	70.0	18.0	99	0.3	1	0.00007	0
Grid 6	77.5	18.1	100	0.0	0	0.00000	0
Grid 8	62.9	17.4	96	0.6	4	0.00005	0
Grid 9	67.6	18.0	100	0.0	0	0.00000	0
Grid 10	59.4	15.9	87	2.3	13	0.00006	0
Grid 12	64.3	12.1	93	0.9	7	0.00007	0
Grid 13	64.9	24.3	85	4.3	15	0.00000	0
Grid 15	73.4	14.2	100	0.0	0	0.00000	0

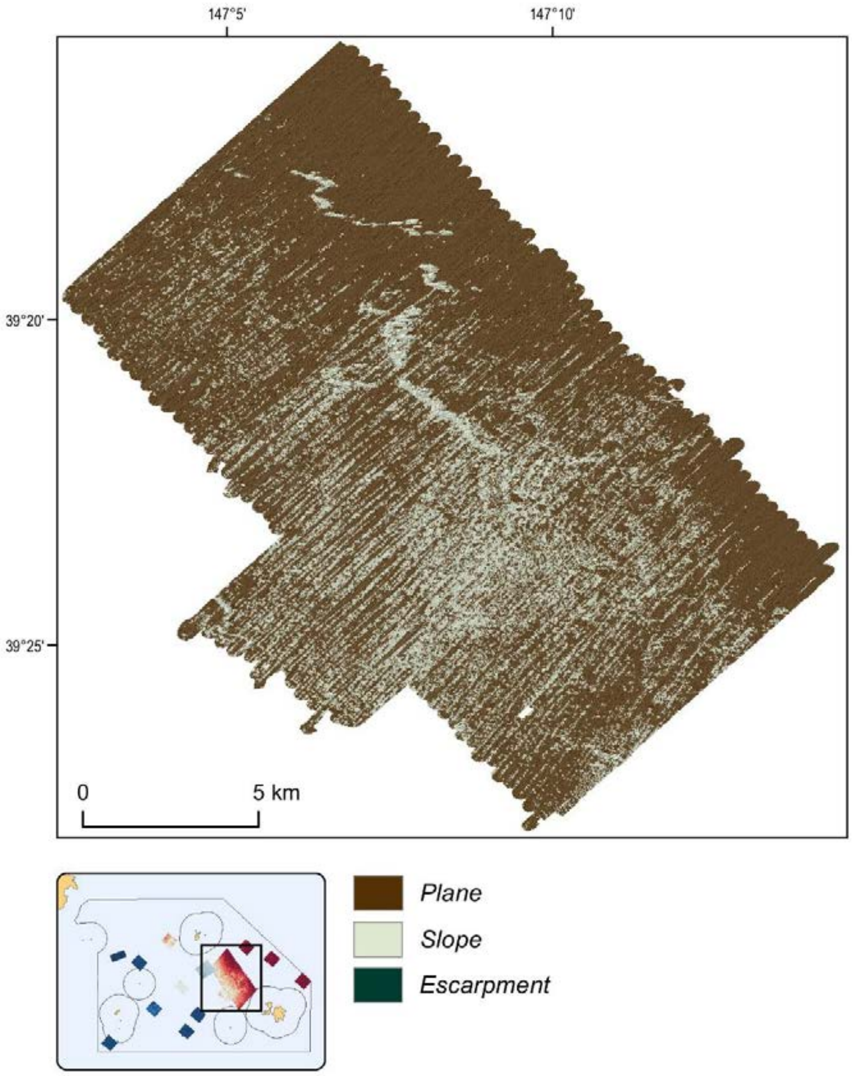


Figure 13. Surface map for grid 0, created using the semi-automated method summarised in section 3.4.4, showing a dominantly planar seabed (76% of mapped area) with slopes associated with linear ridges. Inset map shows the location of grid 0 within the Beagle Marine Park.

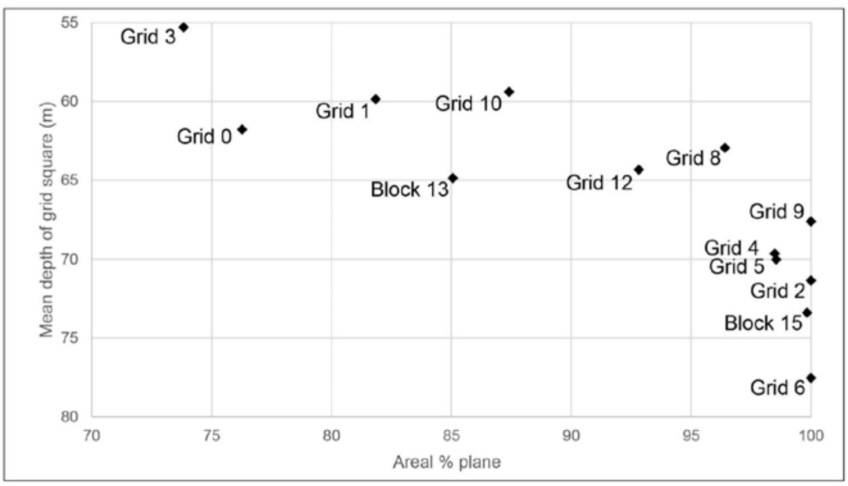


Figure 14. Cross plot of survey area depth, and percentage of the survey area covered by 'plane' (slope 0-2°).

4.1.3 Seabed sediments

Grab samples are composed of poorly sorted, coarse to very coarse carbonate sand and gravel. See Appendix B for sample details and results of grain size and carbonate analysis. Identifiable materials include bryozoan fragments, bivalve shells, gastropods and other skeletal fragments (Figure 15). The single dredge sample recovered a number of cobble sized blocks of 'grainstone' (after Dunham, 1962), characterised by weakly bedded to massive cemented carbonate sand (Figure 16).

Figure 15. Photomicrograph of sediment grab 02GR01 (~57 m water depth) comprising poorly sorted mix of shell and bryozoan fragments. Width of image ~10 cm.

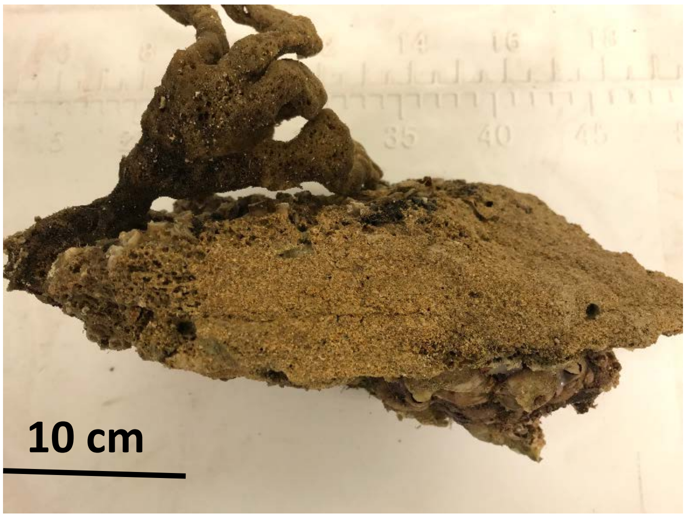


Figure 16. Dredge sample 01DR01 (~59 m water depth) comprising weekly bedded, cemented carbonate sand, termed a 'grainstone' (with attached sponge). Width of image ~50 cm.

4.1.4 Origin of seabed features

Hardground ridges (reefs)

The 2-5 m high ridges that extend for several kilometres in grid 0 form the most pronounced raised seabed features in the park (Figure 17), and appear to be unrelated to the prevailing hydrodynamic regime of Bass Strait. The geologically recent sub-aerial exposure of the Bassian Rise provides a clue as to the most likely origin of these ridges. The morphology and orientation of the ridges is similar to aeolian dunes that have been mapped in southern Victoria and northern Tasmania (e.g. Brooke et al., 2017; Hill and Bowler, 1995). It is therefore likely that these ridges were formed by aeolian (wind) processes when Bass Strait was exposed as a land bridge during the last glacial period (ca. 18,000 – 12,000 years before present) and were sufficiently lithified to remain intact during the post-glacial marine flooding of Bass Strait. This interpretation is supported by the sedimentary composition of the ridges, which is a coarse-grained, cemented carbonate sand ('aeolianite'). These relict dunes are therefore stable features, providing an ideal habitat for reef-dwelling organisms. Relict dunes identified by this new data cover at least 4.5 km^2, corresponding to ~1% of the mapped area of Beagle Marine Park (Figure 16).

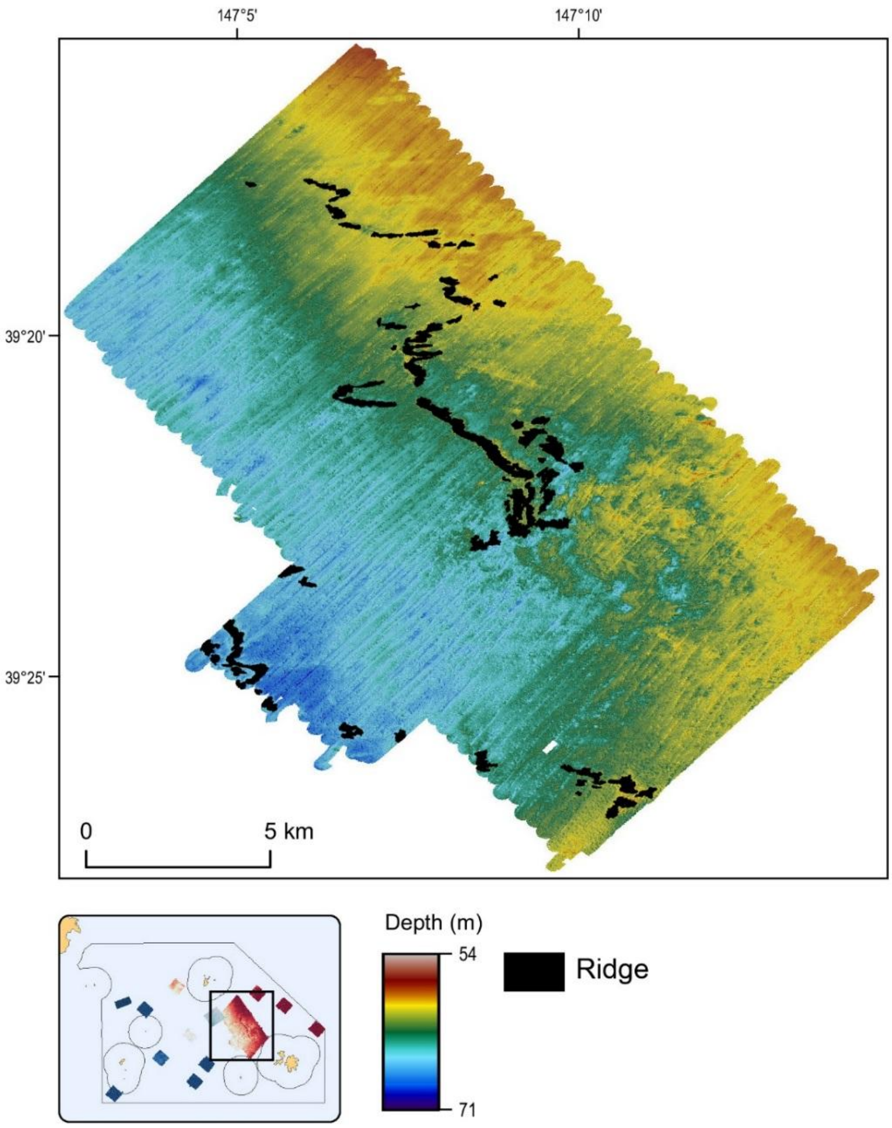


Figure 17. Map showing occurrence of drowned terrestrial dune ridges that form raised reef habitat within grid 0. Inset map shows the location of grid 0 within the Beagle Marine Park.

The long, linear bedforms (ridges) that characterise the mapping grids in the eastern part of Beagle Marine Park have two possible origins: *hydrological* control or *geological* control. Regarding the former, both the speed and power of tidal currents in eastern Bass Strait are high, particularly between Wilsons Promontory and the northern tip of Flinders Island (Baines et al., 1991; Griffin and Hemer, 2010). Given their approximate alignment with the direction of tidal-driven bottom currents, it is possible that these linear features are longitudinal bedforms. Such bedforms are characteristic of high flow energy environments where sediment supply is abundant. However, a geological origin is also possible, and this is supported by the regional geology of Bass Strait.

The Ordivician Mathinna Group is a sequence of turbiditic sandstone and shale that is sporadically sub-aerially exposed across a large region of northern Tasmania stretching at least from the north-east coast to the Furneaux Island group in Bass Strait (Powell and Baillie, 1992; Powell et al., 1993). The unit is at least seven kilometres thick and forms a major component of the East Tasmanian Terrane, which was deformed in the Early to Middle Devonian to produce recumbent folds that verge from NNW to ENE (Powell and Baillie, 1992). A key characteristic of the Mathinna Group is well developed interbedding of the sandstone and shale units, as observed in coastal outcrops (Figure 18). It is therefore possible that the ridges represent a thin veneer of sediment over an extensive area of near-surface bedrock exposure, composed of steeply inclined sedimentary rocks of the Mathinna Group. This is supported by the distinct backscatter intensity response, and the apparent continuation of the lineations underneath unrelated seabed features. A combined hydrological and geological control on these features is also plausible, where the thin sediment over shallow basement is further scoured by tidal currents that are approximately coincident with the geological strike.

Figure 18. Coastal outcrop of interbedded Mathinna Group on Flinders Island, Bass Strait (sourced from http://furneauxgeotrail.flinders.tas.gov.au/html/badger-corner.html).

With these insights into the origin of the geomorphic features within the mapped area of Beagle Marine Park, it is evident that the distribution of raised reef is a legacy of the late Quaternary sea level history and sediment supply regime of the continental shelf within eastern Bass Strait. In particular, the preservation of relict terrestrial dunes appears to be limited to the 50 – 60 m depth range (i.e. survey grid 0) which corresponds to a sea-level mode associated with preservation of paleoshoreline features on the Australian continental shelf (Brooke et al., 2017). Deeper areas of the marine park are characterised by more extensive sediment cover, such that relict terrestrial dunes are either not preserved or buried. It is also noted that the type of terrestrial dune preserved as raised reef (isolated transverse dune) is one that typically forms under conditions of limited sediment supply. Hence, it is not likely that these dunes were spatially extensive when active. On the basis of the mapping results from the survey, it is inferred that raised reef of a dune origin comprises less than 1% of the marine park and sediment covered areas are dominant, likely in excess of 95% of the park.

Anthropogenic features

Two anthropogenic features were mapped, including a cable in the area of overlap between grid 0 and block 13 (Table 2, row 12). This is almost certainly an exposed section of the Basslink Interconnector that runs between Tasmania and Victoria (Sherwood et al., 2016). The second feature was the SS Cambridge wreck in the north-western region of the marine park and was mapped by RV *Investigator* in 2019 (Figure 19). The multibeam sonar data provides a very clear picture of the orientation of the wreck and surrounding seabed. The wreck appears to be laying upright on its keel and is orientated in at south-west to north-east bearing. The wreck appears to be relatively intact with a vertical profile of ~ 10 m from surrounding sediments. Sediment scouring is clear on the south-eastern side of the vessel and a large, elongated sediment ridge to the north-east of the wreck. This scouring and deposit is likely due to the strong east-west tidal currents in the area.

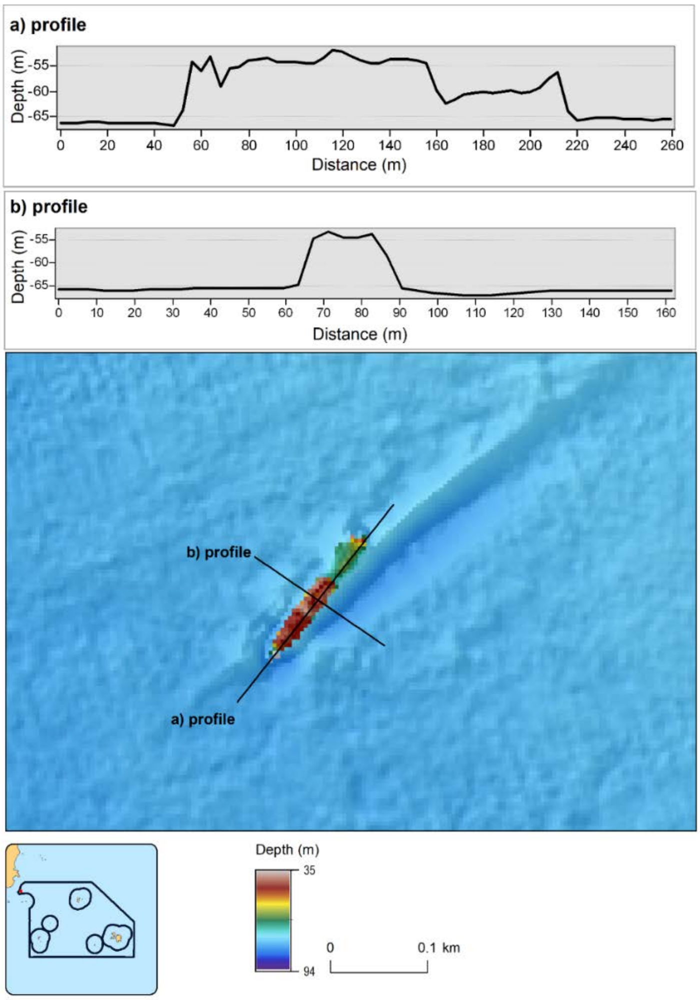


Figure 19. Mapped region of the SS Cambridge showing surrounding seabed and vertical profile of the wreck. Note large shadow dune in the lee of the wreck (northwest).

4.1.5 Sub-seabed features

One sub-bottom profile was collected during voyage GA0364, to assist in characterising the seabed in terms of mapping the thickness of unconsolidated sediment over bedrock. The profile intersects grid 2 (almost the full width of the grid) and grid 4 (overlap of only a few metres), corresponding to water depths of 70-72 metres (Figure 3). Overall, the sub-bottom data suggests uniform shallow sub-surface geology, with a veneer of unconsolidated sediment overlying sedimentary bedrock (Figure 20). The Sparker system used to acquire the data was operated at the highest possible power (2400 joules); the signal therefore penetrated the bedrock but did not finely resolve structure within the sediment.

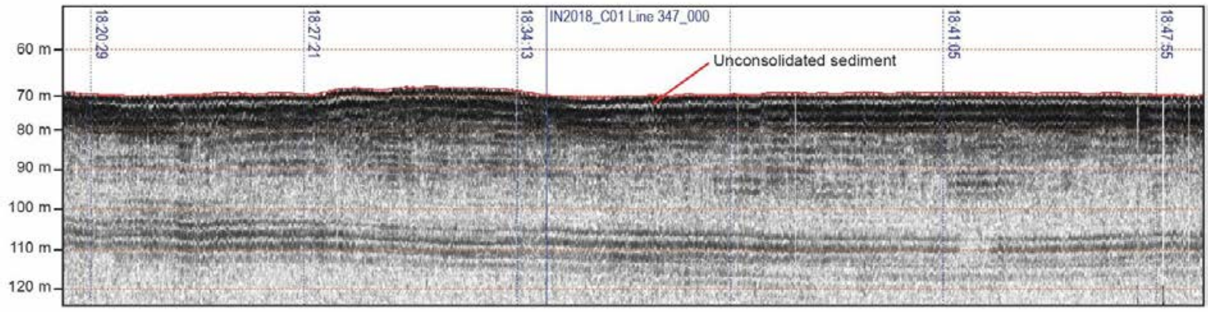


Figure 20. Sub-bottom profile intersecting grids 2 and 4. Solid blue line shows the intersection with line 347_000 acquired by the RV *Investigator* in 2018.

The uppermost acoustic facies are transparent, and bounded by the sea floor above, and a continuous horizontal reflector below. These facies are on average around 3.5 m thick (ranging from around 2.5 to 4 m), and likely represents the accumulation of sediment on the sea floor. This interpretation is supported by an intersecting sub-bottom line that was acquired by the RV *Investigator* during a transit through Beagle Marine Park in 2018 (IN2018_C01). The RV *Investigator* data were acquired with a Chirp system operating at higher frequency than the Sparker used during GA0364. The signal therefore does not penetrate the bedrock, but instead clearly resolves both the contact of sediment with bedrock, and detail within the sediment accumulation overlying bedrock. In the location of the intersection between the two lines (Figure 20), the inferred thickness of sediment from interpreted seafloor and bedrock surfaces is within one metre, although slightly thicker in the IN2018 data. The latter is probably more realistic given the comparatively highly resolved contact in the Chirp data.

The acoustic facies underlying the sediment is characterised by continuous parallel reflectors that are approximately horizontal. The parallel reflectors are interpreted as bedding planes, indicating that the bedrock in this area is likely well bedded sedimentary rock. These facies are also characterised by discrete pockets of acoustic masking. These parallel reflectors have a gradational transition with semi-transparent acoustic facies. This overlies another package of well-bedded sedimentary rock (around 30-40 m below the sea floor), which in turn caps a relatively reflection-free (but not fully transparent) facies.

4.2 Sessile epifaunal communities

4.2.1 Compositional patterns in sessile morphospecies assemblages

Photo mosaics of the AUV imagery revealed four broad habitats categories within grid 0 (see Figure 21 to Figure 24), including: 1) low-profile (<1m) reef features supporting moderate to high densities of sessile invertebrates (mixed sponge, bryozoan and hydroids) (Figure 21a, c) and resting schools of Port Jackson sharks (*Heterodontus portusjacksoni*) (Figure 21b); 2) scallop beds interspersed among unconsolidated coarse sand with shell fragments and 2D/3D ripple features (Figure 21d, e); 3) screw shell beds; and 4) aggregations of shell hash with broken bryozoan skeletons, and disarticulated and live scallops that provide an important substrata for a moderate cover of sessile filter feeding invertebrates (Figure 24a). Distribution maps and nMDS plots relative abundance of these species are provided in Figure 26-Figure 34. The bubble size in the maps and nMDS indicate relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert of the nMDS represent the importance of each habitat type in driving assemblage patterns.

A highly diverse epifaunal assemblage was recorded, with 205 biological morphospecies identified and seven substratum types (Appendix C). Sponges were the dominant organism with 159 morphospecies, massive forms being recorded most, but also representatives of creeping/ramose, encrusting, branching and cup sponges also observed. Representatives from cnidarians, bryozoans and ascidians were also recorded with 14, 11 and 4 morphospecies, respectively (Appendix C).

Similar to other mesophotic reef environments around Tasmania (such as the Flinders MP), matrix classes consisting of turf-like, finely-structured short (<5 cm) sessile invertebrates were observed to have the highest cover (matrix classes; Appendix C) providing an average cover of ~ 2 % in images. For the larger, more identifiable sessile invertebrates, mean cover was generally < 0.1 %. Nearly 34 % of morphospecies were singletons (i.e. only seen once) and nearly half the morphospecies in the assemblage were seen less than twice. This suggests that the benthic assemblage in the Beagle Marine Park consists of morphospecies that are highly diverse and spatially rare. When compared to sessile invertebrates, doughboy scallops and invasive New Zealand Screw shells had considerable coverage (average of 5 and 1%, respectively; Appendix C).

The PERMANCOVA revealed that habitat category accounted for most of the variation (23 %), while depth and the interaction between habitat and depth accounted for a significant, but small proportion of the variation in sessile morphospecies assemblages within the Beagle Marine Park (Table 4). The PERMANCOVA pairwise routine suggested significant difference between all habitats ($p < 0.001$). The pairwise routine also identifies the relative sizes of average similarities (or dissimilarities) between habitats, which suggests that the morphospecies assemblages within the reef habitat had highly variable assemblages (~39 % similarity) and were quite dissimilar to all other habitats (Table 5). Conversely, the screw shell and shelly sand habitats had lower variation (i.e. high similarity within; Table 5). The SIMPER routine revealed that the variations in the cover of the matrix classes, the variations in the presences of red throated ascidian, hydroid white, soft bryozoans (dark red and beige fluffy), hard bryozoan *Celleporaria* like, encrusting sponges (orange and white), simple massive sponges (beige irregular oscula, beige small, beige small oscula), and branching sponge (arborescent purple thin) were responsible for the detected differences between habitat classes (Table 6).

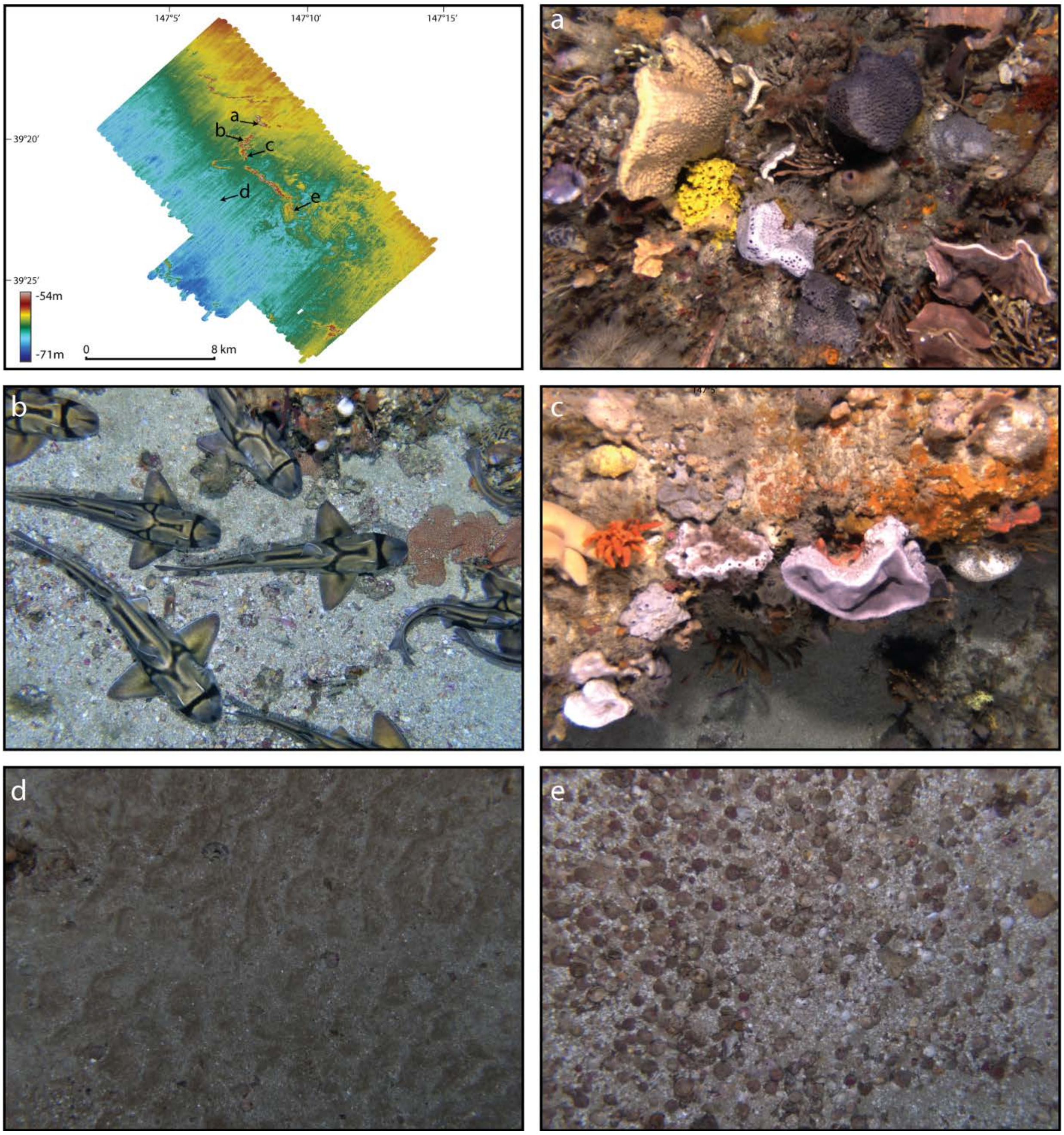


Figure 21. AUV still photographs from grid 0 showing a range of benthic habitats. (a and c) Mixed sponge, bryozoan and hydroid community on low-profile ridges. (b) School of Port Jackson sharks (*Heterodontus portusjacksoni*) resting on the margins of the central ridge reef features mapped in Figure 17. (d) Unconsolidated coarse sand with shell fragments and 2D/3D ripple features. (e) Doughboy scallops interspersed among unconsolidated coarse sand with shell hash.

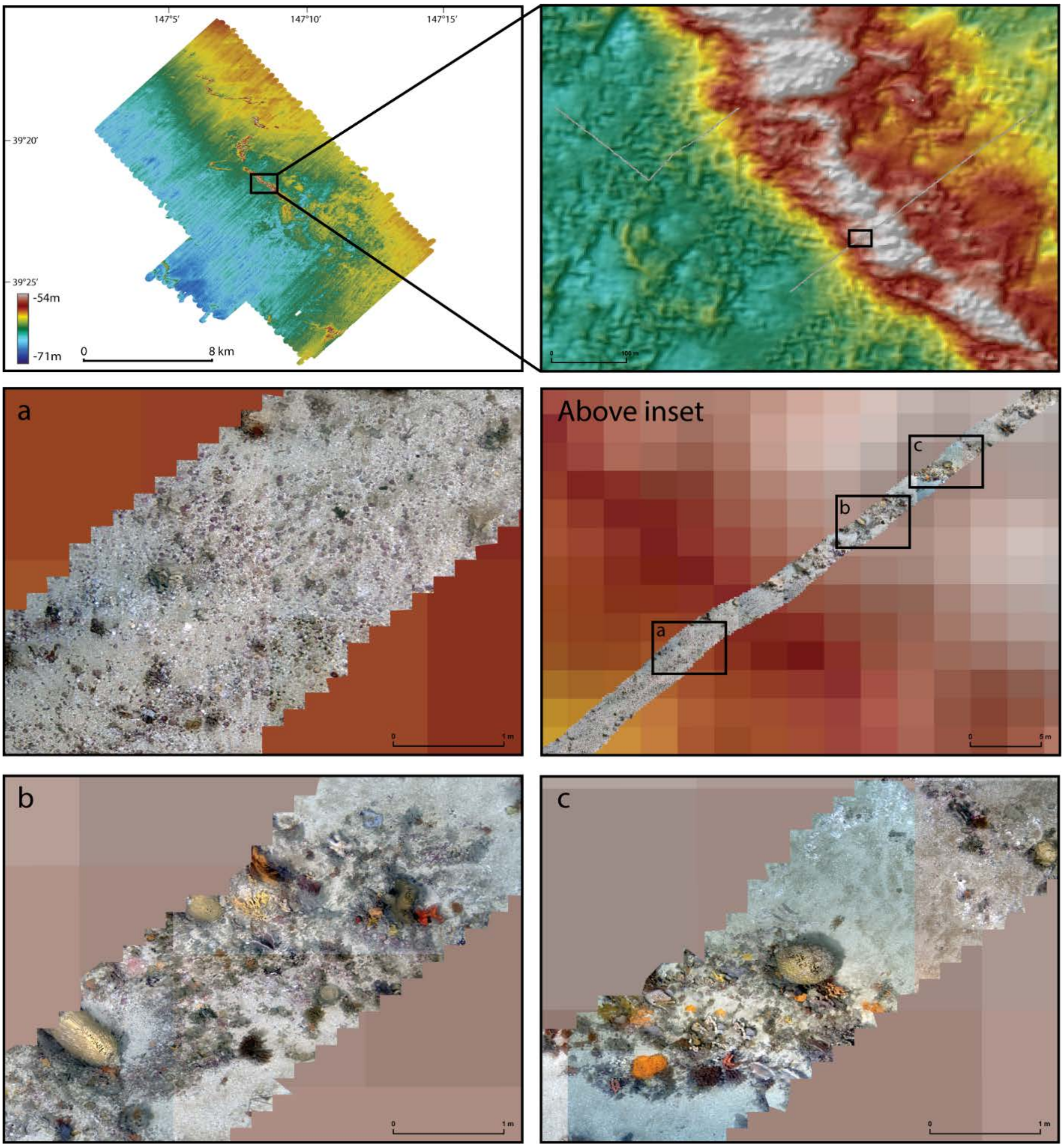


Figure 22. Map showing the location of an AUV transect across the edge of a low-profile, sand-inundated reef within grid 0. (a to c) transition from sparse to moderate densities of sessile invertebrates, including cup and massive sponges, bryozoans, cnidarians (hydroids).

