Marine Biodiversity Hub

National Environmental Science Programme

Elizabeth and Middleton Reefs, Lord Howe Marine Park, Post Survey Report

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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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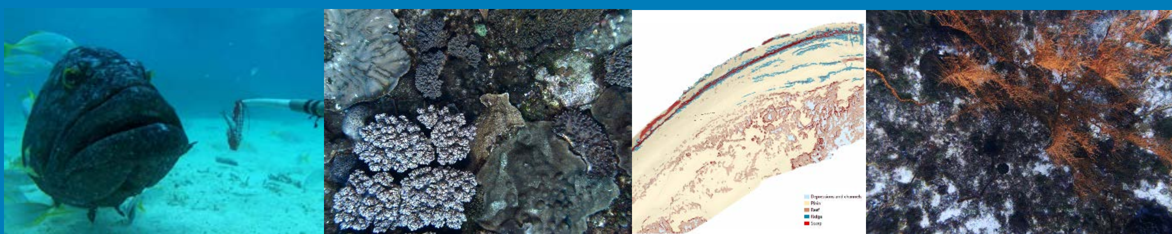

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Important Disclaimer

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EXECUTIVE SUMMARY

This report presents preliminary results of a collaborative seabed mapping and baseline environmental survey (GA4848) of Elizabeth and Middleton Reefs, located within the Lord Howe Marine Park (Temperate East Network). Data acquisition was undertaken in February 2020 by Geoscience Australia, the Institute for Marine and Antarctic Studies (University of Tasmania), the Australian Centre for Field Robotics (University of Sydney) through their involvement with the Integrated Marine Observing System (IMOS), NSW Department of Primary Industries and Parks Australia; 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.*

Elizabeth and Middleton Reefs are isolated oceanic platform reefs located ~550 km east of the Australian continental margin and 150 and 200 km north of Lord Howe Island, respectively. They are unique because they are the southern-most platform reefs in the world and host a diverse range of tropical, sub-tropical and temperate marine species. To date, much of the ecological research at Elizabeth and Middleton Reefs has focused on underwater visual census of reef fishes, macroinvertebrates and sessile biota in depths less than 20 m. These comprehensive biodiversity surveys (undertaken primarily by Reef Life Survey, James Cook University and the Australian Institute of Marine Science) have provided fundamental baseline and time-series datasets from which changes in species assemblages of the inner shelf, and selected lagoon environments can be monitored. However, information on habitat characteristics at Elizabeth and Middleton Reefs beyond these shallow regions is limited, particularly for the deeper shelf areas outside the lagoons. As ocean temperatures continue to increase, a pressing global challenge is to increase our understanding of the spatial distribution and characteristics of the critical habitats that support mesophotic reefs and associated demersal fish assemblages.

In this survey, we applied a suite of sampling methods and integrated national best practice procedures to map and characterise the shallow and mesophotic shelf environments of Elizabeth and Middleton Reefs. Our aim was to fill knowledge gaps on the distribution, extent and structure of seabed habitats and associated sessile and mobile fauna in shallow and mesophotic shelf areas of each reef. Survey activities included seabed mapping using multibeam sonar, seabed imagery acquisition by Autonomous Underwater Vehicles (AUV *Sirius* and AUV *Nimbus*), acquisition of imagery of demersal fish by stereo-baited remote underwater videos (stereo-BRUVs) and sediment grab sampling. Weather conditions associated with ex-tropical cyclone *Uesi* curtailed both seabed mapping and the number of sampling stations completed, with greater coverage and more deployments undertaken at Middleton Reef than Elizabeth Reef.

Our results revealed a complex seafloor on the shelf platform of each reef, characterised by mounds, ridges, planes and depressions. Ridges, mounds and planes observed on the inner shelf (20–50 m depth) were dominated by turfing macroalgae, cnidarian corals (hard reef-building corals and soft leather corals) and bacterial mats. Whereas planes and ridges on the outer shelf (70–110 m) were dominated by black corals (branching and whip morphologies), interspersed among areas of coarse carbonate sand, turfing algae, hard corals, sponges and calcareous rhodoliths beds. A highly diverse epifaunal assemblage was recorded from AUV imagery, with 234 biological morphospecies identified. Hard corals dominated the

assemblage with 96 morphospecies, followed by sponges (59 morphospecies), black and octocorals (31 morphospecies) and macroalgae (28 morphospecies). Representatives from ascidians, bryozoans, hydroids, anemones, crinoids and worms were also recorded.

Demersal fish were abundant across lagoon, inner shelf and mesophotic shelf habitats, with ~6200 individual fish recorded by stereo-BRUVs. This sample was also diverse, comprising 195 species from 36 families (124 species from 30 families at Elizabeth Reef and 168 species from 32 families at Middleton Reef). Elizabeth and Middleton Reefs remain a stronghold for populations of predatory fish and listed threatened species, including mature black cod and tiger sharks, and immature Galapagos sharks.

This new information contributes to the growing temporal record of shallow marine fauna at Elizabeth and Middleton Reefs, and establishes a baseline for mesophotic benthic communities and associated demersal fish assemblages. Collectively, our results highlight the capability of applying AUVs and stereo-BRUVs to fill knowledge gaps for mesophotic seabed areas not readily accessible by divers, and the importance of adopting a nationally consistent and objective suite of sampling methods to facilitate ongoing comparability between temporally offset monitoring surveys.

The shelf environments of each seamount have now been mapped in fine spatial resolution and sampled to better characterise seabed geomorphic features and associated habitats. For Middleton Reef, this mapping was completed for the entire shelf. Elizabeth Reef shelf remains only partly mapped and sampled, due to the early termination of the survey.

A full list of recommendations for future research are provided in the summary of this report. Key recommendations include:

1) Completing seabed mapping and habitat characterisation at Elizabeth Reef to facilitate comparisons between management zones of the Lord Howe Marine Park.

2) Mapping and characterising deeper water habitats around each seamount reef to increase our understanding of the connectivity between shallow, mesophotic and deep benthic habitats.

3) Undertaking repeat sampling of benthic communities and demersal fish assemblages at each reef to examine changes in species assemblages through time, and inform assessments of the effectiveness of management plans.

1. INTRODUCTION

1.1 Background and rationale for the survey

The Elizabeth and Middleton Reefs marine survey was designed to build upon and establish baseline information for benthic habitats and associated demersal fish assemblages at Elizabeth and Middleton Reefs, located at the northern extent of the Lord Howe Marine Park. The specific aim of the survey was to fill knowledge gaps on the distribution, extent and structure of seabed habitats and associated sessile and mobile fauna in shallow and mesophotic shelf areas of Elizabeth (Recreational Use Zone) and Middleton (National Park Zone) Reefs, using a suite of national standard survey tools and best practise sampling procedures (Przeslawski et al. 2019). The new data acquired on this survey will provide an important baseline for mesophotic habitats at these reefs, and support ongoing biodiversity monitoring of shallow marine communities (e.g. Oxley et al. 2004, Choat et al. 2006, Pratchett et al. 2011, Hoey et al. 2014, Edgar et al. 2018, Hoey et al. 2018) as part of the 10-year management plan for the Temperate East Marine Park Network (2018–2028).

Comprehensive biodiversity inventories, combined with knowledge of species-habitat associations, is fundamentally important for marine conservation management, and for monitoring changes through time. Information on the spatial distribution of habitats and threatened and vulnerable species is also critical for structuring conservation planning and monitoring. Lord Howe Marine Park is significant as the fringing reef along the western shore of Lord Howe Island is the southernmost coral reef in the Tasman Sea. There is a clear transition of geological characteristics along the Lord Howe Seamount Chain from south to north, between Balls Pyramid (a single isolated volcanic remnant), Lord Howe Island (the rims and remains of an eroded volcanic island with fringing reef) and Elizabeth and Middleton Reefs (two atoll-like platform reefs). Shallow coral reefs at each of these locations are significant because of their geographic and genetic isolation from other reefs (e.g. Noreen et al. 2009, Noreen et al. 2015). These reefs are also important because they occur at environmental limits set by minimum water temperatures for coral growth (Veron et al. 1979, Harriott et al. 1995) and contain unique associations of tropical species at their southern latitudinal distribution limits, as well as subtropical and temperate species (Edgar et al. 2009).

While Elizabeth and Middleton Reefs are recognised within the regions Marine Bioregional Plan as a Key Ecological Feature (KEF) (i.e. a feature important for either the region's biodiversity or ecosystem function and integrity), the characteristics and spatial extent of geomorphic features on the shelf environments surrounding each reef remained unknown, and they had yet to be described from a geomorphic and ecological perspective. Our research aimed to address this knowledge gap by establishing a baseline against which future changes in the status of mesophotic benthic communities and associated demersal fish assemblages can be detected, assessed and monitored.

Global climate change is having a disproportional impact on coral reefs, with many reefs experiencing bleaching when sea-surface temperatures exceed seasonal maxima for prolonged periods (Hughes et al. 2017). It is less clear what the consequences of climate change are likely to be for reefs at sites that are more marginal or at mesophotic depths, particularly those at the latitudinal limits to reef formation. Rising sea temperatures are predicted to induce more frequent coral bleaching events in future, leading to potential range shifts in reef corals to higher-latitude regions (Greenstein and Pandolfi 2008). There is some evidence to suggest that poleward extension of some reef species has already occurred, perhaps as a response to warmer sea-surface temperatures associated with global warming (e.g. Baird et al. 2012, DeVantier and Turak 2017). However, recent episodes of severe coral bleaching at Lord Howe Island (Harrison et al. 2011, Dalton et al. 2020) demonstrate that even the highest latitude coral reef assemblages are also susceptible to significant bleaching disturbances, which may limit future reef development and predicted range shifts (Harrison et al. 2011, Muir et al. 2015). As shallow coral reefs continue to decline worldwide (Pandolfi et al. 2003, Hughes et al. 2018), the identification, mapping, and characterisation of potential reef refuges has become increasingly important (Cacciapaglia and van Woesik 2015, Weinstein et al. 2020).

Mesophotic coral ecosystems (MCEs) occur in ocean depths between ~30–150 m and attract rapidly growing research interest due to their unique biodiversity and potential as refuges for shallow coral reef taxa subject to thermal stress (Bridge et al. 2012, Beaman et al. 2016, Loya et al. 2016, Kavousi and Keppel 2018, Turner et al. 2019). Although submerged reefs in many regions likely support extensive MCEs, data on the location and extent of submerged reef habitat is generally lacking (Turner et al. 2017), and mesophotic ecosystems in Australia (e.g. Great Barrier Reef) remain largely understudied and underexplored (Eyal et al. 2021). This is particularly true for temperate, high-latitude mesophotic ecosystems (Linklater et al. 2019), which limits our ability to assess refuge potential by better understanding the link between mesophotic fish assemblages, habitat structure, benthic composition and connectivity with shallow reefs (e.g. Williams et al. 2019). The subtropical shelves of Balls Pyramid and Lord Howe Island support relatively diverse MCEs that have the potential to act as deep reef refugia under a changing climate (Linklater et al. 2019). In contrast, very little is known about the spatial extent of seabed features on the shelf environments surrounding Elizabeth and Middleton Reefs, and whether or not these habitats also support MCEs.

Here, we utilise high-resolution multibeam bathymetry, acoustic backscatter, underwater imagery (acquired by autonomous underwater vehicles and stereo baited remote underwater videos), and seabed sediment samples, to characterise shallow (< 30 m) and mesophotic (30 –120 m) benthic communities and demersal fish assemblages at Elizabeth and Middleton Reefs. This new information will augment existing biodiversity studies of shallow habitats and contribute to the ongoing management of the Lord Howe Marine Park by providing baseline information for mesophotic reefs, against which future changes can be assessed.

1.2 Australian Marine Park Context

Lord Howe Marine Park is one of eight Australian Marine Parks in the Temperate East Network, ranging from the State coastal waters limit off New South Wales and Queensland to Norfolk Island. (Director of National Parks, 2018) (Figure 1). The Temperate East Network covers 383,339 km^2 and includes a diverse range of tropical, subtropical and temperate marine species. Key Ecological Features include the Lord Howe and Tasmantid Seamount Chains, Norfolk Ridge, Shelf Rocky Reefs, Tasman Front and Eddy Field, and Canyons on the eastern continental slope (Director of National Parks, 2018). The Temperate East Marine Parks Network Management Plan covers the period between 2018 and 2028 and is the primary tool for conservation and management of marine parks in the temperate east region. It 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. Lord Howe Marine Park is assigned IUCN category IV and includes five zones: National Park Zone (II), Habitat Protection Zone (IV), Habitat Protection Zone (Lord Howe) (IV), Recreational Use Zone (IV) and Multiple Use Zone (VI) (Figure 2).

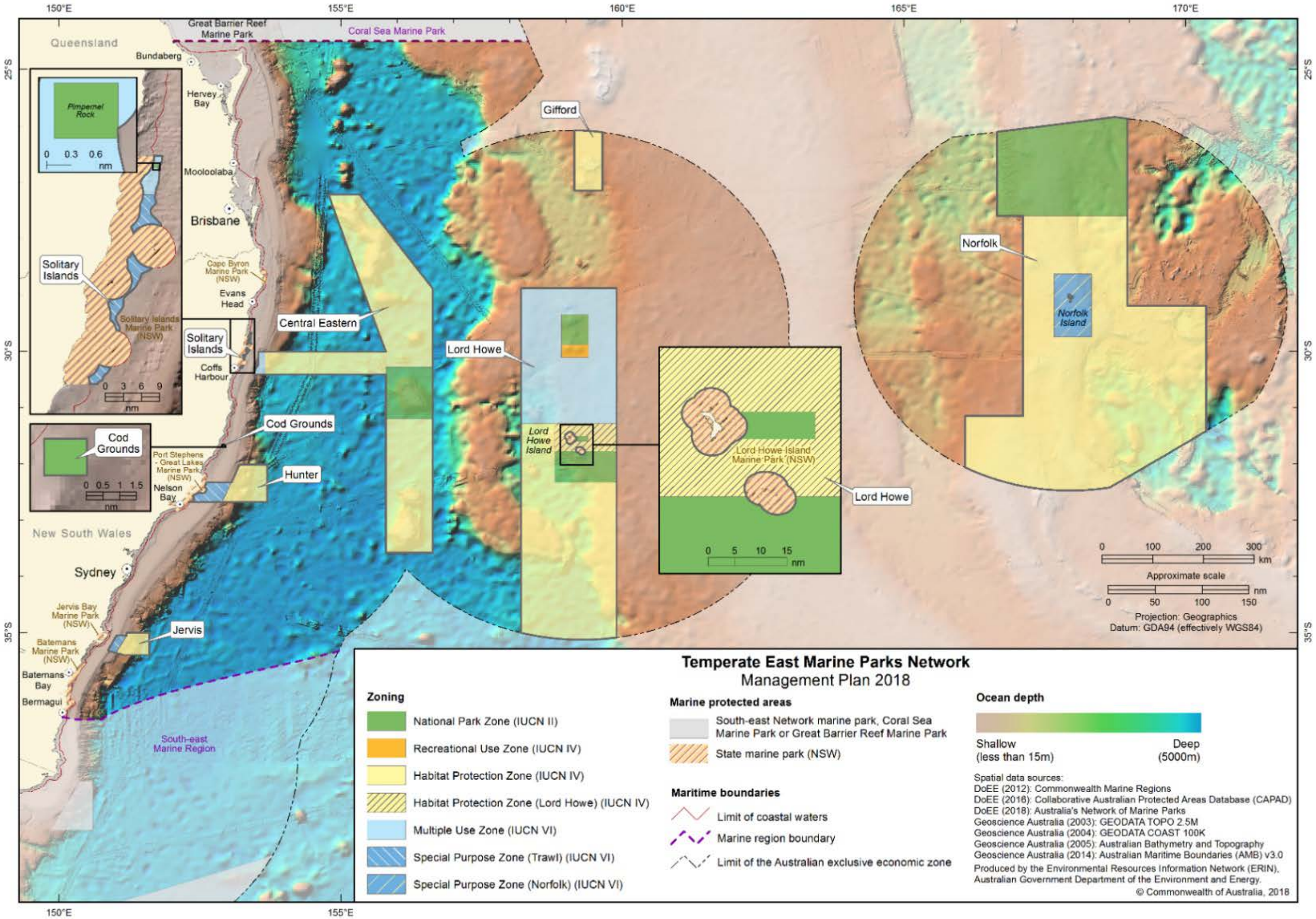


Figure 1. Temperate East Network of Australian Marine Parks, showing the location of Lord Howe Marine Park within the Tasman Sea (Source: Director of National Parks 2018).

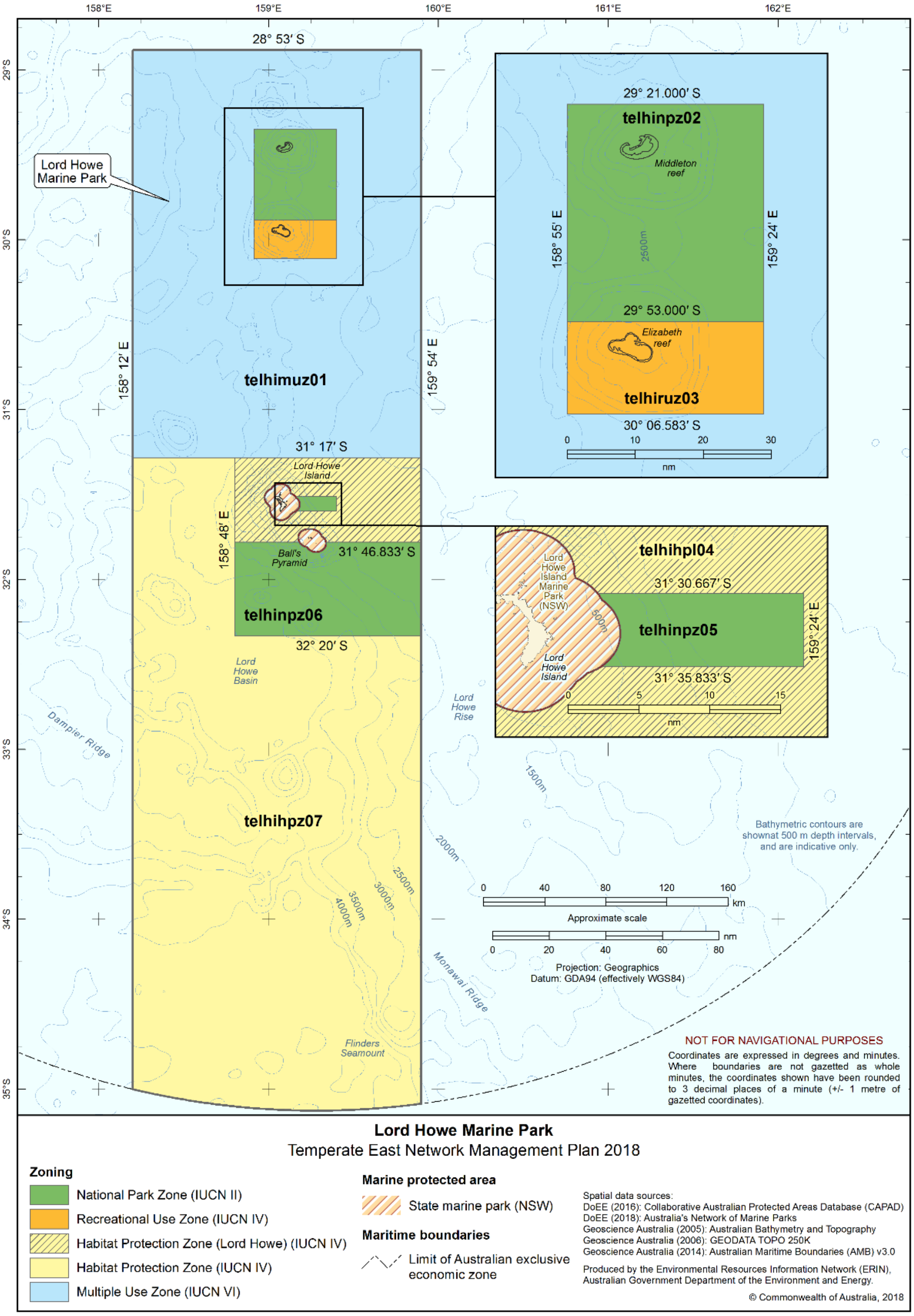


Figure 2. Lord Howe Marine Park showing the location of Elizabeth and Middleton Reefs and spatial extent of specific management zones (Source: Director of National Parks 2018).

1.2.1 Marine Park summary

Lord Howe Marine Park (Figure 2) is located approximately 550 km offshore of New South Wales (NSW), adjacent to the NSW Lord Howe Island Marine Park and World Heritage Area. It covers 110,126 km^2 and a depth range from the high tide mark to 6000 m. The Lord Howe Marine Park was proclaimed under the EPBC Act on 14 December 2013 and renamed Lord Howe Marine Park on 9 October 2017. It includes the areas of the Lord Howe Island Marine Park (Commonwealth Waters) originally proclaimed under the National Parks and Wildlife Conservation Act 1975 on 7 June 2000, and the Elizabeth and Middleton Reefs Marine National Nature Reserve, originally proclaimed under the National Parks and Wildlife Conservation Act 1975 on 11 December 1987.

Elizabeth and Middleton Reefs are located at the northern extent of the marine park, where each reef is assigned a different level of protection status under the management plan for the network (Director of National Parks, 2018). Middleton Reef is located within a National Park Zone (IUCN II) within which no extractive fishing activities are permitted within an area covering 2,767 km^2. Elizabeth Reef, ~45 km to the south, is within a Recreational Use Zone (IUCN IV) covering 1170 km^2 where recreational fishing is permitted (Figure 2). Prior to the proclamation of the marine park in 2013, the reefs were designated as a 'Wetland of International Importance' under the Ramsar Convention in 2002.

1.2.2 Key ecological features

The Lord Howe Marine Park includes three KEFs: the Lord Howe Seamount Chain, Elizabeth and Middleton Reefs, and the Tasman Front and eddy field, all of which are valued for their high productivity, aggregations of marine life, biodiversity and endemism (Director of National Parks 2018). While Elizabeth and Middleton Reefs are recognised as KEFs, prior to this NESP Marine Biodiversity Hub survey the true spatial extent of mesophotic habitats was unknown and remained to be described from a biodiversity and ecological perspective.

1.2.3 Biologically important areas

The Temperate East Network supports important habitats, including biologically important areas, for a range of protected species. 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. Biologically important areas within the Lord Howe Marine Park include breeding and foraging habitat for seabirds, and a migratory pathway for humpback whales (*Megaptera novaeangliae*) between their feeding and breeding areas (Director of National Parks 2018). More information on protected species and biologically important areas can be found in the Marine bioregional plan for the Temperate East Marine Region (2012) and the conservation values atlas on the Department's website.

1.3 Survey Area

1.3.1 Location and site description

Elizabeth Reef (29°56'S; 159°05'E) and Middleton Reef (29°27'S; 159°07'E) are two Holocene age atoll-like reef structures that occur on top of the volcanic seamounts of the Lord Howe Seamount Chain. Seamounts in this chain formed during the Miocene epoch (23–5 Million Years ago) from submarine volcanism as the Indo-Australian plate migrated north across a stationary magma source (“hotspot”), with the Elizabeth and Middleton reef seamounts active during 11–8 million years ago (Woodroffe et al. 2004a, Mortimer et al. 2018, Seton et al. 2019). There is evidence for reef development during the Late Pleistocene epoch (<120 ka), with limestone recovered at 8 m depth by a drilling campaign in 1980 that sampled the Middleton Reef rim (Woodroffe et al. 2004).

Modern coral reef growth was established by at least 6,700 years ago following the post-glacial rise in sea level that fully inundated the seamount summits. Prior to this, the seamount summits would have been partly exposed above sea level to the position of the modern shelf break at ~120 m. Coral reef development was relatively rapid, with the modern reef rim that encloses each lagoon formed by about 5,000 years ago (Woodroffe et al. 2004). Today, the two reefs are of similar size, with Middleton Reef 9.3 km long and 5.7 km wide and Elizabeth Reef 10.7 km by 6.2 km. The lagoons of Elizabeth and Middleton Reefs are characterised by a complex seabed of coral ridges, sand flats, hard pavements, channels, depressions, and spur-and-groove features. Sediments within the lagoons are dominated by medium-coarse gravelly sand (Kennedy and Woodroffe 2004). The sediments are distinctly carbonate, with the bulk sand composition dominated by coral and coralline red algae, as well as a notable proportion of *Halimeda* green algae (Woodroffe et al. 2004).

These emergent reef systems are unique because they are the two southernmost platform reefs in the world, and support a diverse assemblage of tropical, subtropical, and temperate marine species, many of which are at the geographic extent of their range. The remoteness and transition between habitats make these reefs endemism hotspots for reef-building coral, fish and other marine organisms. Over 300 species of fish have been recorded at the reefs, including the regional endemic doubleheader wrasse *Coris bulbifrons*, and the lagoons of both reefs are significant global strongholds for the Vulnerable black cod, *Epinephelus daemelii*, and the Galapagos shark, *Carcharhinus galapagensis* (Hoey et al. 2018).

1.3.2 Oceanography and climate

Surface ocean circulation around Elizabeth and Middleton Reefs is influenced by the East Australian Current (EAC); a highly dynamic western boundary current system of the South Pacific subtropical gyre. The EAC is a baroclinic jet that forms between 10ºS and 20ºS, where the South Equatorial Current bifurcates against the Australian coast (Archer et al. 2017). It flows poleward transporting relatively warm and nutrient-depleted subtropical water from the Coral Sea along Australia’s east coast. The current separates from the continent between 30ºS and 34ºS, to form the “Tasman Front”, an eastern extension of the EAC (Ceccarelli et al. 2013, Cetina-Heredia et al. 2014, Oke et al. 2019). With this origin, the EAC brings to Elizabeth and Middleton Reefs warmer waters and the larvae of tropical species. Like many western boundary currents, the EAC extension is projected to continue warming and strengthening under climate change, which may potentially lead to significant changes in larval supply and physical environmental conditions at these remote oceanic seamount reefs.

The winds around the Elizabeth and Middleton Reefs blow, on average, at ~10 knots. Based on climate data from Lord Howe Island, south-westerly winds dominate in spring and winter, while easterly and south-easterly winds dominate in summer. Consequently, summer upwelling off the southern edge of the reefs is likely to occur, according to the classic Ekman transport theory. Wave energy is moderate, with a mean significant wave height of 2-2.5 m on a mean tidal range of 2.6 m. However, ex-tropical cyclones pass through the area, generating potentially destructive wind and wave conditions for shallow reef communities. In the last 50 years, seven cyclones have crossed Lord Howe Marine Park, the most recent of which was ex-Tropical Cyclone Uesi in February, 2020, leading to the early termination of this survey.

Satellite (MODIS) Sea Surface Temperature (SST) and Chlorophyll-a data were sourced from the Integrated Marine Observing System (IMOS; http://imos.org.au/) to analyse the SST and surface Chlorophyll-a characteristics of the Lord Howe Marine Park. Analysis of MODIS SST showed a clear seasonal pattern (Figure 3a). The highest SST occurs in February with a monthly mean of 24.6°C, while the lowest SST occurs in August with a monthly mean of 19.5°C. There is notable inter-annual variation in SST, without a clear warming trend. Over the last 16 years (2003 to 2018 inclusive), the highest annual mean SST (~ 22.4°C) occurred in 2004, 2010 and 2016, while the lowest annual mean SST (~ 21.3°C) occurred in 2008. The long-term average SST varies little spatially within the marine park (22.11±0.05°C).

Lord Howe Marine Park is located within an oligotrophic (nutrient poor) oceanic environment. Analysis of surface Chlorophyll-a concentrations shows a clear seasonal pattern (Figure 3b). The highest surface Chlorophyll-a concentrations occur in the austral winter and early autumn (June to September), with monthly means of 0.25-0.27 mg/m^3, while summer concentrations are as low as 0.07-0.1 mg/m^3. The inter-annual variation of the surface Chlorophyll-a concentrations over the period 2003 to 2018 are relatively small, without any clear trend (Figure 3b). However, there is a clear spatial pattern in the long-term mean Chlorophyll-a concentrations across Elizabeth and Middleton reefs and surrounding waters. The relatively high surface Chlorophyll-a concentrations occur around the Elizabeth and Middleton Reefs, with concentrations up to 0.3 mg/m^3; while most of the deeper waters have relatively low surface Chlorophyll-a concentrations of ~0.15 mg/m^3.

The waters surrounding Elizabeth and Middleton Reefs have been impacted by several marine heatwaves (MHWs) (Table 1). Analysis of daily MODIS SST data between 2002 and 2019 identified several MHWs occurring across four summer periods: 2009–10, 2010–11, 2016–17 and 2017–18 (Table 1). During the consecutive summers of 2016–17 and 2017–18, the MHWs lasted between a quarter and a third of the season. Using the daily Himawari-8 SST data, which has higher spatial coverage than daily MODIS SST data and SSTAARS climatology (Wijffels et al. 2018), we were able to examine the spatial patterns of the MHWs in these two summers in more detail (Figure 4). According to the Himwari-8 SST data, during the summers of 2016–17 and 2017–18, the marine park was affected by MHWs for a mean duration of 59±8 and 55±5 days, respectively (Figure 5). Shallow-water corals are most at risk of bleaching during summer seasons if exposed to prolonged and intense MHWs. Fortunately, most of the MHWs identified in these two summers were classified as "moderate" according to the definition of Hobday et al. (2018). Indeed, severe coral bleaching of some coral species was recorded within the lagoon at Elizabeth Reef, but not at Middleton Reef, when surveyed in February 2018 (Hoey et al. 2018), which is consistent with the spatial variability of the MHWs duration (Figure 4b). Overall, very little is known about the extent and severity of previous bleaching events at these remote reefs. However, they are likely to be particularly vulnerable to thermal stress and other acute disturbances, given their low rates of population replenishment, which are likely to greatly constrain recovery (see Hoey et al. 2018).

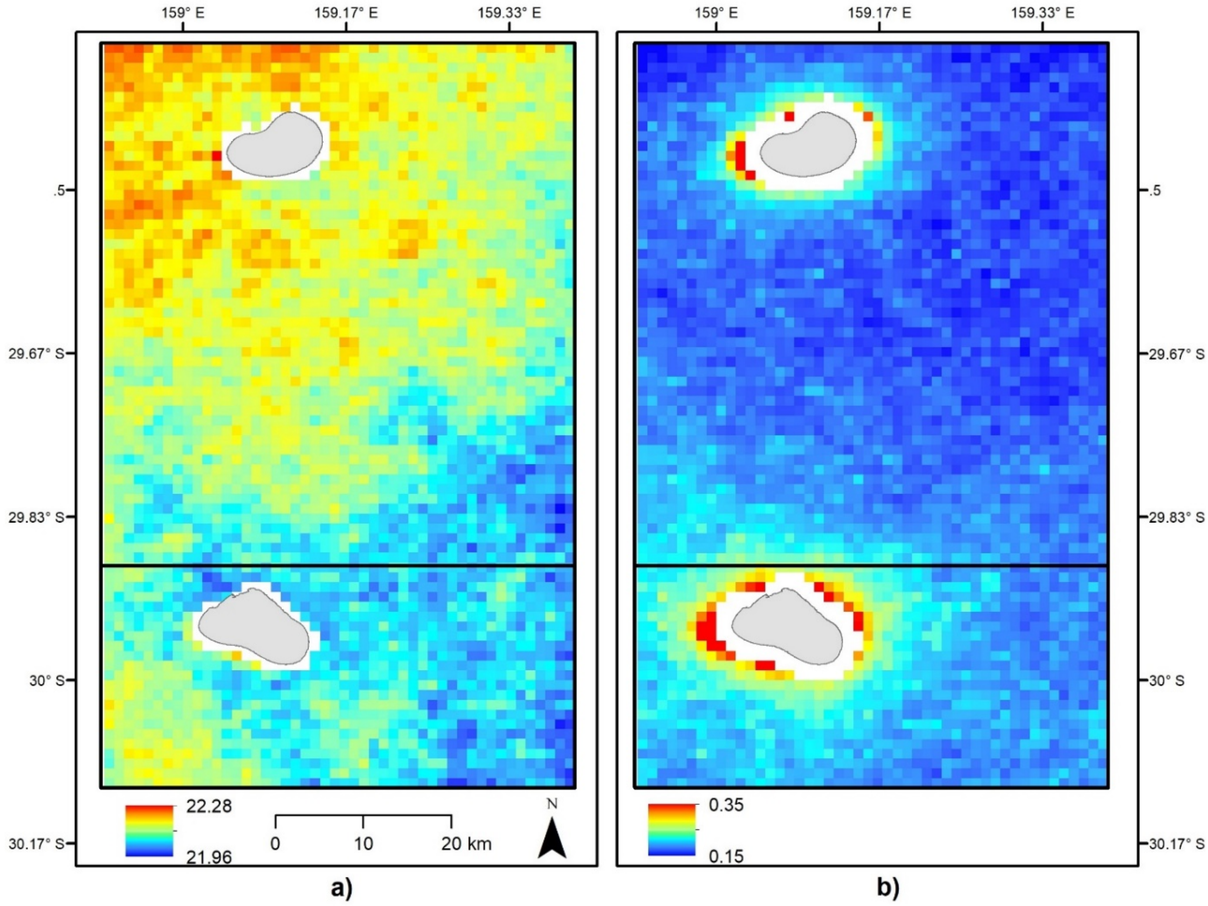


Figure 3. Long-term mean a) SST (°C) and b) Chlorophyll-a (mg/m^3) over the two marine park zones surrounding Elizabeth (bottom) and Middleton (top) Reefs, derived from the daily MODIS satellite imagery for the period 2003 to 2018 inclusive.

Table 1. The seasonal MHWs statistics derived from daily MODIS SST data between July 2002 and June 2019.

Season	Duration[1]	Mean Intensity[2]	Cumulative Intensity[3]	Season	Duration	Mean Intensity	Cumulative Intensity
2003 spring	5	0.84	4.18	**2010-11 summer**	**16**	**0.46**	**7.44**
2003-04 summer	5	0.26	1.28	**2014 spring**	5	0.28	1.41
2004 autumn	15	0.91	13.58	**2014-15 summer**	5	1.10	5.50
2004 winter	51	0.44	22.47	**2015 autumn**	5	0.23	1.15
2004 spring	5	0.38	1.91	**2015 spring**	5	0.68	3.41
2007 summer	6	0.58	3.46	**2016 autumn**	30	0.38	11.43
2009 autumn	5	0.11	0.54	**2016-17 summer**	**27**	**0.34**	**9.20**
2009 spring	6	0.61	3.68	**2017-18 summer**	**25**	**0.80**	**20.00**
2009-10 summer	**19**	**0.89**	**16.85**	**2018 winter**	12	0.38	4.58
2010 winter	23	0.39	8.91	**2019 autumn**	7	0.61	4.27

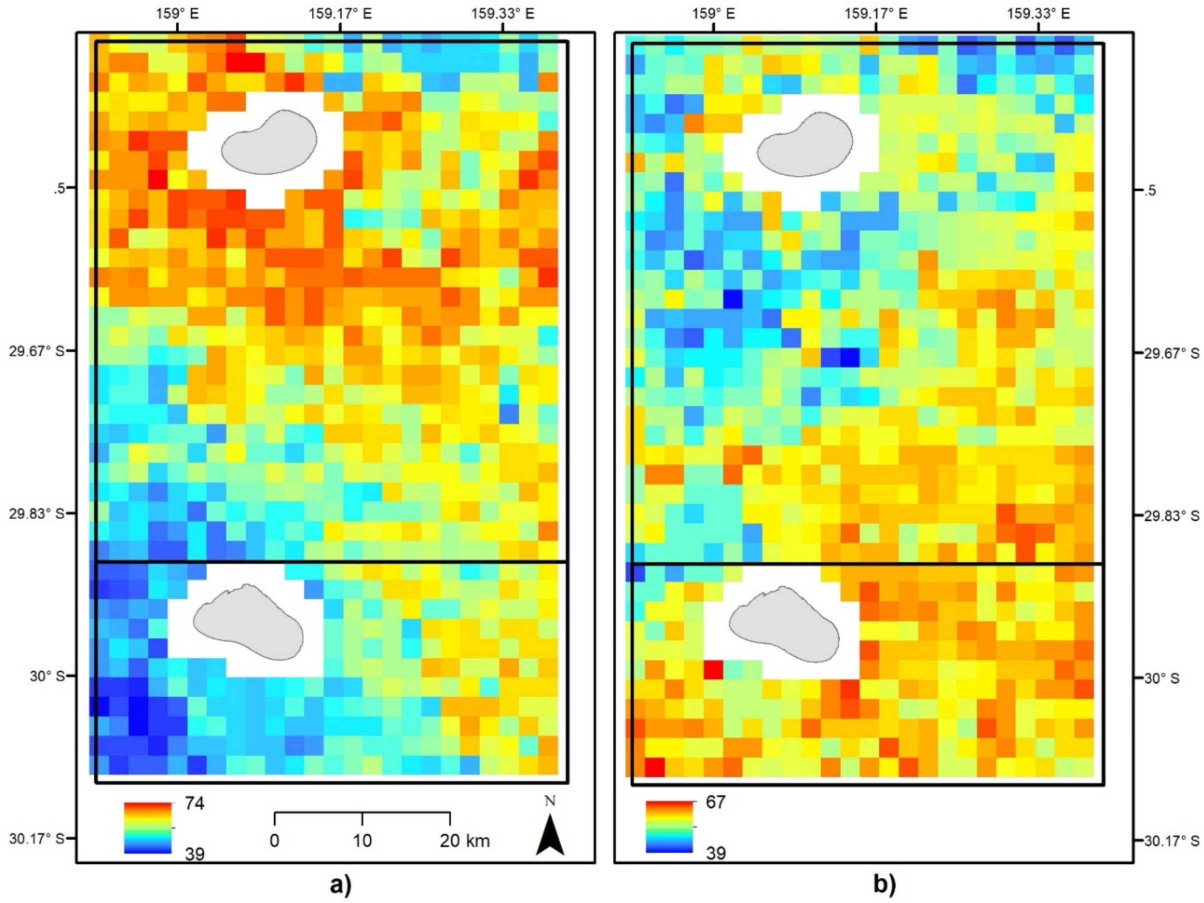


Figure 4. The spatial pattern of the number of MHWs days in the two marine park zones surrounding Elizabeth (bottom) and Middleton (top) Reefs; a) summer 2016-17; b) summer 2017-18.

1.3.3 Existing seabed data

There has been some limited previous seabed mapping at Elizabeth and Middleton Reefs, with a compilation of LIDAR on the shelf and multibeam sonar bathymetry data (2003, 2009, 2011, 2013 transit tracks) in deeper waters providing evidence for complex seabed geomorphic features, including low-profile ridges and mounds. However, the true extent and character of these features was unknown and remained to be fully described and quantified from a biodiversity, habitat and ecological perspective. The resolution of existing bathymetry and LIDAR data was insufficient to identify reef features clearly, but awareness of their existence made these reefs an ideal candidate to develop and test methods for identifying and characterising shelf reef environments.

1.3.4 Existing biology and ecology data

Early research at Elizabeth and Middleton Reefs focused on the taxonomy, distribution and status of Scleractinian reef-building corals, identifying 121 coral species on shallow reefs (Done and Veron, 1981). Subsequent research carried out by Done (1984) and the Australian Museum in 1987 assessed the status of mobile and sessile organisms. This was followed by a series of comprehensive ecological surveys conducted by the Australian

Institute of Marine Science, James Cook University and Reef Life Survey between 2003 and 2018 (Oxley et al. 2004, Choat et al. 2006, Pratchett et al. 2011, Hoey et al. 2014, Edgar et al. 2018, Hoey et al. 2018). These more recent studies (ca. 2-3 years apart) recorded benthic assemblage cover and highlighted the ecological significance of the shallow reefs. Hard coral cover has historically been higher on shallow reef at Elizabeth Reef compared to Middleton Reef. However, there was a decline in coral cover between 1981 and 1994 at Middleton Reef, which was attributed to repeated storm events and outbreaks of Crown-of-Thorn Seastar (Oxley et al. 2004).

Shallow coral cover at each reef is dominated by tropical and cosmopolitan species including branching *Acropora,* Pocilloporids, encrusting *Isopora* and *Porites* species. These species also dominate shallow reefs of Lord Howe Island, which lies approximately 200 km south of Middleton Reef. The biodiversity status of each reef was assessed by collecting data on the abundance and size class structure of fish, abundance of mobile macroinvertebrates and percent cover of sessile benthic assemblages in 2013 and 2018 (Edgar et al. 2018). In 2018, both reefs remained dominated by low-lying turfing algae growing on a dead coral base – indicative of reefs that have suffered past disturbances (e.g. bleaching events) and coral mortality. Other changes between 2013 and 2018 were an increase in the number of species and abundance of cryptic fishes, and signs of increasing prevalence and biomass of large tropical herbivores, which may account for the observed decline in cover of turf algae at each reef (Edgar et al. 2018). Percent cover of hard coral increased at Elizabeth Reef from 34% to 37%, and 16% to 22% at Middleton Reef between survey periods, suggesting that corals were either recovering from earlier disturbances, or have remained relatively stable over the 7-year period to 2018 (Edgar et al. 2018). Recovery, however, is expected to be slow at these remote reefs due to their geographic isolation and low connectivity to potential source reefs, low population size and associated increased extinction risk (Noreen et al. 2009, Edgar et al. 2018).

Examination of population connectivity in the ecologically-specialized endemic three-striped butterflyfish (*Chaetodon tricinctus*) at Elizabeth and Middleton Reefs, Lord Howe Island and Norfolk Island, indicated high levels of self-replenishment and prolonged population recovery following population declines (van der Meer et al. 2013). The abundance of this species and other endemic fishes (*Amphiprion mccullochi*, *Coris bulbifrons*), however, have changed little between 2011 and 2018 (Hoey et al. 2018). Elizabeth and Middleton Reefs remain notable strongholds for the vulnerable black cod, *Epinephelus daemelii*, and the Galapagos shark, *Carcharhinus galapagensis*. Tiger sharks, *Galeocerdo cuvier*, have also been observed (e.g. Choat et al. 2006). Brief descriptions of these vulnerable, data deficient and near threatened species are provided below.

Black cod, *Epinephelus daemelii*

The black cod *Epinephelus daemelii* (also known as the black rockcod, or spotted black grouper; Figure 5), is a large, reef-dwelling species belonging to the family Serranidae (cods and groupers). It ranges from the east coast of Australia, through to the subtropical islands and reefs of the Tasman Sea (Lord Howe Island, Elizabeth and Middleton Reefs and Norfolk Island), Kermadec Islands and northern New Zealand. It is most abundant in the latitudinal range of 28–35º S. *Epinephelus daemelii* is listed as vulnerable under the EBPC Act 1999 and the NSW Fisheries Management Act 1994. This species grows to a maximum length of 1.7 m and weight of ~ 80 kg (Francis et al. 2016). They are highly variable in colour, ranging from white to black, with irregular, often broken and indistinct, bifurcating, oblique dark bars on the body between the nape and caudal fin. A key identifying feature is a black saddle on the caudal peduncle and distinct canine teeth in both the upper and lower jaws. Like most other species in the *Epinephelus* genus, the black cod is a protogynous hermaphrodite – first developing as a sexually mature female and then changing into a male later in life at a length of approximately 100–110 cm. Large black cod (>100 cm) are known to occur at offshore islands and reefs (Harasti and Malcolm 2013, Francis et al. 2016), whereas juvenile and sub-adult black cod are generally found in inshore rock pools and estuaries (Harasti and Malcolm 2013, Harasti et al. 2014). Adult black cod are commonly found in caves, gutters and beneath bommies on rocky reefs, to depths of ~ 50 m. They are considered territorial and will often occupy a particular cave for life.

