Marine Biodiversity Hub

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Mapping and characterising reef habitat and fish assemblages of the Hunter Marine Park

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Project D3 – Implementing monitoring of AMPs and the status of marine biodiversity assets on the continental shelf

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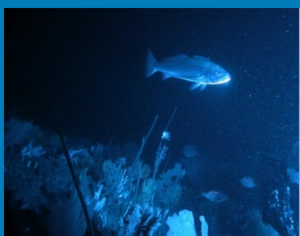
Milestone 10





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Important Disclaimer

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EXECUTIVE SUMMARY

The Hunter Marine Park located in the Temperate East Marine Parks Network is situated between Port Stephens and Saltwater Point near Taree in New South Wales. The Hunter Marine Park is one of the few Australian Marine Parks that borders a state managed marine park. It borders the Port Stephens – Great Lakes Marine Park and thus extends the benefit of marine park protection much further offshore. The Hunter Marine Park is divided into two zones: 1) a Special Purpose Zone (Trawl) extending from the state waters boundary at 3 nm and across the continental shelf to the mid-slope (~1000 m), and 2) a Habitat Protection Zone that covers the lower continental slope with associated canyons and an area of the abyssal sea floor. Continental shelf rocky reefs were identified as a key ecological feature in the Hunter Marine Park management plan. Therefore, this study aimed at identifying and mapping areas of rocky reef using multibeam echo sounder and then ground truthing and identifying habitat features using towed video. Baited remote underwater stereo-video (stereo-BRUV) was also used to sample the fish assemblages on these rocky reefs. These data and information will help develop a monitoring program and better manage the Hunter Marine Park into the future.

A multi-beam echo sounder (MBES) was used to map approximately 125 km^2 of the Hunter Marine Park's seabed to focus on providing 100 % high-resolution bathymetry and backscatter data over key areas of the Hunter Marine Park's inner shelf. These new data increased the total mapped area of bathymetry-backscatter to ~215 km^2 and total bathymetry holdings to ~1235 km^2 across the park's western special purpose zone. An area of less than 5.5 km^2 of the mapped inner shelf appeared to be mesophotic rocky reef (10% upper mesophotic; 90% lower mesophotic) and the remainder characterised by a range of soft sediment types. The range of reef types are described in 'landform' feature terms as: 1) a) low profile and b) low profile patch reefs generally in deeper mesophotic areas, 2) rugose peak reefs in shallow water, and 3) long, linear ridges in deeper water potentially associated with relic coastline. Soft sediments feature as: 1) flat low slope plains, 2) platform/plateau plains and 3) bedform plains or 4) a trough, channel-shaped seabed landform offshore of Seal Rocks/Sugarloaf Point. Mapping indicates that further reef features are expected north of the existing Seal Rocks surveys and between Seal Rocks and Broughton coverages. MBES surveys over unmapped areas in 140-200 m water depth and along upper edge of the continental slope would also complement earlier Southern Surveyor surveys and help characterise seabed communities at the top of the continental slope. These areas should be considered a priority for future mapping effort within the park's Special Purpose Zone, complemented with seabed and landform-type classification assessments.

Towed video transects identified a range of benthic and pelagic organisms within the Hunter Marine Park across depths of ~35 – 110 m. Imagery from reefs in shallower areas (Outer Gibber) indicated benthic communities dominated by branching and turfing brown algae with encrusting and branching sponges, ascidians, sea stars and sea whips. The reef here lies within the upper mesophotic (<70 m) and is relatively high profile characterised by large boulders and or large blocks of consolidated reef with narrow fissures or separated by cobble/pebble filled gutters. Yellow-tailed scad, red morwong and an ornate wobbegong were also observed within the video and still imagery. In deeper areas, lower mesophotic

(>70 m) reef communities are restricted to blocky patch reefs surrounded by soft sediments or sediment veneered reefs. These communities are dominated by branching sponges, corals, sea whips with symbiotic brittle stars, sea stars and urchins. The species *Parascyllium collare*, commonly known as the collared cat shark, was observed on several occasions within the captured footage. Summed semi-quantitative presence/absence scoring of still imagery per transect, indicated that in deeper survey areas reef was present in a greater proportion of images from Broughton Island compared to those from Seal Rocks. In images with soft sediments, infaunal burrows and erect invertebrates (i.e. worm tubes) were almost always present for transects at Seal Rocks but less common in transects offshore of Broughton Island. Further quantitative analysis of the imagery is yet to be undertaken.

With areas of mesophotic rocky reef identified, stereo-BRUVs were used to estimate relative abundance and lengths of benthic reef fish in the Hunter Marine Park. Over four surveys, 180 successful stereo-BRUVs were completed in three distinct locations associated with the MBES mapping. 1) Broughton Island offshore, a patch of low profile and highly fragmented reef in 80-110 m of water, 2) Outer Gibber, a small but high relief reef in 35-60 m of water and 3) Seal Rocks Offshore, a moderate profile reef system in 80-105m. At the time of developing this study the only reef that was mapped in this region was along the state water boundary. Therefore, these stereo-BRUVs were dropped in a sanctuary zone of the Port Stephens - Great Lakes Marine Park. However, these depths were comparable to Broughton Island Offshore and allowed for a fished versus no-take comparison. In total, 112 species were identified during this study. Outer Gibber had the highest numbers of species on a single drop (n = 28). The reef systems in the Hunter Marine Park supported a large number of fishery targeted species, particularly pink snapper and blue morwong. Two listed, threatened and endangered species were also recorded on stereo-BRUV, white shark *Carcharodon carcharias* and grey nurse shark *Carcharias taurus*.

Stereo-BRUVs provide reliable, cost-effective and standardised methods for sampling and monitoring fish assemblages in marine parks. Now that new areas of reef have been mapped it is highly advisable that future sampling be spread into these areas and the implementation of a spatially balance design to sample and monitor a greater spatial coverage of the inner shelf region of the Hunter Marine Park.

At the conclusion of this report a series of recommendations are made for the development of a monitoring program and future survey work for the Hunter Marine Park.

1. INTRODUCTION

1.1 Hunter Marine Park Background

The Hunter Marine Park is located on the mid-north coast of NSW, covering an area of 6,857 km^2 and divided into two management zones (Figure 1.1):

1) an IUCN category VI Special Purpose Zone (Trawl) extending from the state waters boundary to the mid-shelf slope at a depth of ~1000 m (total area 1669 km^2). This zone borders a section of the Port Stephens-Great Lakes Marine Park at the state coastal waters boundary from a point due east of Charlotte Head near Pacific Palms/Forster in the north to Port Stephens. An area of 1,307 km^2 of this Special Purpose Zone (Trawl) lies over the continental shelf (<200 m), and represents ~19% of the total park area. (Monk et al. 2017).

2) an IUCN category IV Habitat Protection Zone that covers the lower continental slope with associated canyons and an area of the abyssal sea floor (Director of National Parks 2018). The marine park is within the Temperate East Marine Park Network, and the offshore Habitat Protection Zone extends from Saltwater Creek in the north to Port Stephens in the south.

The Hunter Marine Park is deemed significant and of value as it encompasses habitats, species and ecological communities representative of the Central Eastern Province and Central Eastern Shelf Province (Director of National Parks 2018). This region is strongly influenced by the East Australian Current (EAC), which influences the ecology of the region and attracts species of interest such as tuna, whales and albatross, There are also over 50 species of fish endemic to this region (Director of National Parks 2018). Three key ecological features of the Hunter Marine Park are canyons on the continental slope, shelf rocky reefs, and Tasman front and eddy field (Director of National Parks 2018).

While there is limited information on the cultural values of the Hunter Marine Park, it is the Worimi People who are the traditional owners of the Port Stephens area adjacent to the Hunter Marine Park Special Purpose Zone (Trawl). The Worimi People are known to have a strong connection with sea country. The Hunter Marine Park also has social and economic significance as it supports commercial fishing, recreational fishing and tourism through a range of activities, including whale, dolphin and bird watching.

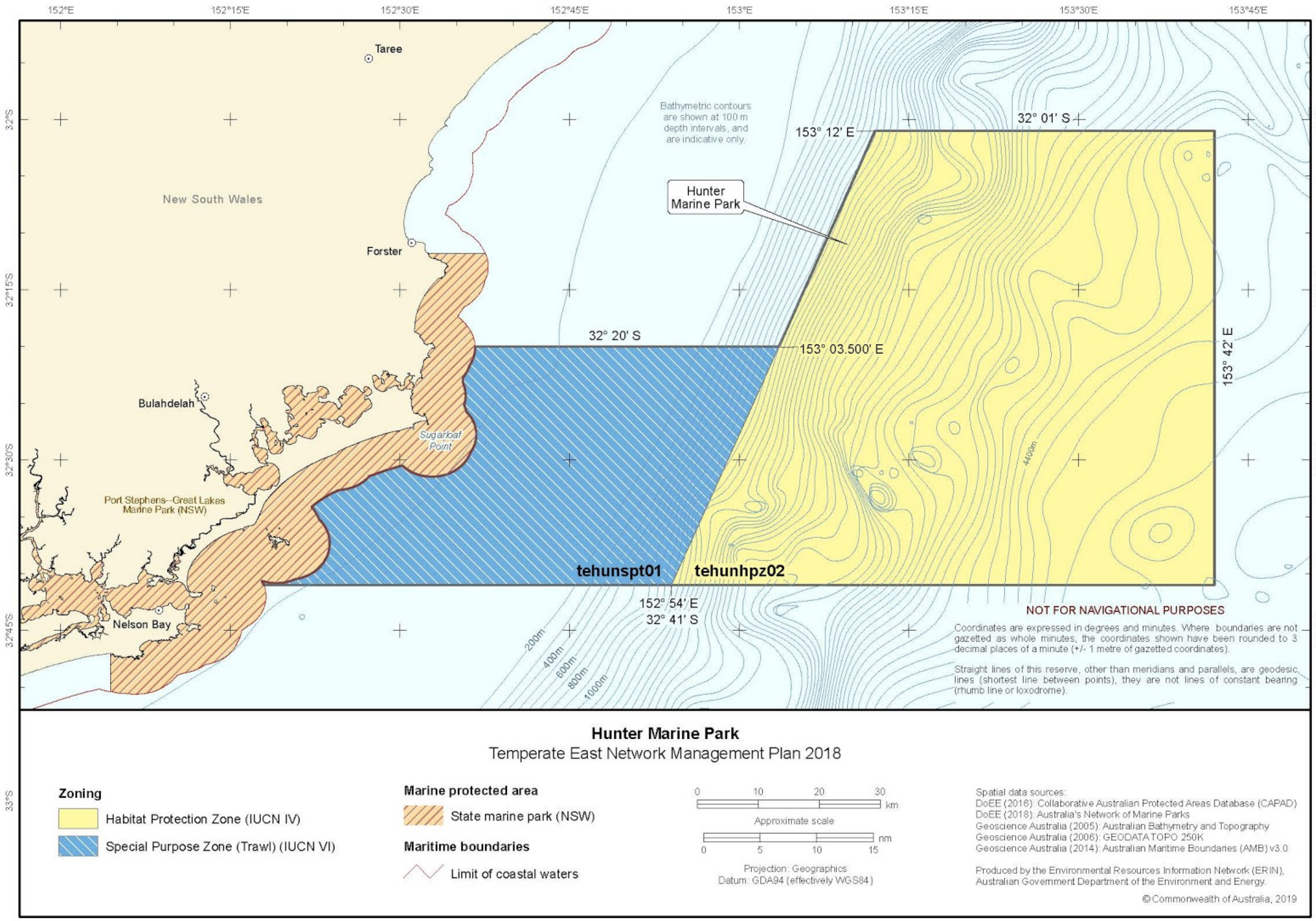


Figure 1-1. The extent of the Hunter Marine Park in relation to the directly adjoining Port Stephens - Great Lakes Marine Park. This study focuses on rocky reefs on the continental shelf within the blue Special Purpose Zone (Trawl).

1.2 NESP Marine Biodiversity Hub D3 Project

The National Environmental Science Program Marine Biodiversity Hub D3 project was established to collate and gather data on rocky reef habitat of the continental shelf (https://www.nespmarine.edu.au/project/project-d3-implementing-monitoring-amps-and-status-marine-biodiversity-assets-continental). Shelf rocky reefs were identified as being a key ecological feature of the Hunter Marine Park, and the remainder of this report is focussed on these habitats.

Prior to this current NESP project, approximately 19% of the Special Purpose Zone had been mapped at high resolution. RV Southern Surveyor multibeam echo sounder (MBES) transects, and more recently, swath acoustic surveys as part of the NESP Marine Biodiversity Hub D3 project (Davies et al. 2016) were the two sources of data available for remotely sensed interpretation of the seabed. Exploratory transects from these surveys highlighted areas of interest for further targeted MBES mapping effort. The aim of the 2018 NESP surveys was to provide 100% coverage over key areas of the seabed to map the spatial extent of reefs and characterise reef (and non-reef) features. Maps of shelf rocky reefs (as well as other adjacent seabed types) derived from these data have provided a baseline with which to structure targeted biological surveys. Previous benthic surveys in the Hunter Marine Park have been conducted as part of the monitoring program with the Port Stephens - Great Lakes Marine Park, where sites in Commonwealth waters have been used as control sites (Jordan et al. 2010, Harasti et al. 2018).

Anecdotal evidence from the ocean trap and line commercial fishery suggests that there are expanses of reef within the Hunter Marine Park, which is supported by Davies et al. (2016). Furthermore, mapping in Port Stephens - Great Lakes Marine Park in 2012 indicated that reefs lying along the edge of the state coastal waters boundary off Broughton Island and Seal Rocks (Lucieer et al. 2019, Ingleton et al. 2020) would likely extend further offshore and into the Hunter Marine Park. This reef is within the mesophotic zone, which is characterised by middle to low levels of light (Baker et al. 2016, Turner et al. 2017). To date, much of the research on rocky reefs on the inner shelf in this region has been focused in the depths <30 m, reflecting the use of SCUBA and the targeting of reefs in the Port Stephens - Great Lakes Marine Park (Harasti et al. 2015, 2018). The identification of adjacent mesophotic reefs highlighted the need to evaluate the benthic assemblages on these reefs within the Hunter Marine Park in order to better understand the environmental assets in the park, but also to establish a baseline of information that could be used to assess changes through time.

1.3 Introduction to Mesophotic Reef

Inner and mid-shelf rocky reefs in the Hunter Marine Park are within the mesophotic zone, which are those characterised by the presence of light-dependent invertebrate assemblages, algae with low light tolerance and associated communities, often between the depths of 30-40 and 150 m in tropical and subtropical regions of the world (Hinderstein et al. 2010, Kahng et al. 2010, Baker et al. 2016, Loya et al. 2016, Turner et al. 2017; Figure 1-2). Furthermore, there is now a broad understanding that this zone can be divided into the upper and lower mesophotic zone, with a transition zone at ~60 m depending on water clarity and temperature (Loya et al. 2016, Tamir et al. 2019; Figure 1-2). How these zones are defined and applied generally across temperate areas is yet to be reported. The recent expansion of multibeam acoustic surveys of continental shelf waters has revealed that reefs at these depths form extensive areas of habitat in many regions within Australian waters (Jordan et al. 2010, Lucieer et al. 2016, 2019, Nichol et al. 2016).

Mesophotic reefs are often continuous with shallow reefs (Figure 1-2), resulting in potentially strong connectivity across a large depth gradient, a feature common in the Great Barrier Reef, Australia, north eastern Brazil and the Hawaiian Archipelago (Kahng et al. 2010, Rooney et al. 2010, Bridge et al. 2011, de Oliveira Soares et al. 2016). They can also form discontinuous areas that are interspersed among areas of unconsolidated habitat, such as in the Gulf of Carpentaria, Australia (Harris et al. 2008, Baker et al. 2016). While the number of studies on mesophotic reef has increased significantly over the past decade (Hill et al. 2014, Loya et al. 2016, Turner et al. 2017, Williams et al. 2019), the majority of this research is focussed in the tropics where such reefs usually contain scleractinian corals (Baker et al. 2016, Turner et al. 2017). Conversely, temperate mesophotic ecosystems tend to be dominated by sponges and octocorals (Jordan et al. 2010, Lucieer et al. 2016, Heyns-Veale et al. 2016, Turner et al. 2019, Williams et al. 2019, Ingleton et al. 2020) except at some seamount islands (Linklater et al. 2016). In comparison to the tropical mesophotic coral ecosystems, little is known about temperate mesophotic ecosystems, particularly the link between fish assemblages, habitat structure, and connectivity with shallower reefs (Bo et al. 2014, Heyns-Veale et al. 2016, Turner et al. 2019).

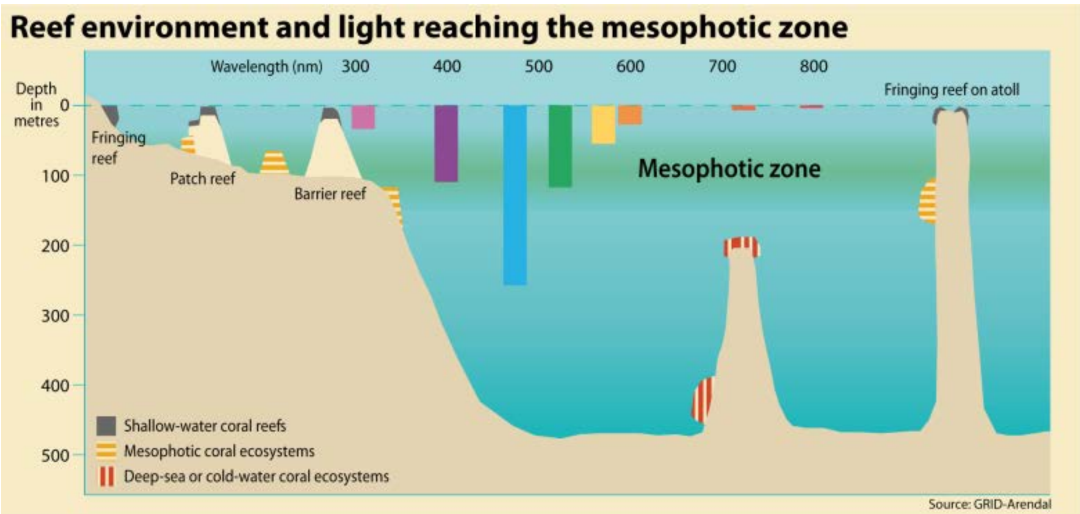


Figure 1-2. An illustration demonstrating the mesophotic zone in relation to depth and how light penetrates through the water column.

Temperate mesophotic reefs have important biodiversity, social and economic values (Hinderstein et al. 2010, Heyns-Veale et al. 2016), so understanding the characteristics of their associated fish assemblages is fundamental to effectively managing them. Habitat type (coral, sponge, bare) and complexity (relief, rugosity, curvature) are known to be important in structuring fish assemblages (Connell and Kingsford 1998, Cameron et al. 2014, Collins et al. 2017, Englebert et al. 2017, Rees et al. 2018). Habitat complexity is considered as the variance in surface structure of the reef and can be defined in terms of relief, slope, rugosity, surface area, and other factors (Beck 2000, Collins et al. 2017, Ingleton et al. 2020). The link between habitat complexity and fish assemblages has been well researched, with many studies showing positive relationships between complexity and fish abundance, biomass and diversity (Ferreira et al. 2001, Harman et al. 2003, Cappo et al. 2004, Pittman and Brown 2011, Harvey et al. 2013, McLean et al. 2016, Rees et al. 2018).

As mesophotic reefs often occur adjacent to inshore shallow reefs, some connectivity across the depth gradient might be expected. It was hypothesised in the late 1990s and early 2000s, for example, that mesophotic reefs provide refuge for some fish species (Thomas et al. 2015, Lindfield et al. 2016, MacDonald et al. 2016). This hypothesis assumed that mesophotic reefs were isolated from most of the stressors that impact inshore shallow reefs such as coral bleaching, pollution, habitat loss and some forms of fishing (Thomas et al. 2015). For temperate reef systems, there are insufficient data over sufficient temporal scales to make generalised conclusions about the extent or nature of any habitat connectivity between shallow and deep components. There is empirical evidence based on genetics and observations that connectivity between mesophotic and shallow reefs occurs, and this has been observed for over-exploited fishery target species (Thomas et al. 2015, Loya et al. 2016). On the other hand, there is also some evidence that mesophotic reefs are not merely extensions of shallow reefs, but host a unique species assemblage and would benefit from increased conservation management (Brokovich et al. 2008, Bejarano et al. 2014, Sih et al. 2017).

Figure 1-3. An example of mesophotic reef in 85m of water.

Surveys of mesophotic reefs have historically been logistically difficult and expensive due to the need for large offshore vessels and the lack of detailed information on their distribution and structure (Armstrong and Singh 2012, Cameron et al. 2014, Trembanis et al. 2017). Earlier studies used coarse scale maps generated through the aggregation of information from commercial fishers, historical hydrographic data and targeted single beam acoustic surveys (Bax et al. 1999, Bax and Williams 2001, Williams and Bax 2001). More recently, the expansion of swath acoustic surveys has resulted in high resolution maps of continental shelf rocky reefs based on the interpretation of bathymetry and backscatter (Lecours et al. 2015, Lucieer et al. 2019, Ingleton et al. 2020). More cost effective and easy to deploy underwater video equipment with sub-sea range positioning (i.e. using transponders), has meant these methods can now be used aboard smaller and more manoeuvrable vessels. It has also facilitated a move away from destructive survey methods such as gillnets, droplines and traps, which are also often not suitable for use in sensitive or protected areas. Baited remote underwater stereo-video (stereo-BRUV) is now commonly used to survey fish assemblages, and advances in camera housings, lights and study designs have enabled the deployment of cameras onto deeper habitats enabling non-destructive sampling of fishes across continental shelf waters (Cappo et al. 2007, Hill et al. 2014, McLean et al. 2016, Whitmarsh et al. 2017, Langlois et al. 2018, Williams et al. 2019). Furthermore, there is evidence that BRUVs provide similar data when used at different depths and when compared to diver surveys (Andradi-Brown et al. 2016, Heyns-Veale et al. 2016).

1.4 Project Aims

This project aimed to identify and map areas of rocky reef habitat in the Hunter Marine Park, ground truth the multibeam mapping data using towed video and identify habitat features. Stereo baited remote underwater video systems and remotely operated vehicle were then used to sample the fish assemblages that are associated with rocky reef habitats in the Hunter Marine Park.

The information and data collected from the project will not only be used as an inventory for occurrence in the Hunter Marine Park, but it can also be used as a baseline dataset for any future monitoring.

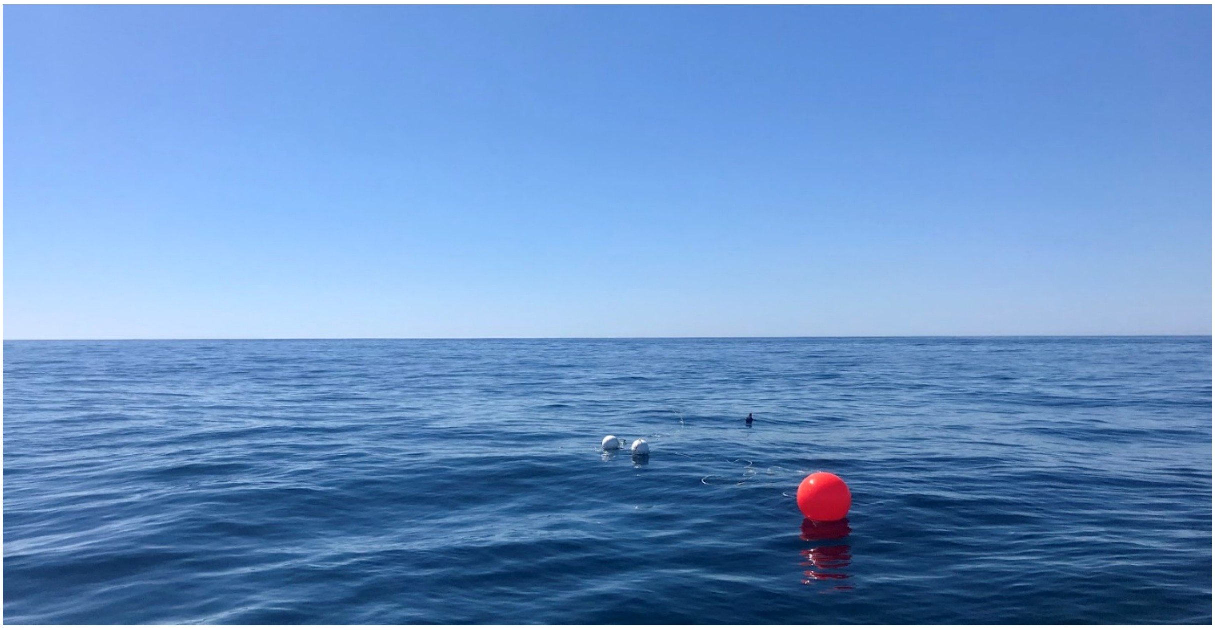


Figure 1-4 Waiting as a stereo baited remote underwater video system is collecting data in 100m of water in the Hunter Marine Park.

2. MULTIBEAM MAPPING

2.1 Background

Multi-beam echo-sounder (MBES) technologies and their use as a remote sensing tool to map marine habitats has been applied widely in Australian shelf environments. Previous to their routine use and earlier this century, our knowledge of the seabed was limited to low resolution lead-line or single-beam soundings (bathymetry) and sparsely distributed sediment samples/cores, underwater imagery and dive transects. MBES provides fundamental baseline data at high-resolution over large, often un-surveyed areas of the seafloor. Bathymetry (depth) and backscatter (hardness) data can then be used to develop substrate and geomorphology maps that reveal the distribution of marine habitats in these environments. With repeat surveys, these data become even more valuable as they can be used to detect changes within the seabed. Combined, these datasets provide an invaluable tool for stakeholders to understand the distribution of marine habitats off our coasts and governments to improve management of the nation's marine resources. A national effort to coordinate MBES and improve seabed data acquisition and availability is currently underway through Geosciences Australia called AusSeabed (www.ga.gov.au/ausseabed).

Prior to the National Environmental Science Program (NESP), high-resolution data available for mapping habitats on the shelf of the Hunter Marine Park was limited. Near full MBES coverage of the shelf break and continental slope was acquired by the Marine National Facility (MNF) RV Southern Surveyor, in recent years, using the vessel's 'deep-water multibeam' capability (Raphael 2016; in Davies et al. 2016). Surveys over the shelf by MNF, however, have been limited to a relatively small number of cross-shelf transects during along-shore transits or port exit/entry. In total, these transit lines provided ~ 177 km^2 of MBES bathymetry and backscatter data (~10 % of the park's on shelf area - Figure 2-1) and identified the first 'shelf rocky reefs' for the Hunter Marine Park. Since the commissioning of the new MNF RV Investigator (2014) and their shallow-water multibeam system, only a small number of additional transects, as along-shore transits, have been obtained over the Hunter Marine Park shelf (http://www.AusSeabed.gov.au search 31/1/2020).

Immediately inshore of the Hunter Marine Park, lies the NSW Port Stephens - Great Lakes Marine Park stretching from One Mile Beach at Forster in the north to Birubi Point (Stockton Bight) in the south. During the period 2005-12 the NSW Department of Planning, Industry and Environment (DPIE) mapped over 300 km^2 of seabed within the state park (Jordan et al. 2010). Targeted ground-truthing surveys using towed underwater video were also completed and used to both ground-truth the MBES-inferred habitat layers and examine the spatial distribution of benthic communities living on the park's shallow and mesophotic reefs (Figure 2.2 from Ingleton et al. 2020). More recently, NSW DPIE has further completed hi-resolution mapping of the near-shore through state-wide marine LiDAR (https://elevation.fsdf.org.au) and MBES (https://portal.aodn.org.au) mapping as part of the state's Coastal Reforms Program (see Figure 2-1). The new datasets contribute an additional ~440 km^2 over the shallowest sections of the inner shelf between Port Stephens and Forster. The data are being used to develop regional seabed substrate and habitat maps (Linklater et al. 2019).

Prior to 2015, only a relatively minor portion of the mapping effort in state waters (<3 nm) had captured data for the Hunter Marine Park (<2-3 km^2 offshore of Broughton Island and Seal Rocks). The first opportunity to conduct targeted high-resolution MBES (bathymetry and backscatter) arose in 2014 with establishment of the NESP Marine Biodiversity Hub with funds approved for the first targeted Hunter MBES surveys in 2015. These surveys focused on characterising the nature and extent of shelf rocky reef features in the park. Surveys were completed as; 1) a series of long transects (exploratory surveys) over areas of the park where there were large gaps in Southern Surveyor coverage and, 2) full high-resolution bathymetry and backscatter coverage over reef features identified from Southern Surveyor transit lines. A total of 80 km^2 of new high-resolution MBES data (Figure 2-1) was acquired in 2015 and reported in Davies et al. (2016). Shelf rocky reef was detailed at several locations with the largest extent located midway between Seal Rocks and Broughton Island in 100-110 m of water (Davies et al., 2016). The report on Hunter Marine Park mapping was made available via the website (www.nespmarine.edu.au) and data available via the Australian Oceanographic Data Network (https://portal.aodn.org.au). Both the NESP and NSW surveys, however, did not capture the full extent of reef in these areas and further mapping was recommended. A local recreational fishing spot, to the northeast of Broughton Island and sitting near the Port Stephens - Great Lakes Marine Park and Hunter Marine Park boundary called Outer Gibber, was also identified as a site of interest to be included in future mapping effort.

In 2017 funding for a second series of surveys in Hunter Marine Park was granted as part of the NESP Marine Biodiversity Hub D3 program. The target of the proposed surveys was to 1) map offshore of the eastern extent of reefs identified from within the state park, 2) map the seabed around the site of the local feature known as Outer Gibber, and 3) further extend the coverage of 2015 surveys to capture the extent of reefs in 80-110 m of water. New surveys were completed during 2018-19 and maps of the extent of seabed habitats including shelf rocky reefs and soft unconsolidated areas, as interpreted from the bathymetry and backscatter, are presented here.

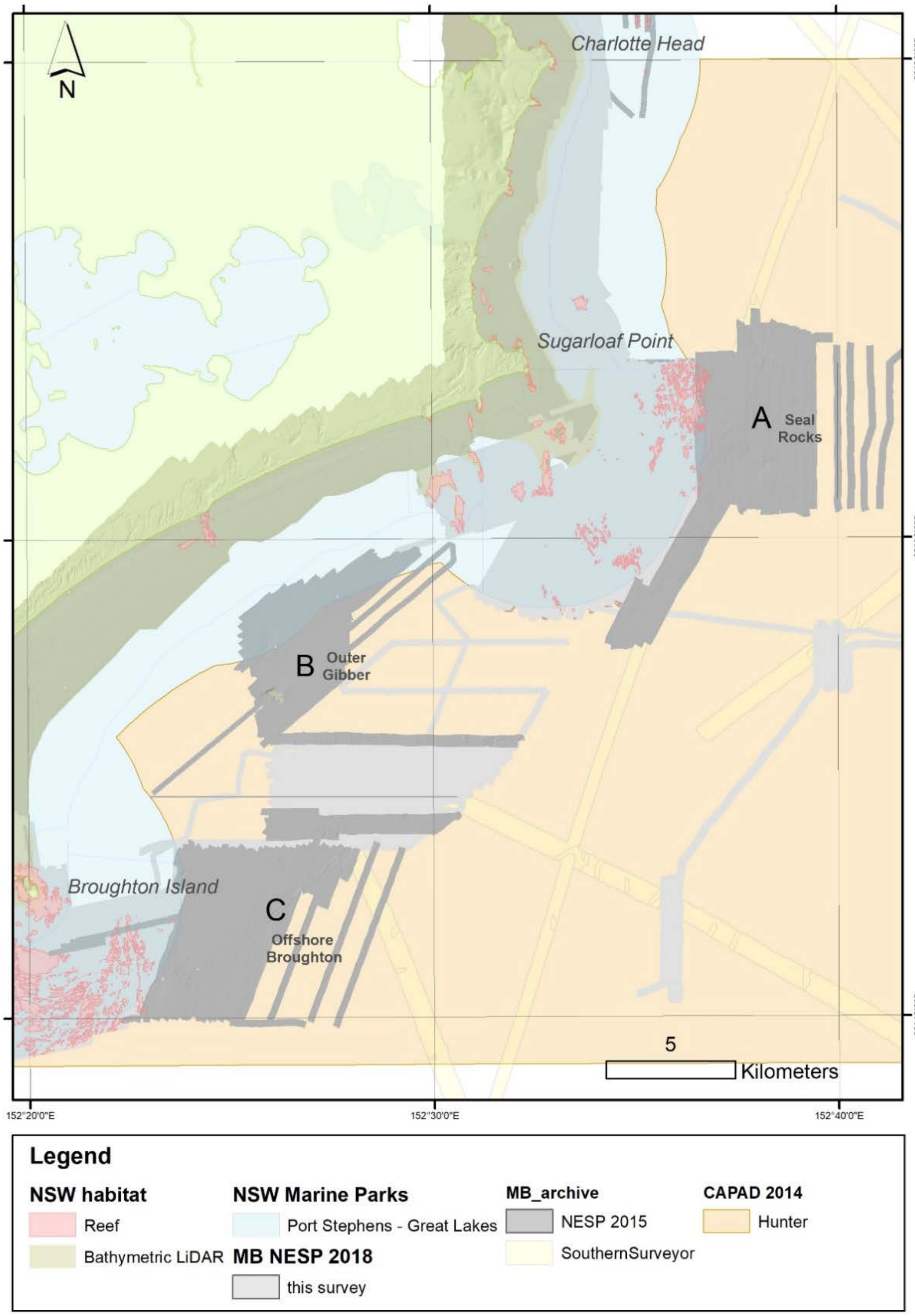


Figure 2-1. Extent of new survey areas (A - Seal Rocks; B - Outer Gibber; and C – Offshore Broughton), existing multibeam surveys, bathymetric LiDAR (LADS) and digitised rocky reef (NSW state waters) within the Special Purpose Zone of the Hunter Marine Park and adjacent Port Stephens - Great Lakes Marine Park areas.

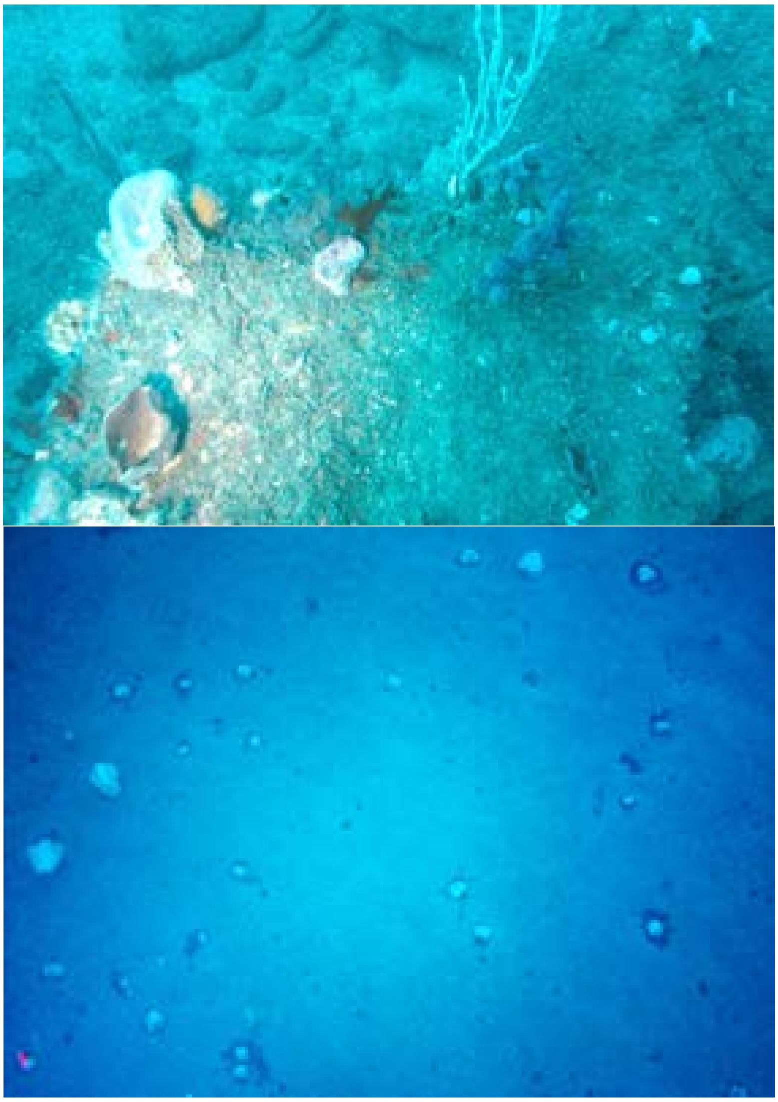


Figure 2-2 Examples of underwater towed video imagery from the NSW Port Stephens – Great Lakes Marine Park (2013) showing mesophotic benthic communities including, i) sponge communities in 40-50 m water depth off Broughton Island and ii) sea pens protruding from unconsolidated sediments in 70 m of water south-east of Seal Rocks (Ingleton et al. 2020).