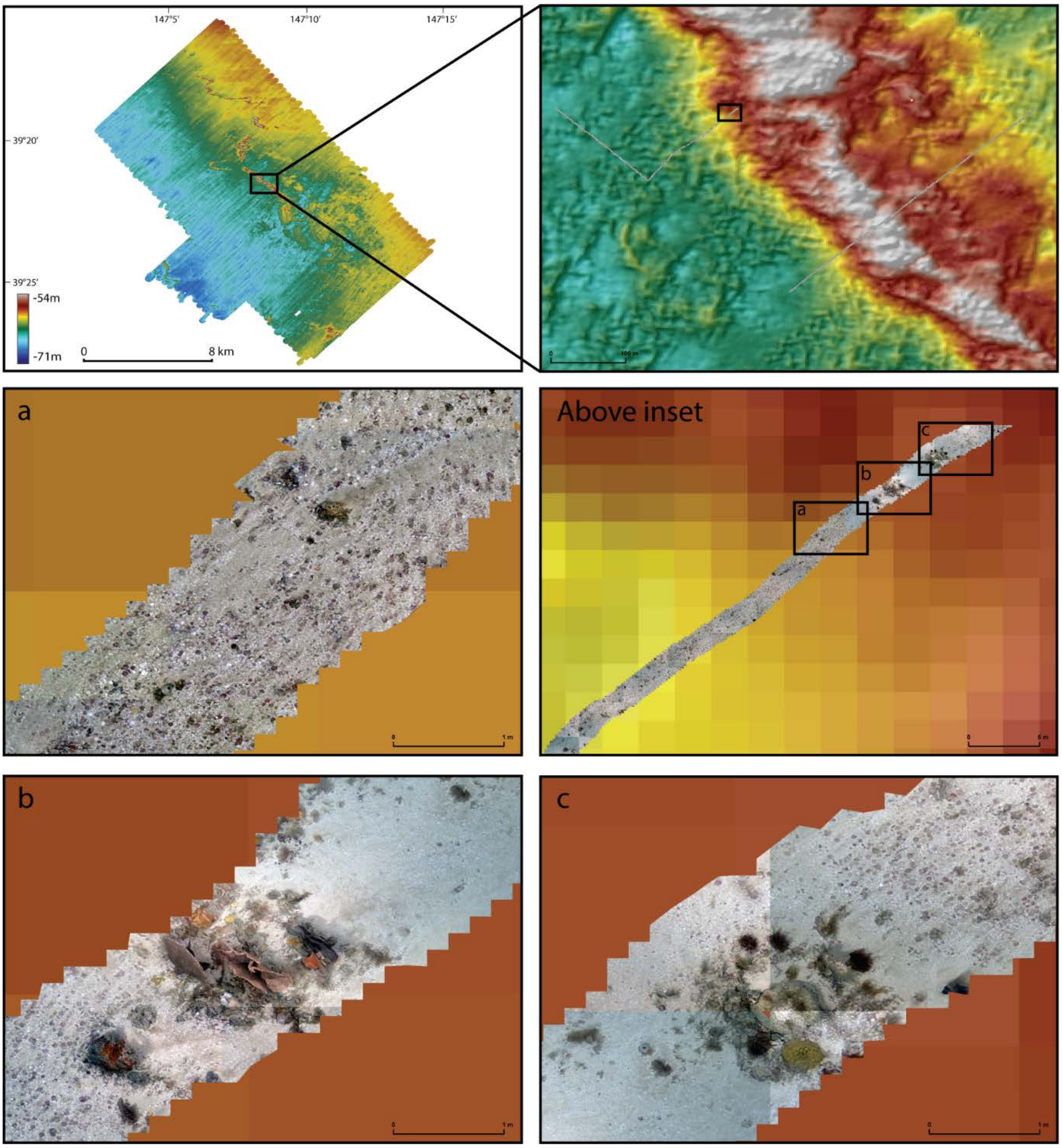


Figure 23. Map showing the location of an AUV transects across the edge of a low-profile, sand-inundated reef within grid 0. (a to c) transition from sparse to moderate densities of sessile invertebrates, including cup and massive sponges, bryozoans, cnidarians (hydroids).

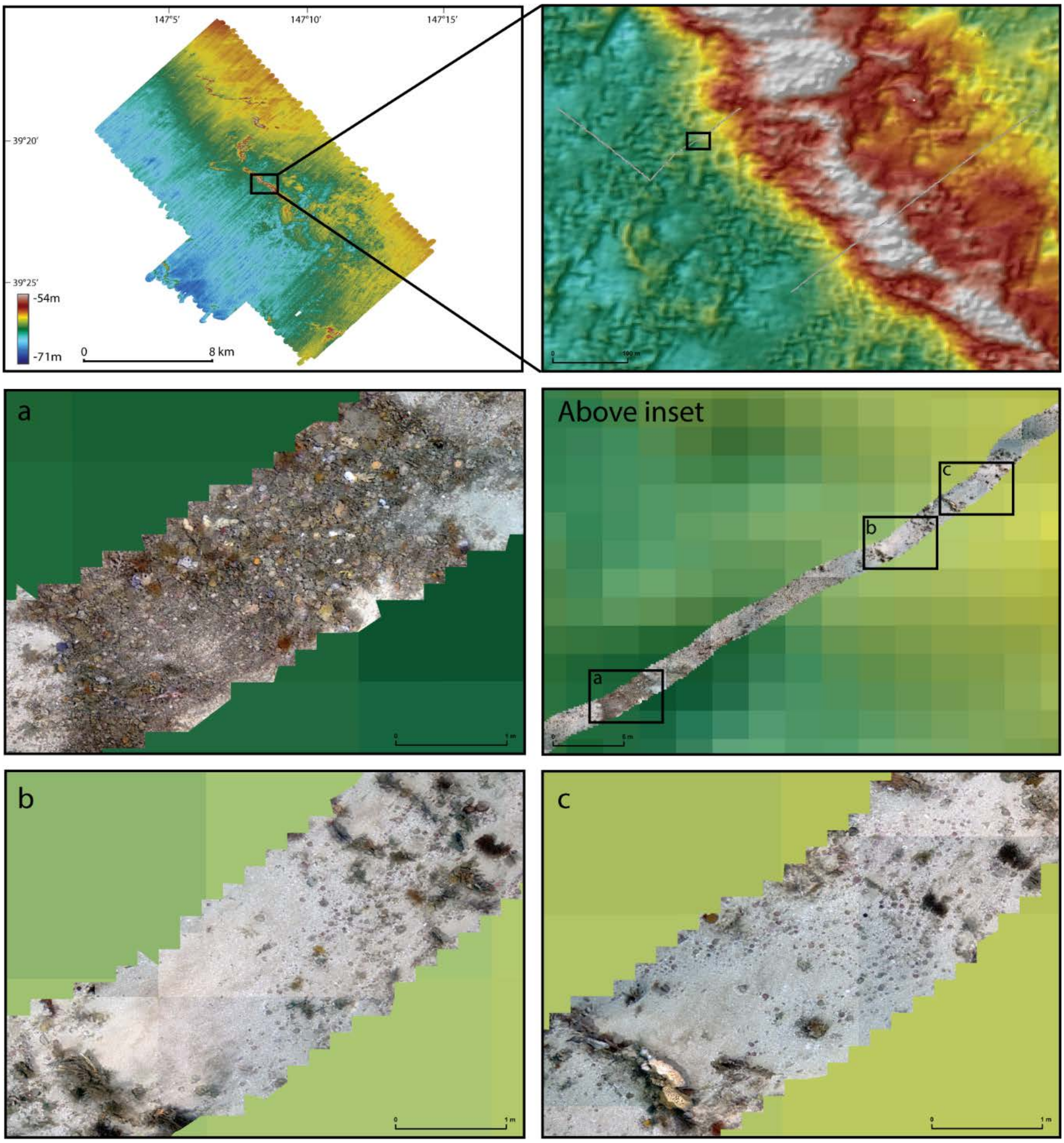


Figure 24. Map showing a section of AUV transect across the margin of a low-profile, sand-inundated reef within grid 0. (a) Dense cover of shell rubble with dead, disarticulated and live scallops, providing a habitat foundation for sessile invertebrates (b and c) sparse densities of sessile invertebrates, including cup and massive sponges, bryozoans, cnidarians (hydroids) interspersed among unconsolidated coarse sand with shell fragments.

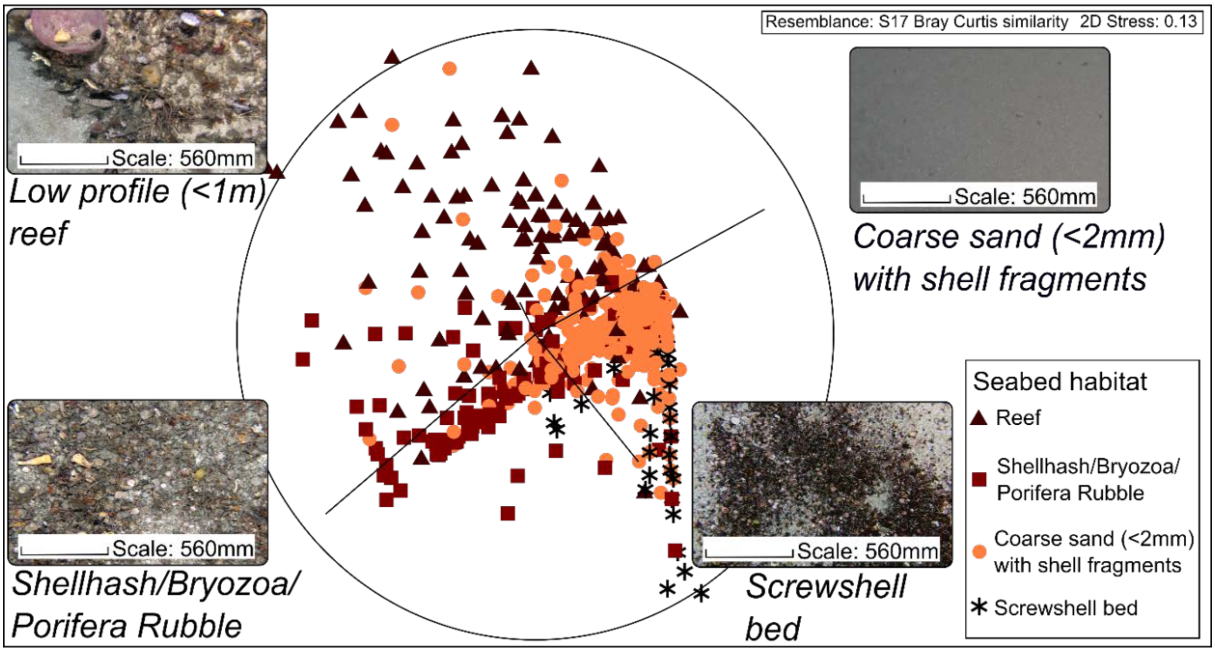


Figure 25. Non-metric multidimensional scaling (nMDS) ordinations highlighting the differences in sessile morphospecies composition between four key seabed habitat types encountered in imagery.

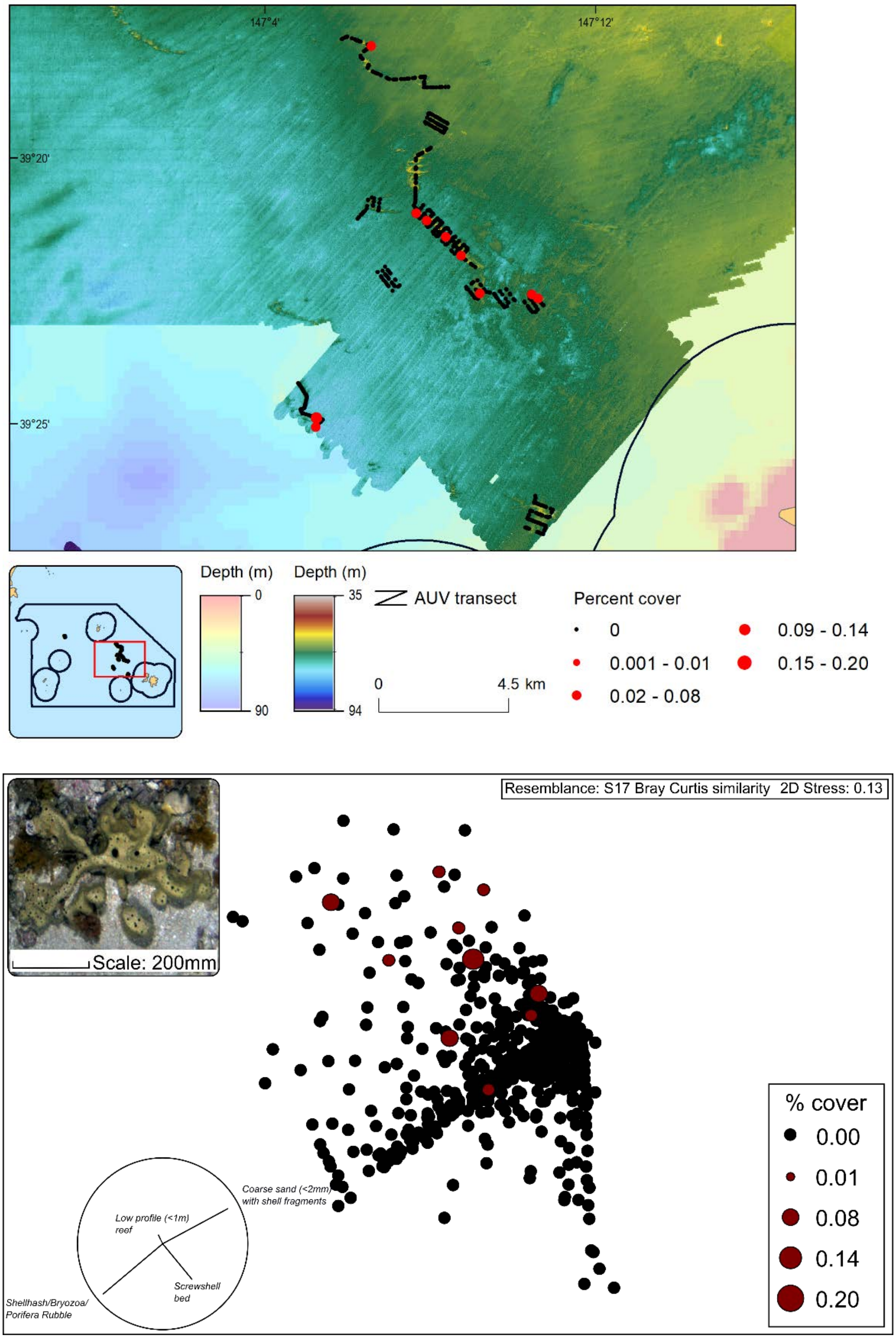


Figure 26. (Top image) Map showing the distribution and percent cover of *'simple beige oscula'* sponge across AUV transects within Grid 0. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this sessile morphospecies. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the morphotype class and an indication of its size.

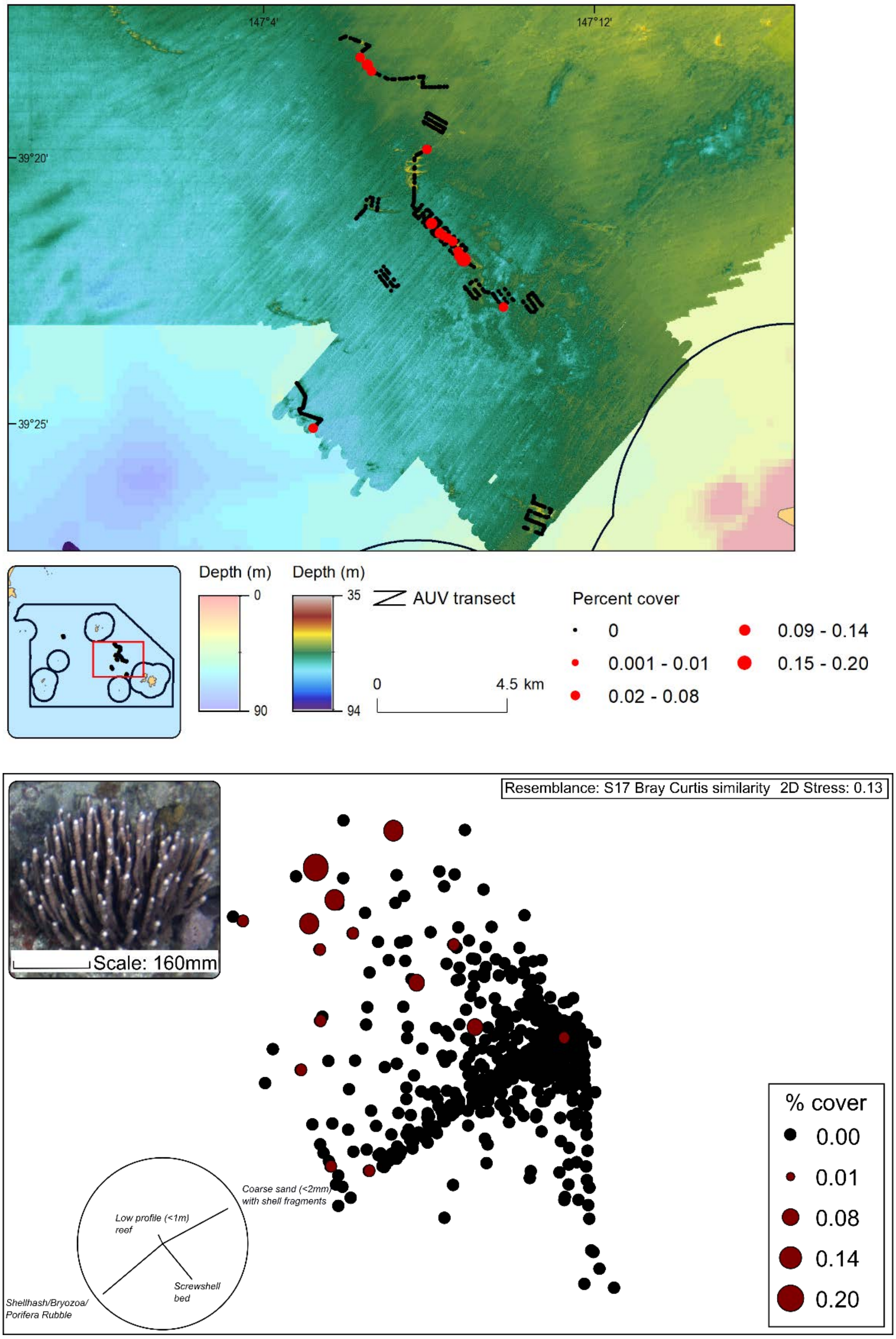


Figure 27. (Top image) Map showing the distribution and percent cover of *'branching thin purple'* sponges across AUV transects within Grid 0. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this sessile morphospecies. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the morphotype class and an indication of its size.

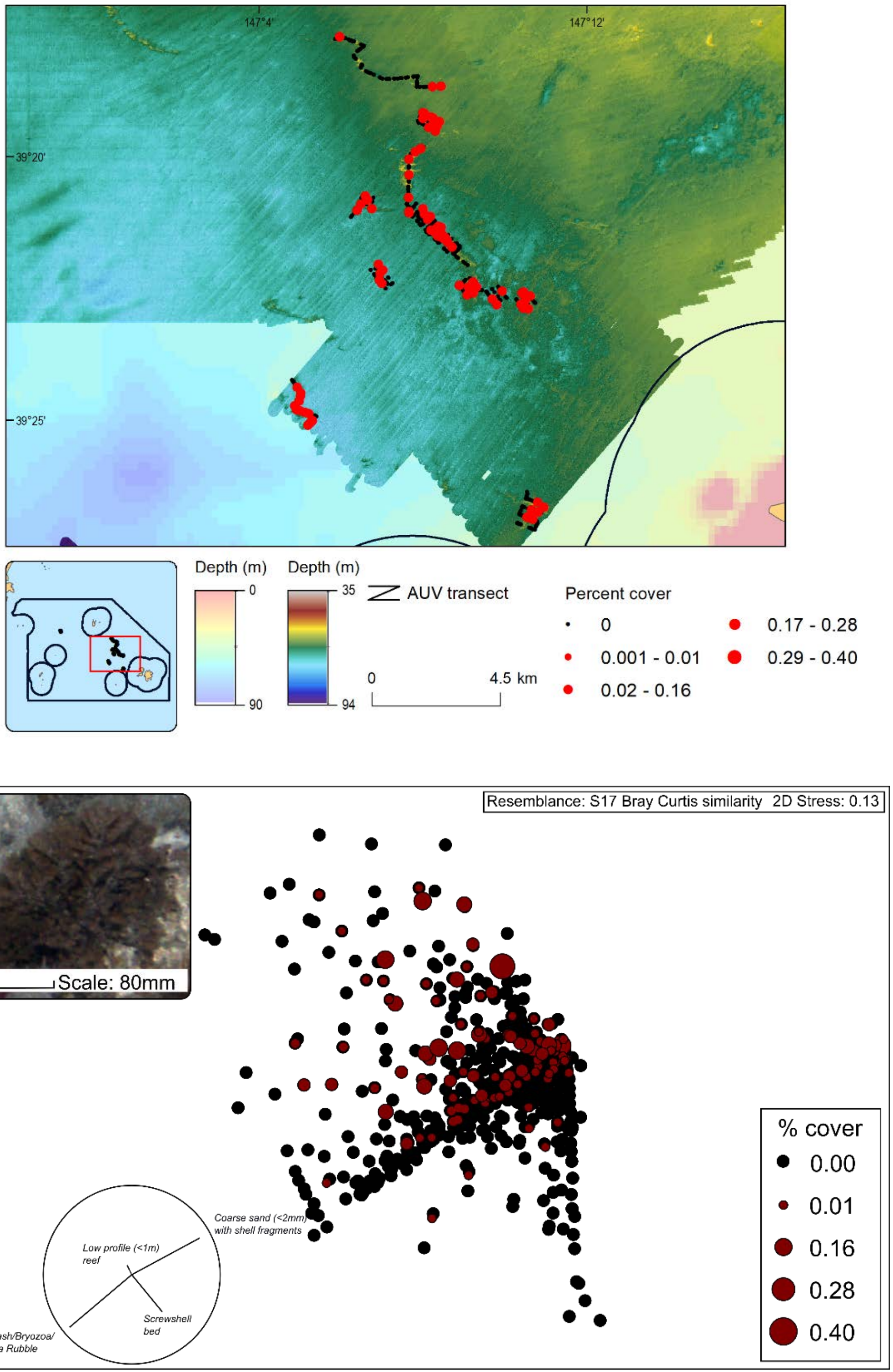


Figure 28. (Top image) Map showing the distribution and percent cover of *'dark red soft'* bryozoan across AUV transects within Grid 0. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this sessile morphospecies. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the morphotype class and an indication of its size.

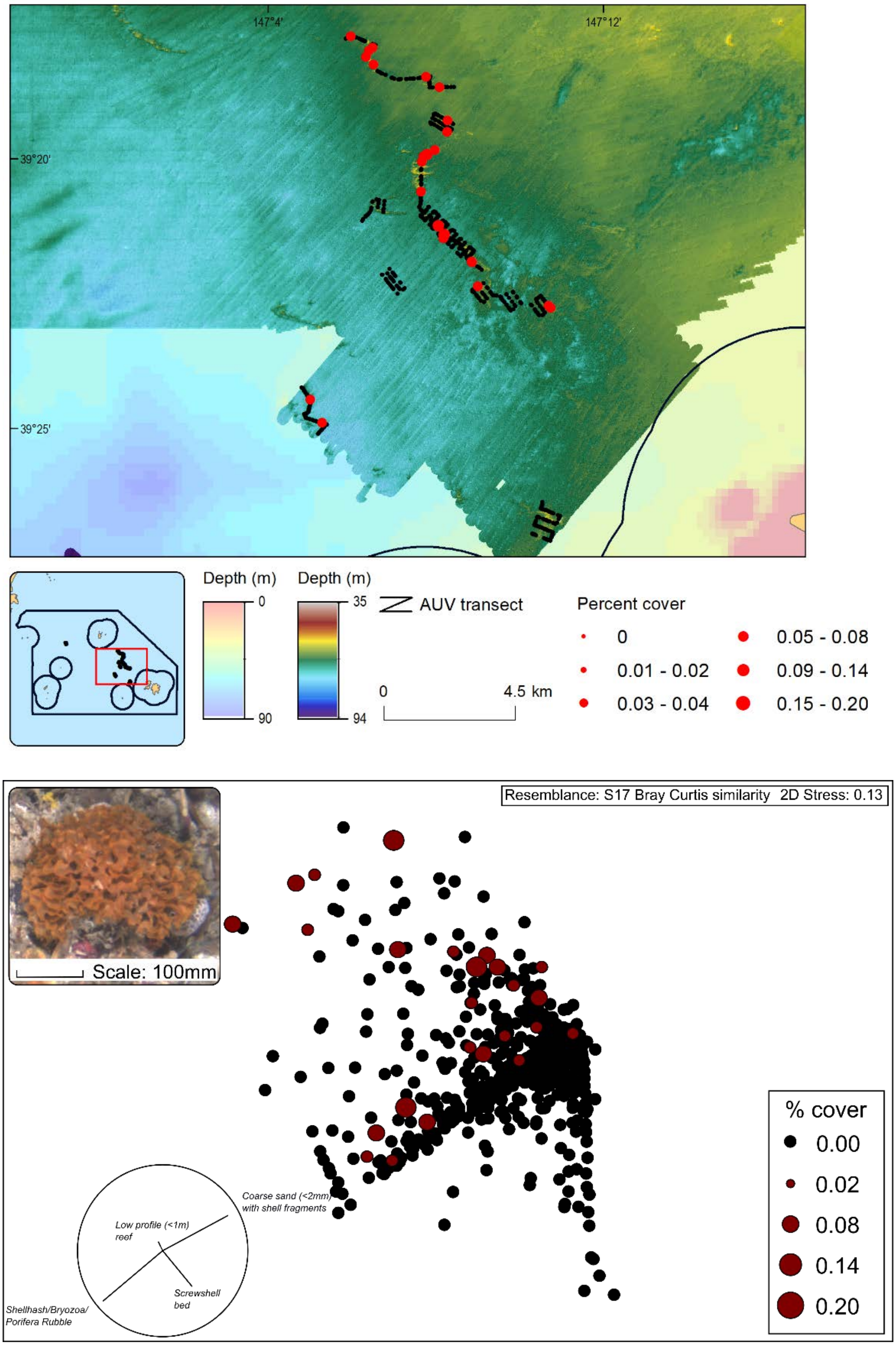
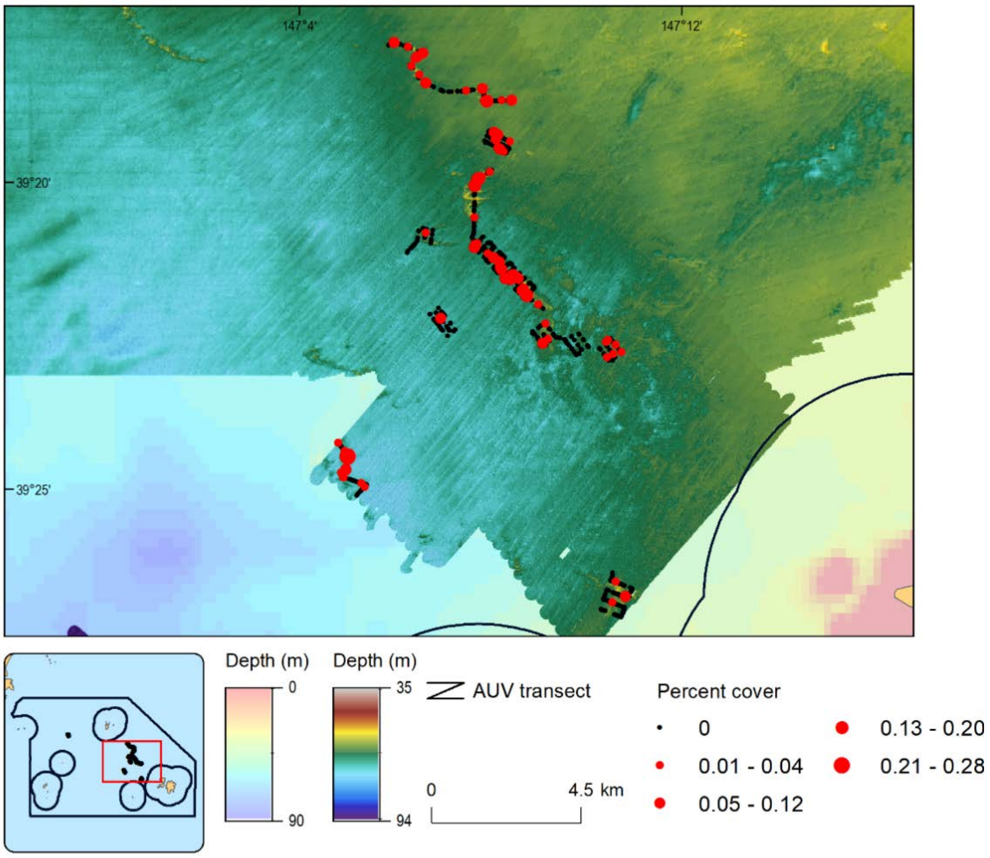


Figure 29. (Top image) Map showing the distribution and percent cover of '*Celleporaria*-like' bryozoan across AUV transects within Grid 0. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this sessile morphospecies. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the morphotype class and an indication of its size.



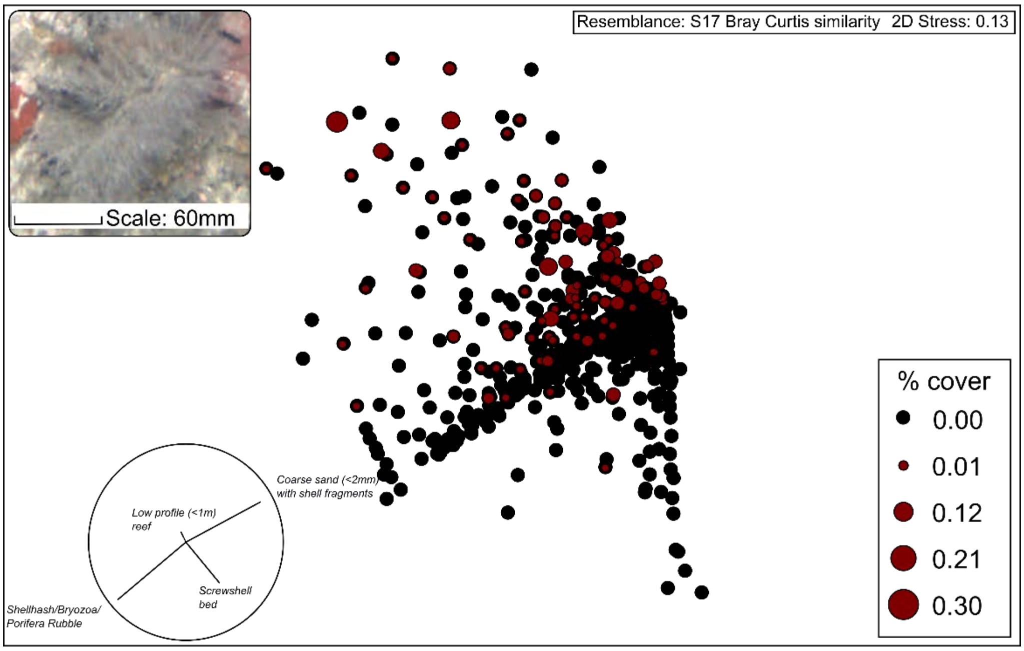


Figure 30. (Top image) Map showing the distribution and percent cover of *'hydroid white'* across AUV transects within Grid 0. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this sessile morphospecies. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the morphotype class and an indication of its size.