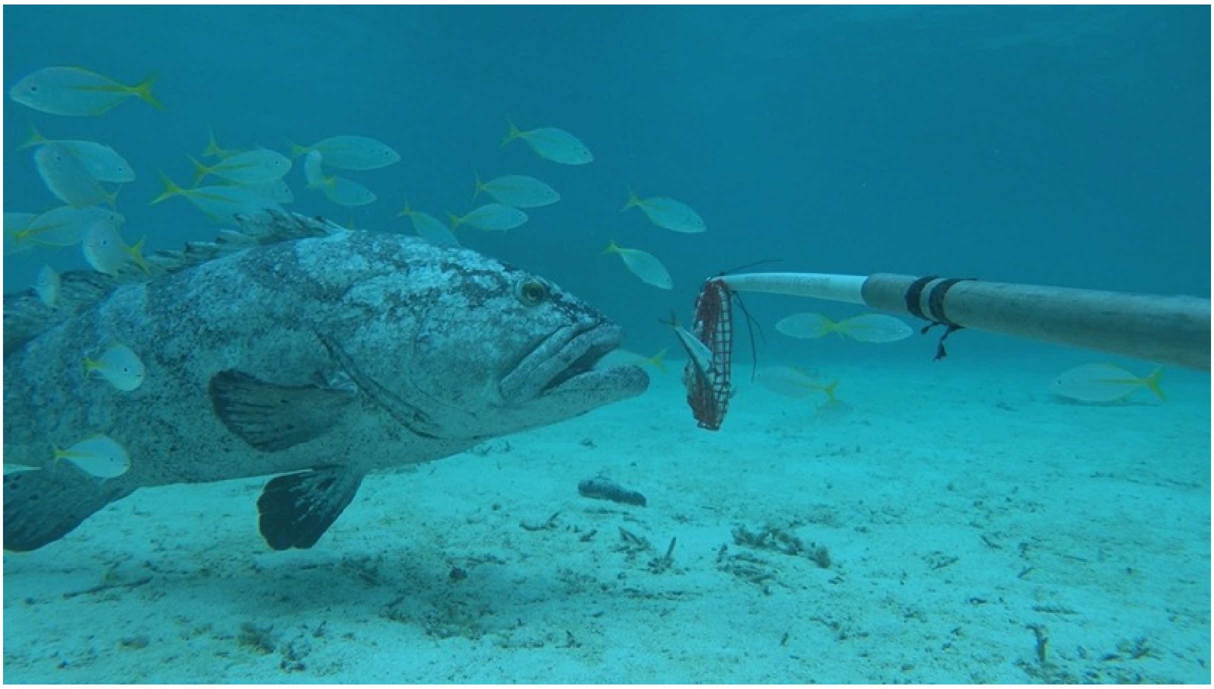


Figure 5. Black cod, *Epinephelus daemelii,* at Middleton Reef lagoon (stereo-BRUV deployment M125 – this survey).

Galapagos shark, *Carcharhinus galapagensis*

Galapagos shark, *Carcharhinus galapagensis* (Figure 6), are found throughout the world's temperate and tropical oceans, primarily distributed around isolated island and reef systems. In Australia, they are known to occur in waters off Lord Howe Island and Elizabeth and Middleton Reefs. Genetic sampling of this species suggests that the population at Elizabeth and Middleton Reefs is a single stock, and is distinct from the Lord Howe Island population (Van Herwerden et al. 2009). Galapagos sharks reach lengths of ~3.7 m and are very slow to reach size at maturity (~ 10 years). They are live bearers and produce few young. The IUCN lists Galapagos shark least as of 'least concern'; however, its slow reproduction limits this species capacity to withstand population depletion. Galapagos sharks are listed as 'data deficient' on the IUCN Australia and Oceania list due to a lack of information and data from the region.

Figure 6. Galapagos shark, *Carcharhinus galapagensis*, at Middleton Reef lagoon (stereo-BRUV deployment M111 – this survey).

Tiger shark, *Galeocerdo cuvier*

The tiger shark, *Galeocerdo cuvier* (Figure 7), is an apex predator found across all of the world's tropical and warm temperate oceans. In Australia, this species migrates up and down the east and west coasts following warm ocean currents. Individuals are capable of moving distances in excess of 1000 km per year. Tiger sharks are a large macropredator, reaching sexual maturity at ~3 m and grow to a maximum size of ~6 m. They are a targeted species for game fishing but their poor eating quality results in a very small commercial catch. This species is identified by the IUCN as 'near threatened'.

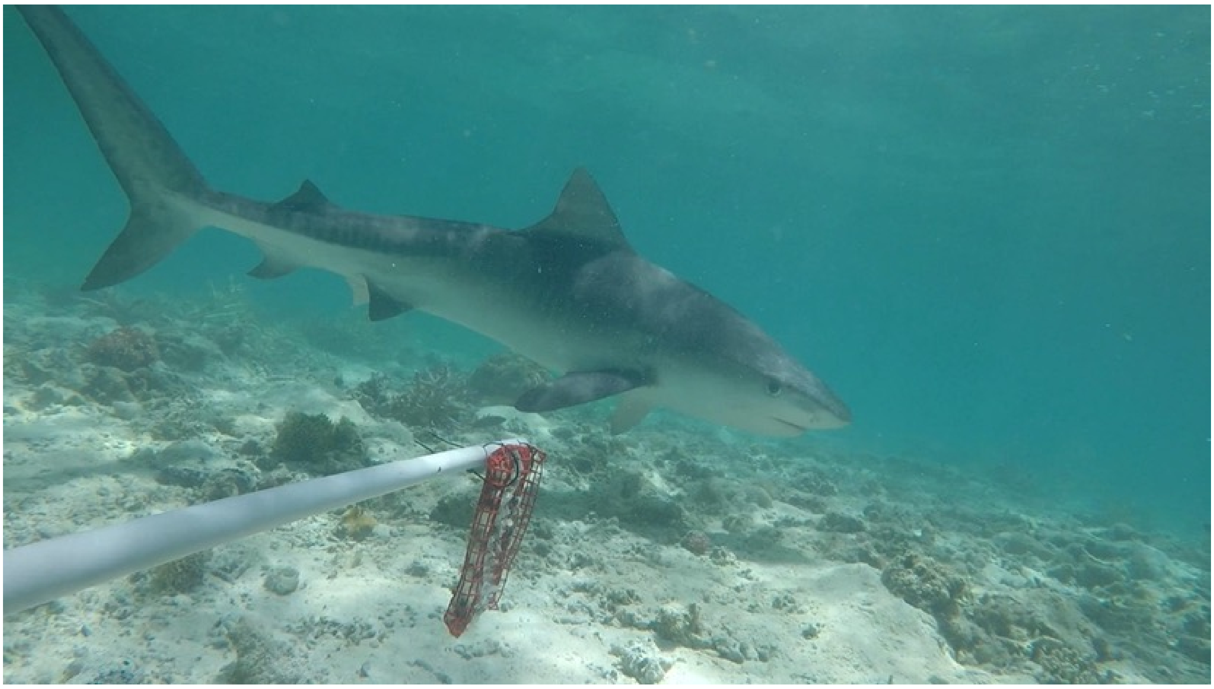


Figure 7. Tiger shark, *Galeocerdo cuvieri*, at Middleton Reef lagoon (stereo-BRUV deployment M111 – this survey M012).

2. SURVEY OVERVIEW

2.1 Aims and objectives

The specific aim of the survey was to fill knowledge gaps on the distribution, extent and structure of seabed habitats and associated sessile and mobile fauna in shallow and mesophotic shelf areas of Elizabeth (Recreational Use Zone) and Middleton (National Park Zone) Reefs. Our survey applied a suite of best practise sampling protocols as set out in the NESP Marine Biodiversity Hub Field Manuals – a standard and consistent approach to national survey-based inventory and monitoring (Przeslawski et al. 2019).

The primary objectives of our multidisciplinary voyage were to acquire:

1. High-resolution multibeam bathymetry and acoustic backscatter data in order to characterise the geomorphology of seabed habitats across the shelf of each reef, and inform future habitat-based biological sampling programs.

2. Autonomous Underwater Vehicle (AUV) imagery of shelf environments to characterise and quantify percent cover of sessile invertebrate communities, and establish a sound quantitative baseline for future monitoring of sessile benthic mesophotic systems.

3. Baited Remote Underwater stereo-Video (stereo-BRUVs) on shelf and lagoon environments to document species richness and abundance of demersal fish communities, and establish a sound quantitative baseline for future monitoring of fish populations in the region.

4. Seabed samples (grabs) of sediment/reef material to characterise substrate types.

3. DATA ACQUISITION AND PROCESSING

3.1 Data acquisition

3.1.1 Seabed features and morphology

This survey was undertaken on the University of Tasmania's *TV Bluefin*, a 34 m research and training vessel operated by Australian Maritime College. The vessel was fitted with a Kongsberg EM2040C multibeam echosounder system (MBES) (in single head configuration) and linked to an Applanix POS-MV V5 motion referencing system, with positioning data acquired on a C-Nav system. Bathymetry data was gridded at an optimal resolution for the acquisition system/water depth, to allow for the identification and mapping of fine-scale geomorphic seabed features. Bathymetry data acquisition was undertaken using the Quality Assurance and Quality Control measures outlined in Picard et al. (2018).

3.1.2 Seabed sediments

A Van Veen sediment grab was deployed opportunistically to collect seabed sediment samples at sites nearby stereo-BRUV sites at each reef. Samples were described in the field following the standard operating procedure set out in Przeslawski et al. (2020) and retained for lab analysis of grain size and carbonate content.

3.1.3 Sessile epifaunal communities

Sessile epifaunal community data were acquired using Autonomous Underwater Vehicles (AUVs) capable of undertaking high-resolution, geo-referenced survey work. This voyage marked an important milestone for the IMOS AUV Facility, as it included simultaneous deployments of AUV *Sirius* and the newly commissioned AUV *Nimbus* (Figure 8), operated by the Australian Centre for Field Robotics, University of Sydney. 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, 12 megapixel cameras (AVT Manta G-1236 CMOS). Illumination is achieved by four 900W LED strobes mounted in the fore and aft-sections of the vehicle and are synchronised with the cameras (see Williams et al. 2012 for full specifications).

AUV *Nimbus* (~120 kg) is a custom designed and developed mid-size robotic vehicle equipped with a suite of instruments and sensors including high-resolution stereo cameras, depth sensor, Doppler Velocity Log (DVL), Compass, Inertial Measurement Unit (IMU), Ultra Short Baseline (USBL), forward and downward looking obstacle avoidance sonar and a conductivity/temperature sensor. Seabed images were collected with a synchronized pair of high-sensitivity 14 bit, 6 megapixel cameras (AVT GT2750). Illumination was achieved by two 1944W LED strobes mounted in the fore and aft-sections of the vehicle, and are synchronised with the cameras. AUV transects were pre-programmed so that each AUV surveyed the seabed at an altitude of 2 m and a cruising speed of 0.5 m per second. All deployments were conducted during daylight hours over 7 days in February 2020 (Campaign EMR202001) in seawater depths ranging from 10–120 m. Deployments followed national best practise procedures as outlined in Monk et al. (2020).

Figure 8. Top image: Deployment of AUV *Sirius* from *TV Bluefin*. Bottom image: Pre-deployment checks of the newly commissioned AUV *Nimbus* by ACRF team (Source: Kristy Brown, IMAS).

The sampling design for AUVs was intended for spatially balanced sampling across depths 20–120 m (inner shelf to shelf break), around the shelf of Elizabeth and Middleton Reefs, through randomized allocation of sample locations in R-package MBHdesign (Foster et al. 2020). Inclusion probabilities within the sampling design were weighted towards complex and reef associated habitats from previous bathymetry data. Locations sampled in reality ranged from complex coral reefs to unconsolidated sandy/gravel seabed. Weather conditions experienced during the voyage meant that the intended spatial balance within the sampling design was not achieved in its entirety, with sampling around Middleton Reef restricted to the NWW and SSE aspects of the shelf and the NWW aspect of Elizabeth Reef.

3.1.4 Demersal fish communities

Demersal fish communities were quantified using baited remote underwater stereo-videos (stereo-BRUVs; Figure 9; Figure 10) to facilitate robust surveys of demersal fish assemblages on mesophotic shelf and shallow lagoon habitats. The sampling design for stereo-BRUVs was intended for spatially balanced sampling across depths 0–120 m, within the lagoon and around the shelf of Elizabeth and Middleton Reefs, through randomized allocation of sample locations in R-package MBHdesign (Foster et al., 2020). Inclusion probabilities within the sampling design were weighted towards complex and reef associated habitats from previous bathymetry data. Locations sampled in reality ranged from complex coral reefs to unconsolidated sandy/gravel seabed. Weather conditions during the voyage meant that the intended spatial balance within sampling design was not achieved in its entirety.

Overall, 136 stereo-BRUVs were deployed at Middleton Reef (26 around the northern perimeter, 36 around the southern perimeter and 74 within the lagoon) to sample fish assemblages and associated benthic habitats. Only 34 stereo-BRUVs were deployed at Elizabeth Reef due to the early termination of the survey (31 on the northwestern shelf and three within the confines of the lagoon). 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 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 ~1 kg of 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 deployment was 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 best practise operating procedures outlined in Langlois et al. (2020a, b).

Figure 9. Top image: Retrieval of stereo-BRUV on TV *Bluefin*. Bottom image: Pre-deployment checks of stereo-BRUV (Source: Aero Leplastrier, GA; Kristy Brown, IMAS).

Figure 10. NSW DPI science staff transiting to deploy shallow stereo-BRUV units at Middleton Reef lagoon.

3.1.5 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 on the vessel with good visibility. No whales were sighted during the survey.

3.1.6 Licences and permits

Prior to the survey, Geoscience Australia and UTAS obtained a permit from the Director of National Parks to conduct research activities within the Lord Howe Marine Park (Permit No: CMR-19-00120-1). An additional permit was issued to GA to undertake research activities within either the Apollo, Franklin, Zeehan and/or Flinders Marine Parks (Permit No: CMR-19-00120-2) as a part of a bad weather contingency plan. These permits allowed for the operation of proposed instrumentation from 20 January 2020 and expired on 29 February 2020. All imagery acquired during this survey (i.e. AUV, stereo-BRUVs) conformed to the requirements of the *Australian code of practice for the care and use of animals for scientific purposes* (8th edition 2013) and was undertaken under approved Animal Care and Ethics Permits held by IMAS (A0018195 – Marine Biodiversity Hub remote imagery-based observations) and NSW DPI (Monitoring of fish communities using visual and video surveys ACEC REF 10/09 – Marine Parks Authority).

3.2 Data processing

3.2.1 Seabed features and morphology

Bathymetry

The MBES bathymetry data from GA4848 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—attitude 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.

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 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°. The final processed data were gridded to 1 m horizontal resolution, and 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 morphology

A semi-automated approach was used to create morphological maps of the seafloor, including a classification of seafloor ‘surfaces’ and ‘landforms’. Surfaces were defined using techniques modified from previous Marine Biodiversity Hub surveys (Barrett et al. 2019), and landforms were classified using techniques modified from Linklater et al. (2019). The mapping approach used here applies the seabed morphology classification scheme of Dove et al. (2020) as well as techniques for seabed classification developed for the New South Wales (NSW) SeaBed NSW program (NSW Department of Planning, Industry and Environment, 2019). The morphology 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. 2020). 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). Here we report on morphology features, with initial observations of the geomorphic origin of those features.

The morphology component of the classification scheme assigns defined names to features that describe the shape of the sea floor. For this report, each bathymetry grid has been mapped to the morphology feature 'surface' level as well as feature 'landform' level. All mapping was done in ArcMap v10.8 using ArcGIS Desktop tools. For the 'surface' classification, the bathymetry grid for each survey area was classified into three categories based on slope: plane (0-2°), slope (2-10°), and escarpment (>10°). Slope was calculated from relevant bathymetry datasets and classified into the three slope categories defined above. The reclassified slope grid was then cleaned using the "boundary clean" function and the majority filter, before being converted to polygon vector data (Barrett et al. 2019).

Seabed 'landform' features were in turn identified using a modified version of the method presented by Linklater et al. (2019), which has subsequently been developed into a Seabed Landform ArcGIS toolset for the SeaBed NSW program (Linklater et al. in prep.). This approach uses an adapted application of the Benthic Terrain Modeler (BTM) toolbox classification (Walbridge et al. 2018), where ruggedness, slope, fine-scale BPI (Bathymetric Position Index) and broad-scale BPI are used as inputs to classify the terrain into a suite of non-overlapping features. BPI (Bathymetric Position Index) grids are derived from bathymetry data and measure the elevation of each pixel relative to the surroundings, within a user-defined window (Weiss, 2001). Ruggedness is a measure of surface roughness and was calculated using Terrain Ruggedness VRM tool in the BTM toolbox. Suitable thresholds were determined for each input variable for the classification dictionary in order to capture the features of interest. See Linklater et al. (2019) for further details on the methodology, and Table X for threshold values utilised in this study.

Bathymetry data associated with 'plane' and 'slope' surface polygons (and 'escarpment' polygons contained by these features) were extracted and used as input bathymetry for the landform classification. The outer bounding 'escarpment' polygon that extends beyond the shelf break (i.e., the 120 m depth contour) of each reef was excluded from further analysis because the landform classification toolset has not been configured for steep settings such as these. The extracted bathymetry dataset was smoothed three times with a median filter before being input into the Seabed Landform ArcGIS toolset.

The Seabed Landform ArcGIS toolset, which utilises a series of ArcGIS tools, was used to classify the bathymetry data into homogenous areas of topographic relief (highs, lows, and flats), ruggedness and slope. The first stage of classification divides the surface into distinct elements including rugose outcrops, smooth outcrops, smooth flats, smooth depressions and rugose depressions. The classification toolset is also able to identify polygons that occur within a rugose outcrop, enabling localised depressions within an outcropping feature to be identified. Procedures also include processes to identify and correct noise within the dataset, reducing the time needed for manual editing. In the resulting classification: all areas greater than 10° slope were classed as 'Scarp'; 'Ridges' and 'Mounds' were generally defined as areas with higher ruggedness and raised topographical relief; and 'Depressions' were generally defined where topographical lows occur within a reef outcrop.

'Ridge' and 'Mound' features identified using the Seabed Landform ArcGIS toolset were then filtered to retain only those with elongate morphology. This was done by creating Minimum

Bounding Rectangle (MBR) (by width) for each feature polygon; and then all polygons with a ratio of MBR length to MBR width less than 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. Thorough review and manual editing were performed on the classified output to ensure categories appropriately captured features of interest. The landform classification was clipped to the 120 m depth interval, which was determined to be a suitable boundary for the shelf break. After that, we merged small polygons with an area less than 45 km^2 with their largest neighbours to obtain the final seabed Landform classification map. Finally, for reporting of surface area statistics the landform classes were grouped into three broad categories: (i) plain, (ii) depression and; (iii) ridge and mound (incorporating scarps).

3.2.2 Seabed sediment samples

Eight seabed sediment samples were collected from Middleton Reef (at water depths ranging between 56 and 62 m), and three sediment samples were collected from Elizabeth Reef (at water depths ranging between 56 and 62 m). Sediment recovery was variable, ranging from 50 g to 500 g wet weight. Sediment samples will be 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 will be recorded as dry weights and calcium carbonate content will be determined using the acid digestion method (Muller and Gastner, 1971). Sediment samples are lodged at Geoscience Australia.

3.2.3 Sessile epifaunal communities

AUV imagery

A total of 288 680 high-resolution georeferenced mages were acquired from seven AUV missions at Middleton Reef (between 31 January and 3 February 2020) and four AUV missions at Elizabeth Reef (between 3 and 6 February 2020). Post-processing of 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. Stereo image pairs will be stitched together to generate composite geo-rectified 3D “meshes” of seabed. These meshes will be imported into ArcGIS to visually assess broad-scale ecological structure and the spatial distribution and abundance of benthic fauna across geomorphic seabed features.

A random sub-sample of ~3000 AUV images were selected across both reefs for annotation (~300 images from 5 separate depth bins per reef). 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 four annotators. This approach allows for aggregation into broader morphological classes, which were graphically and spatially examined along with percent cover of key morphospecies.

The adequacy of sampling effort required to characterise the epibenthic sessile assemblages sampled using the AUV was attained through species accumulation curves, which were created using the “vegan” R package and *specaccum* function set to random with 9999 permutations.

3.2.4 Demersal fish observation

Stereo-BRUV annotations and analyses of patterns in demersal fish communities

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 observed fish 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). Calibrations were completed in the software Cal (www.seagis.com.au) and annotations and measurements done in the software EventMeasure (www.seagis.com.au). The distribution and abundance of trophic feeding guilds and key fish species were graphically plotted. Length-frequency plots were also used for threatened species to explore size class structures. As with the AUV analysis, species accumulation curves were created using the “vegan” R package and *specaccum* function set to random with 9999 permutations to demonstrate sampling adequacy between reefs.

4. RESULTS AND PRELIMINARY INTERPRETATIONS

4.1 Seabed morphology

4.1.1 Middleton Reef

The overall form of Middleton Reef shelf is a gradually steepening seabed that extends from 20 m water depth on the seaward side of the reef lagoon to ~120 m at the shelf break over a distance of 1–2.5 km (Figure 11). The shelf is widest along the northwest sector, where the shelf break is 2.5 km from the lagoon entrance, with an overall gradient of 5–6 degrees, steepening to >15 degrees beyond the shelf break. In contrast, the southeast, south and western sectors of the shelf are 1.5–1.7 km wide, with a gradient of 5–7 degrees, steeping at the 120 m shelf break contour to 10–15 degrees. The shelf width is also more variable on the eastern side of the reef where it ranges from 0.9–1.4 km, with the narrowest sectors associated with local incisions into the shelf edge (Figure 11).

As a proxy of the relative hardness of the seabed of Middleton Reef shelf, acoustic backscatter data revealed a broadly uniform pattern of slightly harder seabed toward the shelf break (Figure 12). Thus, backscatter values range from -15 dB (lower intensity; softer seabed) on the inner and mid shelf to -10 dB (higher intensity; harder seabed) on the outer shelf and ~ -5 dB on the steeper, deeper (~215 m) upper slopes of the seamount. This pattern is consistent around the shelf, with the exception of an area in the north-northwest where backscatter is in the -30 dB to -20 dB range, indicative of the softest (sandy) area of the seabed (Figure 12).

A distinctive feature of the Middleton Reef shelf is a series of stepped terraces that extend around the shelf but are best defined along the east, south and west sectors (Figure 11; Figure 12). Broadly, these terraces are 150–200 m wide, with steps (ledges) at ~50 m, ~60 m, ~80 m and ~90 m water depth. The terraces are not as well defined along the north to northwest sector, where the seabed is more complex at the fine-scale.

The fine-scale morphology of the Middleton shelf seabed comprises five primary feature types: plane, ridge, mound, scarp and depression. Following Dove et al. (2020), these are defined as follows:

- Plane: a flat, or sub-horizontal surface
- Ridge: an elongated elevation of varying complexity, size and gradient (length >width)
- Mound: a distinct elevation with a variable, sometimes rounded profile (which is generally less than 500 m above the surrounding seafloor)
- Scarp: a steep slope, separating areas of relatively lower gradient slope
- Depression: a closed-contour bathymetric low

These features are here simplified into three broad categories: plane, depression and ridge/mound/scarp (Figure 13); the latter category representing all raised and steepened areas of seabed on Middleton Reef shelf. Summary statistics for each category are listed in Table 2, including the area of each feature type across bathymetric zones set at 20 m depth intervals.

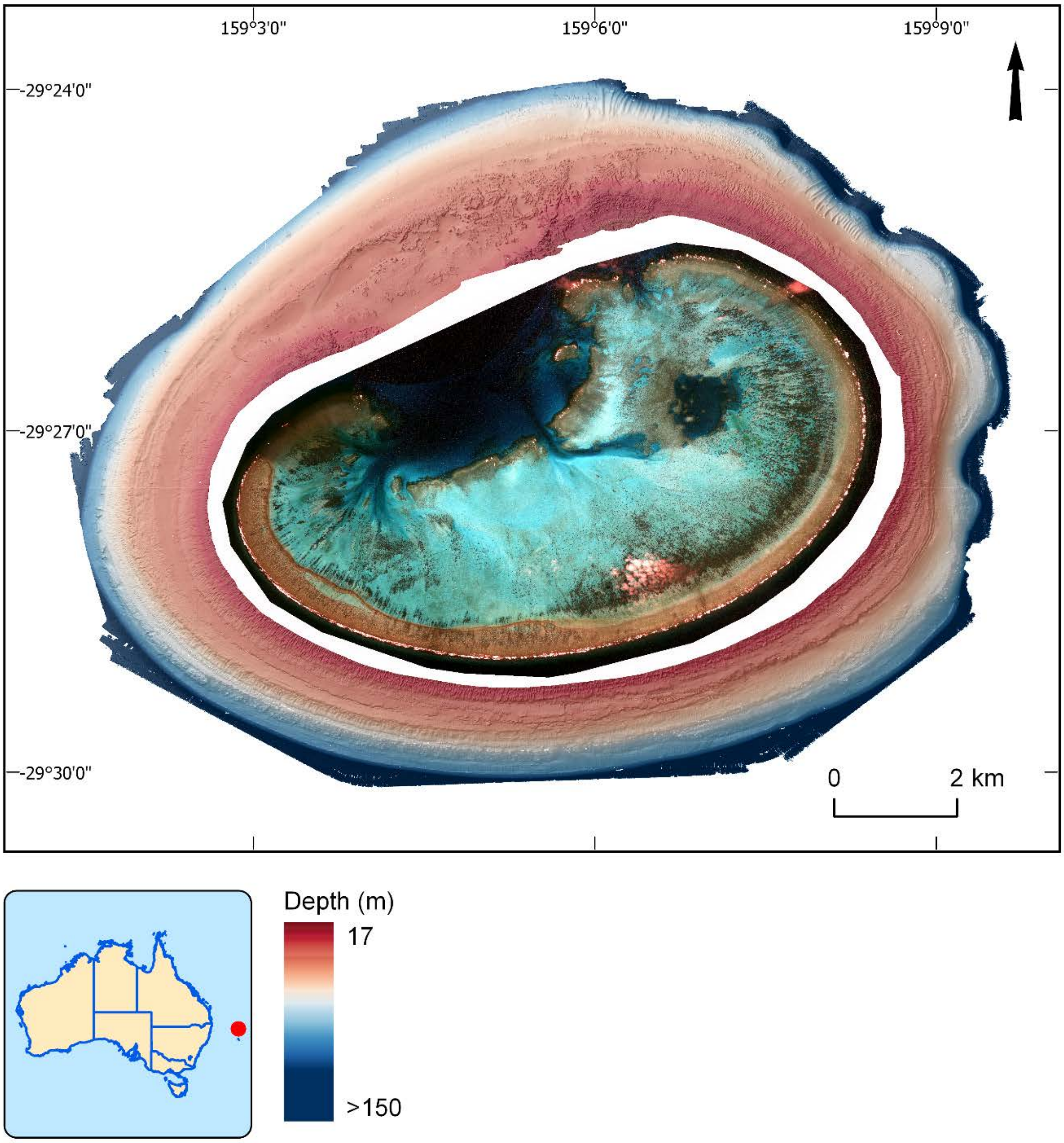


Figure 11. High-resolution multibeam bathymetry data (gridded at 3 m) for Middleton Reef shelf. Centre image – QuickBird satellite imagery). Inset map shows the location of Middleton Reef off the east coast of Australia.

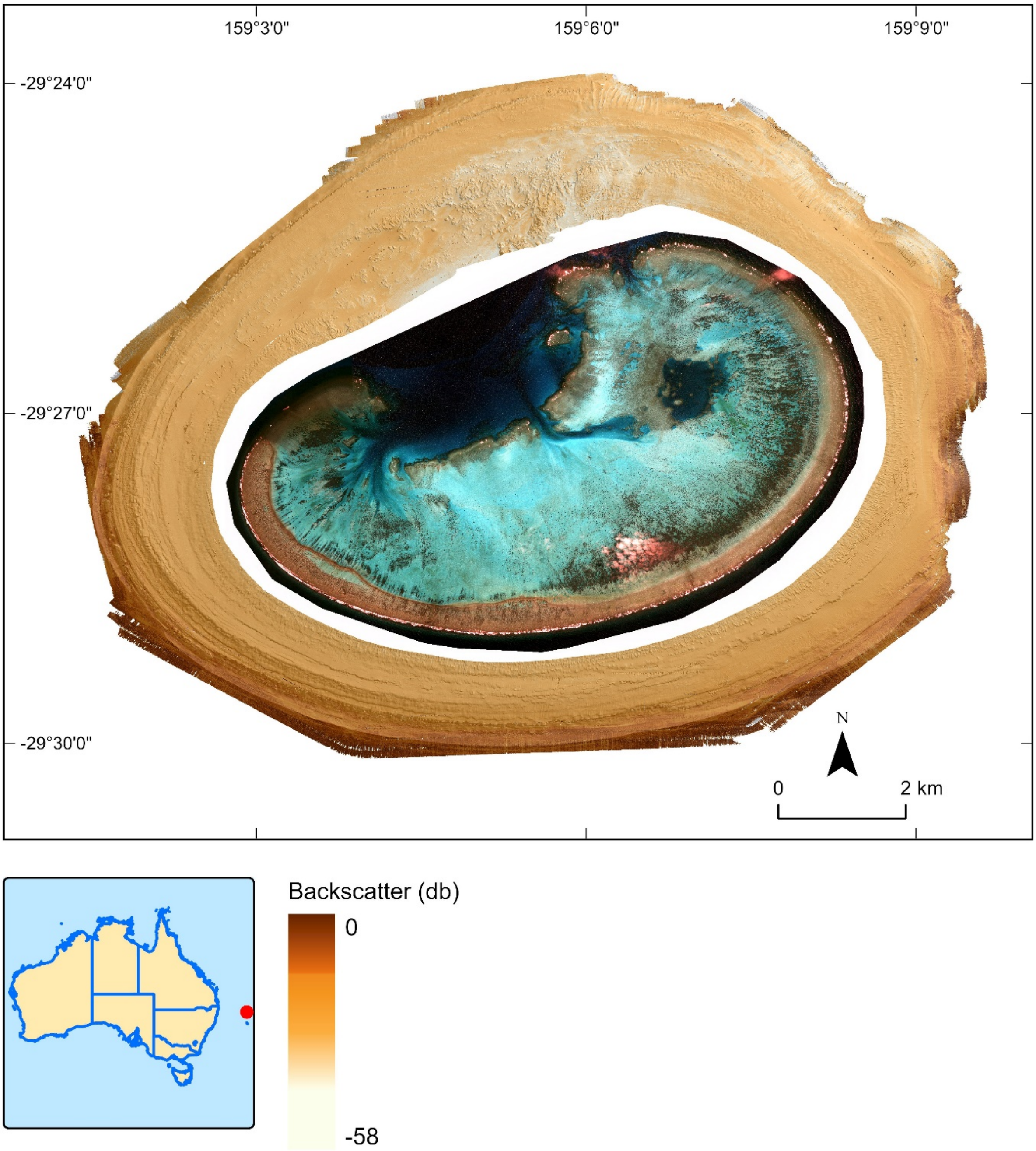


Figure 12. Acoustic backscatter data (gridded at 3 m) for Middleton Reef shelf. Inset map shows the location of Middleton Reef off the east coast of Australia.

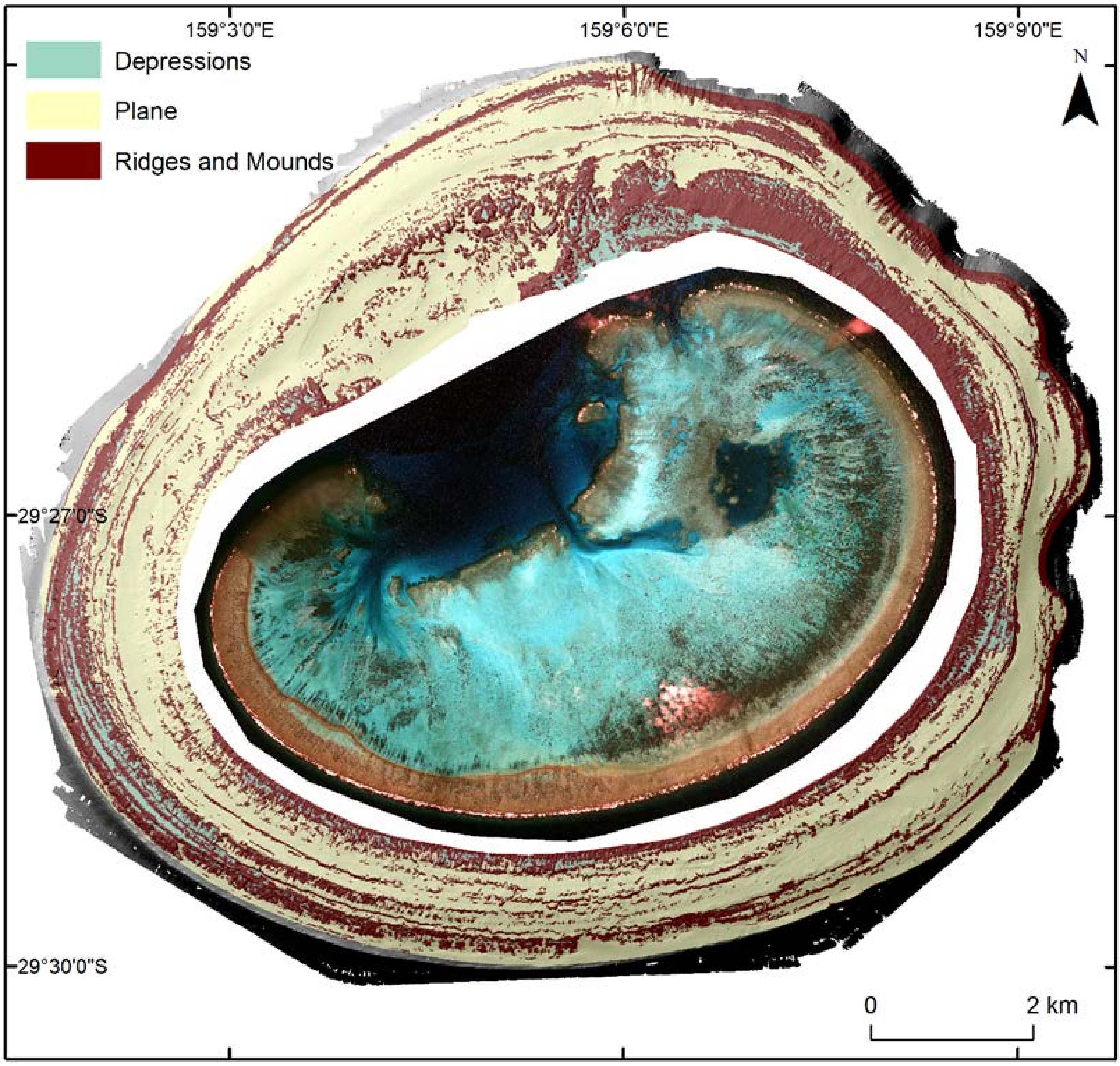


Figure 13. Geomorphological features of Middleton Reef shelf showing three main categories: depressions, plane and ridges and mounds (including scarps); the latter category representing all raised and steepened areas of seabed on the reef shelf.

Table 2: Summary statistics for seabed morphologic features on the mapped area of Middleton Reef shelf.

Seabed morphological feature	Depth zone (m)	Area (km^2)	Percentage of mapped area	Percentage of feature class
Plane	10–30	0.39	0.75	1.3
	30–50	10.62	20.41	34.4
	50–70	10.62	20.41	34.4
	70–90	5.42	10.42	17.6
	90–120	3.79	7.29	12.3
	Total	***30.84***	***59.28***	***100***
Ridge and mound incorporating scarp	10–30	2.97	5.71	16.0
	30–50	6.22	11.96	33.6
	50–70	2.78	5.36	15.0
	70–90	2.82	5.43	15.2
	90–120	3.72	7.15	20.1
	Total	***18.51***	***35.61***	***100***
Depression	10–30	0.58	1.12	22.5
	30–50	0.86	1.67	33.5
	50–70	0.17	0.33	6.6
	70–90	0.71	1.37	27.6
	90–120	0.25	0.48	9.7
	Total	***2.57***	***4.97***	***100***

Planes are the most extensive morphologic feature on the Middleton Reef shelf, covering ~31 km^2 (59.3% of the mapped area), and located mostly across the 30–50 and 50–70 m depth zones (Table 2) where they collectively cover 21 km^2 and represent 68% of that feature class. Within these depth zones, planes form the low gradient (1–3 degrees) relatively smooth surface of the wider terraces.

Acoustic backscatter data for areas of plane indicates the seabed hardness is variable across these surfaces, ranging from low intensity (-15 to -30 dB) on the inner to mid shelf to high intensity (0 to -10 dB) toward the shelf break (Figure 14a, Figure 16a, Figure 17a). This variability in backscatter intensity is interpreted as a response to different type and extent of sediment cover on the planes, with lower intensity likely associated with sand and higher intensity with gravel. For gravel deposits, AUV imagery shows that these sediments in deeper areas are dominated by extensive beds of rhodoliths (gravel-sized nodules of calcareous algae).

Ridges and mounds occupy 18.5 km^2 (35.6% of the mapped area) and are distributed across all depth zones (Table 2); but are more extensive in the 30–50 m zone where they cover 6.2 km^2 and represent 34% of the feature class. These features are also the most numerous (approximately 900 small mounds), forming complex areas of raised seabed (Figure 14). Ridges form a series of semi-continuous linear features that extend around the shelf at different depths. Most ridges are relatively narrow, ranging from 30 to ~100 m in width and are low profile, typically 2–5 m above the adjacent seabed.

The northern part of the Middleton Reef shelf is characterised by a low seaward-sloping ridge that is 700–800 m wide at its widest point and tapers to ~300 m toward the eastern part of the shelf. The western end of this ridge becomes highly segmented, with numerous shallow (1–2 m) depressions creating a complex seabed (Figure 14). Overall, the backscatter signal for ridges and mounds is relatively low intensity (-20 to -30 dB). However, lowest backscatter values are associated with the base of ridges and mounds, indicative of partial sediment cover at these locations. This interpretation is supported by AUV imagery showing that ridges and mounds are characterised by a cover of soft and hard corals with patches of sand.

Ridges and mounds also include areas of scarps (slope >10 degrees) that form localised surfaces of limited extent; scarps cover a combined area of 3.2 km^2 representing 6.1% of the mapped area and occur mostly in the 90–120 m depth zone (28% of that zone) where scarps form an almost continuous surface around the perimeter of the reef platform. Elsewhere, scarps form the edges of ridges and mounds, providing isolated steep to near vertical faces (>30 degrees) as potential habitat for sessile benthic communities (Figure 15). However, the extent of these localised surfaces associated with ridges and mounds is limited, forming a total area of ~1 km^2 across the mapped area of the Middleton Reef shelf.

In contrast to the shelf-parallel ridges that characterise the majority of Middleton Reef shelf, the north and northeast margins are distinguished by two fields of shelf-perpendicular ridges that sit at the shelf edge (Figure 15). These ridges are 2–5 m high, 50–100 m apart and asymmetric in cross-section, with steeper sides facing to the east. Ridge crestlines are 200–450 m long and extend from 80 m to 120 m water depth. Backscatter intensity is slightly weaker on ridge crests, indicating a slightly softer (possibly sandy) substrate. Given the semi-regular spacing and asymmetry of these ridges they are interpreted as active sediment bedforms (dunes), formed by strong tidal currents that flow along the shelf edge.

Depressions occur within the fields of ridges and mounds forming low-lying surfaces that are enclosed by ridges and occupy 2.6 km^2, or ~5% of the mapped area. Depressions are generally less than 1 – 2 m deep and range in planform from linear features that extend several hundred metres to several kilometres along the shelf (e.g. Figure 16), to semi-circular patches less than 0.5 km^2 in area and irregular, interconnected areas that span several square kilometres across the inner shelf (Figure 14). These low-lying areas are characterised by a smooth seabed, with backscatter intensity in the mid- to lower range of intensity for the mapped area, ranging from -20 dB on the shallower inner shelf (e.g. ~25 m; Figure 16b), to -15 dB in deeper waters (e.g. ~80 m; Figure 17b). This is indicative of a broad transition to slightly harder seabed (coarser sediment) in depressions toward the outer shelf.

In summary, the morphology of Middleton Reef shelf is characterised by a gently sloping seabed with distinct terraces and semi-continuous low profile ridges that extend for tens of kilometres around the shelf at consistent depth intervals. The continuity of these ridges is interrupted only on the northwest sector of the shelf, where a spatially complex field of irregular ridges and mounds defines the greatest area of seabed complexity. Importantly, these raised hardground features occur in key mesophotic depth zones (30–50 m and 50–70 m), and collectively occupy approximately 35% of the mapped area of the shelf.

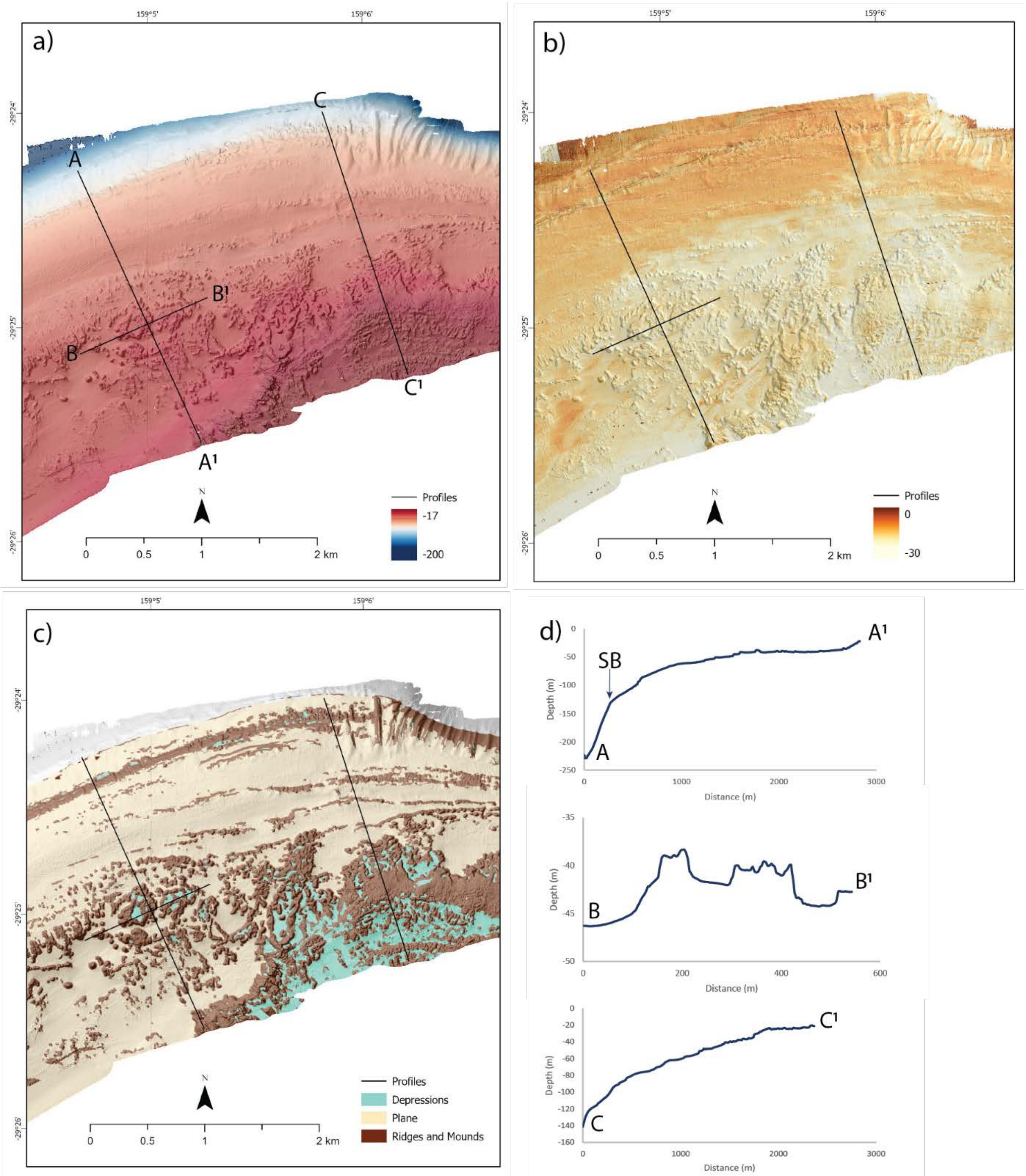


Figure 14. Middleton Reef, northwest shelf showing: a) bathymetry; b) backscatter; c) morphological features; (d) bathymetric profiles. Locations of profiles (A to A[1]; B to B[1]; C to C[1]) are plotted on each map. SB denotes shelf break at ~120 m water depth.