2.2 Methods

MBES bathymetry and backscatter data were acquired between Broughton Island and Seal Rocks within the Hunter Marine Park over 10 survey days during 2018-19. Operation of the MBES was conducted in the manner of a 'baseline' survey as described in the NESP MBH manual '*Seafloor Mapping Field Manual for Multibeam Sonar'* (Picard et al. 2018). Equipment and data handling procedures are detailed in *Seabed NSW: Standardised operating procedures for multibeam surveying* (Ingleton et al. 2019). Target areas, identified during the planning phase for the project, were; A) an area from east to southeast of the existing Seal Rocks coverage and approximately between 3- 5 nm from shore; B) Outer Gibber (an area between Seal Rocks and Broughton Island in 20-50 m of water and surrounding seabed between 2-4 nm from shore; and C) an area due east of Broughton Island approximately 3-5 nm from the islands eastern extent at the edge of existing state survey coverage and areas south of the previous 2015 NESP surveys.

Cleaned MBES soundings (all 2015 and 2018 data) were gridded (5 x 5 m) in Fledermaus (QPS, Netherlands) and then imported into ArcMap for geomorphometric analyses. Morphometric layers (i.e. slope, terrain ruggedness) were calculated using the module Benthic Terrain Modeller in ArcMap. Inferred habitat-types were then delineated in two ways; 1) supervised classification performed for the entire survey area - using slope, ruggedness and a hill-shade of the gridded bathymetry, areas with profile were hand-digitised to be classified as reef or non-reef; and 2) a semi-automated classification performed for selected areas - seabed types delineated based on a geomorphometric analysis using techniques outlined in Linklater et al. (2019). Finally, a qualitative classification of landform features was performed for the entire survey area - landform features observed within the Hunter Marine Park were identified qualitatively using the feature terms outlined in Dove et al. (2016). Geosciences Australia are currently leading further development of this approach into a nationally consistent scheme, that is yet to be finalised.

The semi-automated approach was conducted for two small, selected areas to demonstrate the potential application of these methods for future work. Output from the two techniques are provided here to provide a simple comparison, highlight their differences and demonstrate the relative reliability of the techniques for classifying seabed type. A full morphometric analysis for the entire survey area and substrate classification, using backscatter, sediment and imagery ground-truthing, was beyond the scope of works provided in this report.

2.3 Results and Discussion

Approximately 125 km^2 of new seabed mapping data were acquired over water depths between 40-112 m in 2018 and provide the first high-resolution data for these newly mapped areas of the park's seabed (Figure 2.3-2.10). Total mapping effort acquired during the NESP Biodiversity Hub is now ~215 km^2 that, combined with Southern Surveyor surveys (177 km^2), covers ~30 % of the continental shelf (<200 m water depth) area (~1235 km^2) of the Hunter Marine Park Special Purpose Zone.

From the combined NESP surveys, bathymetry over the inner shelf indicates that the shallowest mapped areas lie at the feature known as Outer Gibber, and the deepest areas lie between ~3-4 nm to the east-south-east and south-east of Sugarloaf Point, Seal Rocks. Operating conditions during the period of data collection in Area A were marginal, providing for 'noisy' backscatter values on outer beams of the sonar. This resulted in a striped backscatter mosaic and loss of detail for the areas offshore of Seal Rocks. However, data around the central beams was relatively reliable that, combined with the low planar bathymetry, indicated that the seabed was likely composed of soft sediments. Elsewhere, (Areas B and C) backscatter data quality was higher and the homogeneous low return backscatter values indicated that the majority of seabed in these areas also appears to be planar unconsolidated sediments. Small scale variability in backscatter, however, observed in soft sediment areas to the north and north-east of Outer Gibber, indicated a mobile seabed at this site. More generally, higher backscatter returns (darker areas) and areas where bathymetry varied over small spatial scales (10s of m) indicated the presence of reef. The reef at Outer Gibber is the most rugose reef feature and the relic coastline, east of Broughton Island, the most continuous reef feature, identified by mapping across the park's inner shelf to date.

2.3.1 Seal Rocks (Area A)

Maps of the bathymetry and backscatter covering survey area A at Seal Rocks (~50 km^2) are presented in Figures 2.3 and 2.4. Mapping, completed inshore of the Hunter Marine Park boundary and within the Port Stephens - Great Lakes Marine Park in 2012, detailed two main seabed features: 1) an inner shelf sand body (Ferland 1990), and 2) low profile (<1-2 m) mesophotic reefs in 80-100 m inshore of and lying across the 3 nm line (Ingleton et al. 2020). Based on the new NESP survey data presented here, mesophotic reefs extend further east, beyond state waters, to 3-4 nm from shore and depths of ~110 m. Another feature with a raised cross-sectional profile relative to the surrounding seabed, lies 4-5 nm south east of Sugarloaf Point and form a plateau (Figure 2-14e). The feature is separated from the inner reefs by a depression or gutter 500-1500 m wide and <10 m deep. These raised features are less rugose than the inner reefs and instead appear as smooth, raised features. The features also exhibit a relatively uniform backscatter, indicating they are potentially sediment veneered.

Elongate features, 5-6 nm from Sugarloaf Point and in the south-eastern most section of survey area A, appear to be relic coastline features. These are between 300-1000 m in length, <1 m in height and oriented NE-SW and parallel to the 'general' orientation of this section of the coast. Backscatter is of low relative intensity and indicates that these features may be inundated with soft sediments.

2.3.2 Outer Gibber (Area B)

Approximately 80 km^2 of multibeam data was acquired across the combined survey areas B and C during 2018 (Figure 2-5 and Figure 2-6). For survey area B, situated between Broughton Island and Seal Rocks, the bathymetry indicated that the shallowest section of the Hunter Marine Park surveyed is ~27 m and associated with the reef feature 'Outer Gibber'. The reef here is between 300-750 m wide and reaches depths of up to 58 m along its eastern edge. A smaller area of additional isolated and lower profile reefs lies ~1 km to the north and straddle the 3 nm line. Seaward of these reefs and surrounding Outer Gibber, the seafloor is planar, with a slope of 0.4-0.5°. The seabed also exhibits a relatively uniform, low reflectivity backscatter indicating areas of soft sediment. Landward, and to the north of these reefs, the seabed is also generally planar over scales of 100's of metres to kilometres. At scales of 10's of metres there is, however, significant variability in the backscatter (low to moderate relative backscatter intensity) and bathymetry (depth scales of 10's of cm). These features are likely to be sand waves/ripples indicating that sediments in these inshore areas are mobile (depths of 40-50 m). The majority of these variable soft sediment features lie at less than 3 nm from the shore and are, therefore, situated inshore of the Hunter Marine Park.

2.3.3 Offshore Broughton Island (Area C)

Survey area C lies further offshore, in deeper water (60-108 m) and covers an area ranging from 5.5 to 18 km east of Broughton Island (Figure 2-7– Figure 2-10). Generally, the seabed appears to be predominantly soft sediments as indicated by its broad (kms) planar nature (slope <0.3°) and relatively uniform, low reflectivity backscatter dominating the area. Mesophotic reefs identified by earlier mapping south and east of Broughton Island extend beyond 3 nm and into the Hunter Marine Park for less than 2 km. These reefs lie in 100-105 m of water, are discontinuous or patchy and less than 2-3 m in height above the surrounding seabed. Approximately 10 km due east of Broughton Island, a series of narrow (20-40 m each) elongated reefs form a single near-continuous feature ~4.5 km long and between 2-3 m high (Figure 2-7). These reefs are of a consistent depth (~100m), lie parallel to the general orientation of the coast, and likely to also be relic coastline, like those identified further north offshore of Seal Rocks. This feature, however, is larger and more conspicuous as observed in the hill-shaded bathymetry, backscatter (high relative reflectivity), derived slope and terrain ruggedness layers, than its northern counterparts. These relic coastline features are expected to have been formed thousands of years ago when sea level was much lower than today (Nichol et al. 2016).

Immediately north of this relic feature, reefs are generally more common and form pockets or clusters of reefs (100's m wide) with relatively low profile (<5 m). These reefs were first identified in Southern Surveyor data and mapped in detail in 2015 (Davies et al., 2016) and across depths of between 85 and 110 m. For the ~30 km^2 of surveys completed for this area of the park to date, reef covers ~1.35 km^2 of the seafloor. Cross-sections of the bathymetry across these reef features indicate that, generally, reefs deeper than 90 m sit in troughs or are surrounded by small (1-3 m deep) depressions (horizontal scale of ~100-300 m; Figure 2-14g). Backscatter for the surrounding seabed is relatively uniform (high scatter, low hardness/reflectivity) indicating soft sediments surround these reefs. The depressions may be associated with currents as they divert around these reefs at or close to the seabed associated with the EAC (Davies et al. 2016).

2.3.4 Habitat Distribution and Seabed Landforms

Based on the combined multibeam data obtained by Southern Surveyor, Davies et al (2016) and this survey (125 km^2), the extent of continental shelf reef currently surveyed is less than 2.5% (5.5 km^2) of mapped area of the Hunter Marine Park (Figure 2-11). This is based on a fully supervised classification of the seabed in ArcGIS (ESRI, USA) using layers of hill-shaded bathymetry and slope/rugosity and then hand-digitising to delineate reef and non-reef areas. This method, however, is likely to overestimate the percentage of the seabed interpreted as reef when compared to using the auto-classification technique (Linklater et al. 2019), as the latter method identifies features (reef as Slope + Smooth Outcrop + Rugose Outcrop) to a higher level of detail and higher spatial resolution. A visual comparison of the techniques over select areas of the Hunter Marine Park are provided in Figure 2-12 and Figure 2-13. Using area calculation functions in Arc indicates that the area of reef identified using hand-digitising, combined across the two sample areas, was 0.7 km^2 compared to 0.3 km^2 using auto-classification (bathymetry derived layers only). Further analysis, by including backscatter in the auto-classification, and using sediment samples and towed underwater imagery to validate seabed type and model seabed typology, would provide for more reliable maps of substrate and landform maps and provide for the development of character and geomorphology classifications for the seabed for surveyed areas of the Hunter Marine Park. This would be the subject of future work and would utilise a national scheme currently being developed by Geosciences Australia.

In summary, the new surveys indicate seabed landform features not previously reported from other surveys (Davies et al., 2016). Qualitative analysis of the seabed features observed within the Hunter Marine Park have been used to identify a range of features (cross-sections of features are provided in Figure 2-14). Using the terms outlined by Dove et al. (2016), the Hunter Marine Park can be considered to host the following features:

- Plain - Flat: smooth, low slope (<0.5°), soft sediments
- Plain - Bedforms: sand waves or mobile seabed as generally flat areas of soft sediment with small scale variability in bathymetry and backscatter, lying in depths of 40-50 m

- Plain - High: plateau or platform with localised soft sediment features possibly as sediments overlying reef, i.e. offshore of Seal Rocks
- Patch: Low profile (<4 m) discontinuous reefs in <40-60 m of water (e.g. inshore of Outer Gibber); 80-105 m of water (e.g. offshore of the 3 nm line at Broughton Island and Seal Rocks
- Reef: high profile (>10 m) isolated 'pinnacle' reef in 25-60 m of water (e.g. Outer Gibber)
- Ridge: Long (100s to 1000's of metres) linear (<50 m wide) low profile (<2-3 m) relic coastline features in ~110 m of water bounded by soft sediment plains, i.e. offshore of Broughton Island
- Channel - Straight: broad channelised feature (<10 m deep), 100's to 1000's m wide, i.e. offshore of Seal Rocks

Examples of these features are provided in Figure 2-14.

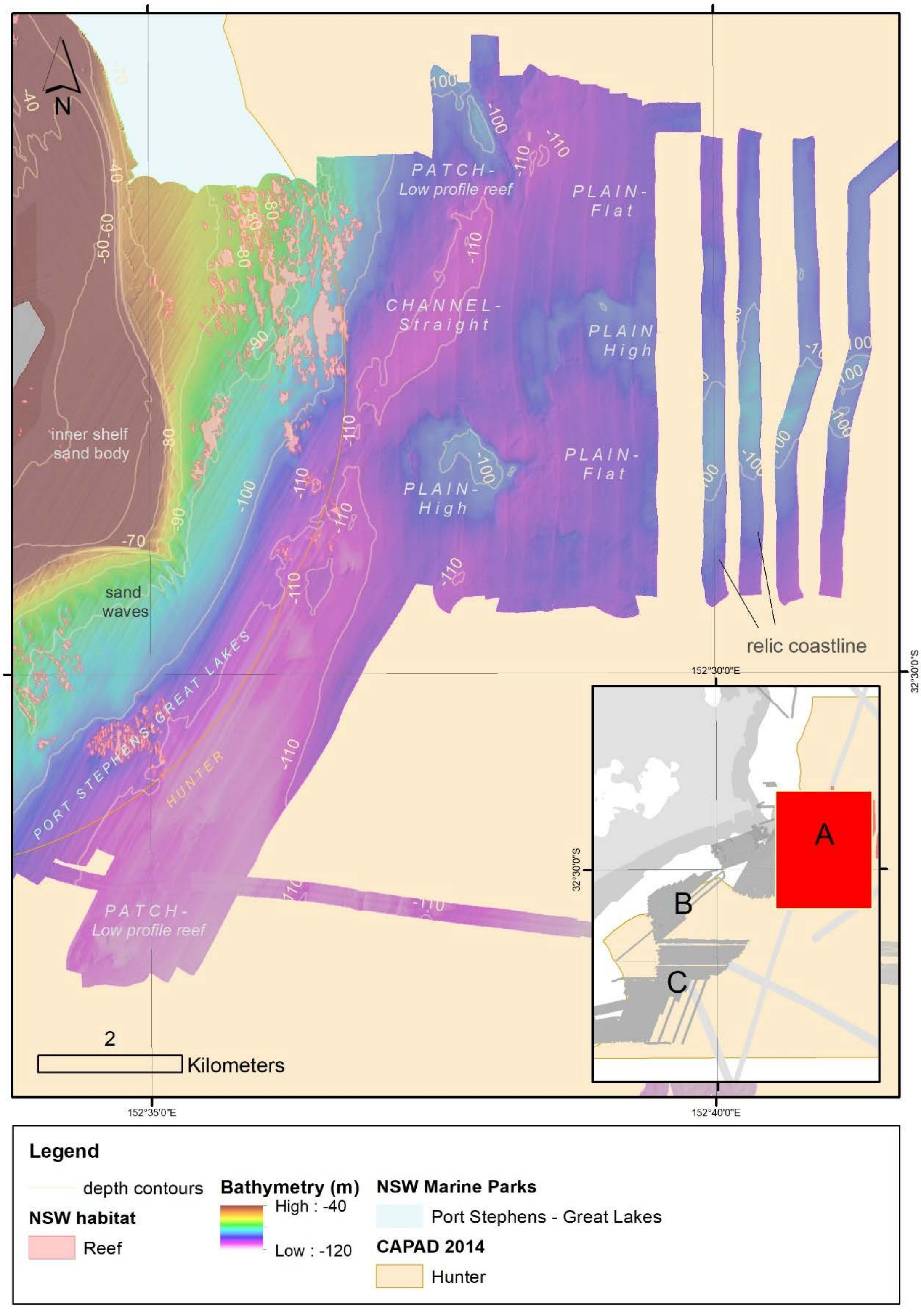


Figure 2-3. False-colour hill-shaded bathymetry of survey area A: Seal Rocks and identified seabed features

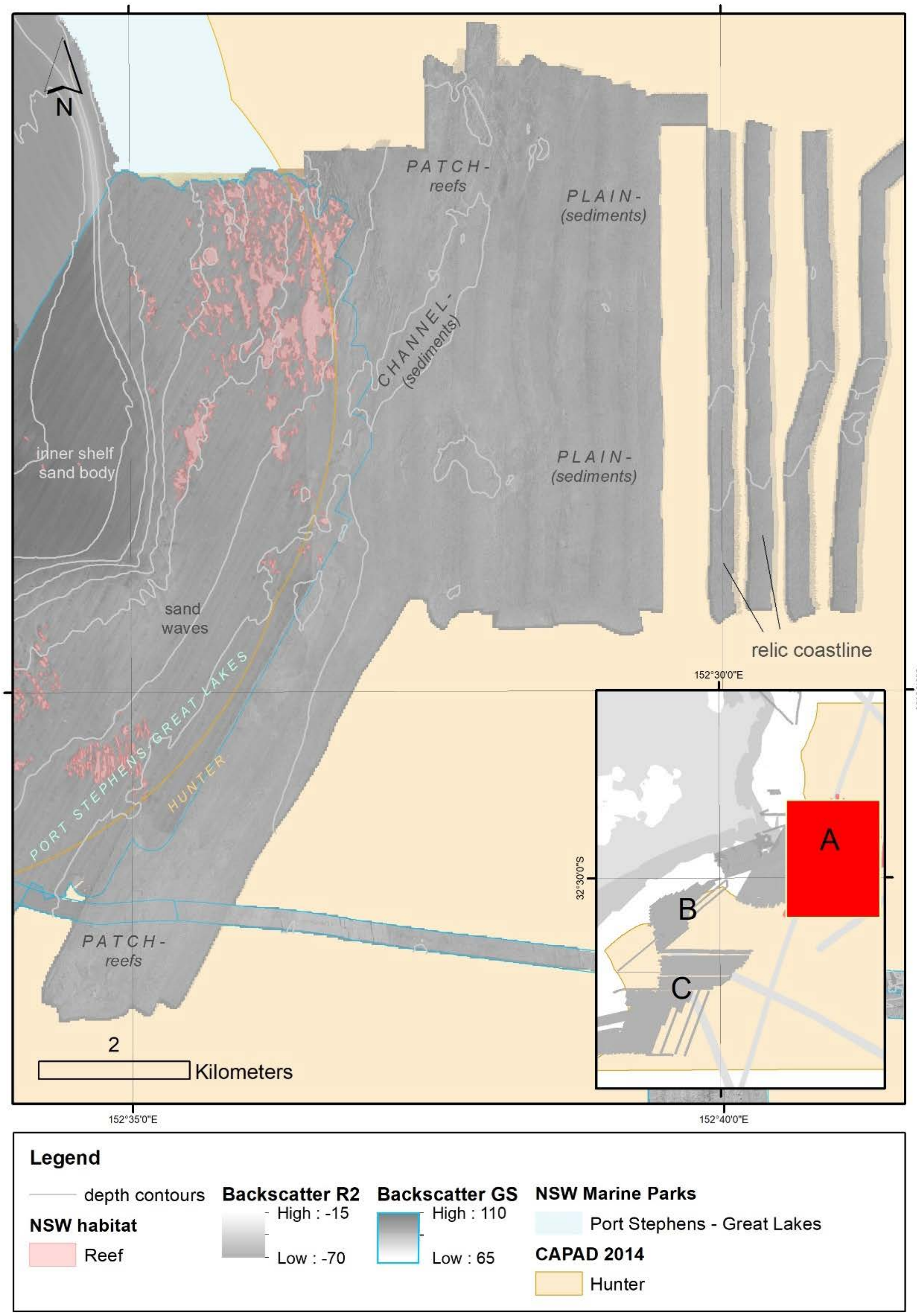


Figure 2-4. Greyscale backscatter (seabed reflectance) for survey area A: Seal Rocks and seabed features

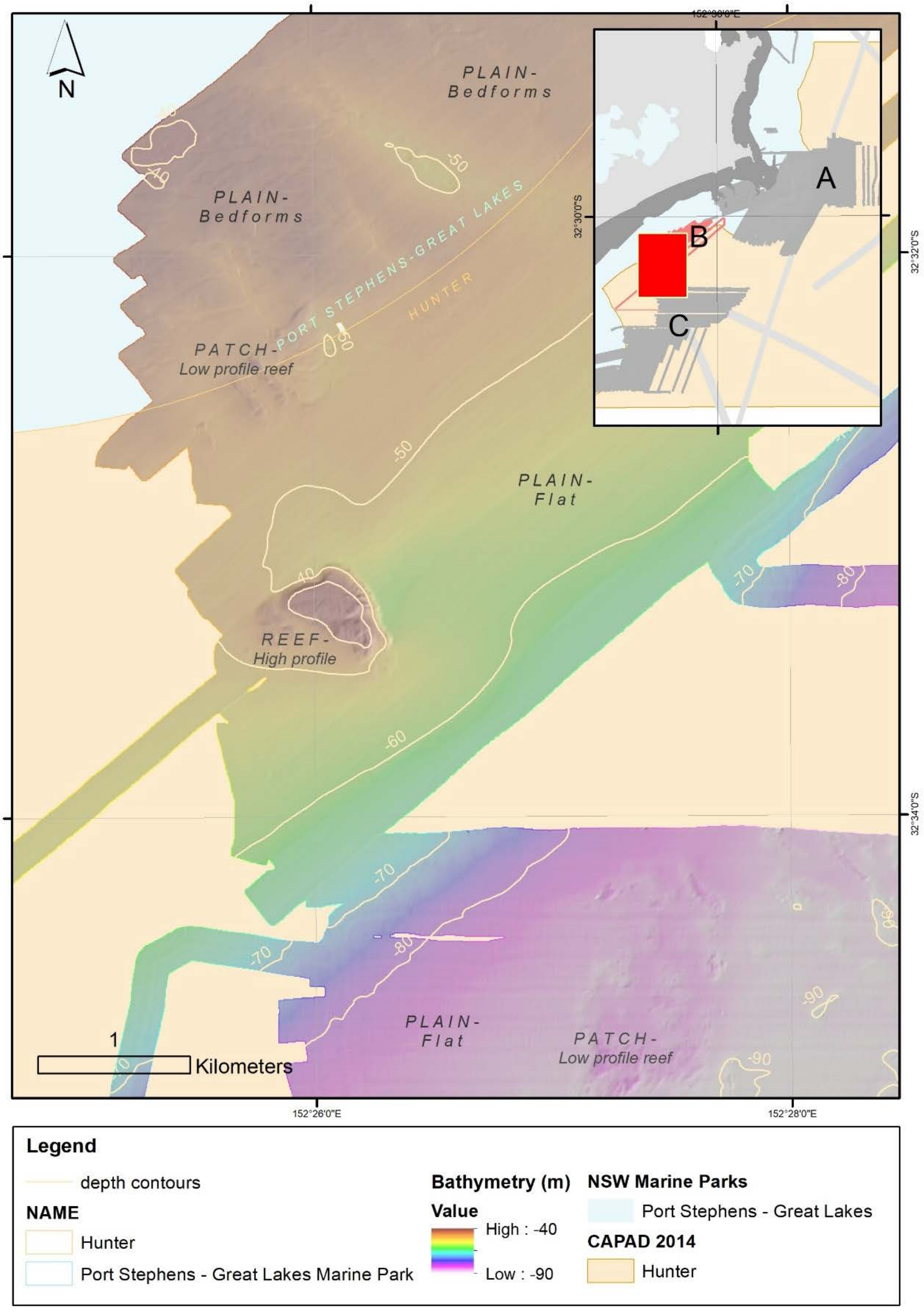


Figure 2-5. False-colour hill-shaded bathymetry of survey area B: Outer Gibber and seabed features

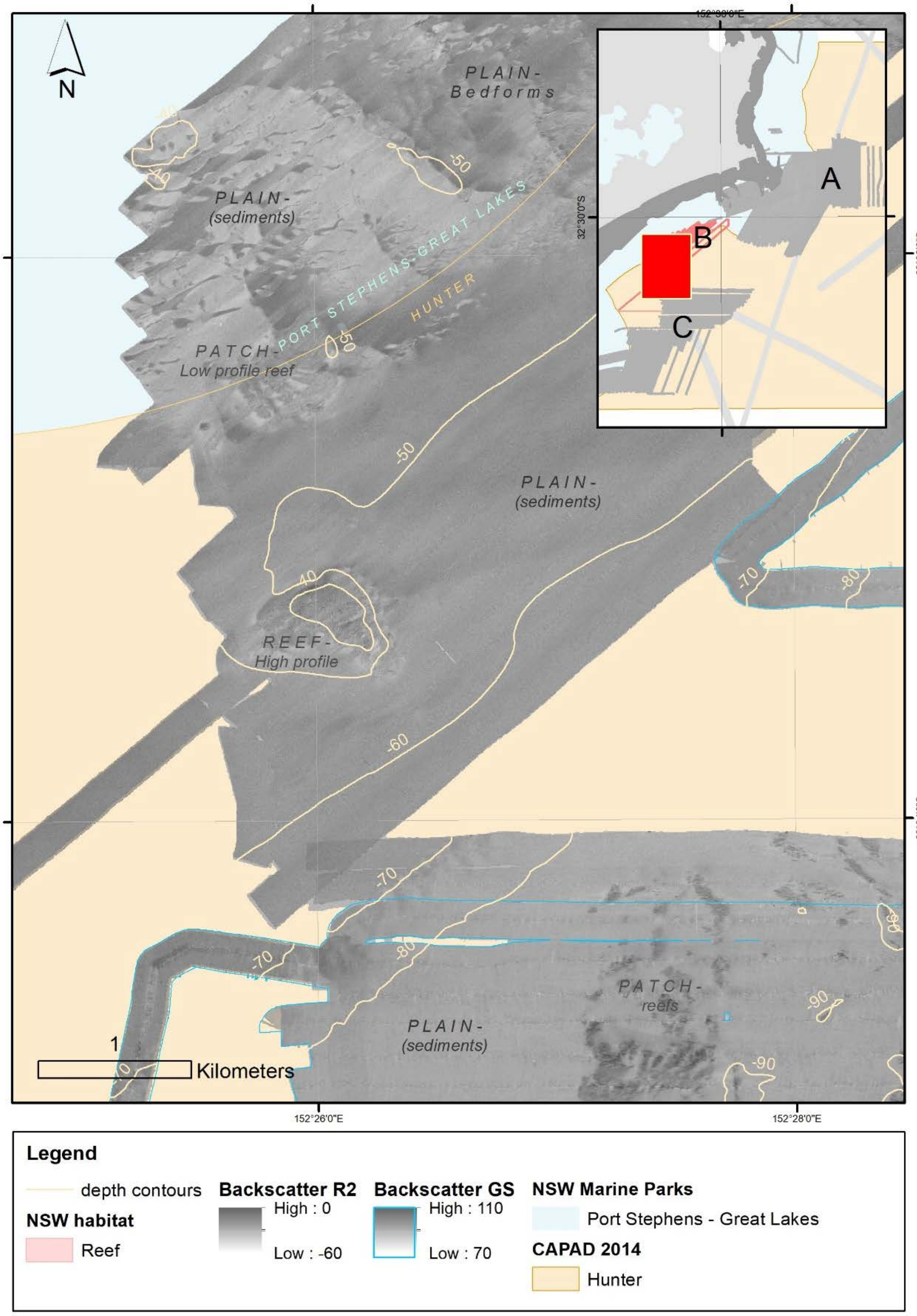


Figure 2-6. Greyscale backscatter (seabed reflectance) for survey area B: Outer Gibber & seabed features

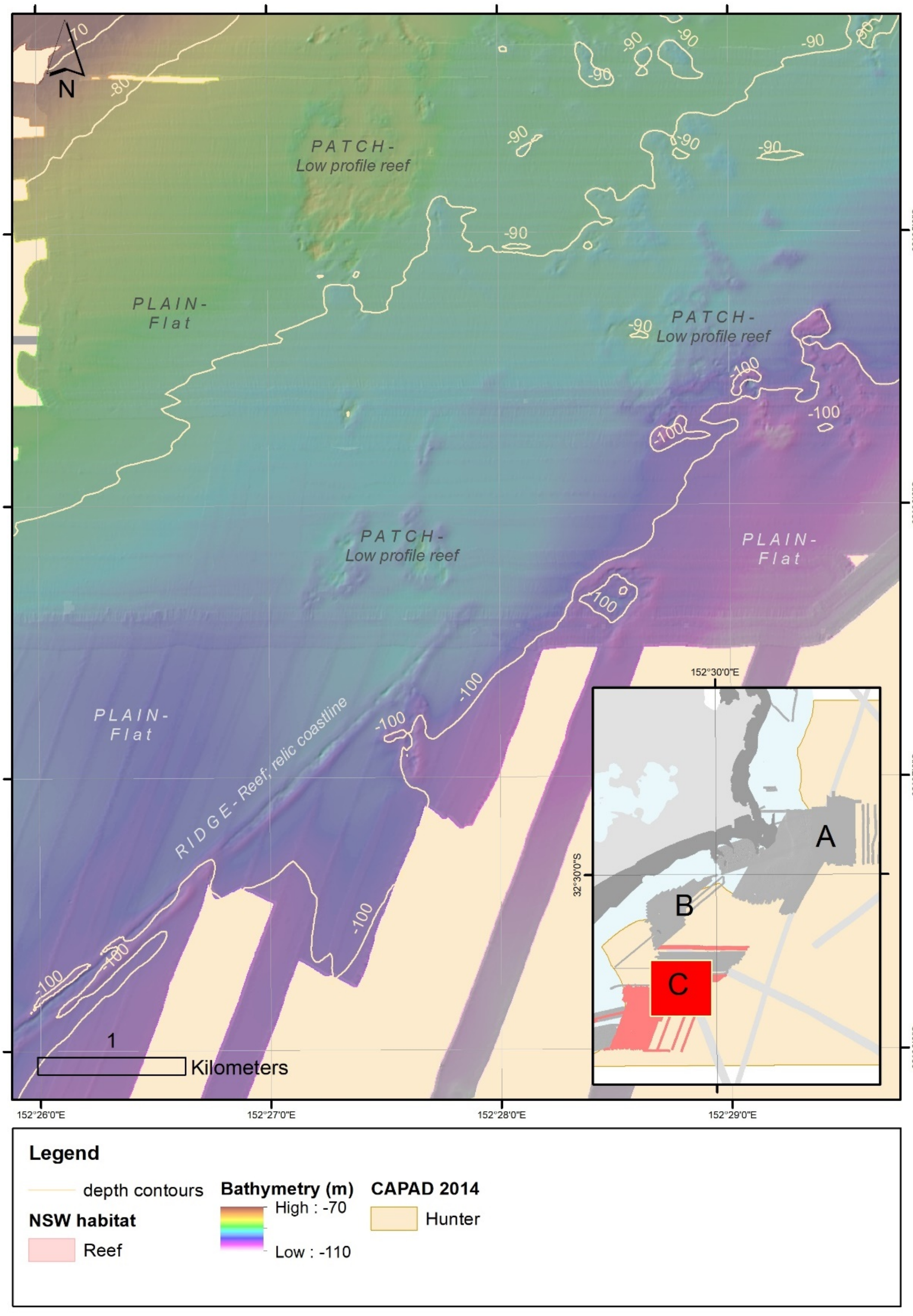


Figure 2-7. False-colour hill-shaded bathymetry of survey area C: Offshore Broughton and seabed features - northern section

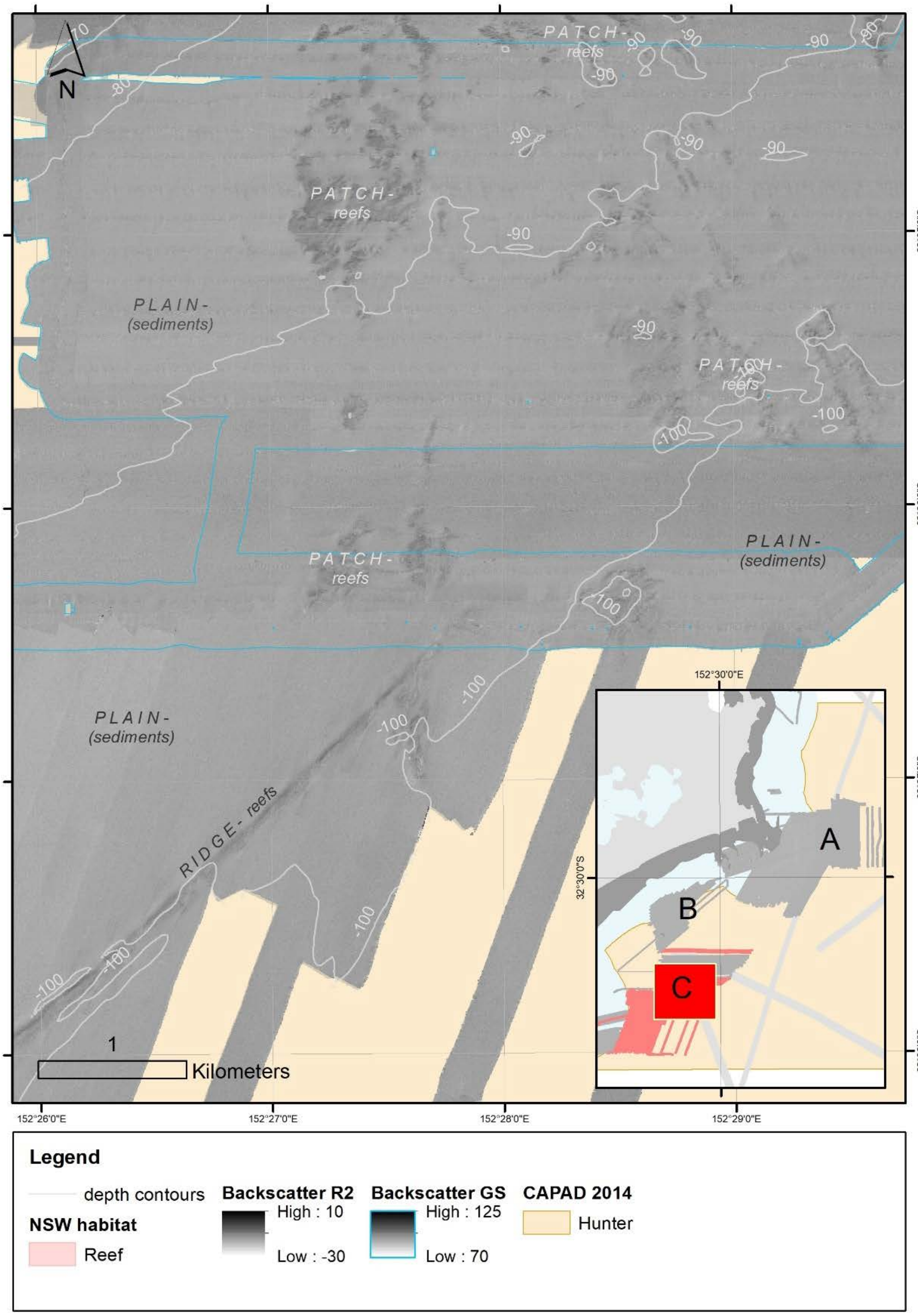


Figure 2-8. Greyscale backscatter (seabed reflectance) for survey area C: Offshore Broughton and seabed features - northern section

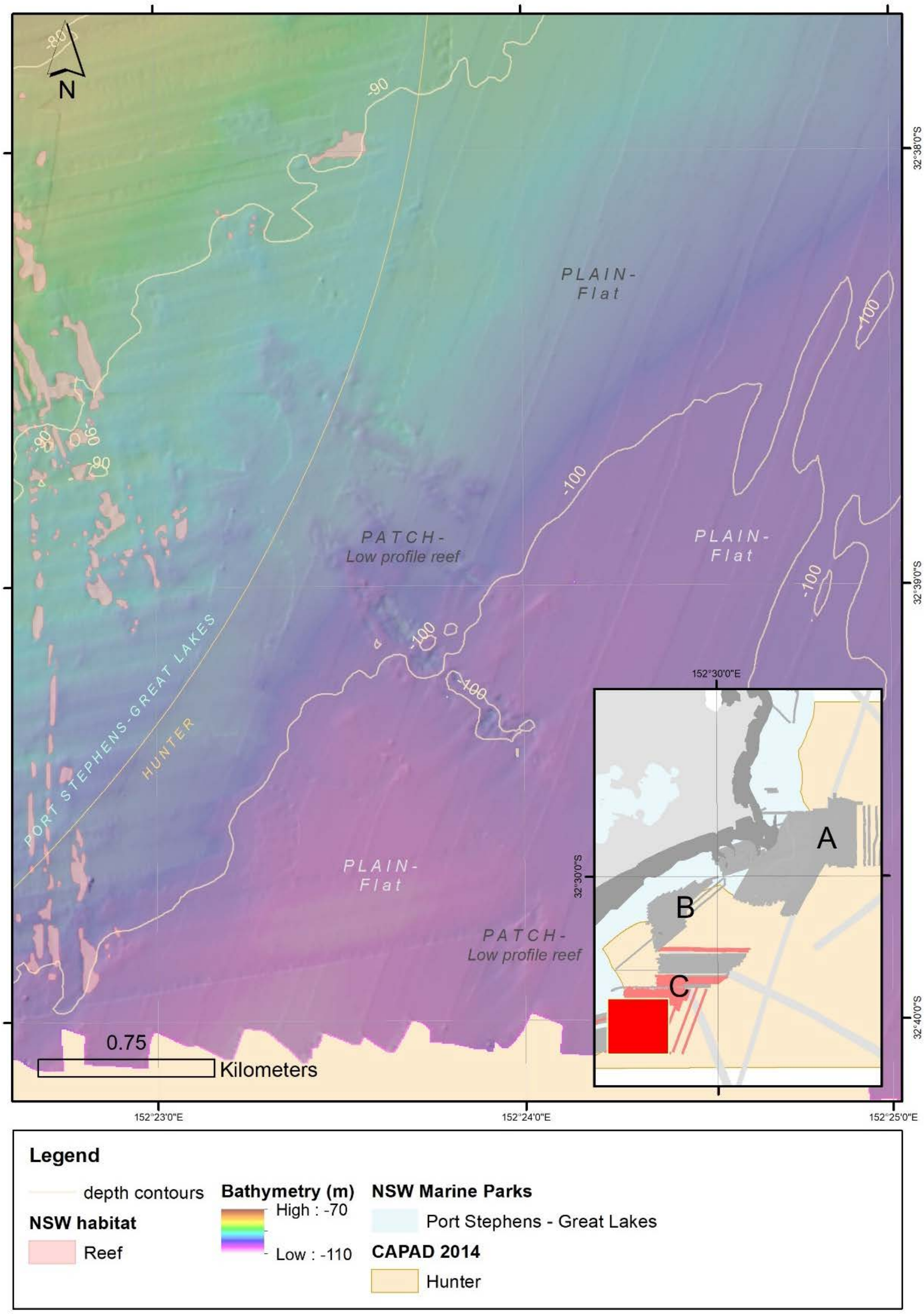


Figure 2-9. False-colour hill-shaded bathymetry of survey area C: Offshore Broughton and seabed features - southern section