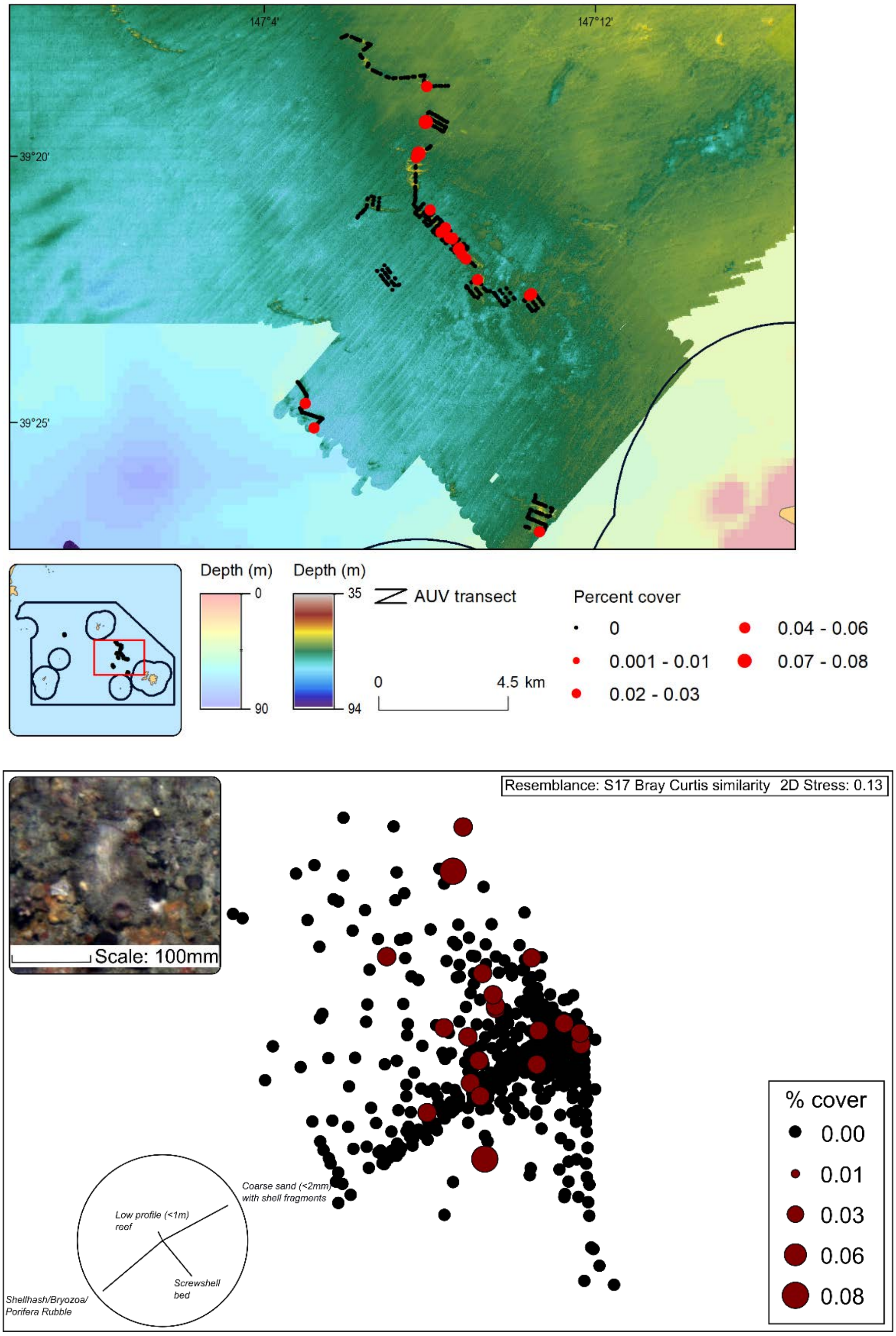


Figure 31. (Top image) Map showing the distribution and percent cover of *'red throat ascidians'* across AUV transects within Grid 0. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this sessile morphospecies. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the morphotype class and an indication of its size.

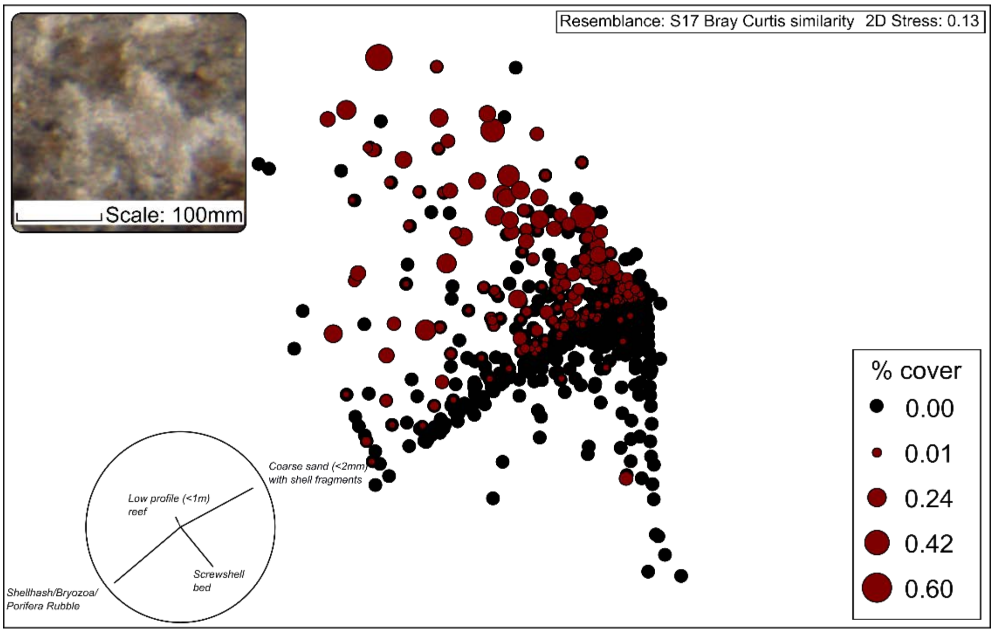


Figure 32. Non-metric multidimensional scaling ordination (nMDS) for the *'Bryozoa / Cnidaria Matrix'* category. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the matrix category and an indication of size.

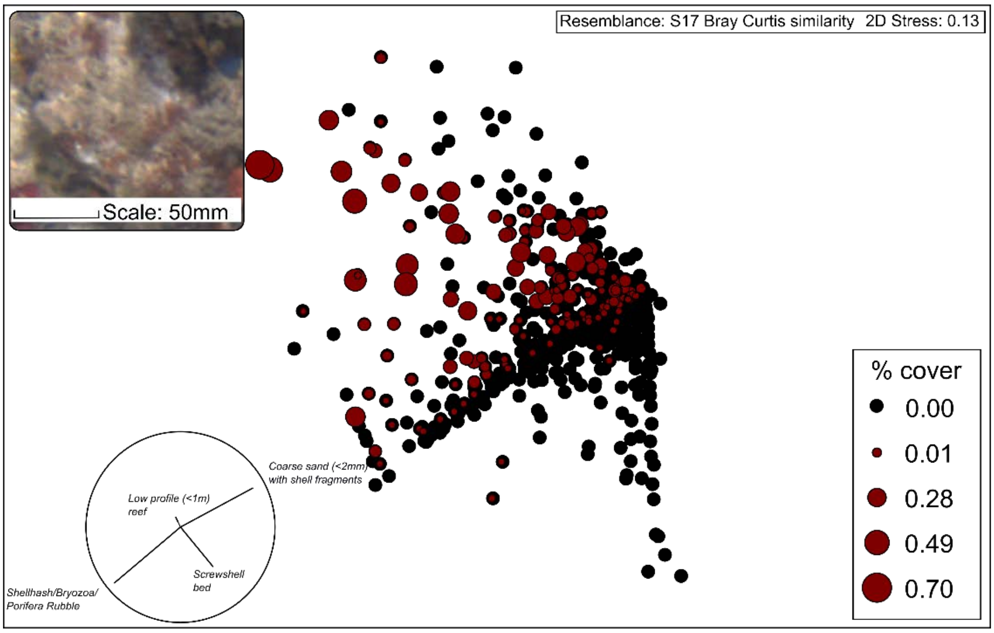


Figure 33. Non-metric multidimensional scaling ordination (nMDS) for the *'Bryozoa / Encrusting Sponge Matrix'* category. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the matrix category and an indication of size.

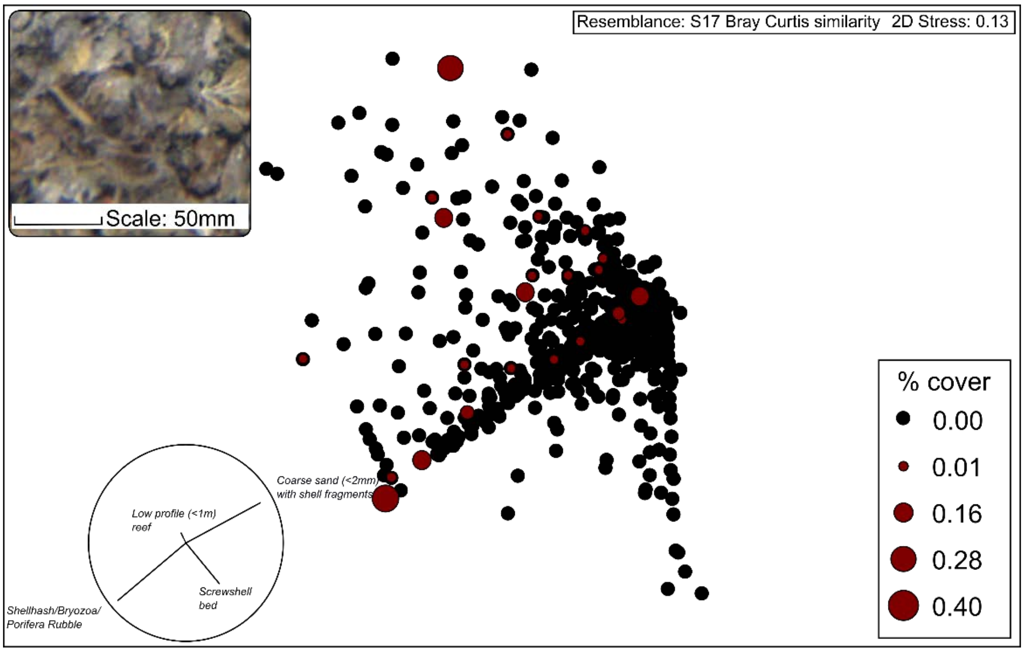


Figure 34. Non-metric multidimensional scaling ordination (nMDS) for the *'Bryozoa / Sponge Matrix'* category. Bubble size indicates relative mean percent cover (i.e. larger bubble = higher percent cover). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type in driving assemblage patterns in the nMDS. Top left insert shows an example image of the matrix category and an indication of size

Table 4. PERMANCOVA revealing that sessile morphospecies recorded in AUV imagery varied by depth and habitat.

Source	**df**	**MS**	**Pseudo-F**	**Unique Permutations**	***p***	**Variance Components (%)**
Depth	1	43636	48.683	9949	0.0001	6.9929
Habitat	3	82330	91.853	9914	0.0001	23.427
Depth x Habitat	3	1856.2	2.0709	9928	0.0272	2.9572
Res	866	896.32				29.939
Total	873					

Table 5. Average similarities (%) in morphospecies composition between Habitat classes from PERMANCOVA pairwise comparisons.

	Reef	Shell hash	Screw shell	Shelly sand
Reef	40			
Shell hash	37	52		
Screw shell	33	37	69	
Shelly sand	45	50	47	71

Table 6. Key morphospecies identified by SIMPER routine that were associated with differences between habitat categories.

Comparison	Morphospecies	Av.Diss	Diss/SD	Contrib%
Reef vs Shelly sand	Bryozoa / Cnidaria Matrix	18.86	0.9	19.79
	Bryozoa / Cnidaria/ Encrusting Sponge Matrix	15.06	0.73	15.8
	Bryozoa / Cnidaria / Sponge Matrix	12.28	0.62	12.89
	Bryozoan Soft Dark Red	6.23	0.44	6.53
	Hydroid white	5.91	0.58	6.2
	Bryozoa / Cnidaria / Creeping / Ramose Sponge Matrix	1.8	0.24	1.89
	Bryozoan Soft Beige Fluffy	1.71	0.32	1.8
	Bryozoan Hard *Celleporaria* Like	1.66	0.31	1.75
	Arborescent Purple Thin	0.98	0.28	1.03
Reef vs screwshell	Bryozoa / Cnidaria Matrix	20.53	0.89	20.6
	Bryozoa / Cnidaria/ Encrusting Sponge Matrix	16.05	0.7	16.1
	Bryozoa / Cnidaria / Sponge Matrix	12.96	0.59	13
	Bryozoan Soft Dark Red	6.62	0.41	6.65
	Hydroid white	6.39	0.57	6.41
	Bryozoa / Cnidaria / Creeping / Ramose Sponge Matrix	1.85	0.23	1.86
	Bryozoan Hard *Celleporaria* Like	1.77	0.31	1.78
	Bryozoan Soft Beige Fluffy	1.65	0.3	1.66
	Arborescent Purple Thin	1.02	0.27	1.02
Reef vs shellhash	Bryozoa / Cnidaria Matrix	17.87	0.89	19.18
	Bryozoa / Cnidaria/ Encrusting Sponge Matrix	14.52	0.74	15.58
	Bryozoa / Cnidaria / Sponge Matrix	13.06	0.67	14.02
	Bryozoan Soft Dark Red	5.77	0.44	6.19
	Hydroid white	5.72	0.6	6.14
	Bryozoa / Cnidaria / Creeping / Ramose Sponge Matrix	1.98	0.26	2.13
	Bryozoan Hard *Celleporaria* Like	1.79	0.33	1.92
	Bryozoan Soft Beige Fluffy	1.42	0.29	1.52
Shelly sand vs screwshell	Bryozoa / Cnidaria Matrix	19.07	0.58	19.15
	Bryozoa / Cnidaria/ Encrusting Sponge Matrix	15.03	0.52	15.09
	Bryozoan Soft Dark Red	14	0.47	14.06

Comparison	Morphospecies	Av.Diss	Diss/SD	Contrib%
	Bryozoa / Cnidaria / Sponge Matrix	10.86	0.42	10.91
	Hydroid white	8.4	0.35	8.43
	Bryozoan Soft Beige Fluffy	2	0.18	2.01
	Simple Beige Irregular Oscula	1.81	0.15	1.82
	Ascidian Red Throated	1.63	0.15	1.63
	Bryozoa / Cnidaria / Creeping / Ramose Sponge Matrix	1.34	0.13	1.35
	Simple Beige Small	1.06	0.16	1.06
	Simple Beige Small Oscula	1.03	0.11	1.03
Shellhash vs Shelly sand	Bryozoa / Cnidaria/ Encrusting Sponge Matrix	18.25	0.6	18.95
	Bryozoa / Cnidaria Matrix	16.95	0.58	17.6
	Bryozoa / Cnidaria / Sponge Matrix	14.64	0.57	15.21
	Bryozoan Soft Dark Red	7.99	0.42	8.3
	Hydroid white	5.42	0.36	5.62
	Encrusting Orange	2.08	0.19	2.16
	Bryozoa / Cnidaria / Creeping / Ramose Sponge Matrix	2.06	0.2	2.14
	Simple Beige Irregular Oscula	1.75	0.16	1.82
	Simple Beige Small	1.59	0.17	1.65
	Ascidian Red Throated	1.51	0.17	1.57
	Bryozoan Hard *Celleporaria* Like	1.51	0.17	1.57
Shellhash vs Screwshell	Bryozoa / Cnidaria/ Encrusting Sponge Matrix	20.81	0.59	20.89
	Bryozoa / Cnidaria / Sponge Matrix	15.8	0.56	15.87
	Bryozoa / Cnidaria Matrix	15.68	0.51	15.74
	Bryozoan Soft Dark Red	9.19	0.41	9.23
	Hydroid white	8.29	0.39	8.32
	Encrusting Orange	3.02	0.2	3.03
	Bryozoa / Cnidaria / Creeping / Ramose Sponge Matrix	2.19	0.21	2.2
	Bryozoan Hard *Celleporaria* Like	2.17	0.18	2.18
	Simple Beige Small	1.88	0.16	1.89
	Simple Beige Irregular Oscula	1.75	0.15	1.76
	Encrusting White	1.49	0.14	1.5
	Ascidian Red Throated	1.33	0.17	1.34
	Ascidian Unstalked Colonial Encrusting	1.12	0.11	1.13

Sampling adequacy, precision, and power to detect change in morphospecies cover

Species accumulation curves showed very different rates of accumulation between habitats (Figure 35). Reef habitat had the steepest accumulation rate, while screwshell habitat exhibited the lowest. Based on the species accumulation curves it appears that more sampling is necessary to encounter all species present within the individual habitats encountered in the marine park (exception being for screwshell habitat). It should be noted that the overall combined species pool across all habitats is close to reaching an asymptote, suggesting that sampling effort at the marine park level was adequate (Figure 35).

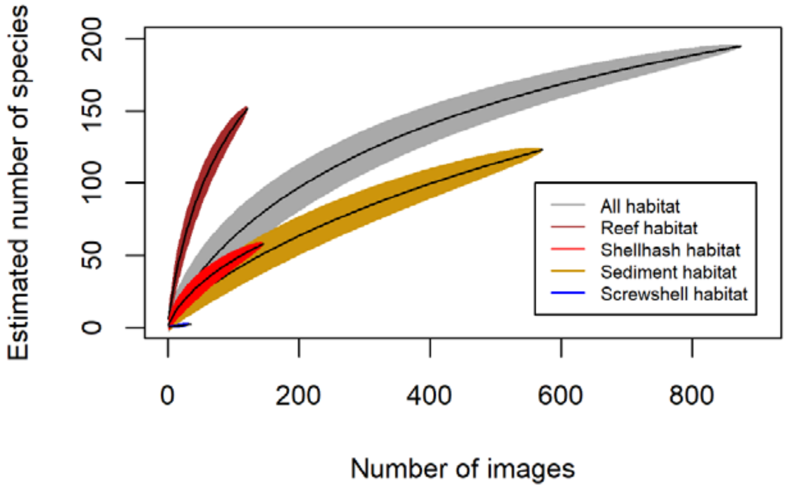


Figure 35. Species accumulation plot for AUV images within the Beagle Marine Park

The appropriate number of replicate images beyond which no substantial decreases in precision would accrue was explored using MultSE (Figure 36). A similar pattern between habitat types to the species accumulation curves was observed with no appreciable precision gained by between 19–85 images depending on habitat category (as indicated with a levelling-off in MultSE in Figure 36).

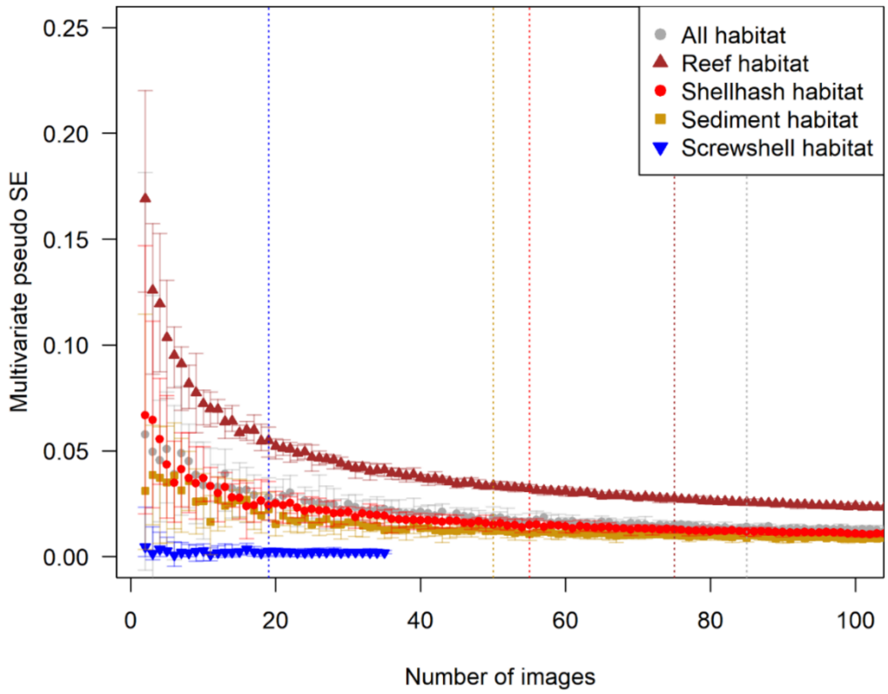


Figure 36. Multivariate pseudo standard error (*MultSE*) as a function of sample size (number of images) based on Bray–Curtis dissimilarities calculated on proportion cover data from the AUV transects broken down by habitat type. Means with 2.5 and 97.5 percentiles as error bars are calculated from 10,000 resamples obtained using a bootstrap approach outlined in Anderson and Santana-Garcon (2014). Colour coded vertical lines provide an estimate for when the means and error bars stabilise within each habitat and indicates sufficient sampling effort.

Power analyses were run on the morphospecies identified by the SIMPER routine as a case study to determine sampling intensity to detect potential increases in cover. The power analyses indicated that in all cases, revisiting the same approximate image location required the least number of transects (Figure 37). As the magnitude of the estimated mean cover increased, the number of images required to detect a difference decreased substantially. For most morphospecies under the sampling scenarios a 50 % increase in mean cover would not be practically achievable (>1000 images) irrespective of habitat category. A 100%, and even more so a 200%, increase in cover could be detected with a reasonable amount of sampling effort (nominally ~ 1000 images at each sampling event; Figure 37).

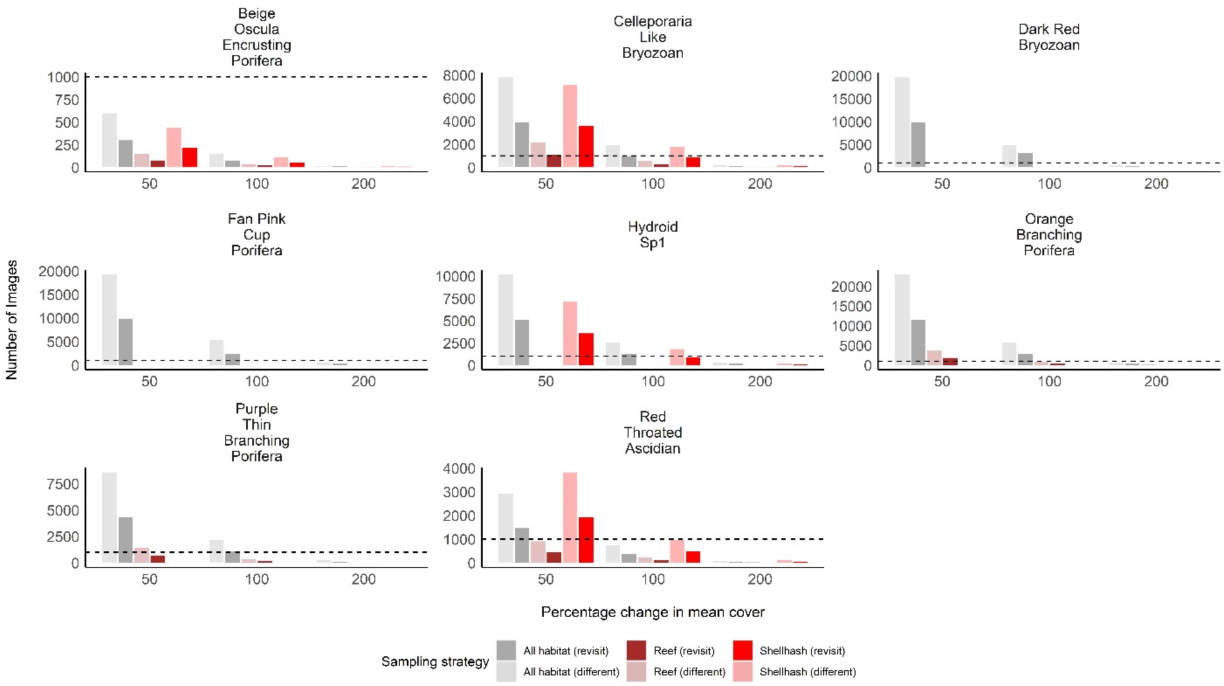


Figure 37. Power analysis of the seven morphospecies (based on Australian morphospecies catalogue) identified by SIMPER routine as important for defining differences between pooled, reef and shellhash habitats within the Beagle Marine Park.

4.3 Demersal fish communities

Compositional patterns in demersal fish assemblages

A total of 3,232 individual fishes belonging to 61 species from 33 families were observed across both the marine park (55 species from 32 families) and reference areas (39 species from 24 families). The most speciose family were monacanthids with eight species, followed by labrids and triglids, each with four species recorded (Appendix D). Degen's leatherjacket (Figure 38), butterfly (Figure 39), barber (Figure 39) and common gurnard (Figure 40) perches, Melbourne silverbelly (Figure 41), jackass morwong (Figure 42), rosy wrasse (Figure 43), cosmopolitan leatherjacket (Figure 43), sand flathead (Figure 44) and draughtboard shark (Figure 45) were the most abundant species recorded (Appendix D). Distribution maps and nMDS of the relative abundance of these species are provided in Figures 46 – 52. Similar to the AUV dataset, the bubble size in the maps and nMDS indicate relative mean abundance (i.e. larger bubble = higher abundance). The direction and length of the vectors in the bottom left insert of the nMDS represent the importance of each habitat type in driving assemblage patterns.

Figure 38. Large schools of Degen’s leatherjackets were a common occurrence throughout the New Zealand Screwshell and soft sediment dominated habitats (depth 67 m). This school of ~200 individuals was encountered at stereo BRUV site 98 (red dot in map insert) in Beagle Marine Park.

Figure 39. Mix schools of barber (black bar near tail) and butterfly (black dot near tail) perch were a common occurrence throughout the low-profile reef encountered at stereo BRUV site 22 (red dot in map insert; depth 61 m) in Beagle Marine Park.

Figure 40. Common gurnard perch encountered at stereo BRUV site 79 (red dot in map insert; depth 62 m) in Beagle Marine Park.

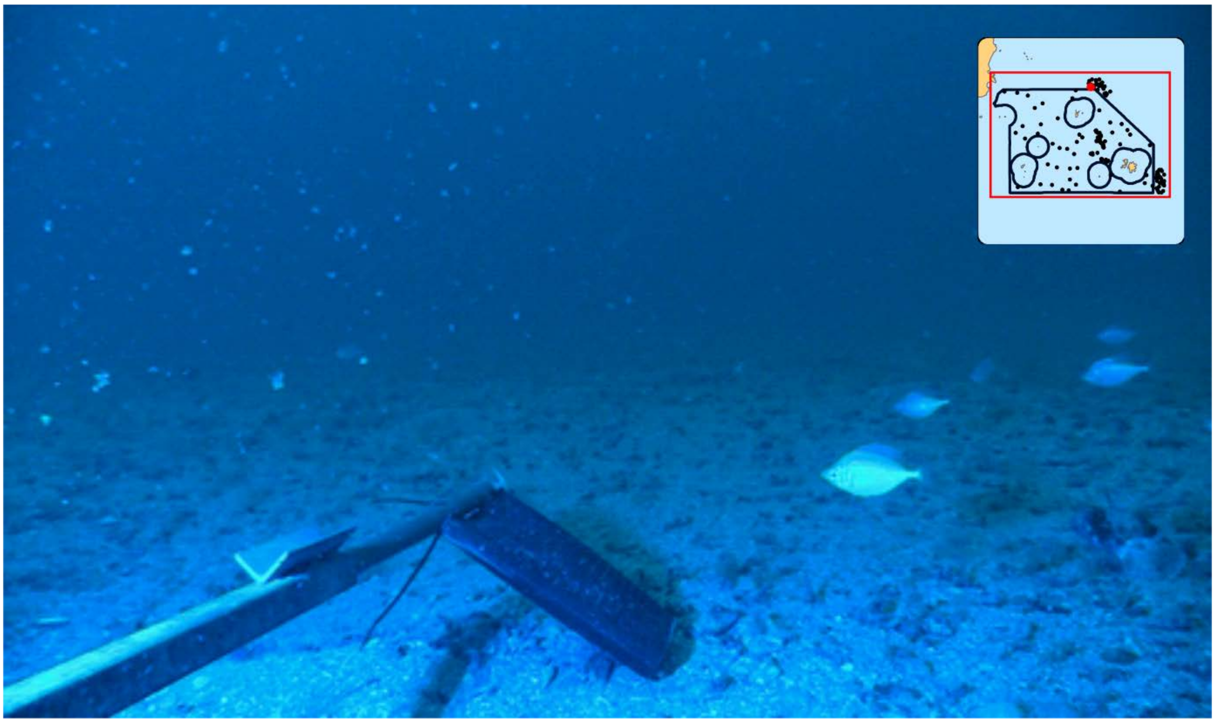


Figure 41. Silverbelly schools were common throughout the New Zealand Screwshell and soft sediment dominated habitats encountered at stereo BRUV site 109 (red dot in map insert; depth 56 m) in northern reference location.

Figure 42. Jackass morwong among the low-profile reef feature encountered at stereo BRUV site 92 (red dot in map insert; 62 m) in Beagle Marine Park.

Figure 43. Rosy wrasse (bottom left) among mixed schools of silverbelly (top left), barber perch (right), cosmopolitan leatherjacket (top centre), blue throat wrasse (centre) and Port Jackson shark (near bait bag) encountered at stereo BRUV site 90 (red dot in map insert; depth 61 m) in Beagle Marine Park.

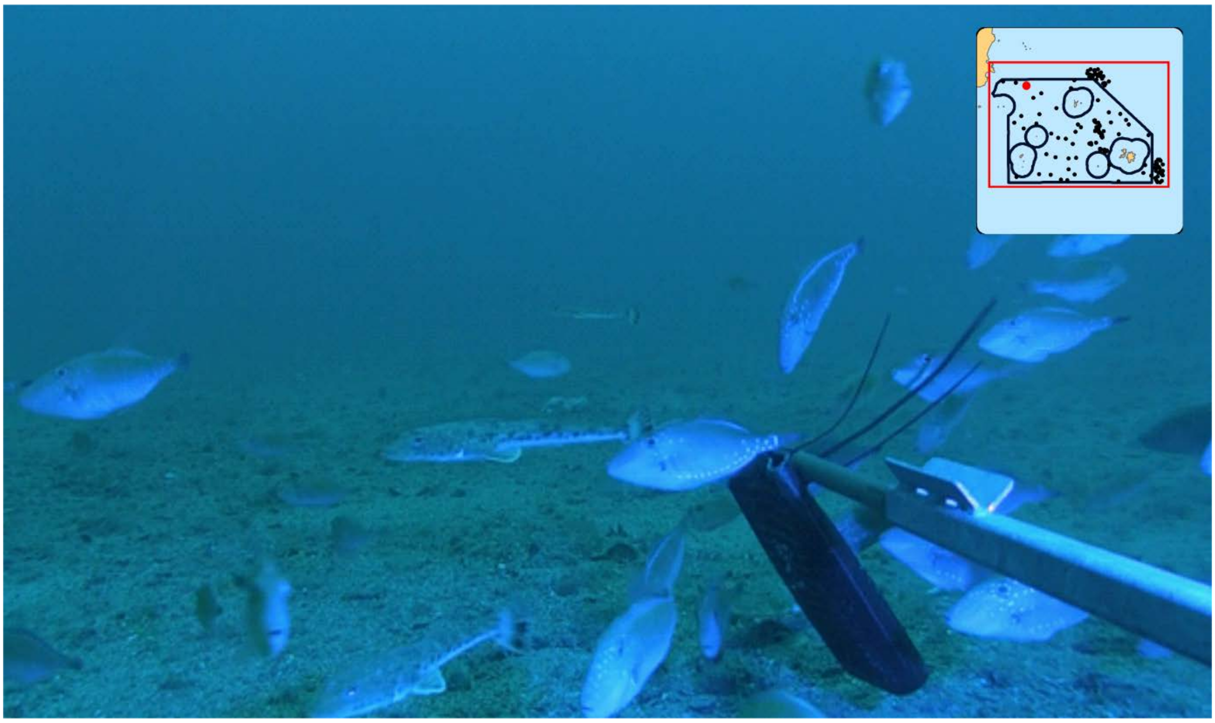


Figure 44. Sand flatheads among a school of Degen's leatherjacket encountered at stereo BRUV site 141 (red dot in map insert; depth 58 m) in Beagle Marine Park.