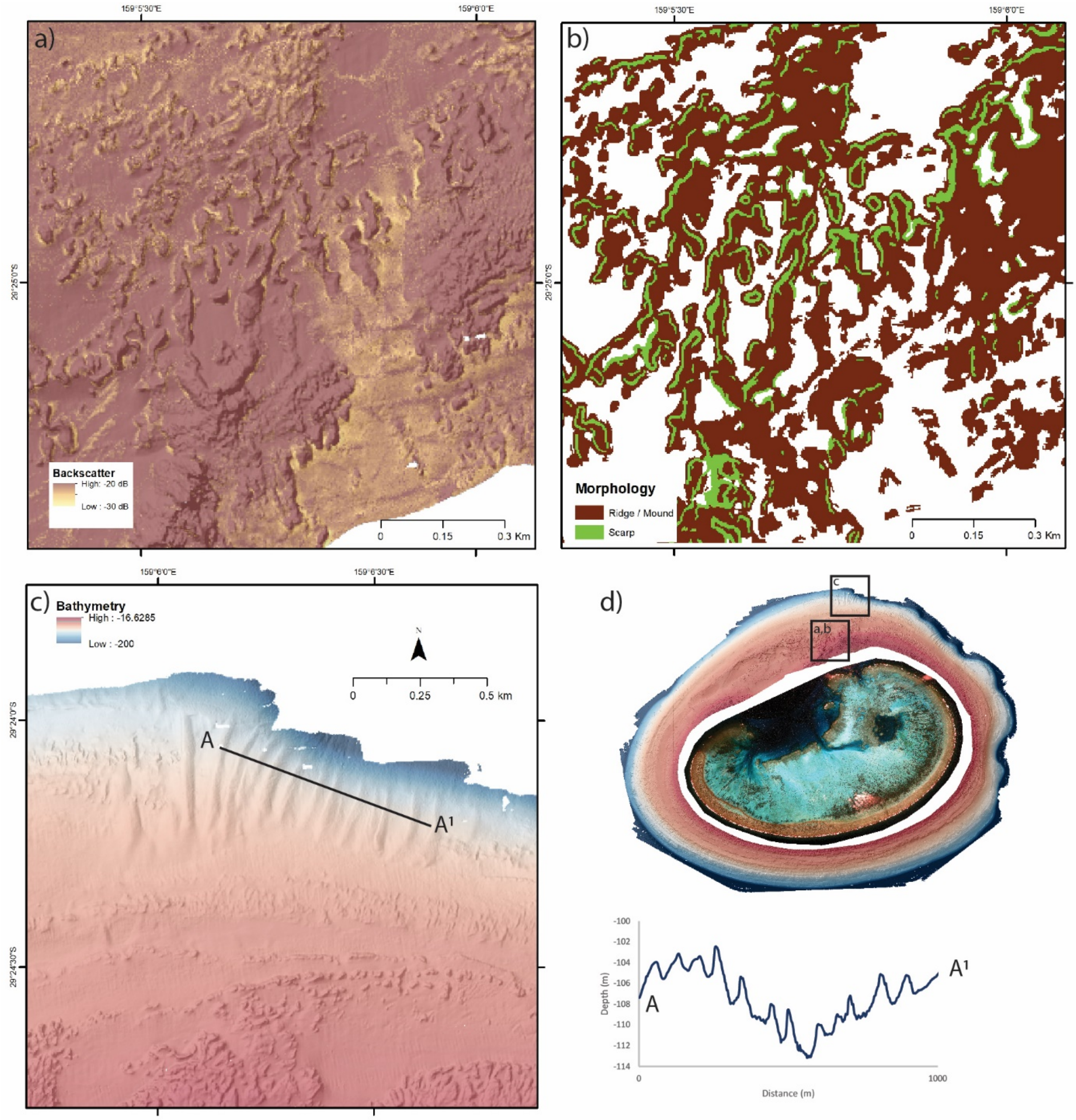


Figure 15. Middleton Reef seabed features, showing: (a) bathymetry and (b) scarp, ridge and mound features for an area on the northwest sector; (c) field of large-scale sedimentary bedforms (ridges) at the shelf edge and (d) west to east elevation profile of the bedform field; location of profile shown on map.

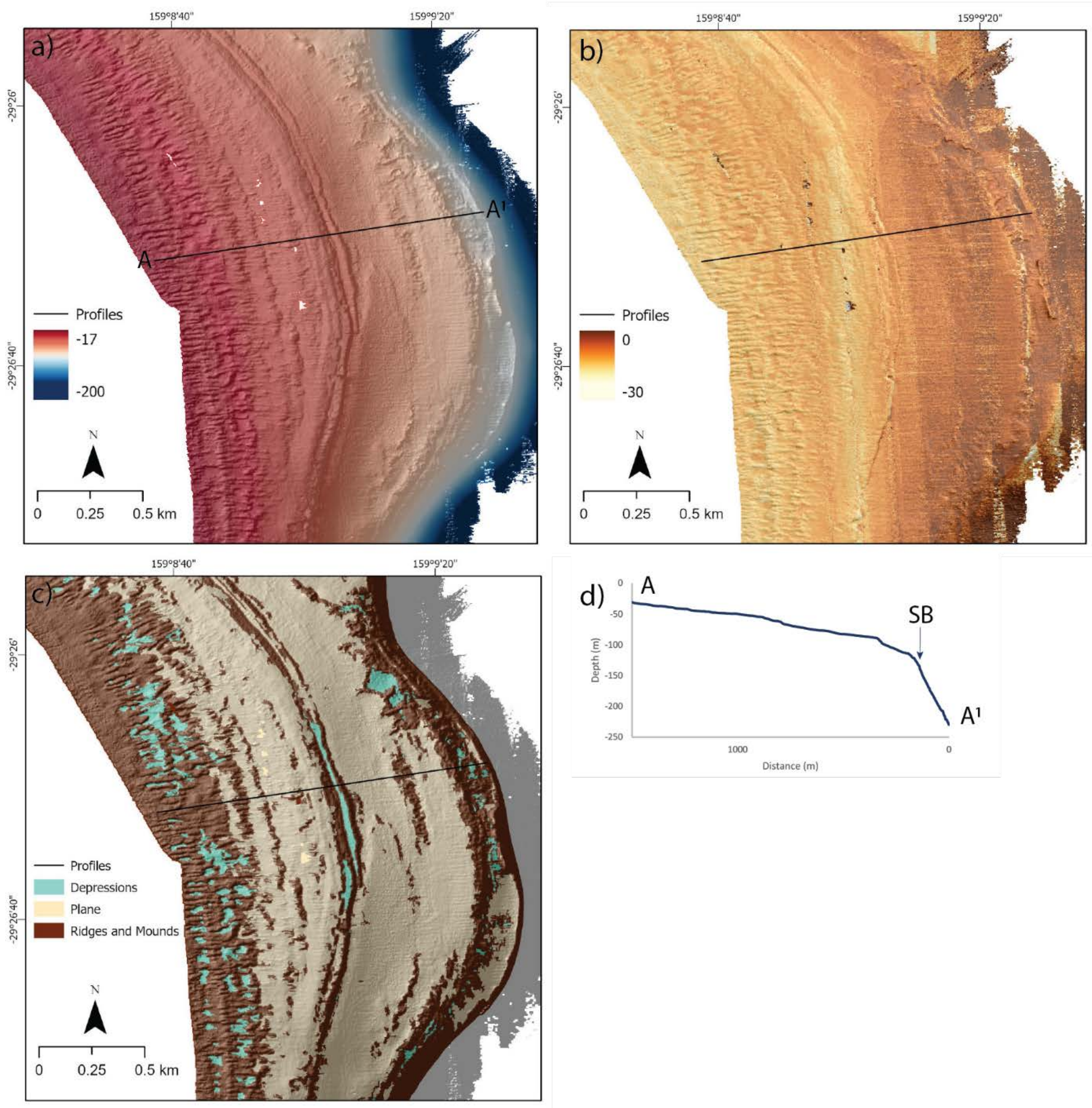


Figure 16. Middleton Reef, eastern shelf showing: (a) bathymetry; (b) backscatter; (c) morphological features, (d) cross-shelf bathymetric profile. Location of profile (A to A^1) is plotted on each map. SB denotes shelf break at ~120 m water depth.

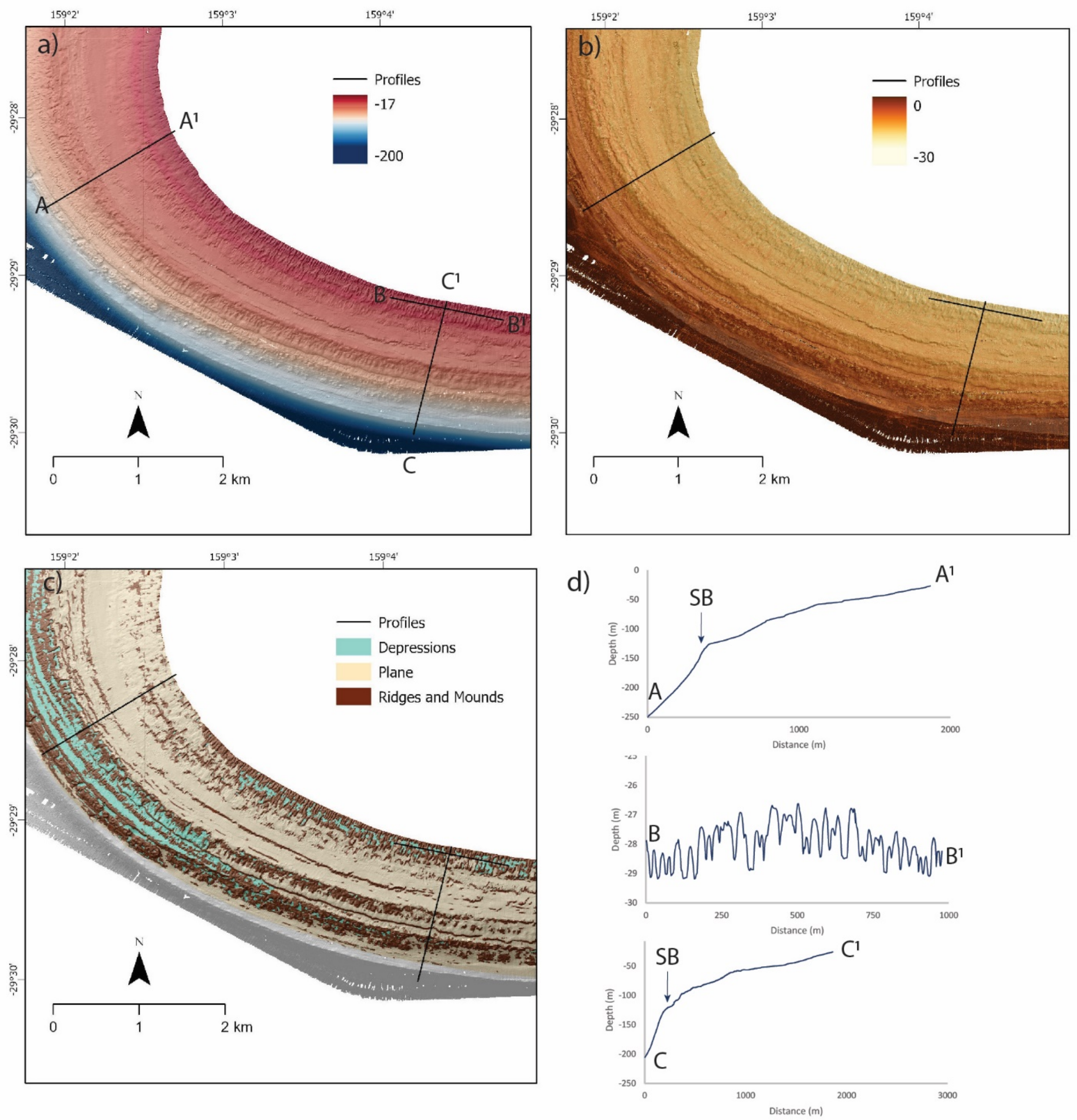


Figure 17. Middleton Reef, southwest shelf showing: (a) bathymetry; (b) backscatter; (c) morphological features, (d) cross-shelf bathymetric profile. Locations of profiles (A to A[1]; B to B[1]; C to C[1]) are plotted on each map. SB denotes shelf break at ~120 m water depth.

4.1.2 Elizabeth Reef

The mapped northwest area of Elizabeth Reef shelf is characterised by a gradually steepening seabed that increases from 15 m water depth at the lagoon entrance to ~120 m at the shelf break (Figure 18). The shelf is widest along the northwest sector, where the shelf break is 3.7 km from the lagoon, with an overall gradient of 3–4 degrees, steepening to >20 degrees beyond the shelf break (Figure 18). To the south and east the shelf is narrower, reducing to ~800 m and 1.4 km, respectively. Along these sections the shelf steepens at the 60–70 m depth contour, beyond which the seabed has a gradient of ~30 degrees (Figure 18).

As a proxy of the relative hardness of the seabed of Elizabeth Reef shelf, acoustic backscatter data reveals a clear transition from relatively soft to harder seabed toward the shelf break (Figure 19). Backscatter values span a greater range than for Middleton Reef shelf, with lowest intensity values of -30 dB (softer seabed) on the inner, increasing to -15 dB on the mid shelf and higher intensity values of -5 dB (harder seabed) on the outer shelf and upper slopes of the seamount. This pattern is consistent for the mapped extent of the shelf.

Based on the limited mapping of the northwest area, the stepped terraces that are identified around the full circumference of Middleton Reef appear to be restricted to a single terrace on the inner shelf, in ~30 m water depth. Thus, there does not appear to be clearly formed terraces at the deeper ranges as observed on Middleton Reef. This lack of clear definition of terrace features is likely due to the steeper and narrower form of the Elizabeth Reef shelf, particularly along the north and western mapped sections.

The fine-scale morphology of the mapped area of Elizabeth Reef shelf seabed comprises five primary feature types: plane, ridge, mound, scarp and depression. These features are simplified into three broad categories: plane, depression and ridges and mounds (Figure 20); the latter category representing all raised and steepened areas of seabed on Elizabeth Reef shelf. Summary statistics for each category are listed in Table 3, including the area of each feature type across bathymetric zones set at 20 m depth intervals.

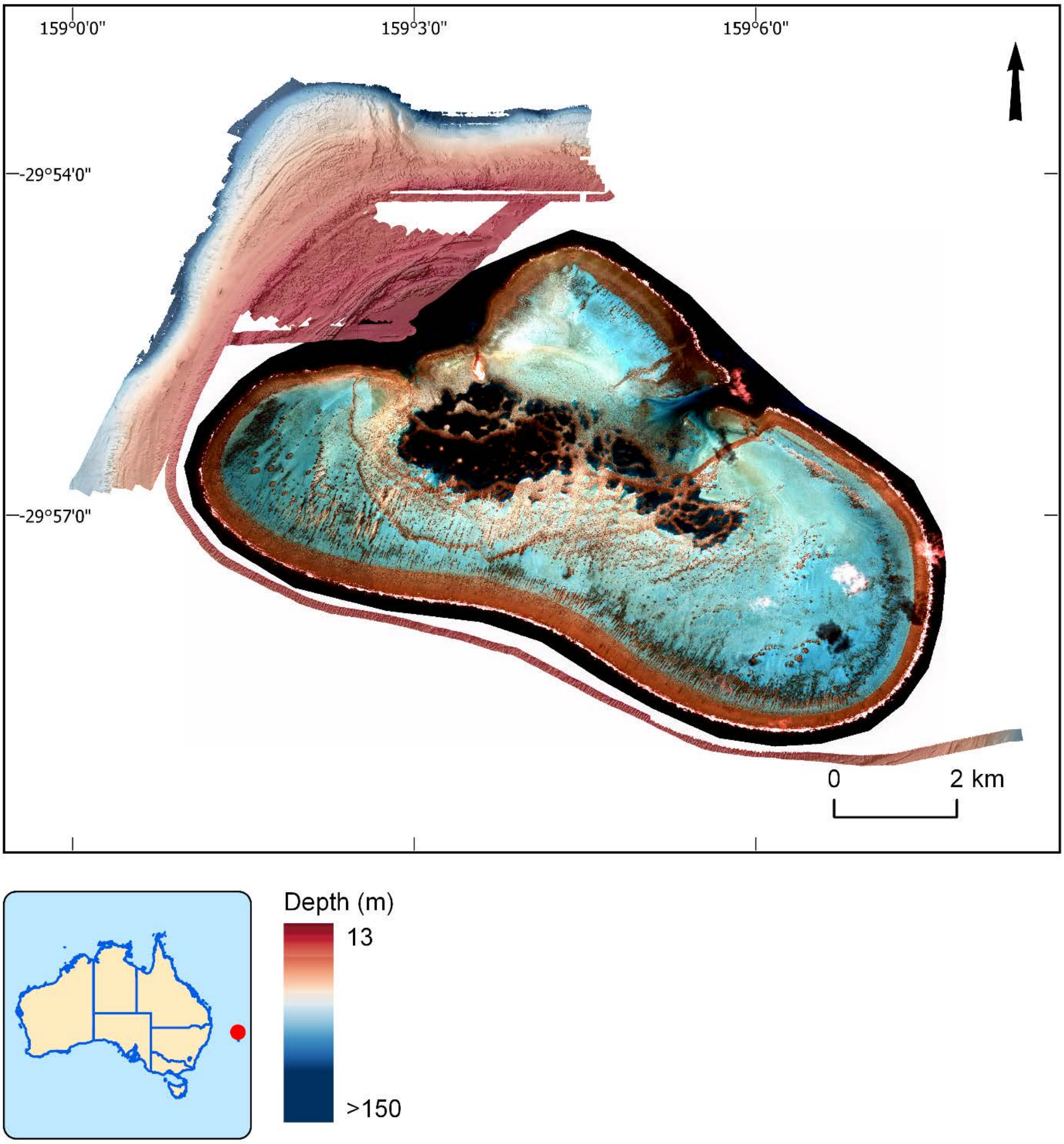


Figure 18. High-resolution multibeam bathymetry data (gridded at 3 m) for Elizabeth Reef shelf. Inset map shows the location of Elizabeth Reef off the east coast of Australia.

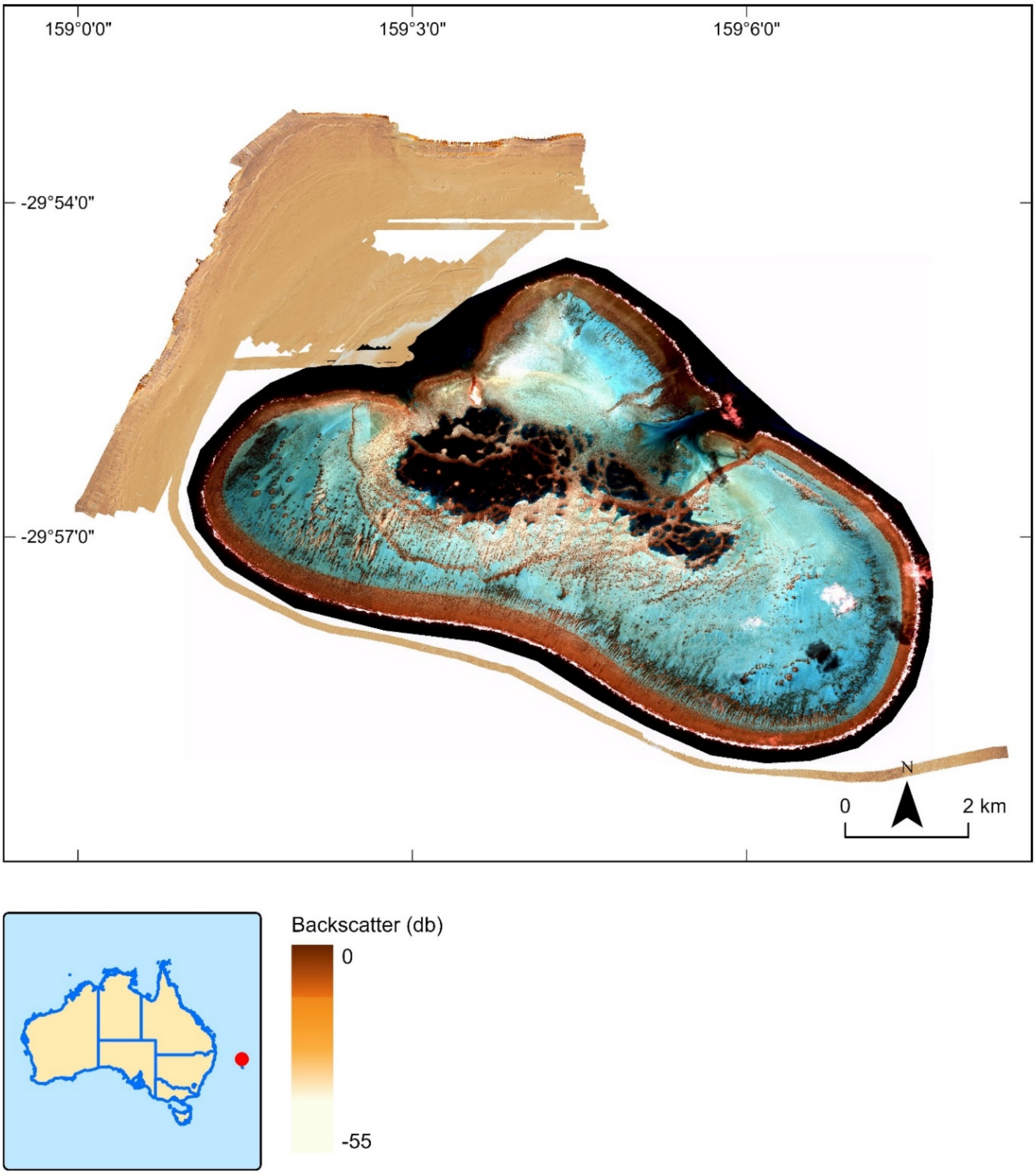


Figure 19. High-resolution acoustic backscatter data (gridded at 3 m) for Elizabeth Reef shelf. Inset map shows the location of Elizabeth Reef off the east coast of Australia.

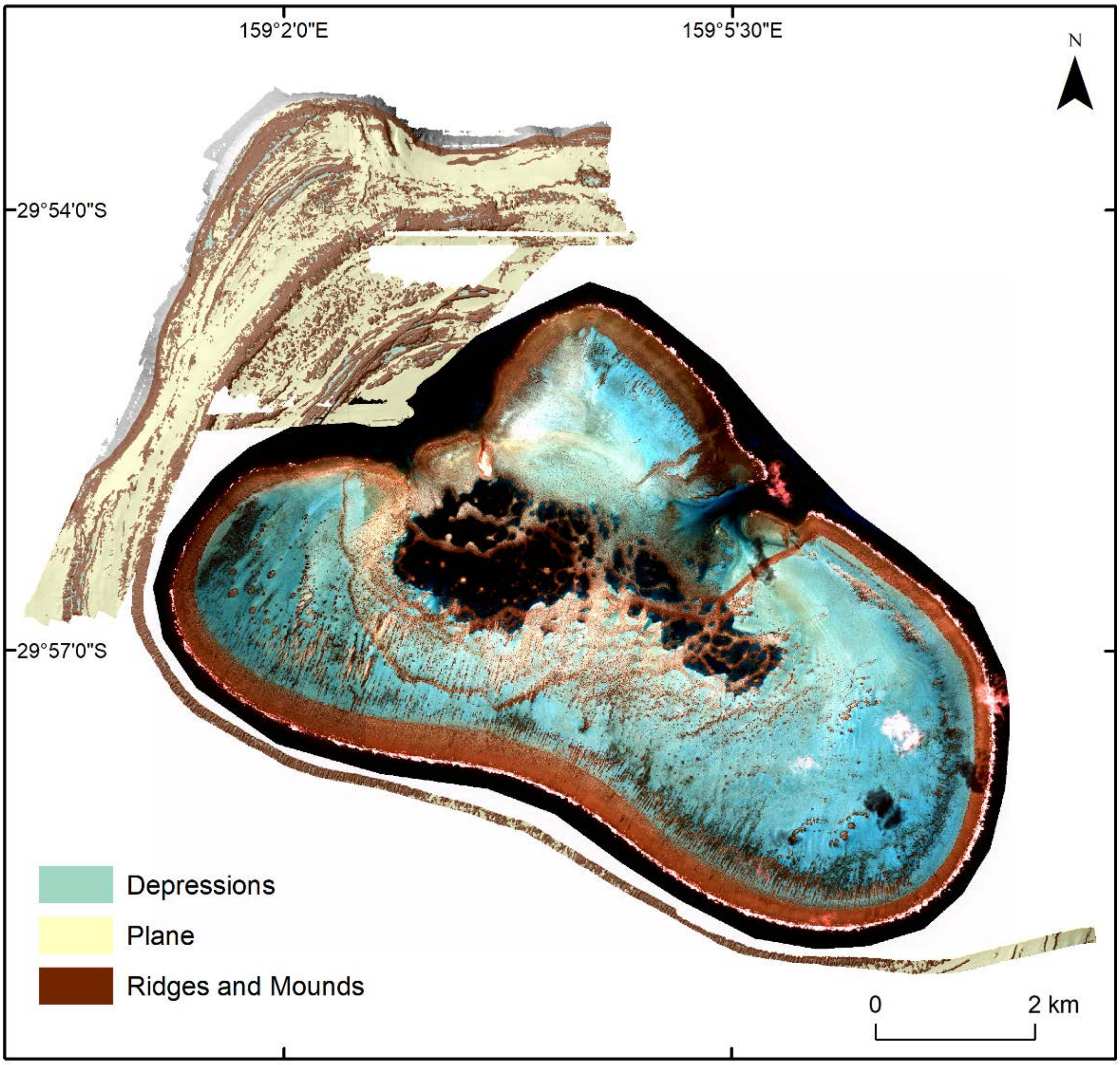


Figure 20. Geomorphological features of the mapped area of Elizabeth Reef shelf showing three main categories: depressions, plane, and ridges and mounds (including scarps); the latter category representing all raised and steepened areas of seabed on the reef shelf.

Table 3. Summary statistics for seabed morphologic features on the mapped area of Elizabeth Reef shelf.

Seabed morphological feature	Depth zone (m)	Area (km^2)	Percentage of mapped area	Percentage of feature class
Plane	10 – 30	1.93	9.8	18.3
	30 – 50	4.00	20.2	37.8
	50 – 70	2.52	12.7	23.7
	70 – 90	1.62	8.2	15.3
	90 – 120	0.52	2.6	4.9
	Total	***10.59***	***53.5***	***100***
Ridge and mound incorporating scarp	10 – 30	2.16	10.9	25.2
	30 – 50	3.20	16.1	37.3
	50 – 70	0.98	5.0	11.5
	70 – 90	1.10	5.6	13.0
	90 – 120	1.11	5.6	13.0
	Total	***8.55***	***43.2***	***100***
Depression	10 – 30	0.20	1.03	31.6
	30 – 50	0.13	0.66	20.2
	50 – 70	0.12	0.63	19.2
	70 – 90	0.12	0.63	18.5
	90 – 120	0.07	0.34	10.4
	Total	***0.64***	***3.29***	***100***

Planes are the most extensive morphologic feature on the mapped area of Elizabeth Reef shelf, covering ~10.6 km^2 (53.5% of the mapped area) and located mostly across the 30–50 m depth zone where they cover 4 km^2 and represent 38% of that feature type (Table 3; Figure 21). Overall, planes form a smooth seabed surface that dips toward the outer shelf along a gradient of ~2 degrees. The acoustic backscatter signal for planes is uniform and within the mid-range for the intensity mapped (~15 dB), indicative of a relatively uniform seabed hardness likely associated with a continuous sediment cover of sand and gravel.

Ridges and mounds occupy 8.55 km^2 (43.2% of the mapped area) and are distributed across all depth zones. Similar to Middleton Reef, these raised features are more extensive in the 30–50 m zone where they cover 3.2 km^2 and represent 37% of that feature class (Table 3). These features are also the most numerous, with greatest concentration on the broad terrace (plane) at 30 m water depth (Figure 21). As on Middleton Reef shelf, ridges form a series of semi-continuous linear features that extend around the shelf at different depths. Here, ridges are defined at four broad depth intervals; 15–25 m, 30–40 m, 50–65 m and 75–100 m. Of these, the ridge complex within the 30–40 m interval is the most prominent; forming a continuous, raised feature that is ~7 km long, up to 350 m wide and rises up to 5 m above the adjacent seabed. The ridges within the shallower 15–25 m depth range are of similar height (4–6 m), but for the most part slightly narrower at 200–250 m width. These shallower ridges were only partially mapped and may terminate near the lagoon entrance.

The backscatter signal for ridges and mounds is relatively moderate intensity (-15 to 20 dB) and slightly stronger in deeper water (-10 dB), indicative of a general trend toward harder surfaces (and possibly more exposed hardground) toward the outer shelf. In contrast, the moderate backscatter intensity on the shallower ridges is indicative of a softer substrate, possibly indicating greater benthic cover of soft corals.

Depressions are of limited extent within the mapped area of Elizabeth Reef shelf, covering 0.64 km^2, or 3.3% of the mapping coverage (Table 3; Figure 21). As on Middleton Reef shelf, depressions occur as enclosed, low-lying surfaces between ridges and are distributed across the shelf. Depressions that lie within the 10–30 m depth zone represent the greatest proportion (32%) of the feature class, but otherwise these isolated surfaces are evenly distributed across all depth intervals. Depressions range in depth from 0.5 m to 2 m and typically form linear features that extend several hundred metres between ridge crests. A small number of isolated semi-circular to irregular depressions also occur within ridge features (Figure 21). Backscatter intensity for depressions records a similar response to ridges with a trend from moderate intensity (-20 dB) on the shallower inner shelf to slightly stronger intensity (-10 to -15 dB) in deeper waters. This is again indicative of a broad transition to slightly harder seabed (coarser sediment) in depressions toward the outer shelf.

In summary, the seabed morphology of Elizabeth Reef northwest shelf is characterised by a series of semi-continuous ridge and mound fields with intra-field depressions, separated by gently sloping planes that steepen toward the shelf edge. Importantly, the ridge and mounds occupy approximately 40% of the mapped area providing extensive raised hardground reef habitat across the full depth range of the shelf.

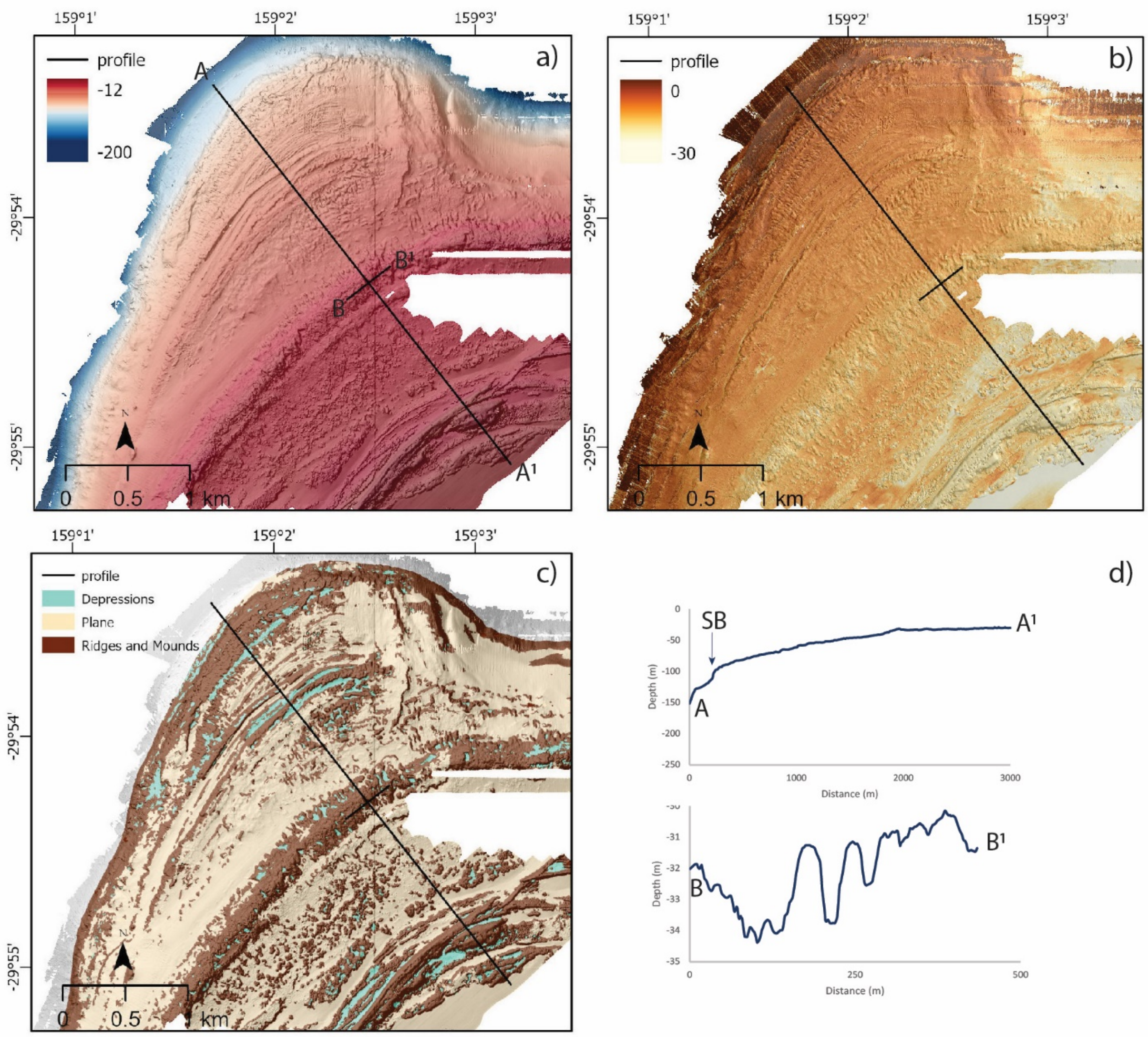


Figure 21. Elizabeth Reef northwest shelf, showing: (a) bathymetry; (b) backscatter; (c) morphological features, (d) bathymetric profiles. Locations of profiles (A to A1; B to B1) are plotted on each map. SB denotes shelf break at ~120 m water depth.

4.2 Sessile epifaunal communities

4.2.1 Compositional patterns in sessile morphospecies assemblages

Annotation of AUV imagery acquired on the shelfs of Elizabeth and Middleton Reefs revealed a range of habitats distributed across key geomorphic features (Figure 22; Figure 23). Ridges, mounds and planes observed on the inner shelf (20–50 m depth) were generally dominated by turfing macroalgae, cnidarian corals (hard reef-building corals and soft leather corals),and bacterial mats (Figure 24; Figure 25), while planes and ridges on the outer shelf (70–110 m) were dominated by black corals (branching and whip morphologies), interspersed among areas of coarse carbonate sand, turfing algae, hard corals, sponges and calcareous rhodoliths beds (Figure 26; Figure 27). This general pattern was confirmed by habitat data derived from stereo-BRUV imagery at each reef (Figure 28; Figure 29; Figure 30).

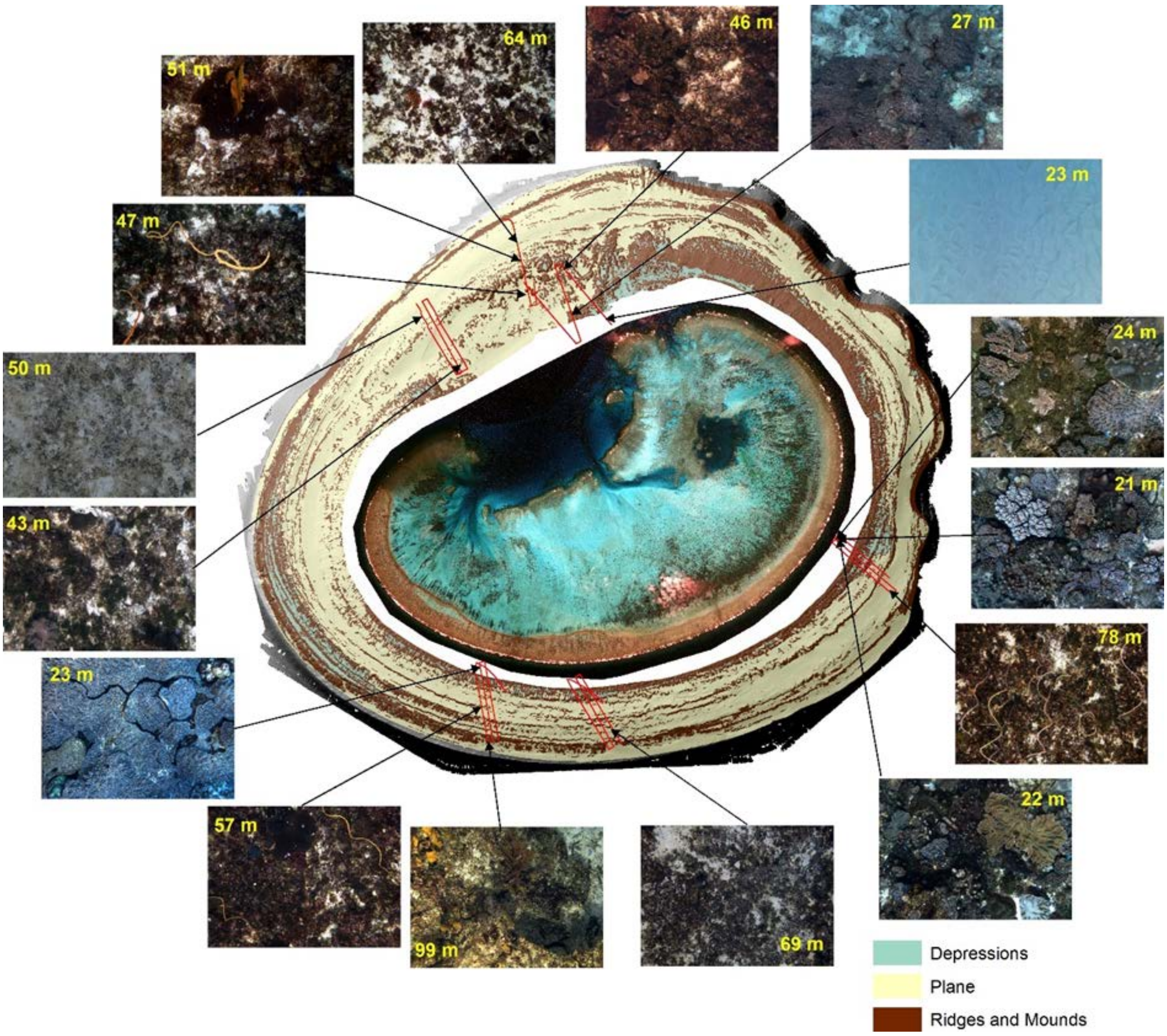


Figure 22. AUV images showing the range of benthic habitats across key geomorphological features at Middleton Reef shelf. Generally, ridges and mounds in mesophotic depths are colonised by a dense cover of hard and soft corals, with planes characterised by a mix of barren sediments and moderate cover of turfing algae, with rhodolith beds in deeper areas toward the shelf edge. AUV track lines are shown in red.

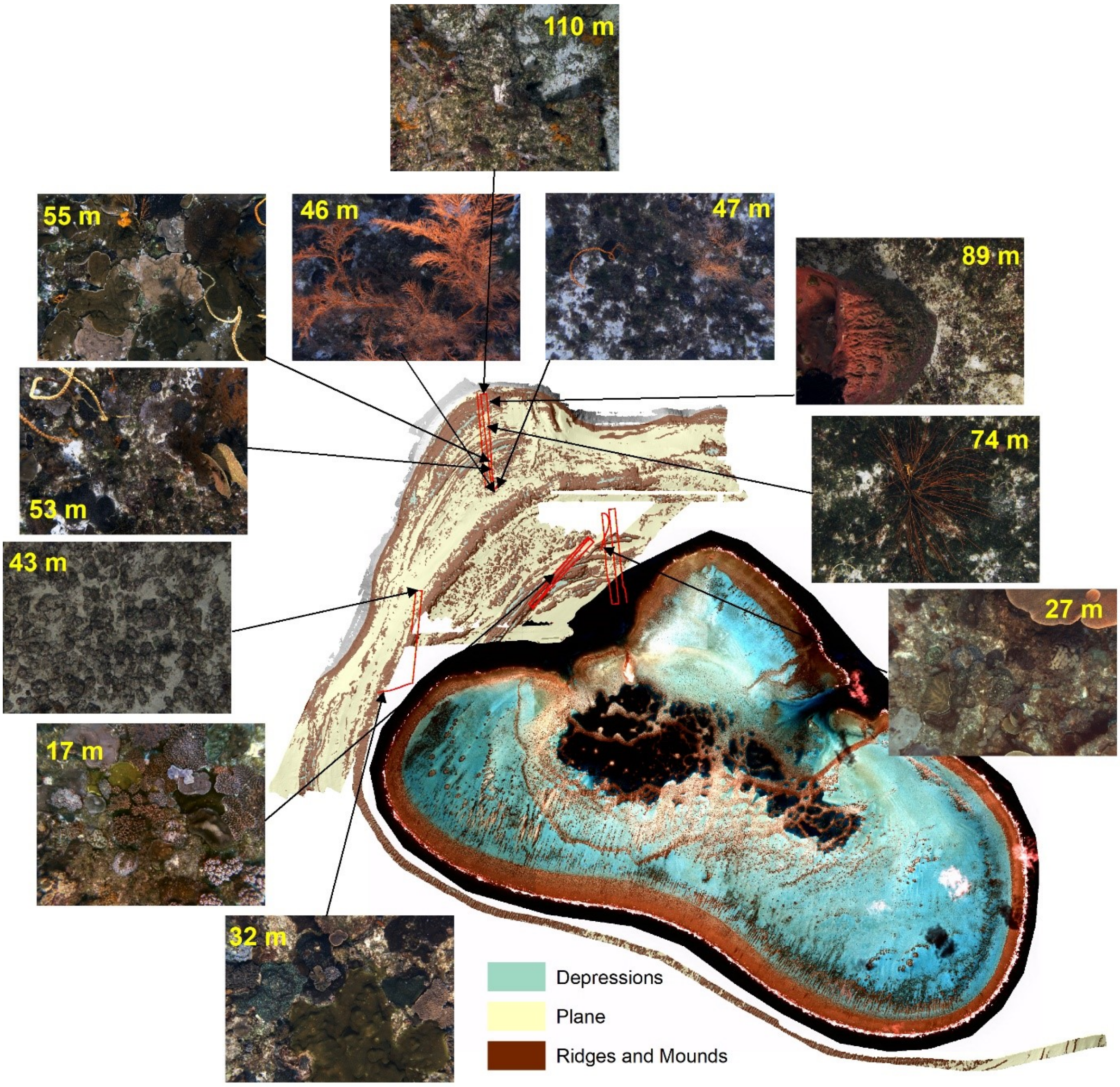


Figure 23. AUV images showing the range of benthic habitats across key geomorphological features at Elizabeth Reef shelf. AUV track lines are shown in red.

A highly diverse epifaunal assemblage was recorded from AUV imagery, with 234 biological morphospecies identified. Hard corals dominated the assemblage with 96 morphospecies, followed by sponges (59 morphospecies), black and octocorals (31 morphospecies) and macroalgae (28 morphospecies). Representatives from ascidians, bryozoans, hydroids, anemones, crinoids and worms were also recorded.