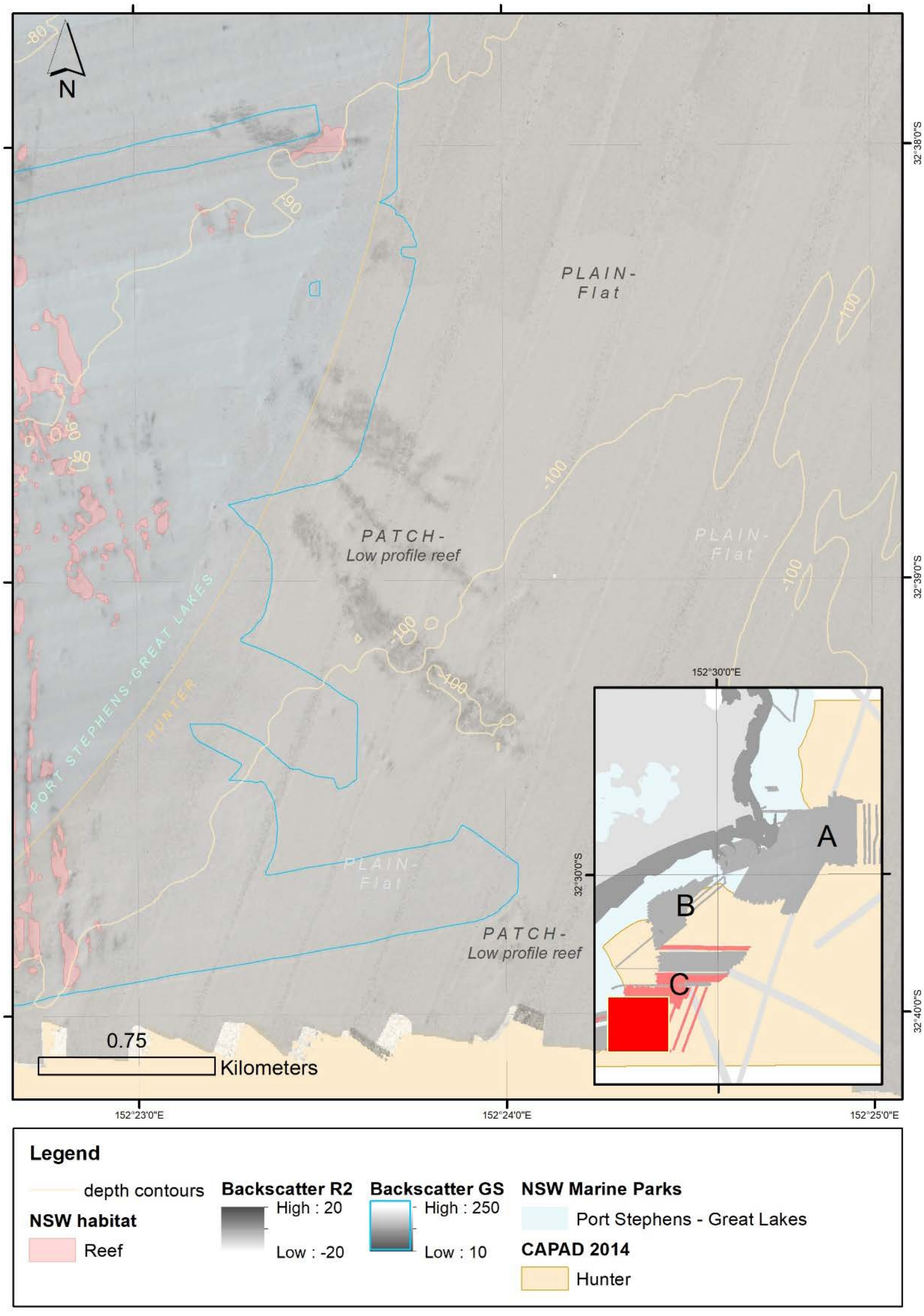


Figure 2-10. Greyscale backscatter (seabed reflectance) for survey area C: Offshore Broughton and seabed features - northern section

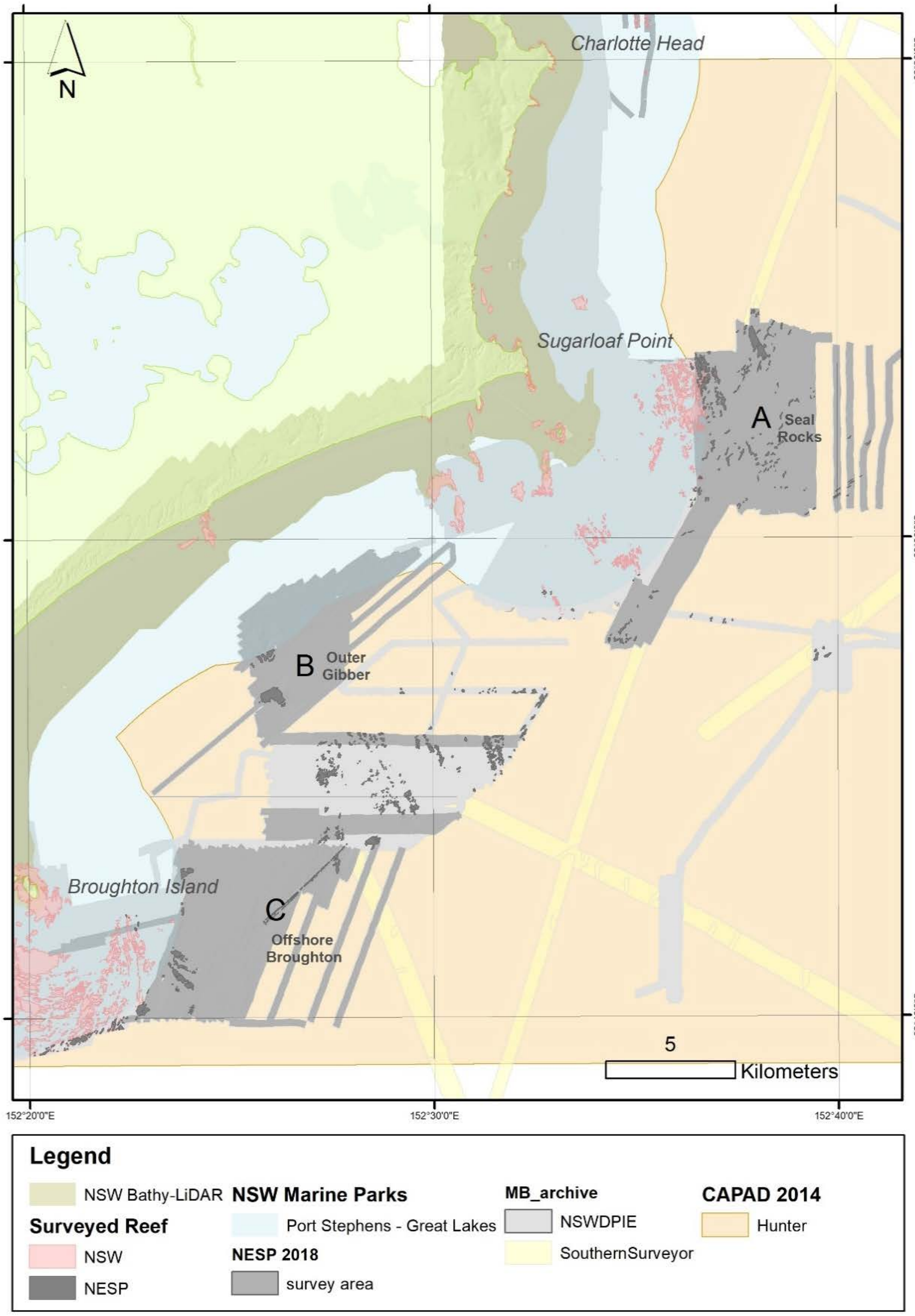


Figure 2-11. Broadscale map of reef and non-reef areas as determined by supervised classification and hand-digitising for mapped areas of Hunter Marine Park

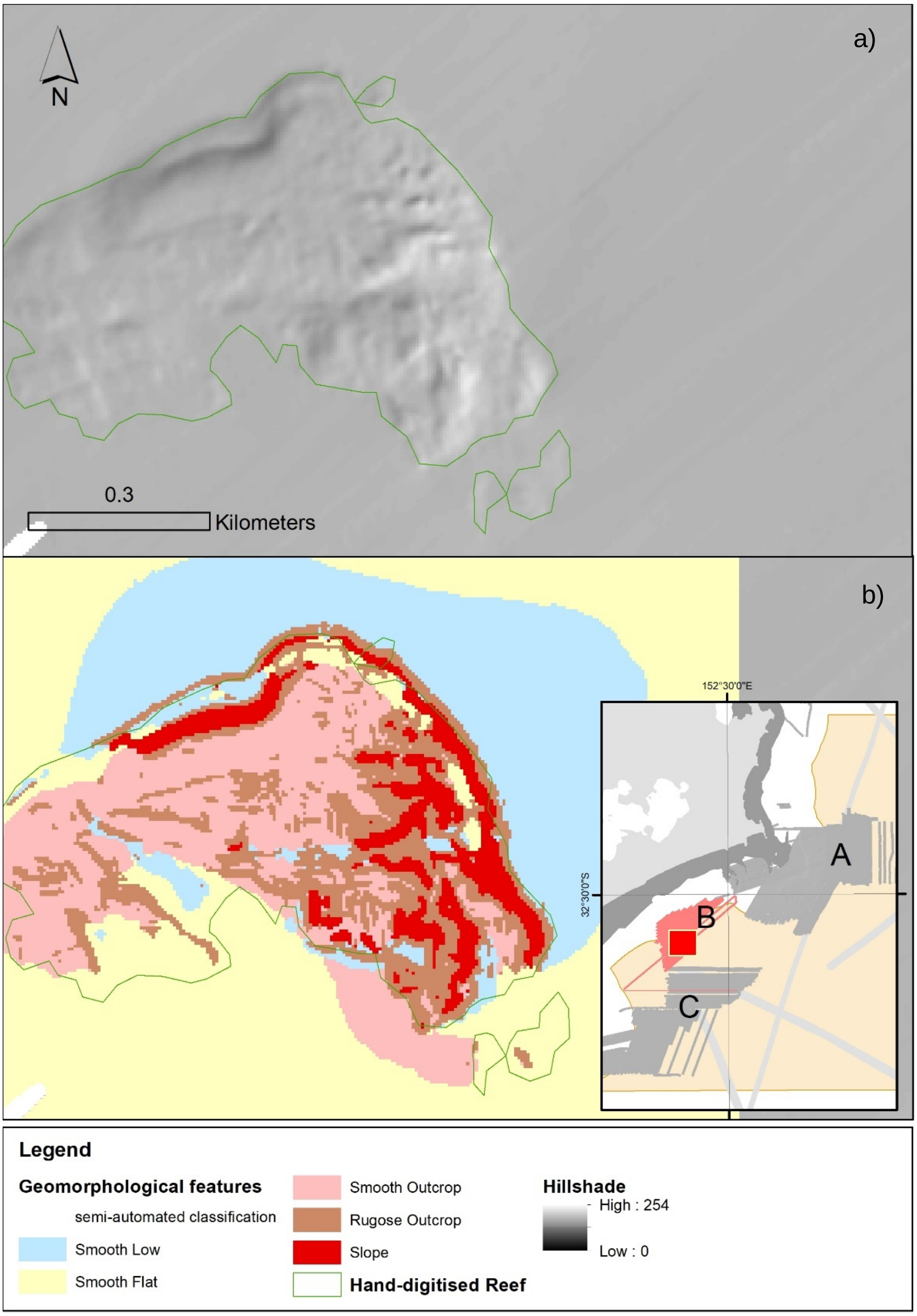


Figure 2-12. Sample area 1: a) hillshaded bathymetry showing relative relief, and b) shape file of colour coded geo-features; comparing hand-digitised (green polygons - supervised) and auto-classification (coloured polygons - semi-automated) techniques used for identifying seabed features in the Hunter Marine Park, at Outer Gibber (Area B).

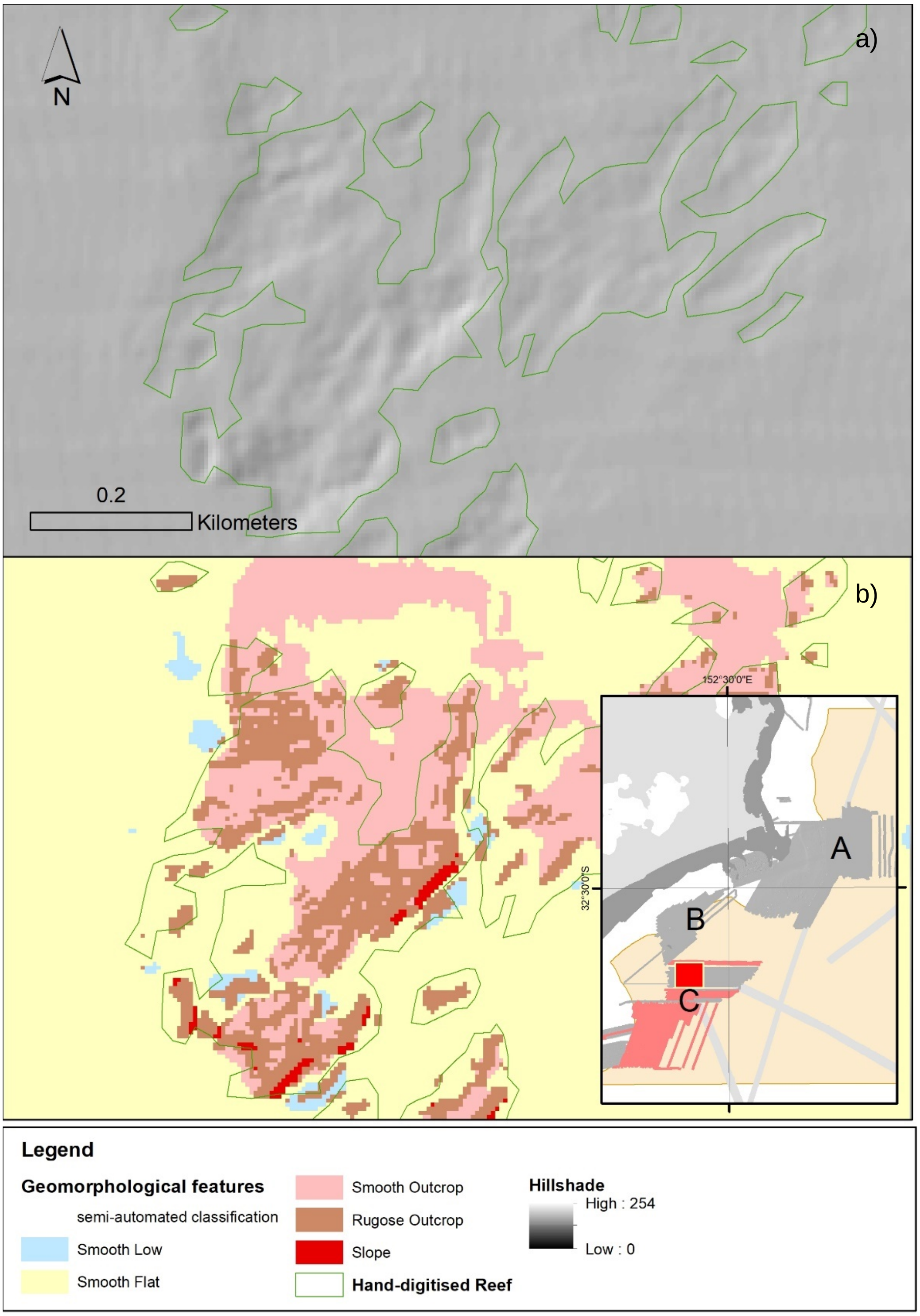


Figure 2-13. Sample area 2: a) hillshaded bathymetry showing relative relief, and b) shape file of colour coded geo-features; comparing hand-digitised (green polygons - supervised) and auto-classification (coloured polygons - comparing hand-digitised (supervised) & auto-classification (semi-automated) techniques used for identifying seabed features in the Hunter Marine Park, offshore of Broughton Island (Area C).

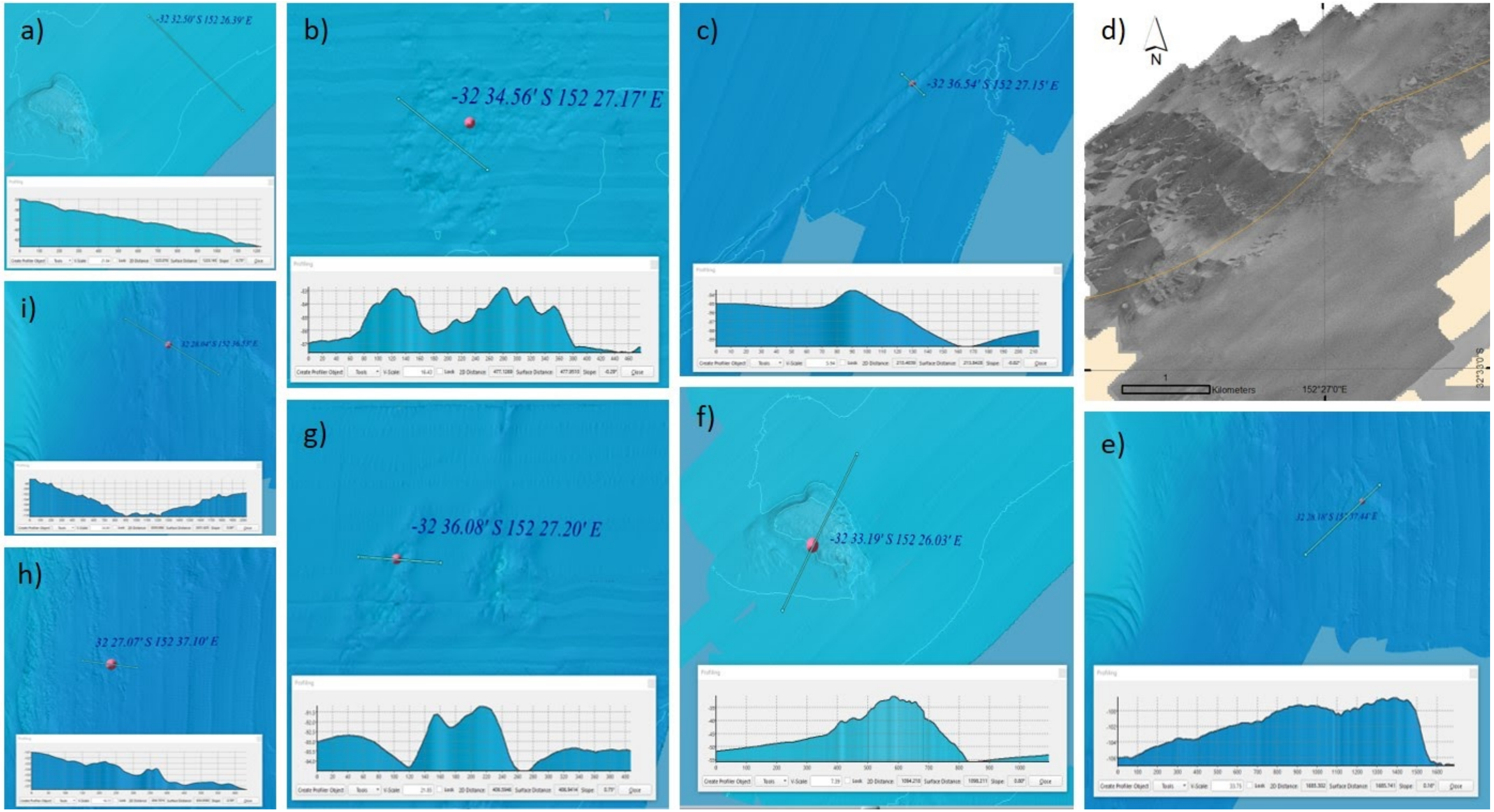


Figure 2-14. Cross-sections of landform features (shaded false colour bathymetry; illumination at 120° N) from surveyed areas of the Hunter Marine Park inner shelf; bathymetry cross section within each inset corresponds with the line on the plan-view map & circle denoting a point on that line with labelled geographic co-ordinates in WGS84. Clockwise from top left: a) plain flat; ii) patch reef - moderate profile; c) ridge - long, linear reef; d) plain - bedforms (denoted by variable backscatter in upper half of image); e) plain - high, plateau; f) reef - high profile; g) patch - reef (with scouring) ; h) patch - low profile reef; & i) channel - straight.

3. BENTHIC HABITAT: TOWED VIDEO

3.1 Background

Prior to this NESP project, very little imagery of the seabed within the Hunter Marine Park has been acquired or made available for public access. BRUVs surveys in 2016 (NSW Fisheries) visited 24 sites within Hunter Marine Park waters providing the first known video footage of benthic community structure over the park's rocky reefs. Imagery of the seabed within the bounds of the Port Stephens - Great Lakes Marine Park has been acquired using the Integrated Marine Observing System's (IMOS) Autonomous Underwater Vehicle '*Sirius*' on relatively shallow reef systems (<30-40 m) at Broughton Island (see AODN surveys 2012, 2020) and using towed video across 20-100 m water at Broughton Island, The Pinnacles and Seal Rocks (Ingleton et al. 2020). Deeper reefs (>80 m depth) were dominated by sea whips, gorgonians and sponges with palmate and branching morphologies offshore of Seal Rocks and Broughton Island. Sea pens occupied areas of seabed in 70 m off Seal Rocks over what appeared to be soft sediments according to low slope and planar nature of the seabed and the relatively uniform backscatter.

Although it is possible that benthic communities on Port Stephens - Great Lakes Marine Park reefs are similar in composition to adjacent reefs at corresponding depths within the Hunter Marine Park, this should not be assumed. Reefs within state waters at Seal Rocks and Broughton Island lie within sanctuary zones or special purpose zones that restrict all or some extractive activities. This differs to the suite of restrictions applied to the Hunter Marine Park Special Purpose Zone over the shelf and immediately offshore. Thus, different benthic communities might occupy these sites. Also, differences in imagery acquisition and analysis and the amount of time passed between surveys (years) could contribute to making a direct comparison between benthic communities invalid.

3.2 Methods

Seabed imagery was obtained by using an underwater towed video system over 7 field days during 20 October 2019 – 13 August 2020. Sample site selection utilised the methods described in the NESP MBH manual: '*Marine Sampling Field Manual for Towed Underwater Camera Systems'* (Carroll et al. 2020) with sites selected using the R script '*MBH Design*' detailed in NESP MBH manual: '*Statistical Consideration for Monitoring and Sampling'* (Foster et al. 2020). Maps of cleaned bathymetry were used to calculate slope values across the combined 2015 and 2018 MB surveyed areas in GIS. Using MBH design (Foster et al, 2019), a series of 95 randomised 200 m transects were then selected from across the combined 2015-2018 survey areas, partitioned on the basis of slope

The equipment used for imagery acquisition and further details around data acquisition and handling are covered in the ground truthing section of *SeaBedNSW: Standardised operating procedures for multibeam surveying* (Ingleton et al. 2019) (Figure 3-1). Digital stills and video were typically obtained at a height of ~1 m from the seabed at 2 second intervals with parallel dual green lasers at ~100 mm separation for measuring seabed features. Forward looking video was recorded continuously and overlain with ship position, depth and site information. All vessel and camera information (roll, pitch, yaw, fish position, depth etc) was also logged using the acquisition software to a log file (text) with USBL positioning backup recorded in Tracklink (LinkQuest, USA).

Still imagery and towed video time stamping was cross checked for synchronicity before renaming stills using a script in MATLAB®© and using the NSW DPIE towed video imagery naming convention using image date and time (UTC). Details of positioning offsets and camera system setup specific to these surveys are provided in the metadata statement. Stills and video were uploaded to the web (NSW environment portal SEED) for public access. Imagery is accessible for use in Squidle+ for annotation and analysis. Annotation and a quantitative analysis of the imagery was not performed here due to time constraints but will be the subject of future journal publications.

To semi-quantify the overall success of the towed video method in capturing the presence of benthic organisms and provide a generalised spatial overview of the survey imagery, still images were assessed by scoring the presence/absence of a small number of key features in previews of raw (uncorrected) imagery. As an indicator of the availability of reef habitat to support benthic organisms, the percentage of images with 'reef' present relative to the total number of usable images acquired per transect was calculated. To assess the presence/absence of benthic infauna and epifauna in soft sediment areas, erect forms (i.e., tube worms, other), as well as other biogenic features (i.e., burrows), was also assessed and summarised.

Figure 3-1. NSW DPIE Towed Video fish setup showing centred forward-looking video camera with live fish-to-surface fibre optic feed and lights, rear deck of RV Bombora (the digital stills camera sits toward the back of the tow-frame and not visible here).

3.3 Results and Discussion

3.3.1 Fieldwork and Image Acquisition

A total of 94 transects were completed during the towed video surveys for Hunter Marine Park during October 2019 to August 2020. The MBH survey design survey was followed as closely as possible when operating in the field. However, weather and sea conditions, vessel and equipment issues as well as local commercial fishing operations restricted our ability to acquire data along 'MBH designed' lines. With up to ~120 m of tethered cable connecting the tow-fish to the surface, the vessel's ability to manoeuvre was, at times, highly restricted. Also, in order to maintain a survey speed of ~1 kt and vessel steerage, engines need to be held at low speed or out-of-gear. As a result, the trajectory of the vessel and camera system was typically dictated by the direction of the dominant prevailing current and local winds. Generally, completed transects commenced within a 100-200 m radius of the planned transect lines (Figure 3-2).

Imagery was acquired at all MBH-designed transect sites within survey area B (Outer Gibber – 6 transects; October 2019) where there were no constraints on video survey operations by commercial fishing operators (Figure 3-2). For survey area C (offshore Broughton), however, commercial fishers (fish-trap) from Port Stephens and Newcastle operate across the area (pers. comms. Forster-Tuncurry Fisherman's Co-operative; > 80 m) and deploy their bottom traps with a line tethered to a float at the surface. Where trap floats and planned MBH designed transects coincided (< 50 m), the transect was abandoned and a new transect proposed at a safe working distance (< 200-300 m). Transects were completed during October 2019 and July-August 2020. A total of 51 transect sites were surveyed in areas offshore of Broughton Island (Figure 3-2).

Initially, complications were also encountered at Seal Rocks (survey area A) where commercial rock lobster fishers operate (season August - April pers. comm., Forster-Tuncurry Fisherman's Cooperative). These fishers use acoustic release systems attached to their lobster pots with tethered subsurface floats to minimise losses of their gear to commercial shipping 'strikes'. Floats are positioned anywhere between 10 m from the bottom to within 20 m of the surface and posed an unacceptable risk to our vessel towed video operations as well as to the installed commercial lobster-fishing equipment. During October 2019 surveys there were greater than 100 'pots' deployed within the Seal Rocks survey area. However, through negotiations with the local commercial operators, two zones of the seabed where lobster pots are not historically deployed, were identified and deemed low risk and acceptable for video surveys. Only 5 of the proposed Seal Rocks transects were completed during this first survey period.

Staff availability and COVID-19 delayed further towed video surveys in late 2019 and during early 2020. Following the lifting of COVID associated restrictions on DPIE fieldwork, surveys recommenced and were completed June-August 2020 and allowing us to acquire video and stills from the remaining Broughton Island sites and all but one of the proposed Seal Rocks sites. In total, 37 transect sites were surveyed at Seal Rocks during the survey periods for this study (Figure 3-2).

3.3.2 Data and Preliminary Image Analysis

A total of 33,855 still images and ~21 hours of towed video were obtained over the seabed within the Hunter Marine Park. Video captured an average of 13 minutes of footage per transect and an average 360 digital stills. Of the stills, between 40-90% of each transect were of a quality (focus, lighting) suitable for annotation. A map summarising the results of presence/absence scoring of transect imagery is presented in Figure 3-3. Example imagery of benthic communities and associated seabed types from within the Hunter Marine Park are presented in Figure 3-4 - Figure 3-13. These figures are accompanied by plan and 3-D view maps denoting transect locations as well as along transect (200 m) cross-sectional profiles to demonstrate transect relief. Examples of mobile fauna observed within towed imagery are also presented in Figure 3-14 - Figure 3-17.

From presence/absence scoring of the raw imagery, benthic organisms almost always occurred when reef or boulders were contained within an image. The percentage of reef within transect imagery was generally greater at the Offshore Broughton survey area than at Seal Rocks. Benthic organisms included algae, sea whips, octocorals and sponges (Figure 3-10 - Figure 3-13). In many images from deeper areas, reef, boulders or cobbles were low profile and draped in sediment. In these areas sessile invertebrates ranged in relative cover but were generally fewer (Figure 3-4, Figure 3-7, Figure 3-11, Figure 3-14) than reef with higher profile. On occasion, reef draped in sediment possessed relatively few to zero observable sessile invertebrates (example Figure 3-13.i).

For imagery dominated by soft sediments, burrows (Figure 3-12 and Figure 3-13) were common to deep areas/transects (60-110 m water depth, areas A and C) but not shallow areas/ transects (< 60 m; area B; Figure 3-9). This indicates the presence of contemporary activity from infaunal organisms (i.e. worms) at these locations. A relatively small number of soft sediment images contained mobile benthic invertebrates such as urchins, scallops and sea stars (Figure 3-5). Grainsize is also likely to be a factor controlling the presence/absence of burrows as is sediment mobility and/or disturbance. Evidence of bedforms was observed within imagery from the shallowest sites in the north and north-east sections of the Outer Gibber survey area (Figure 3-9) indicating a mobile seabed.

Stills from both deep and shallow water transects identified erect invertebrates co-occurring within soft sediments. This was most common in deep transects and was relatively rare in shallow transects and, generally, more common in images from the Seal Rocks survey area than Broughton Island. The presence of erect forms in soft sediment areas i.e. tube worms, may indicate the relative stability (non-mobile) of the seabed at these locations. Some benthic fauna i.e. sponges and fan corals, require attachment to a more ‘fixed’ and harder substrate and, where present, may indicate reefs or harder substrate types lying just below the surface. Not all deep transects, however, possessed images with erect invertebrates. This may either be associated with specific grainsize at these locations or indicate a level of disturbance of the soft sediments such that benthic species are unable to establish themselves.

Further quantitative analyses including the annotation of imagery using packages such as *Squidle+* and the exploration of species and environmental data using multi-variate statistical techniques will allow us to better understand the spatial distribution of species and seabed types and relationships between them. This is to be the subject of future work to be published within the next few years.

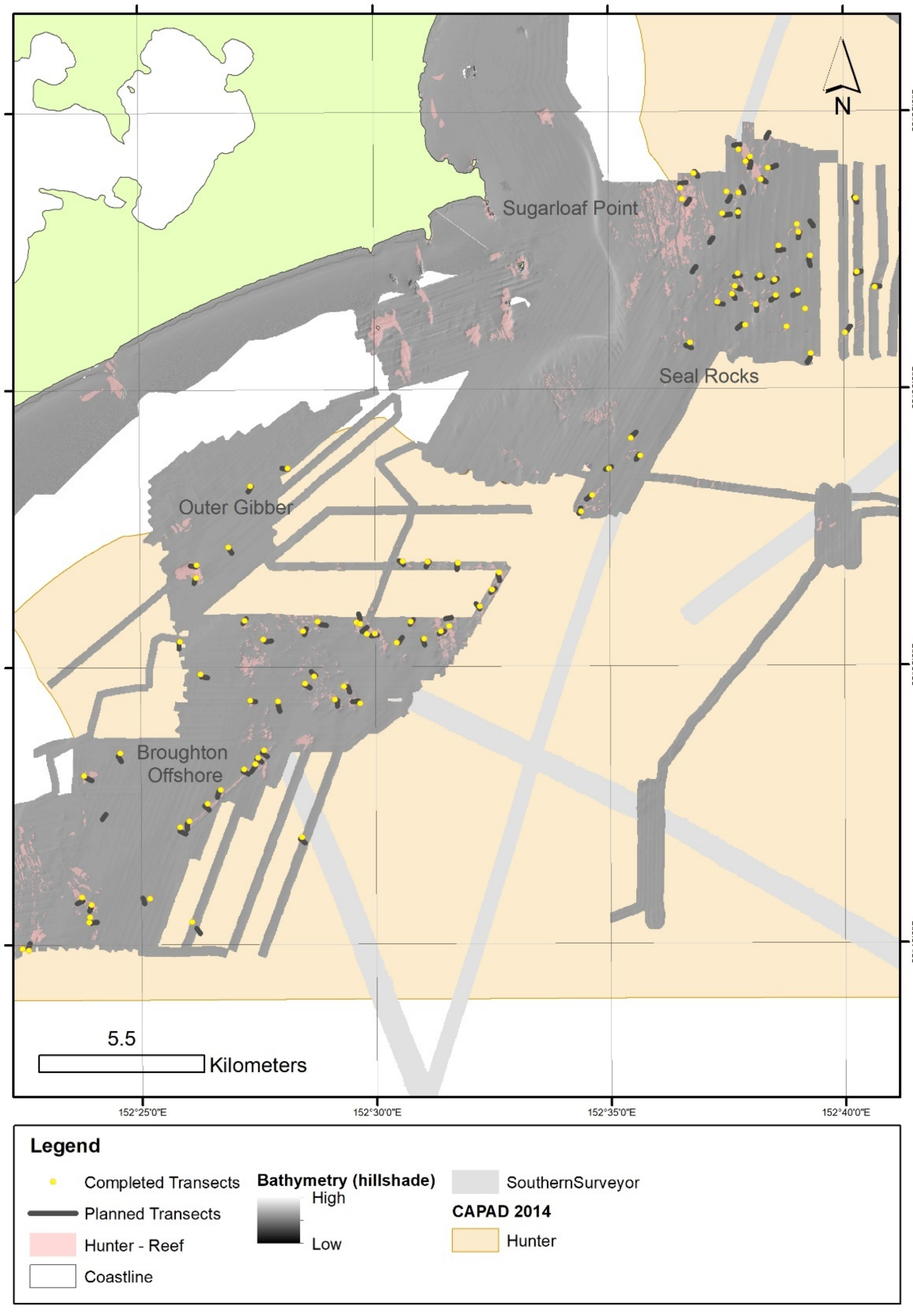


Figure 3-2. Location of planned and completed towed video transects for the Hunter Marine Park surveys 2019-20.