Figure 45. Draught board sharks resting among the low-profile reef feature encountered at stereo BRUV site 103 (red dot in map insert; depth 60 m) in Beagle Marine Park

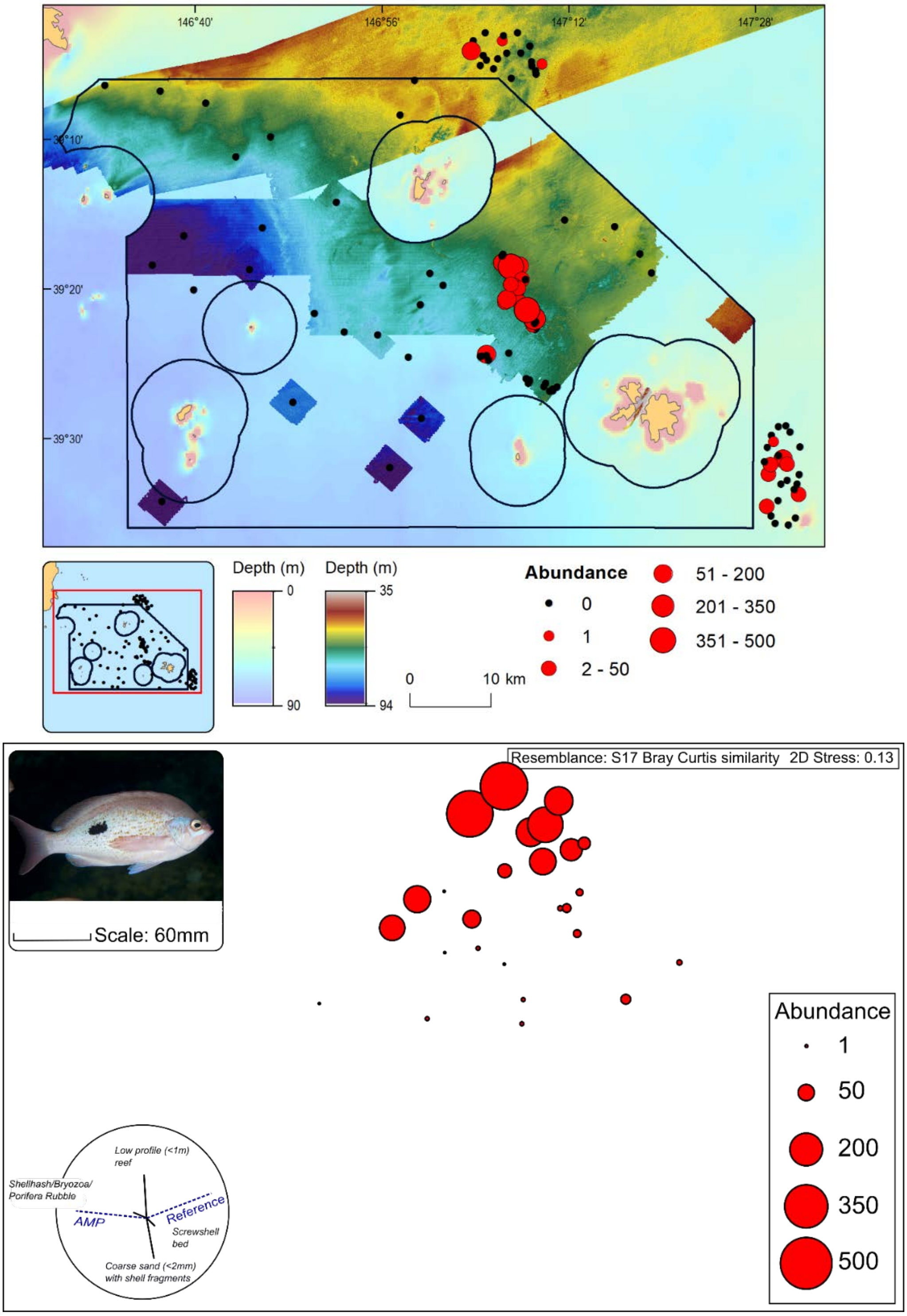


Figure 46. (Top image). Map showing the distribution and abundance of butterfly perch across stereo BRUV deployments. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this species. Bubble size indicates relative abundance (MaxN) (i.e. larger bubble = higher abundances). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type and zoning in driving assemblage patterns in the nMDS. Top left insert shows an example image of the fish species and an indication of its size.

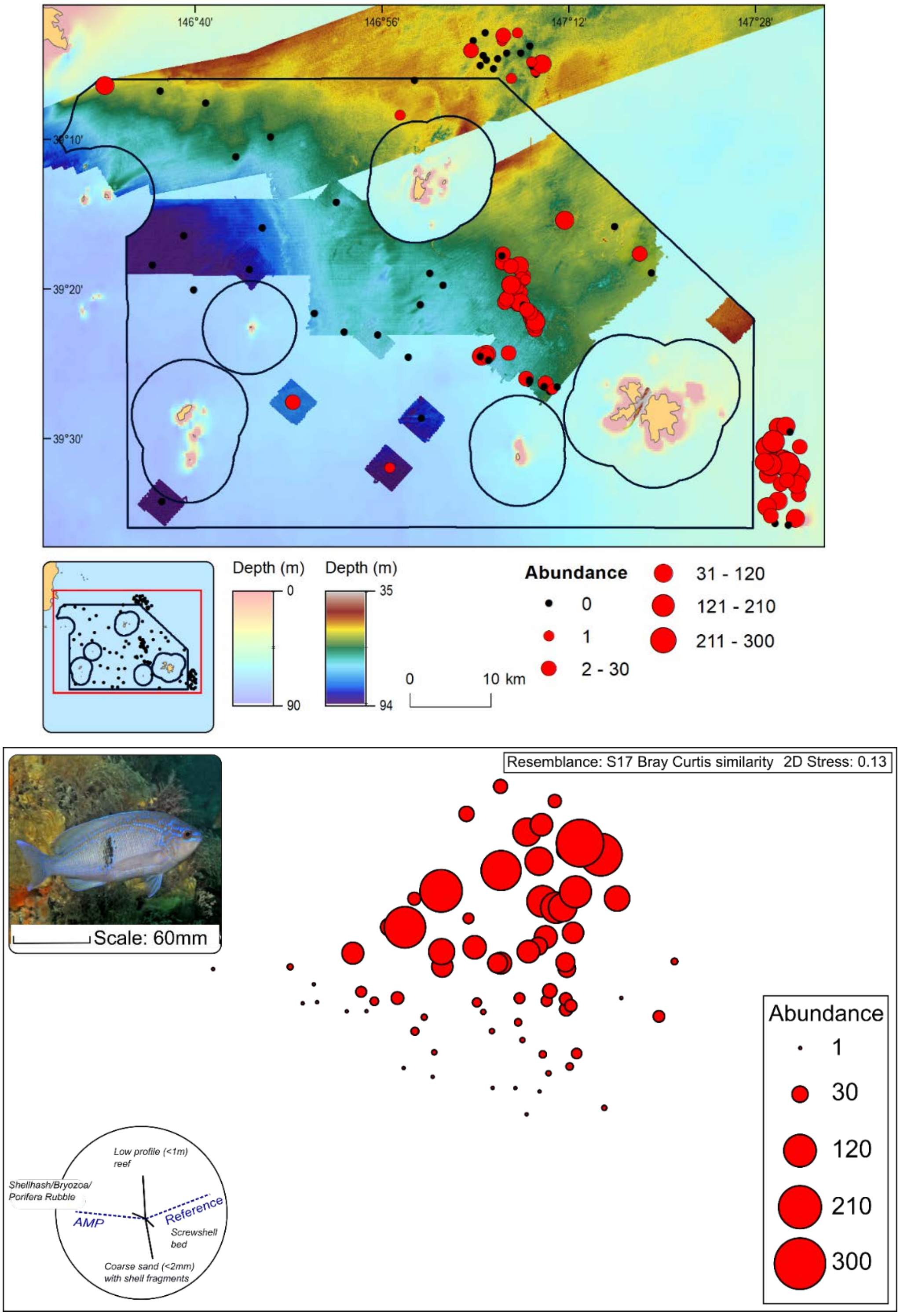


Figure 47. (Top image). Map showing the distribution and abundance of *b*arber perch across stereo BRUV deployments. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this species. Bubble size indicates relative abundance (MaxN) (i.e. larger bubble = higher abundances). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type and zoning in driving assemblage patterns in the nMDS. Top left insert shows an example image of the fish species and an indication of its size.

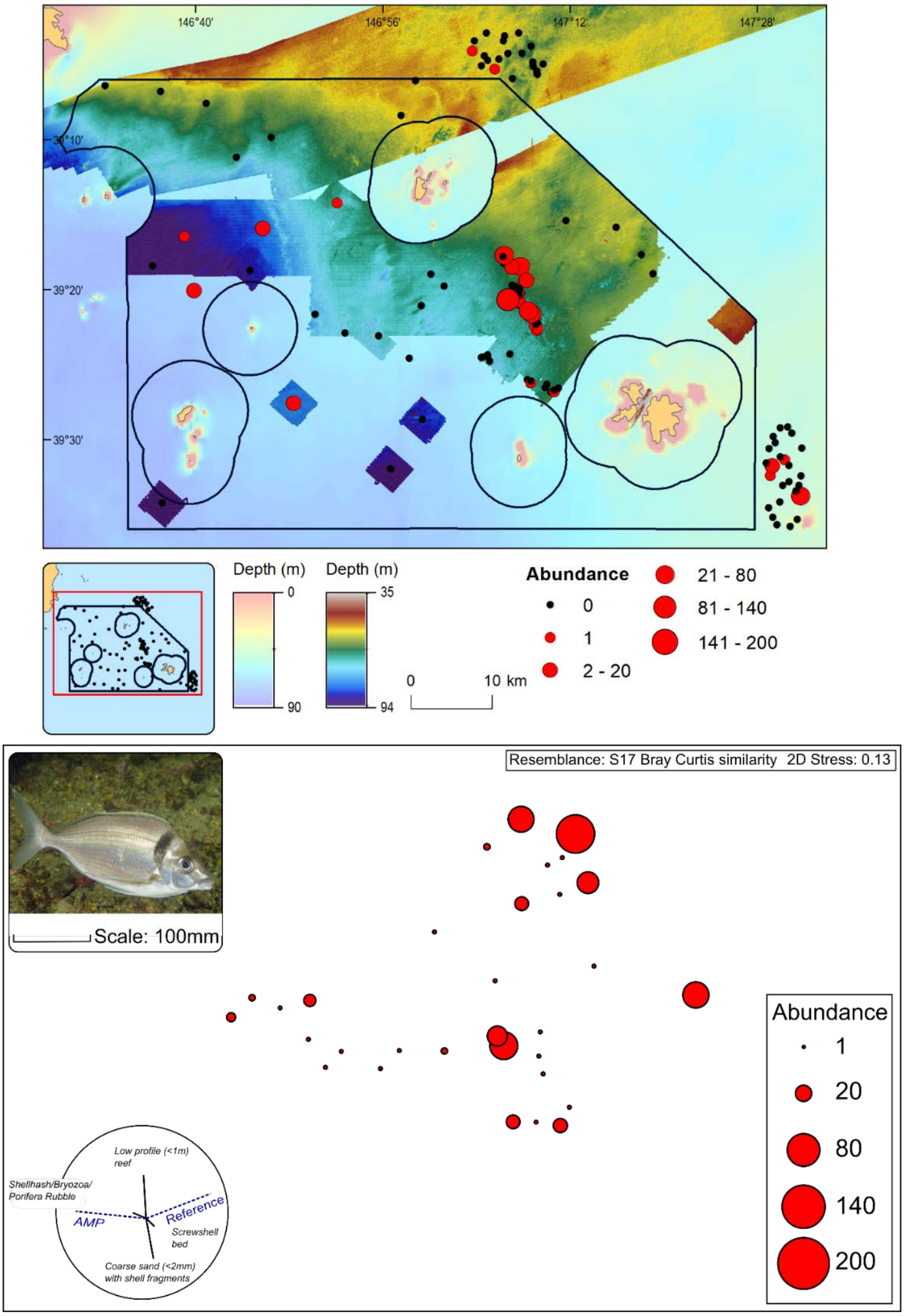
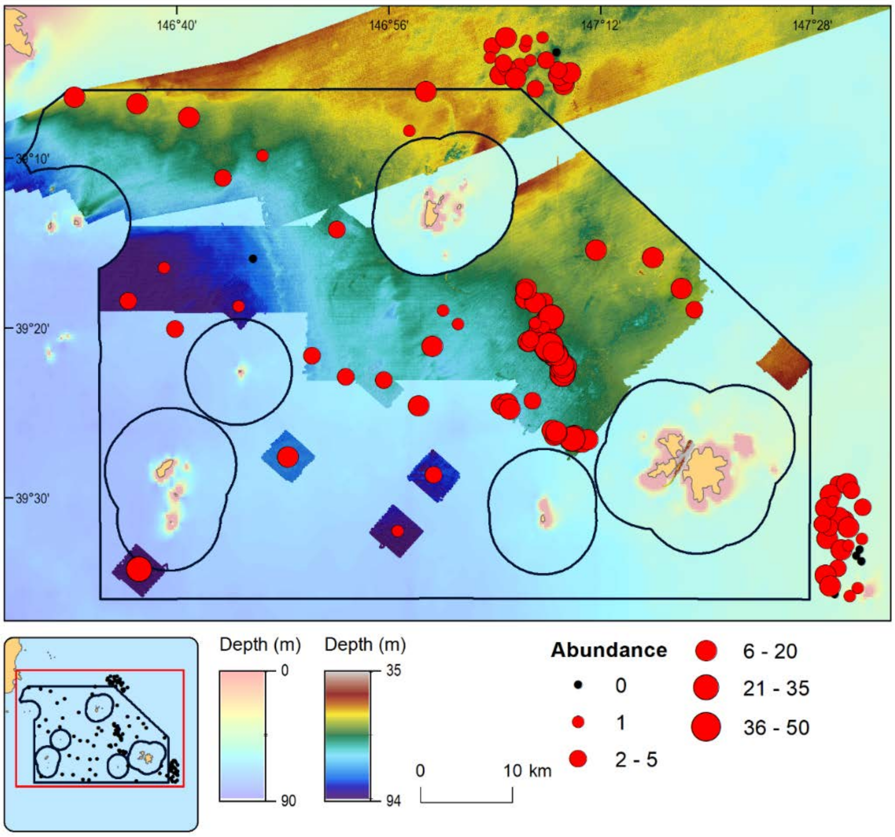


Figure 48. (Top image). Map showing the distribution and abundance of jackass morwong across stereo BRUV deployments. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this species. Bubble size indicates relative abundance (MaxN) (i.e. larger bubble = higher abundances). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type and zoning in driving assemblage patterns in the nMDS. Top left insert shows an example image of the fish species and an indication of its size.



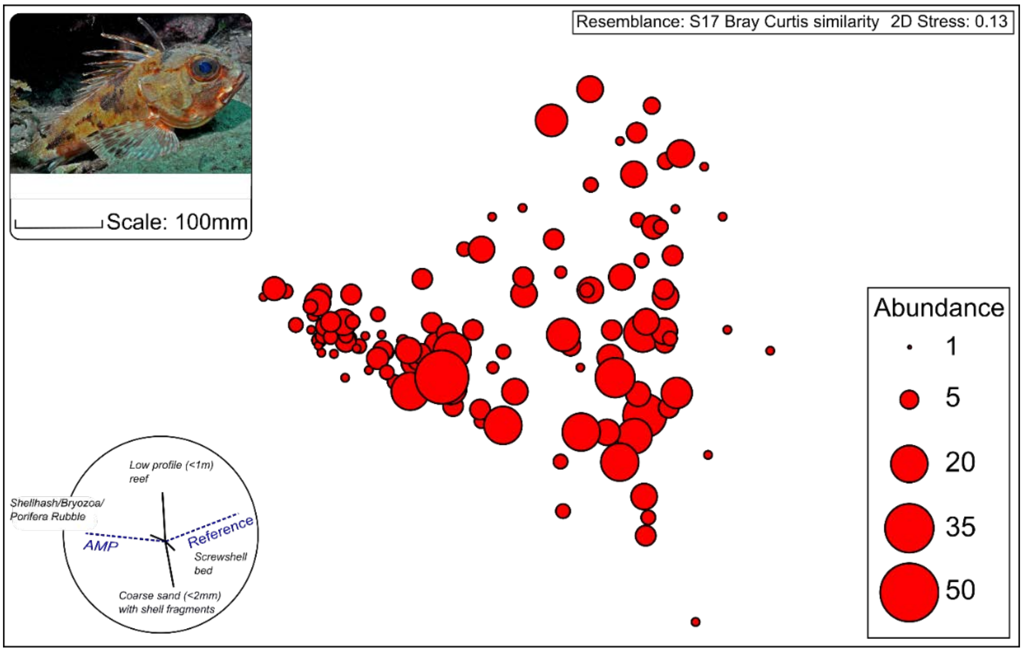


Figure 49. (Top image). Map showing the distribution and abundance of common gurnard perch across stereo BRUV deployments. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this species. Bubble size indicates relative abundance (MaxN) (i.e. larger bubble = higher abundances). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type and zoning in driving assemblage patterns in the nMDS. Top left insert shows an example image of the fish species and an indication of its size.

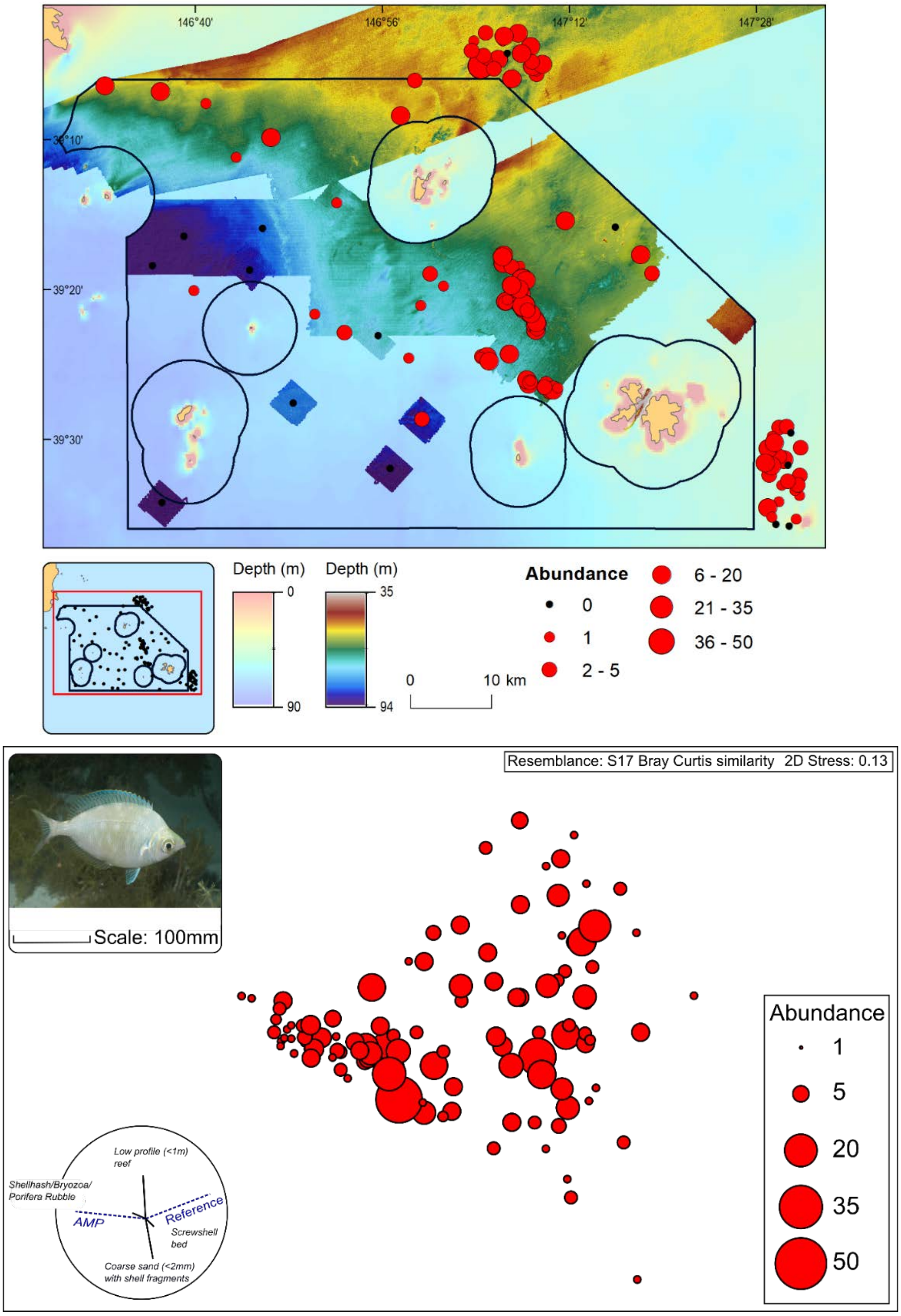


Figure 50. (Top image). Map showing the distribution and abundance of Melbourne silverbelly across stereo BRUV deployments. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this species. Bubble size indicates relative abundance (MaxN) (i.e. larger bubble = higher abundances). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type and zoning in driving assemblage patterns in the nMDS. Top left insert shows an example image of the fish species and an indication of its size.

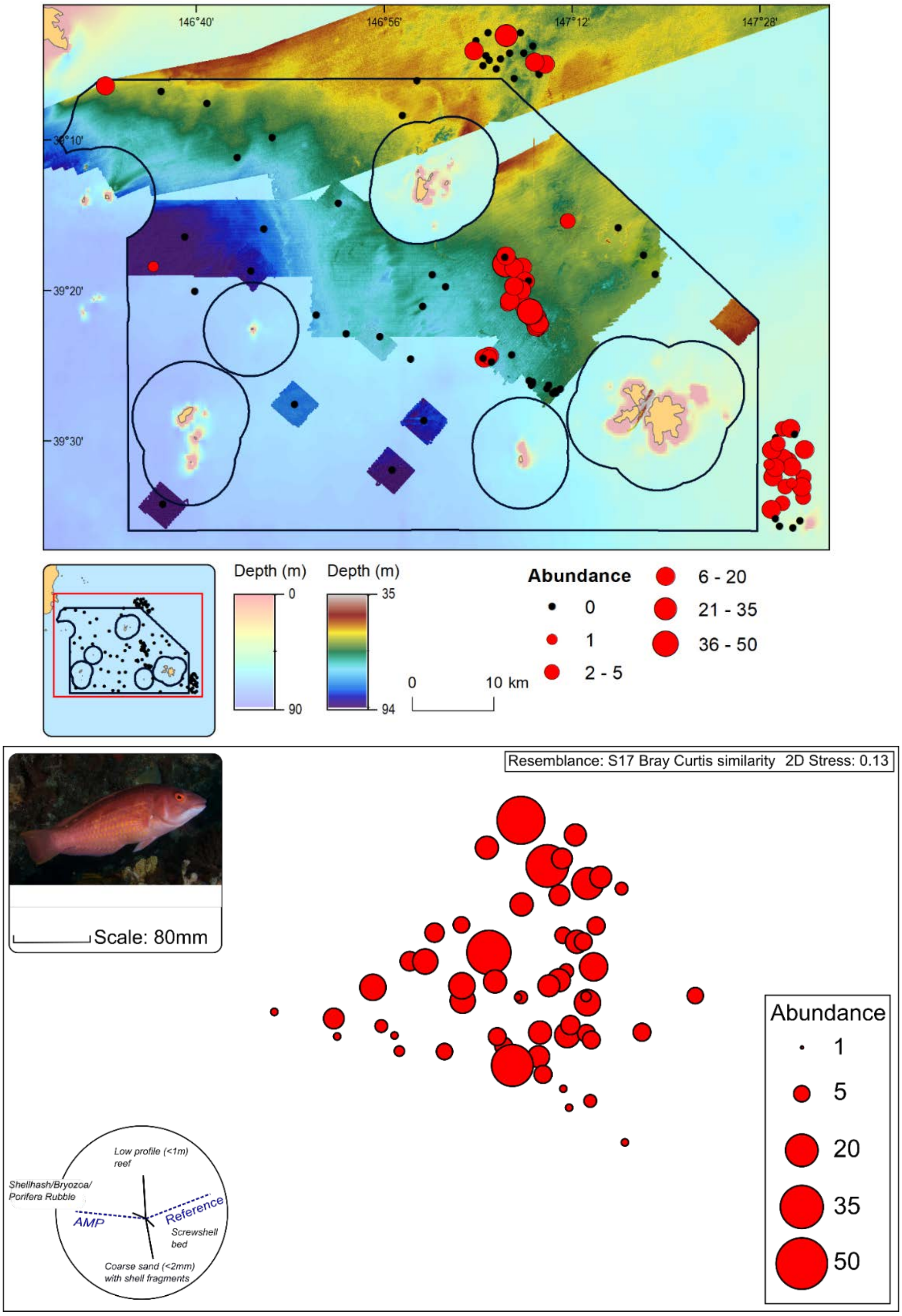


Figure 51. (Top image). Map showing the distribution and abundance of rosy wrasse across stereo BRUV deployments. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this species. Bubble size indicates relative abundance (MaxN) (i.e. larger bubble = higher abundances). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type and zoning in driving assemblage patterns in the nMDS. Top left insert shows an example image of the fish species and an indication of its size.

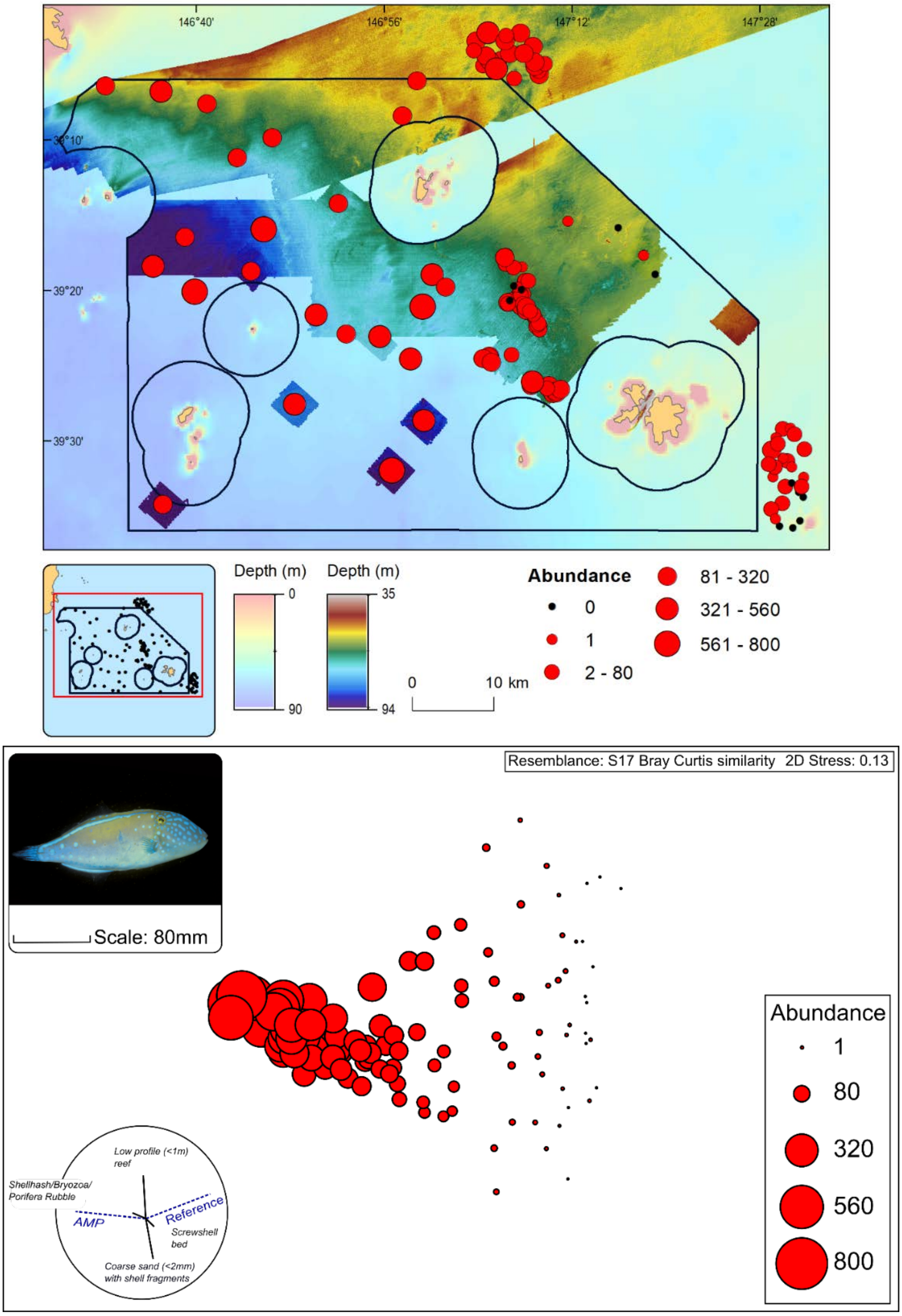


Figure 52. (Top image). Map showing the distribution and abundance of Degen's leatherjacket across stereo BRUV deployments. Newly acquired high-resolution multibeam bathymetry is overlain on pre-existing data. (Bottom image). Non-metric multidimensional scaling ordination (nMDS) for this species. Bubble size indicates relative abundance (MaxN) (i.e. larger bubble = higher abundances). The direction and length of the vectors in the bottom left insert overlay represent the importance of each habitat type and zoning in driving assemblage patterns in the nMDS. Top left insert shows an example image of the fish species and an indication of its size.

Although not included in subsequent statistical analyses a giant spider crab (*Leptomithrax gaimardii*) was recorded in the southern reference location (Figure 53). These crabs are a native species, found throughout marine waters across south eastern Australia, and are known to form large breeding aggregations in Port Phillip Bay and along the north coast of Tasmania.

The same four habitats identified in the AUV imagery were extracted from the stereo BRUV imagery. Mapping of these annotations revealed that deeper (> 60 m) south-western sites were dominated by shelly sand habitat, while the shallower sites were dominated by shell hash and screw shell habitats (Figure 54).

The nMDS displayed structuring of the demersal fish assemblages by habitat and status (Figure 54). The PERMANCOVA further revealed that the interaction between depth, status and habitat category accounted for most of the variation (29 %), while habitat and the interaction between depth and habitat, and status and habitat accounted for significant, but slightly smaller proportion of the variation in demersal fish assemblages in and around the Beagle Marine Park (Table 7). The PERMANCOVA pairwise routine revealed that significant differences in fish assemblages between the marine park and reference locations were limited to between shelly sand (p = 0.0004) and shell hash (p = 0.001) habitats. Further exploration of the average similarities (or dissimilarities) in these two habitat categories suggest that the demersal assemblages within the shell hash habitat had variable fish assemblages (~31 % similarity) and were quite dissimilar between marine park and reference locations (Table 8). By contrast, fish assemblages found within the shelly sand habitat were fairly similar within the park (56 %), but quite variable within reference (20 %) and between reference and marine park locations (14 %; Table 8).

The SIMPER routine revealed that the variations in relative abundance of Degen's leatherjacket, Melbourne silverbelly, barber, butterfly and common gurnard perches, and rosy wrasse were responsible for the detected differences between marine park and reference locations (Table 9).

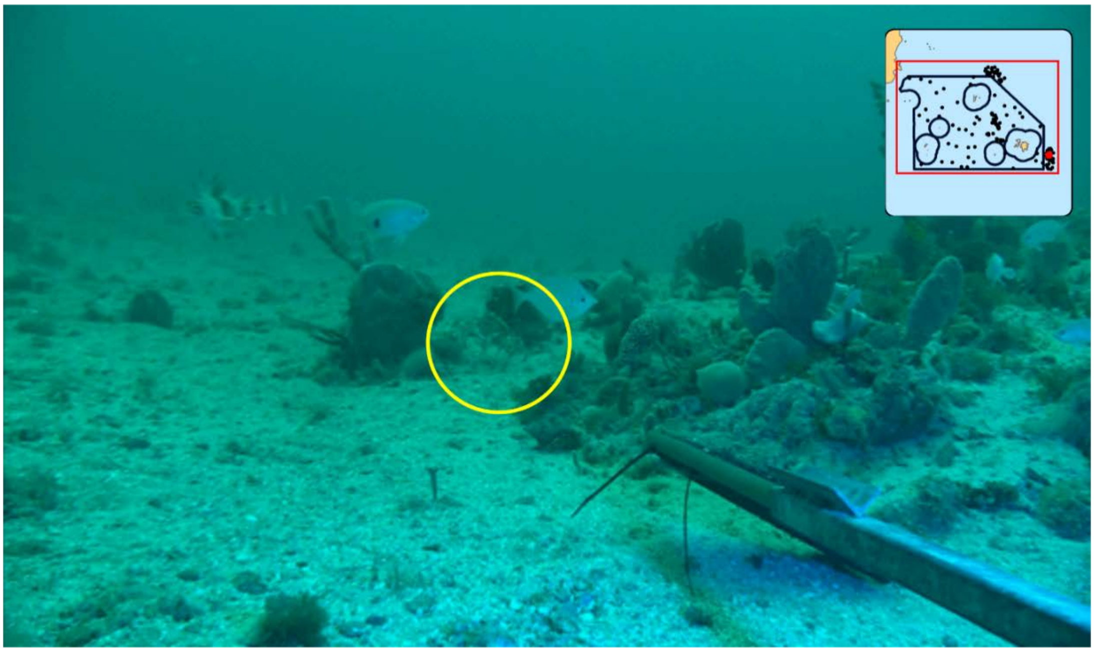


Figure 53. Giant spider crab (highlighted in yellow circle) emerging from massive, branching and fan shaped sponges encountered at stereo BRUV site 21 (red dot in map insert) in southern reference location (depth 55 m).