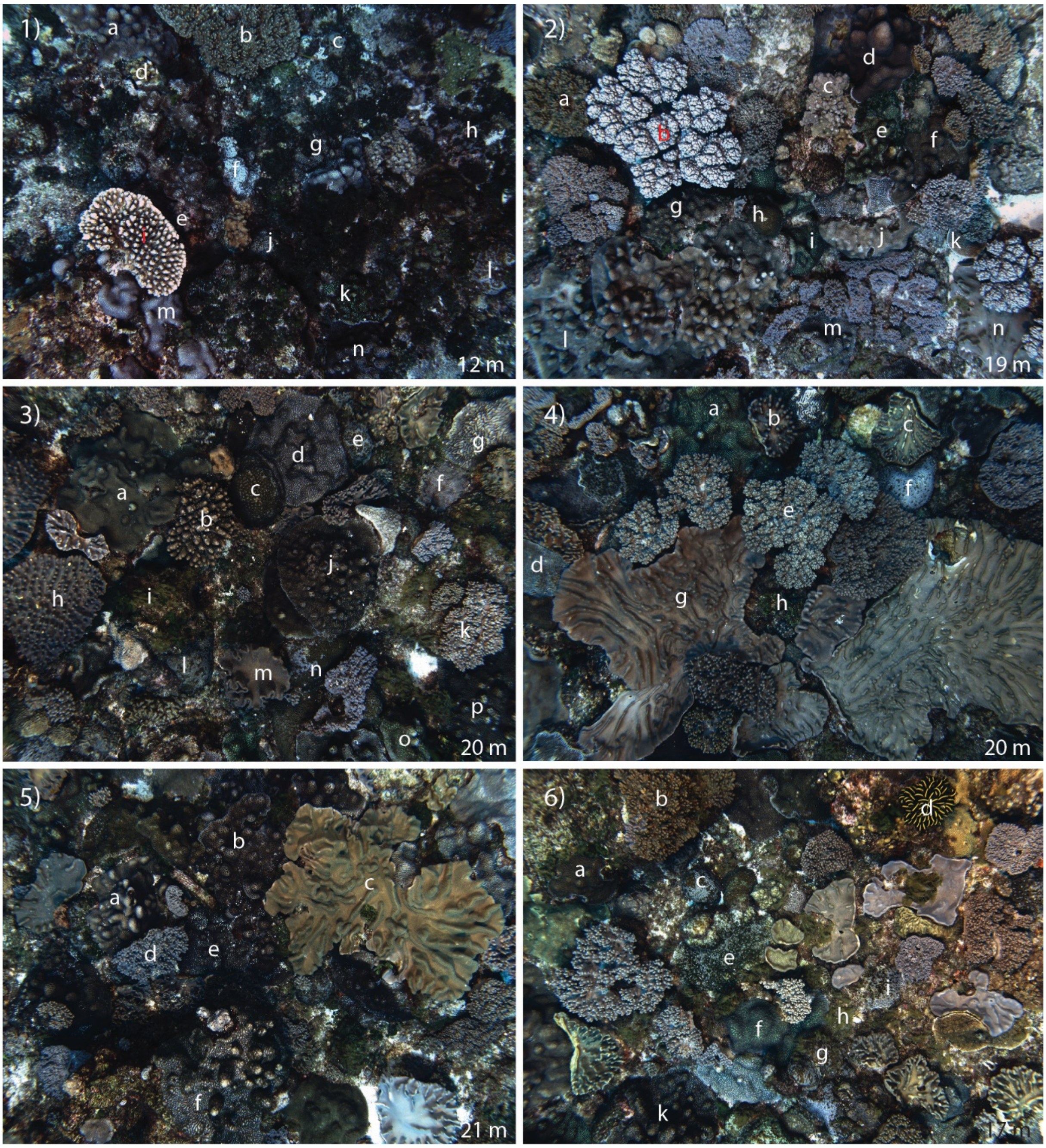


Figure 24. AUV images showing seafloor habitat across inner shelf ridge and mound features in 10–50 m water depth at Middleton Reef. Sessile epifaunal communities are dominated by hard and soft coral, and a high percent cover of turf algae. Pos. = Possibly **1.** (b) *Sinularia* sp. (c, h, j, l) *Dipsastraea* cf *speciosa* (d) Pos. *Cyphastrea* sp. (e) *Astrea curta* (f) Pos. *Favites* sp. (g, n) *Platygyra* sp. (i) *Acropora* sp. (k) *Platygyra* cf *sinensis* (m) *Leptoria* sp. **2.** (a, b) *Sinularia* sp. (c) Pos. *Cyphastrea* sp. (d) Pos. Merulinidae (f, g, m) *Platygyra* sp. (e, i) *Platygyra* cf *daedalea*, (h) *Dipsastraea* cf *matthaii* (j, l) *Hydnophora* sp. (k) *Turbinania* cf *mesenterina* **3.** (a) Pos. *Leptoria* sp. (b) *Acropora* sp. (c) *Dipsastraea* sp. (d, j, p) *Platygyra* sp. (e, l, n) *D.* cf *speciosa* (f) Pos.*Cyphastrea* sp. (g) Pos. *Paragoniastrea* cf *australensis* (h) *Lobophytum* sp. (i) green filamentous algae (k) *Sinularia* sp. (m) *Sarcophyton* sp. (o) *Platygyra* cf *sinensis* **4.** (a) *Platygyra* sp. (b) *Lobophytum* sp. lobate morph (c, g) ridged morph (d) Pos. *Platygyra* (g) *Sinularia* sp. (h) *D.* cf *speciosa* (j) *Halimedia* (algae) **5.** (a) Pos. *Leptoria* (b) Merulinidae (c, (d) *Lobophytum* sp. (e, f, k) *Platygyra* sp. **6.** (a) Merulinidae (b) *Sinularia* sp. (c, g) *D.* cf *speciosa* (d) Crinoid sp. (e, i) Merulinidae (h) green filamentous algae (j) Pos. *Echinophyllia* cf *aspera.*

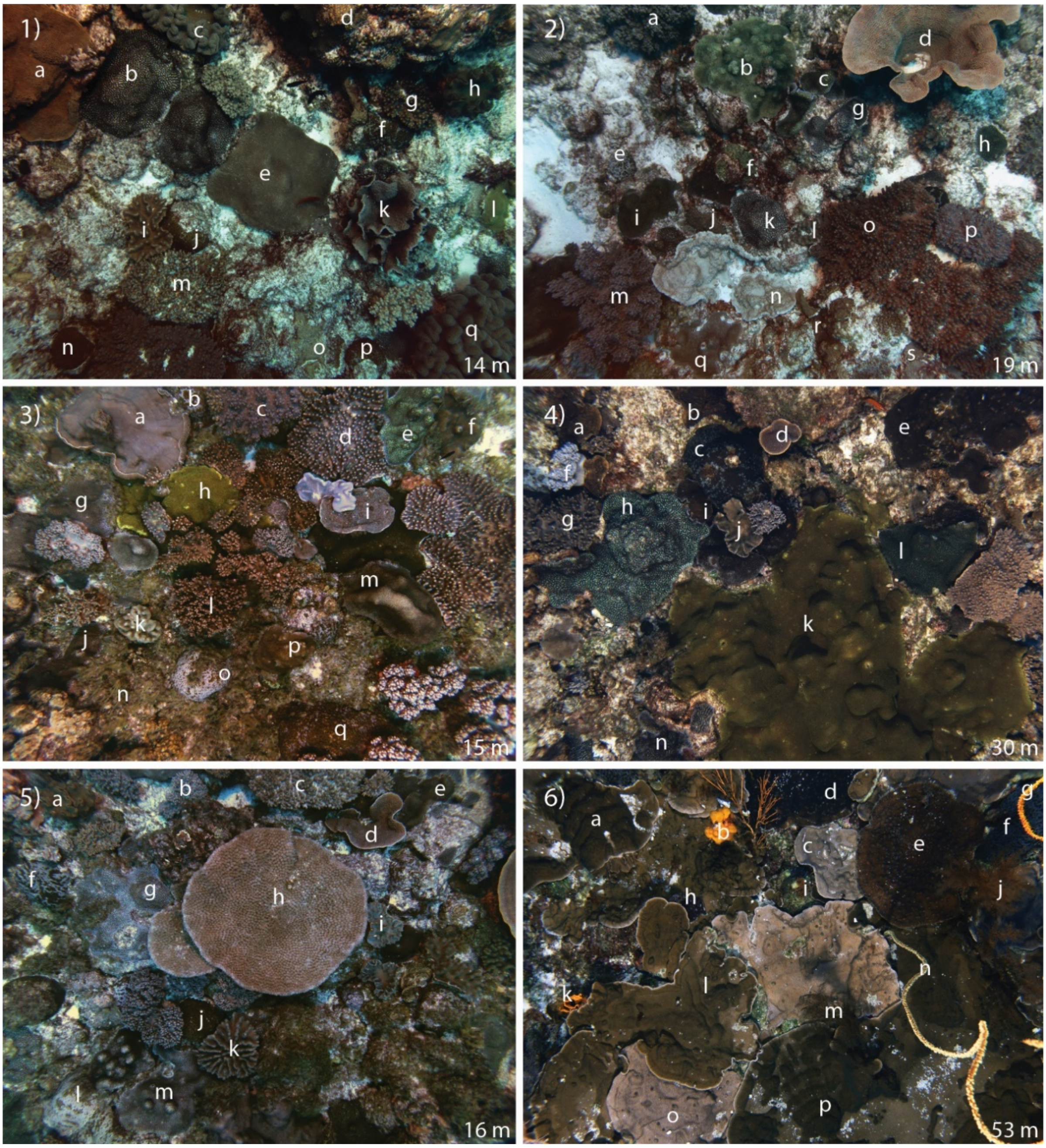


Figure 25. AUV images showing seafloor habitat across ridge and mound features on the outer shelf at Elizabeth Reef. Pos. = Possibly **1.** (a) *Turbinaria* cf *frondens* (b) *Platygyra* sp. (c, h, q) *Sarcophyton* sp. (d) *Astrea curta*, (e) *Hydnophora* sp. (f) *Dipsastraea* cf *speciosa* (g) *Lobophytum* sp. (digitate) (i) (ridged) (j, p) *D.* cf *matthaii* (k) *T.* cf *bifrons* (l) *Coscinaraea* cf *columna* (m) *Sinularia*/*Lobophytum* (n) *Favites* sp. (o) *Cyphastrea* cf *serailia* **2.** (a, m, o, p) *Sinularia* spp. (b, g) Merulinidae spp. (c, h, k, m) *Platygyra* spp. (d) *T.* cf *mesentarina* (e) Pos. *Homophyllia* sp. (f) *Dipsastraea* sp. (i) Pos. *Goniastrea* (j) Pos. *Favites* sp. (l) *Lobophytum* sp. (n) *Montipora* sp. (q) *Hydnophora* sp. (r) *A. curta* (s) *Paragoniastrea* cf *australensis* **3.** (a) *Turbinaria* sp. (colony overturned) (b, o) *D. speciosa* (c, l) *Sinularia* spp. (d) *Lobophytum* sp. (e) *Platygyra* cf *daedalea* (f, g, j, m, p) Merulinidae spp. (h) Pos. *C. columna* (i) *Turbinaria* sp. (k) *Sarcophyton* sp. (n) green filamentous algae (q) *D.* cf *matthaii* **4.** (a, b) *Echinophyllia* cf *aspera* (c) *D. speciosa* (d)*T.* cf *mesenterina* (e) Merulinidae sp. (f) Soft coral (g, p, m) *Sinularia* sp. (h) *P.* cf *daedalea* (j, p) *Lobophytum* sp. (k) *C. cf columna* (I, n) Merulinidae sp. **5.** (a) *Sarcophyton* sp. (b, c) *Sinularia* sp. (d) *T.* cf *mesenterina* (e, g, m) Merulinidae spp. (f, j, l) *Dipsastraea* spp. (h) *Turbinaria* cf *peltata* (i, k) *Lobophytum* sp. **6.** (a, c, l, m, o, p) *Montipora* spp. (b, k) Orange sponge (d, e) *E.* cf *aspera* (f) *Euphyllia* cf *ancora* (g, n, i) Black coral whip *Cirrhipathe* spp. (h) Pos. *Homophyllia* (j, m) black corals, Myriopathes sp. (Myriopathidae).

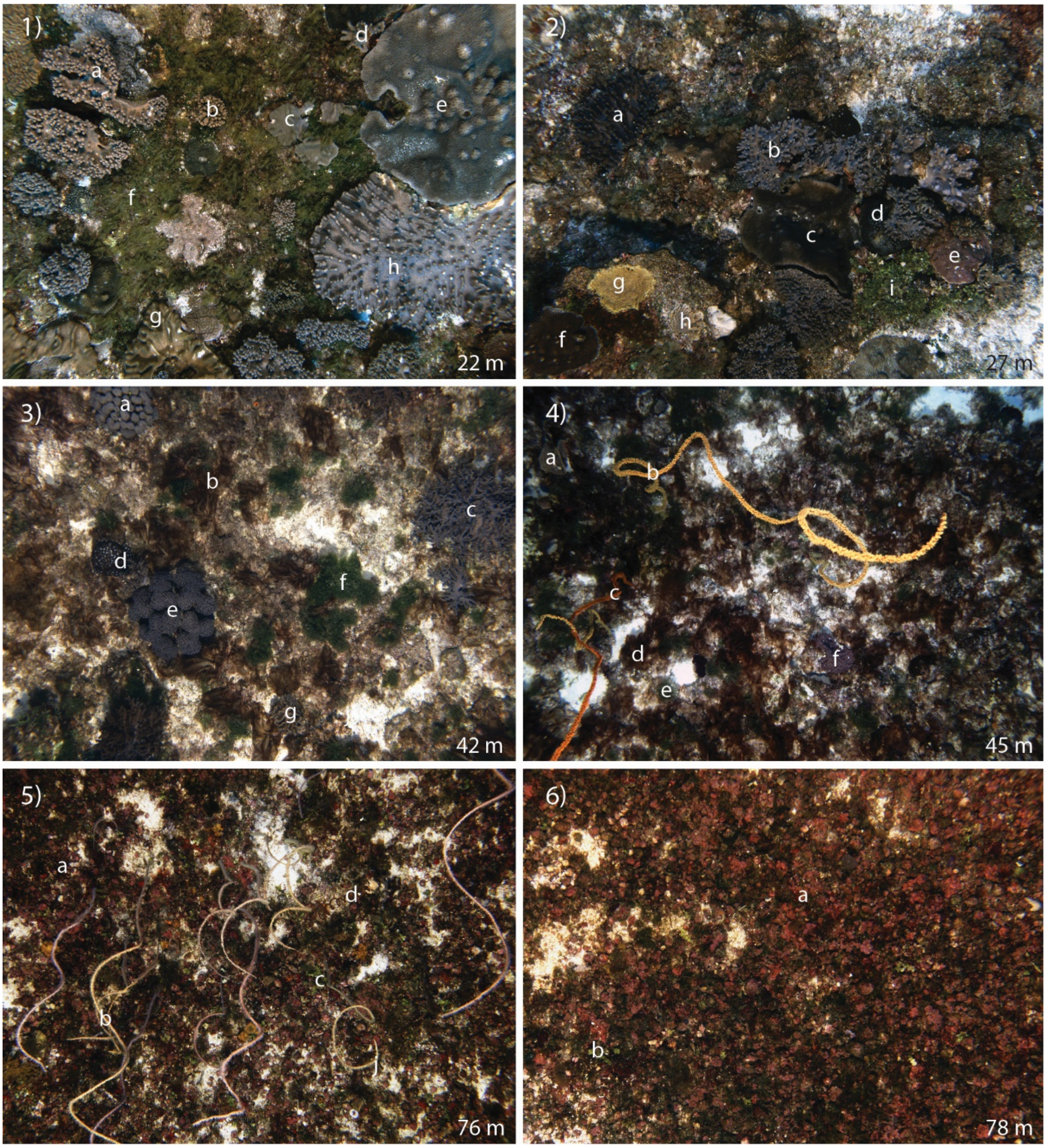


Figure 26. AUV images showing seafloor habitat across Middleton Reef shelf. Sessile epifaunal communities dominated by hard and soft coral interspersed with turf / filamentous algae and increasing abundance of rhodoliths with depth. Pos. = Possibly **1.** (a, d) *Sinularia* sp. (b) *Acropora* sp. (c, g, h) *Lobophytum* sp. (e) *Hydnophora* sp. (f) green filamentous algae **2.** (a, b) *Sinularia* sp. (c) *Hydnophora* sp. (d) *Dipsastraea* cf *speciosa* (e) *Cyphastrea* cf *microphthalma* (f) Merulinidae sp. (g) Pos. *Paramontastraea* cf *salebrosa* (h) *Astrea* cf *curta* (i) *Halimedia* sp. (algae) (k) *Hydnophora* cf *exesa* **3.** a Pos. *Euphyllia* sp. (b) brown filamentous algae/cyanobacteria (c) *Sinularia* sp. arboresent, (d) Pos. *Paragoniastrea* cf *australensis* (e) *Euphyllia* cf *ancora* (f) turfing green algae (g) *Lobophytum* sp. **4.** (a, f) sponges (b, c) Black coral whips, *Cirrhipathe* sp. (d) brown filamentous algae (e) turfing green algae **5.** (a) rhodoliths (b) Black coral whips, *Stichopathes* sp. (c) *Halimedia* sp. (algae) (d) Black coral whip, *Cirrhipathe* sp. **6.** (a) rhodolith bed (b) *Halimedia* sp.

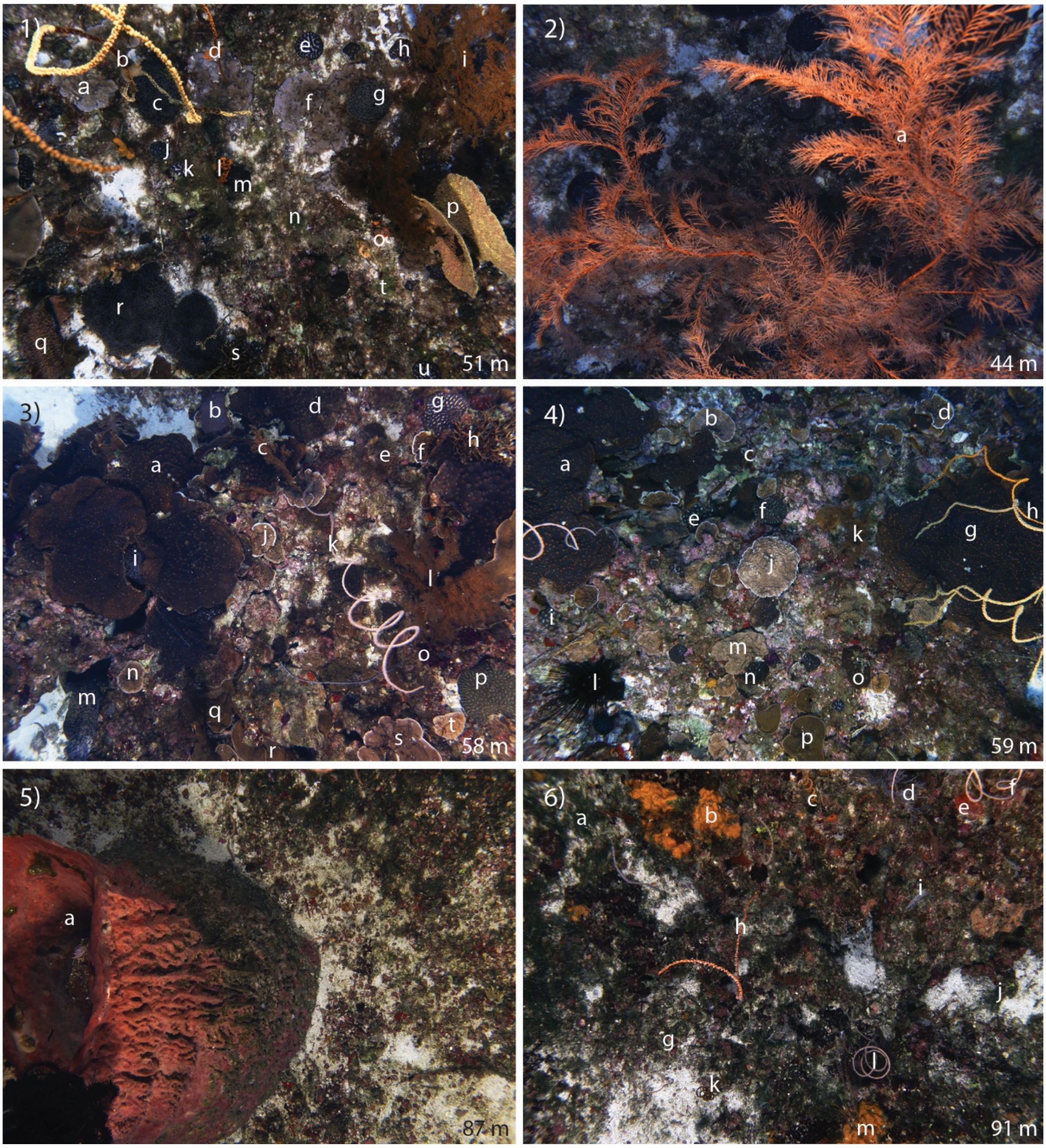


Figure 27. AUV still images showing mesophotic seafloor habitat on the north-western shelf of Elizabeth Reef. Pos. = Possibly **1.** (a, f) *Montipora* sp. (b, d) Black coral whips, *Cirrhipathes* spp. (c, g, r) *Euphyllia ancora* (e, j, k, u) Pos. *Platygyra*/*Paragoniastrea australensis* (l, o, p, q) Sponges (m) Pos. *Dipsastraea* sp. (n, t) green algae (s) *Seriatopora* cf *hystrix* **2.** (a) Black coral, *Myriopathes* sp. (Myriopathidae) **3.** (a, d) *Echinophyllia aspera* (b) Pos. *Plesiastrea* sp. (c, l) Pos. Antipathidae spp. (m) Moray Eel, Pos. *Gymnothorax* sp. (e, k) Antipathidae Pos. *Cirrhipathes* (f, j, n, t) Pos. *Leptoseris* cf *explanata* (g, p) Merulinidae spp. (h) *Seriatopora* cf *hytrizx* (i) *Euphyllia ancora* (q, r, s) *Montipora* sp. **4.** (a, g) *Echinophyllia aspera* (b, d, j) *Leptoseris* cf *explanta* (c) Fish (e, i) Pos. *Favites* sp. (f) Merulinidae spp. (h) Black coral (Antipathidae) *Cirrhipathes* sp. (K) Black coral, *Myriopathes* sp. (Myriopathidae) (l) *Diadema antillarum* (sea urchin) (m) *Porites* cf *heronensis* (n) Pos. *Paragoniastrea australensis* (o) Pos. *Blastomussa* cf *merleti* (p) *Montipora* sp. **5.** Barrel sponge on unconsolidated coarse sand with rhodoliths and green algae **6.** (a, j) green algae (b, e, m) encrusting sponges (c, h, k) Black coral (Antipathidae) *Cirrhipathes* sp. (f, l) Black coral whips, (Antipathidae) *Stichopathes* sp. (d, i) Pos. *Antipathes* sp. (g) rhodoliths.

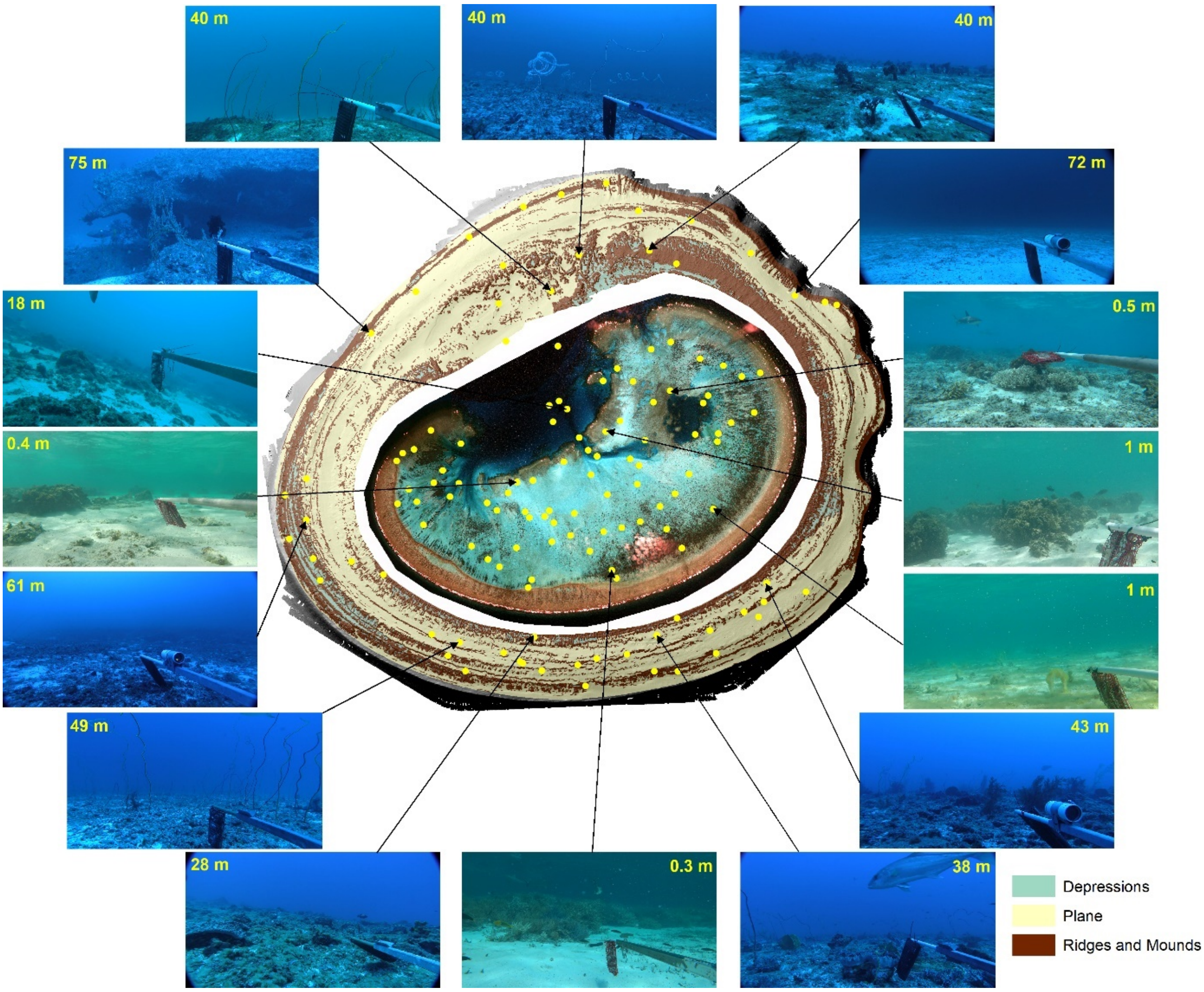


Figure 28. Stereo-BRUV images showing a range of benthic habitats across shelf and lagoon environments of Middleton Reef shelf. Yellow dots indicate stereo-BRUV locations.

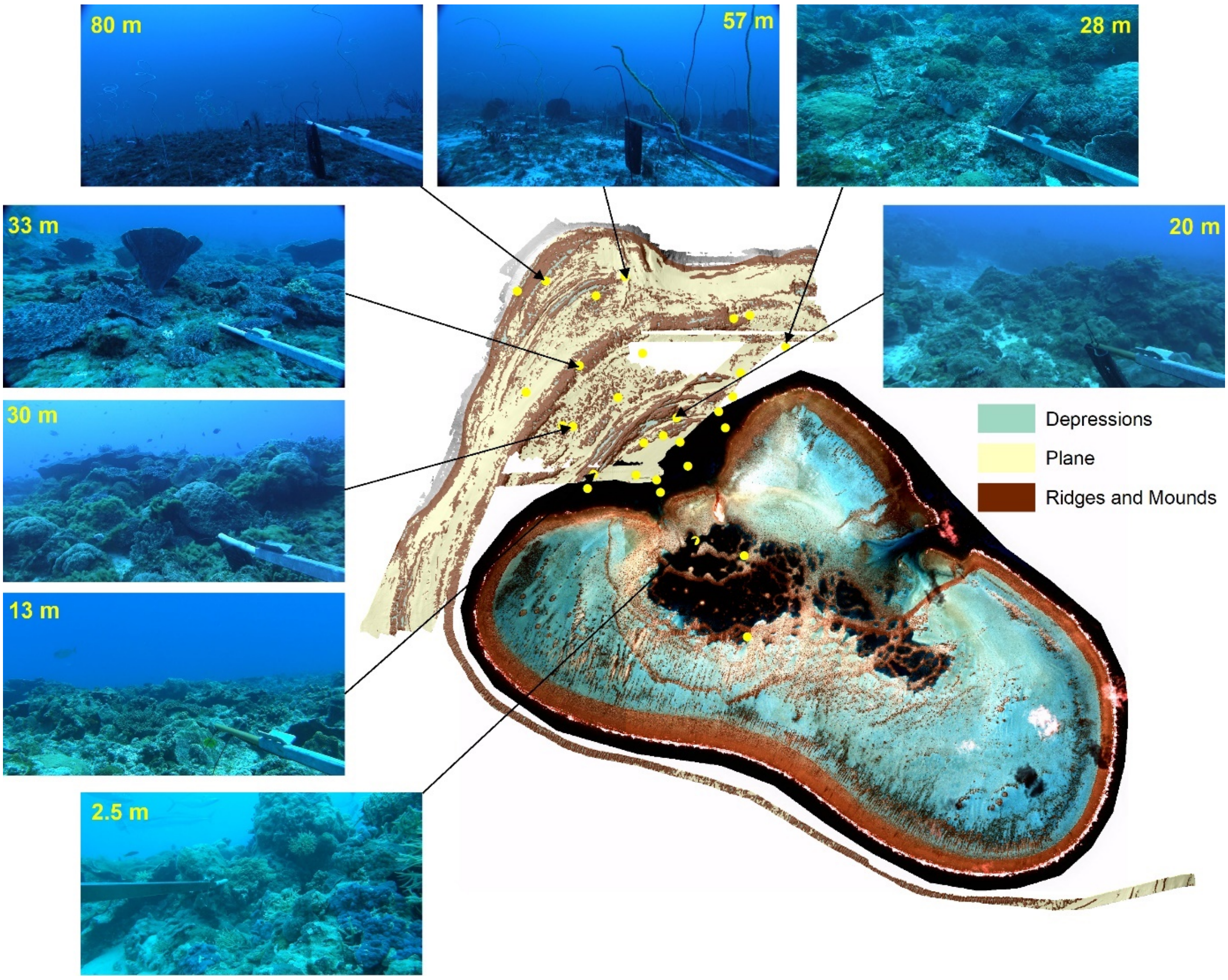


Figure 29. Stereo-BRUV images showing the range of benthic habitats sampled across shelf and lagoon environments at Elizabeth Reef. Yellow dots indicate stereo-BRUV locations.

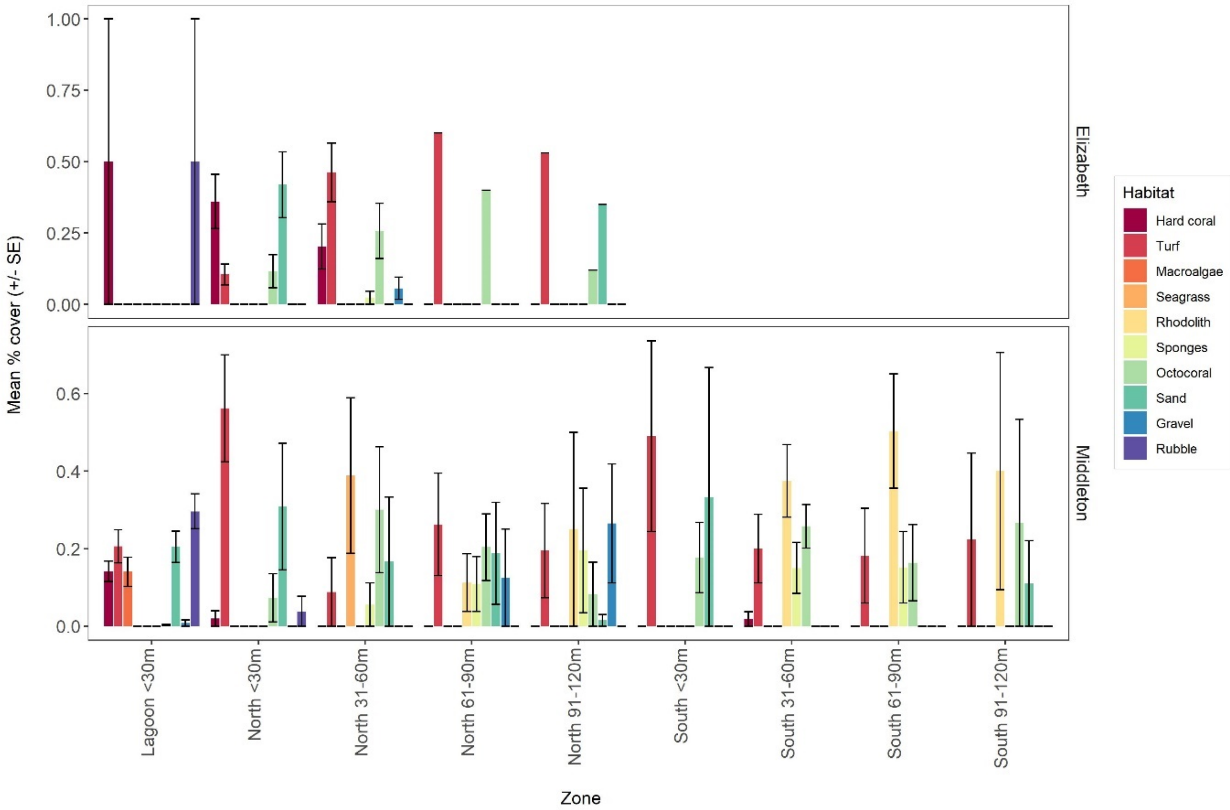


Figure 30. Mean percent cover of benthic habitat categories derived from stereo-BRUV footage acquired across lagoon and shelf environments at Elizabeth and Middleton Reefs.

In the following, we summarise the spatial and depth distribution of the dominant benthic assemblages and sediment types across Elizabeth and Middleton Reefs, as quantified from AUV imagery.

Macroalgae and Rhodoliths

Mean percent cover of turfing macroalgae was consistently high across the shelf to 70 m depth at Middleton Reef and comprised a high proportion of the benthos across all depth gradients at Elizabeth Reef (Figure 31; Figure 32). At Middleton Reef north and south, mean percent cover of turf macroalgae was highest within the 51–70 m (56.2% $\pm$ 0.6) and < 30 m (60% $\pm$ 1.5 depth range), respectively. Beyond 70 m, the cover of turfing macroalgae declined to less than 20% and was lowest on substrate deeper than 90 m (3.4% $\pm$ 0.3 and 1.4% $\pm$ 0.2 north and south, respectively). This coincided with a notable increase in rhodolith cover with increasing depth from 31–50 m. However, this pattern was not observed at Elizabeth Reef (north) where turfing macroalgae cover remained high across the entire shelf. Turfing macroalgae increased from 32.1% ($\pm$ 0.5) on seabed shallower than 30 m to 84.4% ($\pm$ 0.4) in 71–9 0 m, with a < 1% cover decline on the deepest reaches of the shelf. Rhodoliths only occurred at depths > 51 m on Elizabeth Reef shelf and increased only slightly from 1.1% ($\pm$ 0.1) at 51–70 m to 3.4% ($\pm$ 0.2) on substrate deeper than 90 m (Figure 31; Figure 32).

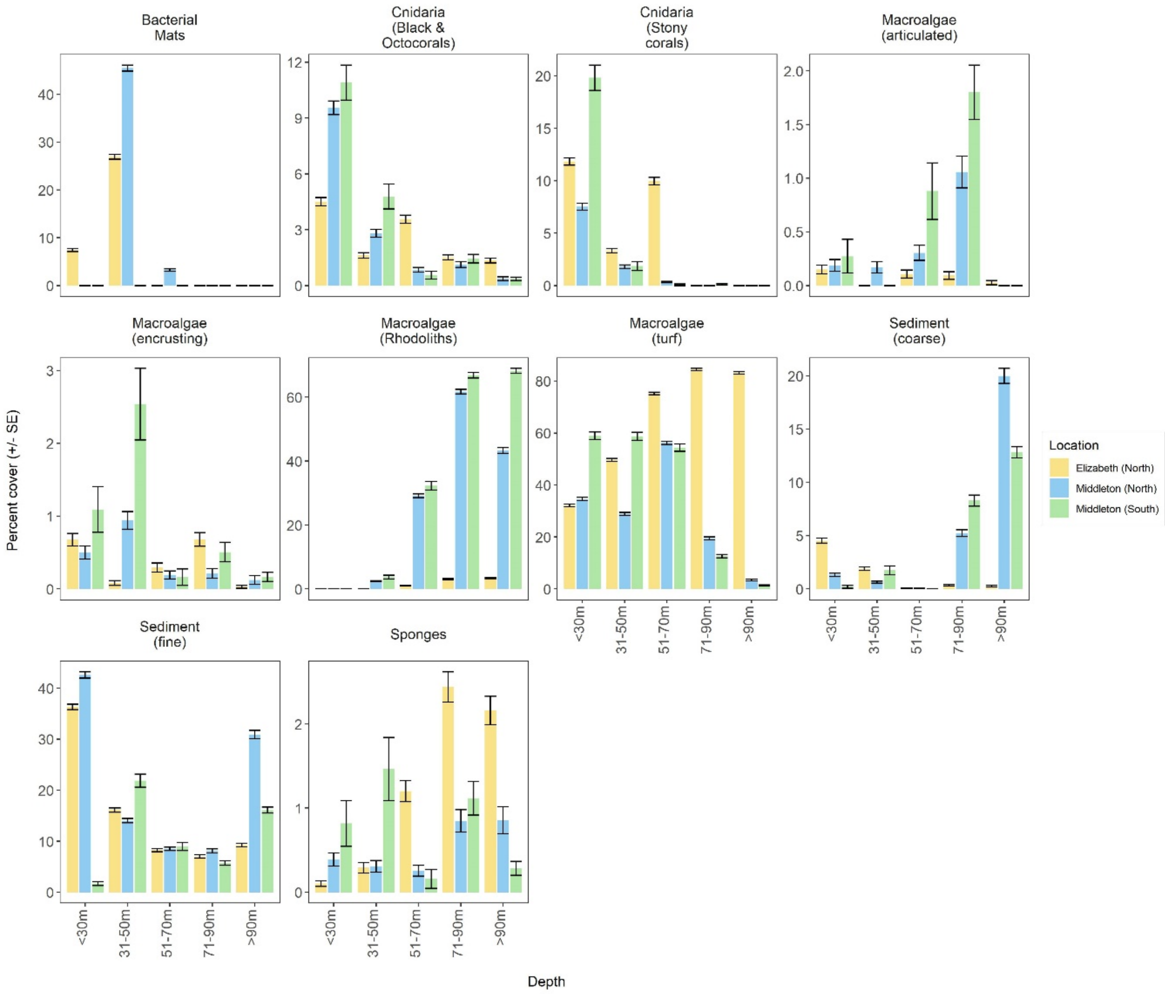


Figure 31. Mean percent cover of pooled morphospecies recorded in AUV imagery acquired across shelf environments at Elizabeth (north) and Middleton (north and south) Reefs.

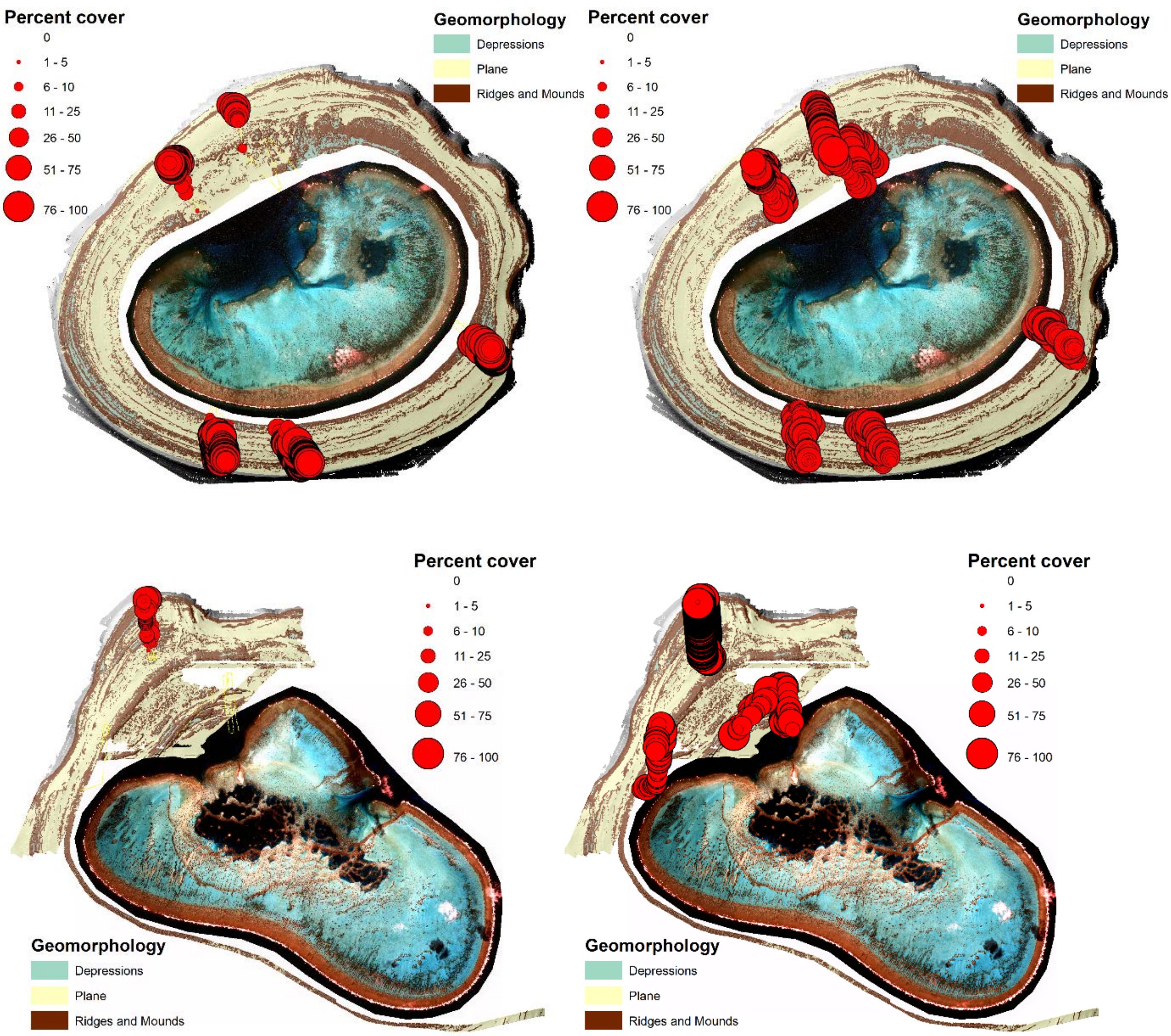


Figure 32. Spatial distribution of rhodoliths (left) and turfing macroalgae (right) for Middleton (top) and Elizabeth (both) Reefs.

Scleractinian reef-building corals

Generally, percent cover of live scleractinian corals was highest at shallow depths (< 30 m) (Figure 31). There was an increase in coral cover at 51–70 m at Elizabeth Reef north, and a general decline in cover across the depth gradient at Middleton Reef (north and south). No hard corals were observed at depths > 90 m at either reef. Branching, encrusting and sub-massive hard coral morphs were recorded at both reefs to approximately 70 m depth (Figure 33; Figure 34; Figure 35). Branching *Acropora* were recorded in low abundance at Middleton Reef (south) at depths < 30 m, while at Elizabeth Reef, this taxon occurred at depths < 70 m. Pocilloporid corals were only recorded on the northern aspect of each reef and mean percent cover declined with increasing depth to 70 m. Encrusting and sub-massive merulinid corals occurred in high abundance on shallow reef (< 30 m) and declined with increasing depth to < 70 m. Corals from the genera *Platygyra*, *Dipsastraea* and *Paragoniastrea* were the dominant reef corals within this taxon group. Encrusting and fleshy coral species from the Family Lobophylliidae increased marginally with depth at Elizabeth Reef, and were not recorded at deeper depths at Middleton Reef. Mean percent cover of encrusting *Montipora* species was highest at 51–70 m at Elizabeth Reef, and remained relatively low across depth zones at Middleton Reef (Figure 33).