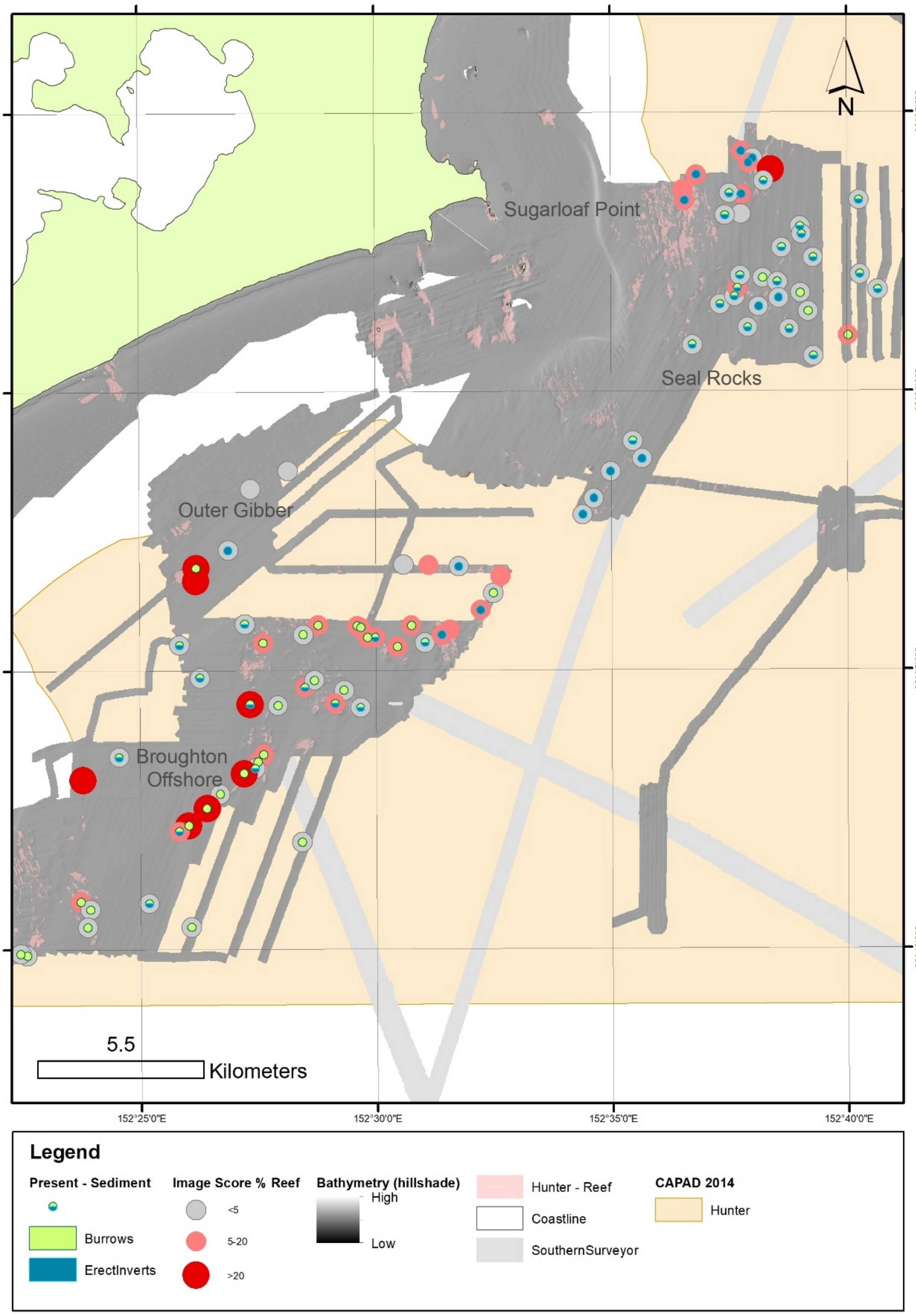


Figure 3-3. Summary of presence/absence scoring of still imagery per transect identifying 1) Reef - percentage of images with reef present; and 2) Soft sediments - presence of infaunal burrows and/or erect invertebrates.

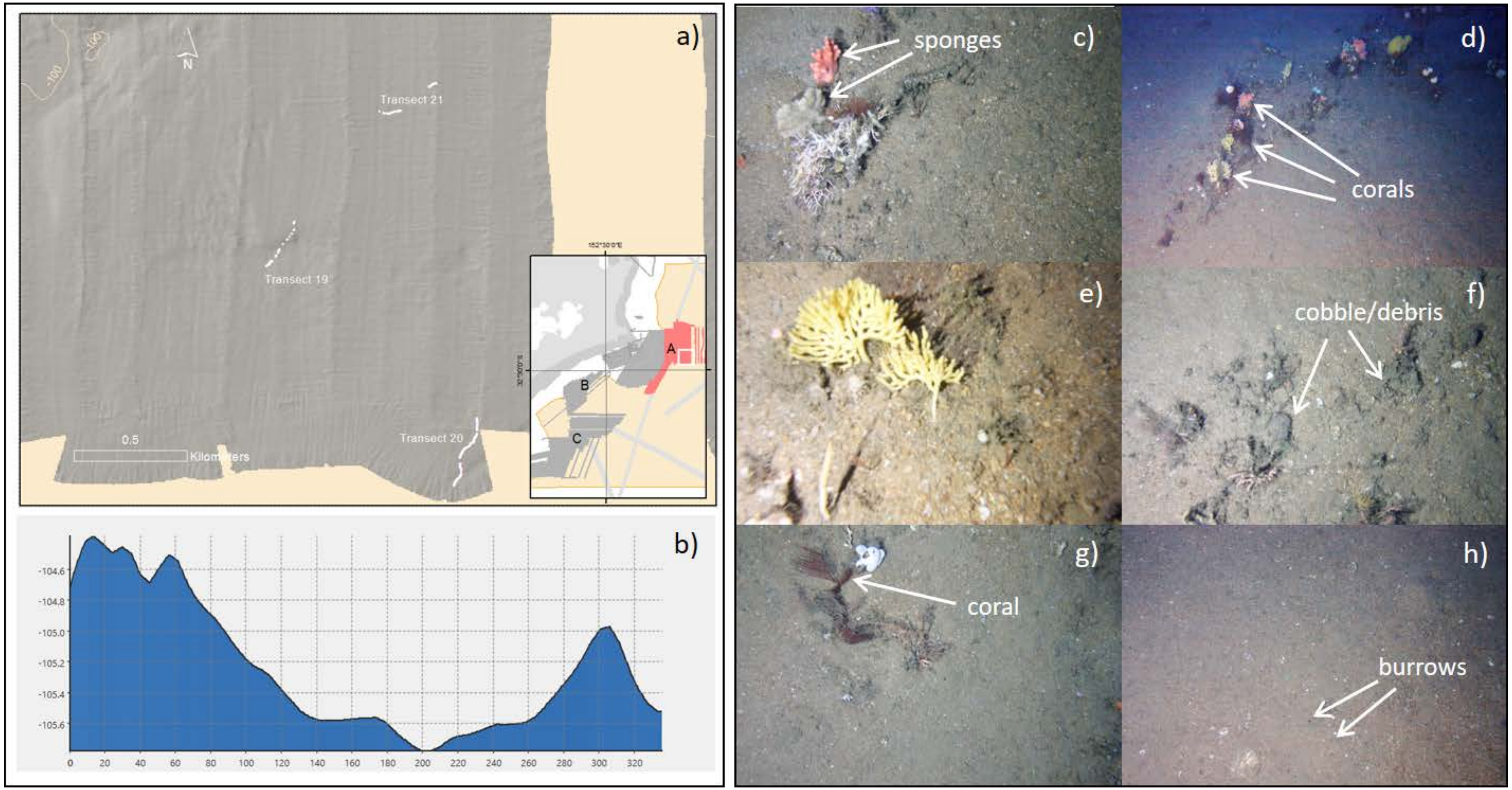


Figure 3-4. a) planar view of hill-shaded bathymetry with location of video transects (T19-20) at Seal Rocks (Area A) October 2019 (*nb. north-south oriented parallel ridges are MBES artefacts*); b) bathymetric cross-section through transect (T19) start-end points; Transects 19 and 20 showing (c-g) erect sponges and branching cnidarian corals on isolated sediment veneered reefs, soft sediment habitat with (f) rocky debris, (g) branching cnidarian fan corals and (h) infaunal burrows. Laser points are 100mm apart.

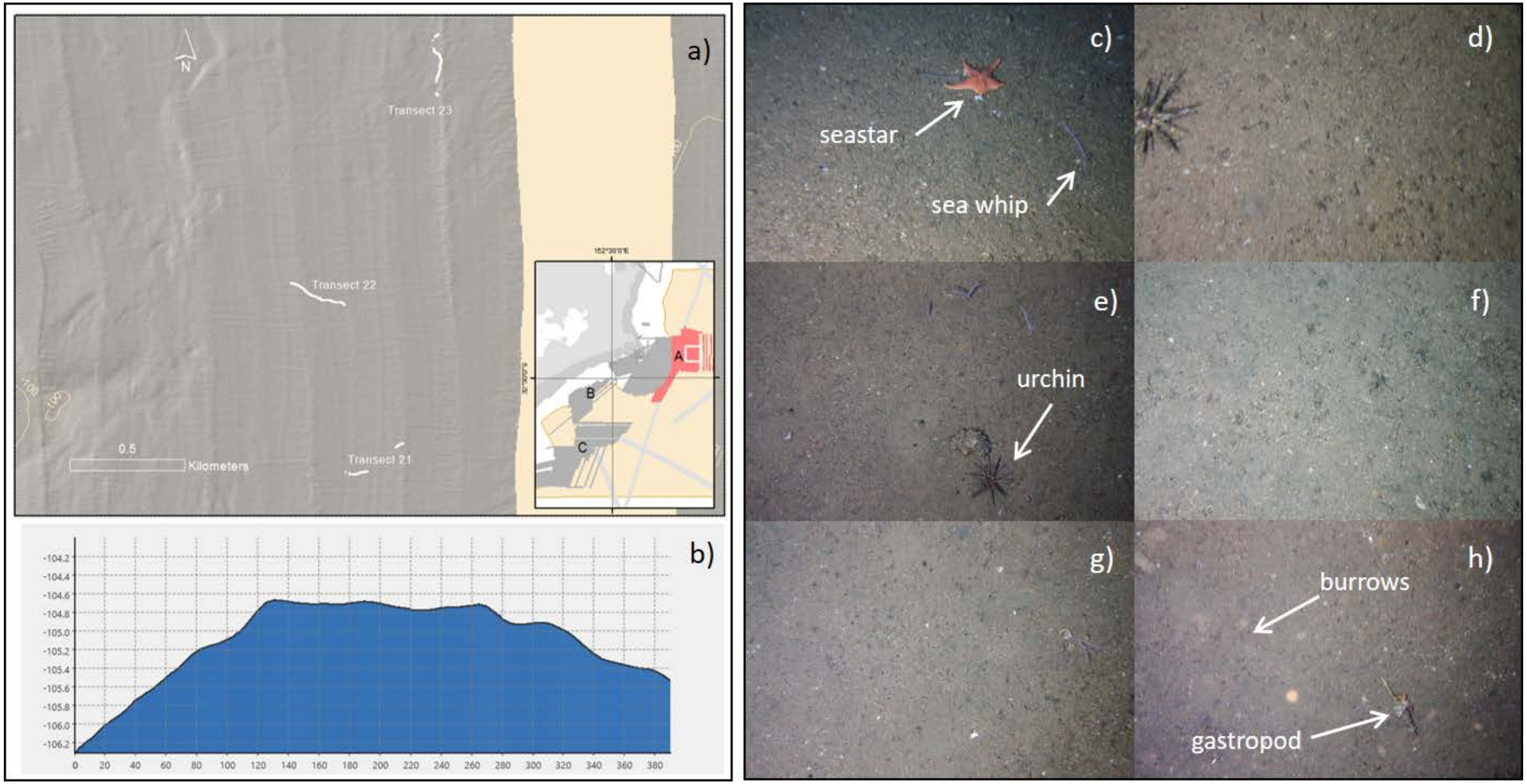


Figure 3-5. a) planar view of hill-shaded bathymetry with location of video transects (T21-22) at Seal Rocks (Area A) October 2019, (*nb. north-south oriented parallel ridges are MBES artefacts*); b) bathymetric cross-section through transect (T21) start-end points; Area A – Seal Rocks: Transects 21 and 22 showing (c,e) sea star and sea whips, (d-e) pencil urchin, (c-h) infaunal sediment burrows (h) unknown gastropod. Laser points are 100 mm apart.

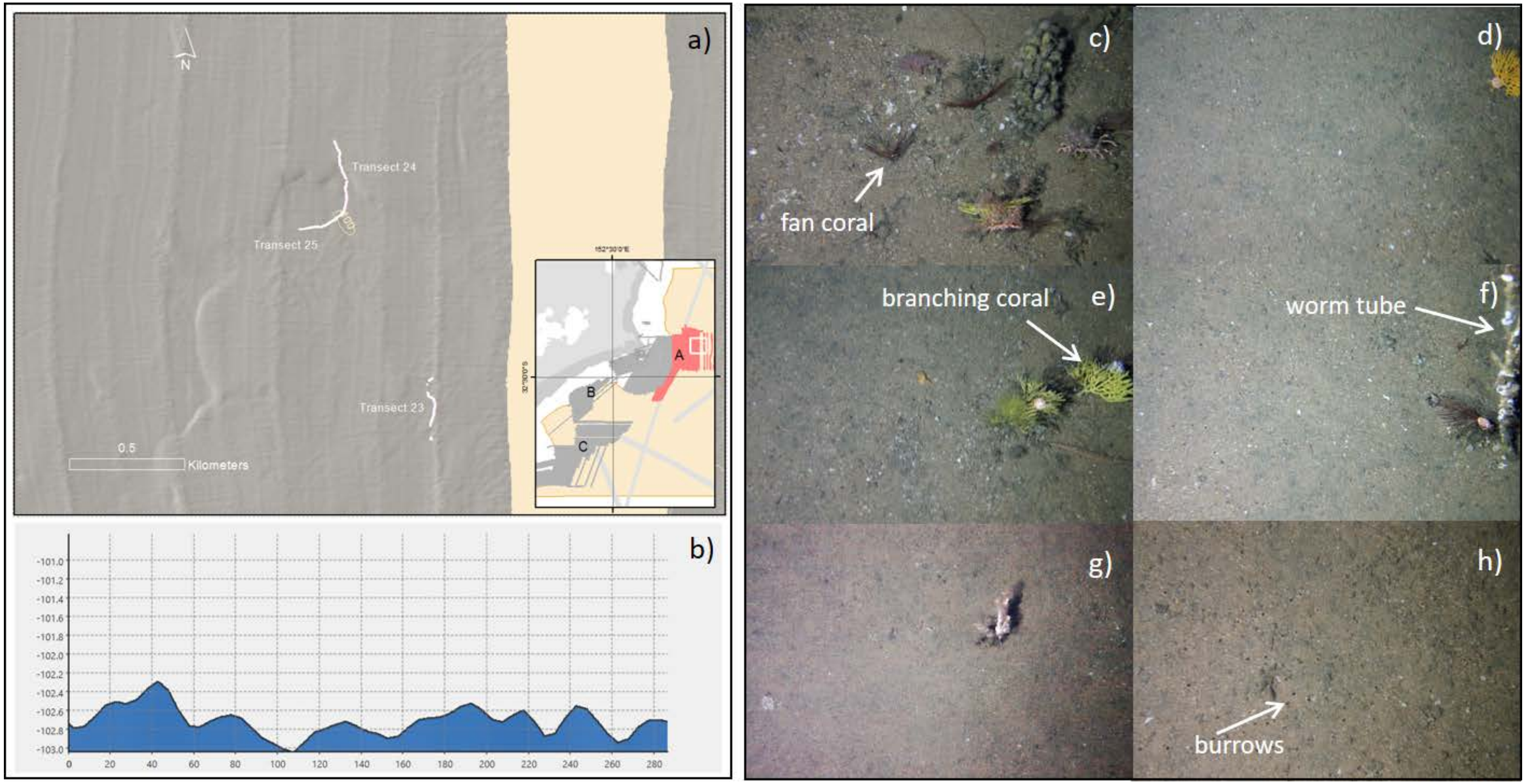


Figure 3-6. a) planar view of hill-shaded bathymetry with location of video transects (T23) at Seal Rocks (Area A) October 2019, (*nb. north-south oriented parallel ridges are MBES artefacts*); b) bathymetric cross-section through transect (T23) start-end points; Transect 23 imagery showing (c-g) small erect sponges, branching cnidarian fan corals, and worm tubes; and (g-h) soft sediment infaunal burrows. Laser points are 100 mm apart where visible.

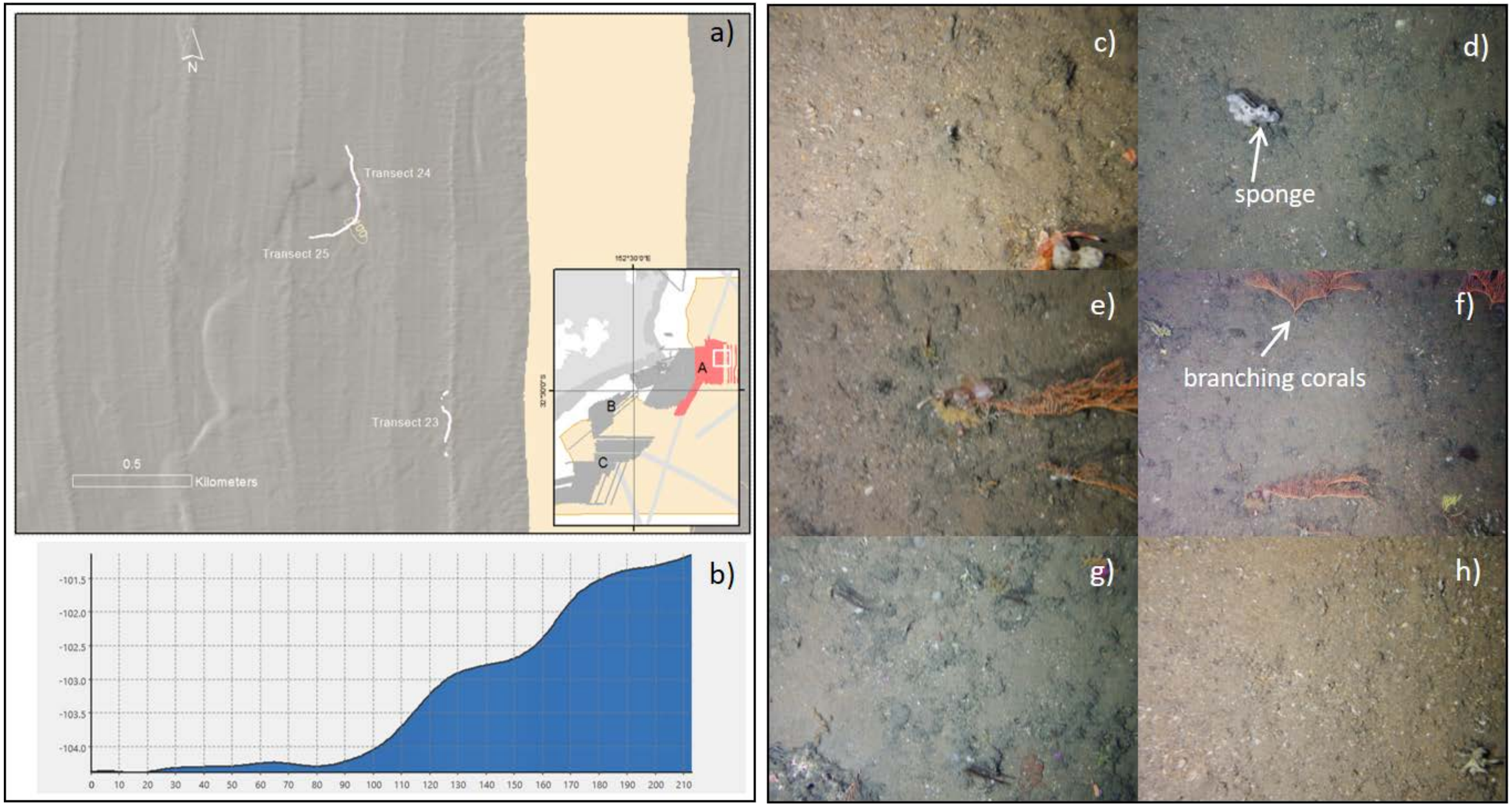


Figure 3-7. a) planar view of hill-shaded bathymetry with location of video transects (T24) at Seal Rocks (Area A) October 2019, (*nb. north-south oriented parallel ridges are MBES artefacts*); b) bathymetric cross-section through transect (T24) start-end points; Transect 24 imagery showing (c-g) veneered soft sediment and sponges, (e-f) corals, (c-d, g) sparse sponges and cobble rubble and (c, h) infaunal sediment burrows and rubble. Laser points are 100 mm apart.

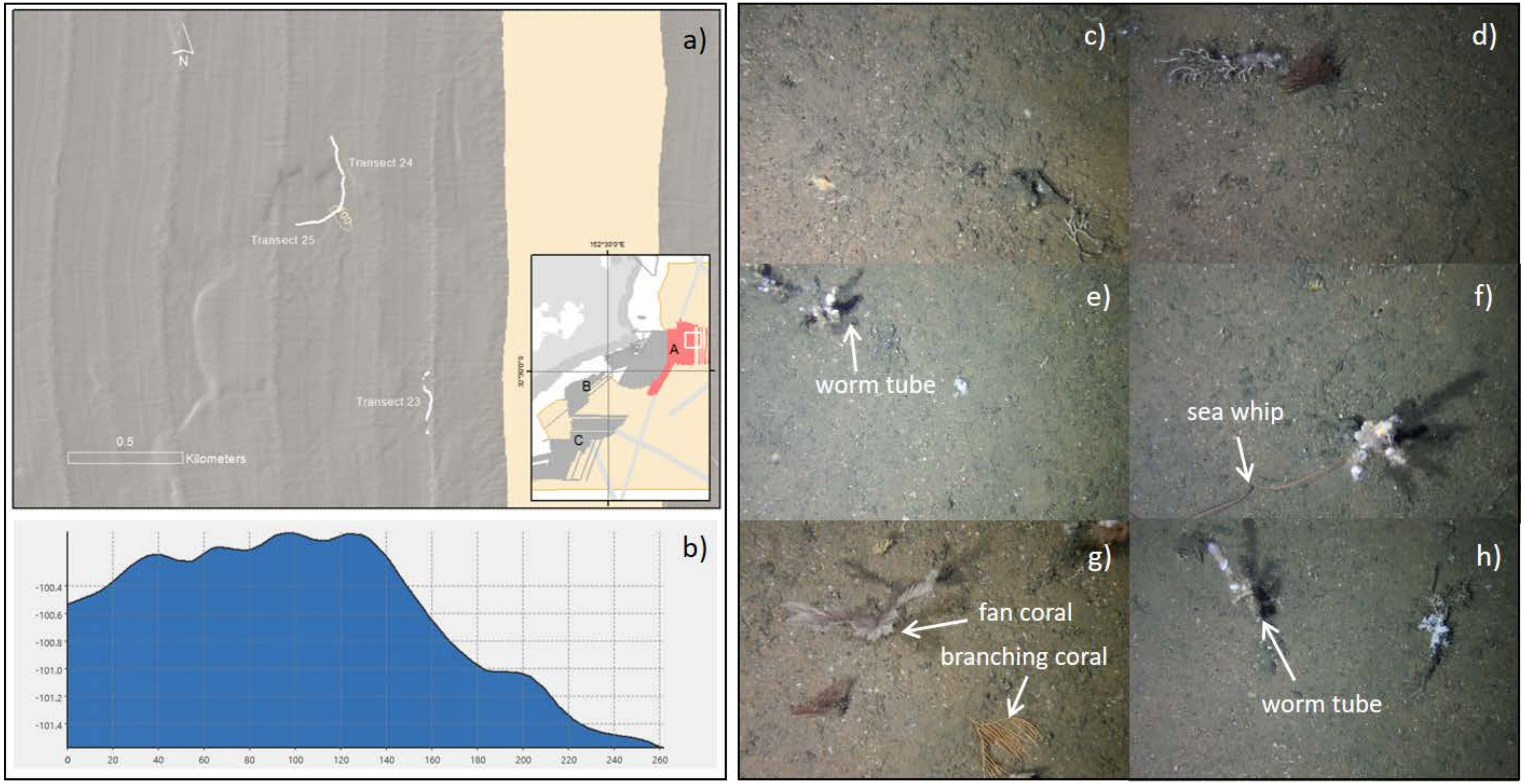


Figure 3-8. a) Planar view of hill-shaded bathymetry with location of video transects (T25) at Seal Rocks (Area A) October 2019 (*nb. north-south oriented parallel ridges are MBES artefacts*); b) bathymetric cross-section through transect (T25) start-end points; Transects 25 (imagery showing (c) soft sediment burrows and debris, (d, g) branching cnidarian fan corals (e-f, h) worm tubes, (f) sea whip. Laser points are 100 mm apart.

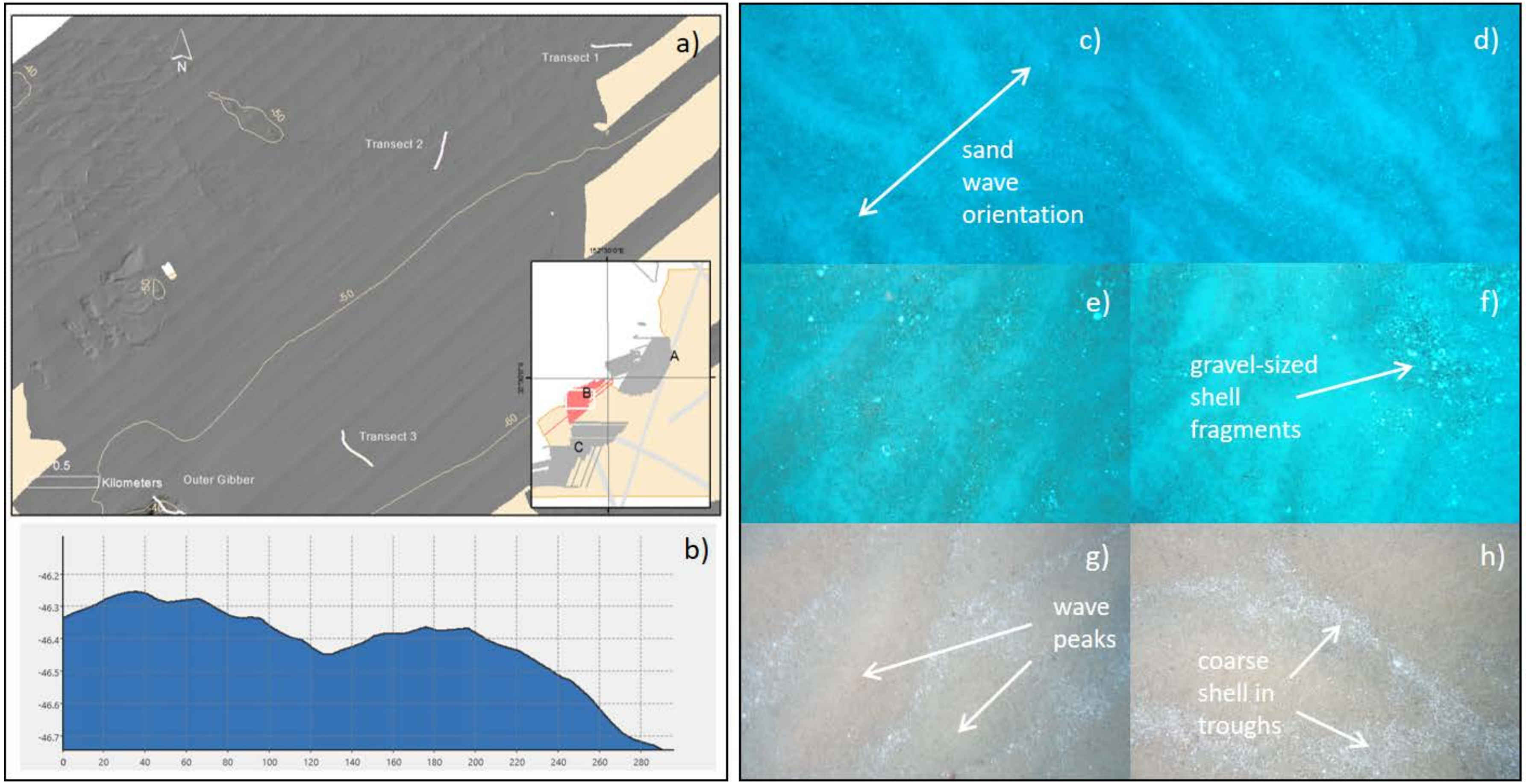


Figure 3-9. a) planar view of hill-shaded bathymetry with location of video transects (T1-3) north of Outer Gibber (Area B) October 2019; b) bathymetric cross-section through transect (T1) start-end points; Area B – Outer Gibber: Downward looking still imagery from along Transects 1 - 3 showing (c-h) soft sediment habitat with sand waves with coarser shelly material located in sand wave troughs. Laser points are 100 mm apart.

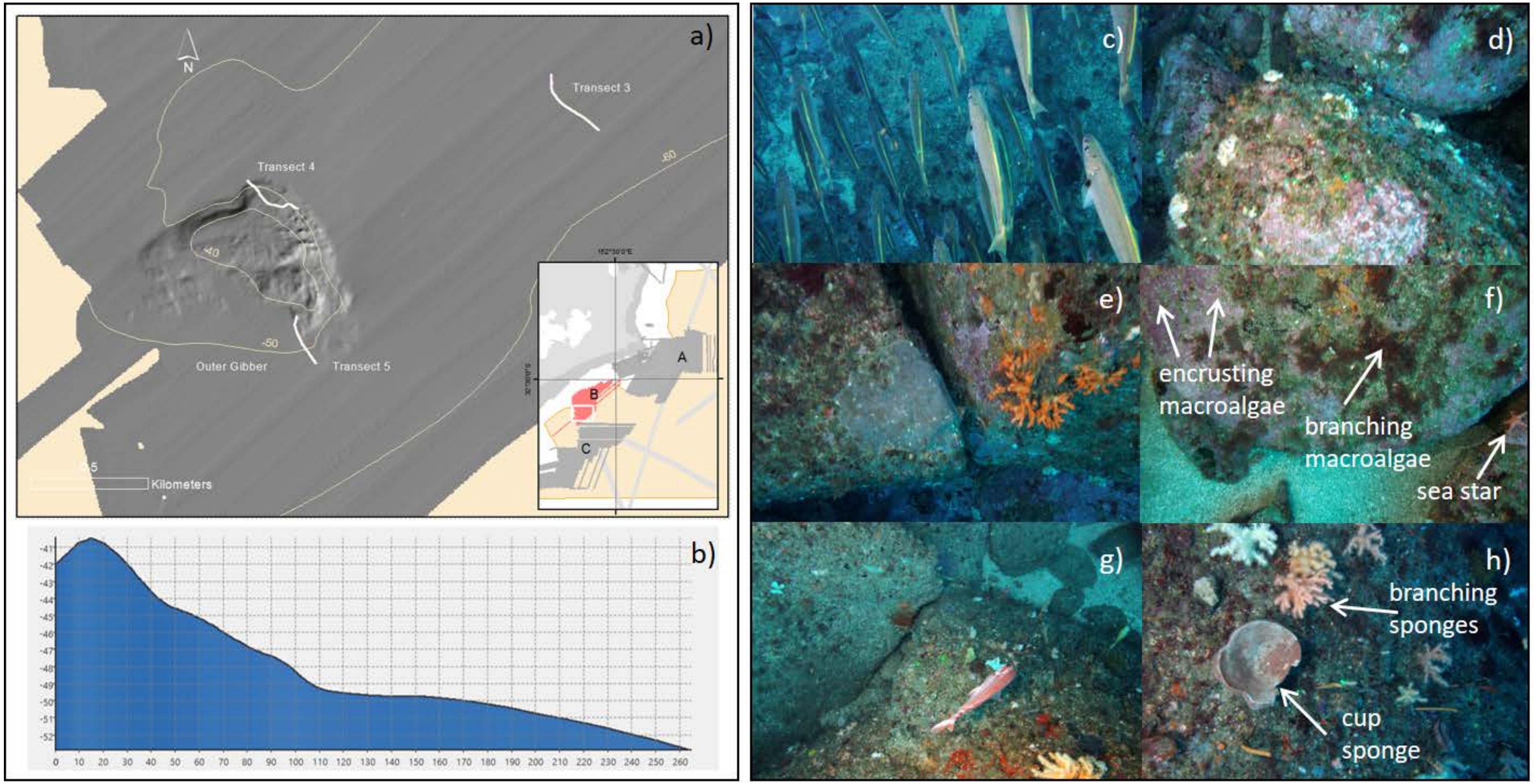


Figure 3-10. a) planar view of hill-shaded bathymetry with location of video transects (T4, T5) at Outer Gibber (Area B) October 2019; b) bathymetric cross-section through transect (T5) start-end points; digital still imagery from transects 4 and 5 showing c) yellow-tail scad (*Trachurus novaezelandiae*), and (d-h) reef habitat with encrusting and branching sponges and algae, ascidians, sea whips, , f) a biscuit sea star *Tosia* sp. and g) red morwong (*Cheilodactylus fuscus*). Laser points are 100 mm apart.

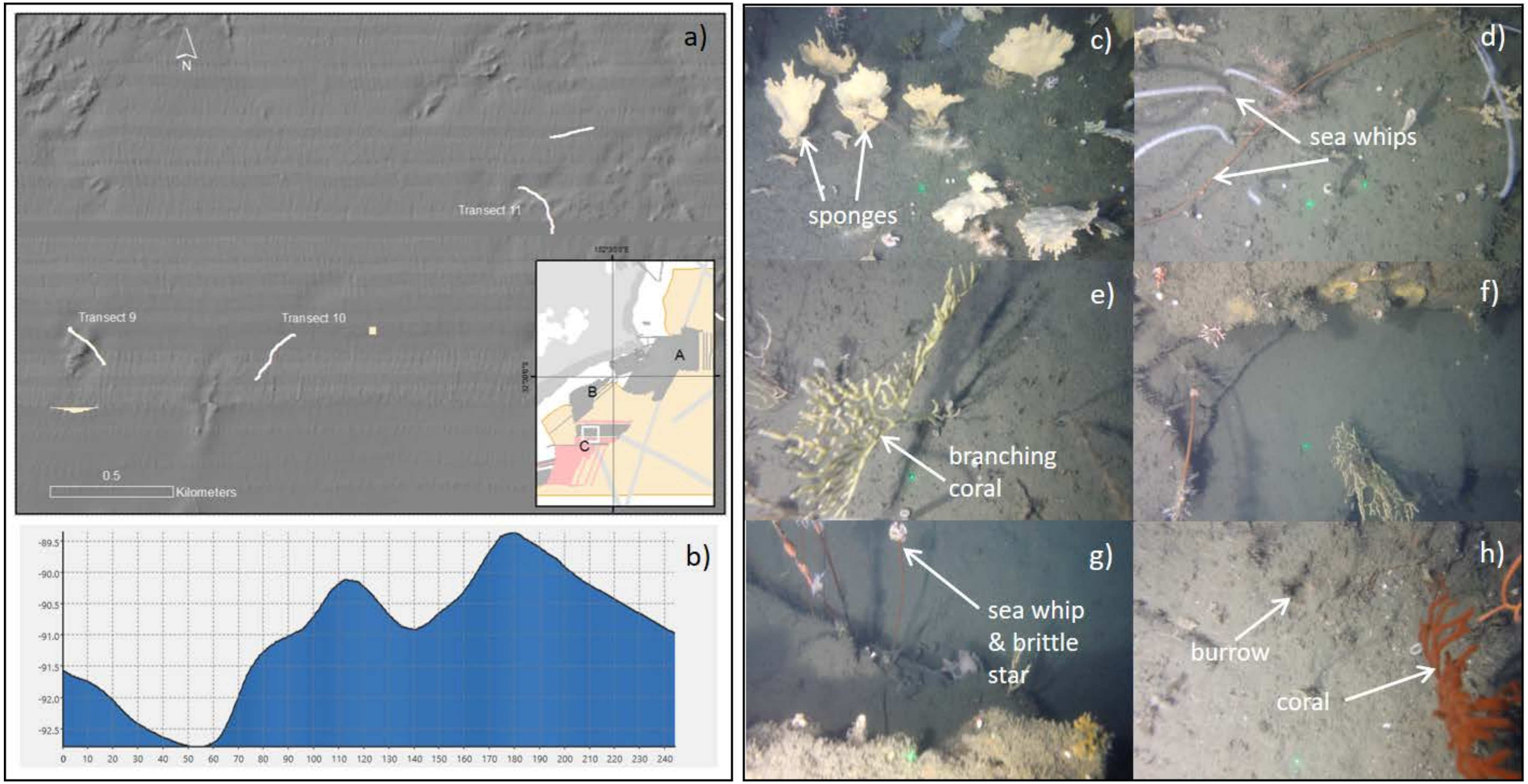


Figure 3-11. a) planar view of hill-shaded bathymetry with location of video transects (T9, T11) offshore of Broughton Island (Area C) October 2019; b) bathymetric cross-section through transect (T9) start-end points; Transect 9 (c-d) and 11 (e-h) showing (c) erect sponges, (d, f-g) sea whips, (d-f, h) corals, (f-g) reef edges with mixed sponge and coral and (e, h) branching cnidarian fan corals on reefs with sediment cover. Laser points are 100 mm apart.