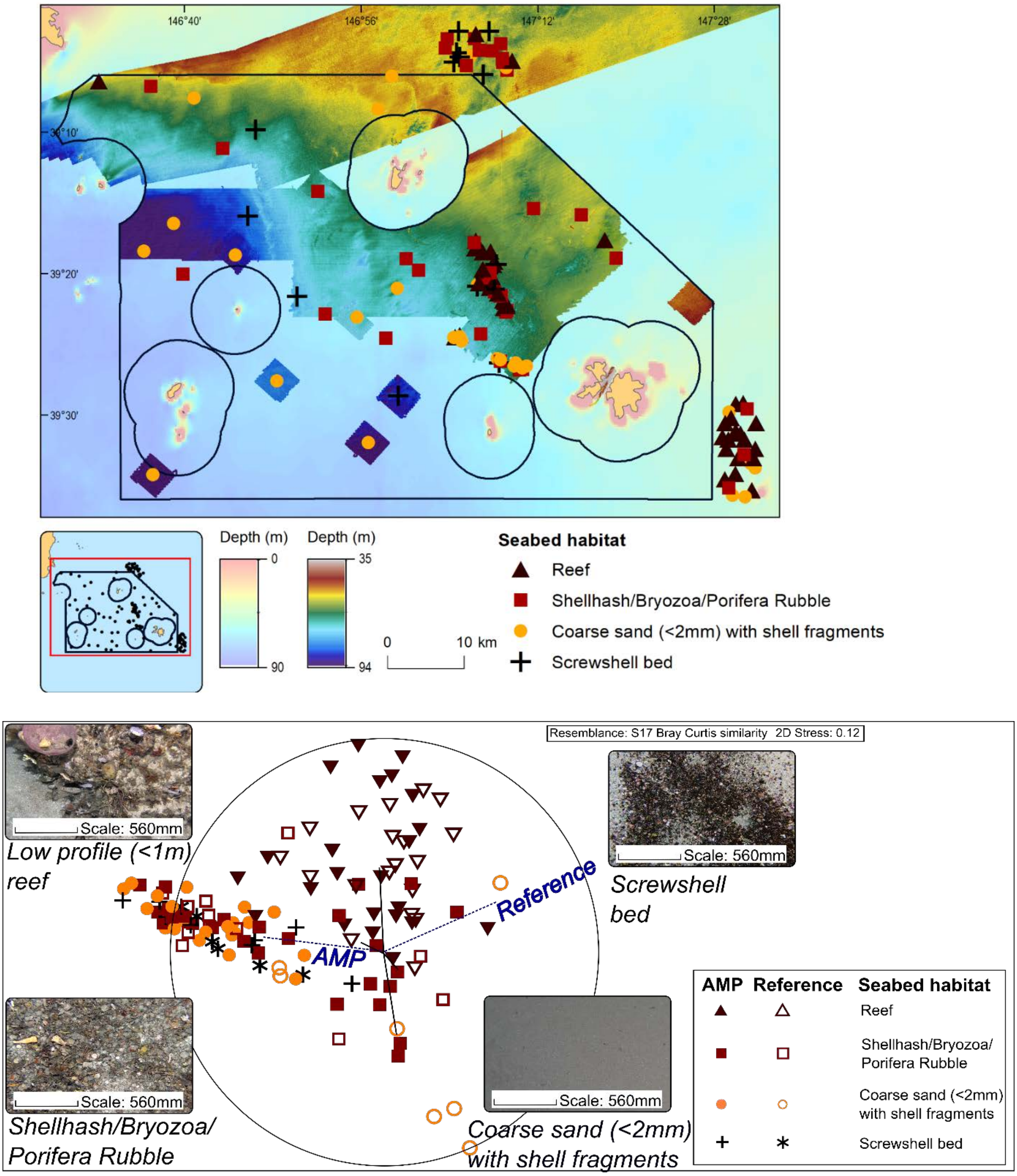


Figure 54. (Top image). Map showing the distribution of key seabed habitat types encountered in stereo BRUVs. (Bottom image). Non-metric multidimensional scaling ordinations highlighting the differences in demersal fish assemblage composition between for key seabed habitat types encountered in stereo BRUVs.

Table 7. PERMANCOVA revealing that demersal fishes recorded in stereo BRUVs varied by status, depth and habitat.

Source	df	MS	Pseudo-F	Unique Permutations	*p*	Variance Components (%)
Depth	1	32012	16.897	9939	0.0001	15.585
Status	1	9647	5.0923	9937	0.0002	17.151
Habitat	3	19912	10.511	9906	0.0001	25.259
Depth x Status	1	12076	6.3744	9929	0.0001	25.534
Depth x Habitat	3	3237	1.7087	9898	0.0318	8.1352
Status x Habitat	3	5451	2.8776	9910	0.0003	28.853
Depth x Status x Habitat	3	3767	1.9886	9915	0.0075	29.147
Residual	108	1894				43.526
Total	123					

Table 8. Average similarities (%) in demersal fish composition within habitat classes between the Beagle Marine Park and reference locations from PERMANCOVA pairwise comparisons. * denotes non-significant pairwise comparisons

Habitat		Reference	Marine Park
Reef*	Reference	46	
	MP	36	34
Shell hash	Reference	41	
	MP	35	31
Screw shell*	Reference	52	
	MP	48	41
Sand	Reference	20	
	MP	14	56

Table 9. Key demersal fish species identified by SIMPER routine that were associated with differences between Beagle Marine Park and Reference locations pooled across all habitats.

Common name	Scientific	Av.Diss	Diss/SD	Contrib%
Degen's leatherjacket	*Thamnaconus degeni*	33.38	1.04	49.21
Barber perch	*Caesioperca rasor*	11.55	0.70	17.02
Butterfly perch	*Caesioperca lepidoptera*	8.15	0.50	12.02
Common gurnard perch	*Neosebastes scorpaenoides*	2.81	0.58	4.14
Jackass morwong	*Nemadactylus macropterus*	2.21	0.36	3.26
Melbourne silverbelly	*Parequula melbournensis*	2.13	0.69	3.14
Rosy wrasse	*Pseudolabrus rubicundus*	1.86	0.56	2.73

Patterns in lengths in demersal fish abundance

Length-frequency patterns were explored for key species identified by SIMPER and those that are targeted by fishers. Significantly different KDE of length-frequencies were revealed between the marine park and reference locations for half of these key species (denoted by the * in Figure 55). Toothy flathead (*Platycephalus aurimaculas*), blue-throat wrasse (*Notolabrus tetricus*), cosmopolitan leatherjacket (*Meuschinia scaber*), draught board shark (*Cephaloscyllium laticeps*) and orange spotted catshark (*Asymbolus rubicundus*) had significantly larger lengths in the park when compared to reference locations (Figure 55). By contrast, southern goat fish (*Upeneichthys vlamingii*), bared grubfish (*Parapercis allporti*) and sergeant baker (*Latropiscis purpurissatus*) exhibited significantly smaller lengths in the marine park when compared to reference locations (Figure 55). No significant difference in length-frequencies were found for the remaining species (Figure 55).

Whole of park estimates in fish abundance

For all datasets, a detection function with a hazard-rate key function with depth and rugosity as covariates, apart from distance, were selected according to AIC and other diagnostics. The deviance explained for each model estimate ranged from 22% for Melbourne silverbelly to 74% for draughtboard sharks, perhaps reflecting differences in how species interact with the seabed habitat. Spatial predictions show the predicted abundance for each species, highlighting preferences to different areas within the marine park (Figure 56). For example, barber perch (*Caesioperca lepidoptera*) were predicted to be most abundant around the central linear reef features mapping Grid 0, with a second hot spot predicted in the south-west of the marine park around Curtis Island. However, the spatial uncertainty suggests that lower degree of confidence in the prediction through this region of the marine park.

The overall model-based abundance estimates for Beagle Marine Park for selected fish species varied from a low of 1093 individuals (240-4978 CI) of jackass morwong to the most abundant species in the marine park of 61,674 individuals (8452-450003 CI) of barber perch (Table 10). It should be noted that the covariate data used in this analysis is very course at this scale and only gives an indication of the spatial arrange of abundance within the marine park. Once full mapping of the Beagle Marine Park using MBES is complete, more refined estimates and predictions will be possible.

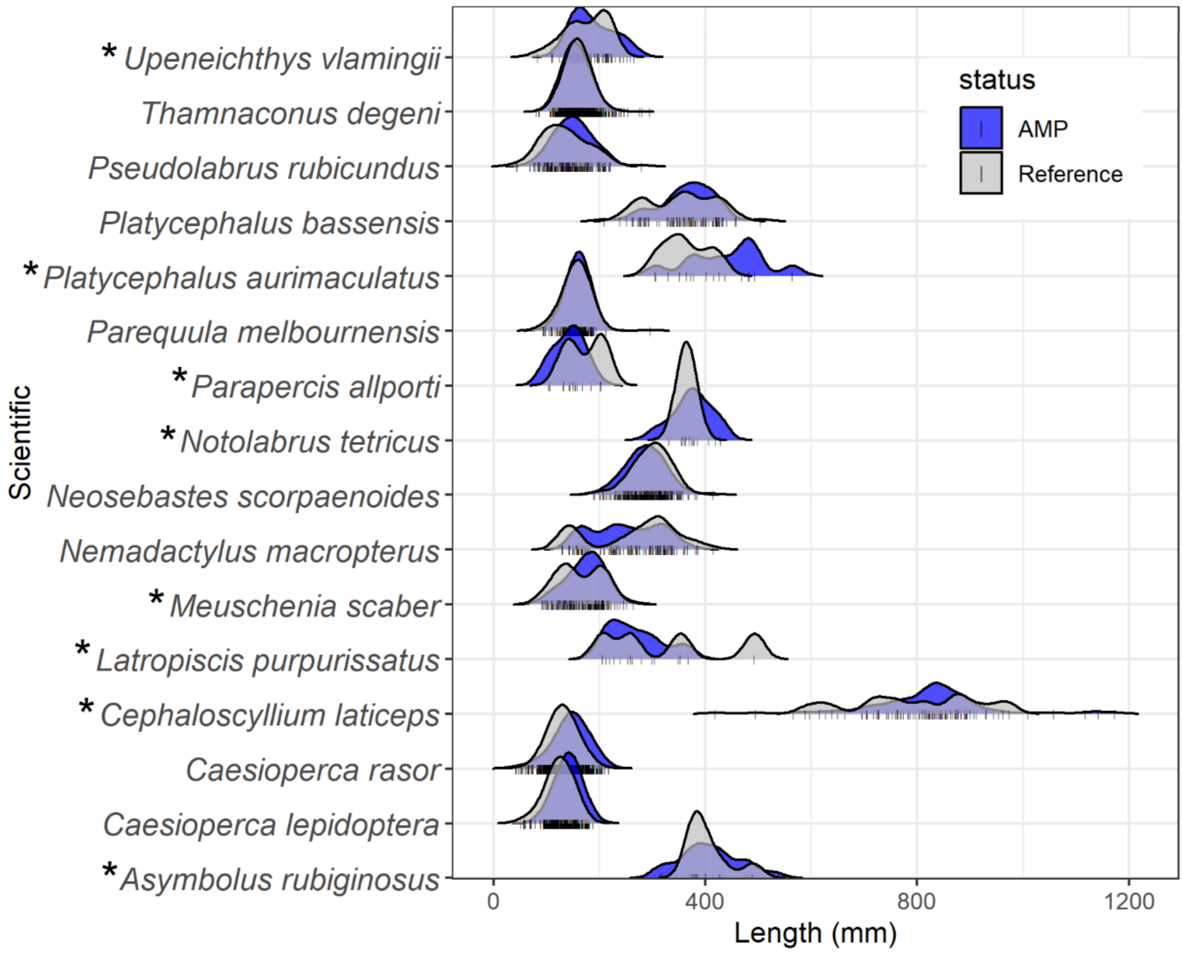
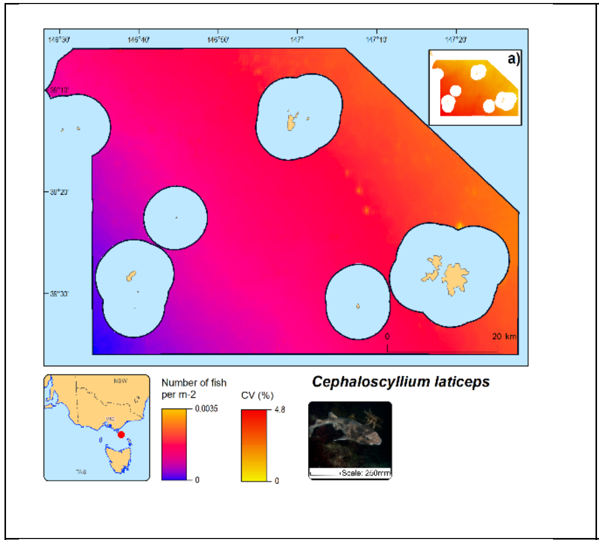
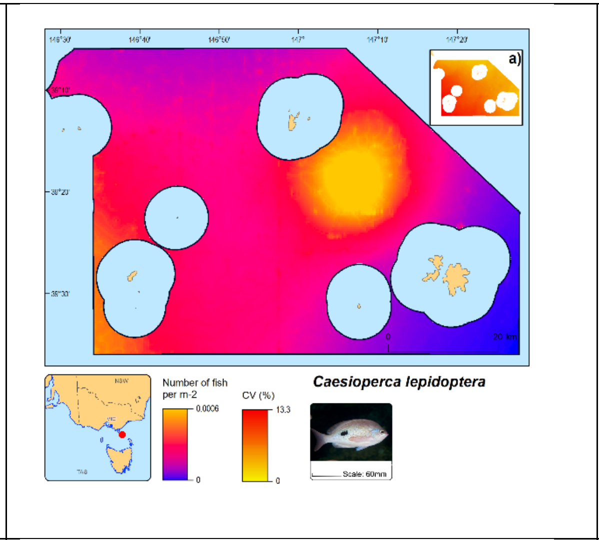
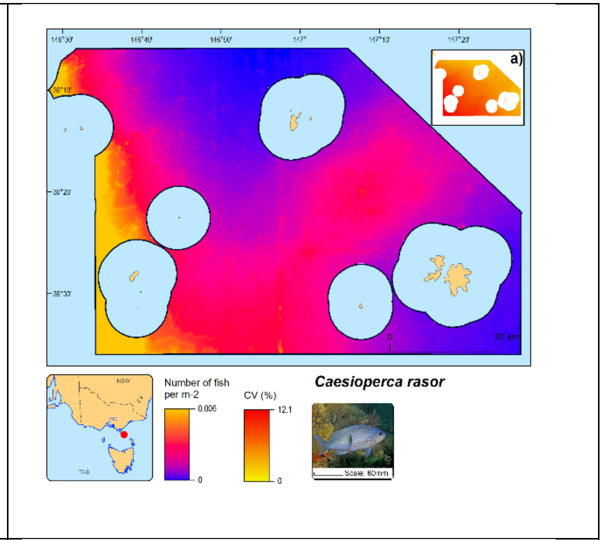
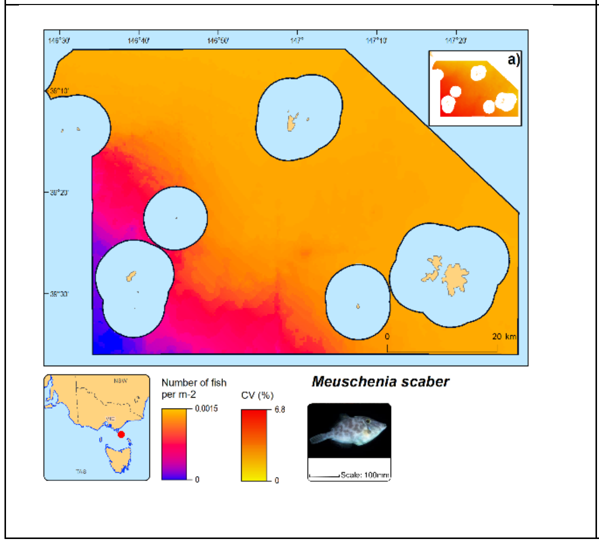


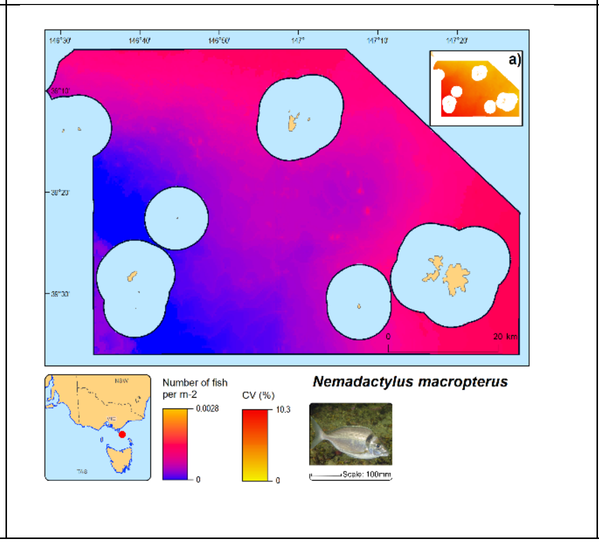
Figure 55. Kernel-density plot highlighting differences in length frequencies between AMP and reference locations. * denotes significant difference between AMP and reference locations based on kernel density estimate probability density functions from Langlois et al. (2012). Jitter lines along x-axis represents data points (length measurements).

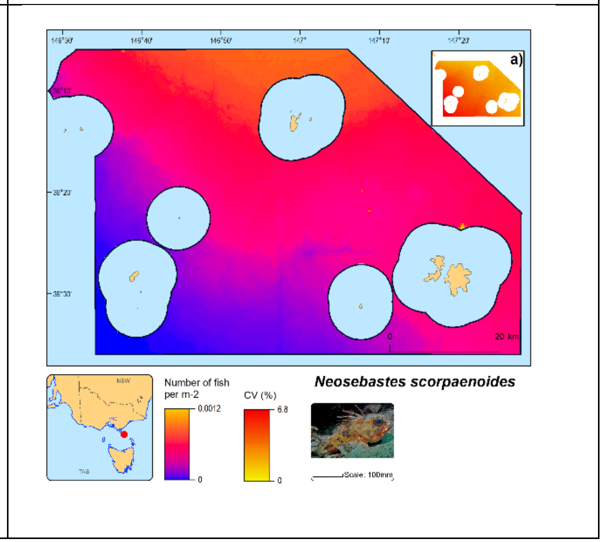

a)
20 km
Number of fish per m-2
0.0035
0
CV (%)
4.8
0
Cephaloscyllium laticeps
Scale: 250mm


a)
20 km
Number of fish per m-2
0.0006
0
CV (%)
13.3
0
Caesioperca lepidoptera
Scale: 60mm


a)
20 km
Number of fish per m-2
0.006
0
CV (%)
12.1
0
Caesioperca rasor
Scale: 60mm


a)
20 km
Number of fish per m-2
0.0015
0
CV (%)
6.8
0
Meuschenia scaber
Scale: 100mm


a)
20 km
Number of fish per m-2
0.0028
0
CV (%)
10.3
0
Nemadactylus macropterus
Scale: 100mm


a)
20 km
Number of fish per m-2
0.0012
0
CV (%)
6.8
0
Neosebastes scorpaenoides
Scale: 100mm

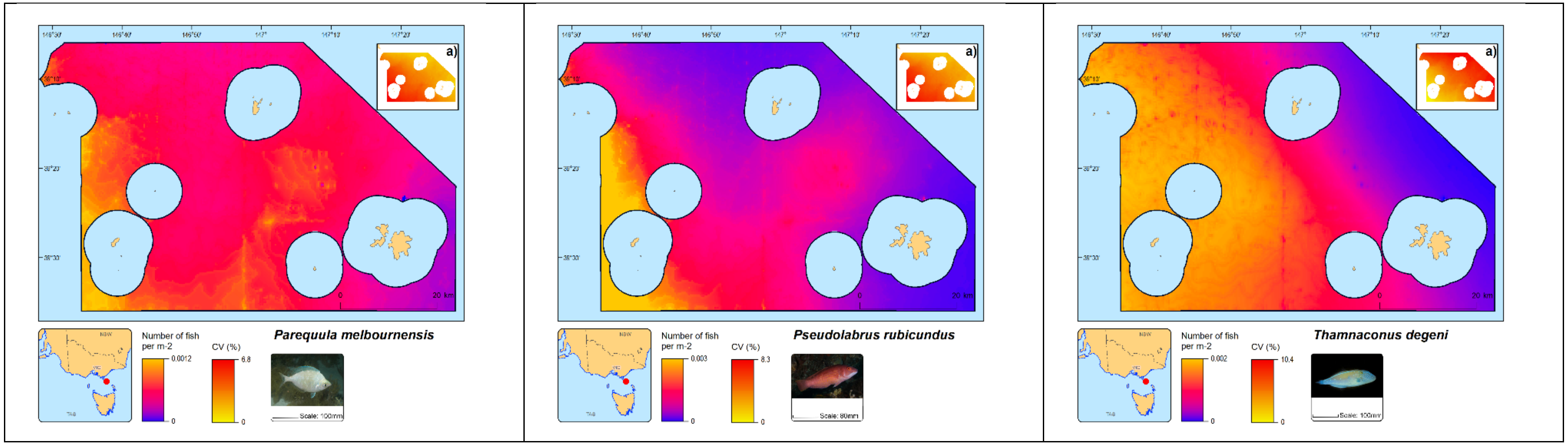


Figure 56. Spatial predictions of fish abundance for select species within the Beagle Marine Park. Zoom box a in each panel indicates CV associated with each prediction.

Table 10. Abundance estimates for select fish species in the Beagle Marine Park based on model-based estimates accounting for detection rates, the interaction between latitude-longitude, depth and rugosity.

Common name	Scientific name	Exp. Dev.	CV from GAM	CV of detection function	Abundance estimate	2.5% CI	97.5% CI
Melbourne silverbelly	*Parequula melbournensis*	22.0	5.67	0.085	1533	384	61251
Degen’s leatherjacket	*Thamnaconus degeni*	50.9	9.02	0.024	26183	18920	36235
Jackass morwong	*Nemadactylus macropterus*	29.6	8.88	0.025	1093	240	4978
Barber perch	*Caesioperca rasor*	38.5	8.12	0.049	61674	8452	450003
Butterfly perch	*Caesioperca lepidoptera*	38.7	11.06	0.050	6960	3024	16016
Common gurnard perch	*Neosebastes scorpaenoides*	37.0	5.72	0.080	10946	268	46325
Rosy wrasse	*Pseudolabrus rubicundus*	49.3	7.22	0.070	41228	825	82067
Cosmopolitan leatherjacket	*Meuschina scaber*	42.9	6.17	0.092	14743	5805	25463
Draught board shark	*Cephaloscyllium laticeps*	74.7	4.12	0.112	1796	1341	2404

Sampling adequacy, precision, and power to detect change in demersal fish abundance

Fish species accumulation curves showed similar rates of accumulation between habitats and zones (Figure 57). Based on the species accumulation curves it appears that more sampling is necessary to encounter all species present within the individual habitats encountered in the marine park, particularly in the reference locations (Figure 57). It should be noted that the overall combined species pool across most habitats is close to reaching an asymptote in the park, suggesting that sampling effort at the marine park level was adequate but more effort is required in the adjacent reference locations (Figure 57).

The appropriate number of replicate stereo BRUV drops beyond which no substantial decreases in precision would accrue was explored using MultSE (Figure 58). Slightly higher precision (i.e., lower MultSE values) was revealed in the marine park when compared to adjacent reference locations (Figure 58). A similar pattern between habitat types to the species accumulation curves was observed with no appreciable precision gained by between 20–40 drops depending on habitat category inside the marine park (as indicated with a levelling-off in MultSE in Figure 58). Examination of reference locations suggests that individual habitats were under sampled due to the lack of levelling-off of the MultSE curve (Figure 58b). Pooled data suggest that sampling was sufficient (grey line in Figure 58b).

The power analyses indicated that in for all species of interest and scenarios, revisiting the same approximate stereo-BRUV location required the least number of stereo-BRUV deployments (Figure 59). As the magnitude of the mean abundance increased, the number of samples required to detect a difference decreased substantially. Considerable variation between species and locations was observed (Figure 59). As with the power analysis based on sessile morphospecies captured in the AUV imagery, interpretation of these figures is relatively straight forward. Take common gurnard perch (*N. scorpaenoides*) for example, if sampling ignored any stratification by habitat (grey bars in Figure 59), it would require ~32 deployments to detect a 50% increase in mean abundance when sampling at new locations, while ~14 stereo-BRUV deployments would be required for resampling sites. But if sampling target specific habitats (depicted by brown, red, orange and blue bars), substantially less sampling would be required if reef habitat (brown bars) was targeted, while substantially more would be require to adequately sample screwshell habitat (blue bars). Overall, it would not be practically achievable (>150 deployments), irrespective of habitat stratification, to detection a 50% increase in mean abundance for some species (such as *C. lepidoptera, P. rubicundus* and *T. degeni*). A 100%, and even more so a 200%, increase in mean abundance could be detected with a small to modest amount of sampling effort (nominally 50-150 stereo-BRUV deployments at each sampling event; Figure 59).

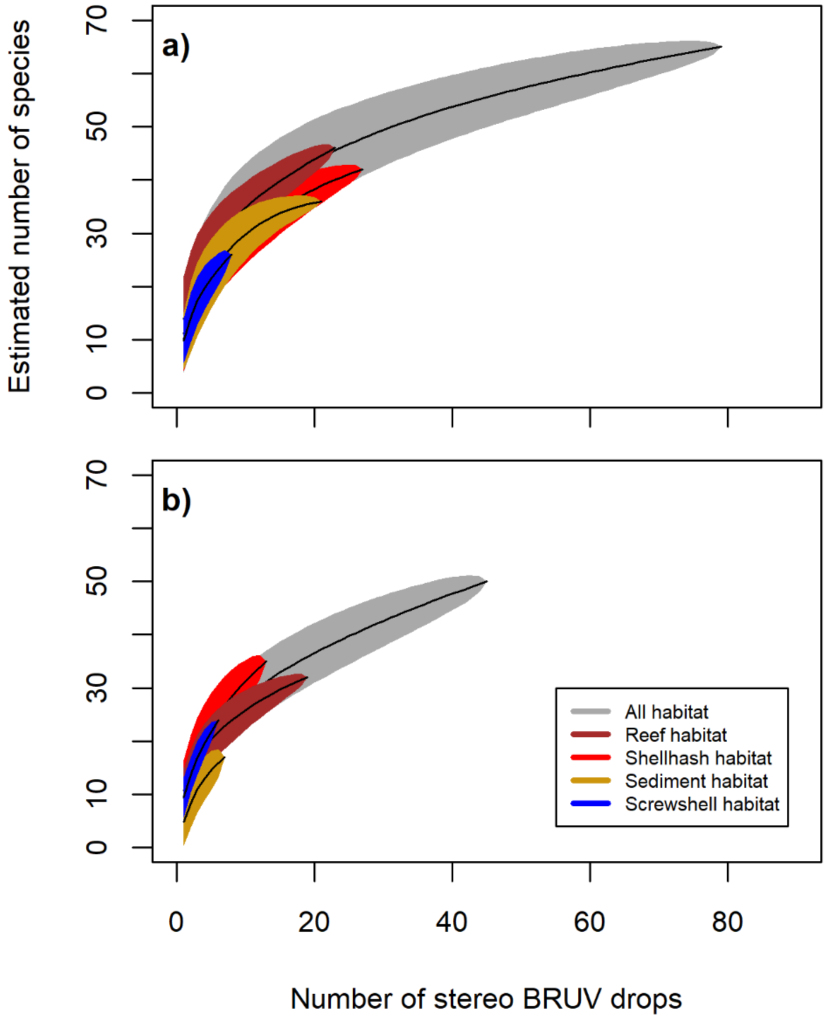


Figure 57. Species accumulation plot for stereo BRUVs within the Beagle AMP (a) and adjacent reference locations (b).

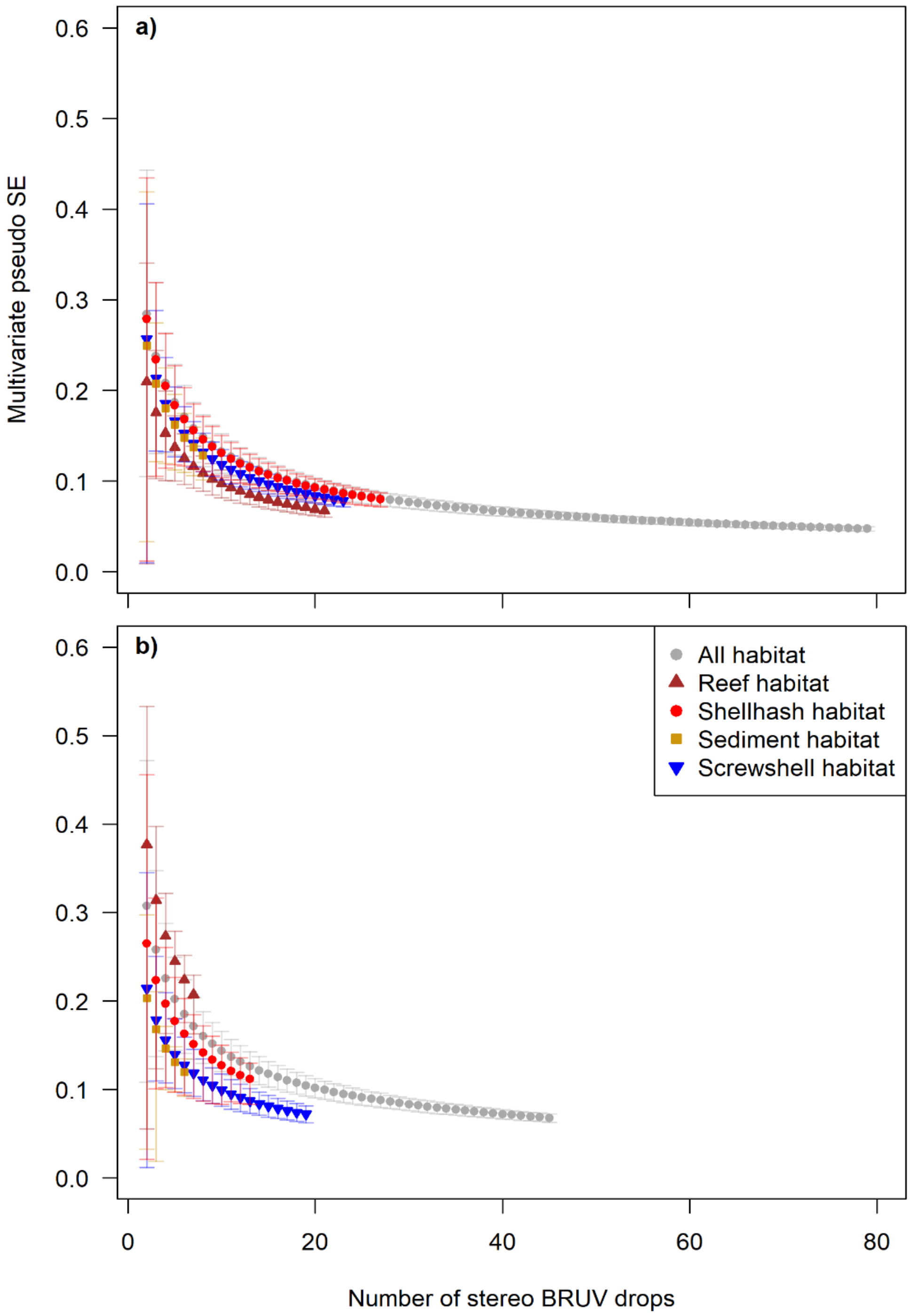


Figure 58. Multivariate pseudo standard error (*MultSE*) as a function of sample size (number of images) based on Bray–Curtis dissimilarities calculated on abundance data from the stereo BRUV samples broken down by habitat type for within the Beagle Marine Park (a) and adjacent reference locations (b). Means with 2.5 and 97.5 percentiles as error bars are calculated from 10,000 resamples obtained using a bootstrap approach outlined in Anderson and Santana-Garcon (2014).