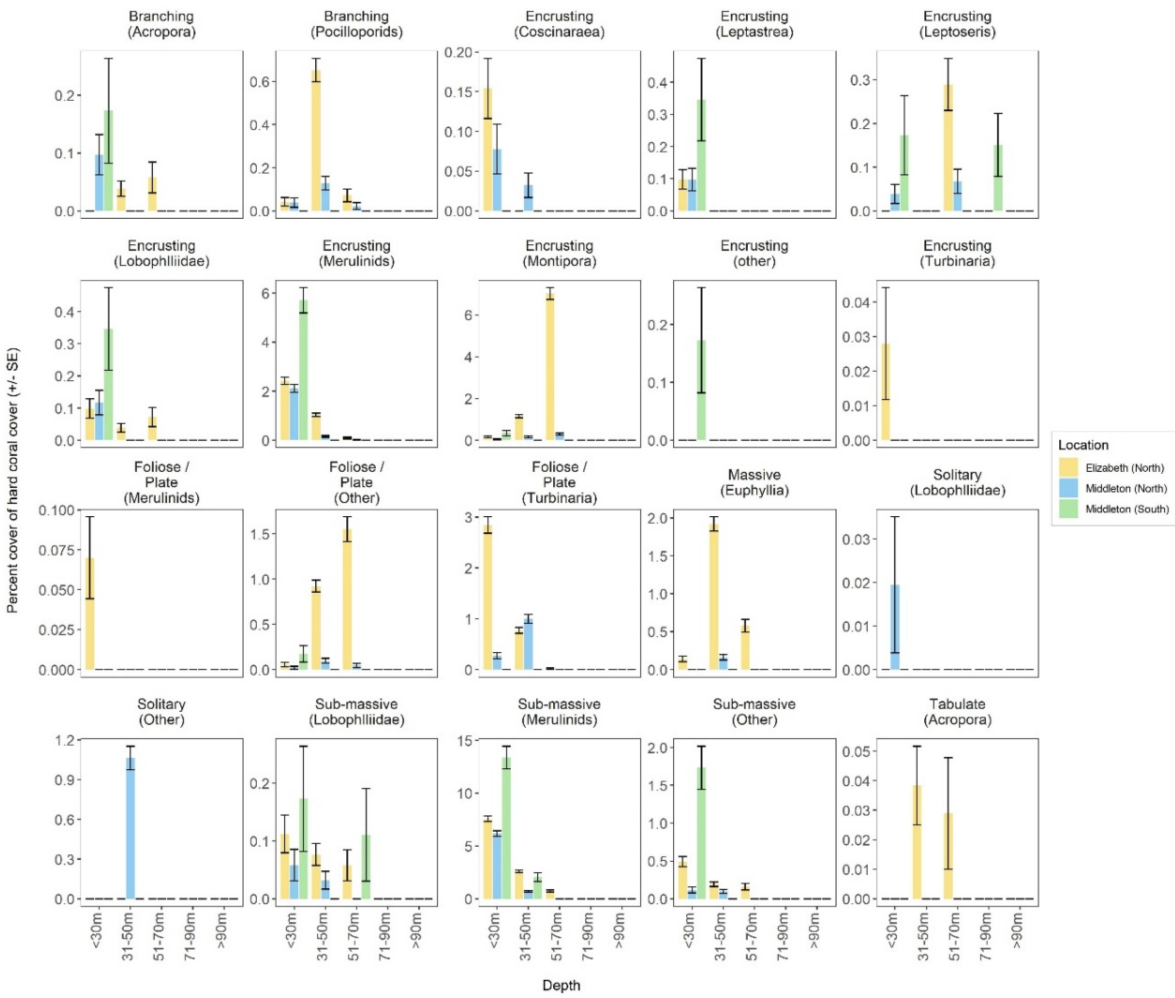


Figure 33. Mean percent cover of hard coral morphospecies recorded from AUV imagery acquired across shelf environments at Elizabeth (north) and Middleton (north and south) Reefs.

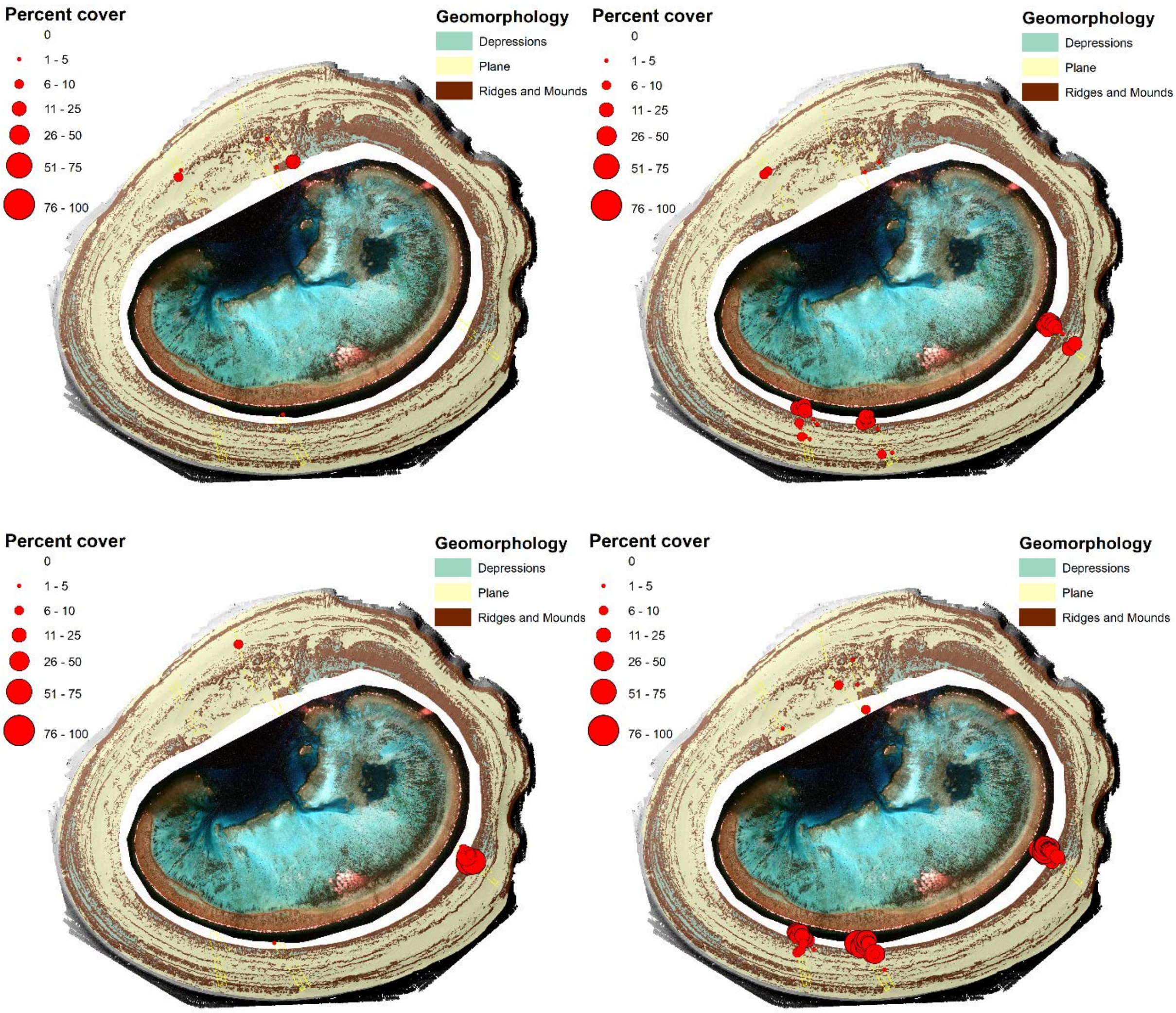


Figure 34. Spatial distribution for branching (top left), encrusting (top right), foliose/plate (bottom left) and (sub) massive (bottom right) growth forms of Scleractinian corals at Middleton Reef.

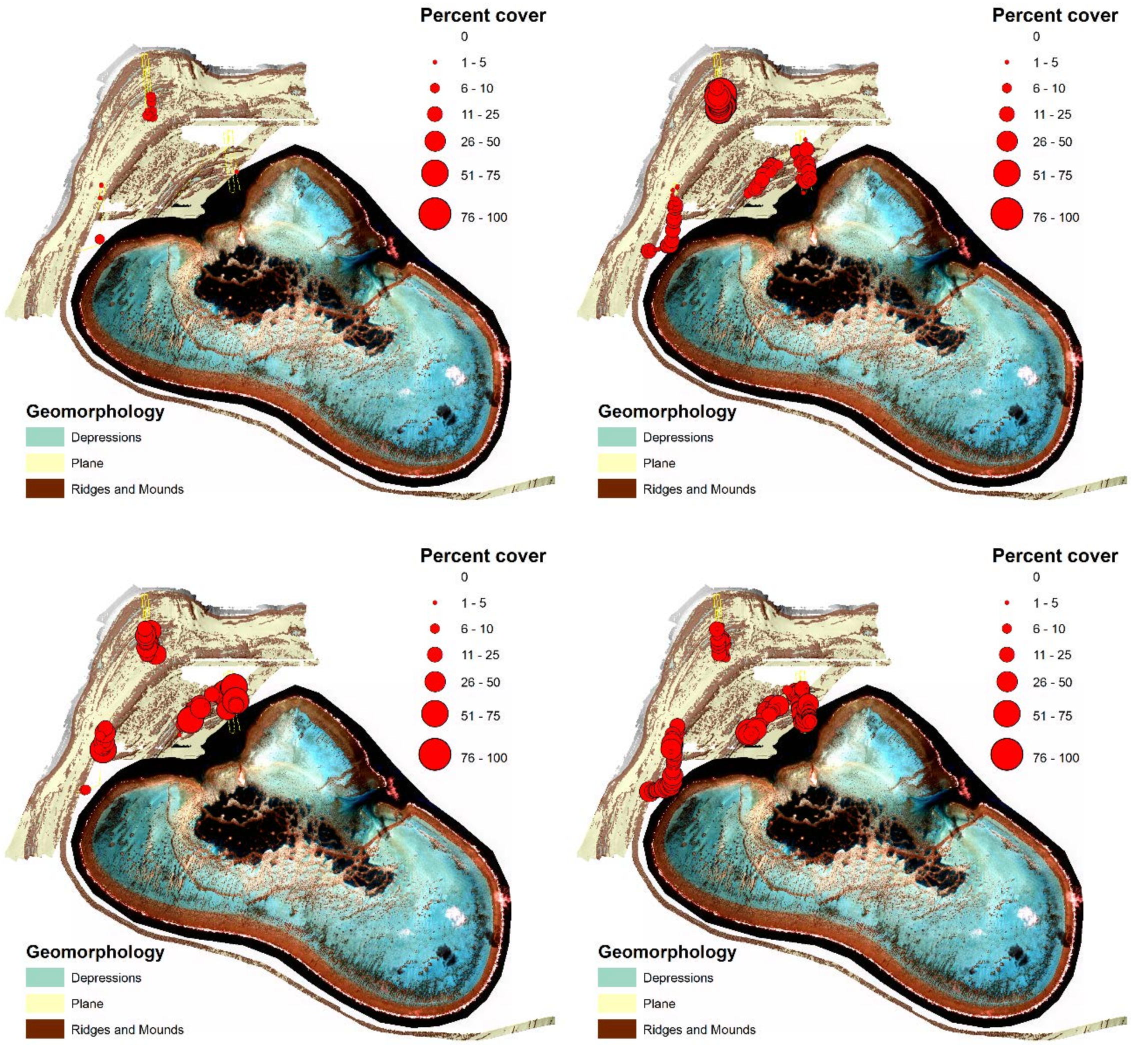


Figure 35. Spatial distribution for branching (top left), encrusting (top right), foliose/plate (bottom left) and (sub) massive (bottom right) growth forms of Scleractinian corals at Elizabeth Reef.

Black coral and octocorals (Antipatharia and Octocorallia)

Black and octocoral cover was highest on hard shallow substrate (< 30 m ridges and mounds) at all sites and ranged between 4.5% (± 0.2) and 10.9% (± 0.9) at Elizabeth Reef and Middleton Reef (south), respectively (Figure 31; Figure 36; Figure 37). Mean percent cover generally declined with depth at all locations and was lowest at the deepest depth interval. Soft leather corals (*Lobophytum* and *Sinularia* spp.) comprised a high proportion of this category within the shallow depth zones at both reefs. There was a general trend for leather coral cover to decline with depth, and no leather corals were recorded at depths > 70 m. In contrast, percent cover of black corals (both branching *Myriopathes* spp. and whip morphologies, *Cirrhipathes* and *Stichopathes* spp.) was highest at both reefs at depths < 50 m and percent cover remained relatively stable on deeper substrate.

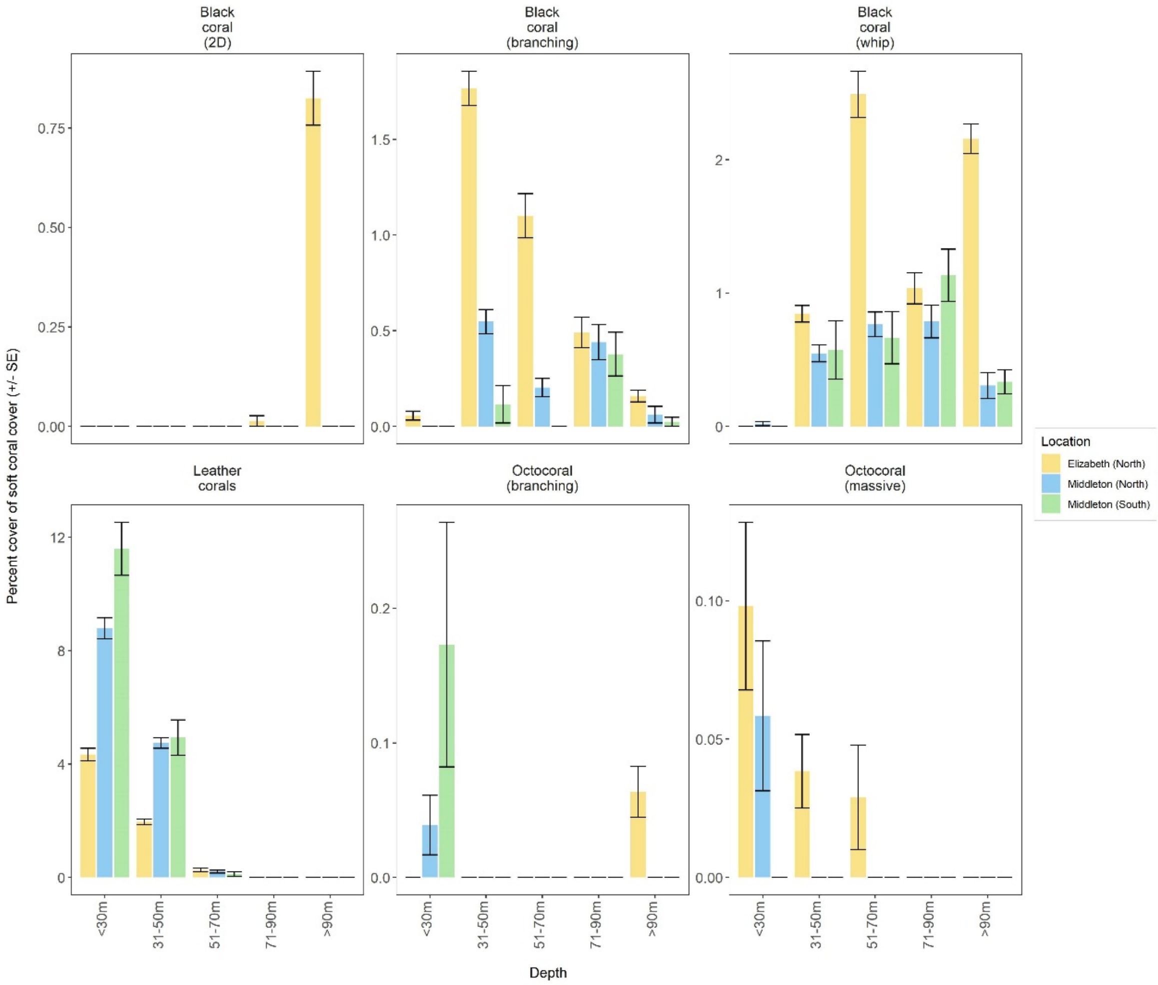


Figure 36. Mean percent cover of black coral and octocoral morphospecies recorded from AUV imagery acquired across shelf environments at Elizabeth (north) and Middleton (north and south) Reefs.

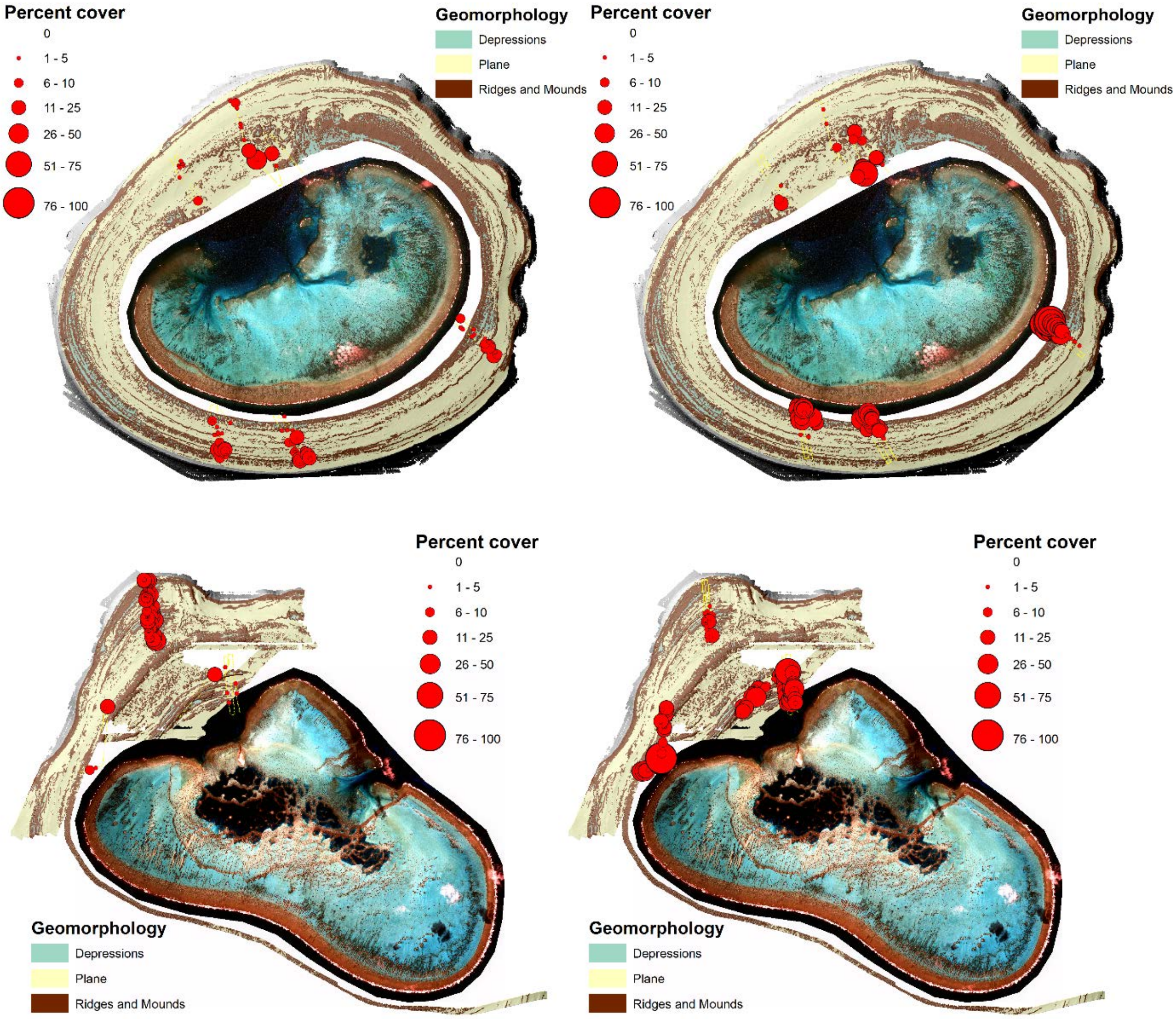


Figure 37. Spatial distribution for black corals (left) and octocorals (right) for Middleton (top) and Elizabeth (bottom) Reefs.

Sponges

Generally, the cover of sessile sponges was low across all substrate and geomorphic feature types and increased only marginally from ~ 1% at shallow (< 30 m) depths to ~ 2% at deeper (< 90 m) sites (Figure 31). Highest percent cover of sponges for all sites was recorded on substrate > 90 m at Elizabeth Reef. Four morphology types (encrusting, simple, barrel and cups) dominated the sponge taxa across most depth ranges at Elizabeth and Middleton Reefs (Figure 38). Encrusting sponges was the only sponge morphospecies that occurred in low abundance across all depths at all sites (Figure 38; Figure 39; Figure 40).

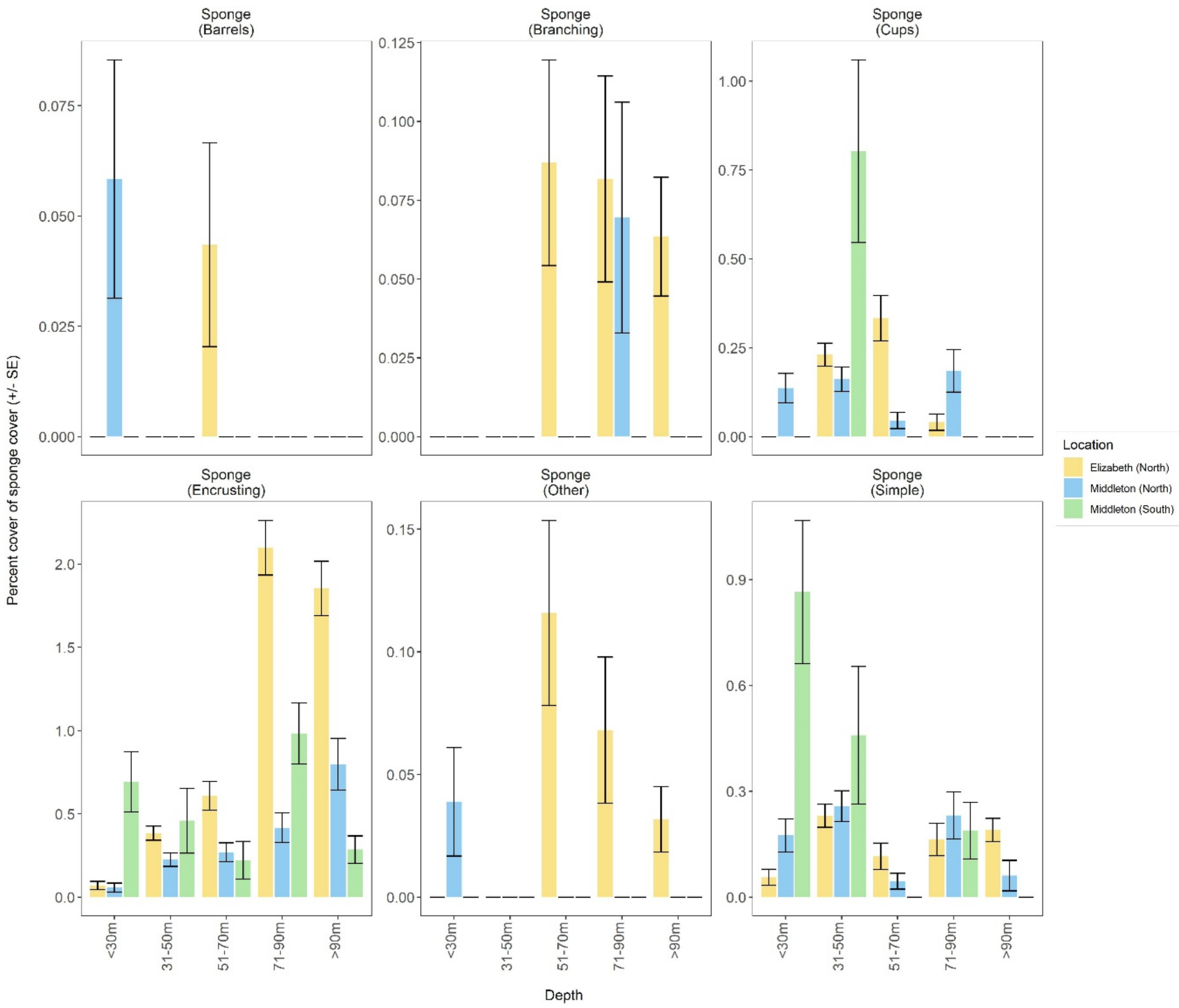


Figure 38. Mean percent cover of sponge morphospecies recorded from AUV imagery acquired across shelf environments at Elizabeth (north) and Middleton (north and south) Reefs.

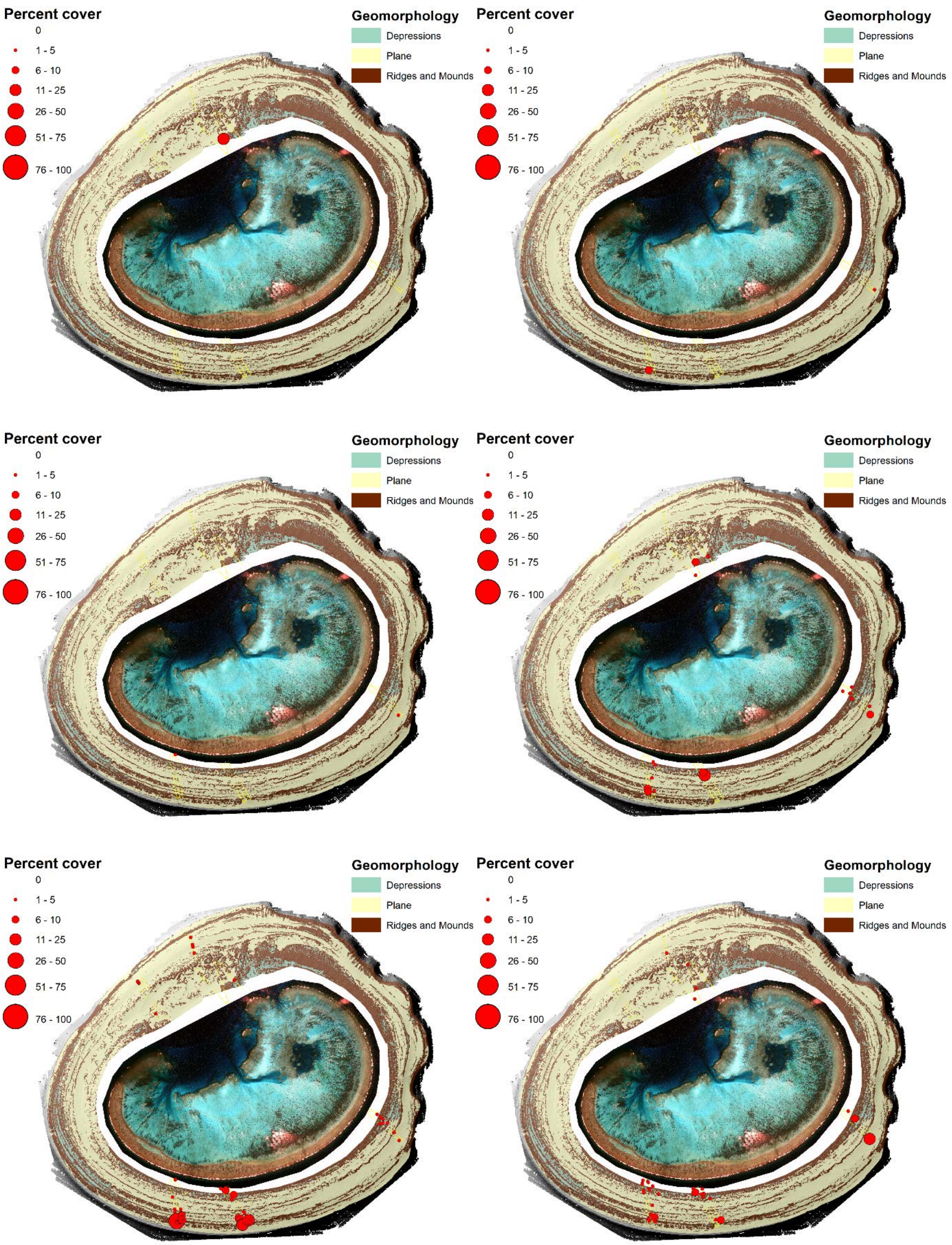


Figure 39. Spatial distribution for barrel (top left), branching (top right), creeping/ramose (middle left), cup (middle right), encrusting (bottom left) and massive (bottom right) growth forms of sponges at Middleton Reef.

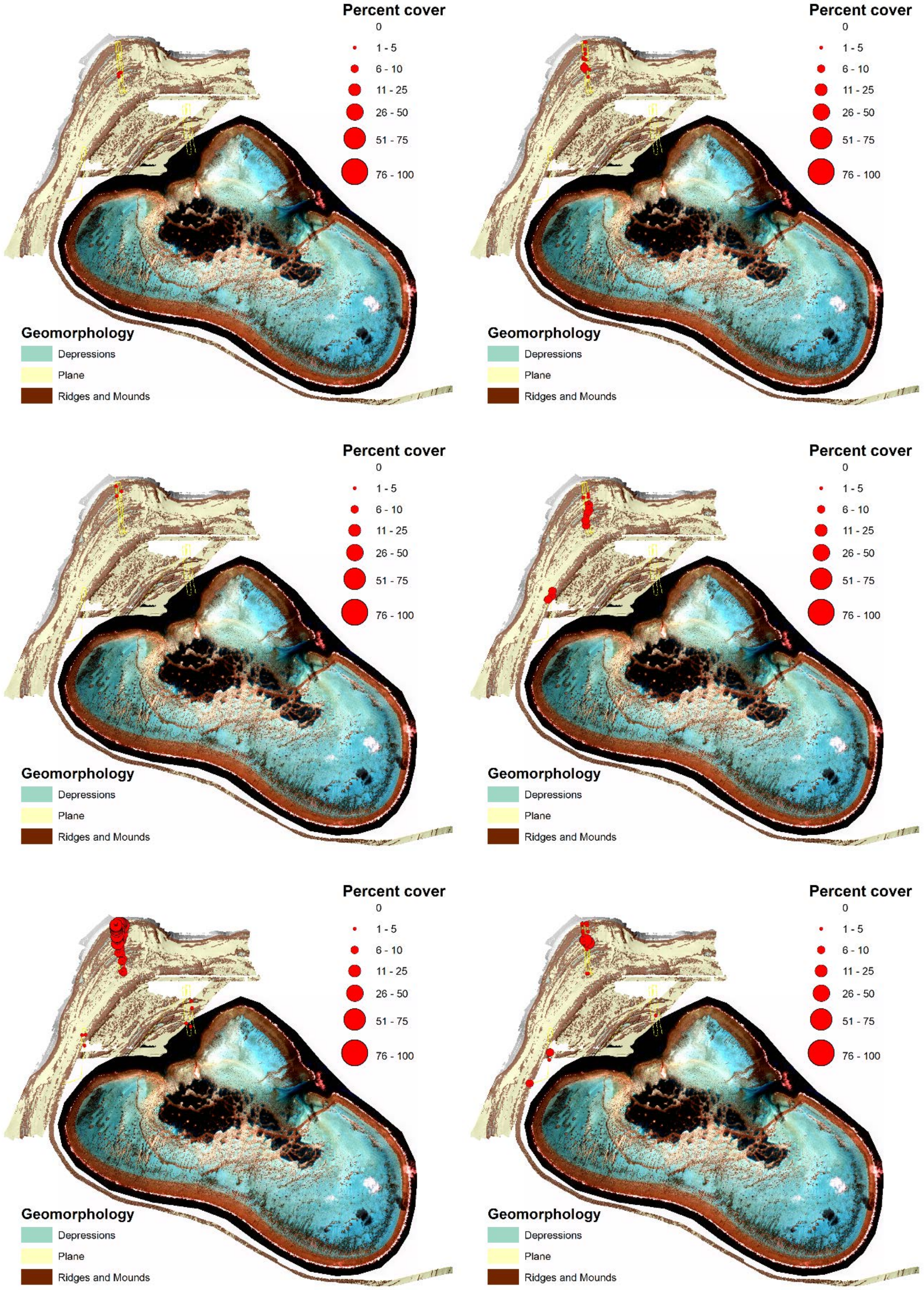


Figure 40. Spatial distribution for barrel (top left), branching (top right), creeping/ramose (middle left), cup (middle right), encrusting (bottom left) and massive (bottom right) growth forms of sponges at Elizabeth Reef.

Bacterial mats

Bacterial mats covered a high proportion of the substrate on the northern aspect of both Elizabeth and Middleton Reefs. At Elizabeth Reef, bacterial mats covered approximately 27% of substrate occurring between 31–50 m. Bacterial mats also dominated Middleton Reef north on substrate within 31–50 m covering 45.5% (± 0.6) of the seafloor, then declined to 3.2% (± 0.2) within the 51–70 m depth bin. Bacterial mats were only associated with fine sand and were not observed in images acquired on the southern side of Middleton Reef (Figure 31).

Sediments

Poorly sorted coarse sand and gravel were recovered from eight sites at Middleton Reef and three sites at Elizabeth Reef (Figure 41). At sites characterised by gravel and sandy gravel, the gravel fraction comprised rhodoliths (see Appendix C). A moderate cover of seabed sediment was recorded across all depth bins, with calcareous sand and coral rubble cover highest at shallow sites (Figure 31). Sediment cover comprised of pebbles/gravel was moderately high at shallow sites, declined with depth to 90 m then became an increasing component of the substrate > 90 m at Middleton Reef.

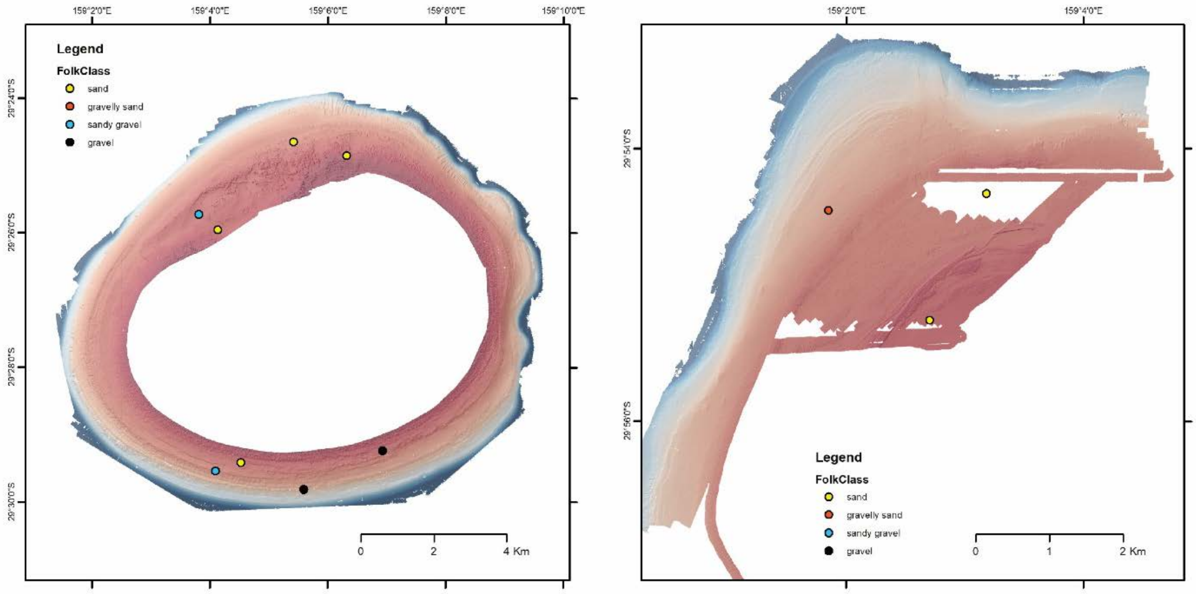


Figure 41. Locations of sediment grab samples with Folk sediment class indicated.

4.2.2 Sampling adequacy for sessile morphospecies assemblages

Species accumulation curves showed similar rates of accumulation between reefs (Figure 42). Elizabeth (north) had the highest accumulation rate peaking at an estimated 144 morphospecies, while Middleton (south) exhibited the lowest with ~ 63 morphospecies (Figure 42). While all curves are close to reaching their asymptotes, additional sampling (or subsampling of imagery) is necessary to encounter all species present within the two reefs (Figure 42).

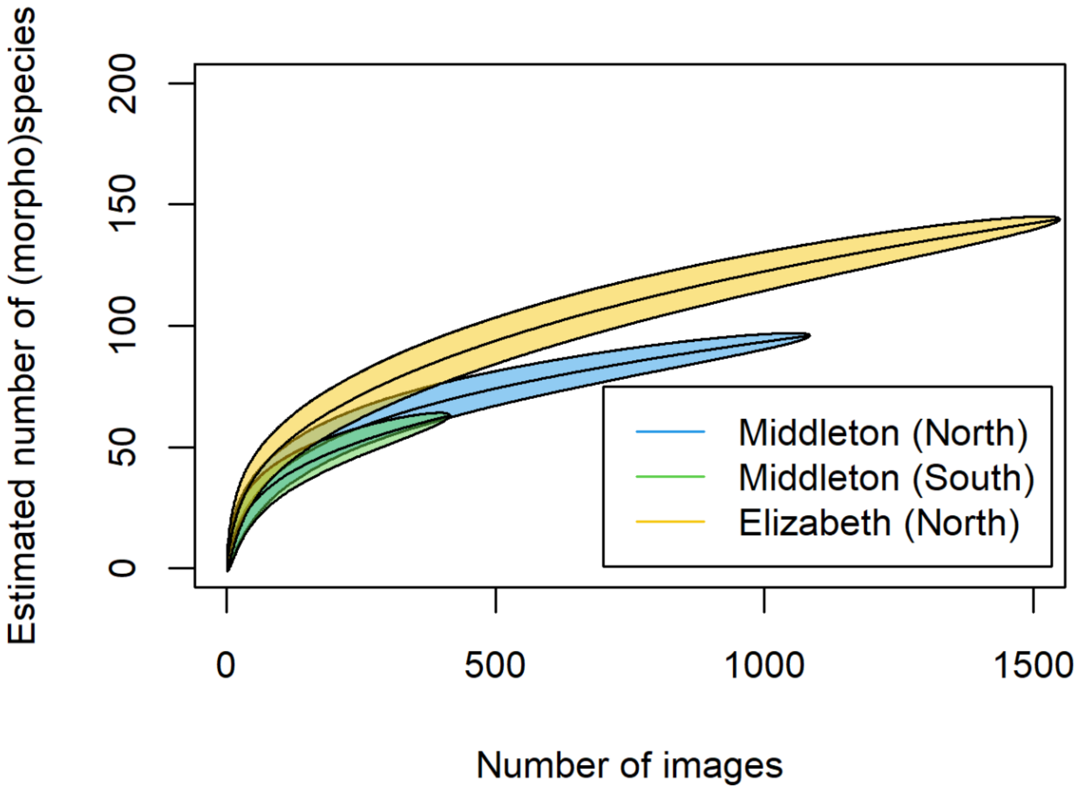


Figure 42. Morphospecies accumulation curve for sessile assemblages sampled using AUV imagery at Middleton (North, South) and Elizabeth (North) Reefs.

4.3 Demersal fish observations

4.3.1 Compositional patterns in demersal fish assemblages

A total of 6214 individual fishes belonging to 195 species from 36 families were observed across Elizabeth (124 species from 30 families) and Middleton Reefs (168 species from 32 families) (Appendix E). The most speciose family on both reefs were Labrids, with 28 and 22 species recorded at Middleton and Elizabeth Reefs, respectively, followed by Chaetodontidae (Elizabeth: 16 species, Middleton: 18 species), Acanthuridae (Elizabeth: 12 species, Middleton: 16 species), Pomacentridae (Elizabeth: 12 species, Middleton: 15 species), Serranidae (Elizabeth: 8 species, Middleton: 15 species) and Scaridae (Elizabeth: 7 species, Middleton: 13 species) (Appendix E).

Clear patterns in some trophic feeding guilds were evident across depths at both reefs, with scraping and browsing herbivore abundance decreasing with increasing depths (Figure 43). By contrast, generalist carnivore abundance appeared to increase with increasing depth (Figure 43). No strong pattern between reefs or depth was evident for planktivore, benthic invertivore or higher carnivores (Figure 43).

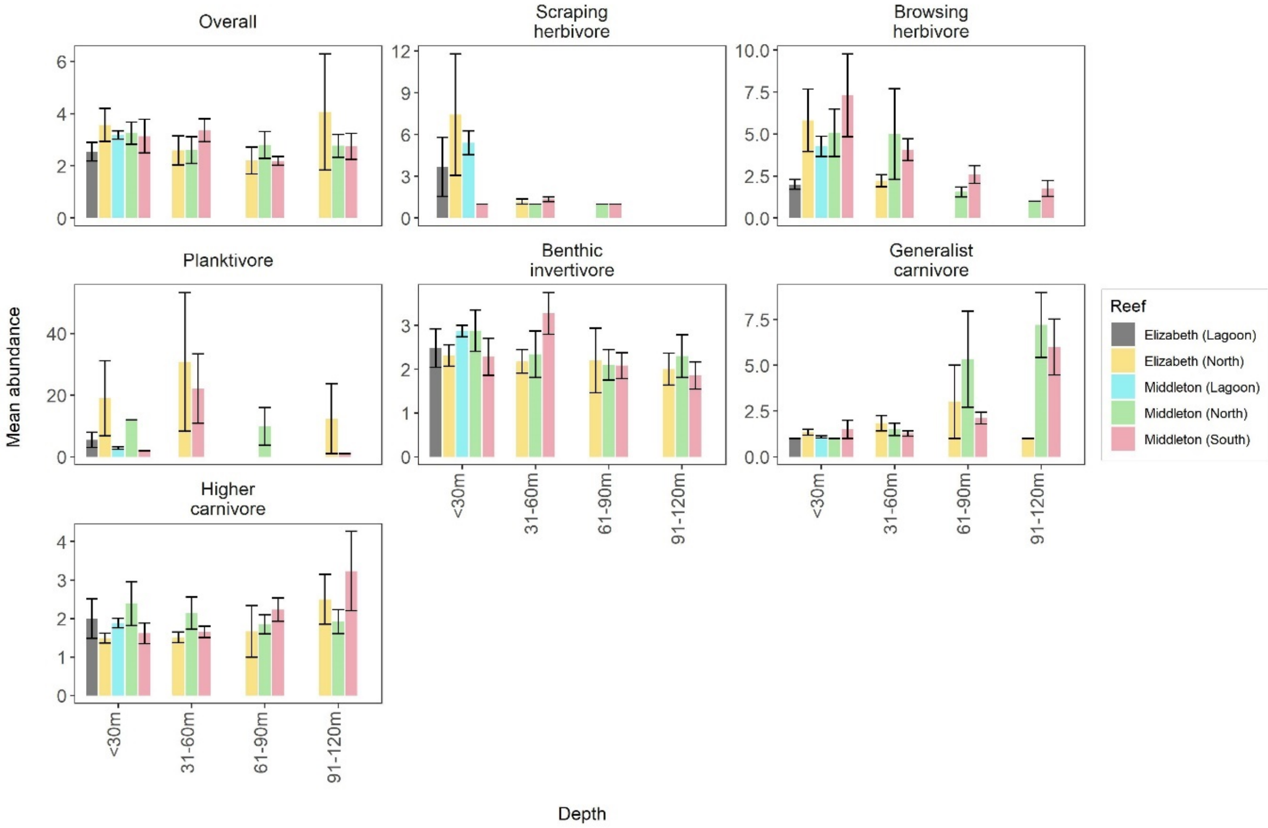


Figure 43. Mean abundance of trophic feeding guild across depths zones at Elizabeth and Middleton Reefs.

Mean abundance of fish species showed clear differences between zones at Elizabeth and Middleton Reefs, with different species dominating the assemblages (Figure 44; Appendix E). For example, Daisy Parrotfish (*Chlorurus sordidus*; Figure 45) were most abundant in the lagoon at Elizabeth Reef, while One-spot puller (*Chromis hypsilepis*; Figure 46) was highly abundant outside the lagoon at Elizabeth Reef. By contrast, Sawtail Surgeonfish (*Prionurus microlepidotus*; Figure 47), Deepsea chromis (*Chromis abyssicola*; Figure 48) and Yellow spotted chromis (*Chromis flavomaculata*; Figure 49) numerically dominated the fish assemblages in the lagoon, and the north and south zones of Middleton Reef (Figure 44; Appendix E). Distinct depth and distribution patterns in relative abundance for other key species are provided in Appendix F.