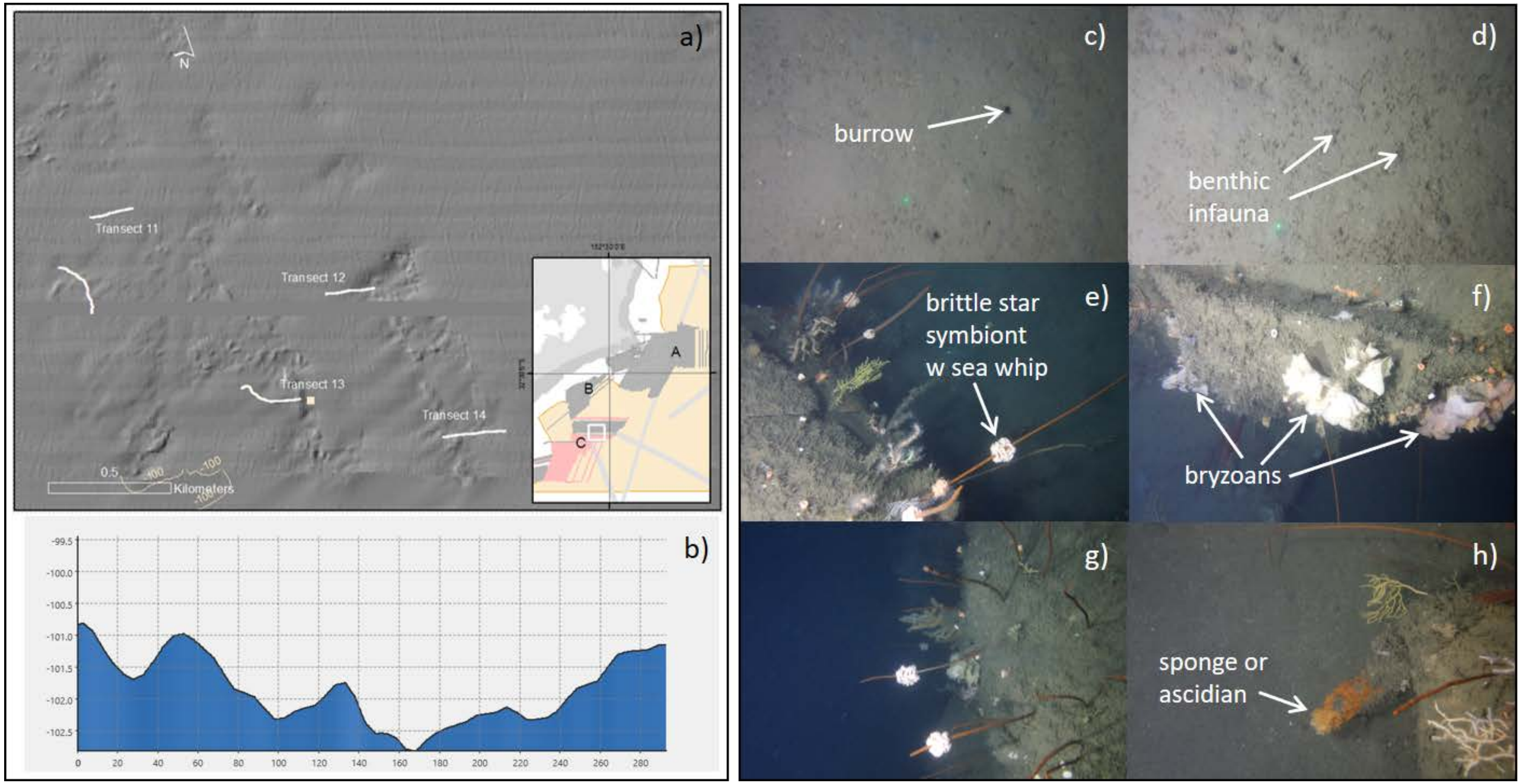


Figure 3-12. a) planar view of hill-shaded bathymetry with location of video transects (T12-15) offshore of Broughton Island (Area C) October 2019; b) bathymetric cross-section through transect (T14) start-end points; Transect 12 (c), 13 (d), 14 (e-f) and 15 (g-h) showing (c-d) burrows of infauna in soft sediments, (e-h) sea whips with symbiotic brittle stars, (i) white-purple coloured bryzoans and (h) sponge or ascidian (orange) with fan and branching corals. Laser points are 100 mm apart.

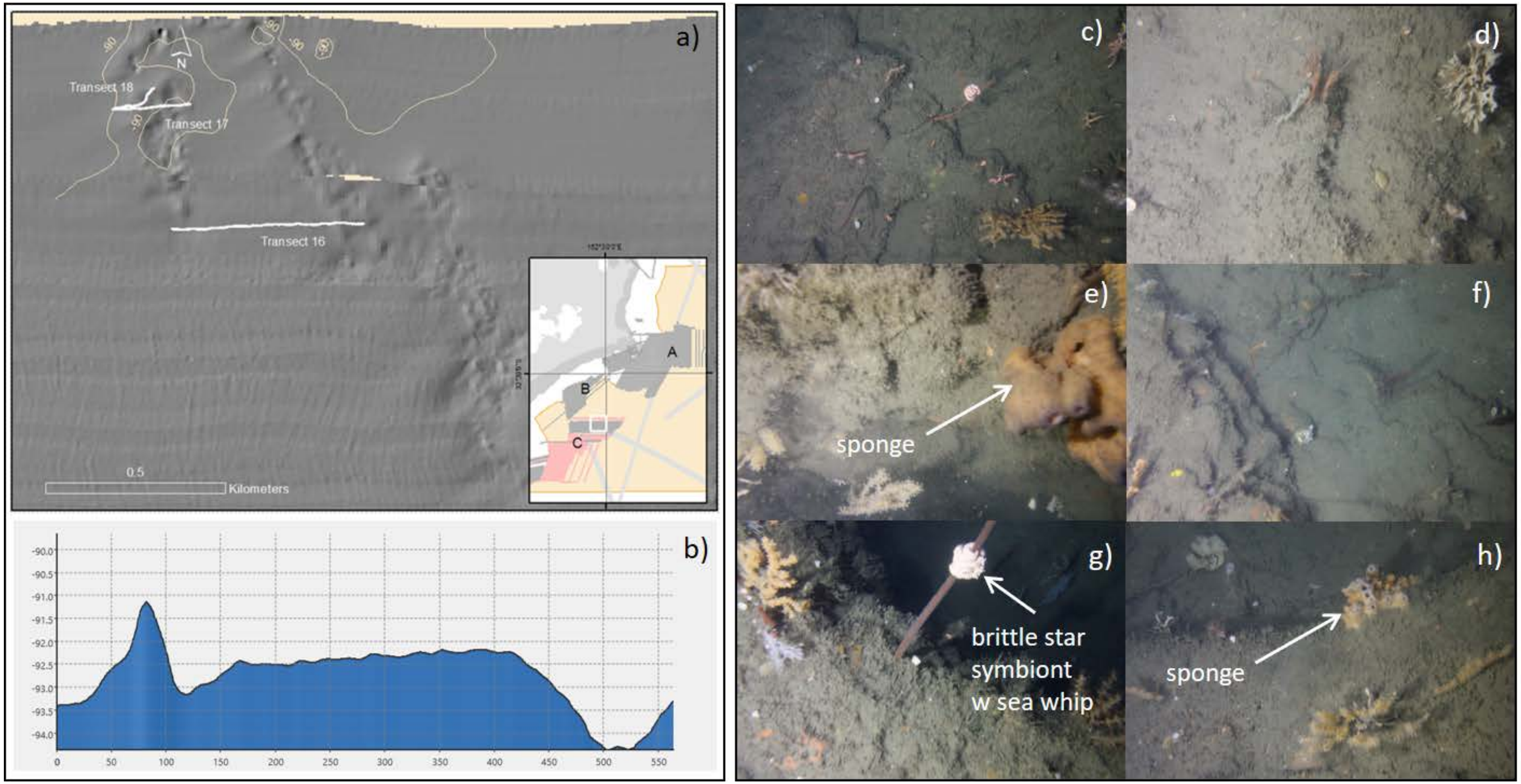


Figure 3-13. a) planar view of hill-shaded bathymetry with location of video transects (T16-18) offshore of Broughton Island (Area C) October 2019; b) bathymetric cross-section through transect (T16) start-end points; Transect 16 (c), 17 (d), 18 ((e-f) showing (c-h) erect sponges and corals, (c-h) sediment inundated reef with emergent sponges, (e, h) massive sponges, (g) sea whip with symbiotic brittle star (*Ophiruroidea*) and (h) sponges and bryzoans. Laser points are 100 mm apart.

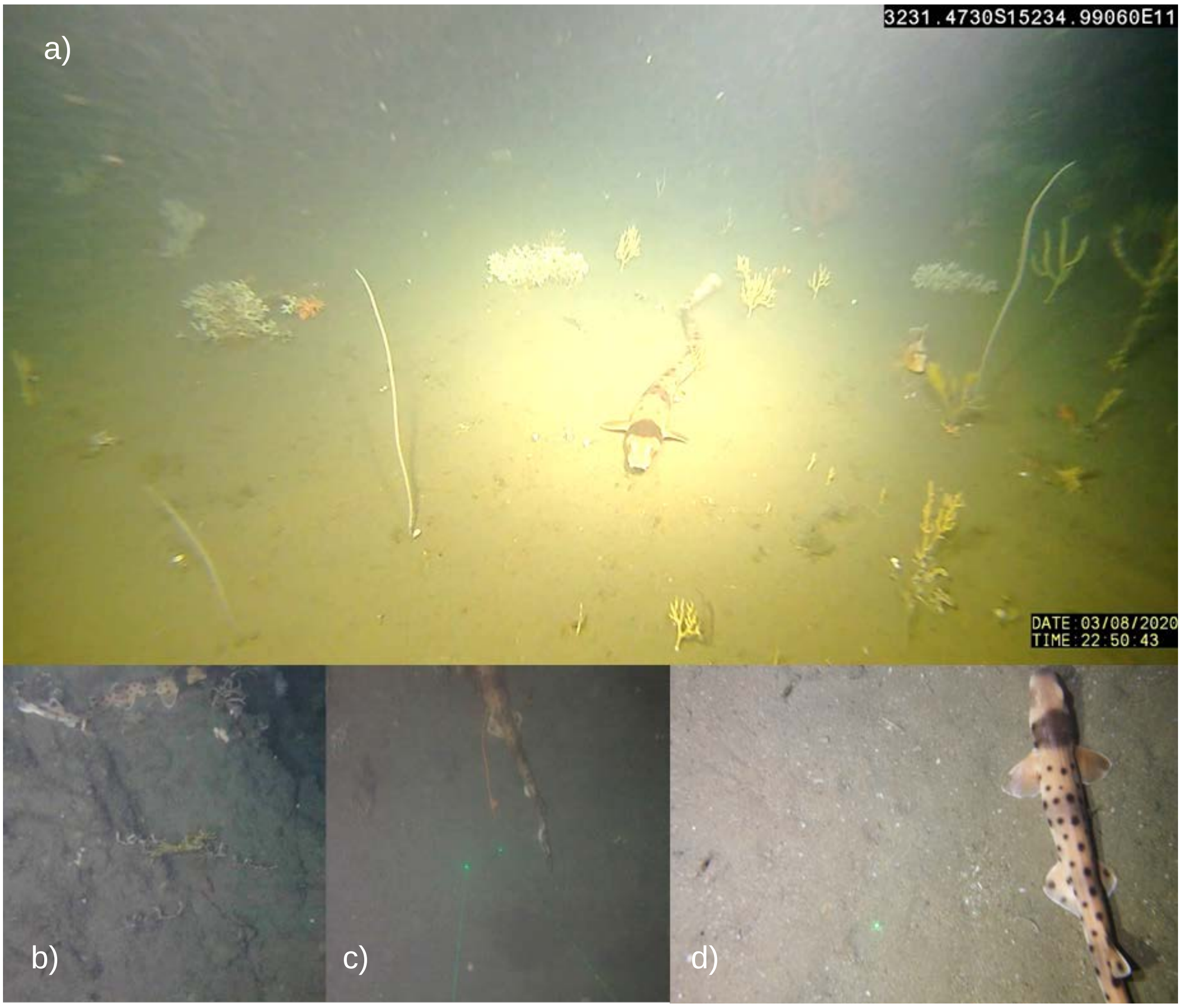


Figure 3-14. Forward looking video and downward looking still images of the collared cat shark *Parascyllium collare* from offshore of Broughton Island, Hunter Marine Park: a) video August 2020; November 2019 b) T9 and c) T18, and d) Seal Rocks August 2020. Note: laser points are 100 mm apart where visible.

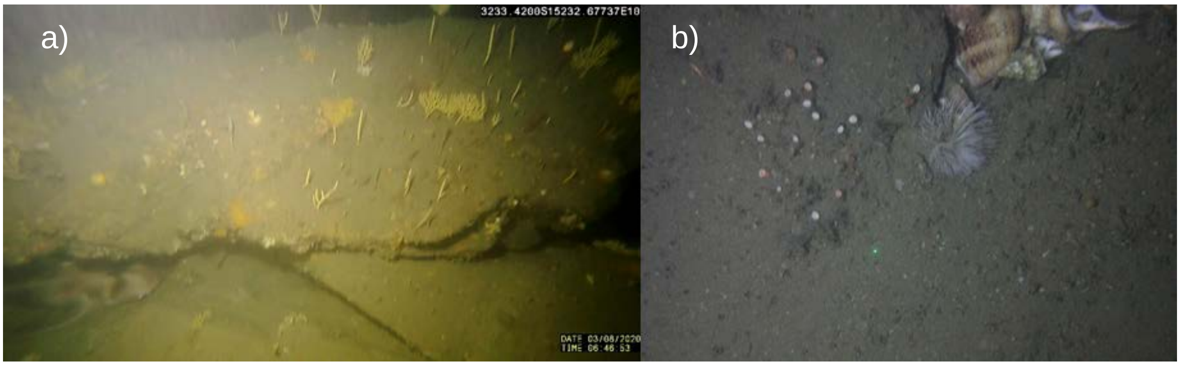


Figure 3-15. a) Port Jackson shark *Heterodontus portusjacksoni* offshore Broughton Island; b) fan worm and gastropod shells

Figure 3-16. a) Sea stars and pencil urchin (*Phyllacanthus* sp.); b) sea star (*Luidia* sp.) offshore Seal Rocks, depth 100-110 m; c) spotted wobbegong *Orectolobus maculatus* ~81cm over a mixed habitat of reef, sand and mixed macroalgae, depth 40 m, Outer Gibber, and d) spotted wobbegong *Orectolobus maculatus* ~70 cm over soft sediment in 100 m of water; e) humpback whales *Megaptera novaeangliae* and a f) fur seal *Arctocephalus* sp. captured in towed video footage offshore of Broughton Island, 3 August 2020, g-h) mooring gear.

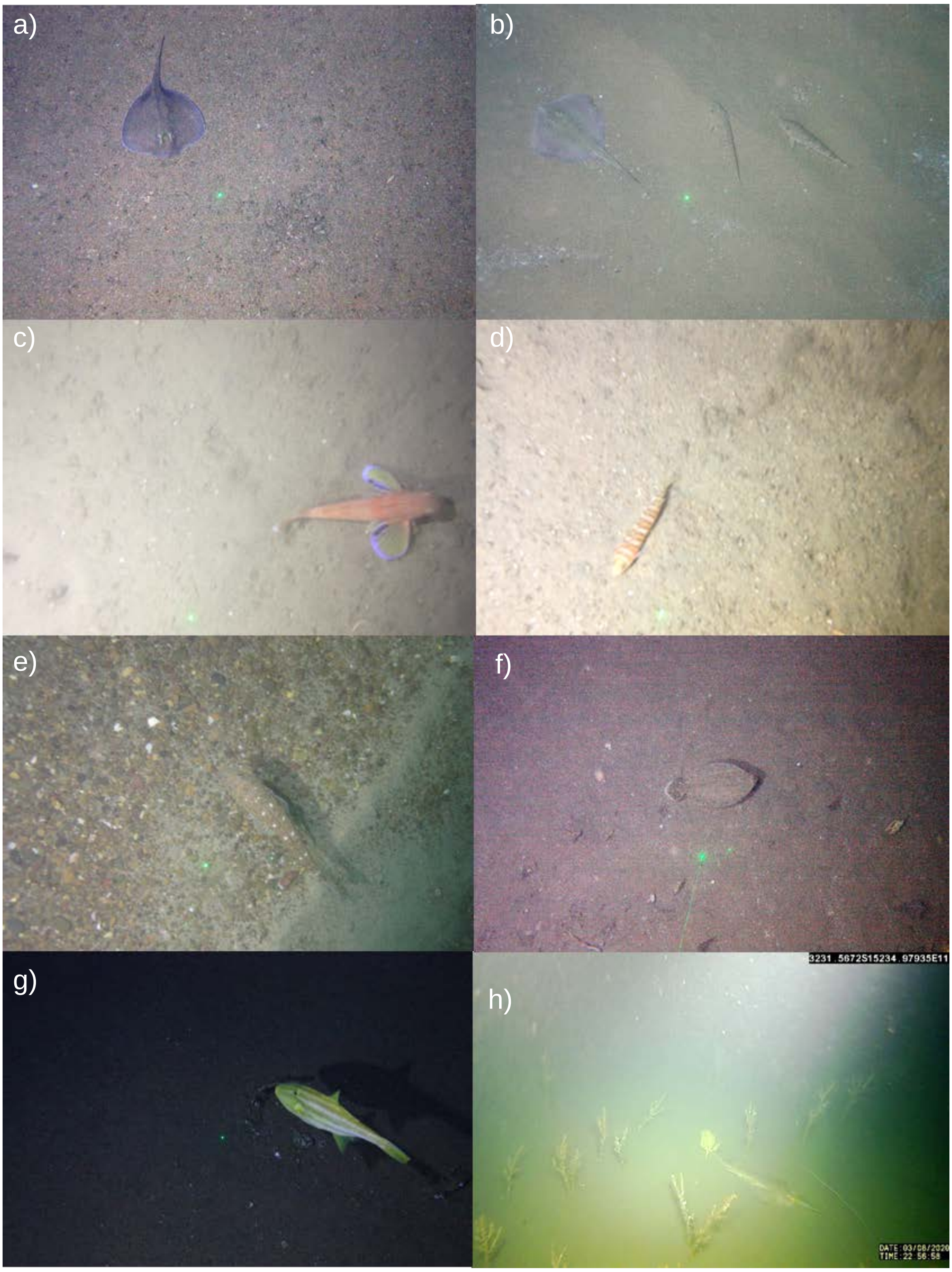


Figure 3-17. Downward looking stills from offshore of Seal Rocks:- a-b) stingaree, *Urolophus* sp. and blue-spotted flathead, *Platycephalus caeruleopunctatus* 100-110 m depth, Seal Rocks Aug-2020; c) red gurnard, *Chelidonichthys kumu*, d) grubfish, *Parapercis* sp., e) long-spine flathead *Platycephalus longispinis* over gravel/pebble seabed, f) flounder species, g) ocean leather jacket *Nelusetta ayraud* and h) towed video grab of shovelnose ray *Aptychotrema rostrata*.

Figure 3-18. The eastern rock lobster *Sagmariasus verreauxi* offshore of Seal Rocks.

4. FISH ASSEMBLAGES: STEREO-BAITED REMOTE UNDERWATER VIDEO (STEREO-BRUV)

4.1 Background

The Hunter Marine Park is positioned in a hydrographically dynamic area of the east coast of Australia, with the region dominant by the flow and downstream eddy field of the western boundary, EAC (Suthers et al. 2011). From October through to March, fast moving nutrient poor waters move down the coast often creating eddies and localised upwelling of cold nutrient rich water close to the coast. Figure 4-1 demonstrates the EAC moving down the coast and through the Hunter Marine Park. How this influences the rocky reef fish assemblages in depths >30 m across the continental shelf is relatively unknown as the majority of information and data for this region comes from near coastal reefs in <30 m of water.

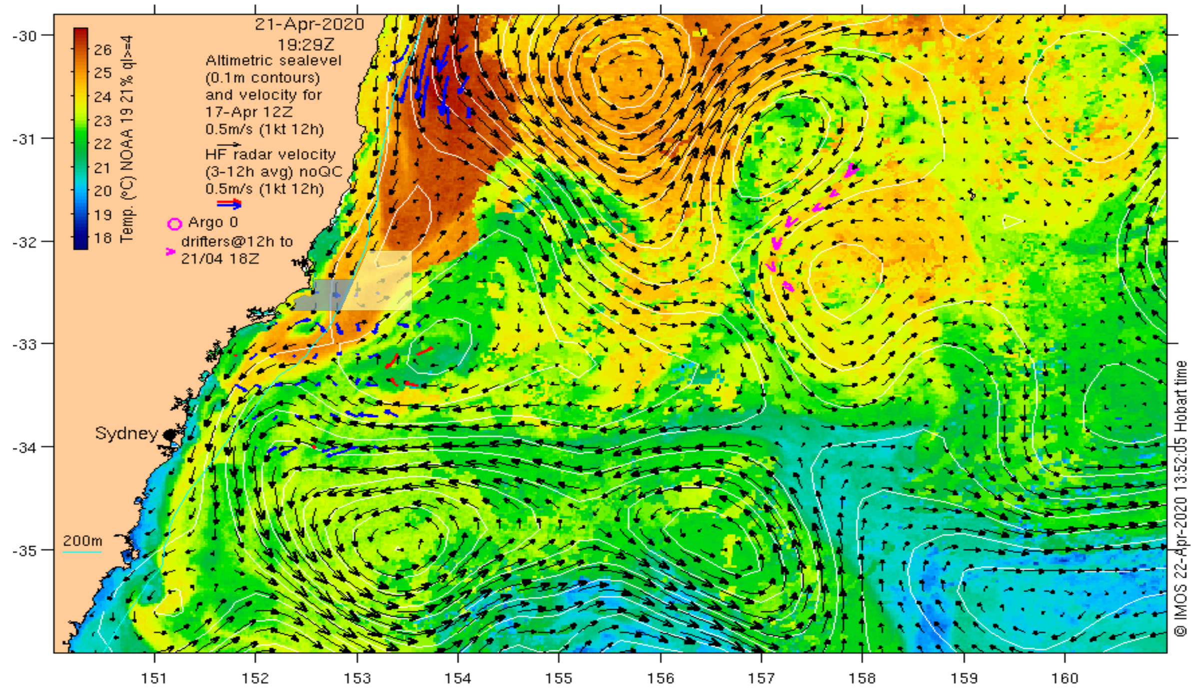


Figure 4-1. Sea surface temperature map from the IMOS data portal (source: http://oceancurrent.imos.org.au/sst.php). The map demonstrates the highly variable and dynamic nature of the oceanography of the Hunter Marine Park.

Very little is known about the fish assemblages of the Hunter Marine Park (Monk et al. 2017). Prior to this current study the only existing fisheries independent data on fish assemblages was from the Port Stephens – Great Lakes Marine Park monitoring program that uses the

Outer Gibber reef as an ‘outside’ reference site. This is despite rocky reefs being identified as a key ecological feature of the Hunter Marine Park (Director of National Parks 2018). The Special Trawl Zone of the Hunter Marine Park extends over a large area of the continental shelf in depths from 27 m to >200 m. Rocky reef that is located in the middle to upper shelf region (i.e. 32 – 150 m) is within the mesophotic zone. The mesophotic zone is referring to depths where medium to low light levels limited the amount of algal growth.

Research published during this study reported that the fish assemblage of the mesophotic reefs of the Hunter Marine Park were distinct from the state managed Port Stephens – Great Lakes Marine Park that covers reef in <40 m of water (Williams et al. 2019). However, the abundance of fishery targeted species was very similar across the depth range sampled. Interestingly, key fishery species weren’t necessarily more abundant but were larger in size in the Hunter Marine Park when compared to the Port Stephens - Great Lakes Marine Park (Williams et al. 2019).

Rocky reefs in the mesophotic zone also have social and economic value through recreational and commercial fisheries. The Special Purpose Zone (Trawl) of the Hunter Marine Park has important value to both ocean trawl, trap and line, and lobster fisheries (New South Wales Department of Primary Industries 2017a, 2017b, Liggins et al. 2018). In regards to recreational fishing, Lynch et al. (2019) investigated the use of state-wide recreational fishing survey data to establish effort and catch in Commonwealth waters with a focus on the Hunter Marine Park. Under the current survey design there is not the spatial resolution in the data to assess the level of recreational fishing in the Hunter Marine Park (Lynch et al. 2020a). However, a following study investigated the charter boat industry that reports effort and catch through a logbook program and at a scale that is possible to assess effort of charter boat recreation fishing with in the Hunter Marine Park (Lynch et al. 2020b). The data in this report suggest that there is notable effort of charter based recreational fishing that is heavily demersal fishing based (Figure 4-2). However, this is noted to occur at the state-waters boundary and it is still unclear how this effort is distributed within the grid cell that the data are aggregated (Figure 4-2).

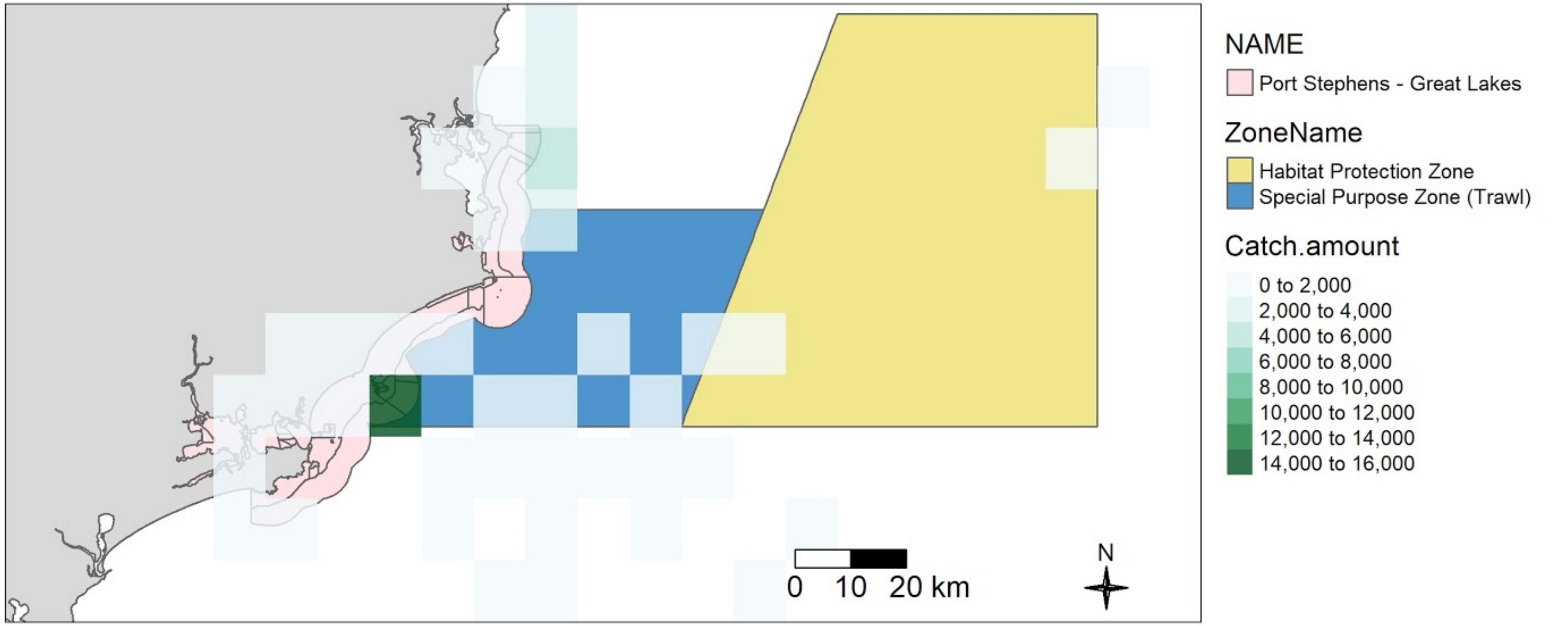


Figure 4-2. Number of fish retained from fishing charter operators. Source: Lynch et al. (2020b).

This component of the study aimed to used baited remote underwater stereo-video (stereo-BRUVS (Langlois et al. 2018) to sample the habitat and fish assemblages of the Hunter Marine Park. Using the bathymetry data that has been collected from this study (Chapter 2), sampling was focused on areas of rocky reef. Furthermore, statistics derived from the bathymetry data was used to explain the spatial distribution of the fish assemblage. This study also samples multiple locations and seasons to gain a better understanding of the temporal and spatial patterns of fish assemblages across the mapped inner shelf region of the Special Purpose Zone (Trawl) of the Hunter Marine Park. These data can provide a baseline for future monitoring and management of the Hunter Marine Park.

4.2 Methods

4.2.1 Sampling Locations

Surveys of fish assemblages within the Hunter Marine Park were restricted to areas of rocky reef that had been identified from MBES mapping in 2015 (See Chapter 2; (Davies et al. 2016); Figure 4-3). The area of mapped reef was limited in area, however, and additional sites at comparable depths were also selected from mapped reefs within the Port Stephens - Great Lakes Marine Park. These sites were <2 km from the boundary of the Hunter Marine Park and are likely to be part of a continuous reef system that extends into the Hunter Marine Park. Also, these additional sites within the Port Stephens - Great Lakes Marine Park are no-take zones where all extractive activities are not permitted. Locations for stereo-BRUVS deployments were spatially balanced across each mapped area that was identified as being rocky reefs and ensuring a minimum of 250 m separation between deployments.

4.2.2 Sampling Fish Assemblage: Baited Remote Underwater Stereo Video (Stereo-BRUV)

Stereo-baited remote underwater video (stereo-BRUV) was used to sample the fish assemblage on rocky reefs in 30-110 m (Figure 4-4). The methodology used in this study followed the NESP Field Manuals benthic stereo-BRUV chapter (Langlois et al. 2018). A stereo-BRUVs deployment consists of one stereo-BRUV unit (Figure 4-4). Four stereo-BRUV units would be deployed at a time. A deployment was considered successful if the stereo-BRUV landed on or immediately adjacent to rocky reef structure, and when both the reef/benthos and water column could be viewed clearly.

Each stereo-BRUV unit consisted of two Canon HG21 video cameras each with a wide angle lens housed in two custom made SeaGIS Pty Ltd housings (http://www.seagis.com.au; Figure 4-4). The camera housings are attached to a large steel frame (Figure 4-4). Approximately one kilogram of pilchard (Sardinops sp.) was crushed in a plastic mesh bait bag and attached to the stereo-BRUV frame using 1.5 m long PVC pole. Due to the low light levels at depths >70 m a Raytech subsea light was mounted to the centre of each stereo-BRUV frame (Figure 4-4). Blue light was used as the 450-465 nm wavelength is thought to be below the spectral sensitivity range of many fish species and therefore likely to have minimal effect on the fish assemblage and its associated behaviour (Fitzpatrick et al. 2013). On occasion (n = 5), white light was used to confirm identification of fish species and to collect qualitative habitat type data. Each deployment was for a period of 60 minutes as recommended by the NESP Marine Biodiversity Hub field manuals (Langlois et al. 2018).

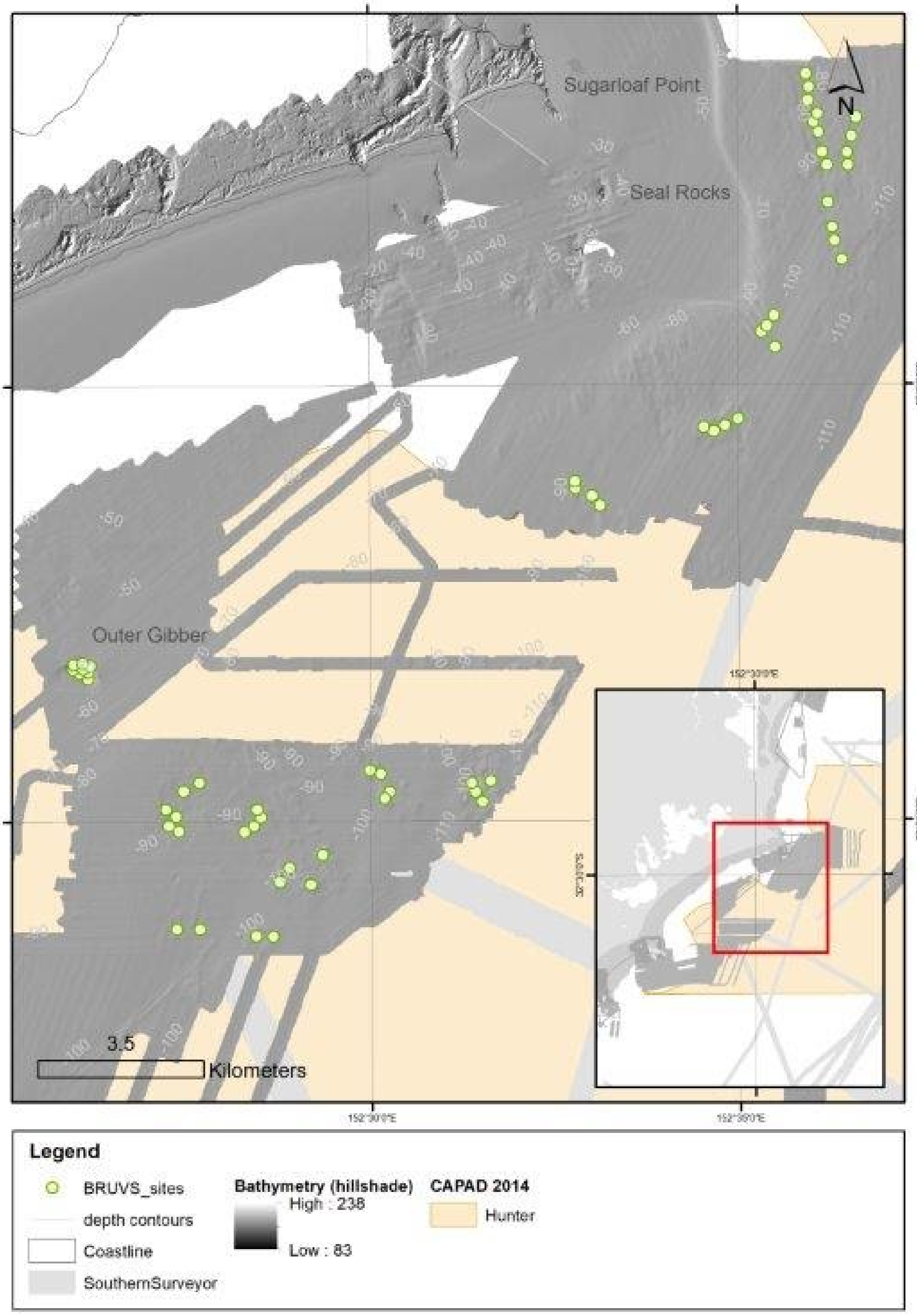


Figure 4-3. Location of all stereo-BRUV deployments in relation to the area that has been mapped and describe in Chapter 2. Note: This map shows MBES coverage for both 2015 and 2018 surveys, while, stereo-BRUV sites were limited to areas that were mapped in 2015.

Figure 4-4. An example of a baited remote underwater stereo-video unit, including blue light, used in this study.

Video collected by stereo-BRUVs was scored using standard metrics including scoring relative abundance (MaxN) as the maximum number of fish occurring in any one frame for each species (Figure 4-5). MaxN is now widely accepted as the best method for estimating relative abundance from video footage (Cappo et al. 2007). All fish were identified to the lowest taxonomic level possible, ideally species level. All fish that were visible and within range (within ~8 m of the camera) of both cameras were measured (Langlois et al. 2018). All stereo-BRUV video analysis and scoring was done using the software EventMeasure (www.seagis.com).

4.2.3 Data Analysis

Data from all BRUV deployments from this study were downloaded from GlobalArchive and data quality checks were completed using R scripts written by Tim Langlois (University of Western Australia), and adapted and edited by Brooke Gibbons (University of Western Australia) and Joel Williams (NSW Department of Fisheries). The R scripts combined data from multiple surveys, checked and updated spelling, numbers of fish above expected abundance and length, lengths outside the minimum and maximum lengths according to FishBase (Froese and Pauly 2019), and species outside their geographical range. Any species or numbers that were deemed questionable were reviewed by re-watching the videos and either corrected or deleted accordingly. Furthermore, data exploration, including histogram plots, were used to identify and check if outliers were real or errors. Descriptive statistics (minimum, maximum, mean, standard deviation) were used to explore general patterns in relative abundance, length and biomass of species richness and species of interest. This included investigating the distribution of species richness across the Hunter Marine Park. Species richness is the number of species recorded on a single stereo-BRUV deployment.

To assist in explaining the spatial distribution of fishes in the Hunter Marine Park, a suite of statistics and metrics were calculated from the bathymetry data collected in Chapter 2 and (Davies et al. 2016). The Benthic Terrain Modeller add-on in ArcGIS v10.3.1 were used to analyse the cleaned 5 m gridded bathymetric data. Common statistics and metrics were calculated and are listed in Table 4.1. Detailed descriptions and formulas for how these are calculated are in Walbridge (2018).

Redundancy analysis (RDA) was used to identify the factors that best explained the variation in the species assemblages (Borcard et al. 2018). The factors used in the RDA were location, season (autumn, winter), status (fished, no-take) and the suite of bathymetry statistics and metrics (Table 4.1). Exploratory data analysis to establish collinearity between factors, patterns in factors and outliers using the ggcor() and ggpair() function in the “GGally” package in R (v4.0). Any variable that had Pearson correlation coefficients >0.80 were excluded from further analysis. No other outliers or concerning patterns were observed. RDA is related to principal components analyses (PCA) and is based on Euclidean distance, implying that each species is an axis orthogonal to all other species, and sites are points in this multidimensional space (Borcard et al. 2018).

RDA is analogous to generalised additive models (GAM) that are used for further investigation of variability in species distributions. For the RDA, all species were Hellinger transformed before using a forward stepwise model selection. Permutation tests were used to test for the statistical significance of each marginal term. A tri-plot was used to visually determine and display the strength of the relationship between species assemblages and the explanatory variables that were driving the variation in species assemblage between stereo-BRUV deployments. RDA was done used the rda() function in “vegan” package with the tri-plots plotted using the ggplot() function as part of the “tidyverse” package of R (v4.0).