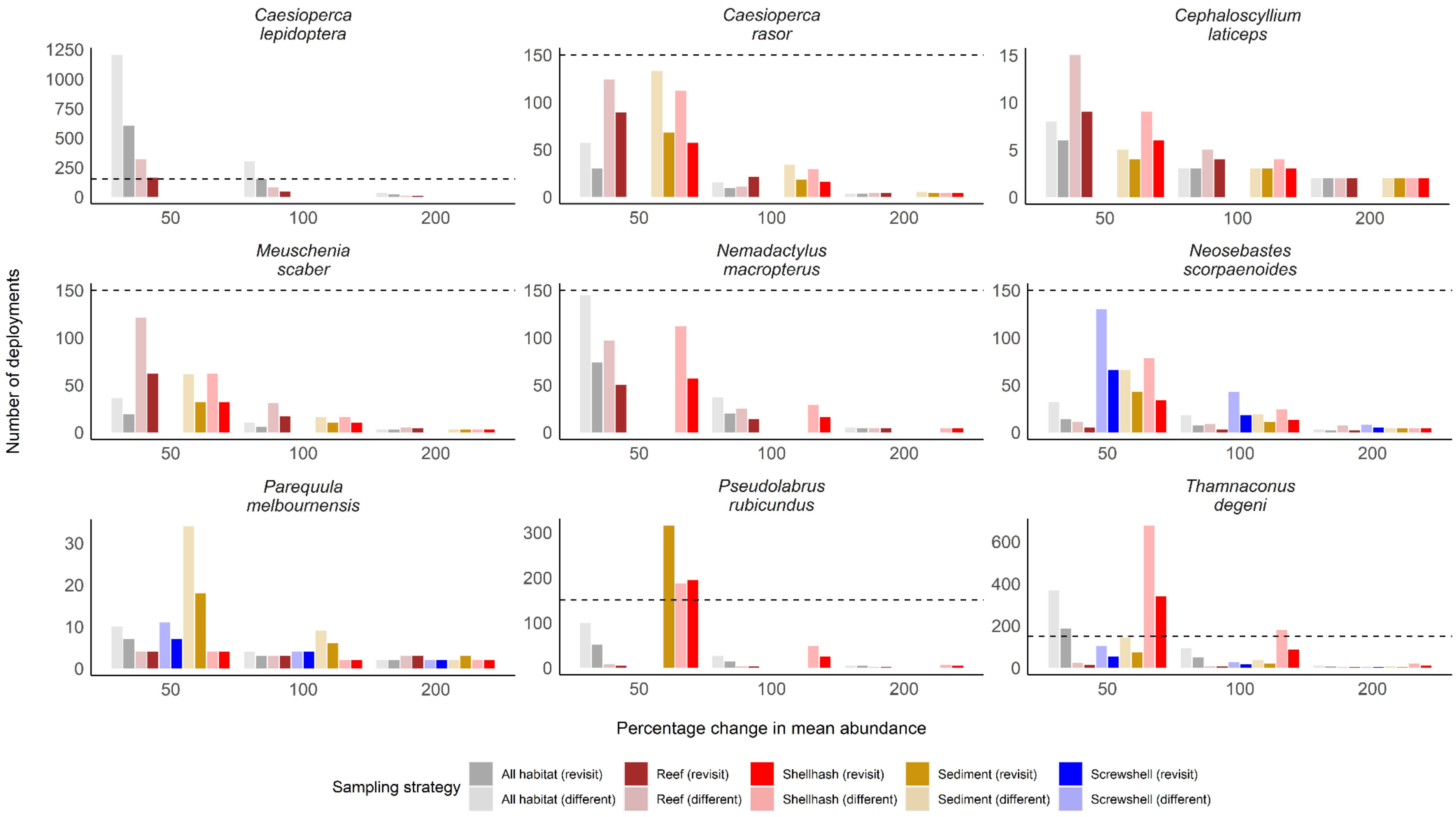


Figure 59. Power analysis of nine fish species that may act as potential indicators for tracking protection effects between habitats within the Beagle AMP and adjacent reference locations.

5. DISCUSSION AND CONCLUSIONS

5.1 Seabed features and morphology

High resolution seabed mapping within Beagle Marine Park using a spatially balanced survey design approach has revealed a broad bathymetric trend of seabed geomorphic features and associated benthic habitats. Across the marine park, these grade from continuous sediment cover in the deeper waters in the western half of the park, to more locally variable cover and sediment type with local areas of reef hardground in the central to eastern part of the park. Among these areas of reef habitat, the km-long ridges that rise 2-5 m above the seabed within grid 0 are an important discovery for several reasons. First, the mapping and sampling completed by this survey has confirmed the ridges as relict terrestrial dunes. Dunes of likely terrestrial origin were also mapped and sampled by Beaman et al. (2005) in eastern Bass Strait where they form a series of parallel ridges less than 1 m high. These low ridges have a cover of loose, weathered quartz sand and are inferred to be of Late Pleistocene age. The samples of aeolianite collected from the dune ridges in Beagle Marine Park are the first physical samples of such material for Bass Strait and the Southeast Marine Park Network and strengthen the interpretation of the ridges as relict dunes. Second, the ridges are the only examples within Beagle Marine Park of the twilight reef habitat that is defined as a key natural value for continental shelf environments. Finally, the reefs may represent an important piece of cultural heritage for Aboriginal peoples whose ancestors first crossed from the Australian mainland to Tasmania over 30,000 years ago when Bass Strait was a land bridge and the ridges formed part of the terrestrial landscape of dunes and grasslands of the Bassian Plain (Bowdler, 2015; Jones, 1995).

Seabed mapping also provided a new insight into the potential geological control on parts of the seabed within Beagle Marine Park. In particular, the fields of linear ridges that extend uninterrupted for several kilometres in the east of the marine park may be the seabed expression of the Mathinna Group of sedimentary rocks that outcrop on mainland northern Tasmania. If these can be confirmed as rocks from this group, this would enable extension of onshore structural maps into Bass Strait, significantly extending current understanding of the deformation history of the East Tasmanian Terrane. In terms of seabed habitats, this insight into geological control of the seabed to produce low profile ridges and swales would suggest that these features are stable (i.e. anchored to shallow rock outcrop), and covered intermittently by local concentrations of shell and gravel transported by tidal currents. The sub-bottom profiles undertaken here and via RV Investigator in this area do suggest that much of this part of Bass Strait may consist of a thin sediment veneer over bedrock. Future studies in this area should therefore include further sampling of bedrock features to better understand the geological control of seabed habitats as well as expanding our understanding of Bass Strait geology.

The combined information now available from historical AHO bathymetric surveys, including a low resolution multibeam sonar survey, more recent AHO funded surveys in the northern region of the park, and our spatially-balanced sub-samples (with additional central reef mapping), now provide a sound understanding of the nature and spatial extent of seabed habitats in the park, and solid basis for ongoing biological studies that are representative of the main habitat features of the park. While much of the park remains to be mapped, we are confident that we have a clear understanding of the location of reef features within the park and that most of these have now been mapped in fine resolution. Likewise, we are confident that the soft-sediment seabed features mapped by the spatially balanced 5 km x 5 km sample areas, coupled with the extensive northern recently mapped by the AHO, are sufficient to adequately characterise the habitat distribution within the park and to underpin all future subsequent biological studies. However, additional spatially-balanced mapping of seabed areas outside the park would be beneficial to planning monitoring programs that contrast changes within the park to changes in adjacent areas, and thereby assess management effectiveness.

5.2 Sessile epifaunal and demersal fishes

Despite the ecological importance of shallow-water epibenthic communities, few studies in Australia have investigated the spatial variation of these assemblages along the outer continental shelf margins (e.g. Monk et al. 2016). This information is critical for conservation planning of continental shelf habitats, and for designing monitoring programs that accurately assess the spatio-temporal variability of epibenthic assemblages.

Seabed mapping and analysis of AUV imagery revealed four key habitat categories within the mapped area of the Beagle Marine Park: 1) low profile (2 – 5 m high) hardground reef supporting moderate to high densities of sessile invertebrates (mixed sponge, bryozoan and hydroids); 2) scallop beds interspersed among unconsolidated coarse sand with shell fragments and extensive fields of sedimentary bedforms; 3) screw shell beds; and 4) aggregations of shell hash with broken bryozoan skeletons, and disarticulated and live scallops that provide an important substrata for sessile filter feeding invertebrates. Mapping of AUV and BRUV annotations revealed that deeper (> 60 m) south-western sites were dominated by shelly sand habitat, while the shallower sites were dominated by shell hash and screw shell habitats. While spatially discrete, the low-profile hardground reef features that characterise this region comprise much of the epibenthic faunal diversity.

A highly diverse epifaunal assemblage was recorded from AUV imagery, with 205 biological morphospecies identified and seven substratum types. Sponges were the dominant organism with 159 morphospecies, of which massive forms were most common. Other sponge forms observed included creeping/ramose, encrusting, branching and cup sponges. Representatives from cnidarians, bryozoans and ascidians were also recorded. Similar to other mesophotic reef environments around Tasmania (such as the Flinders Marine Park), matrix classes consisting of turf-like, finely-structured short (<5 cm) sessile invertebrates were observed to have the highest cover (matrix classes) providing an average cover of ~ 2 % in images. For the larger, more identifiable sessile invertebrates, mean cover was generally < 0.1 %, however, this increases for percent cover when cover is examined on rocky reef, as this habitat provides a more stable point of attachment for many sessile faunal species. For example, the hard bryozoan *Adena grisea* accounted for 6.7 % of all reef cover, the soft bryozoan morphospecies “grey/pink” was nearly 3 % cover, and the hydroid morphospecies “orange 2D” accounted for 10.3 % cover. Likewise, the encrusting sponge morphospecies “beige oscula” accounted for 8.3 % cover. Despite this, the large conspicuous morphospecies such as the sponge “arborescent purple” (0.68 % cover) was somewhat less abundant than found in shelf waters in the nearby Flinders Marine Park.

As we are finding in shelf-based studies in SE Australia, and more generally around Australia, about one-third of morphospecies seen in imagery are singletons (i.e. only seen once) and nearly half the morphospecies in the assemblage are seen less than twice. This suggests that the benthic assemblage in the Beagle Marine Park consists of morphospecies that are highly diverse and spatially rare, again, a pattern observed more widely in shelf biodiversity studies on reefs below algal-dominated zones. When compared to sessile invertebrates, doughboy scallops and invasive New Zealand screw shells had considerable coverage. Clearly soft sediments in this high current region are productive habitat for scallops, however, the vast majority of live scallops seen were very small doughboy scallops rather than commercial scallops, and despite their sizes not being measured, most were quite small (typically 2-5 cm diameter). This productive current flow also appears to be conducive to the growth and spread of the NZ screwshells as well, and these (as dead shells) formed as much as 4.3 % of the overall cover on the AUV transects, and a significantly higher proportion of the soft sediment habitats. While there is no prior quantitative baseline in this region to benchmark the rate at which this invasive species is spreading, it is clear that it is a dominant feature in this part of central-eastern Bass Strait and is likely to continue to increase through time, forming a distinct biogenic habitat, potentially to the exclusion of a range of native species. Ongoing monitoring within this park will play an important role in understanding the longer-term trajectory and biodiversity impact of this invasive species problem.

Significant differences between all habitats surveyed by AUV-based imagery suggests that the morphospecies assemblages within the reef habitat had highly variable assemblages (~39 % similarity) and were quite dissimilar to all other habitats. Conversely, the screw shell and shelly sand habitats had lower variation (i.e. high similarity within these habitats). Sampling adequacy and power to detect change suggest that current image collection and annotation effort was generally sufficient to detect biologically significant changes in the most conspicuous morphospecies. For these, typically 100-200 % change in proportion cover could be achieve with sampling and annotation of <1000 images for most habitats. While this amount of change may sound large, even the most dominant morphospecies are at around 1% cover or less (when sampling is targeted at their core habitat such as reef), so a 100% increase, to 2% cover is indeed the biologically meaningful level of change that we would be intending to detect, so it is encouraging to see that the current level of sampling and annotation (if targeted on core habitat) would achieve that aim.

While fish were not the target of the AUV-based image sampling, of significant note from this work was the observation of a large aggregation of port Jackson shark (*Heterodontus portjacksoni*) in AUV imagery along the central ridge features in Grid 0. While it has yet to be determined if these aggregations are repeated across years, it is possible that this area is a winter feeding ground (potentially on adjacent scallop beds) prior to migration later in the year to lay eggs in NSW coastal waters.

Our study demonstrated that low-profile reef features can significantly influence patterns in proportion cover and composition of benthic morphospecies classes. We also demonstrated that aggregations of shell hash can strongly influence the proportion cover of some sessile filter feeding invertebrates, which require hard substrata to attach themselves. As sand inundation and sediment scour are likely to be important factors explaining spatial gradients and patchiness in epibenthic biota throughout the Beagle Marine Park, future monitoring programs and sampling designs should consider the variable and likely highly-disturbed nature of these spatially-discrete but biologically important features, as it is likely that they are readily and repeatedly buried and exposed.

Among the four habitat types defined from AUV imagery analysis, all have a distinct fauna, and between them, offer the ability to monitor change in a range of reef-associated species (e.g. sponges and bryozoans), soft-sediment species (such as scallops, and sparse structure-forming invertebrates) and habitat engineering introduced species such as the NZ screwshell. Using the techniques employed by this survey, monitoring can detect biologically meaningful changes through time in response to pressures such ocean warming/ marine heatwaves, introduced species and to track the effectiveness of protection from fishing activities.

Demersal fish were abundant across the Beagle Marine Park, with approximately 3,232 individual fish recorded by stereo BRUV video. This sample was also diverse, comprising 61 species from 33 families across the study area (which included sites outside the marine park). However, with the exception of jackass morwong and (rarer) flathead species, few commercially or recreationally targeted species were recorded. The most speciose family were monacanthids with eight species, followed by labrids and triglids with four species of each recorded. Commonly observed fish were Degens leatherjacket, butterfly, barber and common gurnard perches, Melbourne silverbelly, jackass morwong, rosy wrasse, cosmopolitan leatherjacket, sand flathead and draughtboard shark. The overall model-based abundance estimates for Beagle Marine Park for selected fish species ranged from a low of 1093 individuals of jackass morwong to the most abundant species in the marine park of 61,674 individuals of barber perch, largely associated with the central ridge feature mapped in Grid 0. Notably, very few sharks were recorded in this survey, with small numbers of gummy sharks recorded and no school sharks, despite a significant shark fishery operating in the park and in similar habitat targeted by the sampling. Further targeted studies are required to ascertain whether this lack of response was related to the BRUV method (and associated bait) or simply reflects an overall low density of these species in the park and adjacent reference areas at present. From the current information available, it appears that overall trawl and Danish seine fishing effort is quite low in this region of Bass Strait (Pitcher et al. 2018), presumably because of low overall productivity. Inference from Bax and Williams (1994) suggests that where commercial species were targeted in this region, it would have been primarily on tiger flathead at the depths found within the Beagle Marine Park, with Jackass morwong as a by-product.

The BRUV video data from Beagle Marine Park also recorded a variety of demersal fish species that were significantly larger in size than other reference locations. In particular, toothy flathead, blue-throat wrasse, cosmopolitan leatherjacket, draught board shark and orange spotted catshark all had larger lengths than fish observed outside the park. Given that the reference locations were spatially constrained, and the SW reference area (unmapped) was found to have a higher proportion of reef than expected, these patterns (especially for wrasse) more likely reflect habitat-related differences than effects of protection. Importantly though, these results do show that the current sampling effort is sufficient to detect biologically meaningful differences in length distribution that may result from fishing protection, or life-history changes in habitat utilisation. With the current design, the important factor to note is that it is the extent that these patterns change through time between park and reference locations that indicates whether effects of protection are seen, rather than differences noted on an initial baseline/inventory such as this.

Sampling adequacy and power to detect change suggest that current effort was generally sufficient to detect at least a 100% increase in mean abundance between sampling events using a reasonable sampling effort (nominally 50-150 stereo-BRUV deployments at each sampling event) for most common species. This could be further improved by additional sampling or more stratified sampling to target the preferred habitat of species of interest (e.g. sediment-dominated seabed for flathead, reef-dominated habitat for wrasse). This initial baseline/inventory applied a spatially-balanced approach (with some stratification to add weight to reef habitats) in order to undertake both an overall inventory of species across habitats and to use our knowledge of species/habitat relationships, and the extent of cover of each habitat in the park, to then make reliable quantitative estimated of the abundance of key species in the park as a whole, rather than just at sample sites, adding confidence that patterns seen are park-wide and not a bias due to site selection.

Overall, there is a general lack of complex raised reef within Beagle Marine Park that usually provide crevice habitat for commercially important reef species such as rock lobster, striped trumpeter, boarfish, and other commercial species that track such structure. Importantly, none of these species were recorded in the stereo BRUV sampling and are unlikely to be a key asset for this park. The reefs found here are typically shallower and further away from the shelf-break than those typically preferred by adult striped trumpeter, and the location may be in a low-recruitment zone for the larvae of both striped trumpeter and rock lobster. In the adjacent Kent Group Marine Reserve (Tasmania) very low numbers of rock lobster were recorded over a 20-year monitoring program), despite half the reserve (and suitable habitat) being fully protected from fishing activities (Edgar et al. 2017), suggesting this area of central–to eastern Bass Strait was sufficiently isolated from ocean currents to limit arrival of new recruits from the planktonic phase. Given this overall lack of reef-associated target fish species, future monitoring programs in this park may be more usefully focussed on soft-sediment habitats that support commercially targeted shark species (longline and netting) and benthic fishes such as flathead (benthic trawl).

5.3 Summary and Recommendations

The seabed and associated habitats of Beagle Marine Park was found to be dominated by soft sandy sediment, screwshell deposits and sponge/bryozoan rubble habitat, with limited areas of reef. The rubble habitat is particularly extensive and supports characteristic sessile epifaunal assemblages similar to those associated with low-profile reefs in other marine parks in the South-east Network. Despite reefs only forming a very small component of the park, the main reef system forms a long ridge feature spanning much of the distance between the Kent Group and Hogan Group of islands, along what was once the crest of the land-bridge joining Victoria with Tasmania during glacial periods of lower sea level. As such, the ridge forms an important part of Indigenous Peoples' heritage and would have provided shelter for migrating communities at the time. Likewise, as these reefs appear to be formed on lithified dune systems, they also form a unique geological feature, and have intrinsic geo-heritage value. Moreover, as hard substrate in an otherwise expansive area of soft-sediments, these reef systems also form a biodiversity hotspot within the park for sessile invertebrate communities dominated by sponges and bryozoans that in turn attract an abundant and diverse demersal fish community.

The sampling approaches undertaken in this study have followed the NESP Standard Operating Procedures to generate a robust inventory and initial estimates of biological and physical assets within Beagle Marine Park, based wherever possible, on spatially-balanced designs. The knowledge gained here is likely to be sufficient to underpin future monitoring of values and pressures acting on benthic invertebrate and fish assemblages. To support this monitoring as part of the ongoing management of Beagle Marine Park, the following recommendations for further research are provided:

- Additional validation of benthic habitats by AUV and/or BRUV imagery is required to properly interpret habitat distribution currently inferred from multibeam bathymetry mapping (but not yet sampled by AUV and BRUV). In turn, this will improve quantitative estimates of habitat coverage and associated sessile and mobile fauna based on spatially balanced designs.

- Additional targeted physical sampling of seabed geomorphic features to validate interpretations of multibeam sonar and backscatter data. In particular, sampling of the low profile linear ridges that characterise large areas in the eastern part of the park to confirm their composition as outcrop of the Mathinna Group. With this knowledge, it can be assumed that these ridges provide a stable habitat for sessile biota.

- Additional spatially-balanced seabed mapping of areas outside Beagle Marine Park would be beneficial to planning a monitoring program that compares changes within the park to changes in adjacent areas. This is in turn can inform assessment of the effectiveness of the management plan for the marine park.
- As sand inundation and sediment scour are likely to be important factors explaining spatial gradients and patchiness in epibenthic biota throughout the Beagle Marine Park, future monitoring programs and sampling designs should consider the variable and likely highly-disturbed nature of these spatially-discrete but biologically important features. It is likely that they are readily and repeatedly buried and exposed.
- Given the low numbers of sharks (gummy and school sharks in particular) observed on BRUV video from this survey, further targeted studies are required to ascertain whether this result was related to the BRUV method (and associated bait) or simply reflects an overall low density of these species in the park and adjacent reference areas at present.
- Repeat BRUV surveys of demersal fish that employs a spatially balanced design are also recommended. This will allow for detection of any temporal change in the size of certain species, and an assessment as to whether any patterns change through time between park and reference locations are related to the effects of protection rather than differences noted on an initial baseline/inventory. The sampling design could be further improved by additional sampling or more stratified sampling to target the preferred habitat of species of interest (e.g. sediment-dominated seabed for flathead, reef-dominated habitat for wrasse).
- Finally, given the overall lack of raised reef habitat within Beagle Marine Park and reef-associated target fish species, future monitoring programs in this park may be more usefully focussed on soft-sediment habitats that support commercially targeted shark species (longline and netting) and benthic fishes such as flathead (benthic trawl).

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Data Access

AUV imagery

Published via Australian Ocean Data Network (AODN) on this link: https://auv.aodn.org.au/auv/

Search for: **Tasmania 201808** | Beagle Shelf

BRUV imagery

Published via GlobalArchive on this link: https://globalarchive.org/geodata/explore/

Search for: **Beagle AMP** under 'Filter by Project'

Bathymetry and backscatter data

"Beagle Marine Park bathymetry data 2018" plus Data QC and Multibeam Mobilisation reports on this link: http://pid.geoscience.gov.au/dataset/ga/130301
DOI: dx.doi.org/10.26186/5d4cea0bdecb4

"Beagle Marine Park backscatter data 2018" on this link: http://pid.geoscience.gov.au/dataset/ga/130329
DOI: dx.doi.org/10.26186/5d4ceba3cc586

Seabed grain size data

Published in the national MARine Sediments (MARS) database maintained by Geoscience Australia. http://dbforms.ga.gov.au/pls/www/npm.mars.search

APPENDIX A – SUPPLEMENTARY FIGURES

The following Figures S1-S10 show the hill-shaded bathymetry and acoustic backscatter data for individual survey grids (except grids 1, 0, and 12, which are shown in the main text. Grids are ordered from east (grid 3) to west (grid 6) across increasing water depth.

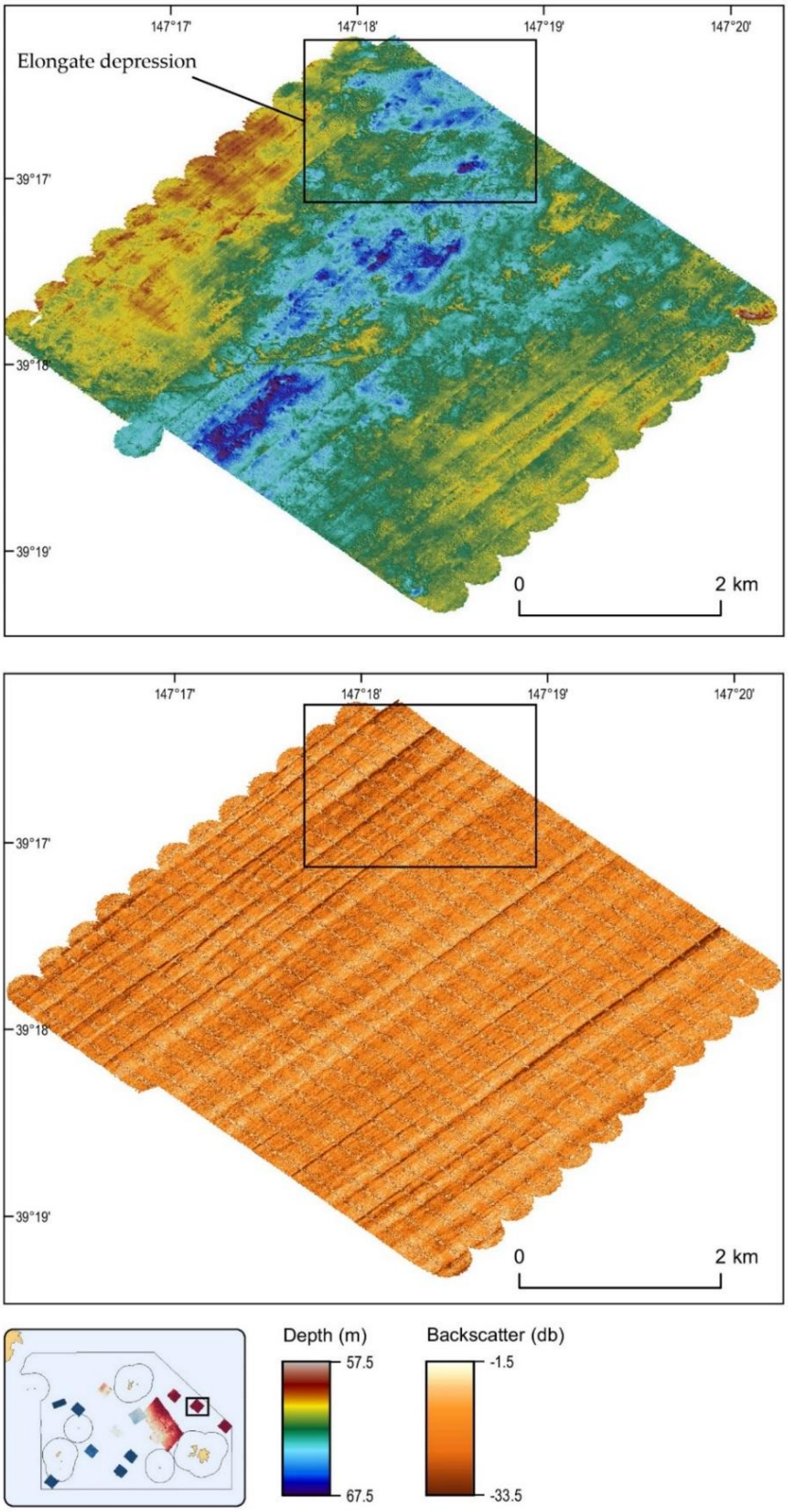


Figure S1

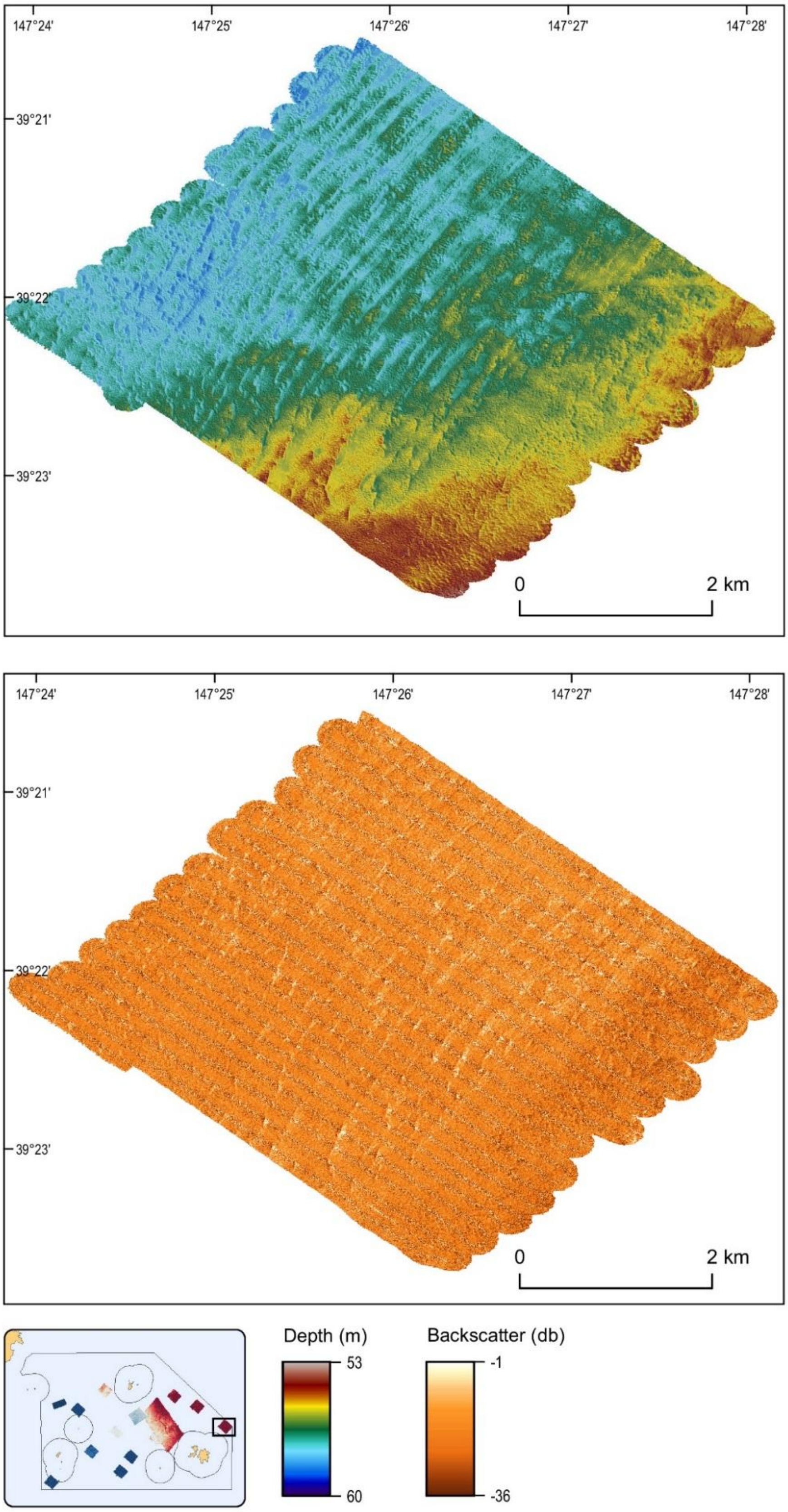

147°24'
147°25'
147°26'
147°27'
147°28'
39°21'
39°22'
39°23'
0
2 km
147°24'
147°25'
147°26'
147°27'
147°28'
39°21'
39°22'
39°23'
0
2 km
Depth (m)
53
60
Backscatter (db)
-1
-36

Figure S2

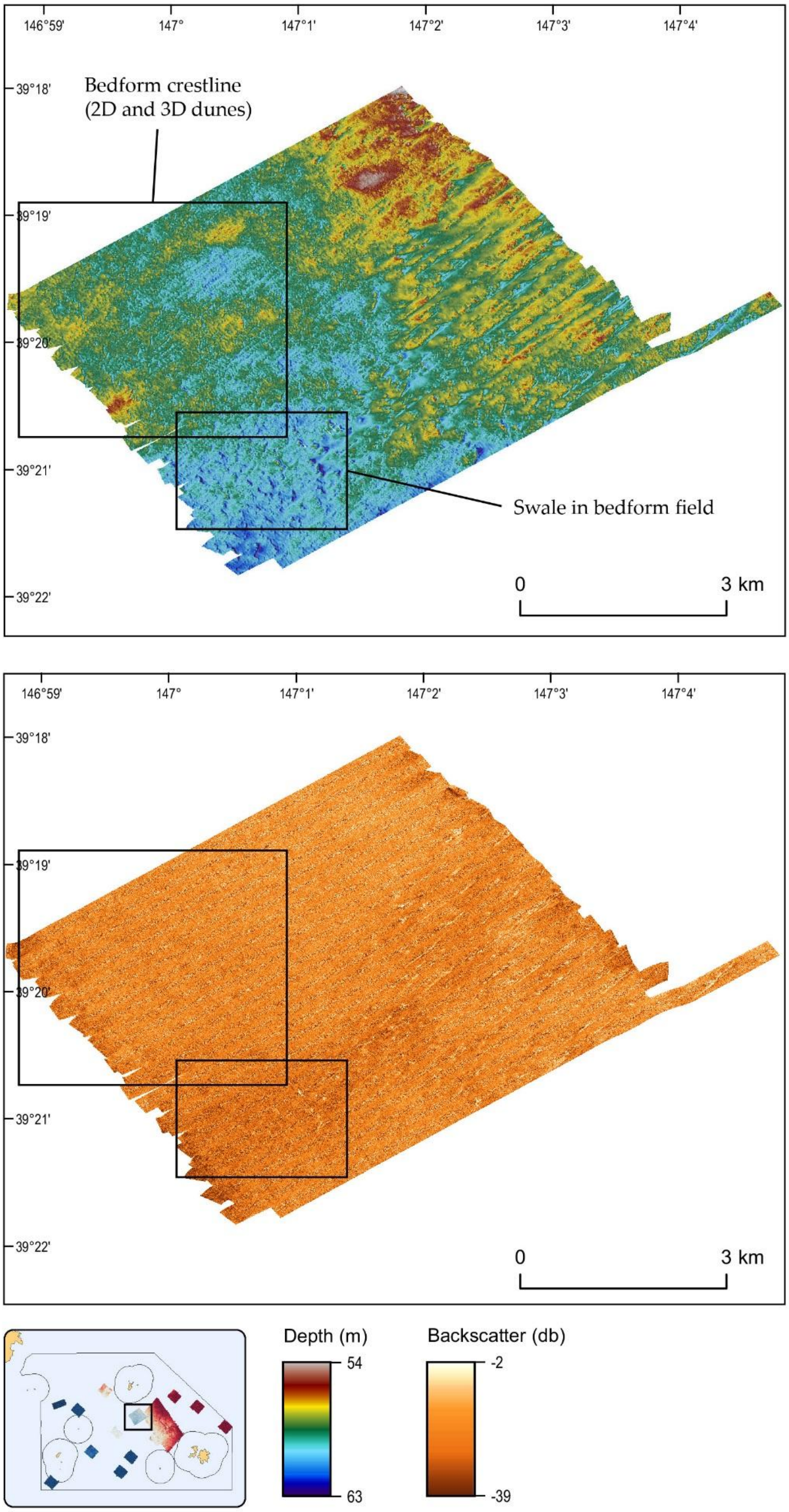

146°59'
147°
147°1'
147°2'
147°3'
147°4'
39°18'
39°19'
39°20'
39°21'
39°22'
Bedform crestline
(2D and 3D dunes)
Swale in bedform field
0
3 km
Depth (m)
54
63
Backscatter (db)
-2
-39