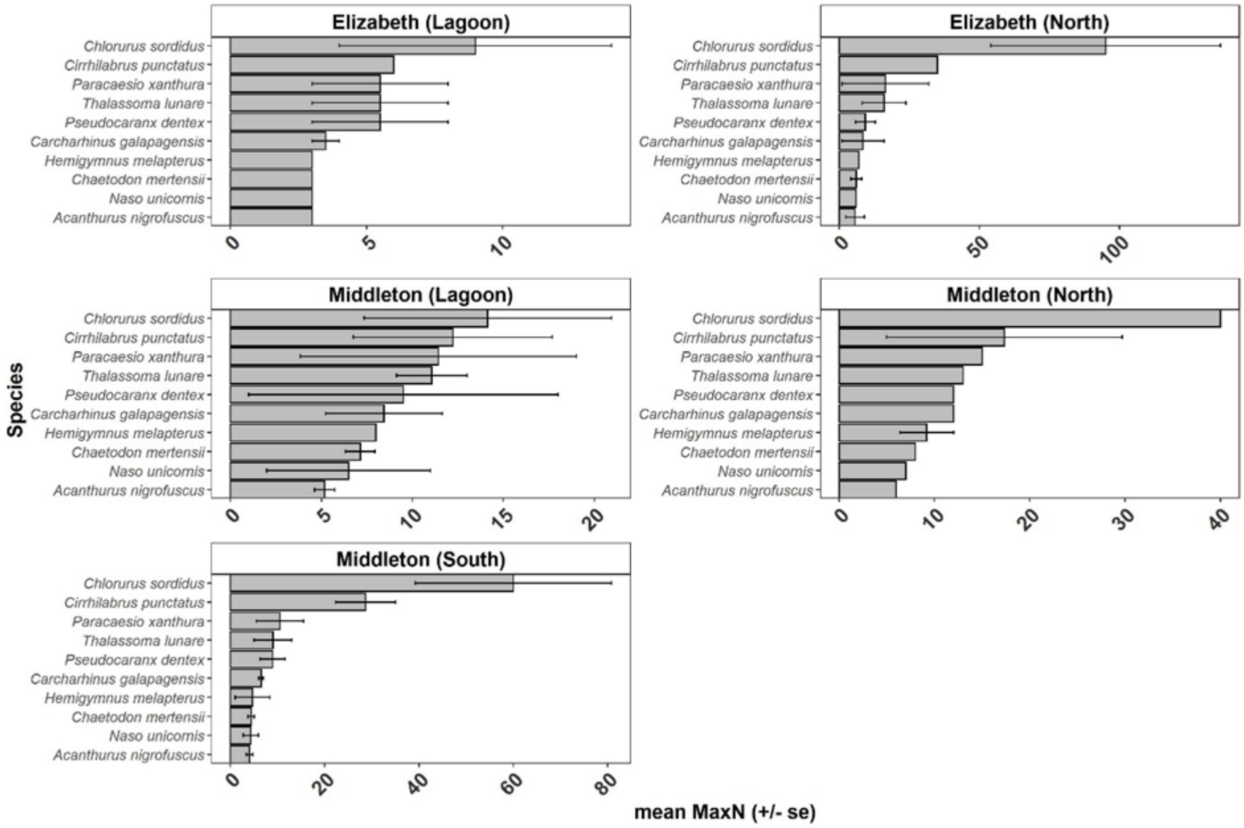


Figure 44. Top ten most abundant fish species for across depth zones at Elizabeth and Middleton Reefs. Bars without error bars indicate a particular species that was only recorded on a single stereo-BRUV drop within a depth zone.

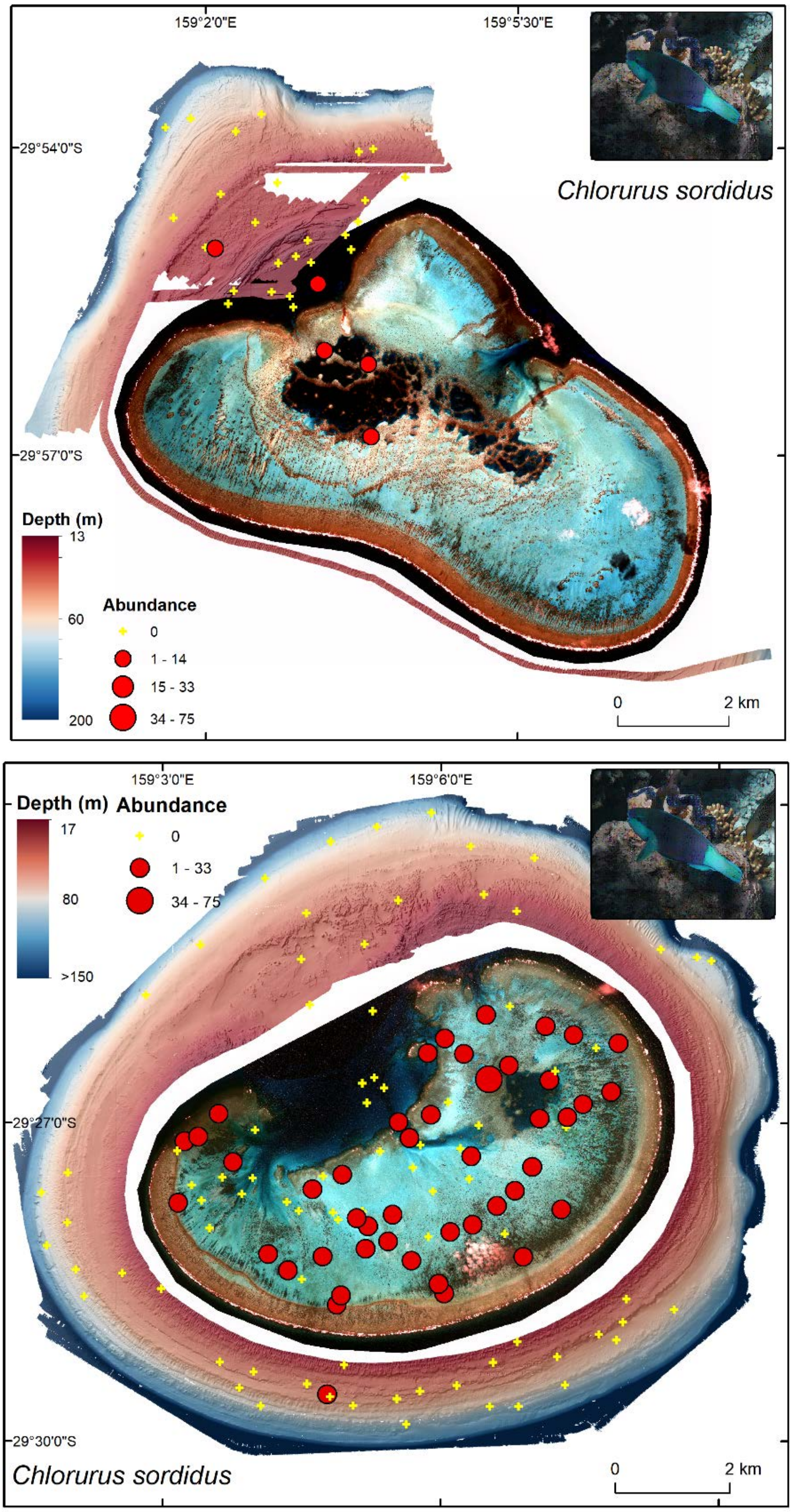


Figure 45. Abundance distribution of Daisy Parrotfish that numerically dominated the fish assemblage at Elizabeth (top) and Middleton (bottom) Reefs.

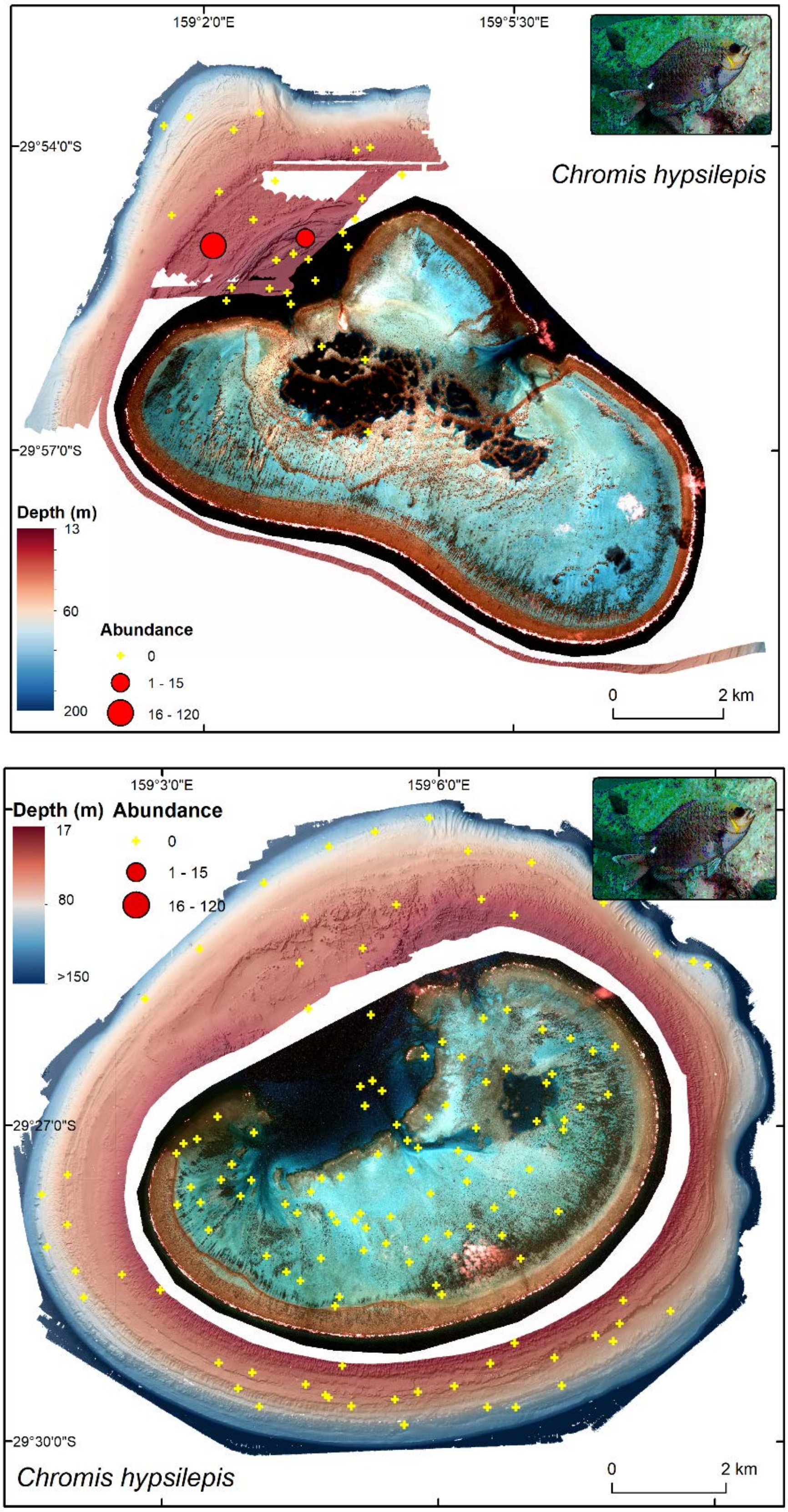


Figure 46. Abundance distribution of One-spot Puller that numerically dominated the fish assemblage at Elizabeth (top) but was not present at Middleton (bottom).

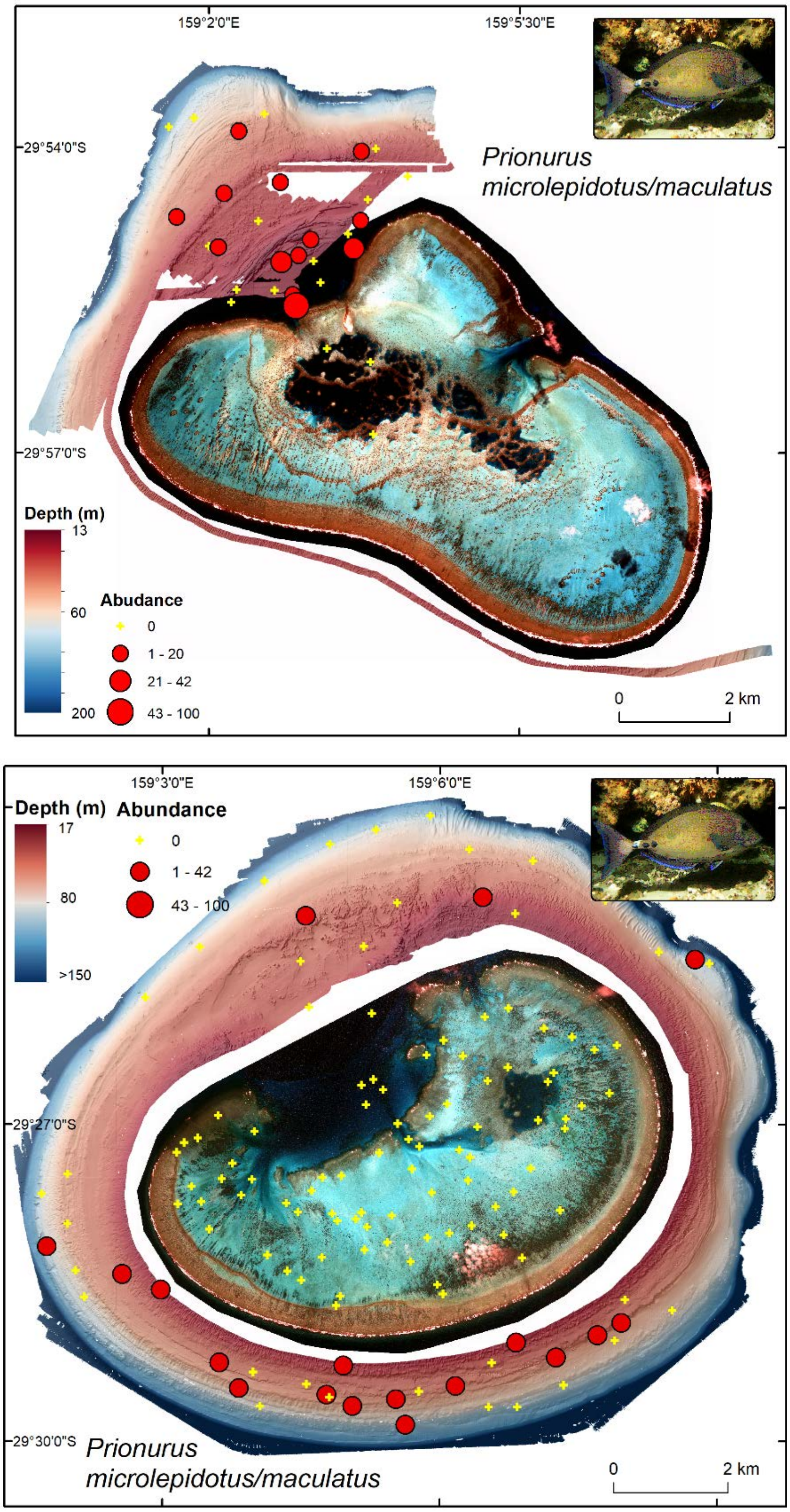


Figure 47. Abundance distribution of Sawtail Surgeonfish that dominated the fish assemblage at Elizabeth (top) and Middleton (bottom) Reefs.

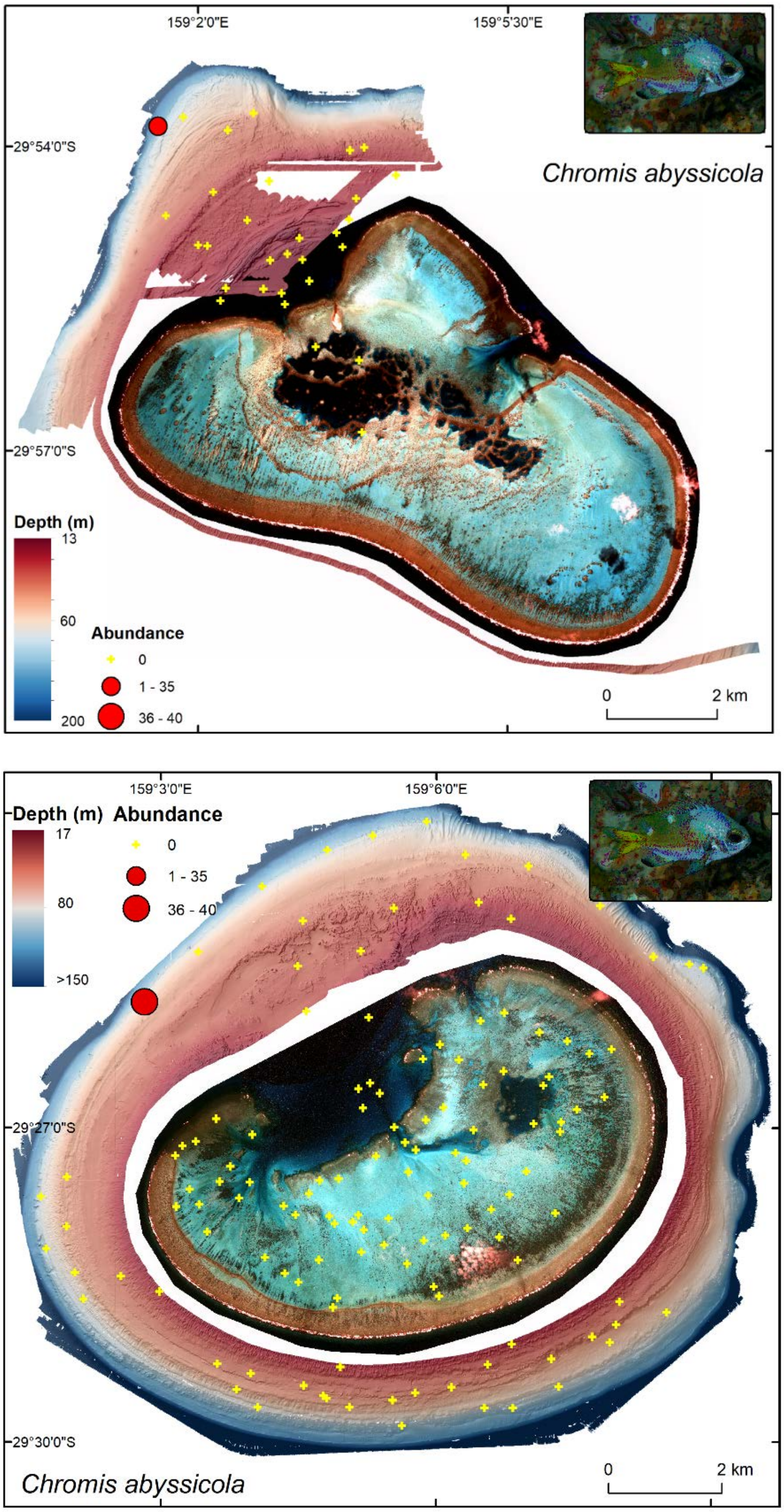
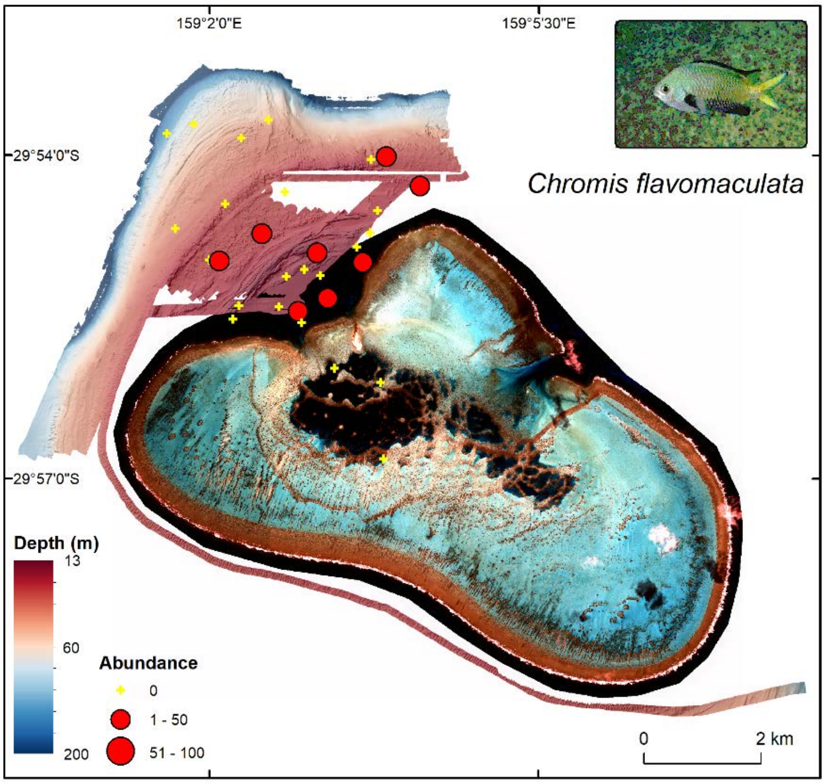


Figure 48. Abundance distribution of Deepsea Puller that, while only found at two locations, was numerically abundant at Elizabeth (top) and Middleton (bottom) Reefs.



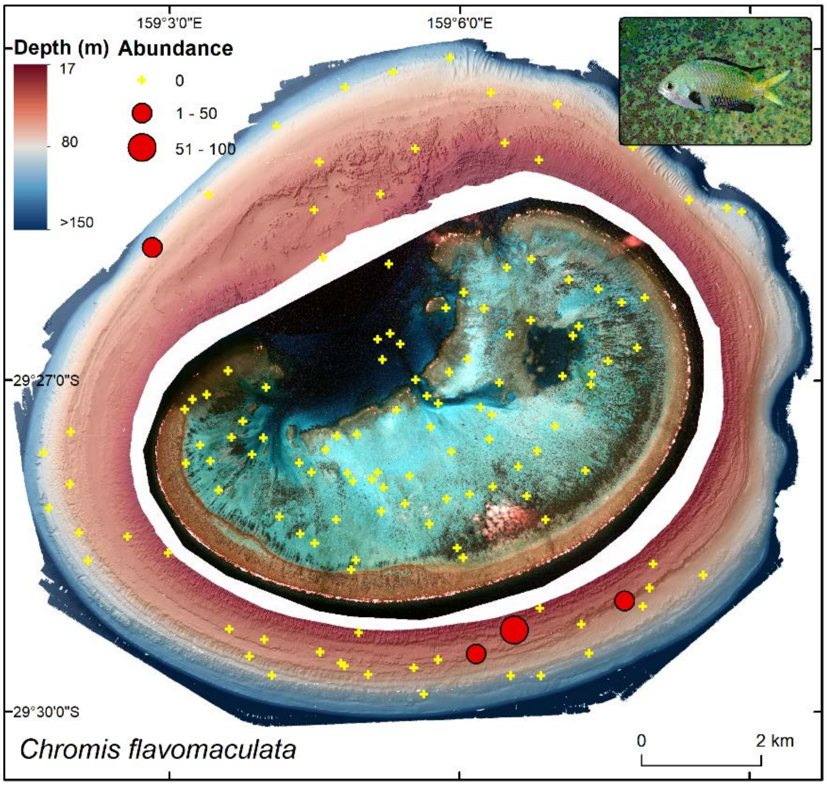


Figure 49. Abundance distribution of Yellow-spotted *Chromis* that numerically dominated the fish assemblage at Elizabeth (top) and Middleton (bottom) Reefs.

4.3.2 Patterns in threatened demersal fish abundance

Black cod, Epinephelus daemelii

Black cod were observed in ~20% of all BRUV drops at Middleton Reef and ~29% of sites sampled at Elizabeth Reef (across a depth range of 1.4–116 m). There were no major differences in the size of fish between depth zones at Middleton Reef (mean size in the lagoon was 933 mm (±100 SE) compared to 990 mm (±30 SE) for deep-water sites). The mean size of this species across all sites at Elizabeth Reef was 829 mm (±61 SE), noting that there were an insufficient number of sites sampled in the lagoon to compare with deep-water sites. Black cod in the lagoon had the greatest variability in lengths, ranging from 400–1400 mm. Length-frequency plots indicate that the majority of individuals were mature (i.e. > 750 mm; (Figure 50), and a healthy population of males (i.e. > 1000 mm; Figure 50). Generally, both Elizabeth and Middleton Reefs had a high abundance of black cod, relative to continental shelf waters off mainland Australia (Figure 51).

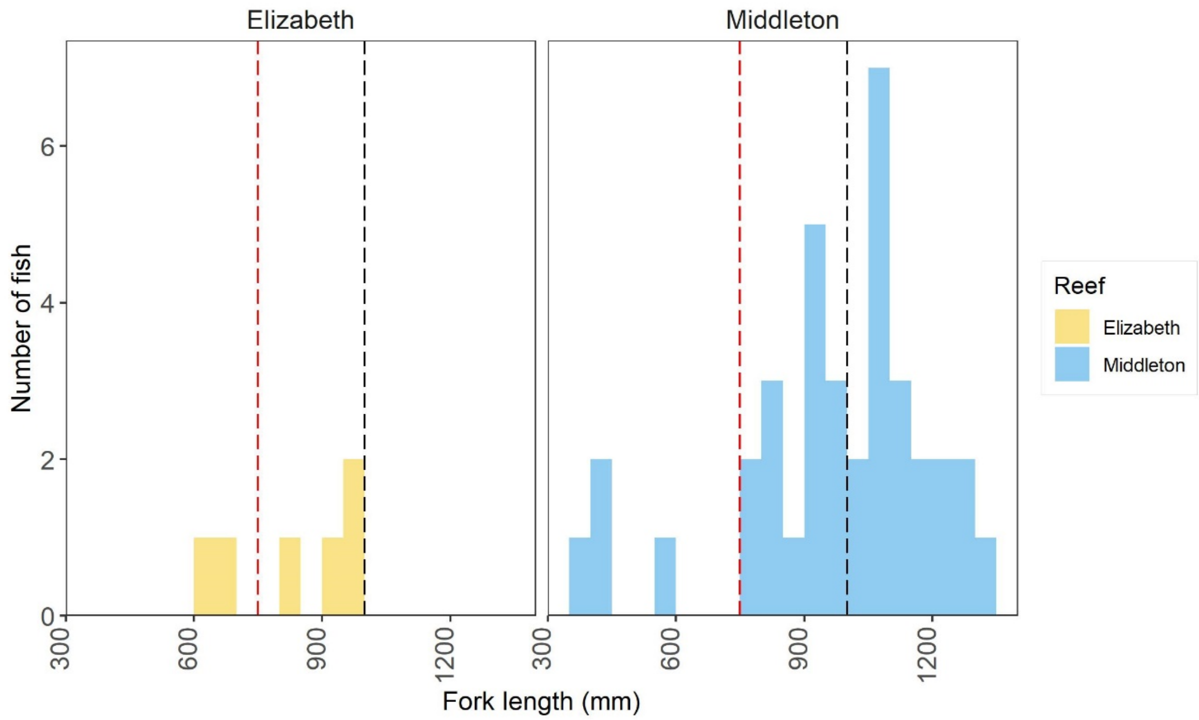
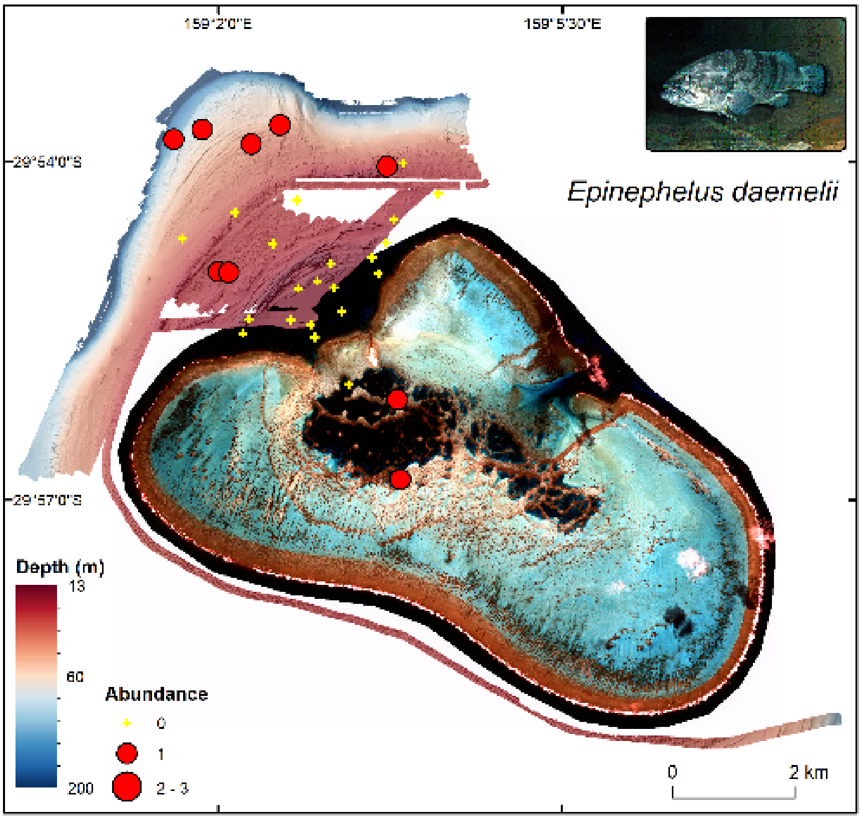


Figure 50. Length-frequency histograms of black cod lengths at Elizabeth and Middleton Reefs. The red dashed line represents the smallest estimated length of maturity for female black cod (Francis et al. 2016). The black dashed line represents the estimate size where female fish change to become males (Francis et al. 2016).



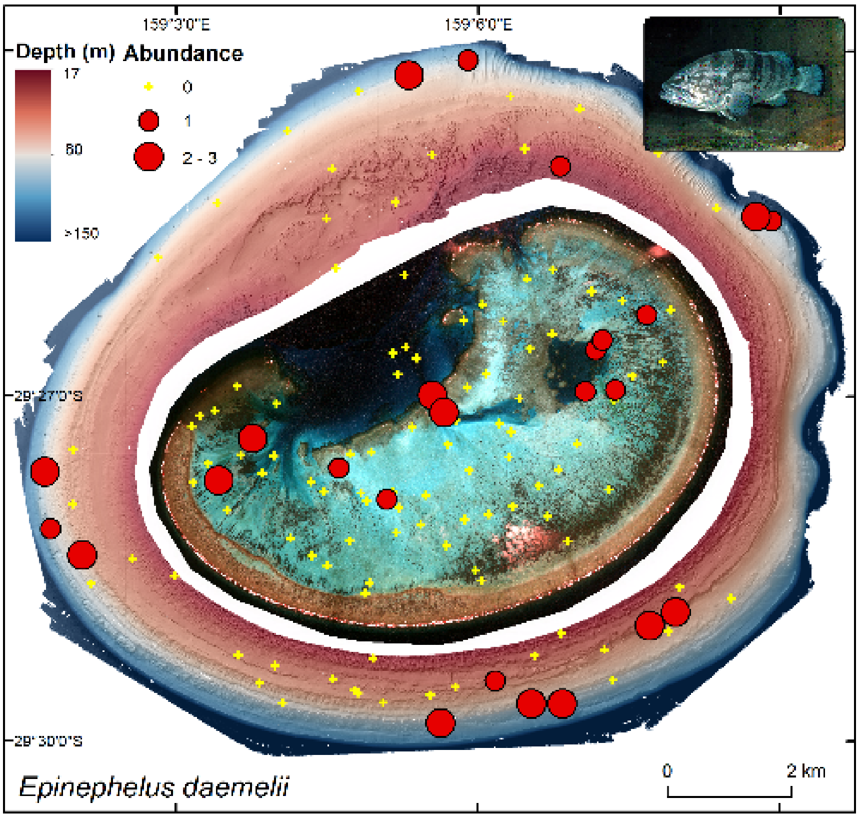


Figure 51. Abundance distribution of black cod at Elizabeth (top) and Middleton (bottom) Reefs.

Galapagos shark, *Carcharhinus galapagensis*

Galapagos sharks were one of the most ubiquitous species, occurring at 86% of sites at Middleton Reef and 97% of sites at Elizabeth Reef, at a depth range of 0.5 to 100 m. The lengths of Galapagos sharks ranged from 655–2142 mm, with a mean length of 1005 mm (±26 mm SE) inside the lagoon and 999 mm (±24 mm SE) on the shelf, demonstrating very little difference in the demography of Galapagos sharks across the reef platform (Figure 52). Interestingly, the length-frequency plots indicate that all but one shark that was measured could be considered an immature juvenile (i.e. < 2100 mm; Figure 52). Average relative abundance of Galapagos sharks was 2.9 (±0.2 SE) at Middleton Reef and 5 (±0.2 SE) at Elizabeth Reef; noting the smaller sample size at Elizabeth Reef (Figure 53). The largest school observed was at Middleton Reef, with 12 individuals, and there were no obvious patterns in the distribution of this species at either reef (Figure 53). However, there were consistently higher abundance of sharks at both lagoon entrances, which is a common observation in coral reef systems.

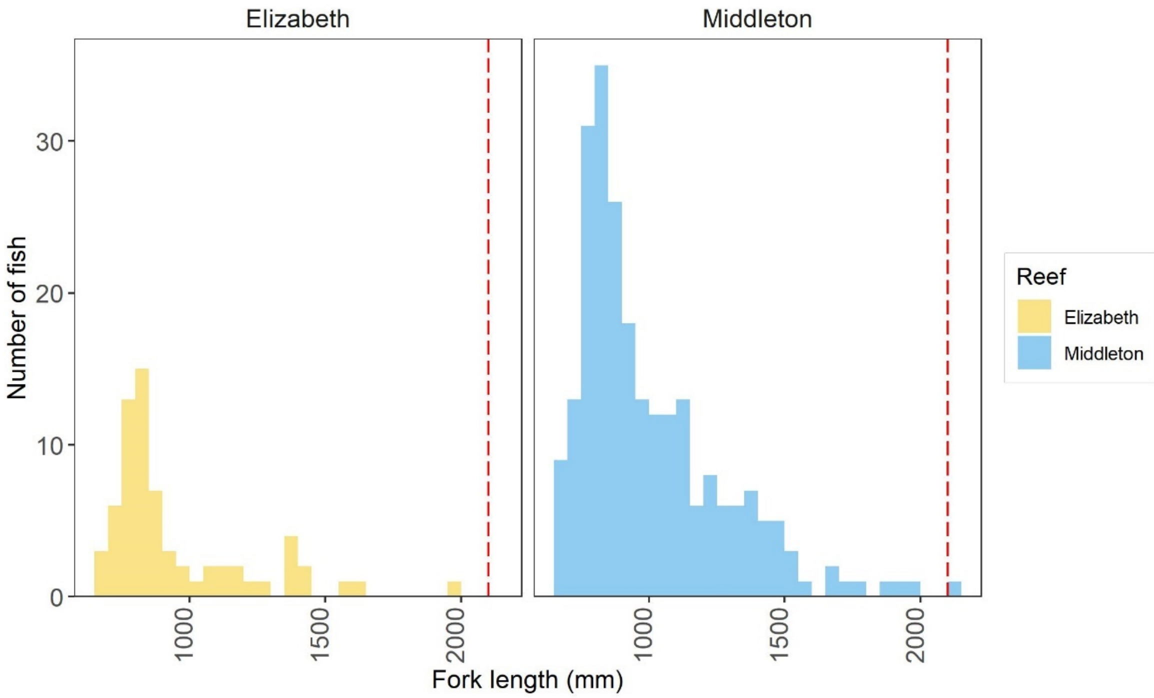
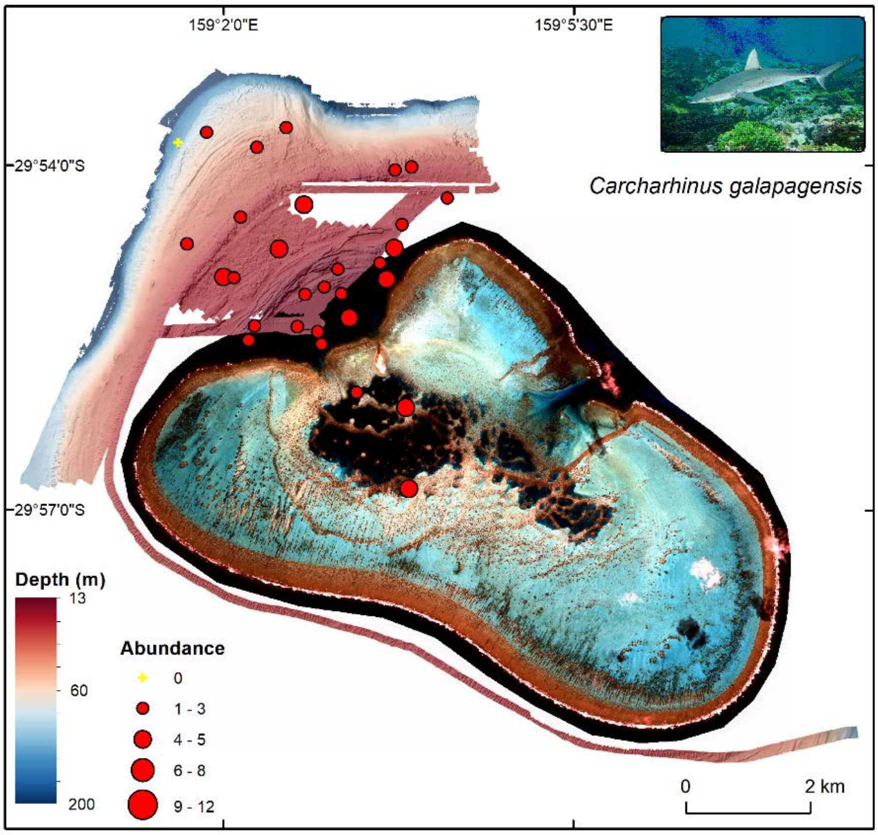


Figure 52. Length-frequency histograms of Galapagos shark lengths at Elizabeth and Middleton Reefs. The vertical red dashed line represents the estimate length at maturity (FishBase).



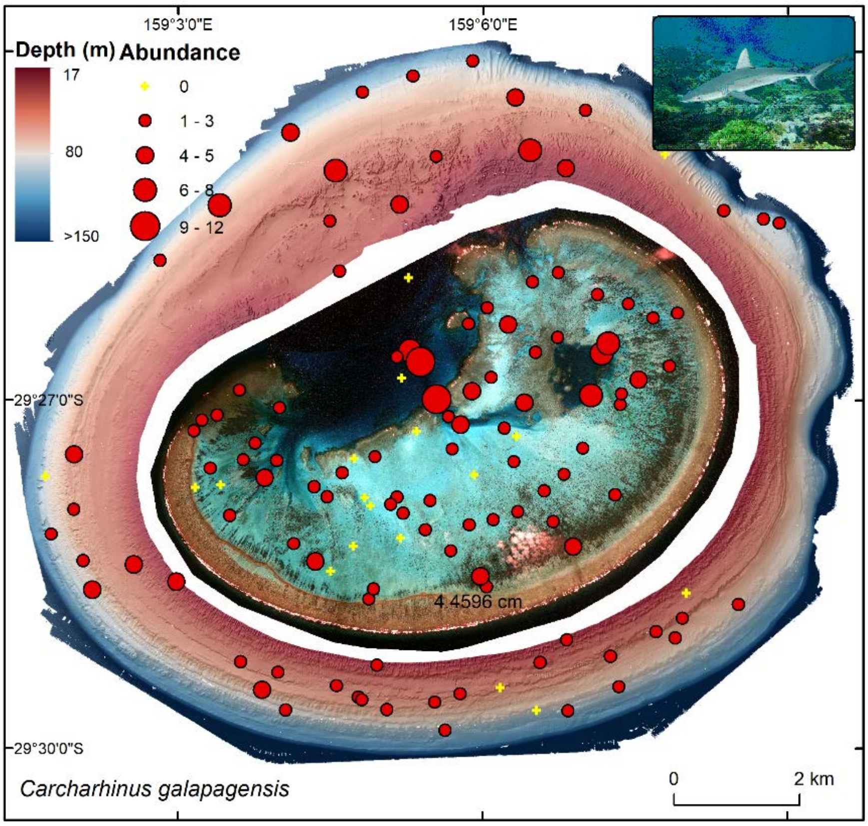


Figure 53. Abundance distribution of Galapagos Shark at Elizabeth (top) and Middleton (bottom) Reefs.

Tiger shark, Galeocerdo cuvier

Tiger sharks were only observed as individual sharks at ~10% of sites at both Middleton and Elizabeth Reefs. The lengths of tiger sharks observed ranged from 1713–4304 mm, with a mean of 3054 mm (±505 mm SE). All tiger sharks measured inside the lagoon at Middleton Reef were immature juveniles (i.e. <3000 mm; Figure 54). Mature sharks were only observed outside the confines of the lagoon on the broad shelves of each reef. There were no obvious patterns in the distribution of tiger sharks across Middleton Reef, however, more sharks were observed inside the lagoon compared to shelf observations (Figure 55). Tiger sharks were only recorded at the lagoon entrance of Elizabeth Reef (Figure 55).

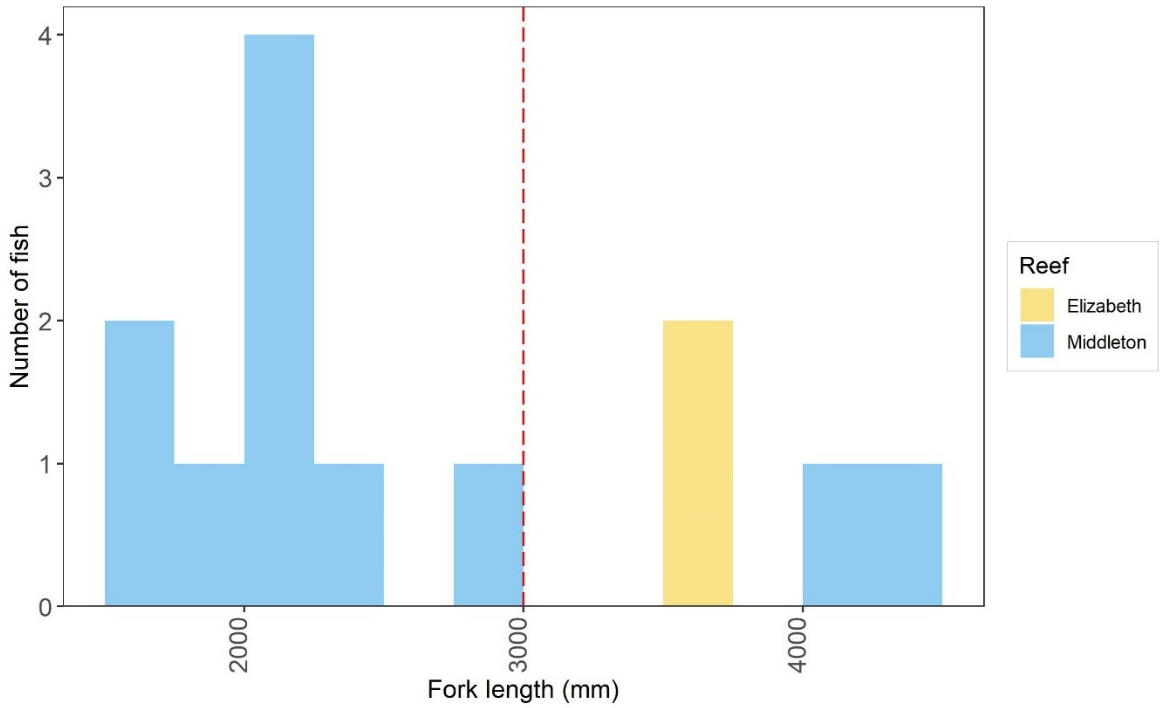
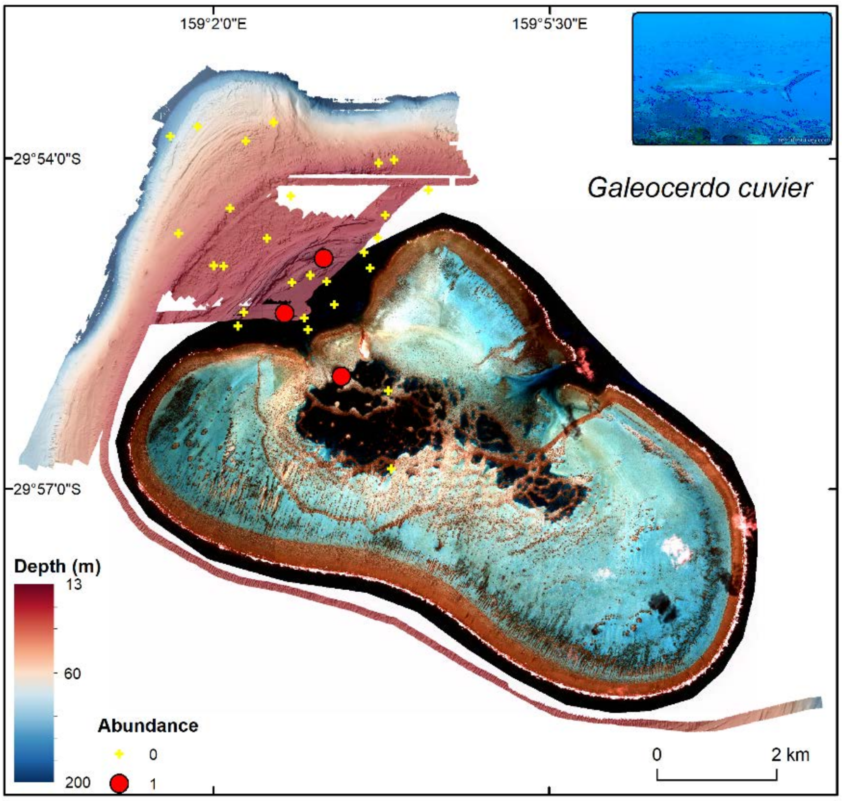


Figure 54. Length-frequency histograms of tiger shark lengths at Elizabeth and Middleton Reefs. The vertical red dashed line represent the estimate length at maturity (FishBase).