Generalised additive models (GAM) were to determine the effect of location, depth, season and bathymetry on the distribution of species richness and relative abundance and lengths of species of interest. GAMs are a powerful tool for modelling non-linear and categorical variables and to select the variables that best explain the variance in the dependant variable (in this case species abundance or length) and therefore make inferences on how a species is distributed through space and time (Hastie and Tibshirani 1986, Wood 2017). Given there are a large number of species of interest and explanatory variables, a full subsets GAM approach was used to fit all combinations of explanatory variables and to establish the best fitting model and to determine the importance of each of the variables used (Fisher et al. 2018). The 'gam() function from the "mgcv" package in R v4.0 (R Core Team 2020) was used for all models (Wood 2017).

Relative abundance was modelled using a Tweedie distribution and length was modelled using a Gaussian distribution. Prior to modelling, the explanatory variables were explored for collinearity using Pearson's correlations and plotted using the ggcor() and ggpairs() function in the "ggally" package in R (R Core Team 2020). If there were two variables with a correlation >0.8 then these two variables were not be used in the same model (Fisher et al. 2018). Many of the statistics and metrics calculated from the bathymetry data were highly correlated and several variables were excluded from any analysis (Table 4.1). Given the complexity of the model and to further avoid overfitting, models were limited to four predictor variables (Fisher et al. 2018). The combination of season and year were fitted as random effects to account for temporal correlation within the dataset. The best fitting model for each species was determined as the model with the lowest AICc or within two points of the lowest AICc.

To demonstrate the importance of each variable across the full subset of models, heatmaps were plotted for each species and for all explanatory variables. Model predictions were made using the "mgcv" package in R v4.0 (R Core Team 2020) and plotted against the raw data.

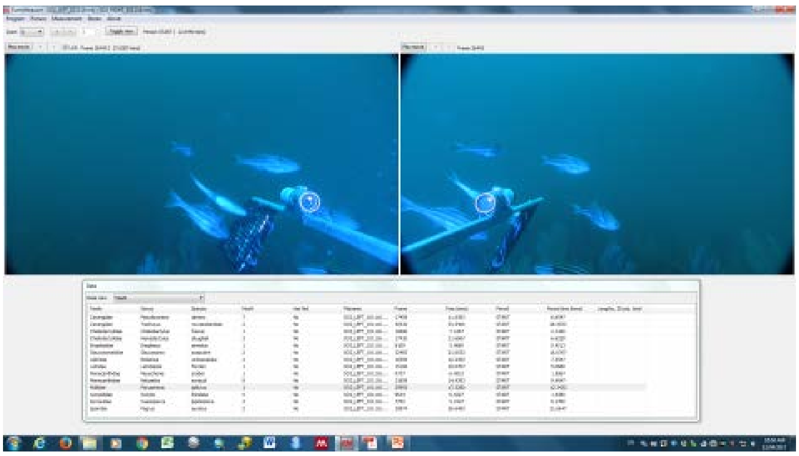


Figure 4-5. A screen grab of EventMeasure, the program used to count and record abundance and length measurements from stereo-BRUV deployments.

Table 4.1. A list of reef physical metrics that were calculated from the multibeam data gridded at 5x5 m grid cells. Each of these factors and calculations were considered during model development to best explain the spatial distribution of the fish assemblage in the Hunter Marine Park. Refer to Walbridge et al. (2018) for a more detailed description and formulas.

Variable	Range	Description
Slope	0.3 - 28.5	Slope or rate of change in the 3x3 (15 m^2) neighbouring cells of the stereo-BRUV location.
Aspect	5-356	The direction of the 3x3 (15 m^2) neighbouring cells of the stereo-BRUV location. This is a cyclic variable that is measured clockwise from the North.
Eastness	-0.99 - 0.99	The direction of the 3x3 (15 m^2) neighbouring cells in relation to east.
Northness	-0.99 - 0.99	The direction of the 3x3 (15 m^2) neighbouring cells in relation to north.
Curvature	-2.5 - 3.2	The slope of the slope within 3x3 (15m^2) neighbouring cells.
Surface to planar ratio	-2.3 - 2.1	A measure of rugosity or terrain complexity.
Bathymetric position index (BPI)		Quantifies the location of stereo-BRUV in relation to the neighbouring seascape.
• broad	-1 - 5	
• fine	-1 - 2	
Bathymetry		The mean, standard deviation and variance of depths across the 3x3,5x5,9x9 and 21x21 grid cells surrounding the stereo-BRUV.
• mean		
o 15 m^2*	-109 - -32	
o 25 m^2	-109 - -32	
o 45 m^2*	-109 - -32	
o 105 m^2	-109 - -32	
• standard deviation		
o 15 m^2*	0.02 - 1.43	
o 25 m^2	0.04 - 2.13	
o 45 m^2*	0.09 - 3.07	
o 105 m^2	0.33 - 4.47	
• variance		
o 15 m^2*	0.00 - 2.04	
o 25 m^2	0.00 - 4.57	
o 45 m^2*	0.01 - 9.48	
o 105 m^2	0.11 - 20.0	

Ruggedness		Vector ruggedness measure. Measures terrain ruggedness as the variation in three-dimensional orientation of grid cells within a 3x3, 5x5, 9x9, 21x21 cell grid.
o 15 m^2*	0.0 - 0.01	
o 25 m^2	0.0 - 0.02	
o 45 m^2*	0.0 - 0.03	
o 105 m^2	0.0 - 0.3	
Interquartile range (IQR)		A distribution statistic calculated as the difference between the 75th and 25th percentiles in bathymetry.
o 15 m^2*	0.03 - 2.33	
o 25 m^2*	0.04 - 3.66	
o 45 m^2*	0.13 - 5.07	
o 105 m^2*	0.26 - 7.67	
Kurtosis		A distribution statistic that measures the weight of the tails of the distribution relative to the overall distribution.
o 15 m^2*	-1.52 - 1.09	
o 25 m^2	-1.46 - 1.66	
o 45 m^2*	-1.50 - 2.06	
o 105 m^2	-1.47 - 2.36	
Status	Fished or No-Take	Some sites within NSW state waters were in no-take sanctuary zones. Therefore, status was included as factor that could explain fish relative abundance.
Season	Autumn or Spring	Season was included to test for temporal variability.

*These variables had multiple Pearson correlation coefficients >0.80 when tested with other variables data exploration analysis and were therefore excluded from any further analysis. This is to avoid overfitting RDA and GAM models.

Power analyses were used to estimate the level of sampling needed to capture changes in key fish species as candidate indicators. The power analyses were conducted with simplistic assumptions to gain a coarse estimate of feasibility. It is assumed that the mean abundance of fishery targeted species could increase under the removal of fishing pressure. Therefore, the approximate number of stereo-BRUV deployments were determined to establish the required sampling to detect a 50, 100 and 200 percent increase in mean abundance between two sampling events within the Hunter Marine Park for scenarios where; (1) the same sites are revisited (i.e. a paired t-test), and (2) new sites are sampled (i.e. an un-paired t-test). The significance level for detecting a difference between the sampling events was set at 0.05, and the power to detect an effect set at 0.8. The effect sizes corresponding to a 50, 100 and 200 % increase in mean abundance were calculated using Cohens-D formula (which is essentially the standardised mean difference between mean abundance at the two sampling times (Cohen, 1988)) for each fish species and an appropriate multiplier for sampling event 2 (i.e. 1.5 for 50 % increase and so on). The mean abundance was taken across all four sampling events and the same variance was used for both sampling events as for most species there was little difference between sampling events. Since the focus is on detecting an increase in mean abundance, tests were one-tailed. Separate power calculations were run for each fish species and for each location (i.e. Broughton offshore, Outer gibber and Seal rocks offshore). Power analyses were carried out using the R statistical package “pwr” (Champely et al. 2020).

4.3 Results and Discussion

4.3.1 Number of Stereo-BRUV Deployments

The fish assemblages of the Hunter Marine Park were sampled over four surveys (Spring 2016, Autumn 2017, Spring 2017 and Autumn 2018; Table 4.2). The benefit of multiple surveys is that both the cold-water period in spring and the warm water period in autumn were sampled, therefore allowing for temporal seasonal comparisons to be made.

A total of 182 successful stereo-BRUV deployments occurred over the period (Table 4.2, Figure 4-6 and Figure 4-7). The majority of Seal Rocks Offshore samples are within NSW state waters and within a no-take (Sanctuary) zone (Figure 4-6). However, they are within depths of 65-105 m, similar to other sites within the Hunter Marine Park. This is due to lack of mapped reef in the Hunter Marine Park at the time of designing this study. However, this allowed us to compare an area that has been a no-take zone for over 10 years to an area at a similar depth within the Hunter Marine Park and that are open to fishing activities.

Sampling was completed over three distinct locations, Broughton Island Offshore, Seal Rocks Offshore and Outer Gibber (Figure 4-6). The lower number of BRUV deployments in 2017 Spring at Seal Rocks Offshore was due to the early onset of the EAC that meant the current was too strong to safely deploy a stereo-BRUV. Stereo-BRUV deployments occurred in depths from 32 to 106 m in depth (

Table 4.3).

Table 4.2. The number of successful stereo-BRUV deployment that were completed during this study.

Year	Season	Broughton Isd. Offshore	Outer Gibber	Seal Rock Offshore
2016	Spring	14	8	22
2017	Autumn	23	0*	24
	Spring	23	7	8**
2018	Autumn	24	8	20

* Due to technical difficulties it was not possible to sample.

** The low number of samples is due to the East Australia Current moving south earlier than expected, and the currents were too strong to safely deploy equipment.

Table 4.3. The minimum, mean and maximum depth of stereo-BRUV deployments at each of the location's samples

Location	Min.	Mean	Max.
Broughton Is. Offshore	80 m	93 m	106 m
Outer Gibber	37 m	42 m	48 m

Seal Rock Offshore	65 m	91m	107 m

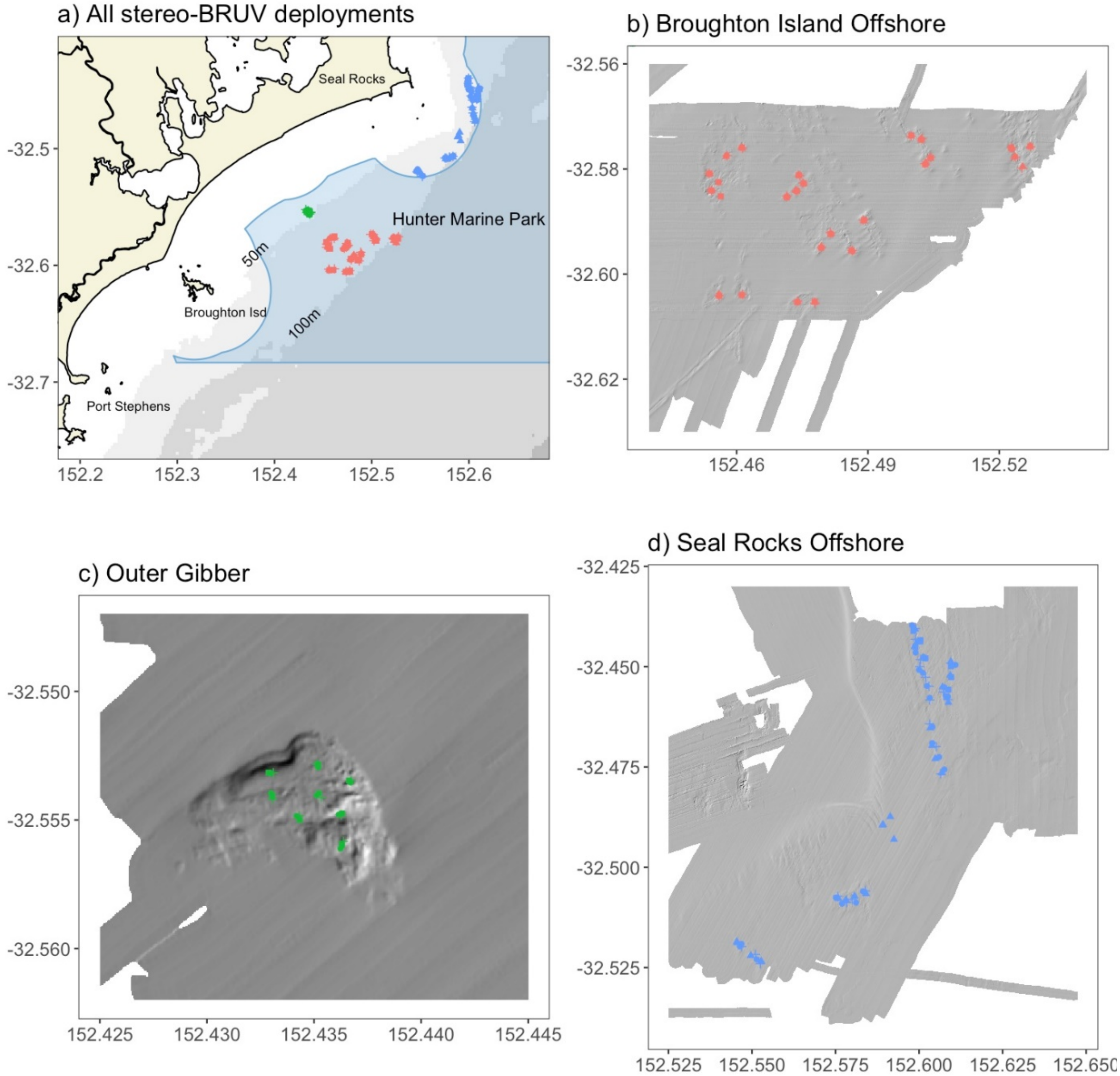


Figure 4-6. a) Map of the locations of all stereo-BRUV deployment from 2016 to 2018 (● 2016-spring, ▲ 2017-autumn, ▪ 2017-spring, ┼ 2018-autumn). The stereo-BRUVs were deploy across three distinct locations: ● Broughton Island Offshore, ● Outer Gibber, ● Seal Rocks Offshore. Location of stereo-BRUV deployments in relation to reef mapped by multibeam sonar at b) Broughton Island offshore, c) Outer Gibber and d) Seal Rocks offshore.

Figure 4-7. A montage of the fish assemblages recorded using stereo-BRUV on reef habitats in 80-100 m of water in the Hunter Marine Park. a) An example of mado (*Atypichthys strigatus*) and ocean leatherjacket (*Nelusetta ayraudi*). b) An example of Port Jackson shark (*Heterodontus portusjacksoni*) and silver sweep (*Scorpis lineolata*). c) An example of a school of nannygai (*Centroberyx affinis*) and an eastern wirrah (*Acanthistius ocellatus*). d) A conger eel (*Conger verreauxi*) and a school of nannygai (*Centroberyx affinis*). e) An example of a school of pearl perch (*Glaucosoma scapulare*), mado (*Atypichthys strigatus*), and Port Jackson shark (*Heterodontus portusjacksoni*). f) An example of a teraglin (*Atractoscion aequidens*).

4.3.2 Habitat

Sampling the fish assemblages using stereo-BRUV also provides imagery of reef structure and associated habitat. While this component of the study never aimed at providing a quantitative assessment of the habitat (i.e. identify and count/estimate cover of sessile invertebrate), it does give an insight into reef structure and the complexity of the sessile invertebrate assemblage. Below is a pictorial description of the habitats encountered at each of the locations, Broughton Island Offshore, Outer Gibber and Seal Rocks Offshore (Figures 4.9-4.21).

Macroalgae (algae large enough to see with the naked eye) was observed at Outer Gibber to a maximum depth of 40 m (Figure 4-14, Figure 4-15, Figure 4-16). This is not to say macroalgae doesn't occur at deeper depths. Macroalgae, such as the kelp *Ecklonia* and red algae, have been reported at depths of 70 m at some locations in NSW (pers comms. authors). All sampling for this project occurred within the mesophotic zone where purple, blue and green light can still penetrate. Therefore it is highly possible microalgae, turfing algae and red algae would occur at all sites sampled during this project. However, without collecting samples of habitat is difficult to distinguish. Without the use of light meters, it is difficult to estimate the amount of light reaching the depths sampled during this project. On occasions the lights on the stereo-BRUVs would turn off towards the end of the deployments. However, it was still possible to see reef, fish and habitat even at depth between 70-100 m.

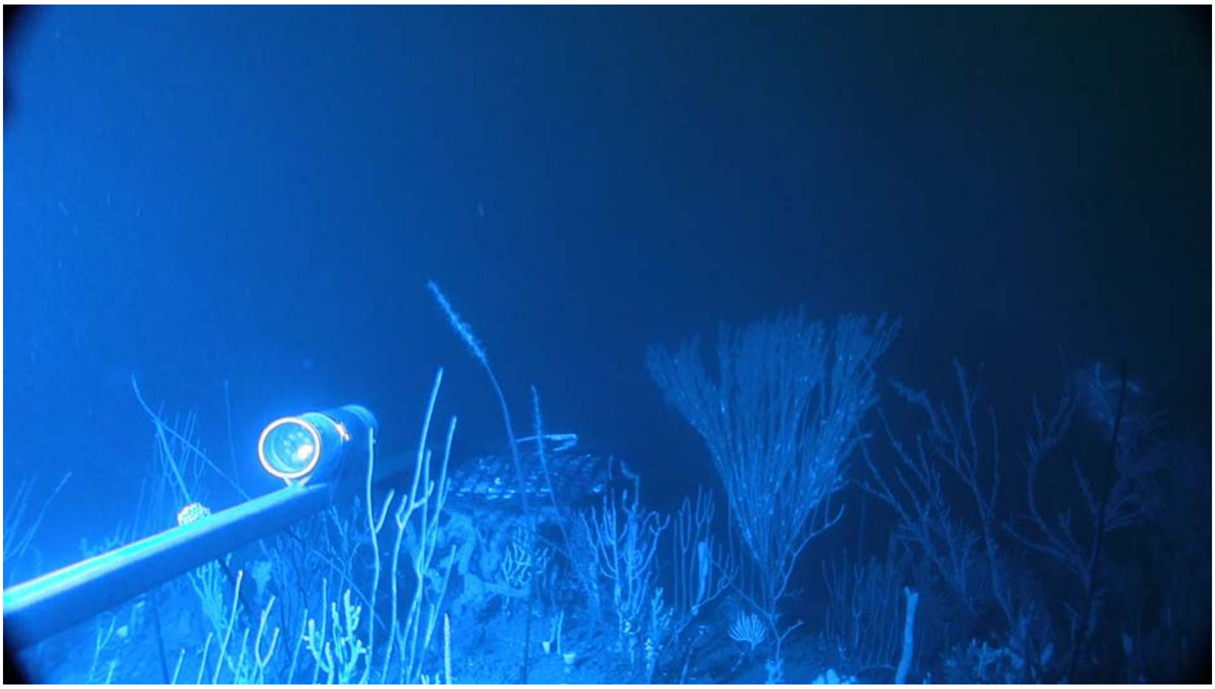


Figure 4-8. Broughton Island Offshore sessile invertebrate assemblage on moderate relief reef in 95 m of water.

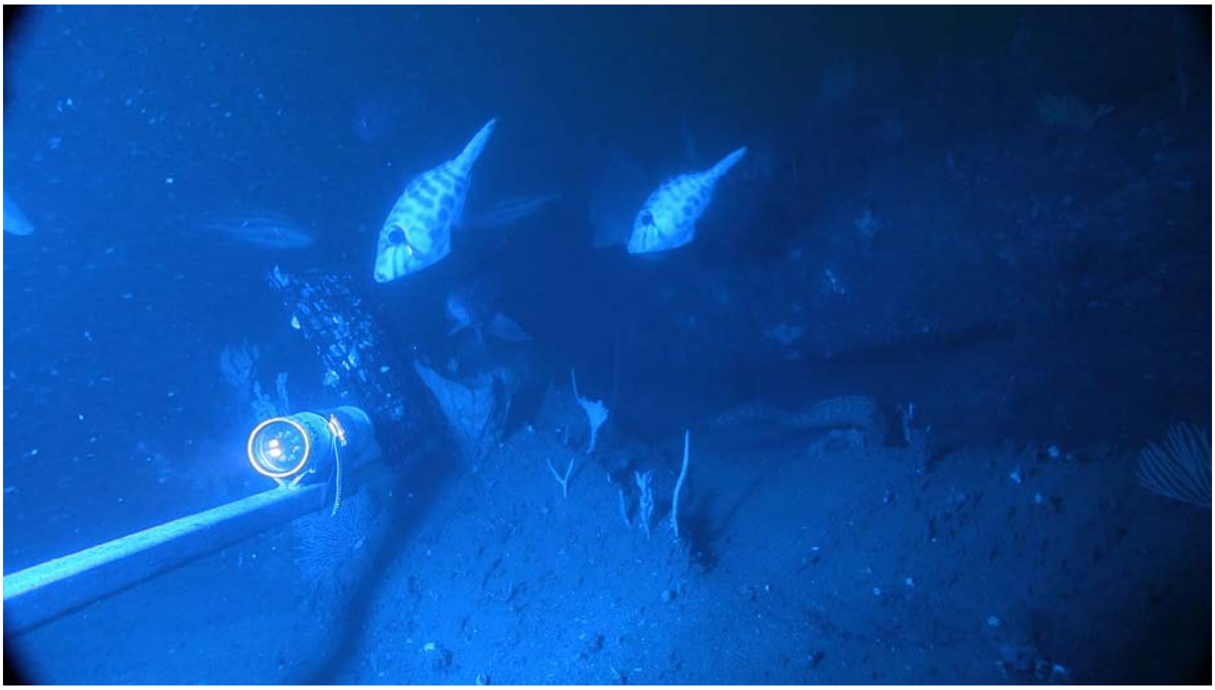


Figure 4-9. Broughton Island Offshore, sediment covered reef edge in 100 m of water. Note the reef ledge in the background.

Figure 4-10. Broughton Island Offshore, sessile invertebrate assemblages on top of a reef structure with a common sawshark swimming over the top.

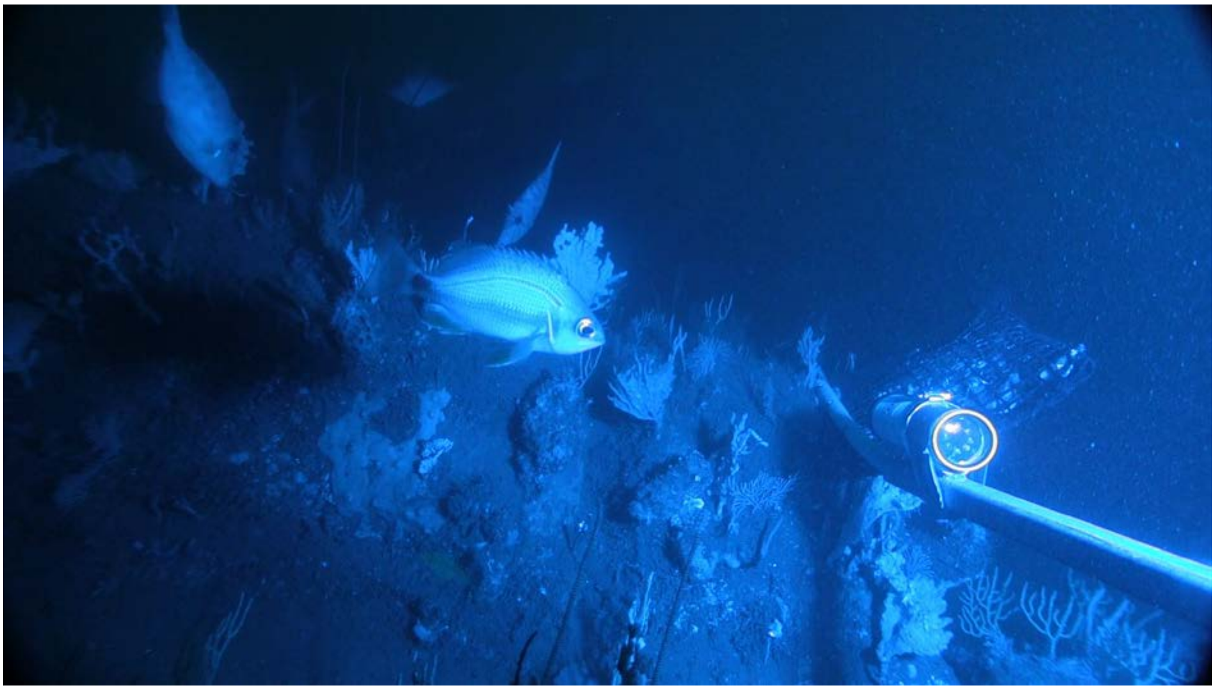


Figure 4-11. Broughton Island Offshore, example of small interspersed sessile invertebrate assemblage in 92 m of water.

Figure 4-12. Broughton Island Offshore, example of sessile invertebrate assemblage on the side of a reef in 93 m of water.

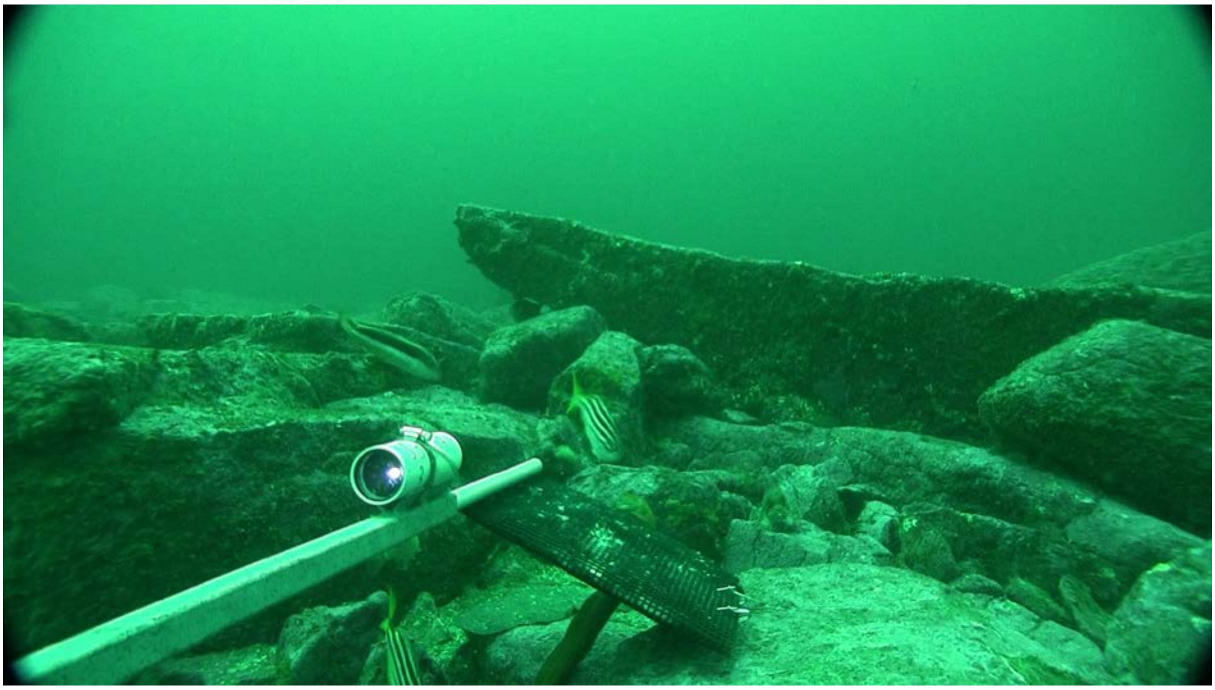


Figure 4-13. Outer Gibber, a common site is bare granite boulders in 37 m of water.

Figure 4-14. Outer Gibber, short turfing and foliose algae with interspersed sea tulip ascidians in 35 m of water.

Figure 4-15. Outer Gibber, small clumps of algae on the reef edge in 37 m of water.

Figure 4-16. Outer Gibber, example of reef edge in 35 m of water.

Figure 4-17. Seal Rocks Offshore, example of high relief reef top with complex sessile invertebrate assemblage in 84 m of water.

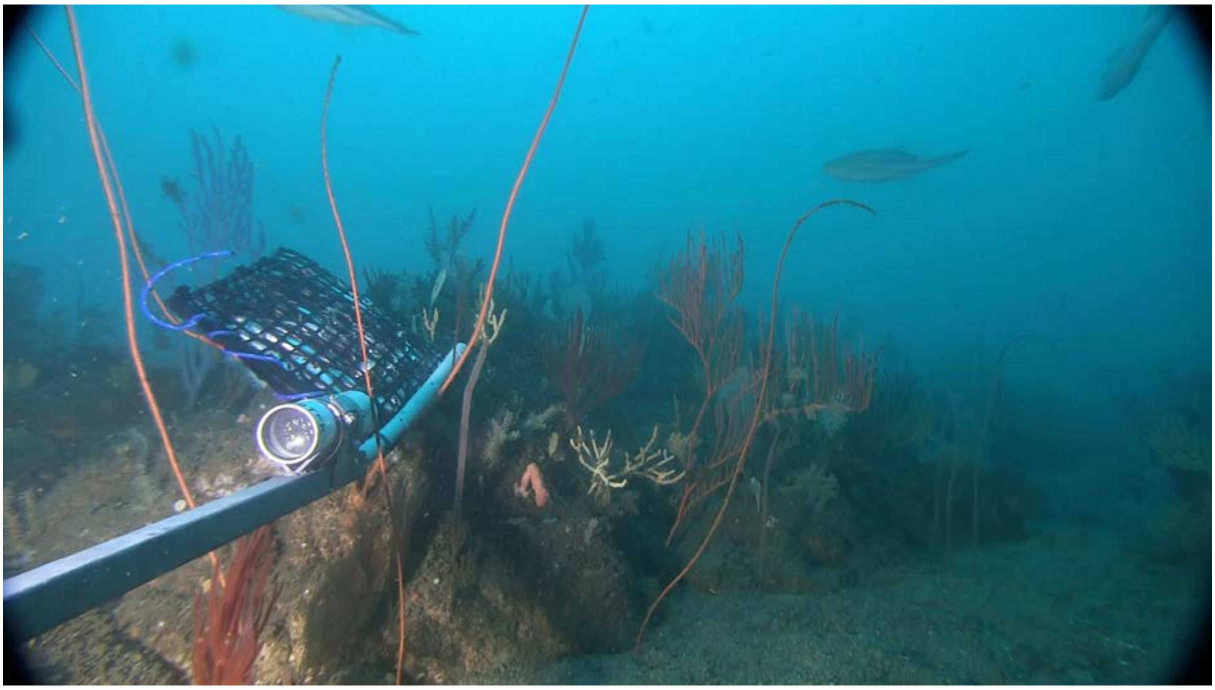


Figure 4-18. Seal Rocks Offshore, example of low relief reef with sea whip octocorals and other complex sessile invertebrate assemblages in 80 m of water.

Figure 4-19. Seal Rocks Offshore, example of the diverse sessile invertebrate assemblage in 92 m of water. Note the basket star on the sea whip.

Figure 4-20. Seal Rocks Offshore, example of low relief reef sessile invertebrate assemblages in 95 m of water.

4.3.3 Summary of Fish Assemblages

A total of 113 species and family groups, represented by 58 families, were recorded from stereo-BRUV deployments during this study (Figure 4-7). The 15 most commonly recorded species are listed in (Table 4.4). As expected, the 3 most abundant and ubiquitous species are semi-benthic or pelagic schooling species such as yellowtail scad *Trachurus novaezelandiae*, Australian mado *Atypichthys strigatus* and redfish *Centroberyx affinis* (Table 4.4 and Figure 4-1). Each of these three species were regularly observed in schools larger than 10 individuals. Species of fisheries significance were also observed across the Hunter Marine Park. Several species that are highly targeted by both recreational and commercial fishers were also recorded in higher abundances, particularly pink snapper *Chrysophrys auratus* and blue morwong (often referred to as grey morwong) *Nemadactylus douglasii* (Figure 4-21).

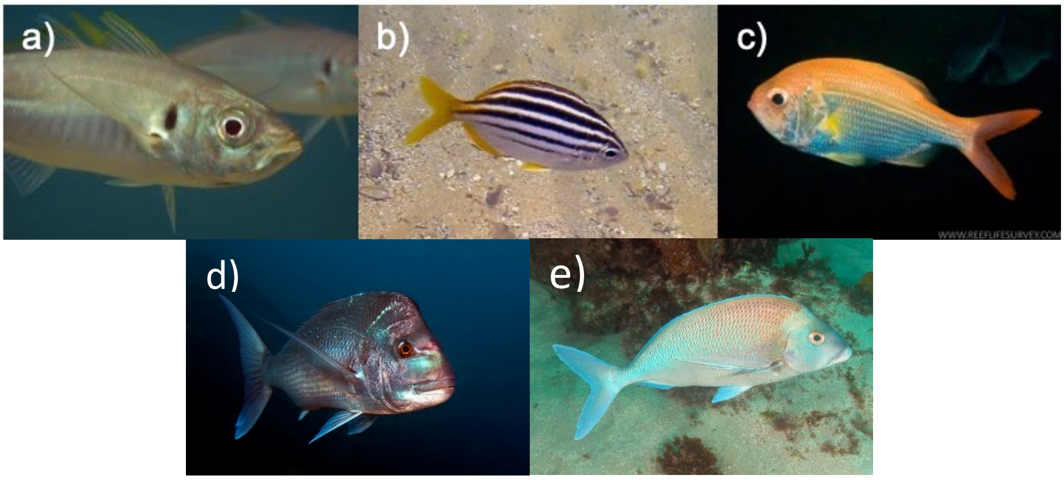


Figure 4-21. Examples of some of the highly abundant species schooling species a) yellowtail scad (*Trachurus novaezelandiae*), b) Australian mado (*Atypichthys strigatus*) and c) redfish (*Centroberyx affinis*) and two of the most important fishery species d) pink snapper (*Chrysophrys auratus*) and e) blue morwong (*Nemadactylus douglassi*). Photo credits: Reef Life Survey and David Harasti.

Table 4.4. A list of the top 15 numerically abundant species observed during this study. Species are ranked by the percent contribution to the total relative abundance of all individuals counted (percent)

Common name	Genus species	Mean	Percent
Australian mado	*Atypichthys strigatus*	7	22
Yellowtailed scad	*Trachurus novaezelandiae*	12	19
Redfish	*Centroberyx affinis*	8	13
Velvet leatherjacket	*Meuschenia scaber*	4	6
Silver trevally	*Pseudocaranx georgianus*	3	6
Pink snapper	*Chrysophrys auratus*	2	4
Ocean leatherjacket	*Nelusetta ayraud*	2	3
Blue morwong	*Nemadactylus douglasii*	2	3
Long-finned pike	*Dinolestes lewini*	1	2
Reef ocean perch	*Helicolenus percoides*	1	2
Sawtooth moray	*Gymnothorax prionodon*	1	1
Silver sweep	*Scorpis lineolata*	1	1
Teraglin	*Atractoscion aequidens*	1	1
Black-spot goatfish	*Parupeneus spilurus*	1	1
Eastern pigfish	*Bodianus unimaculatus*	1	1

The redundancy analysis (RDA) indicated that location, bathymetry mean over 25 m^2, season, kurtosis over 45 m^2 and aspect, when combined, explained 24% of the variance in the species assemblages across all stereo-BRUV deployments (Table 4.5 and Figure 4-22). Location alone explained the majority of the variation in species assemblage (Figure 4-22a). With the ordination plot showing clustering at the location it could be considered that Broughton Offshore, Outer Gibber and Seal Rocks Offshore reef systems each support a distinct species assemblage (Figure 4-22a). Samples from Outer Gibber were more closely related to samples from Seal Rocks Offshore, while some samples from Seal Rocks Offshore were similar to Broughton Island Offshore.

The species that are shaping these patterns were some of the deeper water species at Broughton Island Offshore, such as Redfish *Centroberyx affinis,* Reef Ocean Perch *Helicolenus percoides* and Velvet Leatherjacket *Meuschenia scaber*. Each of these species were ubiquitous across stereo-BRUV deployments at depths >80 m. In contrast, shallower reef associated species, such as Australian Mado *Atypichthys strigatus* and Yellowtail Scad *Trachurus novaezelandiae* explained the clustering of Outer Gibber and some Seal Rocks Offshore stereo-BRUV deployments.

The seasonal effect on species assemblage was small, but it appears to be greatest at Seal Rocks Offshore. This is most likely due to the Seal Rocks being an important oceanographic feature that lies within the separation zone for the EAC (Booth et al. 2007, Suthers et al. 2011, Vergés et al. 2016). As the EAC moves down the coast in spring, warm water remains relatively close to shore north of Seal Rocks, and the current is then pushed offshore as it moves past, creating cold water eddies in lee of the feature and to the south (Suthers et al. 2011, Schilling et al. 2020). This is due to a number of factors including change in orientation of the coast and the geostrophic conditions. The warm water conditions may be more favourable for a greater range of species or different species assemblage than when there is a cold-water eddy forming over Outer Gibber or Broughton Island Offshore. Species may even converge at these current convergence sites.

Table 4.5. Marginal effects of terms for the variables selected from the forward stepwise RDA model selection. Listed in order of importance in explaining the variation in species assemblages.

Variable	DF	Variance	F	P
Location	2	0.070	13.748	**0.001**
Bathymetry mean 25 m^2	1	0.021	8.320	**0.001**
Season	1	0.007	2.799	**0.003**
Kurtosis 45 m^2	1	0.006	2.230	**0.016**
Aspect	1	0.006	2.288	**0.013**
Residual	174	0.441		

Bolded P values are significant at p>0.05.