Figure S3

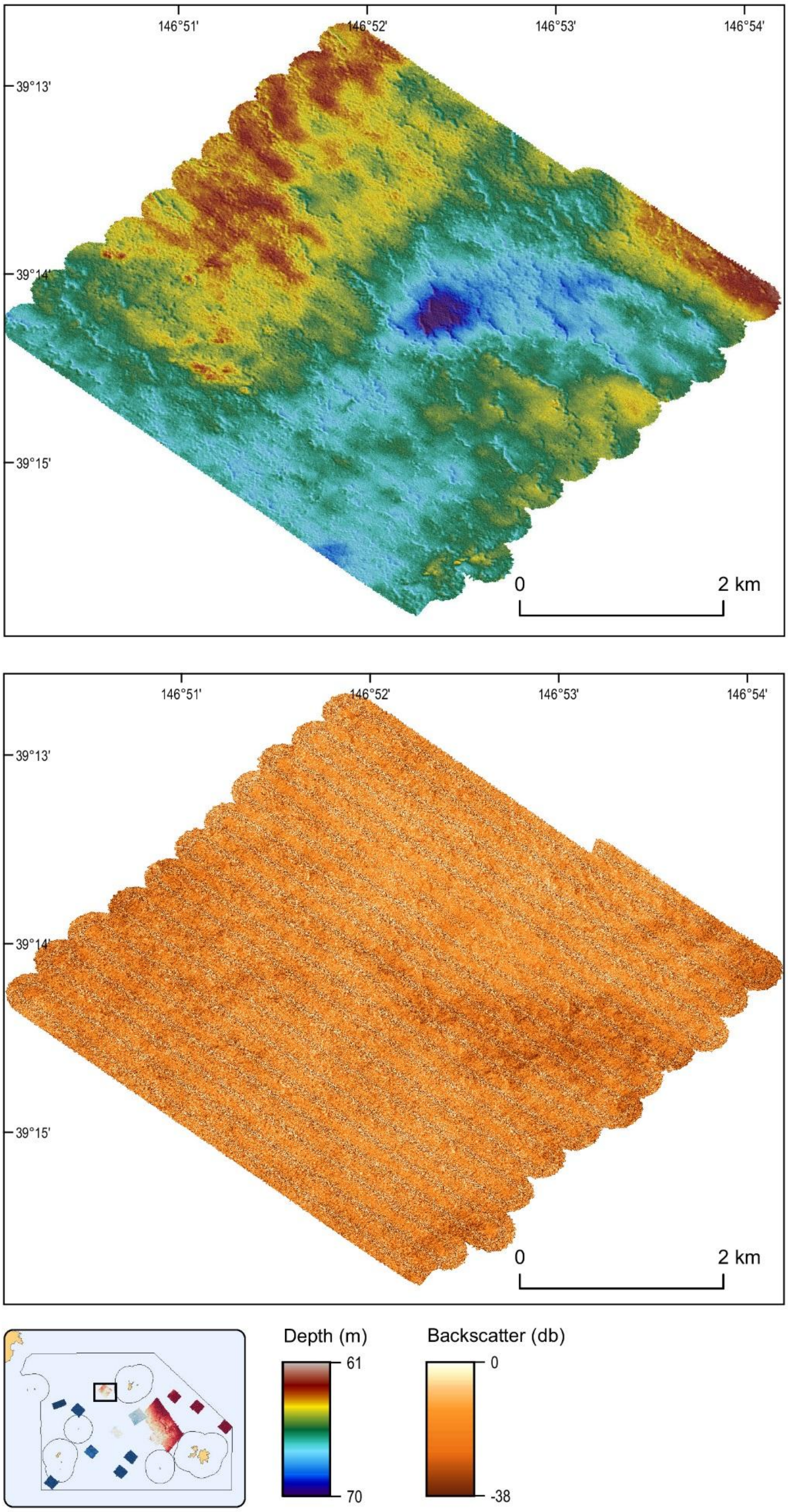

146°51'
146°52'
146°53'
146°54'
39°13'
39°14'
39°15'
0
2 km
146°51'
146°52'
146°53'
146°54'
39°13'
39°14'
39°15'
0
2 km
Depth (m)
61
70
Backscatter (db)
0
-38

Figure S4

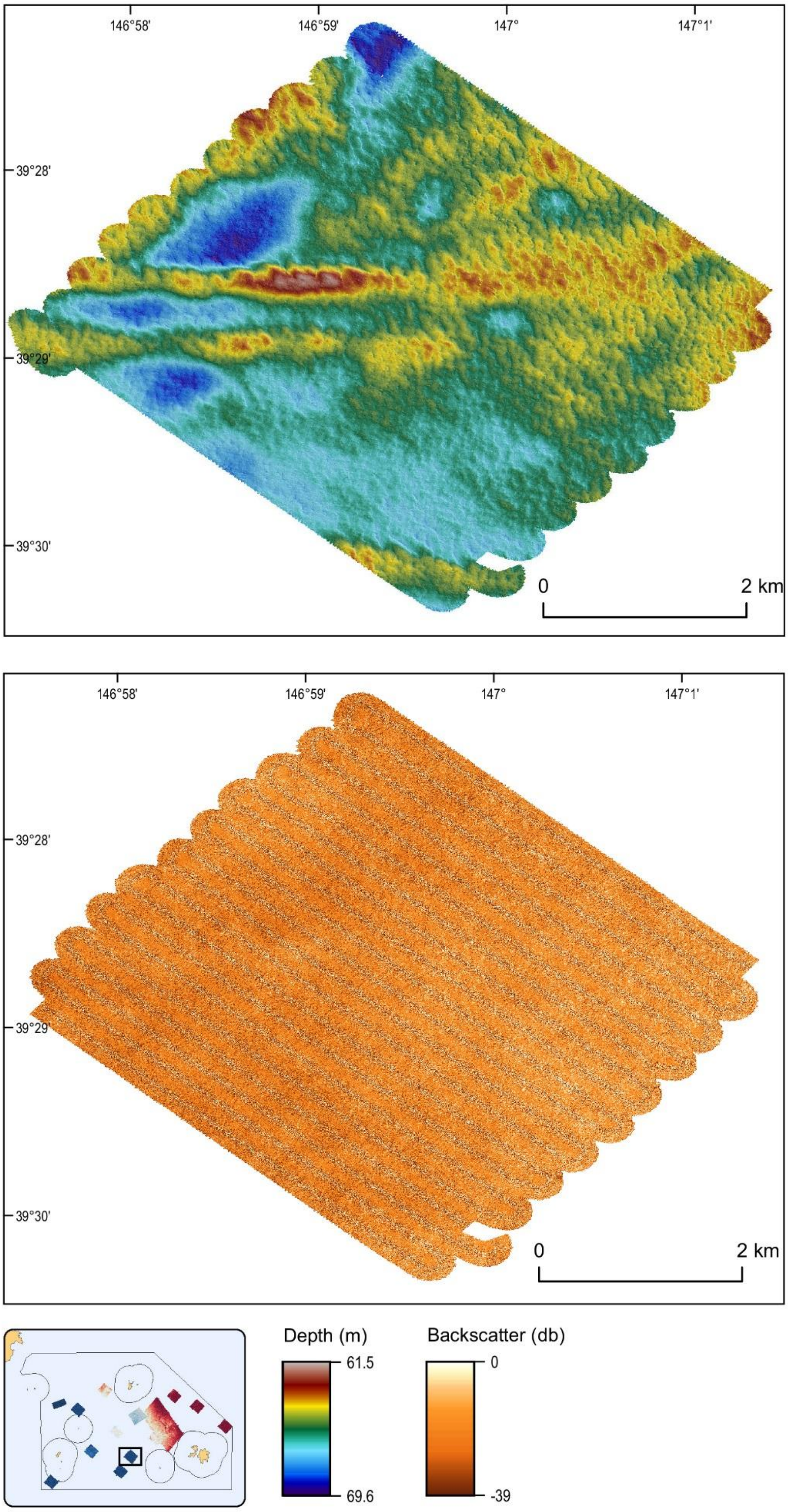

146°58'
146°59'
147°
147°1'
39°28'
39°29'
39°30'
0
2 km
146°58'
146°59'
147°
147°1'
39°28'
39°29'
39°30'
0
2 km
Depth (m)
61.5
69.6
Backscatter (db)
0
-39

Figure S5

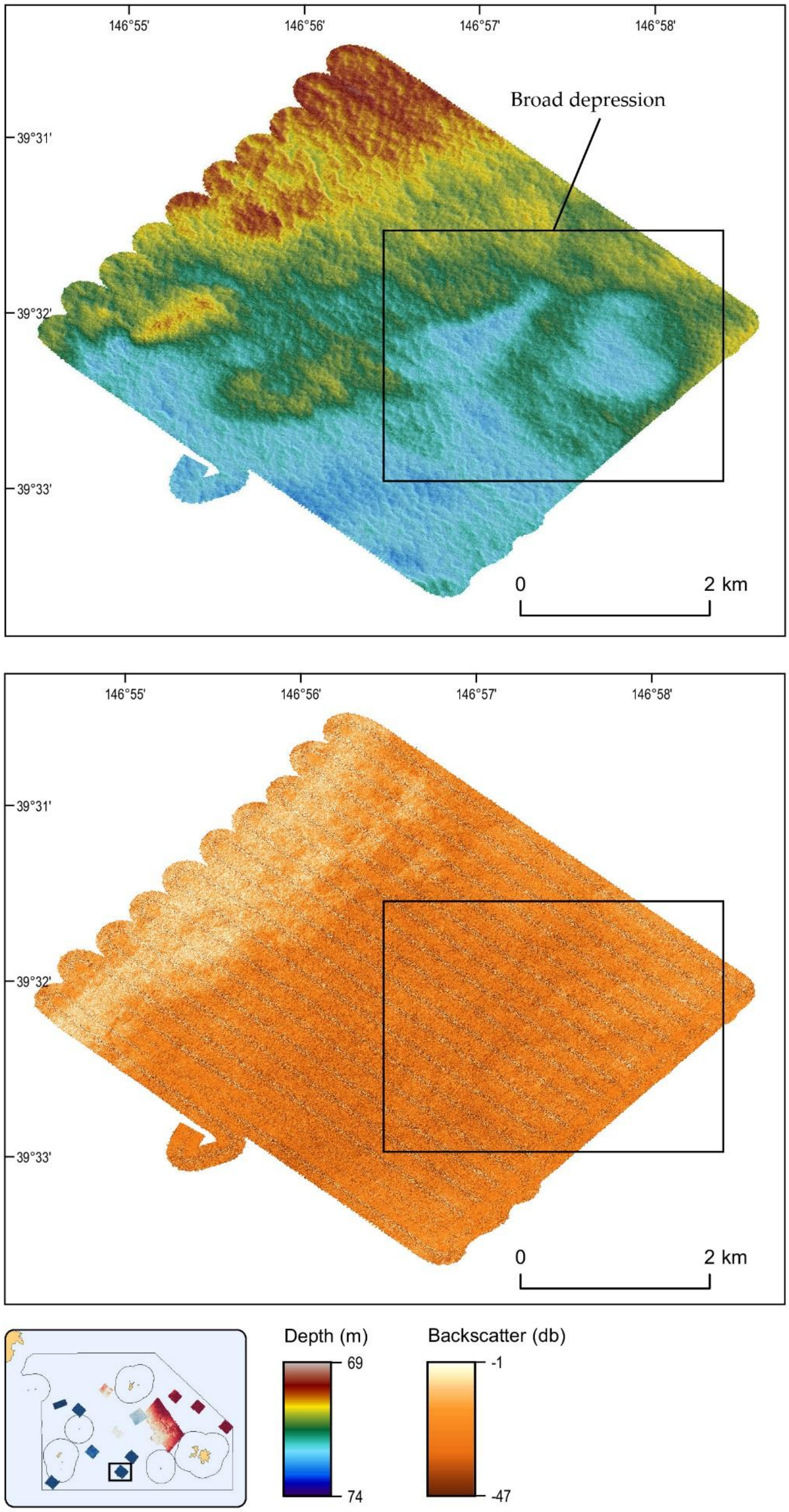
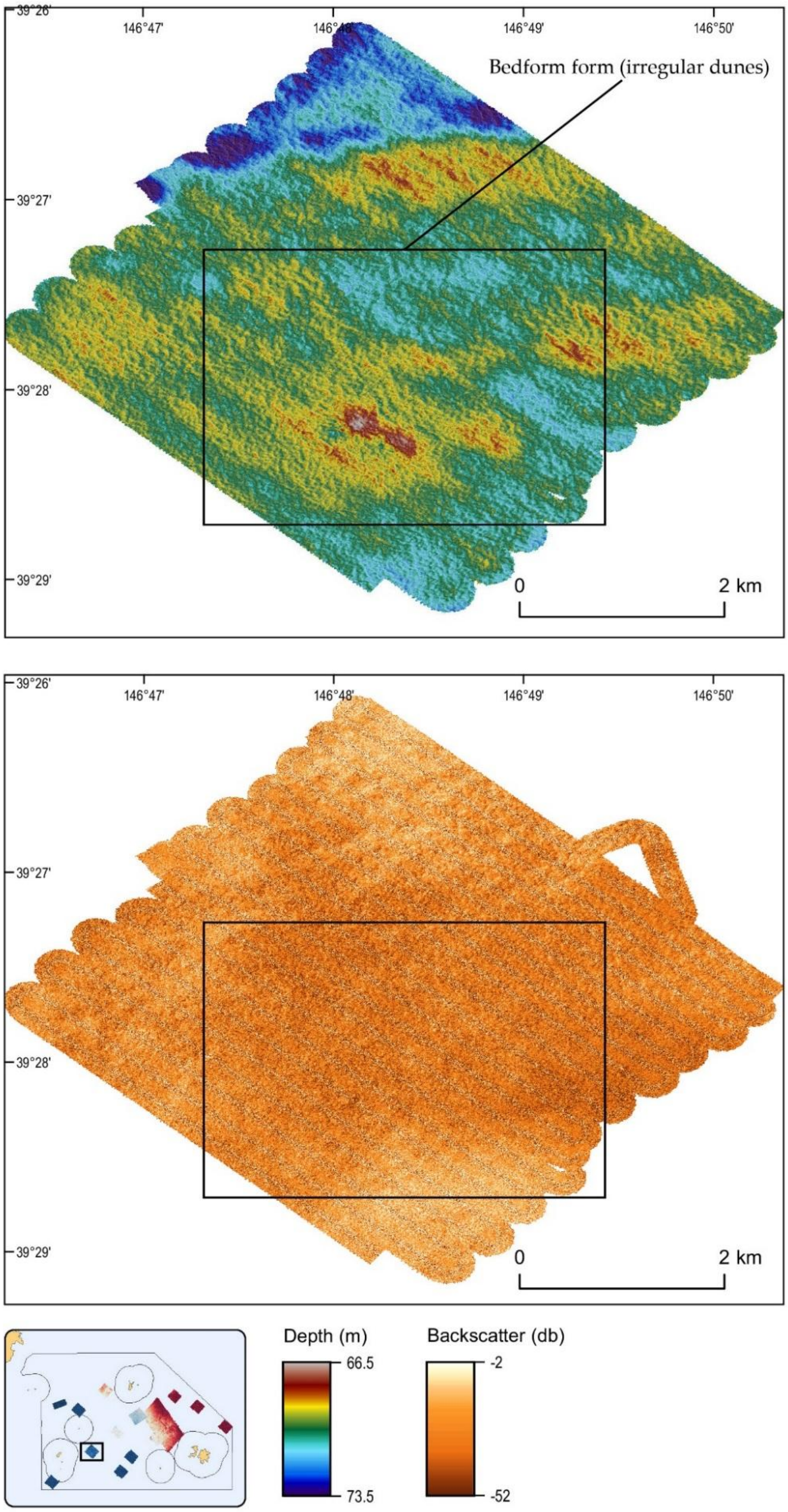

146°55'
146°56'
146°57'
146°58'
39°31'
39°32'
39°33'
Broad depression
0
2 km
Depth (m)
69
74
Backscatter (db)
-1
-47

Figure S6



39°26'
146°47'
146°48'
146°49'
146°50'
Bedform form (irregular dunes)
39°27'
39°28'
39°29'
0
2 km
39°26'
146°47'
146°48'
146°49'
146°50'
39°27'
39°28'
39°29'
0
2 km
Depth (m)
66.5
73.5
Backscatter (db)
-2
-52

Figure S7

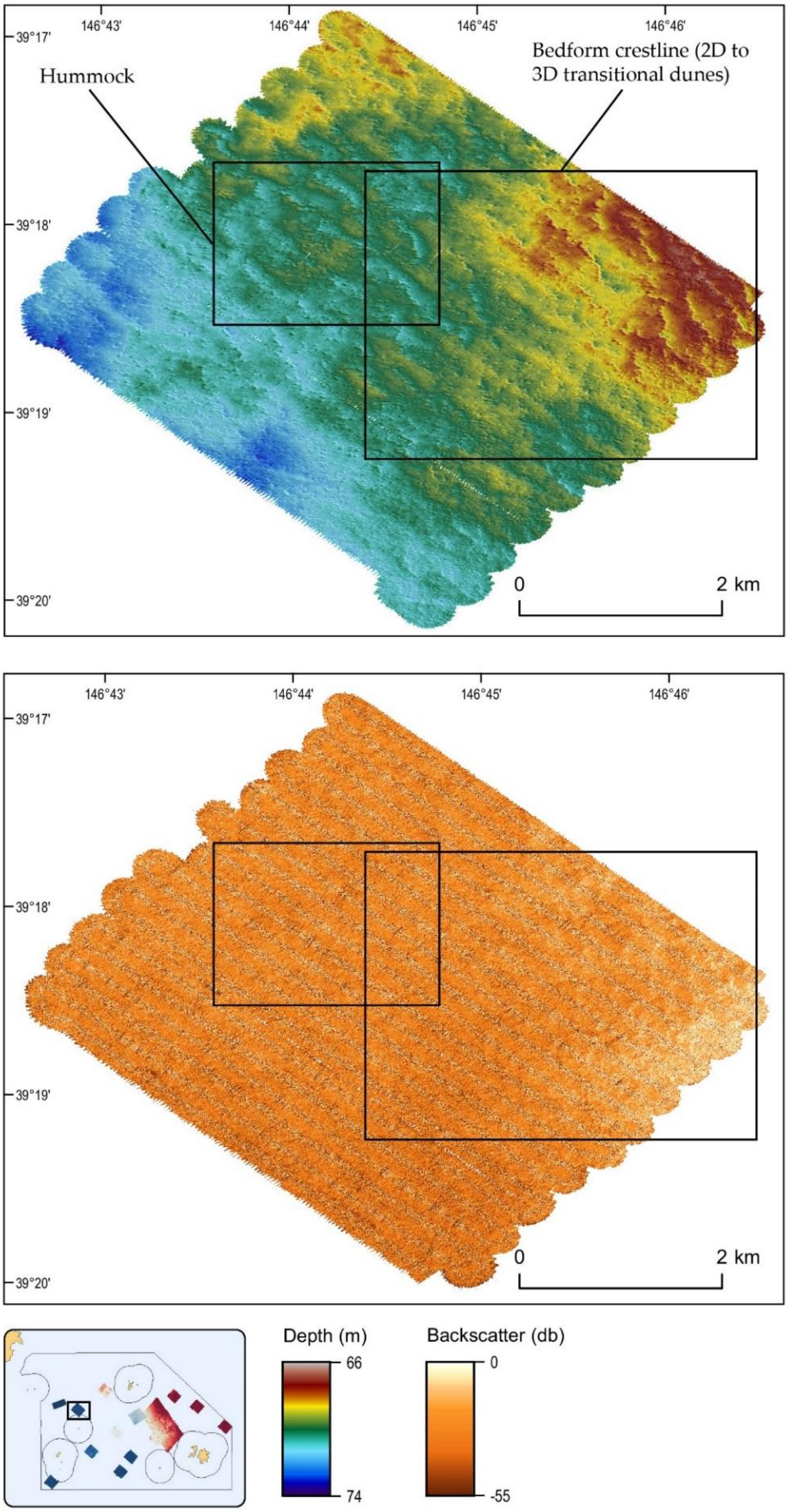

146°43'
146°44'
146°45'
146°46'
39°17'
39°18'
39°19'
39°20'
Hummock
Bedform crestline (2D to 3D transitional dunes)
0
2 km
Depth (m)
66
74
Backscatter (db)
0
-55

Figure S8

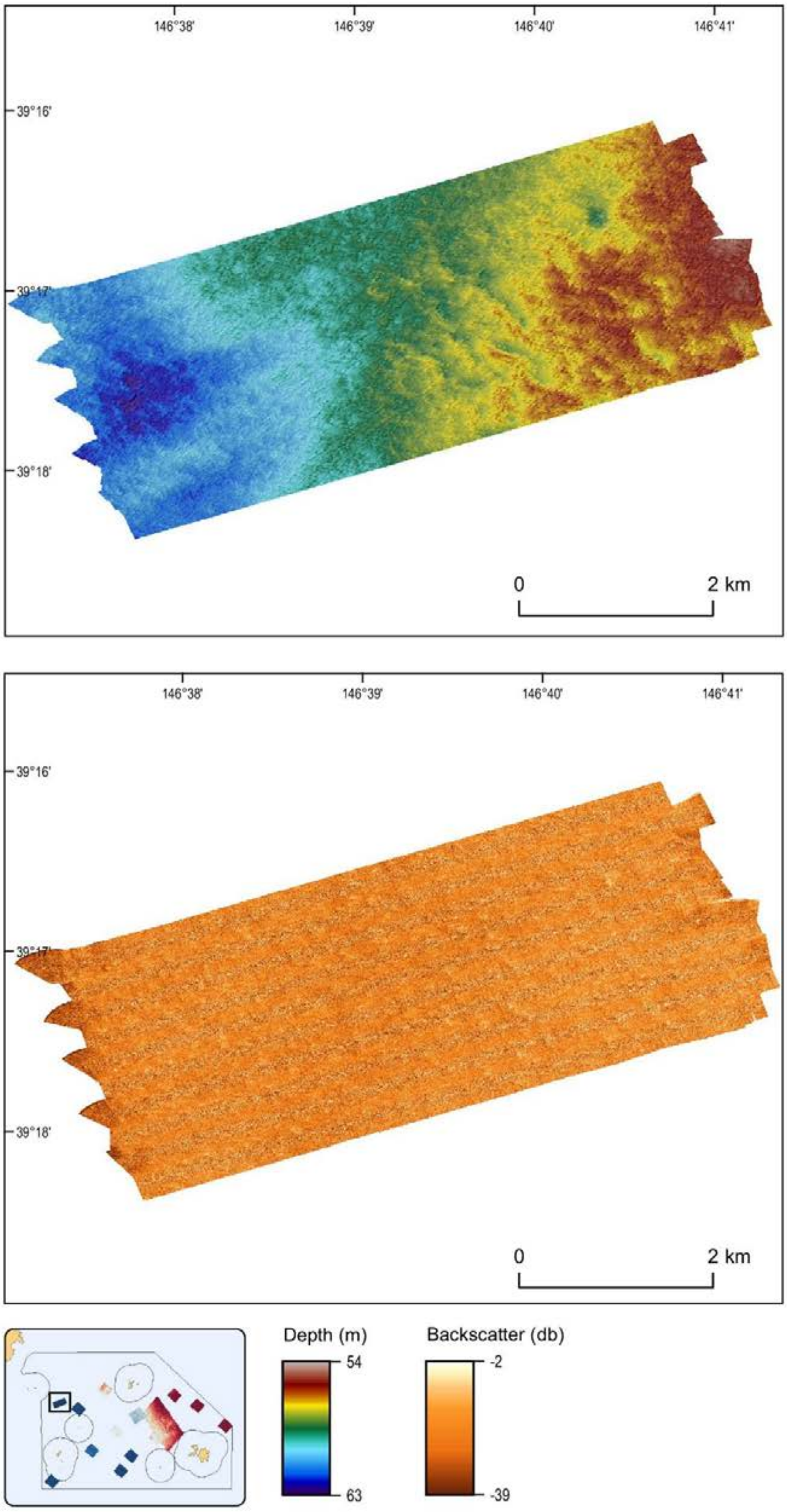
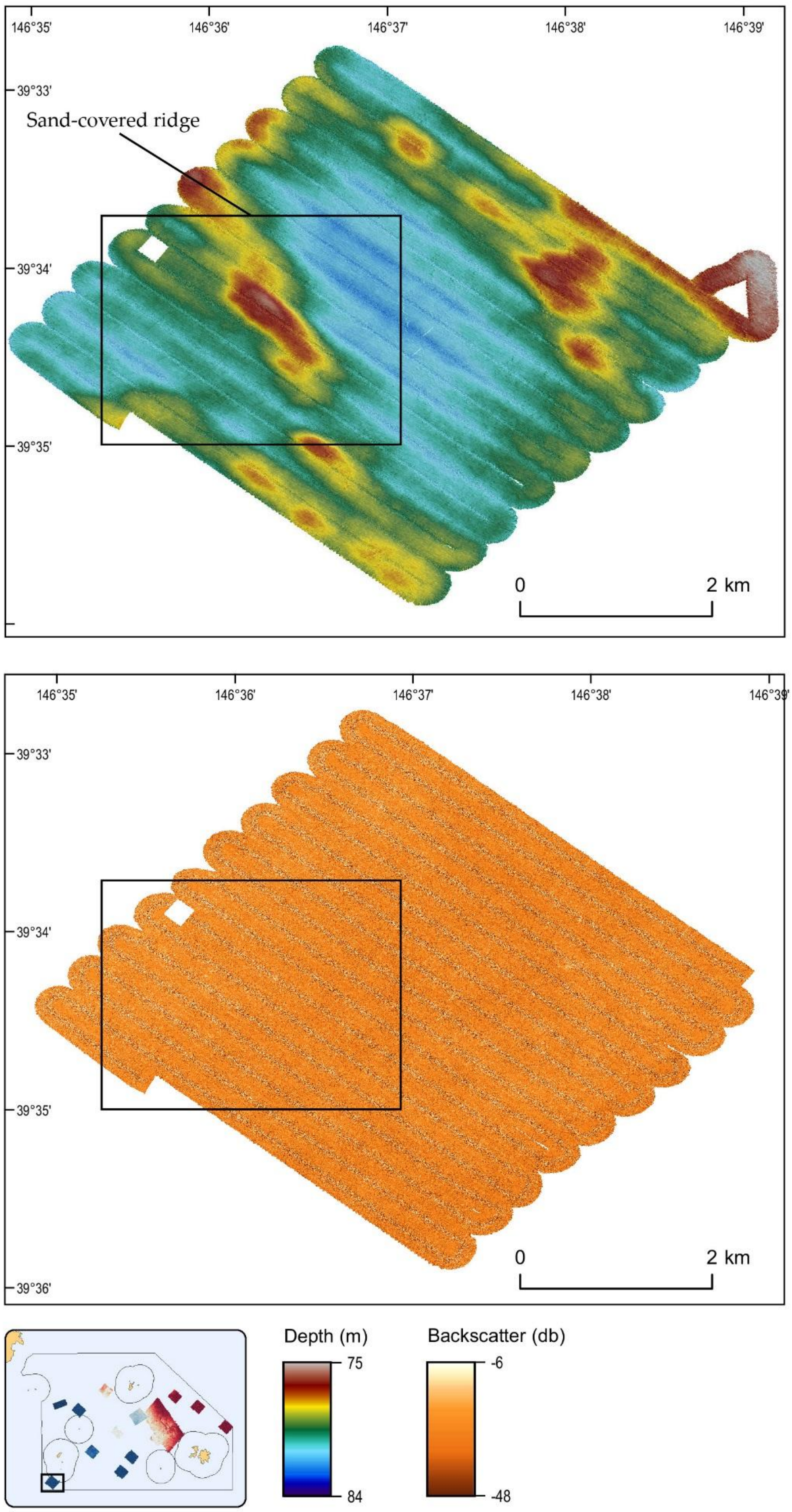

146°38'
146°39'
146°40'
146°41'
39°16'
39°18'
0
2 km
Depth (m)
54
63
Backscatter (db)
-2
-39

Figure S9



146°35'
146°36'
146°37'
146°38'
146°39'
39°33'
Sand-covered ridge
39°34'
39°35'
0
2 km
146°35'
146°36'
146°37'
146°38'
146°39'
39°33'
39°34'
39°35'
0
2 km
39°36'
Depth (m)
75
84
Backscatter (db)
-6
-48

Figure S10

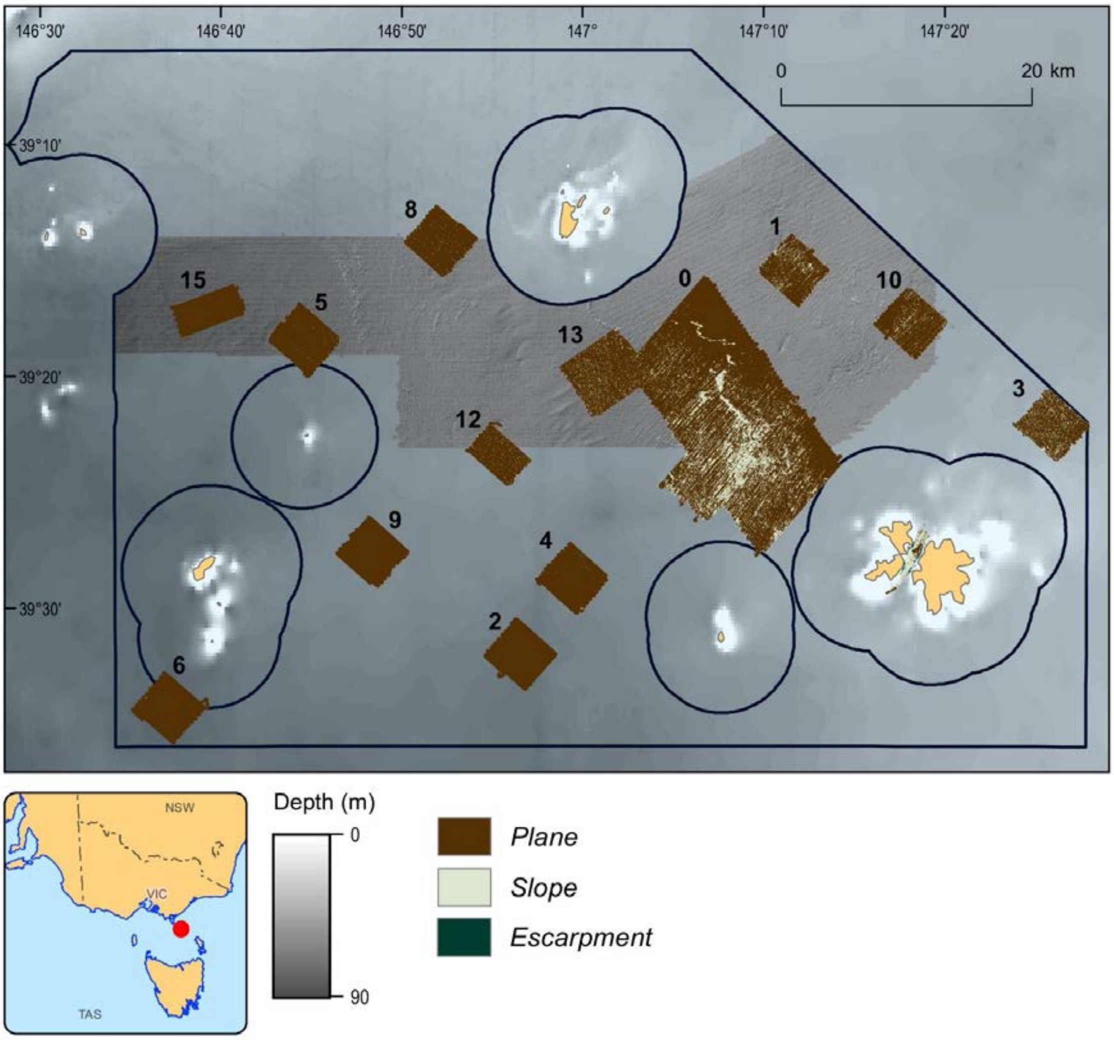

146°30'
146°40'
146°50'
147°
147°10'
147°20'
0
20 km
39°10'
39°20'
39°30'
0
1
2
3
4
5
6
8
9
10
12
13
15
NSW
VIC
TAS
Depth (m)
0
90
Plane
Slope
Escarpment

Figure S11

APPENDIX B – SEDIMENT SAMPLES

Sample ID	Gear type	Latitude Deg (S)	Longitude Deg (E)	Water depth (m)	Date	Description	%Mud	%Sand	%Gravel	%CaCO3	Repository	Sample Code
01GR01	Grab	39.35441	147.1375	58.4	23-Aug-2018	Poorly sorted gravelly carbonate sand; bryozoan & shell fragments	0.38	88.97	10.66	91	Geoscience Australia	2931687
02GR01	Grab	39.35536	147.1363	57.4	23-Aug-2018	Poorly sorted gravelly carbonate sand; bryozoan & shell fragments	0.67	81.24	18.08	92	Geoscience Australia	2931688
03GR01	Grab	39.35506	147.1367	56.4	23-Aug-2018	Very poorly sorted sandy carbonate gravel; shell fragments & whole valves	0.25	35.22	64.53	91	Geoscience Australia	2931689
04GR01	Grab	39.35344	147.1382	61.6	23-Aug-2018	Very poorly sorted sandy carbonate gravel; shell fragments & whole valves	0.48	55.91	43.60	90	Geoscience Australia	2931690
05GR01	Grab	39.35314	147.1379	62.0	23-Aug-2018	Moderately sorted gravelly carbonate sand; bryozoan & shell fragments	0.49	89.61	9.90	91	Geoscience Australia	2931691
01DR01	Dredge	-39.354	147.138	59.0	23-Aug-2018	Poorly sorted gravelly carbonate sand; mud trace; cobble clast of cemented calcareous sand (aeolianite)	2.73	76.03	21.24	91	Geoscience Australia	2931692

Notes: Mud, sand and gravel fractions were measured by wet sieve separation and carbonate content determined by acid dissolution. Full grain size distributions are published in the National Marine Sediments database (MARS). http://dbforms.ga.gov.au/pls/www/npm.mars.search

APPENDIX C – MORPHOSPECIES AND SUBSTRATE TYPES (AUV)

Summary of morphospecies and substratum types recorded in AUV imagery.