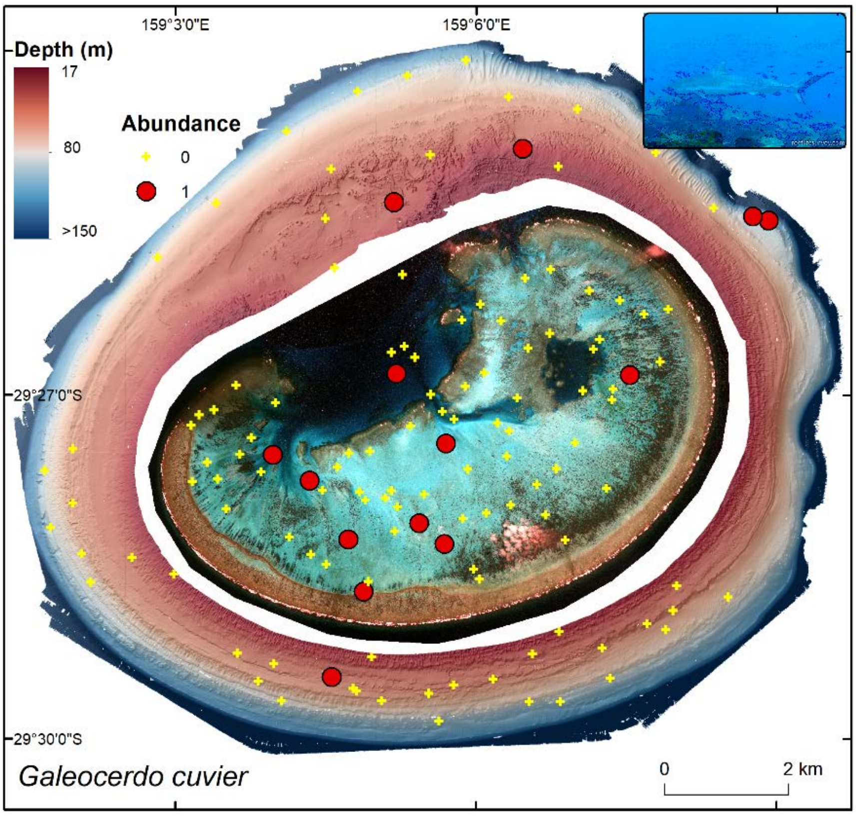


Figure 55. Abundance distribution of tiger shark at Elizabeth (top) and Middleton (bottom) Reefs.

4.3.3 Sampling adequacy and power to detect change

Species accumulation curves slightly showed different rates of accumulation of fish species between reefs (Figure 56). Elizabeth (pooled north and lagoon due to low samples) and Middleton (lagoon) had the highest accumulation rates peaking at an estimated 110 species, while Middleton (south) exhibited the lowest with around 73 species (Figure 56). With exception to Middleton Reef (lagoon), additional sampling is necessary to encounter all fish species present at the two reefs (Figure 56).

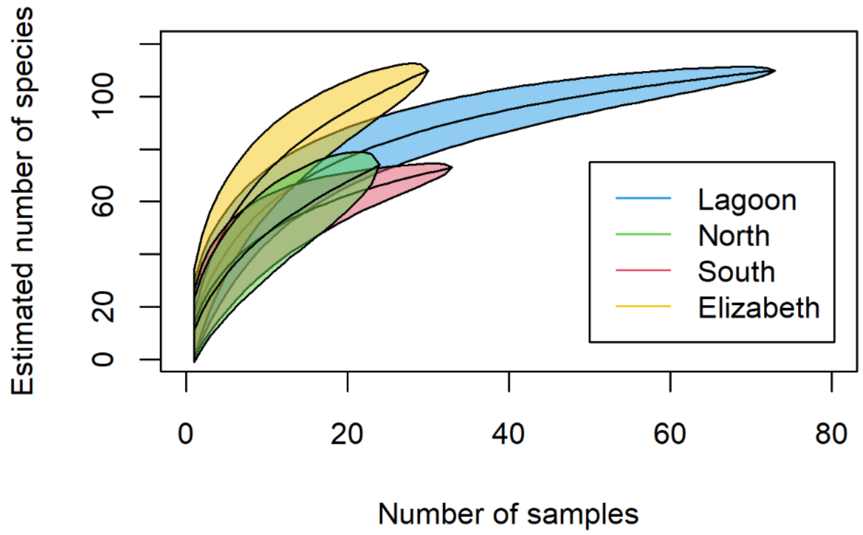


Figure 56. Species accumulation curve for fish assemblages sampled using stereo BRUVs at Middleton (Lagoon, North, and South) and Elizabeth (pooled) Reefs.

Geographic comparison of demersal fish assemblages within the temperate east and GBR

The most recent stereo-BRUV survey undertaken at Lord Howe Island (2017) recorded 103 species, representing 35 families and similar abundances of black cod and Galapagos sharks (NSW Department of Primary Industries, Unpublished data). However, it is important to highlight that the sampling size at Lord Howe Island was considerably smaller (i.e. 70 stereo-BRUV drops at Lord Howe Island vs. 170 in this survey) and only sampled depths between 28 and 40 m. The fish assemblages observed at Elizabeth and Middleton Reefs and Lord Howe Island are cosmopolitan and represented by both tropical and warm temperate species. The most speciose family at Lord Howe Island were also the Labrids. The Hunter Marine Park and neighbouring Port Stephens – Great Lakes Marine Park are located in a warm temperate region of the east coast of Australia. Recent stereo-BRUV surveys undertaken at these locations (10–20 m depth) recorded 124 temperate species represented by 53 families (Williams et al. 2019, 2021). Stereo-BRUV surveys in depths ranging from 50–300 m on the Great Barrier Reef reported 130 species, represented by 29 families (Sih et al. 2017). These regional comparisons demonstrate the rich biodiversity that occurs at Elizabeth and Middleton Reefs.

5. SUMMARY

The two volcanic seamounts upon which Elizabeth Reef and Middleton Reef have formed, are major geomorphic features within the northern part of Lord Howe Marine Park that provide a diversity of benthic habitats for seabed biota across water depths that range from ~3000 m to intertidal depths. Our understanding of the deeper water habitats associated with the seamounts remains limited. However, the shelf environments of each seamount have now been mapped in high spatial resolution and sampled to improve our understanding of the spatial distribution of geomorphic features and associated sessile and mobile fauna. For Middleton Reef, this mapping was completed for the entire shelf to reveal the detail of the seabed geomorphology that influences the patterns of biodiversity of this reef system. Elizabeth Reef shelf remains only partly mapped, due to early termination of the 2020 survey by cyclone *Uesi*. However, the seabed geomorphic features appear very similar on mapped areas of both shelves.

In summary, each shelf is characterised by a gently sloping seabed with distinct terraces and semi-continuous low-profile ridges that extend for tens of kilometres around the shelf at consistent depths. On Middleton Reef shelf, the continuity of these ridges is interrupted on the northwest where a field of irregular ridges and mounds defines the greatest area of seabed complexity and benthic habitat. In general terms, the geomorphic seabed features of Elizabeth and Middleton Reefs are broadly similar to those mapped for Lord Howe Island and Balls Pyramid. Clearly the shelves of Elizabeth and Middleton Reefs are smaller, which has limited the accommodation space for reef development, and it remains unknown whether Elizabeth and Middleton Reefs preserve fossil reef, as has been discovered on the Lord Howe Island and Balls Pyramid shelves (Woodroffe et al., 2010; Linklater et al., 2015).

Analysis of underwater imagery confirmed the presence of shallow and mesophotic coral ecosystems that support a diverse assemblage of demersal fish. Generally, ridges, mounds and planes observed on the inner shelf (20–50 m depth) were dominated by turfing macroalgae, cnidarian corals – Scleractinian reef-building corals (predominately corals from the genera *Platygyra*, *Dipsastraea, Paragoniastrea,* and *Montipora*), soft leather corals (predominately (*Lobophytum* and *Sinularia* spp.) and bacterial mats. Planes and ridges on the outer shelf (70–110 m) were dominated by black corals (both branching *Myriopathes* spp. and whip morphologies, *Cirrhipathes* and *Stichopathes* spp.), interspersed by areas of coarse carbonate sand, turfing macroalgae, hard corals, octocorals, sponges and calcareous rhodoliths beds. These results are similar to benthic habitats described on the shelves surrounding Lord Howe Island and Balls Pyramid, where mesophotic communities vary among inner-, mid- and outer-shelf areas (Linklater et al. 2019). Inner- and mid-shelf reefs around Lord Howe Island and Balls Pyramid are also characterised by a diverse array of hard scleractinian corals, black corals, massive soft corals (including *Lobophytum* sp.) and filamentous and branching algae, while outer-shelf reefs comprise greater proportions of biogenic substrates, including rhodoliths.

Demersal fish were abundant across both lagoon and mesophotic shelf habitats, with ~6200 individual fish comprising 195 species from 36 families (124 species from 30 families at Elizabeth Reef and 168 species from 32 families at Middleton Reef). The most speciose family on both reefs were Labrids, followed by Chaetodontidae, Acanthuridae, Pomacentridae, Serranidae and Scaridae. Clear patterns in some trophic feeding guilds were evident across depths at both reefs, with scraping and browsing herbivore abundance decreasing with increasing depth. By contrast, generalist carnivore abundance appeared to increase with increasing depth. Whether due to protection or isolation, or a combination of both, the reef systems surveyed here had a large proportion of top predators relative to continental shelf waters off eastern Australia, including black cod, Galapagos sharks and tiger sharks. Despite being limited by the truncated stereo-BRUV survey at Elizabeth reef, these initial results suggest a greater number of larger predators at the fully protected Middleton Reef vs. Elizabeth Reef, which is open to fishing. However, further sampling is required to determine whether this is a spatial pattern or one likely related to the extent of protection.

This study presents a first attempt to document mesophotic ecosystems on the shelf platforms of Elizabeth and Middleton Reefs, using a suite of integrated survey tools. The sampling approach undertaken in this study followed the NESP standard operating procedures to generate a robust inventory of biological and physical assets, based on spatially balanced sampling designs. The knowledge gained here of mesophotic reef geomorphology and associated sessile invertebrate and demersal fish assemblages, augments existing baseline knowledge of shallow benthic habitats, and provides an improved understanding of the representativeness of a Key Ecological Feature within the Lord Howe Marine Park. This new information will help underpin future monitoring of values and pressures acting on benthic invertebrate and demersal fish assemblages.

5.1 Future work and recommendations

Due to the early termination of this survey, not all planned data sets were acquired at Elizabeth Reef, which remains only partly mapped and sampled. Additional validation is needed to fully interpret habitat distribution currently inferred from high-resolution bathymetry away from areas sampled by AUVs and stereo-BRUVs. This will improve quantitative estimates of habitat coverage and associated sessile and mobile fauna, based on spatially balanced designs.

To facilitate comparisons between management zones of the Lord Howe Marine Park and examine changes in species assemblages through time we recommend:

- Completing the acquisition of high-resolution multibeam bathymetry and acoustic backscatter data at Elizabeth Reef to characterise the geomorphology of seabed habitats across the shelf.
- Where possible, using satellite imagery to derive bathymetry of shallow areas (~5–15 m depth) on the inner shelf and within the lagoons of Elizabeth and Middleton Reefs (satellite-derived bathymetry) to characterise shallow geomorphic features.
- Completing the characterisation of shelf features at Elizabeth Reef by implementing spatially balanced AUV missions to quantify percent cover of sessile invertebrate communities.
- Completing characterisation of shelf habitats at Elizabeth and Middleton Reefs by fully implementing spatially balanced stereo-BRUVs on shelf and lagoon environments to document species richness and abundance of demersal fish communities. This may facilitate population size estimates of key species (e.g. black cod) following the approach applied by Barrett et al. (2021).
- Undertaking targeted geological mapping and sampling of each reef to determine the age and thickness of limestone formations (e.g. shallow drilling and sub-bottom

profiling) following the approach applied by Linklater et al. (2015, 2016) at Lord Howe Island and Balls Pyramid shelves.

- Mapping and characterising deeper water habitats around each seamount to increase our understanding of the connectivity between shallow, mesophotic and deep benthic habitats.
- Undertaking repeat sampling of benthic communities and demersal fish assemblages at each reef to examine changes in species assemblages through time and inform evaluation of the effectiveness of management plans.

6. ACKNOWLEDGEMENTS

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APPENDIX A – PERMITS

UNIVERSITY of TASMANIA

Animal Ethics Committee

ETHICS APPROVAL PERMIT

Office of Research Services
Phone : 03 62267283
Fax: 03 62267148
animal.ethics@utas.edu.au

To: Associate Professor Neville Barrett

From: Gina Zappia

Date: 08 October 2019

Project: A0018195 - Marine Biodiversity Hub remote imagery-based observations

Approved on: 07 October 2019

Approval expires: 06 October 2022

1st Annual Report due: 06 October 2020

Please read this permit carefully as **approval may be withdrawn** for non-compliance with the conditions stated below.

The Animal Ethics Committee has approved the above project and a copy of the initial application document is attached. The approval is subject to the review and AEC approval of an annual report which is due before the approval anniversary. **Please note the due date in your diary.**

As the Responsible Investigator, you MUST ensure that:

1. All aspects of the work conform to the requirements of the current edition of the *Australian code of practice for the care and use of animals for scientific purposes* 8th edition 2013

2. The project is conducted in accordance with the provisions of the Tasmanian Veterinary Surgeons Act 1987 and Veterinary Surgeons Regulations 2012. If the project involves a veterinary service or other animal service, it is **your responsibility** to contact the University Veterinarian to discuss the legal requirements of competency assessment.

Department of Primary Industries

ANIMAL RESEARCH AUTHORITY

Names of Applicants:		Location of Research:	Conditions of Authority:
David Harasti Brett Louden Joel Williams Peter Gibson Roger Laird Gwen Cadiou Ben Kearney Victoria Cole Adam Wiltshire Tom Davis Melinda Coleman Justin Gilligan	Caitlin Woods Sally-Ann Gudge Nathan Knott Matt Hammond Matt Rees Marty Hing Matt Carr David Maguire Jackie Corlass Hamish Malcolm Geoff McDonald Art Shultz Phoeve Colbrelli-Cox	Cape Byron, Lord Howe Island, Solitary Islands, Port Stephens Great Lakes, Jervis Bay and Batemans Bay Marine Parks and some areas immediately adjacent to the parks and Multiple sites in the Hawkesbury Shelf Marine Bioregion in between Jervis Bay and Port Stephens Marine Park	As per application

are authorised by

NSW Department of Primary Industries

to conduct the following type of research

Monitoring of fish communities using visual and video surveys
ACEC REF 10/09 – Marine Parks Authority

as approved by and in accordance with the establishment's
Animal Care and Ethics Committee

Primary Industries (Fisheries) Animal Care & Ethics Committee

This authority remains in force from

4 DECEMBER 2019 to 4 DECEMBER 2020

unless suspended, cancelled or surrendered.
(Major five yearly review due in 2021)

RACHEL KERMA
EXECUTIVE OFFICER

MICHAEL LOWRY
CHAIR

9 December 2019

APPENDIX B – SCIENTIFIC PERSONNEL

Scientific Personnel		
Name	**Principal Role**	**Responsibility**
GA Personnel		
Andrew Carroll	Chief Scientist / Marine ecologist	Survey leader & all operations
Nick Dando	Marine technician	Multibeam sonar operations
Justy Siwabessy	Seabed acoustician	Multibeam sonar acquisition & processing
Aero Leplastrier	Marine scientist	Multibeam sonar acquisition & Drone
IMAS Personnel		
Jacquomo Monk	IMAS Lead / Marine ecologist	Survey co-leader, ROV, AUV & BRUV
Neville Barrett	IMAS lead / Marine ecologist	Operations support, ROV, AUV & BRUVs
Justin Hulls	Marine technician / fish biologist	Technical support, ROV, AUV & BRUVs
Kristy Brown	Honours student, field assistant	Technical support, ROV & BRUVs
Taryn Swete	Masters student, field assistant	Technical support, ROV & BRUVs
DPI NSW Personnel		
Dave Harasti	Marine scientist	Benthic ecology – BRUVs / Snorkel surveys
Brett Louden	Marine scientist	Benthic ecology – BRUVs / Snorkel surveys
Matt Hammond	Marine scientist	Benthic ecology – BRUVs / Snorkel surveys
ACRF Personnel		
Lachlan Toohey	AUV technician	AUV operations & data management
Dave Henderson	AUV technician	AUV operations & maintenance
Christian Reeks	AUV technician	AUV operations & maintenance
Christian Lees	AUV technician	AUV operations & maintenance
Parks Australia Personnel		
Cath Samson	Marine Parks officer	Assist with operations, Parks advice

APPENDIX C – SEDIMENT SAMPLES

Elizabeth Reef				
Sample ID	**Latitude**	**Longitude**	**Water Depth (m)**	**Description**
GA4848_01GR01	-29.9054703	159.0530253	no data	Coarse sand (carbonate)
GA4848_02GR02	-29.9075498	159.030825	46.8	Slightly gravelly sand (carbonate)
GA4848_03GR03	-29.9209985	159.0450396	19.8	Medium sand (carbonate)
Middleton Reef				
GA4848_04GR04	-29.4142065	159.105308	30.5	Coarse sand (carbonate)
GA4848_05GR05	-29.4108378	159.0902223	56.2	Coarse sand (carbonate)
GA4848_06GR06	-29.4326007	159.0688669	41.4	Coarse sand (carbonate)
GA4848_07GR07	-29.4287171	159.0634675	46.8	Sandy gravel (rhodoliths)
GA4848_08GR08	-29.4872978	159.1155494	45.7	Gravel (rhodoliths)
GA4848_09GR09	-29.4901756	159.0753891	45.9	Coarse sand (carbonate)
GA4848_10GR10	-29.4923101	159.0682646	60.1	Sandy gravel (rhodoliths)
GA4848_11GR11	-29.4968585	159.093201	84.2	Cobble (carbonate)

APPENDIX D – MEAN PERCENTAGE COVER FOR SESSILE MORPHOSPECIES

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Elizabeth										
Biota > Ascidians > Unstalked > Solitary	5									
Biota > Bacterial mats	72	72								
Biota > Bryozoa > Hard > Fenestrate > Bryozoa Celleporaria Like					4					
Biota > Bryozoa > Hard > Fenestrate > Bryozoa orange lace					4					
Biota > Bryozoa > Soft > Foliaceous > Bryozoa Soft Beige Fluffy				4						
Biota > Cnidaria > Corals	4									
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Arborescent	5									
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Arborescent > Alcyoniidae	4									
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Arborescent > Dendronephthya spp					4					
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Arborescent > Sinularia		7	8							
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Arborescent > Soft Capnella Like					4					
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Mushroom > Sarcophyton spp	4									
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Mushroom > Sinularia	4									
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Non-fleshy > Arborescent > Black thin branching (Ellisellidae)			6							
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Non-fleshy > Arborescent > Large Black Coral White Feathers		20	4							
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Non-fleshy > Arborescent > Orange thin branching (Ellisellidae)		4	6	6	7					

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Non-fleshy > Bushy > Orange bushy		9	5							
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting	4	4								
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Alcyoniidae	7	4	4							
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Lobate		12								
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Lobate > Alcyoniidae	5		4							
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Lobate > Lobophytum spp	9	4	4							
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Lobate > Sinularia	9	5								
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Ridged/Folded > Lobophytum spp	6	8	8							
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Sinularia	15	8	4							
Biota > Cnidaria > Corals > Black & Octocorals > Fan (2D) > Fern-frond > Complex > Dark purple octocoral					4					
Biota > Cnidaria > Corals > Black & Octocorals > Fan (2D) > Fern-frond > Complex > Grey fan					5					
Biota > Cnidaria > Corals > Black & Octocorals > Fan (2D) > Fern-frond > Complex > Peach fan					4					
Biota > Cnidaria > Corals > Black & Octocorals > Fan (2D) > Rigid > Thin branching grey				4						
Biota > Cnidaria > Corals > Black & Octocorals > Massive soft corals > Sarcophyton spp	7	8	4							
Biota > Cnidaria > Corals > Black & Octocorals > Whip > Sea Whip		4	5							
Biota > Cnidaria > Corals > Black & Octocorals > Whip > Sea Whip > Black Cirrhipathes sp				4						
Biota > Cnidaria > Corals > Black & Octocorals > Whip > Sea Whip > Cirrhipathes		4	6	5	5					
Biota > Cnidaria > Corals > Stony corals	4									
Biota > Cnidaria > Corals > Stony corals > Branching		5								
Biota > Cnidaria > Corals > Stony corals > Branching > Acropora		4	8							

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Stony corals > Branching > Pocillopora	4	4								
Biota > Cnidaria > Corals > Stony corals > Branching > Seriatopora	8	4	4							
Biota > Cnidaria > Corals > Stony corals > Branching > Seriatopora caliendrum		6								
Biota > Cnidaria > Corals > Stony corals > Branching > Seriatopora hystrix		4								
Biota > Cnidaria > Corals > Stony corals > Branching > Stylophora pistillata		4								
Biota > Cnidaria > Corals > Stony corals > Corymbose > Acropora aculeus			8							
Biota > Cnidaria > Corals > Stony corals > Encrusting	5	5								
Biota > Cnidaria > Corals > Stony corals > Encrusting > Astrea curta	5									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Astreopora	4									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Columnar > Platygyra	8	4								
Biota > Cnidaria > Corals > Stony corals > Encrusting > Coscinaraea	4									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Coscinaraea columna	6									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Dipsastraea	4									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Echinophyllia aspera	6	4	10							
Biota > Cnidaria > Corals > Stony corals > Encrusting > Euphyllia	4									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Euphyllia ancora	9	8	7							
Biota > Cnidaria > Corals > Stony corals > Encrusting > Favites	4	4								
Biota > Cnidaria > Corals > Stony corals > Encrusting > Favites flexuosa			4							
Biota > Cnidaria > Corals > Stony corals > Encrusting > Goniastrea	8									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Goniopora	4		5							
Biota > Cnidaria > Corals > Stony corals > Encrusting > Leptastrea	5									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Leptoseris			5							
Biota > Cnidaria > Corals > Stony corals > Encrusting > Montipora	6	12	22							

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Stony corals > Encrusting > Platygyra	6	4								
Biota > Cnidaria > Corals > Stony corals > Encrusting > Platygyra/Paragoniastrea	5		4							
Biota > Cnidaria > Corals > Stony corals > Encrusting > Plesiastrea versipora	6	4								
Biota > Cnidaria > Corals > Stony corals > Encrusting > Plesiastreidae			4							
Biota > Cnidaria > Corals > Stony corals > Encrusting > Porites	8		4							
Biota > Cnidaria > Corals > Stony corals > Encrusting > Turbinaria radicalis	8									
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Echinophyllia			4							
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Echinophyllia/Oxypora	4	8	7							
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Echinopora	4									
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Merulina ampliata	4									
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Montipora		12	11							
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Mycedium	16									
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Oxypora		8	15							
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria	12	8								
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria frondens	19	36								
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria heronensis	9									
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria mesenterina	23	9								
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria patula		4	4							
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria peltata	12	4								
Biota > Cnidaria > Corals > Stony corals > Massive > Platygyra/Paragoniastrea		5								
Biota > Cnidaria > Corals > Stony corals > Sub-massive	7	4								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Acanthastrea	6		4							

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Alveopora spongiosa	4	6								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Astreopora	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Blastomussa		4								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Blastomussa wellsi			7							
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Coscinaraea exesa	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Cyphastrea	6	4								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Cyphastrea serailia / salae	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea	7	4	4							
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea favus	6									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea matthaii	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea speciosa	5									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Favites	4	4								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Goniastrea	8	4								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Goniastrea favulus	6									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Goniastrea pectinata		4								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Goniopora	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Homophyllia	4		12							
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Hydnophora	7	4								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Hydnophora exesa	6									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Hydnophora microconos	8									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Hydnophora pilosa	8									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Leptoria phrygia	8									

Morphospecies	North					South				
	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Lobophyllia hemprichii	6	8								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Merulinidae	5	4	5							
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Oulophyllia crispa	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Paragoniastrea	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Paragoniastrea australensis	5	5	8							
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Paragoniastrea russelli	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Pavona	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Platygyra	8	10								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Platygyra daedalea	8	7								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Platygyra sinensis	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Platygyra/Paragoniastrea	6	4	5							
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Porites	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Psammocora	5									
Biota > Cnidaria > Corals > Stony corals > Tabulate > Acropora		4	8							
Biota > Cnidaria > Hydroids > Hydroid Brown Feathers			7	5	4					
Biota > Cnidaria > Hydroids > Hydroid complex white			6							
Biota > Cnidaria > Hydroids > Hydroid White			4	4						
Biota > Cnidaria > Hydroids > Stylasteridae			4							
Biota > Cnidaria > True anemones					8					
Biota > Cnidaria > True anemones > Other anemones	4									
Biota > Echinoderms					8					
Biota > Echinoderms > Feather stars				4						
Biota > Echinoderms > Feather stars > Unstalked crinoids > Oxycomanthus bennetti		4								

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Echinoderms > Sea cucumbers	4									
Biota > Echinoderms > Sea urchins					4					
Biota > Echinoderms > Sea urchins > Regular urchins					4					
Biota > Fishes > Bony fishes			4							
Biota > Fishes > Bony fishes > Myripristis spp (CAAB 37 261901)			8		4					
Biota > General Unknown Biology				4	4					
Biota > Macroalgae > Articulated calcareous > Green > Halimeda spp	6		5	4	8					
Biota > Macroalgae > Articulated calcareous > Red	4									
Biota > Macroalgae > Articulated calcareous > Red > Articulated Calcareous Red	4			4						
Biota > Macroalgae > Encrusting > Green		4								
Biota > Macroalgae > Encrusting > Green > Codium spp		8		4						
Biota > Macroalgae > Encrusting > Red	6	6	4	5						
Biota > Macroalgae > Encrusting > Red > Calcareous	7		6	5	4					
Biota > Macroalgae > Erect coarse branching	4									
Biota > Macroalgae > Erect coarse branching > Green > Caulerpa spp	4									
Biota > Macroalgae > Erect fine branching	4			5						
Biota > Macroalgae > Erect fine branching > Red			4	4						
Biota > Macroalgae > Filamentous / filiform > Turfing Algae	44	62	73	81	83					
Biota > Macroalgae > Filamentous / filiform > Turfing Algae > Green turf	9	19	6	25						
Biota > Macroalgae > Globose / saccate > Green	4									
Biota > Macroalgae > Laminate > Brown > Lobophora spp			5	6	5					
Biota > Macroalgae > Sheet-like / membraneous > Brown > Padina spp		6	6							
Biota > Matrix > Mixed Sessile Invertebrate	24									
Biota > Molluscs	4									

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Molluscs > Gastropods					4					
Biota > Sponges > Crusts > Creeping / ramose > Repent Purple				4						
Biota > Sponges > Crusts > Creeping / ramose > Repent Simple Brown				4						
Biota > Sponges > Crusts > Encrusting > Encrusting Beige Smooth					4					
Biota > Sponges > Crusts > Encrusting > Encrusting Black	4	4	5	6	7					
Biota > Sponges > Crusts > Encrusting > Encrusting Black Lumpy				4						
Biota > Sponges > Crusts > Encrusting > Encrusting Brown			4							
Biota > Sponges > Crusts > Encrusting > Encrusting dark red			5	5	5					
Biota > Sponges > Crusts > Encrusting > Encrusting Green		4								
Biota > Sponges > Crusts > Encrusting > Encrusting Light Orange	4		4							
Biota > Sponges > Crusts > Encrusting > Encrusting Orange	4	5	4	4	5					
Biota > Sponges > Crusts > Encrusting > Encrusting Orange Nodular		4	4	4	4					
Biota > Sponges > Crusts > Encrusting > Encrusting orange spikey				7						
Biota > Sponges > Crusts > Encrusting > Encrusting Purple Lumpy			4	4	5					
Biota > Sponges > Crusts > Encrusting > Encrusting White Granular					4					
Biota > Sponges > Crusts > Encrusting > Encrusting Yellow Smooth				4						
Biota > Sponges > Cup-likes > Barrels > Barrel red rippled base			4							
Biota > Sponges > Cup-likes > Barrels > Barrel Red Thick Wall			4							
Biota > Sponges > Cup-likes > Cups > Incomplete cup / curled fan > Spikey orange lace fan		8	6	4						
Biota > Sponges > Erect forms > Branching > Arborescent Black			5	4						
Biota > Sponges > Erect forms > Branching > Arborescent Orange				4						
Biota > Sponges > Erect forms > Branching > Branching Dark Purple					4					
Biota > Sponges > Erect forms > Branching > Branching Orange			4	4						
Biota > Sponges > Erect forms > Branching > Branching Orange Lumpy				4						

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Sponges > Erect forms > Branching > Branching Purple				4						
Biota > Sponges > Erect forms > Branching > Branching Purple Ramose Like					4					
Biota > Sponges > Erect forms > Laminar > Laminar White Small				4						
Biota > Sponges > Erect forms > Palmate > Arborescent Orange Flat			4							
Biota > Sponges > Erect forms > Simple > Simple Erect Orange					4					
Biota > Sponges > Massive forms > Balls > Ball Pink Oscula			8							
Biota > Sponges > Massive forms > Balls > Globular Orange					4					
Biota > Sponges > Massive forms > Balls > Globular Orange Tethya Like				4						
Biota > Sponges > Massive forms > Balls > Globular Pink Tethya Like			4	4						
Biota > Sponges > Massive forms > Balls > Papillate Black Ball				4						
Biota > Sponges > Massive forms > Balls > Smooth Orange Ball			4							
Biota > Sponges > Massive forms > Simple > Massive Orange				4						
Biota > Sponges > Massive forms > Simple > Massive Orange Ribbon		4		16						
Biota > Sponges > Massive forms > Simple > Massive Purple Laminar Oscula				4						
Biota > Sponges > Massive forms > Simple > Massive Red				4						
Biota > Sponges > Massive forms > Simple > Massive White Shapeless				4						
Biota > Sponges > Massive forms > Simple > Massive Yellow Holey					4					
Biota > Sponges > Massive forms > Simple > Massive Yellow Irregular Ball				4						
Biota > Sponges > Massive forms > Simple > Massive Yellow Shapeless			4							
Biota > Sponges > Massive forms > Simple > Purple Massive					4					
Biota > Sponges > Massive forms > Simple > Simple Beige Small		4								
Biota > Sponges > Massive forms > Simple > Simple Orange Smooth					4					
Biota > Sponges > Massive forms > Simple > Simple Pink Irregular				4						
Biota > Sponges > Massive forms > Simple > Simple Yellow Lumpy					4					

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Sponges > Massive forms > Simple > Smooth Black Massive					4					
Biota > Sponges > Massive forms > Simple > Spikey pink massive	5	5	8							
Biota > Worms				4						
Biota > Worms > Polychaetes > Tube worms			4							
Physical > Bedforms > None			4							
Physical > Substrate > Consolidated (hard)			4	4						
Physical > Substrate > Consolidated (hard) > Boulders	5									
Physical > Substrate > Consolidated (hard) > Rock	10									
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel		4								
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel > Biologenic > Coral rubble	28	21		4						
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel > Biologenic > Rhodoliths			9	9	16					
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel > Gravel (2-10mm)	10	4	6	5	10					
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel > Pebble (10-64mm)	15	8	4	5	4					
Physical > Substrate > Unconsolidated (soft) > Sand / mud (<2mm)	4									
Physical > Substrate > Unconsolidated (soft) > Sand / mud (<2mm) > Coarse sand (with shell fragments)	19	20	12	8	13					
Physical > Substrate > Unconsolidated (soft) > Sand / mud (<2mm) > Fine sand (no shell fragments)	44	16	13	10	13					
Unscorable	7			4	10					
Middleton										
Biota > Bacterial mats		83	34							
Biota > Bryozoa > Hard > Fenestrate > Bryozoa Celleporaria Like				6	5				4	5
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Arborescent > Dendronephthya spp	8					4				

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Arborescent > Sinularia	6	7	4			8	4	4		
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Mushroom > Sarcophyton spp		6					6			
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Fleshy > Mushroom > Sinularia		4								
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Non-fleshy > Arborescent > Black thin branching (Ellisellidae)				4						
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Non-fleshy > Arborescent > Large Black Coral White Feathers			4	4						
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Non-fleshy > Arborescent > Orange thin branching (Ellisellidae)		4	4	9	8				6	4
Biota > Cnidaria > Corals > Black & Octocorals > Branching (3D) > Non-fleshy > Bushy > Orange bushy		21	8							
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Lobate > Alcyoniidae	4	9	4			7	9			
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Lobate > Lobophytum spp	10	6				6	8			
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Lobate > Sinularia	15	10				10	4			
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Ridged/Folded > Lobophytum spp	9		4			8				
Biota > Cnidaria > Corals > Black & Octocorals > Encrusting > Sinularia	9	10				10	7			
Biota > Cnidaria > Corals > Black & Octocorals > Fan (2D) > Fern-frond > Simple							4			
Biota > Cnidaria > Corals > Black & Octocorals > Massive soft corals > Alcyoniidae	4									
Biota > Cnidaria > Corals > Black & Octocorals > Massive soft corals > Sarcophyton spp	4	5				8				
Biota > Cnidaria > Corals > Black & Octocorals > Quill (seapen)			4							
Biota > Cnidaria > Corals > Black & Octocorals > Whip		4								

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Black & Octocorals > Whip > Sea Whip	4	4	4	7	4		4		4	8
Biota > Cnidaria > Corals > Black & Octocorals > Whip > Sea Whip > Black Cirrhipathes sp		9								
Biota > Cnidaria > Corals > Black & Octocorals > Whip > Sea Whip > Cirrhipathes		5	4	5	5		5	6	6	6
Biota > Cnidaria > Corals > Stony corals > Branching > Astreopora	20									
Biota > Cnidaria > Corals > Stony corals > Branching > Pocillopora		4								
Biota > Cnidaria > Corals > Stony corals > Branching > Seriatopora	8	4	4							
Biota > Cnidaria > Corals > Stony corals > Branching > Seriatopora hystrix		4								
Biota > Cnidaria > Corals > Stony corals > Corymbose > Acropora						4				
Biota > Cnidaria > Corals > Stony corals > Encrusting	5	5	4			8				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Alveopora						4				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Astrea curta	4	4				5				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Columnar > Platygyra	9					11				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Coscinaraea columna	8	4								
Biota > Cnidaria > Corals > Stony corals > Encrusting > Dipsastraea	4									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Echinophyllia	4									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Echinophyllia aspera	7					8				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Euphyllia ancora		5								
Biota > Cnidaria > Corals > Stony corals > Encrusting > Favites	5					4				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Leptastrea	5					4				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Leptoseris	4		12			4			5	

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Stony corals > Encrusting > Merulinidae	4					4				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Montipora	8	5	7			4				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Platygyra	5					4				
Biota > Cnidaria > Corals > Stony corals > Encrusting > Platygyra/Paragoniastrea	4									
Biota > Cnidaria > Corals > Stony corals > Encrusting > Plesiastrea versipora	4	4					4			
Biota > Cnidaria > Corals > Stony corals > Encrusting > Porites	4									
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Echinophyllia/Oxypora	4	4				4				
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Montipora			8							
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Oxypora		8								
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria frondens	5	4								
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria mesenterina	20	56								
Biota > Cnidaria > Corals > Stony corals > Foliose / plate > Turbinaria patula		4								
Biota > Cnidaria > Corals > Stony corals > Solitary > Homophyllia australis	4									
Biota > Cnidaria > Corals > Stony corals > Solitary > Mushroom (Fungiidae) > Cycloseris distorta		33								
Biota > Cnidaria > Corals > Stony corals > Sub-massive	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Acanthastrea	4					4				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Astreopora						4				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Cyphastrea	5	4				10				

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Cyphastrea microphthalma	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea	6	4				7	5			
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea favus	4	4				5				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea matthaii	8					4				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea rotumana	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Dipsastraea speciosa						4				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Favites	5					4				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Goniastrea	8									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Goniastrea edwardsi						4				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Goniastrea pectinata	8									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Goniopora		4				4				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Homophyllia		4								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Hydnophora	8	6				11	28			
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Hydnophora exesa	12	6								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Hydnophora pilosa	8									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Leptoria	4									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Leptoria phrygia	9									

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Lobophyllia hemprichii	8									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Merulinidae	6					9	4			
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Micromussa lordhowensis								4		
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Paragoniastrea australensis	5	4				5				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Platygyra	9	4				10	4			
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Platygyra daedalea		12								
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Platygyra sinensis	6									
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Platygyra/Paragoniastrea	4	5				7	7			
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Porites						14				
Biota > Cnidaria > Corals > Stony corals > Sub-massive > Psammocora		8								
Biota > Cnidaria > Hydroids > Hydroid Branching Brown Feathers				4						
Biota > Cnidaria > Hydroids > Hydroid Brown Feathers			14	6					6	
Biota > Cnidaria > Hydroids > Hydroid Dark Grey				4				4		
Biota > Cnidaria > True anemones					4					
Biota > Cnidaria > True anemones > Other anemones			4					4		
Biota > Crustacea > Hermit crabs				4						
Biota > Echinoderms > Feather stars					4					
Biota > Echinoderms > Feather stars > Unstalked crinoids				4	4					
Biota > Echinoderms > Sea cucumbers	4									
Biota > Echinoderms > Sea stars				4						4

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Echinoderms > Sea urchins > Regular urchins					4					4
Biota > Echinoderms > Sea urchins > Regular urchins > Diadema spp	4									
Biota > Fishes > Bony fishes					4					
Biota > Fishes > Bony fishes > Chilomycterus reticulatus (CAAB 37 469014)	4									
Biota > General Unknown Biology						4				
Biota > Macroalgae > Articulated calcareous > Green	4									
Biota > Macroalgae > Articulated calcareous > Green > Halimeda spp	6	6	6	5		4		6	5	
Biota > Macroalgae > Articulated calcareous > Red	4	4		4		8			4	
Biota > Macroalgae > Articulated calcareous > Red > Articulated Calcareous Red	4	4	4					8		
Biota > Macroalgae > Encrusting > Brown	5	4				4	4			
Biota > Macroalgae > Encrusting > Green	9					7	4			
Biota > Macroalgae > Encrusting > Green > Codium spp						4				
Biota > Macroalgae > Encrusting > Red	4		4			6				
Biota > Macroalgae > Encrusting > Red > Calcareous	6	8	5	7	5	8	8	8	14	9
Biota > Macroalgae > Encrusting > Red > Non-calcareous	4									
Biota > Macroalgae > Erect coarse branching > Brown						4				
Biota > Macroalgae > Erect fine branching	5	9	4			4		4		
Biota > Macroalgae > Erect fine branching > Brown > Brown Understory Algae > Dictyotaceae spp	4		4					10		
Biota > Macroalgae > Erect fine branching > Green > Caulerpa spp	4	14	13					7		
Biota > Macroalgae > Erect fine branching > Red	7	17	4				4	4		
Biota > Macroalgae > Filamentous / filiform > Green > Cladophoropsis spp	4									

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Macroalgae > Filamentous / filiform > Turfing Algae	55	41	64	25	12	58	58	57	22	16
Biota > Macroalgae > Filamentous / filiform > Turfing Algae > Green turf	5	8	4						12	
Biota > Macroalgae > Globose / saccate > Brown	4									
Biota > Macroalgae > Globose / saccate > Green	7					4				
Biota > Macroalgae > Globose / saccate > Green > Codium spp	6									
Biota > Macroalgae > Laminate > Brown						4				
Biota > Macroalgae > Laminate > Brown > Lobophora spp				6					8	
Biota > Macroalgae > Laminate > Red			4				28			
Biota > Macroalgae > Sheet-like / membraneous > Brown	4		4							
Biota > Macroalgae > Sheet-like / membraneous > Brown > Padina spp		4	4	6				4	4	
Biota > Matrix > Mixed Sessile Invertebrate	5									
Biota > Sponges > Crusts > Creeping / ramose	4									
Biota > Sponges > Crusts > Creeping / ramose > Repent Orange				4						
Biota > Sponges > Crusts > Encrusting > Encrusting Beige Oscula						4				
Biota > Sponges > Crusts > Encrusting > Encrusting Black	4			4	8				5	4
Biota > Sponges > Crusts > Encrusting > Encrusting Brown		4								
Biota > Sponges > Crusts > Encrusting > Encrusting dark red		4		5	4			4	7	8
Biota > Sponges > Crusts > Encrusting > Encrusting Orange	4	4	4	4	6	4	5	4	5	7
Biota > Sponges > Crusts > Encrusting > Encrusting Orange Nodular	4									
Biota > Sponges > Crusts > Encrusting > Encrusting White						4				
Biota > Sponges > Cup-likes > Barrels > Barrel red rippled base	12									
Biota > Sponges > Cup-likes > Cups > Incomplete cup / curled fan > Spikey orange lace fan	4	5	4	6			7			
Biota > Sponges > Erect forms > Branching > Arborescent Black				8						

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Biota > Sponges > Erect forms > Branching > Arborescent Purple Thin				4						
Biota > Sponges > Erect forms > Laminar > Laminar Orange Irregular	8									
Biota > Sponges > Massive forms > Simple > Massive Brown						4				
Biota > Sponges > Massive forms > Simple > Massive Dark Purple		4		4						
Biota > Sponges > Massive forms > Simple > Massive Orange Ribbon				12						
Biota > Sponges > Massive forms > Simple > Simple Beige Small					4		4		4	
Biota > Sponges > Massive forms > Simple > Simple Pink Oscula				5						
Biota > Sponges > Massive forms > Simple > Simple Red Ball Like									4	
Biota > Sponges > Massive forms > Simple > Spikey pink massive	4	5	4		4	4	4		6	
Biota > Worms	10									
Biota > Worms > Polychaetes > Tube worms	4	12	4			4		6		
Physical > Substrate > Consolidated (hard)		4								
Physical > Substrate > Consolidated (hard) > Boulders	18									
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel	12									
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel > Biologenic > Coral rubble	10	11				4	8			
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel > Biologenic > Rhodoliths		20	44	63	47		13	41	67	71
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel > Gravel (2-10mm)	4			11	27				12	20
Physical > Substrate > Unconsolidated (soft) > Pebble / gravel > Pebble (10-64mm)	16	8	8							
Physical > Substrate > Unconsolidated (soft) > Sand / mud (<2mm)	4									
Physical > Substrate > Unconsolidated (soft) > Sand / mud (<2mm) > Coarse sand (with shell fragments)	17	19	12	15	33	14	31	16	17	31

	North					South				
Morphospecies	<30 m	31-50 m	51-70 m	71-90 m	>90 m	<30m	31-50 m	51-70 m	71-90 m	>90 m
Physical > Substrate > Unconsolidated (soft) > Sand / mud (<2mm) > Fine sand (no shell fragments)	79	23	14	19	51	4	10	5	14	40
Unscorable	9	10	6	8	5	12	7	7	6	5

APPENDIX E – RELATIVE ABUNDANCE (MAXN) OF DEMERSAL FISHES (STEREO-BRUVS)