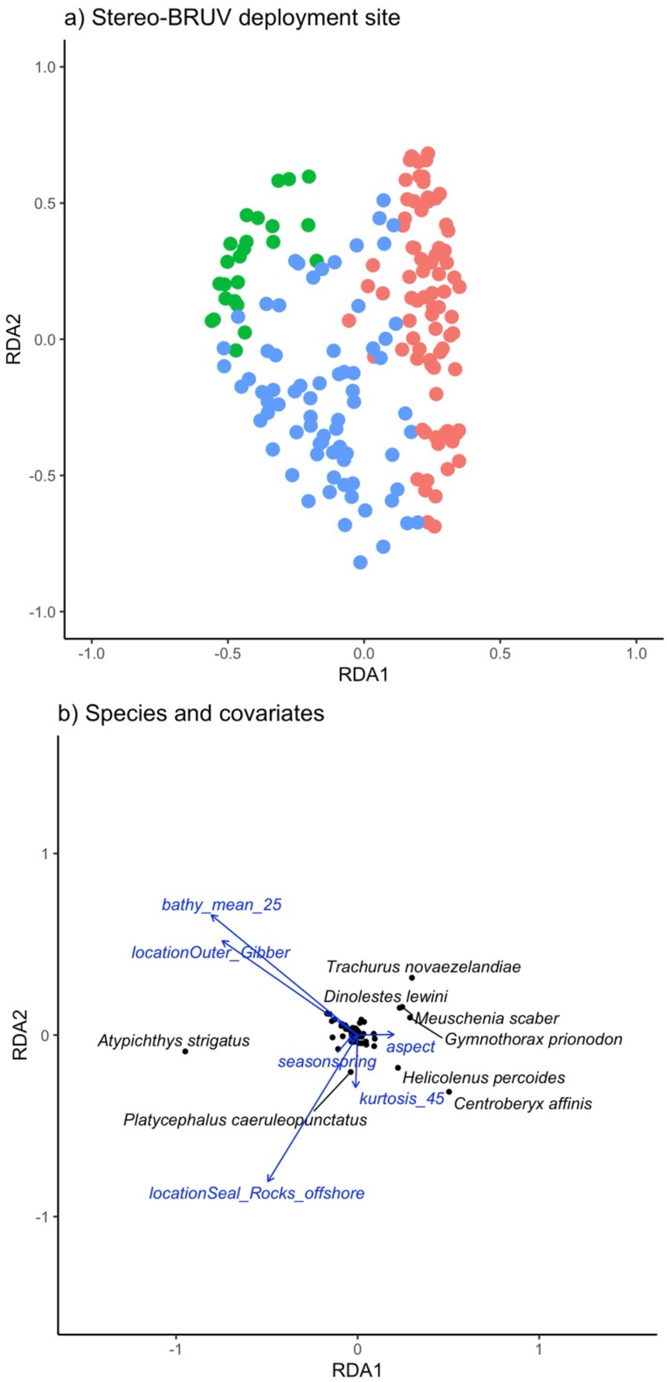
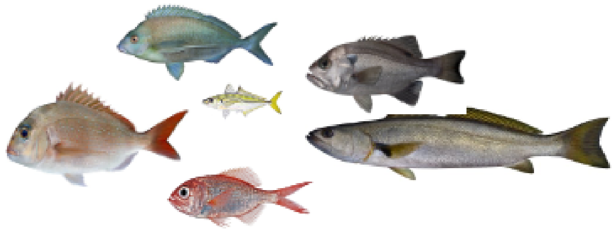


Figure 4-22. Ordination plots from the RDA results. a) Ordination of stereo-BRUV deployment sites (● Broughton Island Offshore, ● Outer Gibber, ● Seal Rocks Offshore). The further apart the points the greater the dissimilarity in species assemblages between stereo-BRUV deployments. b) Ordination of species with the vectors for each covariate selected in the 'best' model for species assemblage. The further away from centroid the greater the influence of the species and covariate. The names of the eight species that explain the greatest variation between stereo-BRUV deployments have been provided.

Figure 4-23. Example of high fish abundance at Broughton Island Offshore. The species include Australian mado, redfish and pearl perch.

4.3.4 Species Richness



Species richness, the number of species recorded per stereo-BRUV deployment, was consistent across each time period per location (Figure 9). This suggests that there is minimal temporal variability in the species composition on rocky reefs in the Hunter Marine Park. However, there was great spatial variability in species richness between the three locations (Figure 4-24 and Figure 4-25). Outer Gibber consistently had the highest species richness, with a mean of 21 species per stereo-BRUV deployments and a maximum of 27 (Figure 4-24), while Broughton Island Offshore and Seal Rocks Offshore both had a mean species richness of 12 and maximums of 23 and 21, respectively (Figure 4-24). This is most likely due to the fact this is a much shallower reef with high relief. Both Broughton Island offshore and Seal Rocks offshore had greater variability in species richness.

Species richness was consistent across the Outer Gibber reef (Figure 4-24), while Broughton Island Offshore had some patches of reef, particularly to the east in 100 m of water, that had higher species richness (Figure 4-24). Seal Rocks offshore was also patchy, with the highest species richness consistently on stereo-BRUV deployment to the north of the location (Figure 4-24). The best model to describe the variance in species richness included the factors depth and fine bathymetric position index (BPI; Figure 4-27 and Table 4.7), confirming that the shallower reefs the higher the species richness and the higher the BPI the higher the species richness (Appendix A).

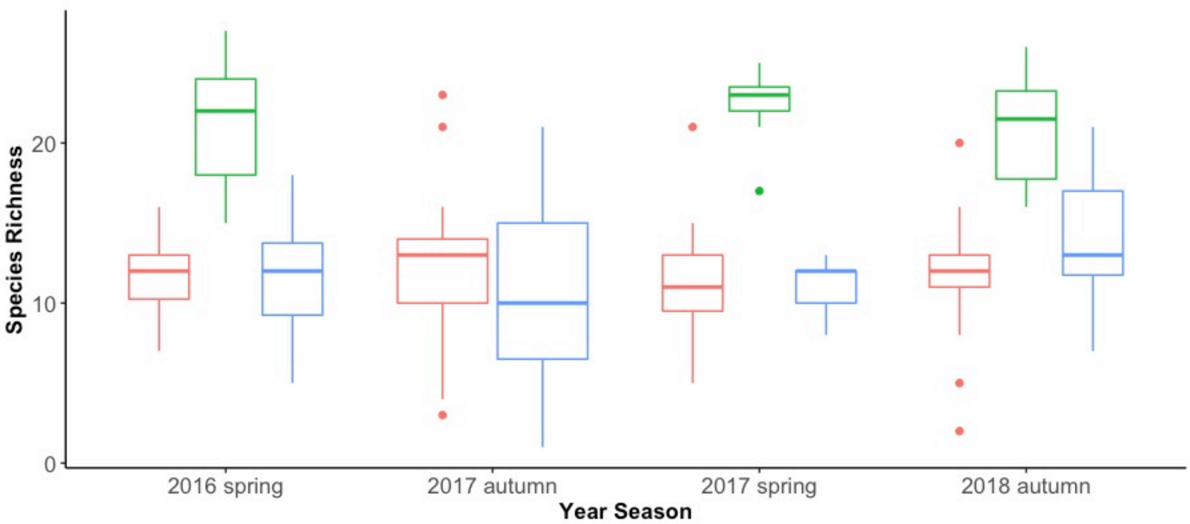


Figure 4-24. Boxplots of species richness across each season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

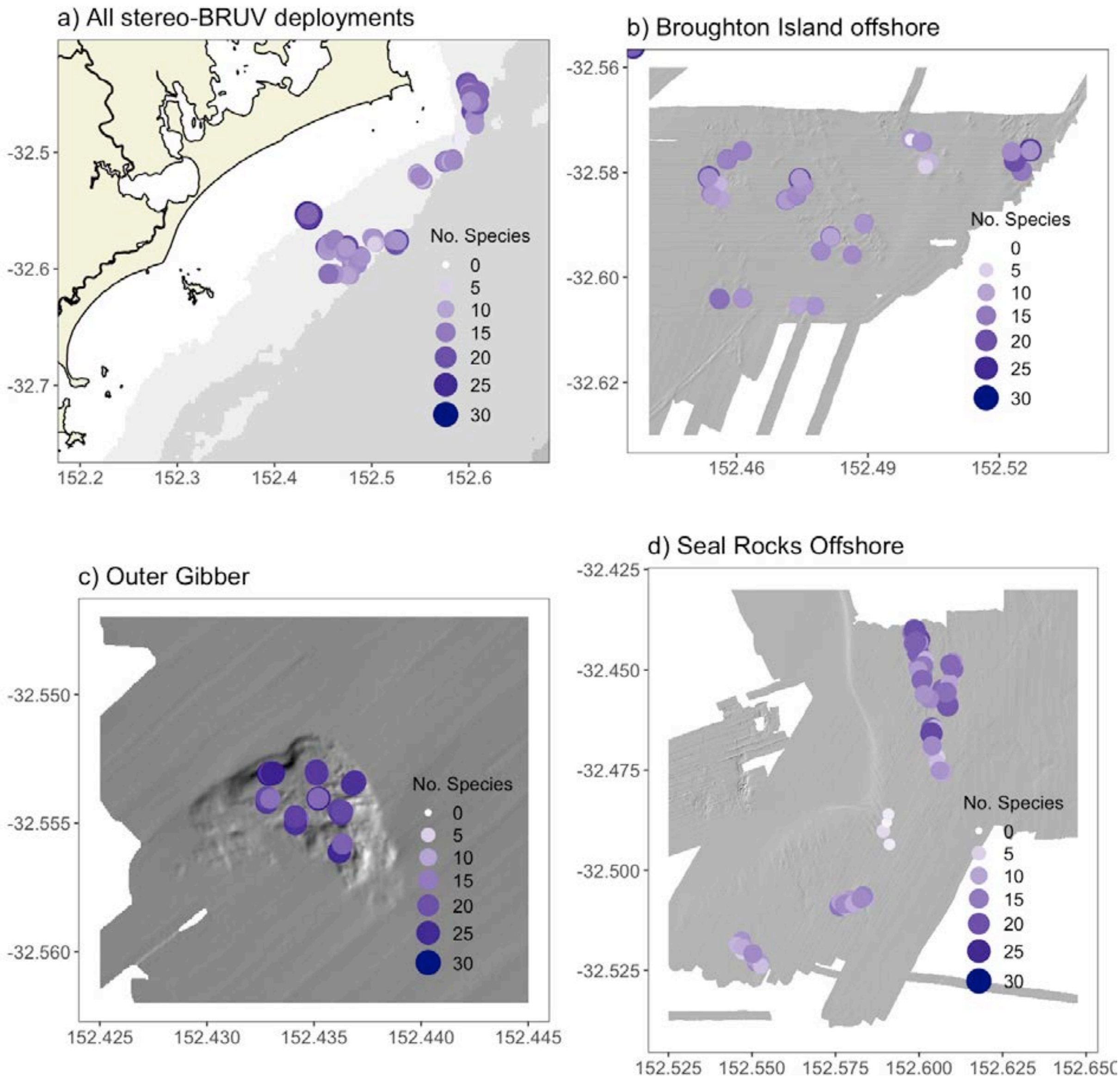


Figure 4-25. Bubble plots of species richness of individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the number of species recorded on a stereo-BRUV deployment.

4.3.5 Summary of Species of Interest

A selection of 14 species were chosen *a priori* that were deemed worthy of further investigation. This list included species that were highly abundant from a range of families, range of sizes, of fisheries significance, or of conservation interest (Table 4.6), and could be used as indicator species for future monitoring of the Hunter Marine Park, particularly as these species are also consistently sampled by using stereo-BRUV.

A full subset generalised additive mixed model was used to establish the importance of location, season, depth and reef structure (Table 4.1) for the spatial and temporal distribution of each of these 14 species (Figure 4-27 and Table 4.7). The model with the lowest corrected Akaike information criterion (AIC_c), or if a model was within 2 AIC_c points then the model with the fewest variables, was deemed to be the 'best' model or the 'best' variables that explain the distribution of each of these species (Zuur et al. 2012, Fisher et al. 2018) (Table 4.7).

Figure 4-26. A common scene when analysing stereo-BRUV footage with several of the species of interest included, such as, blue morwong, velvet leatherjacket and eastern pigfish.

Table 4.6. List of the 14 selected species of interest including their know state distributions, depth distribution, targeted by either recreational or commercial fishers and the stock status as defined by either FRDC report cards 2020 (www.frdc.gov.au) or NSW Department of Fisheries stock status (www.dpi.nsw.gov.au). Distribution and length information sourced from www.fishesofaustralia.net.au (2020).

Common Name	Genus species	Max Length (mm)	Distribution	Depth	Fished	Fishery Status
Pink snapper	*Chrysophrys auratus*	1300	QLD, NSW, Vic, Tas, SA, WA	1-200 m	Yes	Sustainable
Blue morwong	*Nemadactylus douglasii*	980	NSW, Vic, Tas, SA, WA	3-240 m	Yes	Depleted
Redfish	*Centroberyx affinis*	400	QLD, NSW, Vic	10-365 m	Yes	Depleted
Silver trevally	*Pseudocaranx georgianus*	940	NSW, Vic, Tas, SA, WA	0-240 m	Yes	Sustainable
Yellowtail scad	*Trachurus novaezelandiae*	500	QLD, NSW, Vic, Tas, SA, WA	0-500 m	Yes	Sustainable
Velvet leatherjacket	*Meuschenia scaber*	320	NSW, Vic, Tas, SA, WA	2-200 m	No	NA
Teraglin	*Atractoscion aequidens*	>1000	QLD, NSW	1-200 m	Yes	Fully-fished (NSW)
Pearl perch	*Glaucosoma scapulare*	700	QLD, NSW	5-90 m	Yes	Depleted
Silver sweep	*Scorpis lineolata*	300	QLD, NSW, Vic, Tas	1-30 m	Yes	NA
Reef ocean perch	*Helicolenus percoides*	470	NSW, Vic, Tas	10-425 m	Yes	Fully-fish (NSW)
Sawtooth moray	*Gymnothorax prionodon*	1500	QLD, NSW	No data	No	NA
Bluespotted flathead	*Platycephalus caeruleopunctatus*	600	QLD, NSW, Vic	25-100 m	Yes	Sustainable
Eastern pigfish	*Bodianus unimaculatus*	500	QLD, NSW, Vic	6-60 m	No	NA
Eastern rock lobster	*Sagmariasus verreauxi*	260	NSW, Vic, Tas, SA	1-200 m	Yes	Sustainable

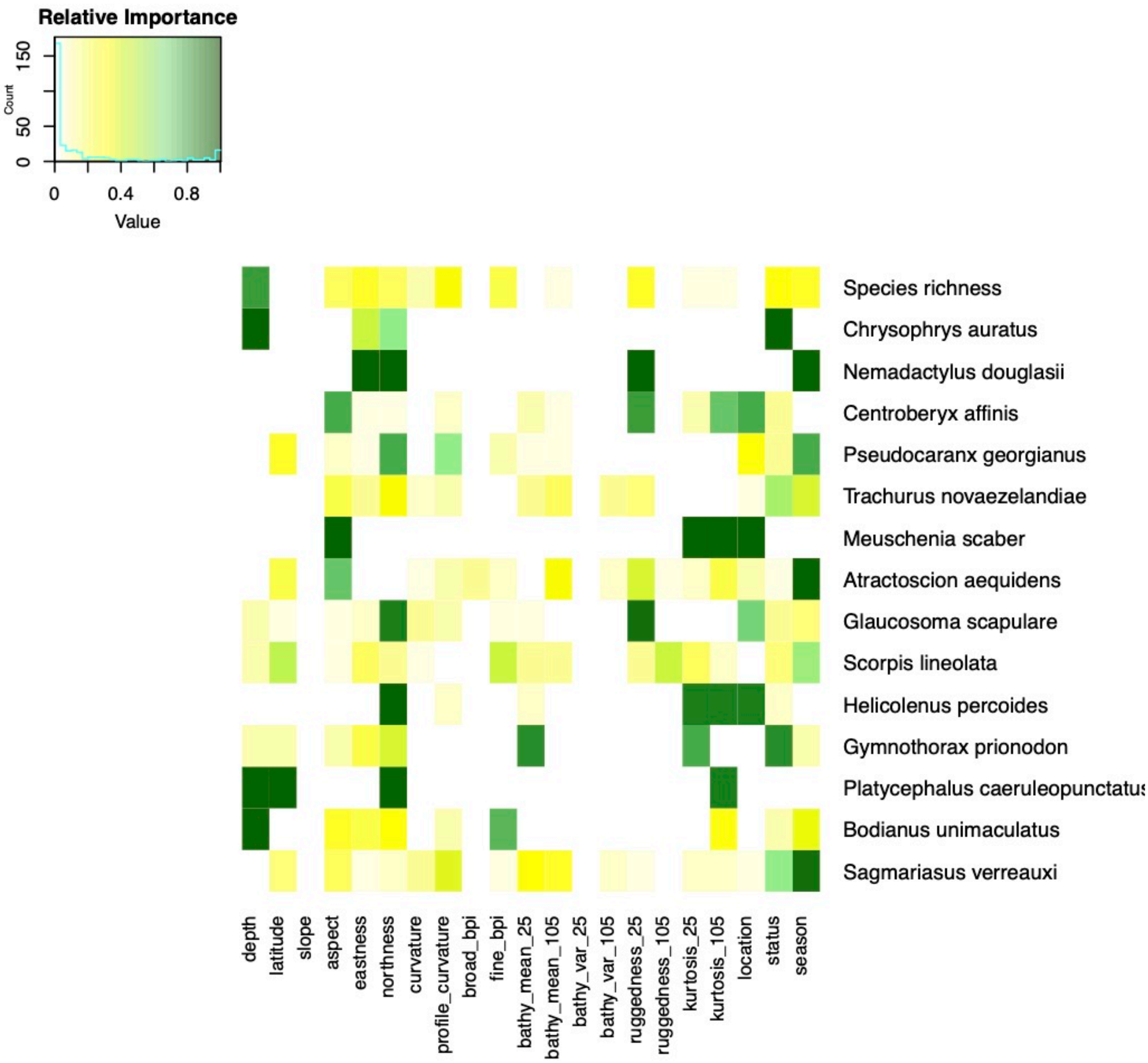


Figure 4-27. Heatmap demonstrating the importance of each of the explanatory variables (x-axis) in explaining the variability in the spatial and temporal distribution of species richness and the 14 species of interest. The darker the green the more important that variable is in explaining the distribution of that species.

Table 4.7. Summary table from full subsets GAMM analyses showing the 'best' model with the lowest AICc, with multiple models within 2 AICc values then the model with fewest variables, including estimated degrees of freedom (EDF), AICc weights and R^2 estimates. x indicates an interaction between variables.

Species	Model	AIC_c	BIC	w_iAICc	w_iBIC	EDF	R^2
Species richness	Depth + Fine BPI	991.78	1094.18	0.02	0.03	35.83	0.73
Pink snapper	Depth +Status	511.55	609.82	0.17	0.17	34.14	0.62
Blue morwong	Eastness x Season + Northness x Season + Ruggedness25 x Season +Season	324.43	431.07	0.99	1.00	40.14	0.35
Redfish	Aspect x Location + Kurtosis 105 x Location + Location + Ruggedness 25	1014.38	1124.63	0.70	0.01	40.14	0.05
Silver trevally	Location + Northness x Season + Curvature + Season	804.90	918.07	0.08	0	40.7	0.46
Yellowtail scad	Bathy. Mean 105 + Ruggedness 25 x Season +Season + Status	1043.97	1152.36	0.22	0	36.8	0.34
Velvet leatherjacket	Aspect x Location + Kurtosis 105 x Location + Kurtosis 25 x Location + Location	660.43	788.57	0.99	0.99	49.28	0.60
Teraglin	Aspect x Season + Bathy Mean 105 + Latitude x Season+ Season	284.91	381.22	0.21	0.3	32.78	0.04
Pearl perch	Location + Northness x Location + Ruggedness 25	275.70	362.06	0.37	0.64	29.68	0.03
Silver sweep	Fine BPI x Season + Latitude + Ruggedness 105 x Season + Season	282.00	365.13	0.481	0	25.95	0
Reef ocean perch	Kurtosis 105 x Location + Kurtosis 25 x Location+ Location + Northness x Location	535.21	641.77	0.93	0.91	40.58	0.08
Sawtooth moray	Bathy mean 25 x Status + Kurtosis 25 + Status	280.32	375.64	0.21	.02	31.55	0.38
Bluespotted flathead	Depth + Kurtosis 105 + Latitude + Northness	429.41	493.19	0.91	0.80	15.6	0.31
Eastern pigfish	Depth +Fine BPI	269.43	372.78	0.05	0.07	36.79	0.30
Eastern rock lobster	Bathy mean 25 x Status + Curvature x Season + Season + Status	211.46	262.77	0.18	0.507	14.98	0.04

Pink snapper, Chrysophrys auratus

Pink snapper, *Chrysophrys auratus* is a highly targeted and valuable species to both recreational and commercial fishers in NSW (Stewart et al. 2010). Pink Snapper where found throughout the Hunter Marine Park and occurred on 74% of stereo-BRUV deployments during this study. On average, Pink Snapper were observed as single fish or pairs of fish, however, the largest school of pink snapper consisted of 10 fish.

Outer Gibber consistently had the highest abundance of pink snapper across each survey period (Figure 4-28 and Figure 4-29), and abundance was uniform across the Broughton Island Offshore location (Figure 4-29). At Seal Rocks Offshore it was reef to the north and south of the location that had the highest abundances (Figure 4-29). There were no obvious season or annual patterns in the abundance of pink snapper (Figure 4-28). The model with depth and status explained the large variance in the spatial and temporal distribution (Table 4.7 and Figure 4-27). The status effect is driven by the high abundance of pink snapper at Seal Rocks Offshore on reef within the no-take zone of the Port Stephens - Great Lakes Marine Park. This is consistent with long-term marine park monitoring programs that demonstrated that the species show increased abundance and larger fish in no-take zones when compared to areas that are fished (Harasti et al. 2018, Malcolm et al. 2018, Knott et al. 2020).

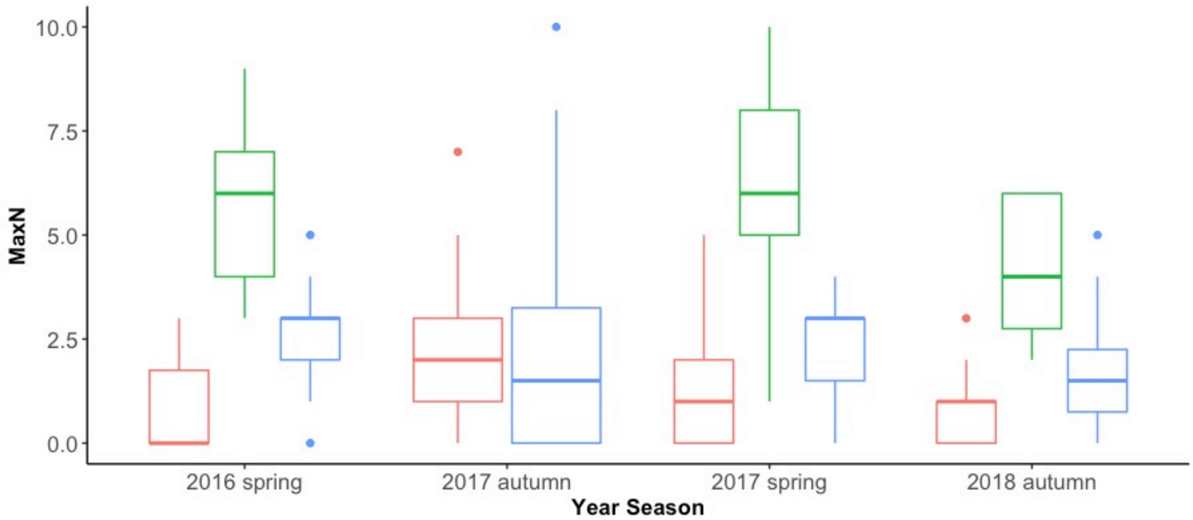


Figure 4-28. Boxplot of pink snapper relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

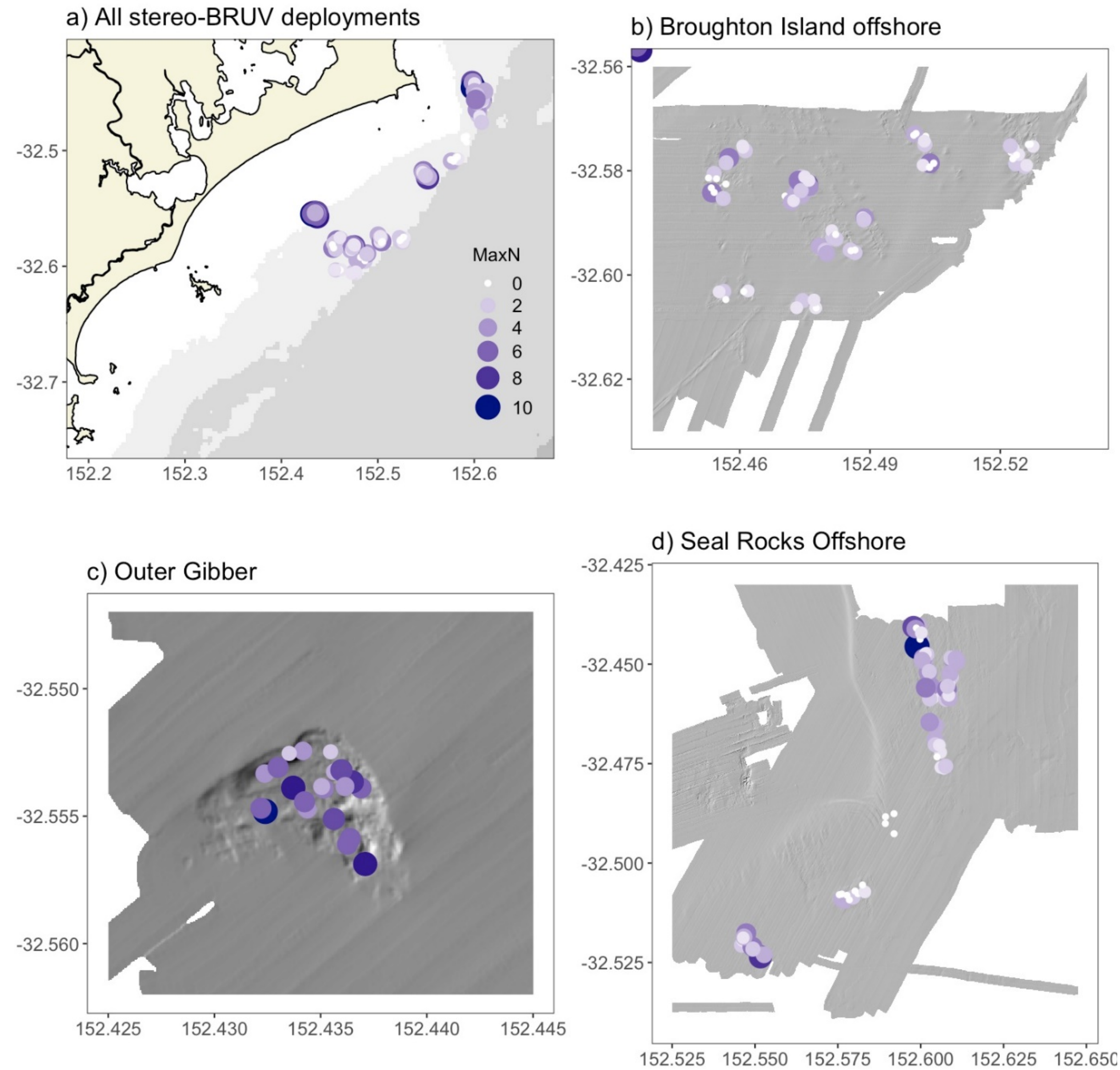


Figure 4-29. Bubble plots of pink snapper relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

The distribution of lengths for pink snapper varied greatly between locations (Figure 4-30). The largest (644 mm) and the highest number of fish above the minimum legal length (MLL) occurred at Seal Rocks Offshore, a no-take zone in the Port Stephens - Great Lakes Marine Park. Broughton Island Offshore, that is mainly fished by trap and line commercial fishers, also had a large proportion of fish above the MLL. Interestingly, Outer Gibber, a highly fished reef compared to the other two locations (pers. obs.), had the fewest number of fish above the MLL. Although this site is shallower this could indicate either an ontogenetic shift or is an indication of the effects of fishing pressure. Fishing effort data is not at a resolution that could test this theory.

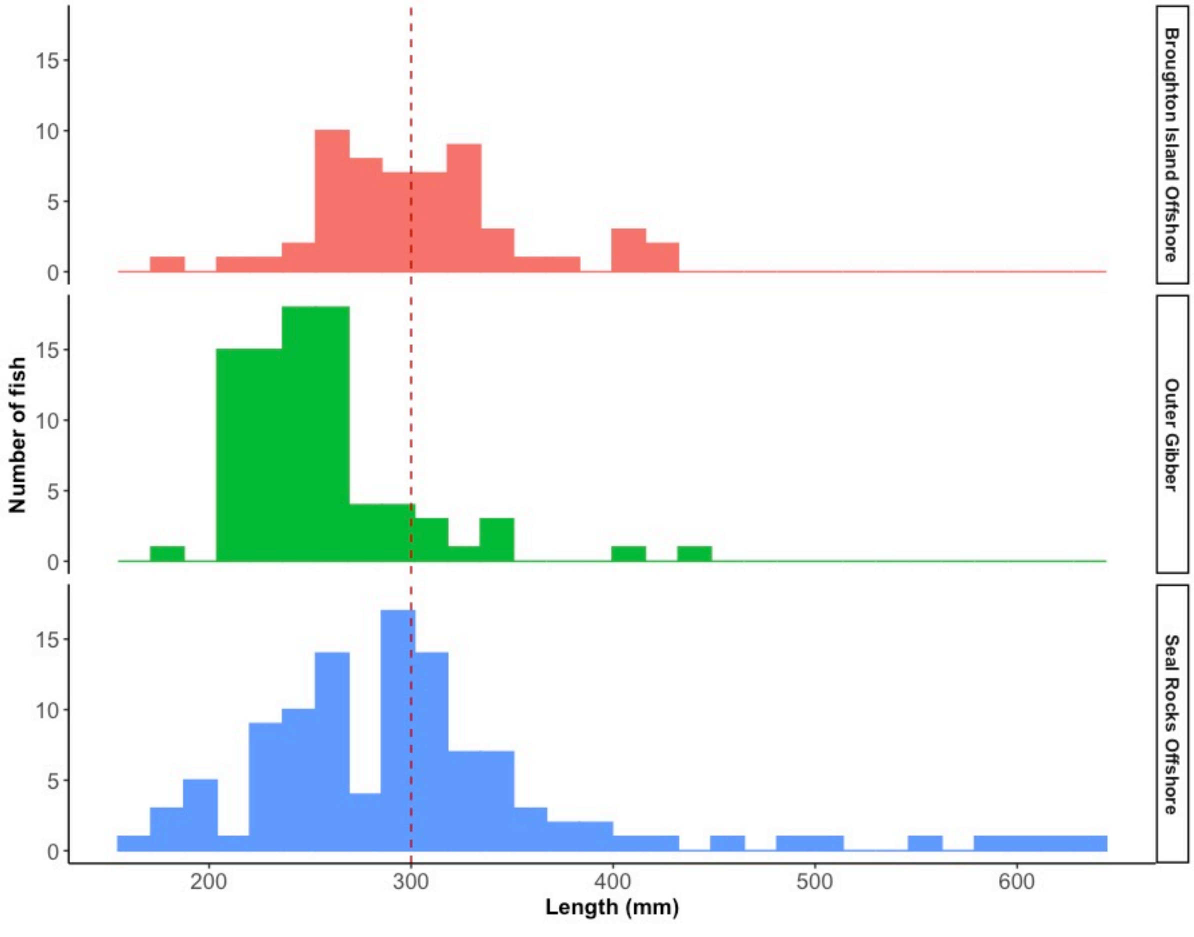


Figure 4-30. Histograms of the lengths for pink snapper at each of the three locations. The dashed red line represents the minimum legal length for retaining in NSW.

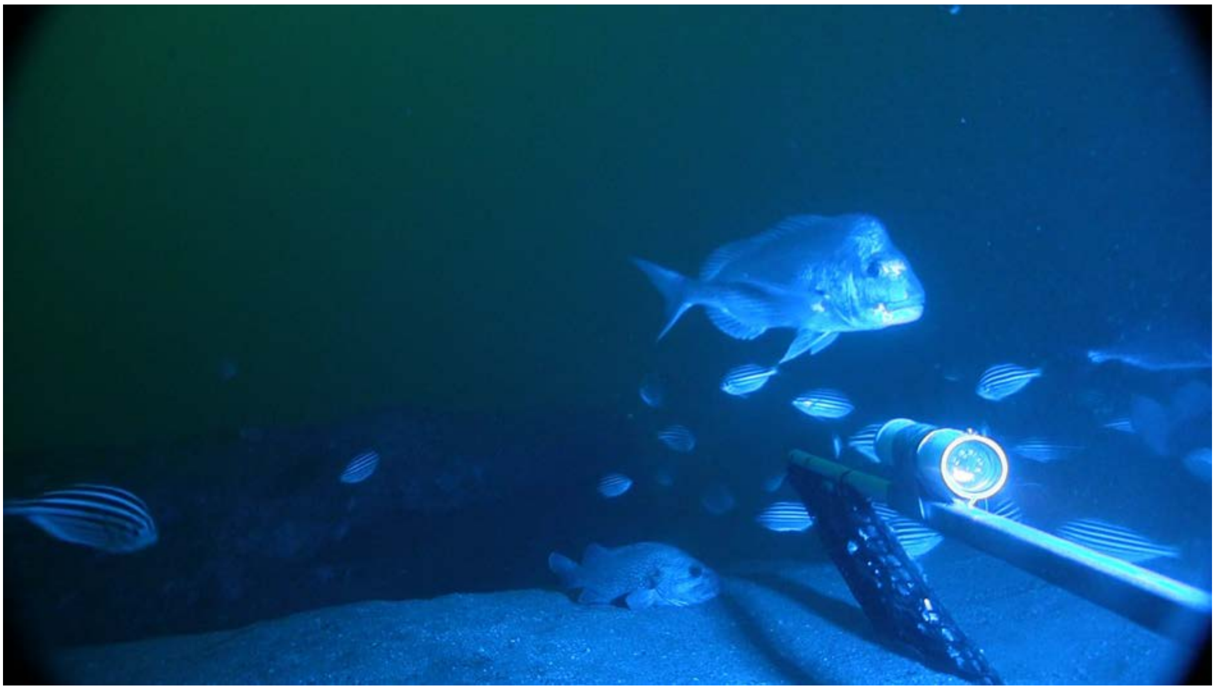


Figure 4-31. A 650 mm pink snapper, the largest pink snapper recorded during this study at Seal Rocks Offshore.

Blue (grey) morwong, Nemadactylus douglasii

Blue morwong, also known as grey morwong, is a reef species that is also targeted by both recreational and commercial fishers (Stewart and Hughes 2009). However, numbers have dramatically declined since the 1970s ("Grey Morwong, Status of Fisheries Resources in NSW 2008/09" 2010). Blue morwong were recorded on 70% of all stereo-BRUV deployments. On average, blue morwong were observed in pairs (Figure 4-32 and Figure 4-33), although on one occasion a school of 35 fish was observed at the deepest site at Broughton Island Offshore (Figure 4-32 and Figure 4-33). It is thought that this is an unusual siting and was possibly a spawning aggregation as this was observed in autumn during the spawning season.

The distribution of blue morwong was fairly even across reefs (Figure 4-33). The best model for explaining the distribution of blue morwong included the factors eastness by season, northness by season, ruggedness by season and season (Table 4.7 and Figure 4-27). These results suggest that the location of blue morwong on reef is dependent on season. During the warm water period of autumn fish tend to be on the southern slope of reef. This is compared to spring when fish appear for evenly distributed across all reef slopes.