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
Ascidiacea	Stalked (solitary)	Ascidian Stalked Purple *Pyura* Like	0.01	0.23	0.11	0.65	0	0	0	0	0	0
	Unstalked (colonial)	Ascidian Unstalked Colonial Encrusting	0	0.14	0	0	0.03	0.32	0	0	0	0
	Unstalked (solitary)	Ascidian Red Throated	0.1	0.68	0.32	1.22	0.1	0.78	0	0	0.06	0.5
		Ascidian Solitary Grey	0	0.14	0	0	0.03	0.32	0	0	0	0
Bryozoa	Hard (fenestrate)	Bryozoan Hard *Celleporaria* Like	0.04	0.45	0.11	0.65	0.03	0.32	0	0	0.04	0.44
		Bryozoan *Adeona grisea*	1.84	6.3	6.71	11.62	2.74	7.89	0	0	0.74	3.37
		Bryozoan Purple Lettuce	0.18	1.17	0.93	2.57	0.15	1	0	0	0.06	0.62
		Bryozoan White Lace Fan	0	0.14	0	0	0	0	0	0	0.01	0.17
	Soft (dendroid)	Soft Red-Brown Dendroid	0	0.14	0	0	0	0	0	0	0.01	0.17

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
	Soft (foliaceous)	Bryozoan Soft Dark Red	0	0.14	0	0	0	0	0	0	0.01	0.17
		Bryozoan Soft Grey Pink	0.97	2.96	3.29	5.74	0.56	1.67	0.11	0.68	0.68	2.23
		Bryozoan Soft Orange	0.02	0.49	0.11	1.13	0	0	0	0	0.01	0.33
		Bryozoan Unknown Soft	0	0.14	0	0	0	0	0	0	0.01	0.17
		Bryozoan Soft Pinky White	0.02	0.3	0.04	0.38	0.03	0.32	0	0	0.02	0.29
Cnidaria	Corals (black & octocorals-Branching (3D) Fleshy Arborescent)	Coral 2 Soft *Capnella* Like	0.02	0.33	0.11	0.84	0	0	0	0	0.01	0.17
		Soft Coral 3 Dark Red	0.02	0.27	0.11	0.65	0	0	0	0	0.01	0.17
	Corals (black & octocorals-Branching (3D) Non-Fleshy Arborescent)	Bramble *Acabaria* sp	0	0.14	0.04	0.38	0	0	0	0	0	0
		Bramble *Asperaxis Kareni*	0.05	0.6	0.29	1.49	0.03	0.32	0	0	0.02	0.29
Cnidaria	Corals (black & octocorals-Branching (3D) Non-	Branching Grey Octocoral	0	0.14	0	0	0.03	0.32	0	0	0	0

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
	Fleshy bottlebrush)											
	Corals (black & octocorals-Complex (2D) fern frond)	Gorgonian Red *Mopsella* like	0.03	0.69	0.18	1.89	0	0	0	0	0.01	0.17
		Dark purple octocoral	0.01	0.19	0	0	0.03	0.32	0	0	0.01	0.17
		Gorgonian Pink	0.04	0.6	0.21	1.6	0	0	0	0	0.01	0.24
	Whip		0	0.14	0	0	0.03	0.32	0	0	0	0
	Corals (stony-mushroom)	Coral Orange Solitary	0.01	0.3	0	0	0	0	0	0	0.02	0.37
	Hydroids	Hydroid white	0.03	0.38	0	0	0.03	0.32	0	0	0.04	0.44
	Hydroids	Hydroid Brown Feathers	0.72	2.59	2.93	4.86	0.54	1.99	0.11	0.68	0.37	1.85
		Hydriod Orange 2D	2.39	6.38	10.29	12.49	1.67	4.5	0	0	1.18	3.5
	True Anemones		0.04	0.75	0.25	2.03	0	0	0	0	0.01	0.24
Echino-dermata	Sea Urchins (Heart urchin)		0.03	0.47	0	0	0	0	0.46	2.12	0.01	0.24
	Sea Urchins (Pencil Urchin)		0	0.14	0	0	0	0	0	0	0.01	0.17
	Feather Stars (Unstalked Crinoids)	*Comanthus tasmaniae*	0	0	0	0	0.03	0.32	0	0	0.01	0.17

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
	Brittle / Snake Stars		0	0.14	0	0	0	0	0	0	0.01	0.17
Fishes	Bony Fishes	*Caesioperca lepidoptera*	0.03	0.49	0.04	0.38	0	0	0	0	0.04	0.58
		Neosebastes scorpaenoides	0.02	0.36	0.11	0.84	0.03	0.32	0	0	0.01	0.17
	Elasmo-branchs	*Heterodontus portusjacksoni*	0	0.14	0	0	0	0	0	0	0.01	0.17
Jellies	Salps		0.05	0.98	0.21	2.27	0.1	1.28	0	0	0	0
Macro-algae	Encrusting	Calcareous red	0	0.14	0	0	0	0	0	0	0.01	0.17
Mollusca	Bivalves	Scallop (doughboy)	0	0.14	0	0	0	0	0	0	0.01	0.17
		Scallop (commercial alive)	0	0.14	0	0	0	0	0	0	0.01	0.17
		Scallop (commercial dead)	4.89	7.1	1.46	2.74	8.15	9.3	1.6	3.66	4.87	6.74
		Pipi like	0.05	0.47	0.04	0.38	0.13	0.84	0	0	0.03	0.33
	Gastropods	New Zealand Screw Shell	0	0.14	0	0	0	0	0	0	0.01	0.17
		Spindle Shell	1.2	3.54	0.25	1.35	1.26	2.76	0.8	4.73	1.39	3.91
Mollusca		Volute	0.03	0.6	0	0	0.15	1.43	0	0	0	0
		Unknown	0.02	0.27	0	0	0.05	0.45	0	0	0.01	0.24

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
Porifera	Crusts (creeping /ramose)	Repent Purple	0.02	0.27	0.11	0.65	0	0	0	0	0.01	0.17
		Repent Yellow	0.06	0.74	0.43	1.96	0.03	0.32	0	0	0.01	0.17
		Repent 1 Brown	0.04	0.38	0.18	0.83	0.03	0.32	0	0	0.01	0.24
		Repent 2 Brown	0	0.14	0	0	0	0	0	0	0.01	0.17
	Crusts (creeping /ramose)	Ramose Single Cream	0.03	0.38	0.11	0.84	0.03	0.32	0	0	0.01	0.24
		Lumpy Shapeless Grey	0.01	0.19	0.07	0.53	0	0	0	0	0	0
		Repent Orange	0.04	0.45	0.25	1.11	0.03	0.32	0	0	0.01	0.17
		Creeping Fat White	0.23	1.9	0.54	2.31	0.46	2.98	0	0	0.12	1.43
		White Tempura	0.06	0.66	0.21	1.05	0.13	1.06	0	0	0.02	0.37
		Repent Brown Dark Blue Lace	0.06	0.59	0.11	0.65	0.15	1	0	0	0.03	0.41
	Crusts (encrusting)	Encrusting Orange	0.01	0.23	0	0	0.03	0.32	0	0	0.01	0.24
		Encrusting Beige Oscula	2.09	6.44	8.32	12.83	1.56	4.1	0	0	1.13	4.25
		Encrusting Orange Lumpy	0.01	0.41	0.11	1.13	0	0	0	0	0	0
		Encrusting Beige Smooth	0	0.14	0.04	0.38	0	0	0	0	0	0

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Encrusting Purple Lumpy	0.11	0.79	0.25	1.11	0.23	1.22	0	0	0.06	0.55
		Encrusting Yellow Rough	0	0.14	0.04	0.38	0	0	0	0	0	0
		Encrusting White	0.01	0.3	0.04	0.38	0.05	0.64	0	0	0	0
		Encrusting Light Orange	0	0.14	0.04	0.38	0	0	0	0	0	0
		Encrusting Orange Papillate	0.05	0.63	0.25	1.45	0.03	0.32	0	0	0.03	0.41
		Encrusting Purple Oscula	0	0.14	0	0	0	0	0	0	0.01	0.17
		Encrusting Yellow 2	0.02	0.27	0.04	0.38	0.08	0.55	0	0	0	0
		Encrusting Yellow Oscula	0.07	0.7	0.5	1.87	0	0	0	0	0.01	0.17
		Encrusting Black	0	0.14	0	0	0	0	0	0	0.01	0.17
		Encrusting Black Papillate	0.05	0.62	0.18	1.25	0.05	0.64	0	0	0.03	0.41
Porifera		Encrusting Brown 5	0	0.14	0	0	0.03	0.32	0	0	0	0
		Dark purple massive	0.04	0.38	0.07	0.53	0.08	0.55	0	0	0.02	0.29
		Encrusting Yellow 3	0.01	0.19	0.04	0.38	0	0	0	0	0.01	0.17
	Cup-Likes (barrels)	Tubular Tan Singular	0.02	0.36	0.07	0.53	0	0	0	0	0.02	0.37

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
	Cup-Likes (cups)	Cup Stalked Purple	0.02	0.45	0.11	1.13	0	0	0	0	0.01	0.24
		Cup Red	0.02	0.33	0.04	0.38	0	0	0	0	0.02	0.37
		Cup Red Smooth	0	0.14	0	0	0	0	0	0	0.01	0.17
		Cup Black Smooth	0	0.14	0.04	0.38	0	0	0	0	0	0
	Cup-Likes (cups)	Cup Brown Irregular	0.01	0.19	0.04	0.38	0	0	0	0	0.01	0.17
		Cup Yellow	0.11	1.17	0.36	2.77	0.08	0.71	0	0	0.07	0.67
	Cup-Likes (Incomplete Cup / Curled Fan)	Fan Pink	0	0.14	0	0	0	0	0	0	0.01	0.17
	Cup-Likes (Incomplete Cup / Curled Fan)	Fan Orange Frilly	0	0.14	0.04	0.38	0	0	0	0	0	0
	Cup-Likes (tubes and chimneys)	Chimney Grey Single	0.1	1.01	0.5	2.41	0.03	0.32	0	0	0.05	0.6
		Tubular Solitary	0	0.14	0	0	0	0	0	0	0.01	0.17
Porifera		Tubes Beige Prostrate	0.01	0.23	0.07	0.53	0	0	0	0	0.01	0.17
		Tube Beige Irregular	0	0.14	0.04	0.38	0	0	0	0	0	0
		Chimney White Round	0.02	0.36	0.18	0.99	0	0	0	0	0	0
		Tubular Apricot Community	0.02	0.27	0.07	0.53	0.03	0.32	0	0	0.01	0.17
	Erect forms (branching)	Arborescent Orange	0.01	0.19	0.07	0.53	0	0	0	0	0	0

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Arborescent Orange / Brown Fingers	0.02	0.3	0.18	0.83	0	0	0	0	0	0
		Arborescent Orange Thin	0.06	0.65	0.21	1.3	0	0	0	0	0.05	0.55
		Arborescent Purple	0.12	1.12	0.68	2.73	0.08	0.55	0	0	0.04	0.55
		Arborescent Purple Thin	0.06	0.7	0.39	1.86	0	0	0	0	0.01	0.24
		Arborescent Tan	0.03	0.45	0.11	0.84	0.03	0.32	0	0	0.02	0.37
		Arborescent Yellow	0	0.14	0	0	0	0	0	0	0.01	0.17
		Branching Beige Frilly	0.01	0.3	0.11	0.84	0	0	0	0	0	0
		Branching Beige Spindles	0.01	0.27	0	0	0	0	0	0	0.01	0.33
Porifera		Branching Beige Stumpy	0.02	0.36	0.14	0.92	0	0	0	0	0.01	0.17
		Branching Black Fingers	0.02	0.27	0.07	0.53	0.03	0.32	0	0	0.01	0.17
		Branching Brown 4	0.01	0.19	0.07	0.53	0	0	0	0	0	0
		Branching Cream	0.02	0.41	0.04	0.38	0	0	0	0	0.03	0.47
		Branching Grey Repent Like	0.01	0.19	0	0	0	0	0	0	0.01	0.24
		Branching Grey Stumpy	0.02	0.33	0.04	0.38	0.08	0.71	0	0	0	0

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Branching Grey Thorny	0	0.14	0.04	0.38	0	0	0	0	0	0
		Branching Orange	0.01	0.19	0.07	0.53	0	0	0	0	0	0
	Erect forms (branching)	Branching Orange Frilly	0	0.14	0	0	0.03	0.32	0	0	0	0
		Branching Orange Long Fine	0.01	0.23	0.07	0.53	0	0	0	0	0.01	0.17
		Branching Orange Lumpy	0.02	0.36	0.11	0.84	0.03	0.32	0	0	0.01	0.17
		Branching Orange Prostrate	0.03	0.4	0.18	0.99	0.03	0.32	0	0	0.01	0.17
		Branching Purple	0.01	0.19	0.04	0.38	0	0	0	0	0.01	0.17
Porifera		Branching Purple Ramose Like	0	0.14	0.04	0.38	0	0	0	0	0	0
		Branching White Thorny Lumps	0.06	0.78	0.43	2.1	0	0	0	0	0.01	0.17
		Fan Brown	0	0.14	0.04	0.38	0	0	0	0	0	0
		Tubular Pink Small Oscules	0	0.14	0	0	0	0	0	0	0.01	0.17
		Yellow French Fries	0	0.14	0.04	0.38	0	0	0	0	0	0
	Erect forms (laminar)	Fan Peach Thick	0	0.14	0.04	0.38	0	0	0	0	0	0
		Fan Orange Flat	0	0.14	0.04	0.38	0	0	0	0	0	0

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Fan Orange Thorny	0.02	0.3	0.11	0.65	0	0	0	0	0.01	0.24
		Fan Orange Thick	0.03	0.43	0.07	0.53	0.05	0.64	0	0	0.01	0.33
		Fan Yellow	0	0.14	0	0	0	0	0	0	0.01	0.17
		Laminar White Small	0	0.14	0.04	0.38	0	0	0	0	0	0
		Fan White Thick	0	0.14	0.04	0.38	0	0	0	0	0	0
		Laminar Grey Fungi	0	0.14	0	0	0	0	0	0	0.01	0.17
		Fan Brown Thin	0	0.14	0.04	0.38	0	0	0	0	0	0
Porifera		Fan Light Pink Lumpy	0	0.14	0	0	0	0	0	0	0.01	0.17
		Fan Orange	0.02	0.43	0.11	1.13	0	0	0	0	0.01	0.17
		Fan Thick Large Oscules	0.03	0.59	0.07	0.53	0	0	0	0	0.04	0.69
		Fan White Thin	0.01	0.3	0.04	0.38	0	0	0	0	0.01	0.33
		Laminar Apricot Stalked	0.02	0.33	0.04	0.38	0.08	0.71	0	0	0	0
		Laminar Orange Irregular	0.01	0.19	0.04	0.38	0.03	0.32	0	0	0	0
		Laminar White Irregular	0	0.14	0	0	0.03	0.32	0	0	0	0
	Erect forms (palmate)	Palmate Orange Flat	0.01	0.23	0	0	0	0	0	0	0.02	0.29
	Erect forms (palmate)	Orange Flat Pronghorn	0.02	0.36	0.14	0.92	0	0	0	0	0.01	0.17

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Arborescent Orange Fan	0.02	0.33	0.07	0.76	0.03	0.32	0	0	0.01	0.17
		Palmate Beige Flat	0.02	0.33	0.11	0.84	0	0	0	0	0.01	0.17
		Palmate Grey Fingers	0.01	0.23	0.07	0.53	0	0	0	0	0.01	0.17
		Simple Erect Pink	0.02	0.49	0.11	1.13	0	0	0	0	0.01	0.33
Porifera	Massive forms (balls)	Ball Yellow Papillate Irregular	0.01	0.19	0.07	0.53	0	0	0	0	0	0
		Ball Pink Oscula	0.02	0.43	0.14	1.19	0	0	0	0	0	0
		Papillate Black Ball	0	0.14	0	0	0.03	0.32	0	0	0	0
		Globular Grey	0.02	0.27	0.07	0.53	0	0	0	0	0.01	0.24
		Globular Orange Tethya Like	0	0.14	0	0	0	0	0	0	0.01	0.17
		Globular White Tethya Like	0	0.14	0	0	0	0	0	0	0.01	0.17
	Massive forms (cryptic)	Cryptic Purple Brain	0.01	0.19	0.04	0.38	0	0	0	0	0.01	0.17
		Cryptic Spiky White Massive	0.02	0.27	0.11	0.65	0.03	0.32	0	0	0	0
	Massive forms (simple)	Simple Beige Small	0.04	0.4	0.18	0.83	0	0	0	0	0.03	0.33
		Simple Beige	0	0.14	0	0	0	0	0	0	0.01	0.17

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Irregular Oscula										
		Simple Orange Globes	0.02	0.3	0.04	0.38	0.05	0.45	0	0	0.01	0.24
Porifera		Simple Beige Shapeless	0.02	0.43	0.11	1.13	0.03	0.32	0	0	0	0
		Massive Yellow Irregular Ball	0	0.14	0	0	0	0	0	0	0.01	0.17
		Massive Beige Shapeless	0.01	0.23	0.07	0.53	0	0	0	0	0.01	0.17
		Simple Beige Small Oscula	0.05	0.52	0.14	0.75	0.1	0.78	0	0	0.02	0.37
		Massive Peach Shapeless Oscula	0.01	0.23	0.07	0.53	0.03	0.32	0	0	0	0
		Lumpy Orange	0.01	0.19	0.04	0.38	0	0	0	0	0.01	0.17
		Massive White Shapeless	0	0.14	0	0	0	0	0	0	0.01	0.17
		Simple Orange Smooth	0.06	0.52	0.29	1.03	0	0	0	0	0.04	0.44
		Massive Yellow Papillate	0.05	0.66	0.18	1.25	0.05	0.64	0	0	0.02	0.5
		Yellow Shapeless Smooth	0.01	0.23	0	0	0.03	0.32	0	0	0.01	0.24

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Bronze Bumpy Oscula Massive Laminar like	0	0.14	0	0	0.03	0.32	0	0	0	0
	Massive forms (simple)	Massive Blue Lumpy	0.01	0.3	0.11	0.84	0	0	0	0	0	0
		Massive Dark Purple	0.03	0.44	0.14	1.03	0	0	0	0	0.01	0.24
		Massive Purple	0.01	0.19	0.07	0.53	0	0	0	0	0	0
		Simple Beige Laminar Like	0.07	0.62	0.07	0.53	0.08	0.55	0	0	0.07	0.67
		Simple Grey Doughnut	0	0.14	0	0	0	0	0	0	0.01	0.17
		Massive Beige Nodular	0.01	0.41	0	0	0.08	0.96	0	0	0	0
		Massive Pink	0.04	0.72	0.04	0.38	0	0	0	0	0.05	0.87
		Simple Red Globes	0.01	0.19	0	0	0.03	0.32	0	0	0.01	0.17
		Simple Yellow Lumpy	0	0.14	0.04	0.38	0	0	0	0	0	0
		Lumpy Yellow	0.03	0.36	0.18	0.83	0	0	0	0	0.01	0.24
		Massive Black Oscula Papillate	0.03	0.57	0.21	1.6	0	0	0	0	0	0
		Massive Grey Laminar Like	0.02	0.44	0.07	0.76	0.03	0.32	0	0	0.01	0.17

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Massive Orange	0.01	0.23	0.04	0.38	0	0	0	0	0.01	0.24
		Massive Orange Ribbon	0	0.14	0.04	0.38	0	0	0	0	0	0
		Massive Red	0	0.14	0	0	0	0	0	0	0.01	0.17
		Massive Yellow Shapeless	0.03	0.69	0.21	1.92	0	0	0	0	0	0
		Simple Beige Lumpy	0.01	0.19	0.04	0.38	0	0	0	0	0.01	0.17
		Simple Pink Irregular	0.03	0.36	0.11	0.65	0.08	0.55	0	0	0.01	0.17
		Simple Purple Shapeless	0	0.14	0.04	0.38	0	0	0	0	0	0
		Yellow Oscula Laminar like	0	0.14	0.04	0.38	0	0	0	0	0	0
		Massive Black Oscula Papillate	0.04	0.45	0.11	0.65	0.05	0.45	0	0	0.03	0.41
		Massive White Holey	0.01	0.23	0.11	0.65	0	0	0	0	0	0
		Massive White Papillate	0.01	0.27	0.07	0.76	0	0	0	0	0	0
		Orange Massive Ball	0.01	0.41	0.11	1.13	0	0	0	0	0	0
		Simple Beige Lumpy Shapeless	0.02	0.36	0.11	0.84	0	0	0	0	0.01	0.24
		Simple Blue Shapeless	0	0.14	0.04	0.38	0	0	0	0	0	0

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
Porifera	Massive forms (simple)	Simple Red Ball Like	0.01	0.3	0	0	0.03	0.32	0	0	0.01	0.33
		Smooth Black Massive	0.01	0.41	0.11	1.13	0	0	0	0	0	0
		Lumpy White	0.01	0.19	0.04	0.38	0	0	0	0	0.01	0.17
		Massive Blue	0	0.14	0.04	0.38	0	0	0	0	0	0
		Massive Blue Shapeless	0	0.14	0	0	0	0	0	0	0.01	0.17
		Massive Dark Purple	0.01	0.23	0.11	0.65	0	0	0	0	0	0
		Laminar Black	0	0.14	0.04	0.38	0	0	0	0	0	0
		Massive Purple Chunks	0.02	0.33	0.11	0.84	0	0	0	0	0.01	0.17
		Massive Red White Shapeless	0.02	0.45	0.14	1.19	0	0	0	0	0.01	0.17
		Massive White Lumpy	0.03	0.4	0.11	0.84	0.05	0.45	0	0	0.01	0.24
		Massive Yellow Holey	0.03	0.45	0.14	0.92	0.08	0.71	0	0	0	0
		Purple Massive	0	0.14	0	0	0	0	0	0	0.01	0.17
		Simple Beige Honeycomb	0	0.14	0	0	0.03	0.32	0	0	0	0
		Simple Beige Smooth	0.1	0.71	0.25	1.11	0.08	0.55	0	0	0.08	0.66

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Simple Blue Shapeless Oscula	0.02	0.36	0.04	0.38	0.1	0.78	0	0	0	0
		Simple Grey Creep	0.01	0.19	0.04	0.38	0.03	0.32	0	0	0	0
		Simple Pink Oscula	0.01	0.41	0.11	1.13	0	0	0	0	0	0
		Simple White Rough	0	0.14	0.04	0.38	0	0	0	0	0	0
		Smooth Grey Globes	0.02	0.33	0.11	0.84	0	0	0	0	0.01	0.17
Matrix	Bryozoa / Cnidaria Matrix		0.01	0.19	0.04	0.38	0.03	0.32	0	0	0	0
	Bryozoa / Cnidaria/ Encrusting Sponge Matrix		0	0.14	0	0	0.03	0.32	0	0	0	0
	Bryozoa / Cnidaria / Sponge Matrix		0	0.14	0	0	0	0	0.01	0	0	0.17
	Bryozoa / Cnidaria / Creeping / Ramose Sponge Matrix		0.01	0.19	0.04	0.38	0	0	0.01	0	0	0.17
Substrata	Unconsolid-ated (Sand / Mud (<2mm))	Coarse Sand (With Shell Fragments)	65.33	26.37	41.5	23.48	45.49	27.47	44.8	19.83	76.68	18.84

			Overall		Low profile (<1m) reef		Shellhash/ Bryozoa/ Porifera Rubble		Screw-shell		Coarse sand (<2mm) with shell fragments	
Family	**Growth form**	**Morpho-species**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**	**Mean % cover**	**SD % cover**
		Fine Sand (No Shell Fragments)	0.01	0.19	0.04	0.38	0	0	0	0	0.01	0.17
	Unconsolid-ated (Pebble / Gravel)	Pebble (10-64Mm)	0.01	0.19	0	0	0	0	0	0	0.01	0.24
	Unconsolid-ated (Pebble / Gravel-biologenic)	Coquina / Shell hash	11.74	17.34	6.54	12.29	30.9	24.2	3.54	8.05	8.04	12.02
Substrata	Unconsolid-ated (Pebble / Gravel-biologenic)	Screw shells	4.36	13.72	0.71	4.78	2.92	12.07	48.57	23.19	2.76	9.29
Substrata	Consolidated (Hard- Rock)		0.02	0.27	0.04	0.38	0.03	0.32	0	0	0.01	0.24
	Consolidated (Hard-Cobbles)		0.01	0.19	0.04	0.38	0.03	0.32	0	0	0	0
Bio-turbation	Dwelling traces		0.04	1.22	0.32	3.4	0	0	0	0	0	0

APPENDIX D – RELATIVE ABUNDANCE OF DEMERSAL FISHES (BRUVS)

Summary of relative abundance of demersal fishes recorded in stereo BRUV imagery by habitat type. Number of deployments are provided in parenthesis in header.

			AMP (79)				AMP Total	Reference (44)				Reference Total	Grand Total
Family	Scientific	Common name	Low profile (<1m) reef (21)	Shellhash/Bryozoa /Porifera Rubble (23)	Screwshells (8)	Coarse sand (<2mm) with shell fragments (27)		Low profile (<1m) reef (6)	Shellhash/Bryozoa /Porifera Rubble (19)	Screwshells (6)	Coarse sand (<2mm) with shell fragments (13)		
Bony fishes													
Aulopidae	*Latropiscis purpurissatus*	Sergeant baker	6	7	1	3	17	4	2			6	23
Callanthiidae	*Callanthias australis*	Splendid perch	1				1						1
Cheilodactylidae	*Cheilodactylus nigripes*	Magpie perch	9				9		2			2	11
	Nemadactylus macropterus	Jackass morwong	261	55	23	12	351	16	2		51	69	420
	Nemadactylus valenciennesi	Blue morwong	1				1						1
Cyttidae	*Cyttus australis*	Silver dory		5		4	9		1	1		2	11
Diodontidae	*Diodon nicthemerus*	Globefish		1			1		1			1	2
Enoplosidae	*Enoplosus armatus*	Old wife	2				2						2
		Unknown fish							1			1	1
Gerreidae	*Parequula melbournensis*	Melbourne silverbelly	163	127	50	63	403	83	45	61	14	203	606

			AMP (79)				AMP Total	Reference (44)				Reference Total	Grand Total
Family	Scientific	Common name	Low profile (<1m) reef (21)	Shellhash/Bryozoa /Porifera Rubble (23)	Screwshells (8)	Coarse sand (<2mm) with shell fragments (27)		Low profile (<1m) reef (6)	Shellhash/Bryozoa /Porifera Rubble (19)	Screwshells (6)	Coarse sand (<2mm) with shell fragments (13)		
Labridae	*Eupetrichthys angustipes*	Snakeskin wrasse						10	1			11	11
	Notolabrus tetricus	Bluethroat wrasse	32	1			33	2	1			3	36
	Ophthalmolepis lineolata	Maori wrasse	5				5						5
	Pseudolabrus rubicundus	Rosy wrasse	269	26	5	4	304	166	17		5	188	492
Monacanthidae	*Acanthaluteres vittiger*	Toothbrush leatherjacket	7				7	2				2	9
	Eubalichthys gunnii	Gunns leatherjacket	3				3						3
	Eubalichthys mosaicus	Mosaic leatherjacket	1				1	2				2	3
	Meuschenia freycineti	Sixspine leatherjacket	24	8			32	1				1	33
	Meuschenia scaber	Cosmopolitan leatherjacket	134	52	4	22	212	69	19		1	89	301
	Meuschenia venusta	Stars and stripes leatherjacket		1			1	1				1	2
		Unidentifiable leatherjacket							1			1	1
	Nelusetta ayraud	Ocean leatherjacket	1				1						1
	Thamnaconus degeni	Degen's leatherjacket	642	3862	1787	5181	11472	277	2239	892	85	3493	14965

			AMP (79)				AMP Total	Reference (44)				Reference Total	Grand Total
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Moridae	*Lotella rhacina*	Largetooth beardie	2				2						2
	Pseudophycis bachus	Red cod	3	41	6	35	85						85
	Pseudophycis barbata	Bearded rock cod	13				13						13
Mullidae	*Upeneichthys vlamingii*	Southern goatfish	23	19	3	10	55	30	20	1		51	106
Muraenidae	*Gymnothorax prasinus*	Green moray	1				1		1			1	2
Neosebastidae	*Neosebastes scorpaenoides*	Common gurnard perch	156	223	82	144	605	96	52	26	20	194	799
Ostraciidae	*Aracana aurita*	Shaw's cowfish	1				1	2	1		1	4	5
Pempherididae	*Pempheris multiradiata*	Common bullseye	3				3						3
Pentacerotidae	*Pentaceropsis recurvirostris*	Long snouted boarfish							1			1	1
Pinguipedidae	*Parapercis allporti*	Bared grubfish		11		10	21	1	3	3		7	28
Platycephalidae	*Platycephalus aurimaculatus*	Toothy flathead	2	2		8	12	1	3	3		7	19
	Platycephalus bassensis	Sand flathead	38	43	14	83	178	6	58	49	16	129	307
	Platycephalus sp	Flathead	1				1						1
Sebastidae	*Helicolenus percoides*	Ocean reef perch	4			2	6						6

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Serranidae	*Caesioperca lepidoptera*	Butterfly perch	1660	19	3		1682	213	136		5	354	2036
	Caesioperca rasor	Barber perch	853	121	5	41	1020	1775	36	2	6	1819	2839
	Hypoplectrodes nigroruber	Banded seaperch						1				1	1
Sparidae	*Chrysohrys auratus*	Pink snapper	2	1			3						3
Syngnathidae	*Solegnathus spinosissimus*	Spiny pipehorse				1	1						1
Tetraodontidae	*Omegophora armilla*	Ringed toadfish	1				1			1		1	2
Triglidae	*Chelidonichthys kumu*	Bluefin gurnard		1	1	2	4			1		1	5
	Lepidotrigla papilio	Spiny gurnard		2			2						2
	Lepidotrigla sp	Gurnard		1		1	2			1		1	3
	Lepidotrigla vanessa	Butterfly gurnard			1	4	5						5
Zeidae	*Zeus faber*	John dory		2	2	3	7						7
Sharks and rays													
Squalidae	*Squalus megalops*	Spikey dogfish				1	1						1
Triakidae	*Mustelus antarcticus*	Gummy shark		2	2	8	12						12

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Heterodontidae	*Heterodontus portusjacksoni*	Port Jackson shark	9	12		5	26		1			1	27
Hexanchidae	*Notorynchus cepedianus*	Sevengill shark	4	3		2	9	2				2	11
Rajidae	*Dentiraja lemprieri*	Thornback skate		3	1	2	6						6
	Spiniraja whitleyi	Melbourne skate	1	2	3	2	8	1		1		2	10
Rhinobatidae	*Trygonorrhina dumerilii*	Southern fiddler ray		1	1		2		1			1	3
	Trygonorrhina fasciata	Eastern fiddler ray		1			1						1
	Trygonorrhina sp	Fiddler ray								1		1	1
Scyliorhinidae	*Asymbolus rubiginosus*	Orange spotted catshark	3	17	6	17	43		8	2		10	53
	Cephaloscyllium laticeps	Draught board shark	43	50	23	51	167	9	12	8	3	32	199
Urolophidae	*Trygonoptera testacea*	Common stingaree	1				1						1
	Urolophus cruciatus	Crossback stingaree	1	1			2						2
Urolophidae/ Plesiobatidae		Unidentifiable skate								1		1	1

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