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
Elizabeth	***No. stereo-BRUVs***	***2***	***19***	***10***	***1***	***2***					
Acanthuridae	*Acanthurus albipectoralis*		9	2							11
	Acanthurus blochii	1									1
	Acanthurus dussumieri	2	18	17							37
	Acanthurus nigrofuscus	3	2								5
	Acanthurus olivaceus			1							1
	Naso annulatus		1								1
	Naso caesius		1	11							12
	Naso tonganus		10								10
	Naso unicornis	6	15	14							35
	Prionurus maculatus		6								6
	Prionurus microlepidotus/maculatus		187	21							208
	Zebrasoma veliferum		2								2
Apogonidae	*Ostorhinchus doederleini*		1	2							3
Aulostomidae	*Aulostomus chinensis*		1	3							4
Balistidae	*Pseudobalistes fuscus*			2							2
	Sufflamen chrysopterum		1	1							2
	Sufflamen fraenatum		7	5							12

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
Blenniidae	*Meiacanthus phaeus*		4								4
Blenniidae	*Plagiotremus tapeinosoma*		1								1
Carangidae	*Carangoides orthogrammus*		1								1
	Caranx sexfasciatus		2								2
	Pseudocaranx dentex	11	72	36	2						121
	Seriola lalandi	3	9	11		4					27
	Seriola rivoliana		4	5		2					11
Carcharhinidae	*Carcharhinus galapagensis*	7	39	26	3						75
	Galeocerdo cuvier	1	2								3
Chaetodontidae	*Chaetodon auriga*	2	8	3							13
	Chaetodon citrinellus		2								2
	Chaetodon flavirostris		5	2							7
	Chaetodon guentheri		10	4		3					17
	Chaetodon kleinii	2	4	2							8
	Chaetodon lineolatus		3	14							17
	Chaetodon melannotus		5								5
	Chaetodon mertensii	3	14	2							19
	Chaetodon pelewensis	2	6	1							9
	Chaetodon plebeius		7	2							9
	Chaetodon speculum		1								1
	Chaetodon tricinctus	1	9	2							12
	Chaetodon trifascialis		1								1

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Chaetodon ulietensis	2									2
	Chaetodon unimaculatus	1	3								4
Chaetodontidae	*Forcipiger flavissimus*			2							2
Cheilodactylidae	*Cheilodactylus francisi*		1	1		2					4
Cirrhitidae	*Cirrhitichthys aprinus*			1							1
	Cirrhitichthys falco		2								2
Dasyatidae	*Dasyatis thetidis*	2	2								4
	Taeniurops meyeni		2		1						3
Echeneidae	*Echeneis naucrates*		1								1
Fistulariidae	*Fistularia commersonii*		1	1							2
Grammistidae	*Aulacocephalus temminckii*					1					1
Haemulidae	*Plectorhinchus picus*		7	4							11
Kyphosidae	*Kyphosus sectatrix*		9	4							13
	Kyphosus sydneyanus		1								1
Labridae	*Anampses elegans*		3								3
	Anampses femininus	1									1
	Anampses geographicus		1								1
	Anampses neoguinaicus		1	1							2
	Bodianus bilunulatus			3							3
	Bodianus masudai					1					1
	Bodianus perditio	1	9	8	1						19
	Bodianus unimaculatus			1		2					3

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Cirrhilabrus punctatus	6									6
	Coris bulbifrons	2	18	10							30
	Coris picta		6	7	5	3					21
Labridae	*Gomphosus varius*		1								1
	Hemigymnus melapterus	3									3
	Iniistius pavo		7	1							8
	Labroides dimidiatus	2	8	3							13
	Labropsis australis			1							1
	Pseudolabrus guentheri			1							1
	Pseudolabrus luculentus	1	23	6	1						31
	Stethojulis bandanensis		2								2
	Thalassoma lunare	11	7								18
	Thalassoma lutescens	3	24	1							28
	Thalassoma nigrofasciatum		1								1
Lethrinidae	*Gymnocranius euanus*		23	40	2						65
	Lethrinus miniatus			5							5
Lutjanidae	*Aprion virescens*		2								2
	Lutjanus bohar		4	4							8
	Paracaesio xanthura	11				0					11
	Pristipomoides filamentosus			3	5	1					9
Malacanthidae	*Malacanthus brevirostris*		2	7							9
Mullidae	*Parupeneus barberinus*			1							1

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Parupeneus multifasciatus	1	12	2							15
	Parupeneus pleurostigma	1	31	17		1					50
	Parupeneus spilurus			1							1
Muraenidae	*Gymnothorax annasona*		13	12							25
Muraenidae	*Gymnothorax prionodon*		1								1
	Gymnothorax undulatus		2	2							4
Ostraciidae	*Ostracion cubicus*		1								1
Pinguipedidae	*Parapercis schauinslandii*			7							7
Pomacanthidae	*Centropyge tibicen*	2	4	5							11
	Chaetodontoplus conspicillatus		10	9							19
	Genicanthus semicinctus		2	2		1					5
Pomacentridae	*Chromis abyssicola*					35					35
	Chromis axillaris					1					1
	Chromis flavomaculata		43	32							75
	Chromis hypsilepis		165	120							285
	Chrysiptera notialis		42	5							47
	Dascyllus aruanus	1									1
	Dascyllus reticulatus		17								17
	Neoglyphidodon melas		1								1
	Neoglyphidodon polyacanthus	3	26	2							31

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Parma alboscapularis		1								1
	Plectroglyphidodon johnstonianus		1								1
	Pomacentrus moluccensis		2								2
Scaridae	*Chlorurus microrhinos*			2							2
Scaridae	*Chlorurus sordidus*	18	16	1							35
	Hipposcarus longiceps			1							1
	Scarus altipinnis		1	1							2
	Scarus flavipectoralis	1									1
	Scarus ghobban	2	2	8							12
	Scarus schlegeli	1	33								34
Serranidae	*Cephalopholis argus*		2	1							3
	Epinephelus cyanopodus		1	2	1						4
	Epinephelus daemelii	1	1	5	1	1					9
	Epinephelus fasciatus		1	4							5
	Epinephelus maculatus			9							9
	Epinephelus morrhua					3					3
	Epinephelus rivulatus		1	9							10
	Variola louti		5	7							12
Tetraodontidae	*Canthigaster axiologus*		1								1
	Canthigaster callisterna		1								1
Zanclidae	*Zanclus cornutus*	1	5	5							11

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Total	**122**	**1085**	**576**	**22**	**61**	**Not surveyed**	**Not surveyed**	**Not surveyed**	**Not surveyed**	**1866**
Middleton	***No. stereo-BRUVs***	***74***	***8***	***6***	***8***	***4***	***3***	***17***	***12***	***4***	
Acanthuridae	*Acanthurus albipectoralis*			1				27			28
	Acanthurus blochii	44									44
	Acanthurus dussumieri	29	11	10	5		7	39	9		110
Acanthuridae	*Acanthurus nigrofuscus*	20	3								23
	Acanthurus olivaceus	4	2				2	1			9
	Acanthurus triostegus	1									1
	Naso brevirostris	2									2
	Naso caesius		10	10	3	1	13	57	23	4	121
	Naso lituratus	2									2
	Naso tonganus	1									1
	Naso unicornis	84	1	2	2		3	20	3		115
	Prionurus maculatus	194	9				2	19	5		229
	Prionurus microlepidotus	99									99
	Prionurus microlepidotus/maculatus			49	3		50	77	4	3	186
	Zebrasoma scopas	3									3
	Zebrasoma veliferum		1								1
Aulostomidae	*Aulostomus chinensis*	4		2	1						7
Balistidae	*Pseudobalistes fuscus*						1	1			2

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Rhinecanthus aculeatus	2									2
	Sufflamen chrysopterum	2		1			1				4
	Sufflamen fraenatum	2	2	4	2		2	13	2		27
Belonidae	*Tylosurus crocodilus*	8									8
Blenniidae	*Plagiotremus sp*							0			0
Bothidae	*Bothus pantherinus*	1									1
Carangidae	*Carangoides orthogrammus*	18					1	2			21
Carangidae	*Caranx lugubris*							2			2
	Pseudocaranx dentex	421	5	26	17	20	13	60	46	8	616
	Seriola lalandi	60	5	12	18	5	3	29	35	19	186
	Seriola rivoliana	2	1	5	8	4	2	13	14	20	69
Carcharhinidae	*Carcharhinus galapagensis*	180	29	22	21	11	5	35	23	3	329
	Carcharhinus plumbeus			1							1
	Galeocerdo cuvier	8	1	2	1	1		1			14
Chaetodontidae	*Amphichaetodon howensis*				1						1
	Chaetodon auriga	50	4	1			2	4			61
	Chaetodon citrinellus	12									12
	Chaetodon ephippium	3									3
	Chaetodon flavirostris	23									23
	Chaetodon guentheri				13			86			99
	Chaetodon lineolatus	22	2				2				26
	Chaetodon lunulatus	26									26

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Chaetodon mertensii	11	4	2			2	4			23
	Chaetodon pelewensis	10									10
	Chaetodon plebeius	11									11
	Chaetodon sp	0									0
	Chaetodon tricinctus	29									29
	Chaetodon trifascialis	12									12
	Chaetodon vagabundus	2	1								3
	Forcipiger flavissimus							3			3
Chaetodontidae	*Heniochus acuminatus*						2				2
	Heniochus diphreutes							2			2
Cheilodactylidae	*Cheilodactylus ephippium*	1									1
	Cheilodactylus francisi	3			3		2	1			9
Dasyatidae	*Dasyatis thetidis*	12		1	1	1		1			16
	Taeniurops meyeni	1		1	1			1	3		7
Diodontidae	*Diodon hystrix*	4		2							6
Fistulariidae	*Fistularia commersonii*	5	1					1			7
Gobiidae	*Trimma caesiura*								0		0
Grammistidae	*Aulacocephalus temminckii*				2						2
Haemulidae	*Plectorhinchus picus*	9	1	3			1	4	2		20
Kyphosidae	*Kyphosus bigibbus*	80	12								92
	Kyphosus sectatrix	110	15				17	5			147
	Kyphosus sydneyanus	1									1

		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Kyphosus vaigiensis	2									2
Labridae	*Anampses elegans*	8									8
	Anampses femininus	20						2			22
	Anampses melanurus				1						1
	Anampses neoguinaicus	14									14
	Bodianus bilunulatus			2	3	1	1	1	2	1	11
	Bodianus perditio	8	5	7	5	3	2	16	7	2	55
	Bodianus unimaculatus			1	12	6		13	8	7	47
	Cheilio inermis	7									7
Labridae	*Cirrhilabrus laboutei*		12								12
	Cirrhilabrus punctatus	1									1
	Coris bulbifrons	97	7	3			3	14	6		130
	Coris dorsomacula		3	1	1			15	3		23
	Coris picta				2	4		10	1		17
	Coris sandeyeri	3									3
	Gomphosus varius	15									15
	Halichoeres trimaculatus	259	8								267
	Hemigymnus melapterus	16									16
	Iniistius pavo	4	2	1	1				2		10
	Labrichthys unilineatus	1									1
	Labroides dimidiatus	4			1		1	4			10
	Novaculichthys taeniourus	2									2

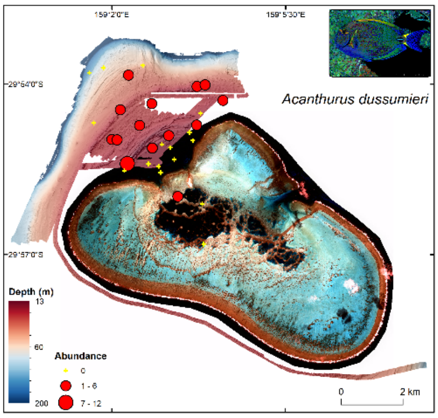
		Lagoon	North				South				
Family	**Scientific name**	**<30m**	**<30m**	**31-60m**	**61-90m**	**91-120m**	**<30m**	**31-60m**	**61-90m**	**91-120m**	**Grand Total**
	Pseudolabrus luculentus	45	1				2	6			54
	Stethojulis bandanensis	4									4
	Suezichthys arquatus		2					1		2	5
	Thalassoma hardwicke	27									27
	Thalassoma lunare	227									227
	Thalassoma lutescens	194	0								194
	Thalassoma purpureum	1									1
Lethrinidae	*Gymnocranius euanus*	18	29	29	15	8	13	71	22	5	210
	Gymnocranius grandoculis			1	2	2					5
	Lethrinus miniatus							8	2		10
Lethrinidae	*Lethrinus nebulosus*	1									1
	Lethrinus rubrioperculatus			1	1		1	12	4		19
Lutjanidae	*Aprion virescens*	5		3	2			2	7		19
	Lutjanus bohar	9	1	1			5	8	1		25
	Paracaesio xanthura	11									11
	Pristipomoides filamentosus				57	35		1	26	18	137
Malacanthidae	*Malacanthus brevirostris*	1		2	3			5	1		12
Monacanthidae	*Aluterus monoceros*				1			1			2
	Aluterus scriptus			1							1
	Cantherhines dumerilii	1									1
	Pervagor alternans	2									2
Mullidae	*Mulloidichthys flavolineatus*	13									13

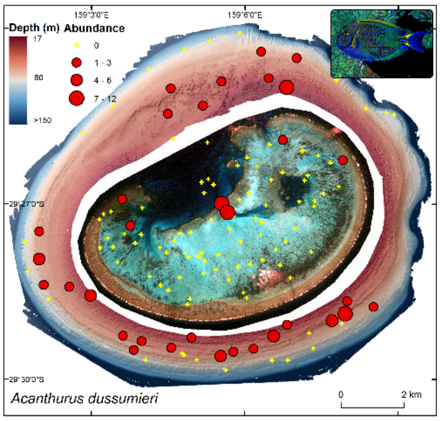
		Lagoon	North				South				
Family	**Scientific name**	**<30m**	**<30m**	**31-60m**	**61-90m**	**91-120m**	**<30m**	**31-60m**	**61-90m**	**91-120m**	**Grand Total**
	Parupeneus barberinus	4	2								6
	Parupeneus multifasciatus	23									23
	Parupeneus pleurostigma	48	14		1			42			105
	Parupeneus spilurus	19				2		14			35
Muraenidae	*Gymnothorax annasona*	4		1			2	5	2		14
	Gymnothorax meleagris	1									1
	Gymnothorax nubilus	1									1
	Gymnothorax thyrsoideus	8									8
Pentacerotidae	*Evistias acutirostris*							1			1
Pinguipedidae	*Parapercis australis*	6									6
	Parapercis queenslandica	14									14
Pomacanthidae	*Centropyge tibicen*	9		1				4			14
	Chaetodontoplus conspicillatus	7	1	3	1		8	13	2		35
	Genicanthus semicinctus				6			3			9
	Genicanthus watanabei				1						1
Pomacentridae	*Amphiprion mccullochi*	8									8
	Chromis abyssicola				40						40
	Chromis atripectoralis	7									7
	Chromis axillaris				7					1	8
	Chromis flavomaculata				1			180			181
	Chromis viridis	35									35

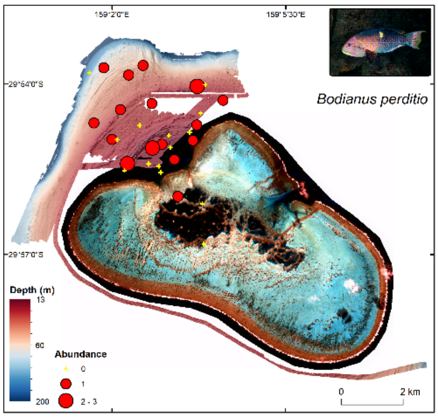
		Lagoon	North				South				
Family	Scientific name	<30m	<30m	31-60m	61-90m	91-120m	<30m	31-60m	61-90m	91-120m	Grand Total
	Chrysiptera notialis			1				1			2
	Dascyllus aruanus	60									60
	Dascyllus reticulatus	33									33
	Dascyllus trimaculatus	18									18
	Neoglyphidodon polyacanthus	38	2				1	1			42
	Parma alboscapularis	1									1
	Parma polylepis	2									2
	Stegastes fasciolatus	48									48
	Stegastes gascoynei	21									21
Scaridae	*Chlorurus microrhinos*	2		1			2	2			7
	Chlorurus sordidus	498						1			499
Scaridae	*Hipposcarus longiceps*	19		1				3			23
	Scarus altipinnis	2					1	2			5
	Scarus chameleon	51									51
	Scarus flavipectoralis	1									1
	Scarus frenatus	1									1
	Scarus ghobban	23		2	1		1	10	2		39
	Scarus longiceps	7									7
	Scarus oviceps	6									6
	Scarus psittacus	18									18
	Scarus rivulatus	1									1

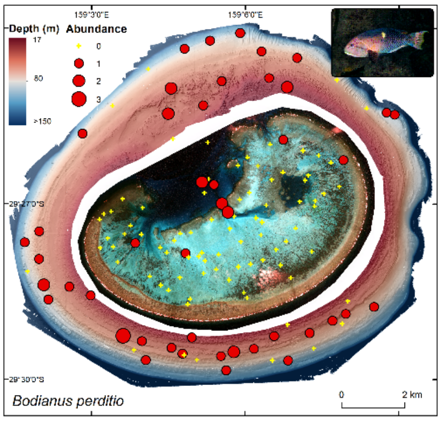
		Lagoon	North				South				
Family	**Scientific name**	**<30m**	**<30m**	**31-60m**	**61-90m**	**91-120m**	**<30m**	**31-60m**	**61-90m**	**91-120m**	**Grand Total**
	Scarus schlegeli	10						1			11
Serranidae	*Acanthistius cinctus*	1	1								2
	Cephalopholis argus		1				1	4			6
	Cephalopholis miniata							2			2
	Epinephelus cyanopodus	2		1	4	1		6	4	2	20
	Epinephelus daemelii	17	1		4	2		5	6	7	42
	Epinephelus fasciatus	2	1				1	2			6
	Epinephelus maculatus	5	1	7	1			4	1		19
	Epinephelus morrhua				2	1			3	4	10
	Epinephelus rivulatus	1		3	1		3	5	2		15
	Epinephelus tauvina							1			1
	Pseudanthias cooperi							1			1
	Pseudanthias engelhardi				4						4
Serranidae	*Pseudanthias pictilis*							13			13
	Trachypoma macracanthus	1									1
	Variola louti	3	1	1			1	4			10
Tetraodontidae	*Canthigaster callisterna*									1	1
	Canthigaster valentini	21	1								22
	Lagocephalus sceleratus		2	5	2				1		10
Zanclidae	*Zanclus cornutus*	10									10
	Total	**3765**	**218**	**237**	**285**	**108**	**182**	**1028**	**284**	**107**	**6214**

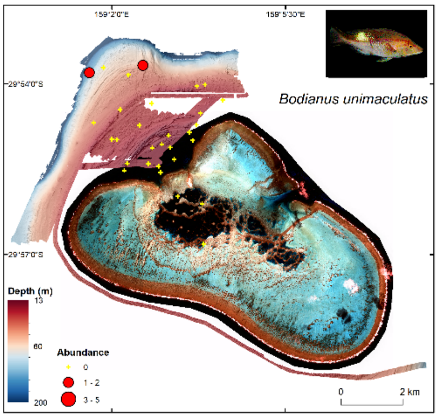
APPENDIX F – RELATIVE ABUNDANCE DISTRIBUTION PATTERNS OF DEMERSAL FISHES (STEREO-BRUVS)

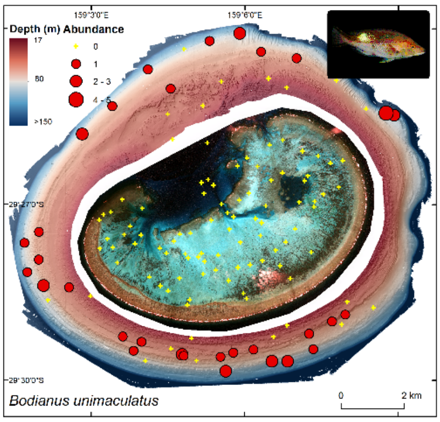


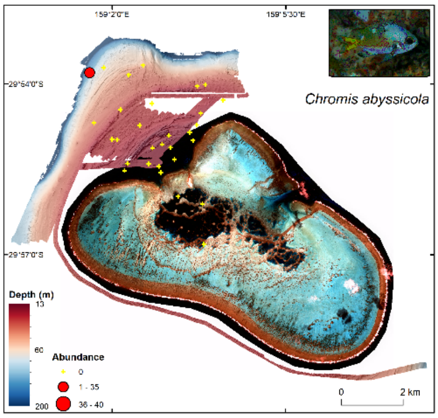


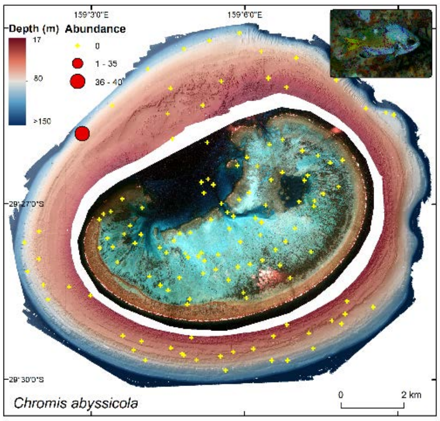


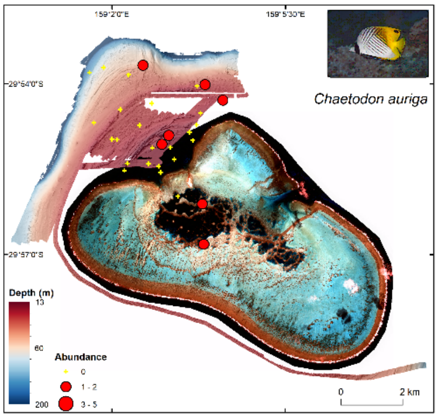


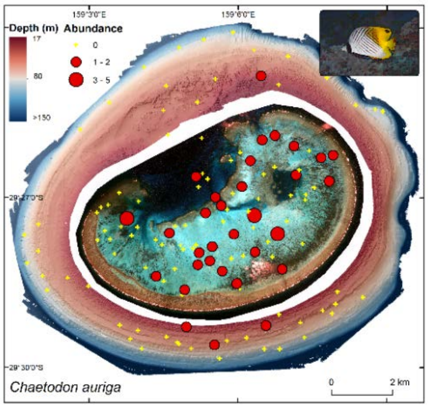


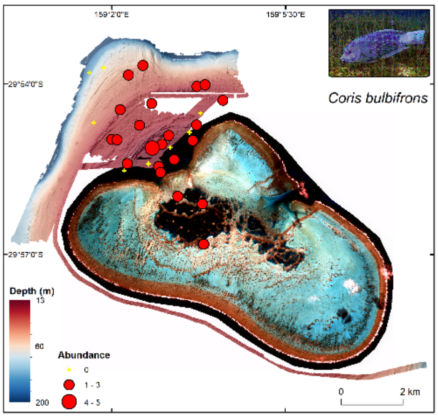


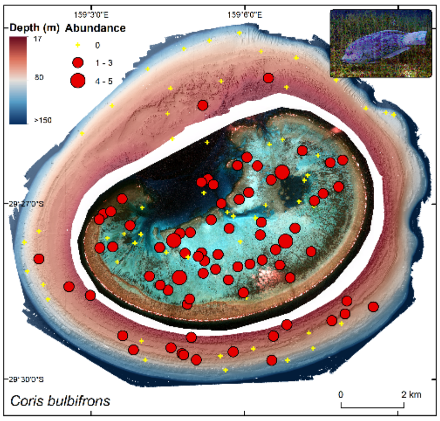

159°2'0"E
159°5'30"E
29°54'0"S
29°57'0"S
Chromis abyssicola
Depth (m)
13
60
200
Abundance
0
1 - 35
36 - 40
0
2 km

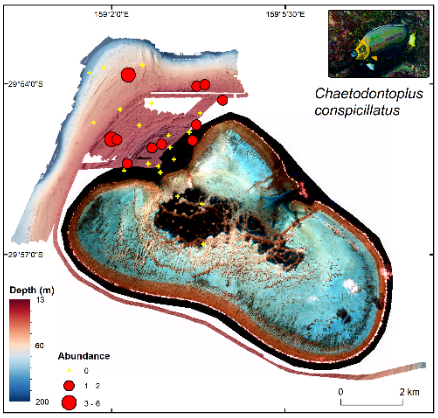

159°3'0"E
159°6'0"E
Depth (m)
Abundance
17
80
>150
0
1 - 35
36 - 40
29°27'0"S
29°30'0"S
Chromis abyssicola
0
2 km

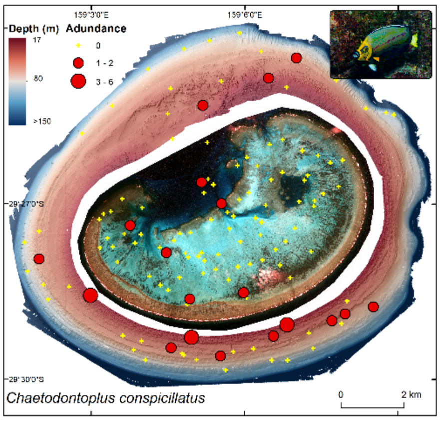

159°2'0"E
159°5'30"E
29°54'0"S
29°57'0"S
Chaetodon auriga
Depth (m)
13
60
200
Abundance
0
1 - 2
3 - 5
0
2 km

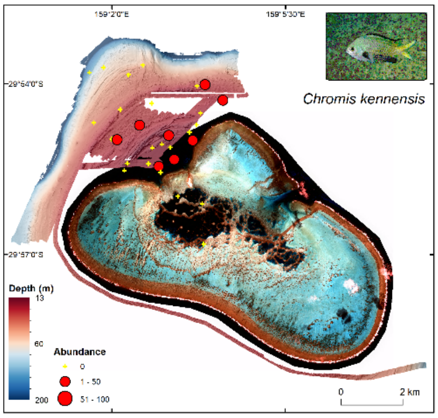

159°3'0"E
159°6'0"E
Depth (m)
Abundance
17
80
>150
0
1 - 2
3 - 5
29°27'0"S
29°30'0"S
Chaetodon auriga
0
2 km

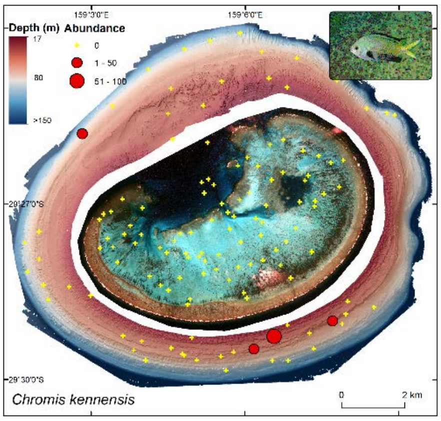

159°2'0"E
159°5'30"E
29°54'0"S
29°57'0"S
Coris bulbifrons
Depth (m)
13
60
200
Abundance
0
1 - 3
4 - 5
0
2 km

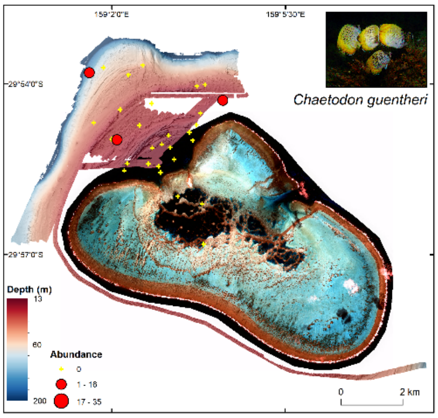

159°3'0"E
159°6'0"E
Depth (m)
Abundance
17
80
>150
0
1 - 3
4 - 5
29°27'0"S
29°30'0"S
Coris bulbifrons
0
2 km

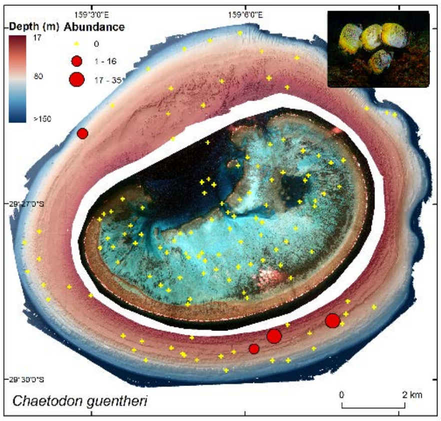

Chaetodontoplus conspicillatus
Depth (m)
Abundance
2 km

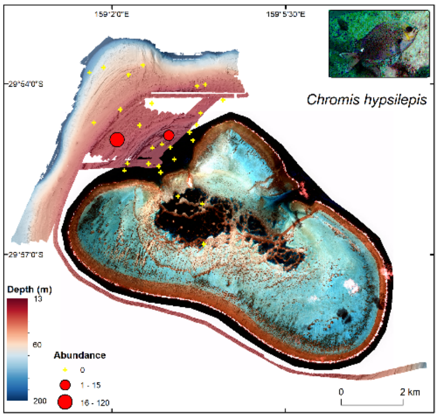

Depth (m) Adundance
Chaetodontoplus conspicillatus
2 km

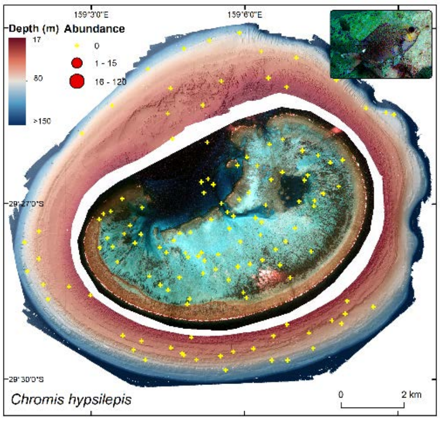

Chromis kennensis
Depth (m)
Abundance
2 km

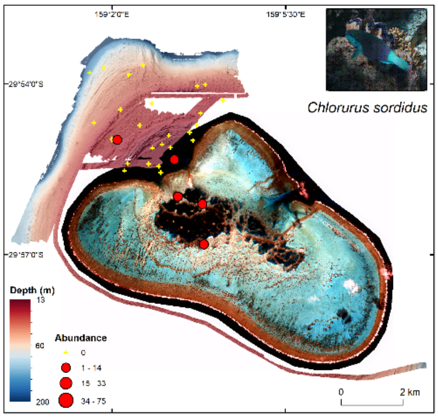

Depth (m) Abundance
Chromis kennensis
2 km

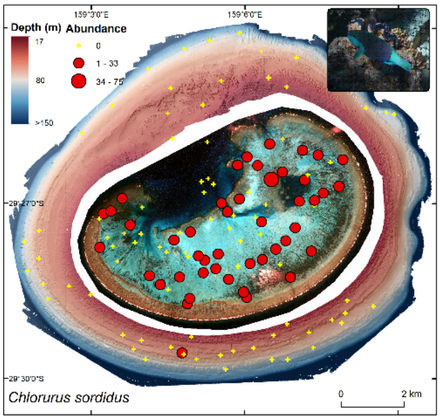

Chaetodon guentheri
Depth (m)
Abundance
2 km

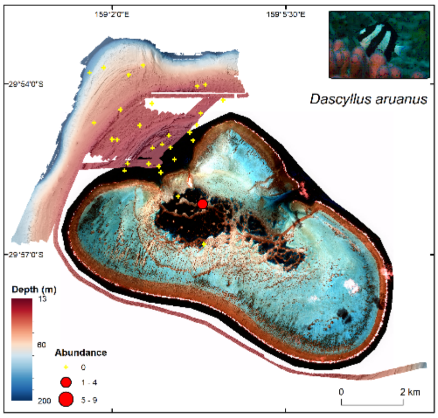

Depth (m) Abundance
Chaetodon guentheri
2 km

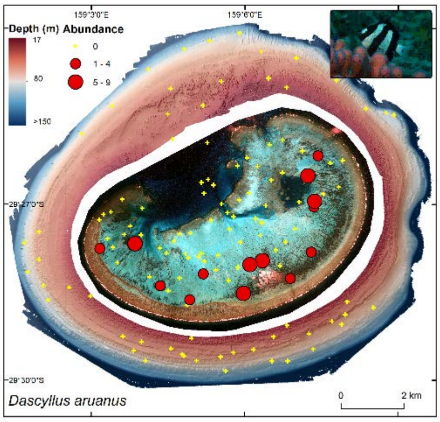

Chromis hypsilepis
Depth (m)
Abundance
0
1 - 15
16 - 120
2 km

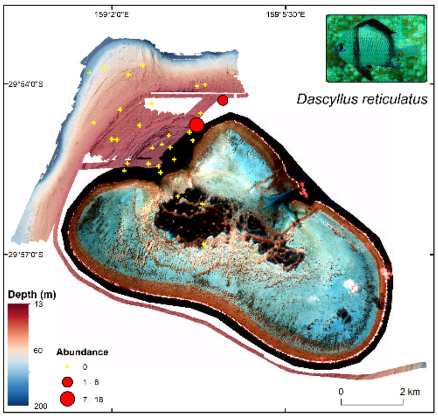

Depth (m) Abundance
0
1 - 15
16 - 120
Chromis hypsilepis
2 km

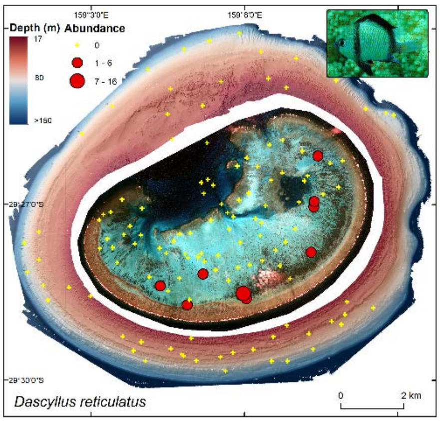

Chlorurus sordidus
Depth (m)
Abundance
0
1 - 14
15 - 33
34 - 75
2 km

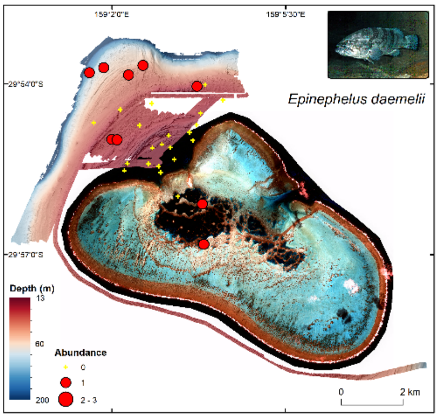

Depth (m) Abundance
0
1 - 33
34 - 75
Chlorurus sordidus
2 km

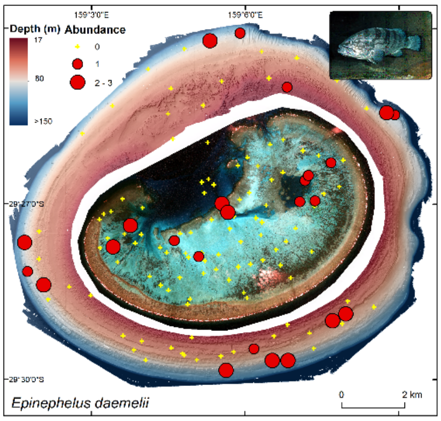

Dascyllus aruanus
Depth (m)
Abundance
0
1 - 4
5 - 9
2 km

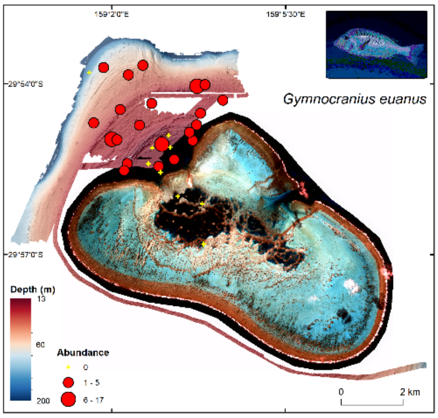

Depth (m) Abundance
0
1 - 4
5 - 9
Dascyllus aruanus
2 km

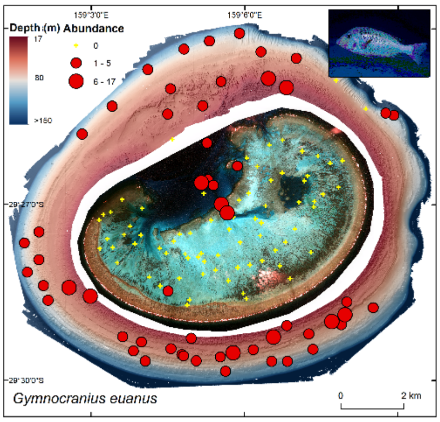

Dascyllus reticulatus
Depth (m)
Abundance
2 km

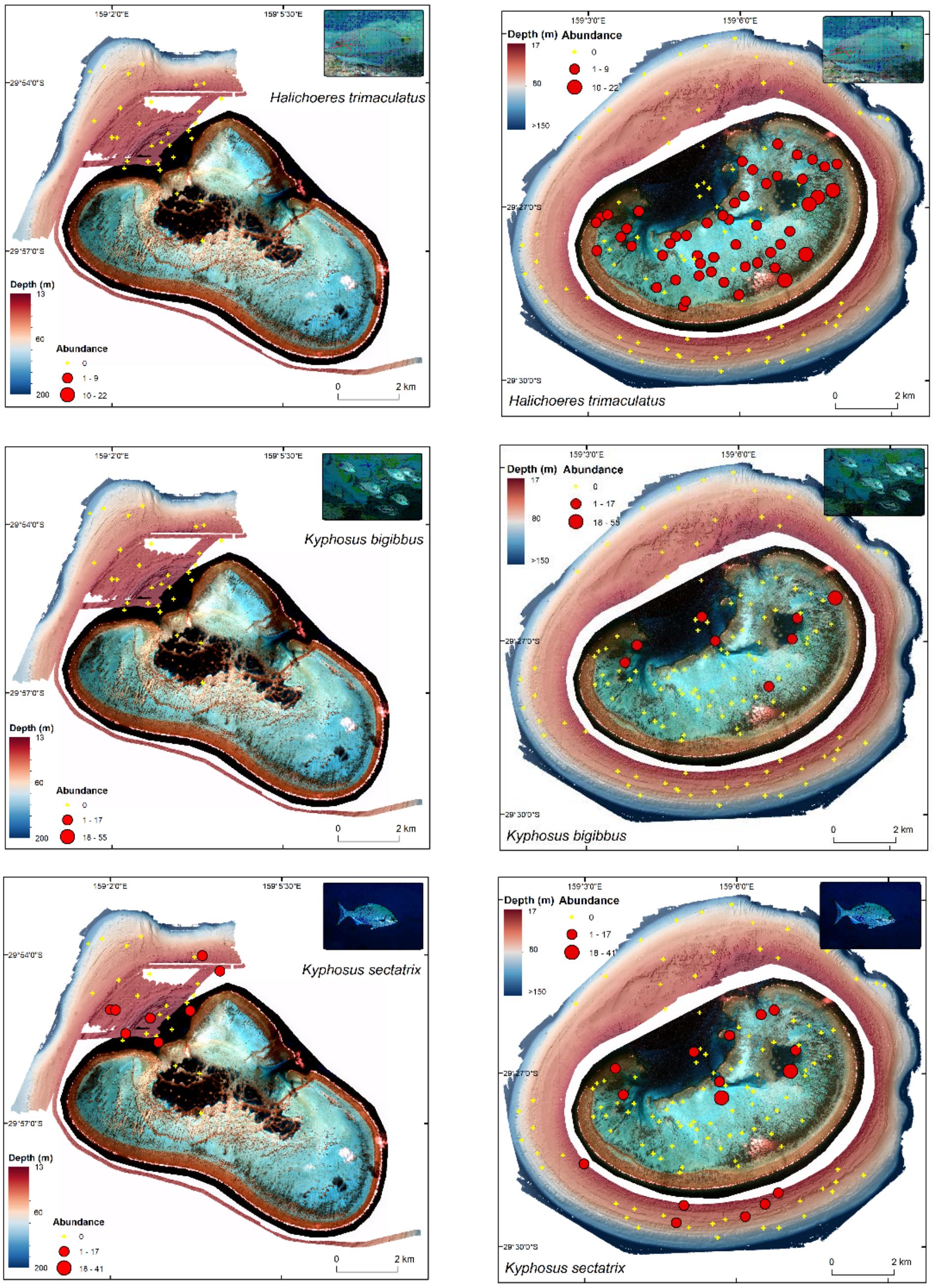

Depth (m) Abundance
Dascyllus reticulatus
2 km

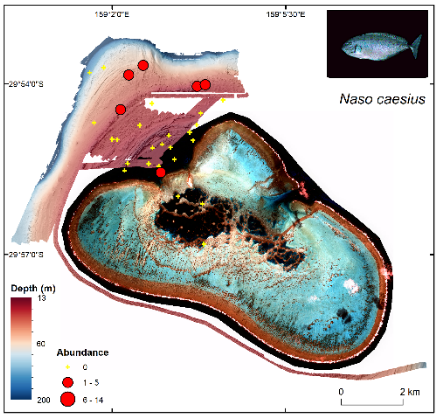

Epinephelus daemelii
Depth (m)
Abundance
2 km

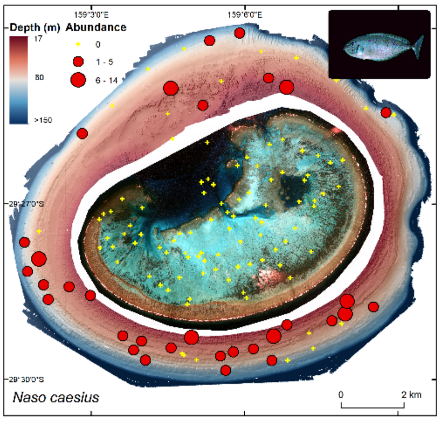

Depth (m) Abundance
Epinephelus daemelii
2 km

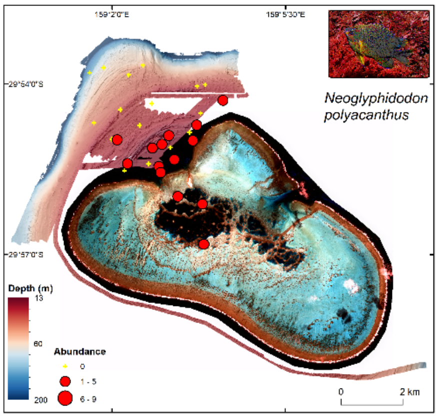

Gymnocranius euanus
Depth (m)
Abundance
2 km

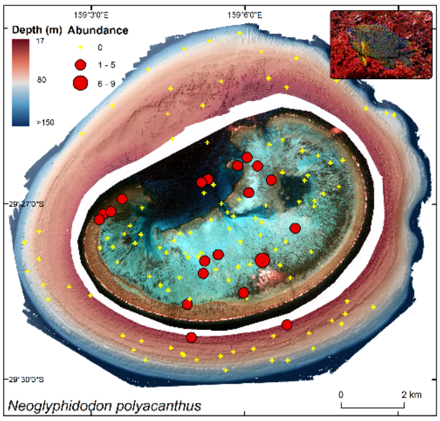

Depth (m) Abundance
Gymnocranius euanus
2 km


Halichoeres trimaculatus
Depth (m)
13
60
200
Abundance
0
1 - 9
10 - 22
0
2 km
Halichoeres trimaculatus
Depth (m)
Abundance
17
80
>150
0
1 - 9
10 - 22
0
2 km
Kyphosus bigibbus
Depth (m)
13
60
200
Abundance
0
1 - 17
18 - 55
0
2 km
Kyphosus bigibbus
Depth (m)
Abundance
17
80
>150
0
1 - 17
0
2 km
Kyphosus sectatrix
Depth (m)
13
60
200
Abundance
0
1 - 17
18 - 41
0
2 km
Kyphosus sectatrix
Depth (m)
Abundance
17
80
>150
0
1 - 17
0
2 km


159°2'0"E
159°5'30"E
Naso caesius
-29°54'0"S
-29°57'0"S
Depth (m)
13
60
200
Abundance
0
1 - 5
6 - 14
0
2 km


159°3'0"E
159°6'0"E
Depth (m)
Abundance
17
80
>150
0
1 - 5
6 - 14
-29°27'0"S
-29°30'0"S
Naso caesius
0
2 km


159°2'0"E
159°5'30"E
Neoglyphidodon polyacanthus
-29°54'0"S
-29°57'0"S
Depth (m)
13
60
200
Abundance
0
1 - 5
6 - 9
0
2 km


159°3'0"E
159°6'0"E
Depth (m)
Abundance
17
80
>150
0
1 - 5
6 - 9
-29°27'0"S
-29°30'0"S
Neoglyphidodon polyacanthus
0
2 km

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