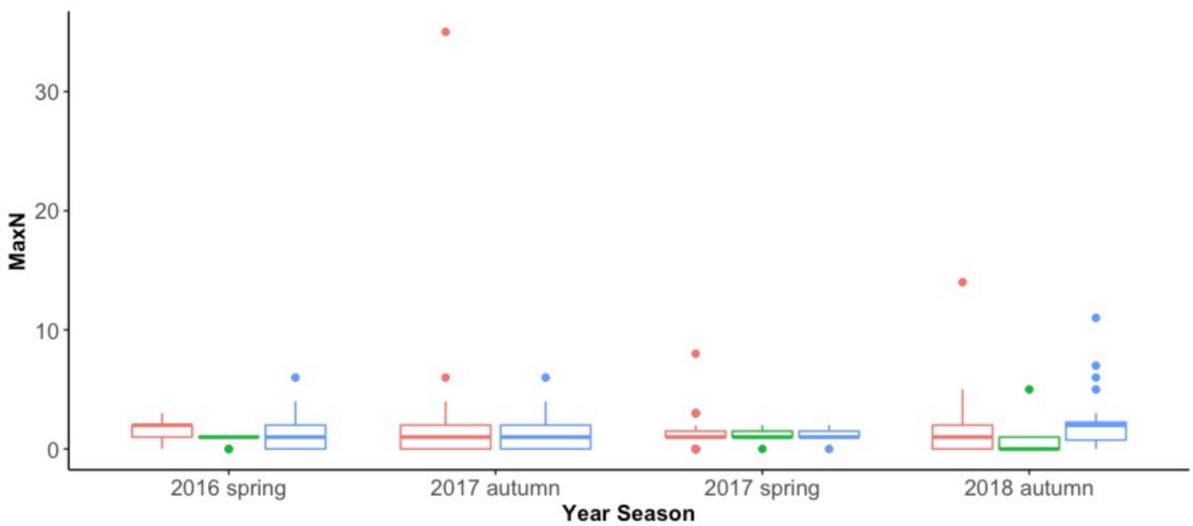


Figure 4-32. Boxplot of blue morwong relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

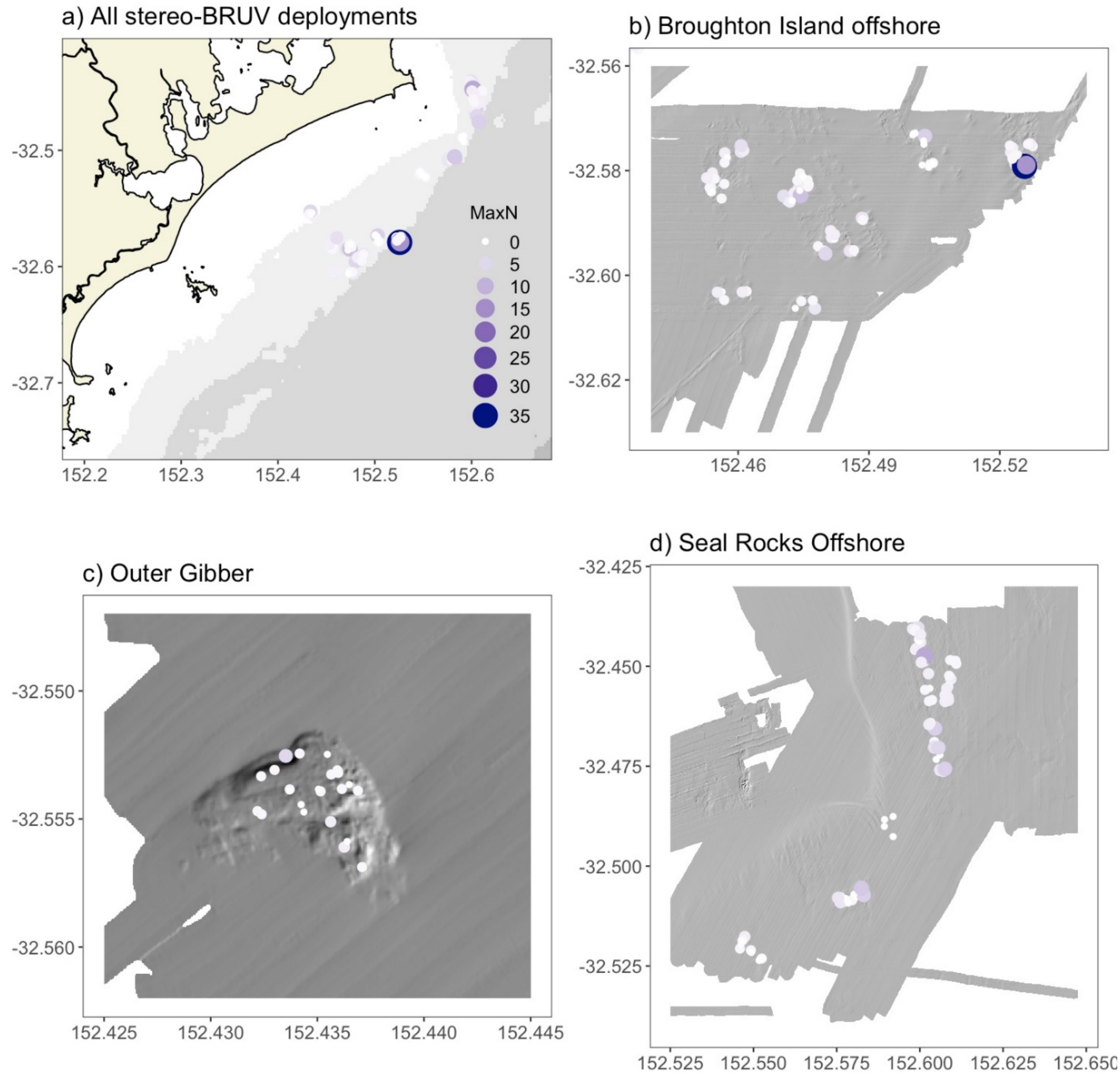


Figure 4-33. Bubble plots of blue morwong relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

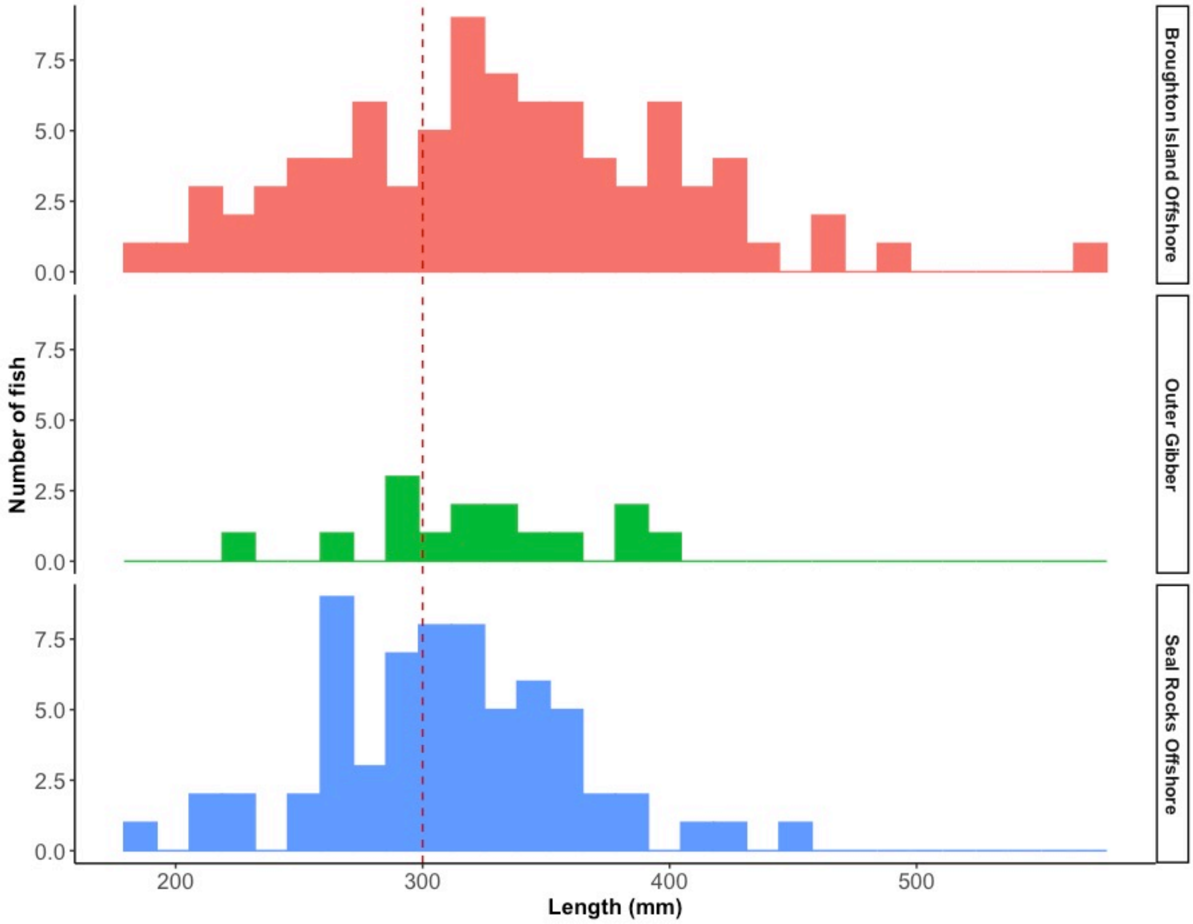


Figure 4-34. Histograms of the lengths for blue morwong at each of the three locations. The dashed red line represents the minimum legal length for retaining in NSW.

The distribution of lengths of blue morwong was fairly consistent between locations (Figure 4-34). Blue morwong range in length from 180 mm to 600 mm. Blue morwong reach maturity at approximately 250 mm and have a minimum legal length for retention of 300 mm. Therefore, the majority of fish measured during this study were deemed to be mature fish and above the minimum legal length for retention (Figure 4-34).

Redfish, Centroberyx affinis

Redfish are a moderate size schooling pelagic species that is endemic to NSW and southern Queensland. While, juveniles commonly inhabit estuaries and coastlines, it is the adults that are more commonly found on deeper reefs out to 450 m (Chen et al. 1997, Morison and Rowling 2001). It is a species that are targeted by commercial trawl fisheries and recreational fishing and catches have notably declined significantly since the 1980's. During this study redfish were recorded on 68% of stereo-BRUV deployments. On average, they were recorded in schools of 10 fish, but were also observed in schools as large as 105 fish (Figure 4-35 and Figure 4-36).

There were no obvious seasonal patterns detected in redfish distribution (Figure 4-35). As well as no obvious patterns in the spatial distribution of redfish with the exception that Broughton Island Offshore consistently had higher relative abundance throughout the study. The best model selected to explain the distribution of redfish included the interactions between location and aspect, location and kurtosis (105 m^2), as well as the factors location and ruggedness (25 m^2; Figure 4-27 and Table 4.7). This is mostly likely due to the higher abundance at Broughton Island Offshore. With a low R^2 value of 0.04 suggested that there is high variability in this species distribution that could not be attributed to location, season or reef structure (Table 4.7).

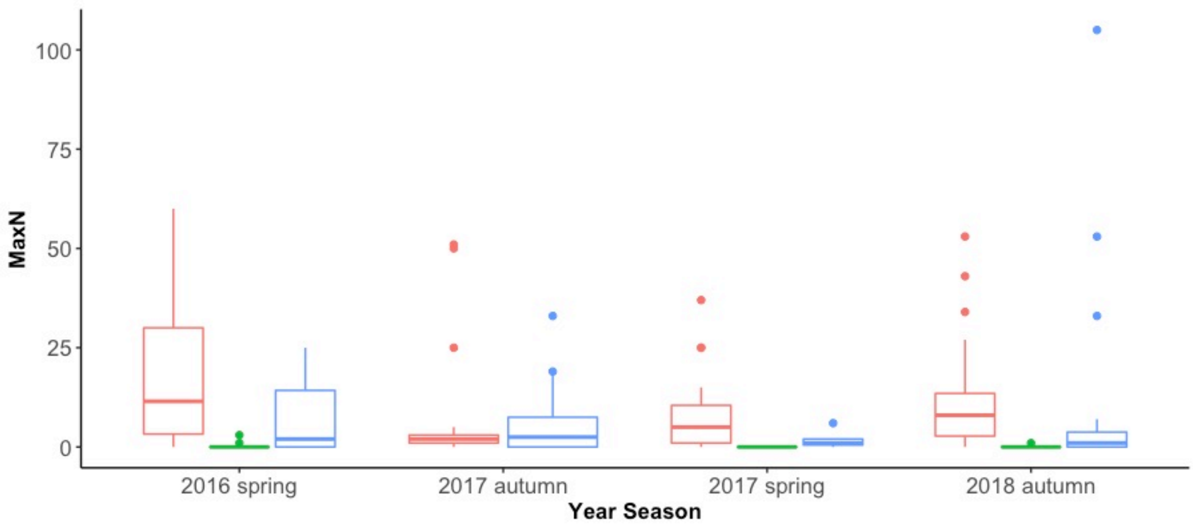


Figure 4-35. Boxplot of redfish relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

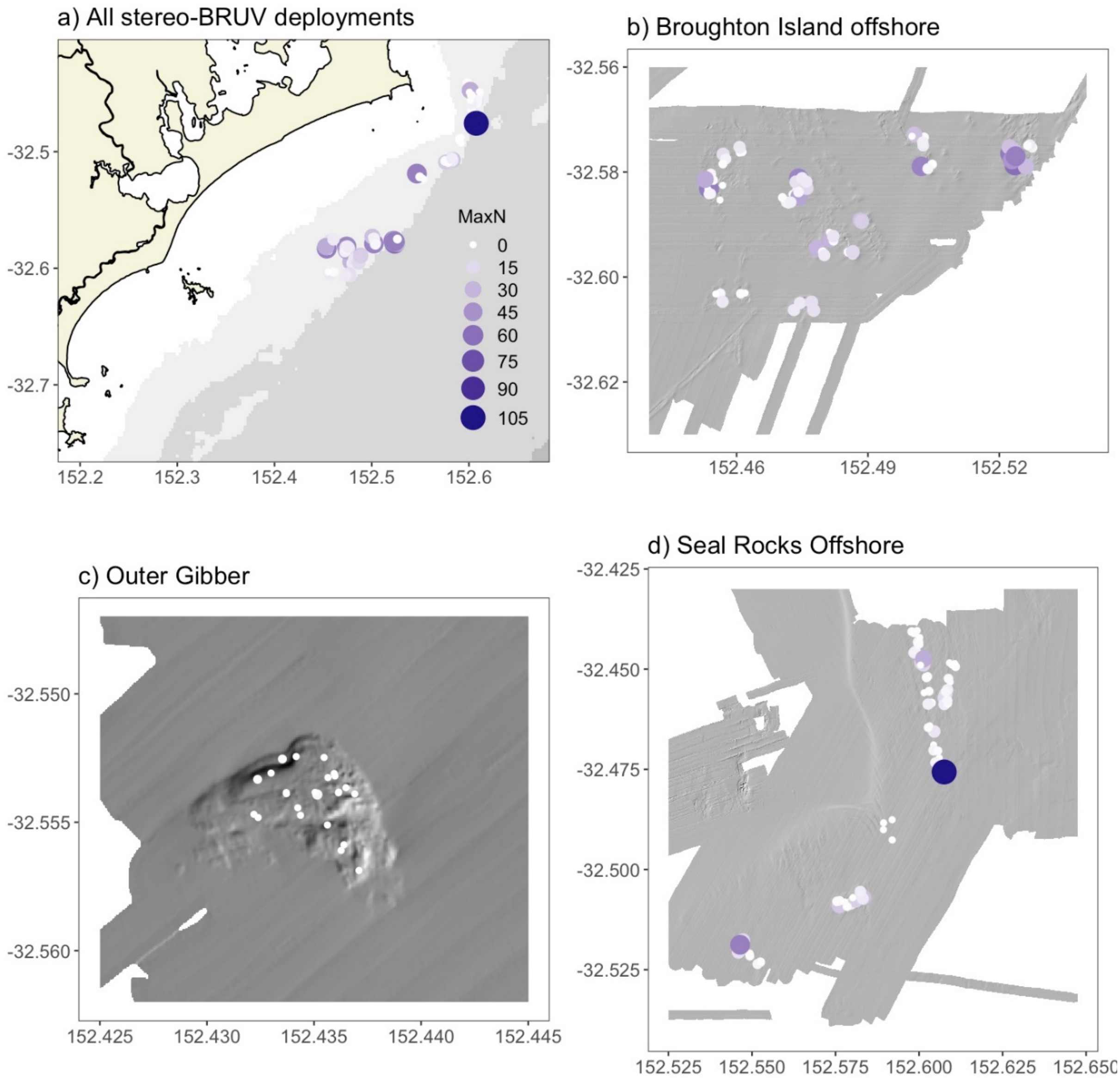


Figure 4-36. Bubble plots of redfish relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

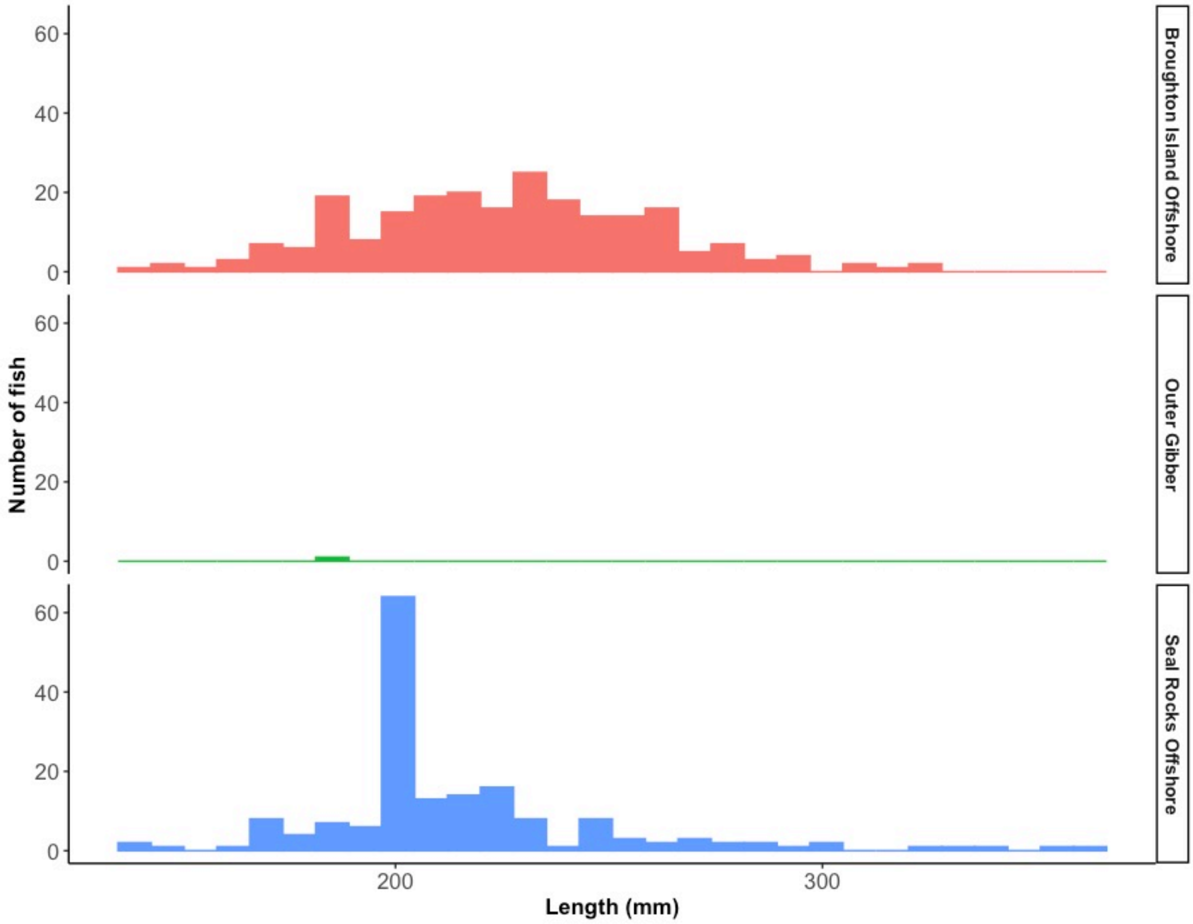


Figure 4-37. Histograms of the lengths for redfish at each of the three locations. There is no minimum legal length for retention for redfish.

The length distribution for redfish was consistent between Broughton Island Offshore and Seal Rocks Offshore (Figure 4-37). These findings are consistent with the fact older, adult sized fish are more commonly observed on reef deeper than 40 m (Chen et al. 1997). The average length being 230 mm.

Silver trevally, Pseudocaranx georgianus

Silver trevally are a moderate sized pelagic species that is common across temperate and sub-tropical Australia (Chick et al. 2018, Fowler et al. 2018). It is thought that species is relatively site attached moving across small spatial scales (Fowler et al. 2018). It is still unclear how this species moves across a depth gradient. Silver trevally were observed on 62% of stereo-BRUV deployments. Silver trevally were recorded in schools ranging from 2 to 50 fish.

The model that explained the greatest variability in the distribution of silver trevally included the factors locations, season and curvature with an interaction between northness and season (Figure 4-27 and Table 4.7). The highest abundance of silver trevally occurred during spring on high profile reef, facing north on stereo-BRUV deployment to the north of Seal Rocks Offshore (Figure 4-38 and Figure 4-39). Silver Trevally at Outer Gibber and Broughton

Offshore were fairly uniform in distribution (Figure 4-39).

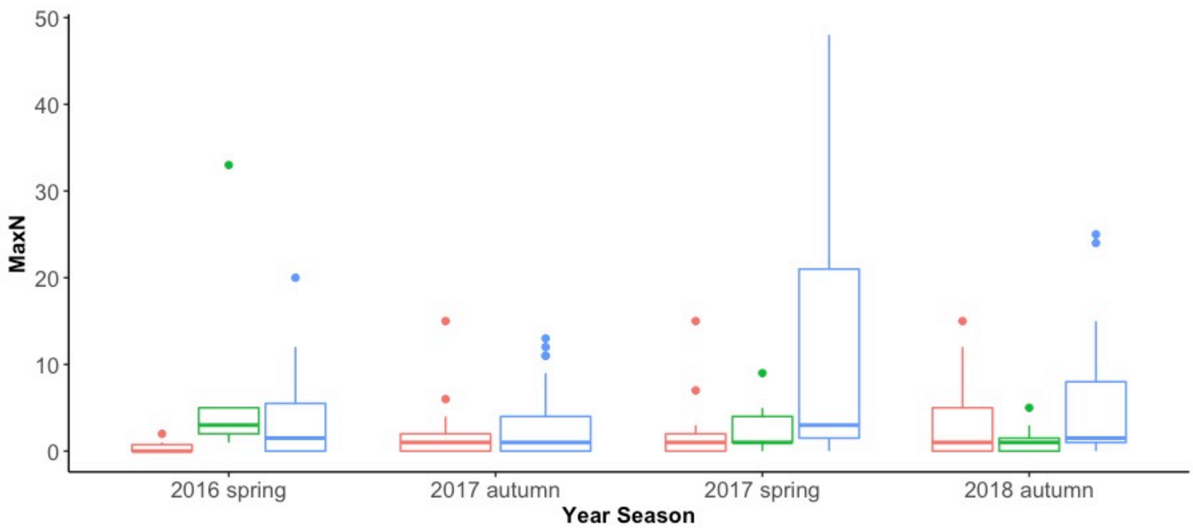


Figure 4-38. Boxplot of silver trevally relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

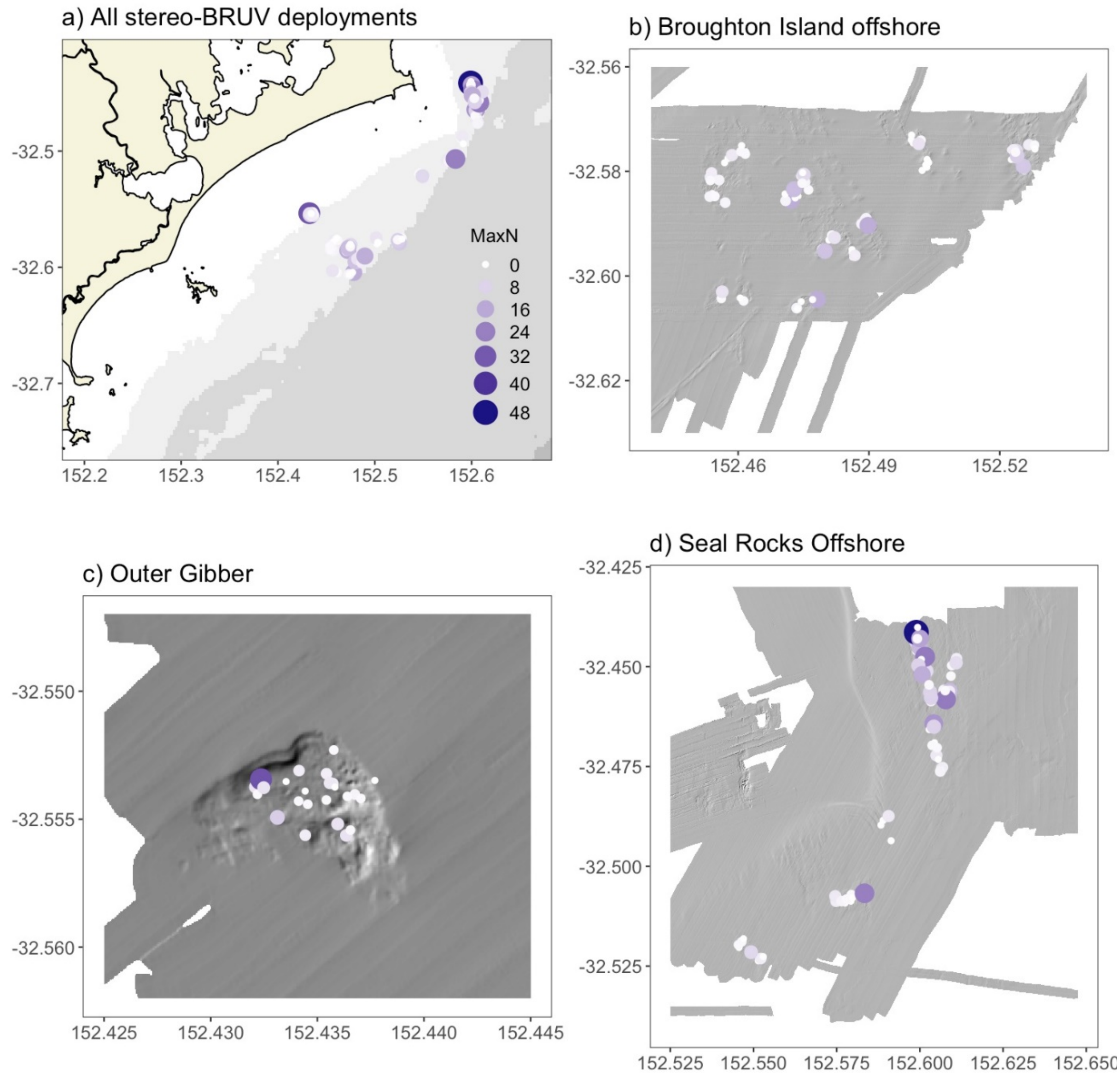


Figure 4-39. Bubble plots of silver trevally relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

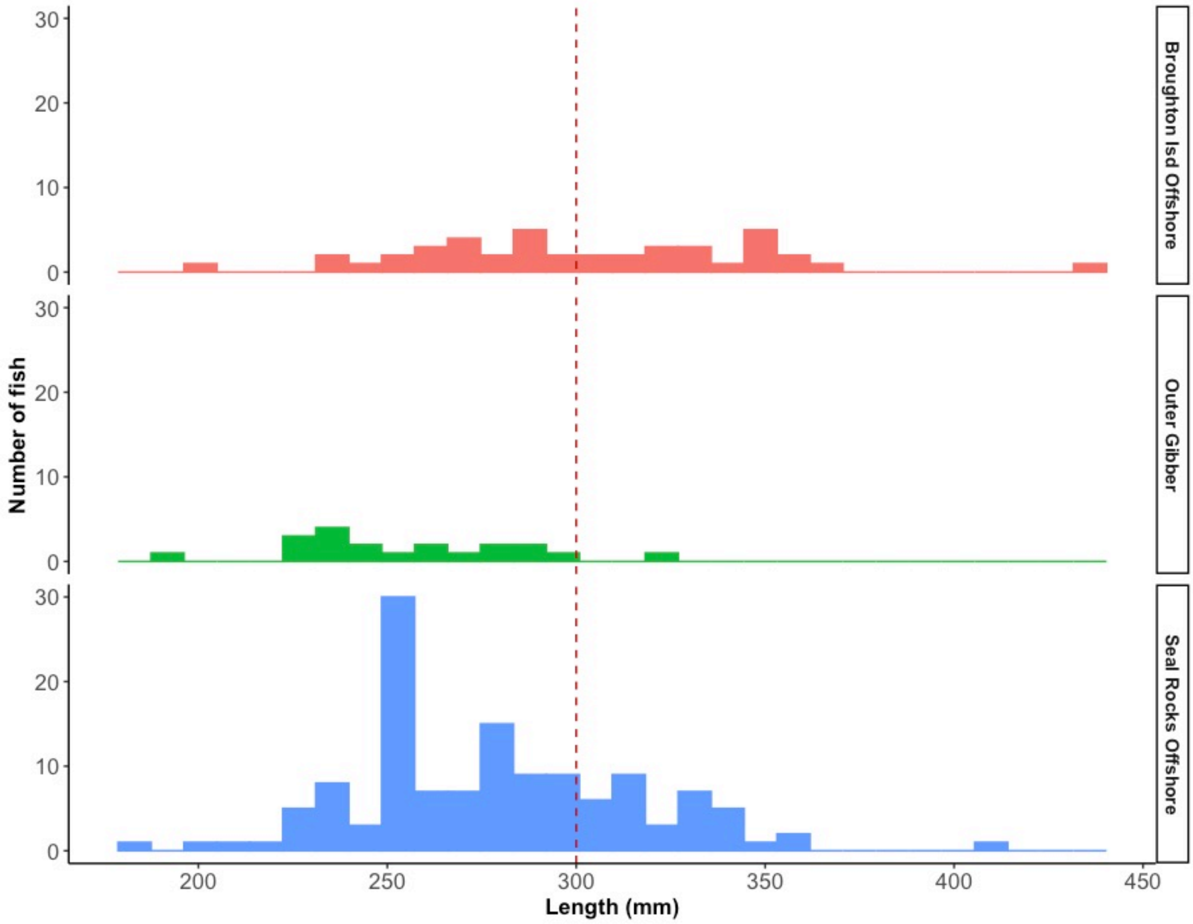
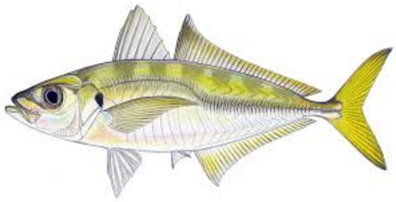


Figure 4-40. Histograms of the lengths for silver trevally at each of the three locations. The dashed red line represents the minimum legal length for retaining in NSW.

The length distribution for silver trevally showed a clear location effect with a greater range of lengths measured at Broughton Island Offshore and Seal Rocks Offshore (Figure 4-40). This included a large proportion of fish over 300 mm in length or above the minimum legal length (MLL) for retainment. In comparison, despite Outer Gibber having fewer silver trevally, all but one fish was below the MLL (Figure 4-40).

Yellowtail scad, Trachurus novaezelandiae



Yellowtail scad are a small schooling pelagic species that are common along the NSW coastline (Stewart and Ferrell 2001). It is a species that is also highly targeted by fishers and often used as a bait species. Yellowtail scad were widespread and recorded on 58% of stereo-BRUV deployments and in schools of 10 to 150 fish during this study (Figure 4-41 and Figure 4-42).

The model that explained that most variance in yellowtail scad distribution included the factors season, status, bathymetry (105 m^2) and the interaction between ruggedness and season (Figure 4-27 and Table 4.7). The highest abundances of yellowtails scad occurred during spring (cool water period) and in the no-take zone of the Port Stephens - Great Lakes Marine Park (Figure 4-41 and Figure 4-42). Some of the highest abundance recorded during this study occurred on the moderate relief reef in the northern half of Seal Rocks Offshore. There was a non-linear depth pattern in distribution with the highest abundances occurring in 80-90 m.

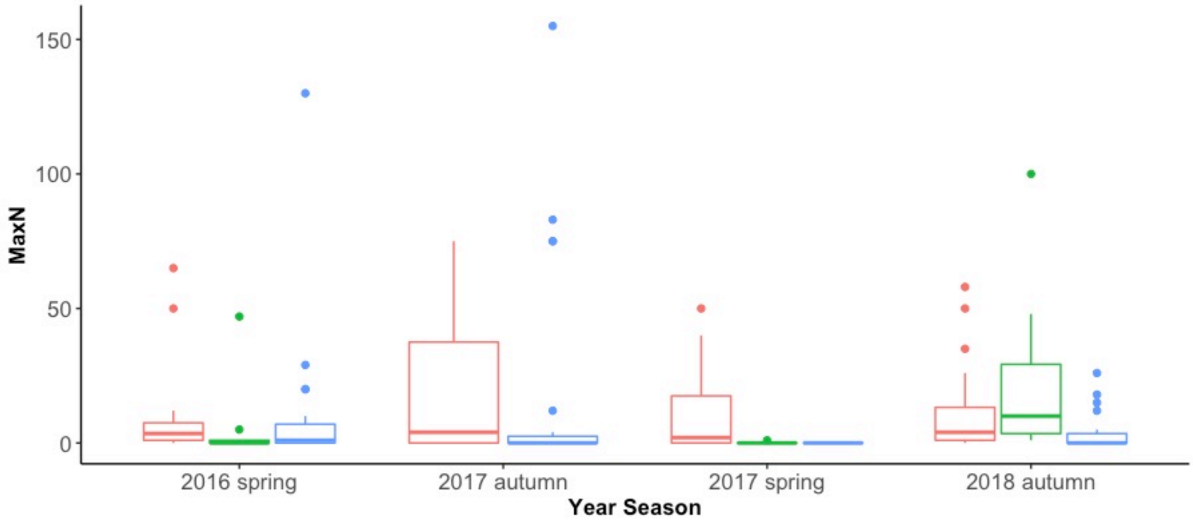


Figure 4-41. Boxplot of yellowtail scad relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

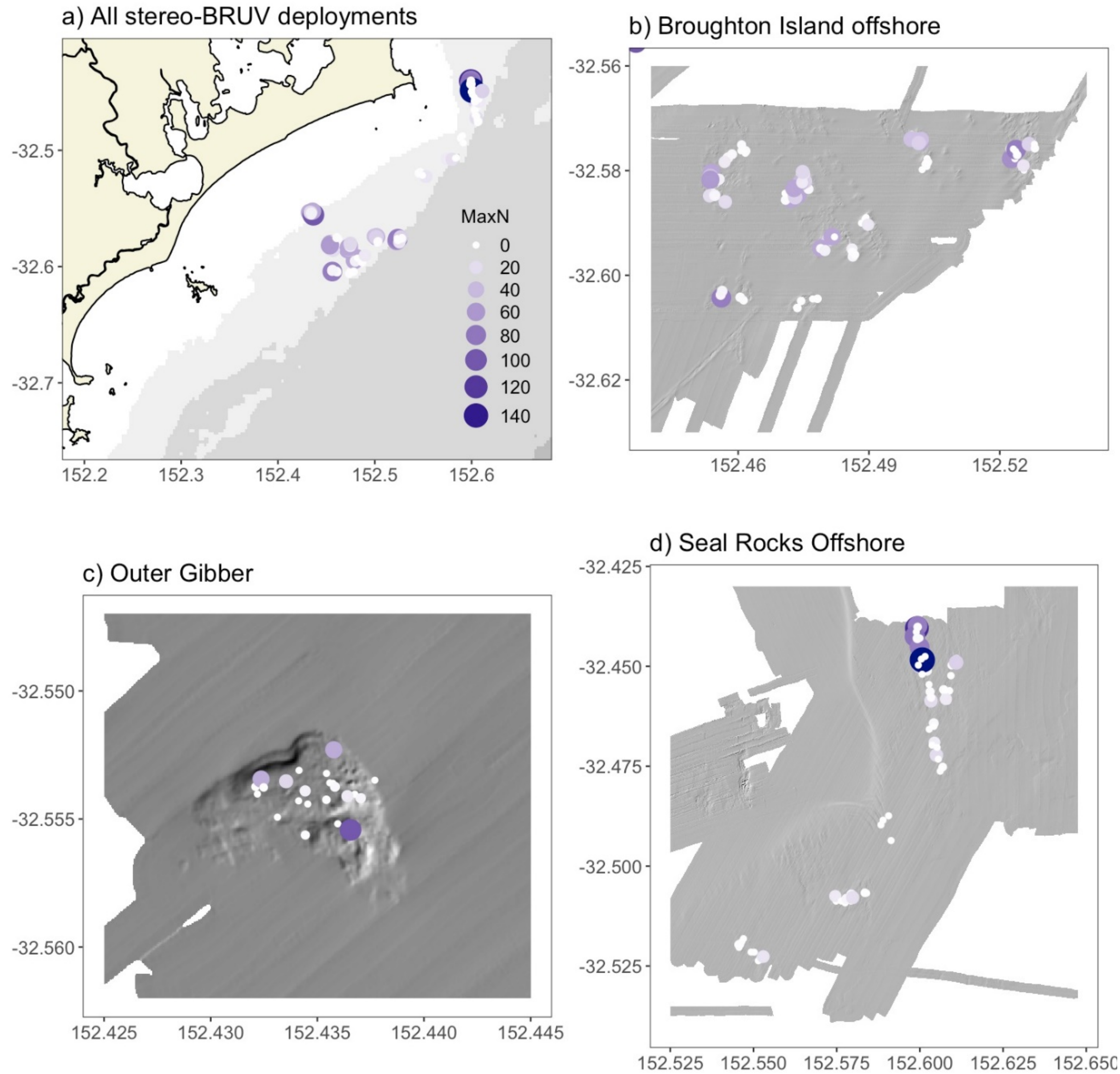


Figure 4-42. Bubble plots of yellowtail scad relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

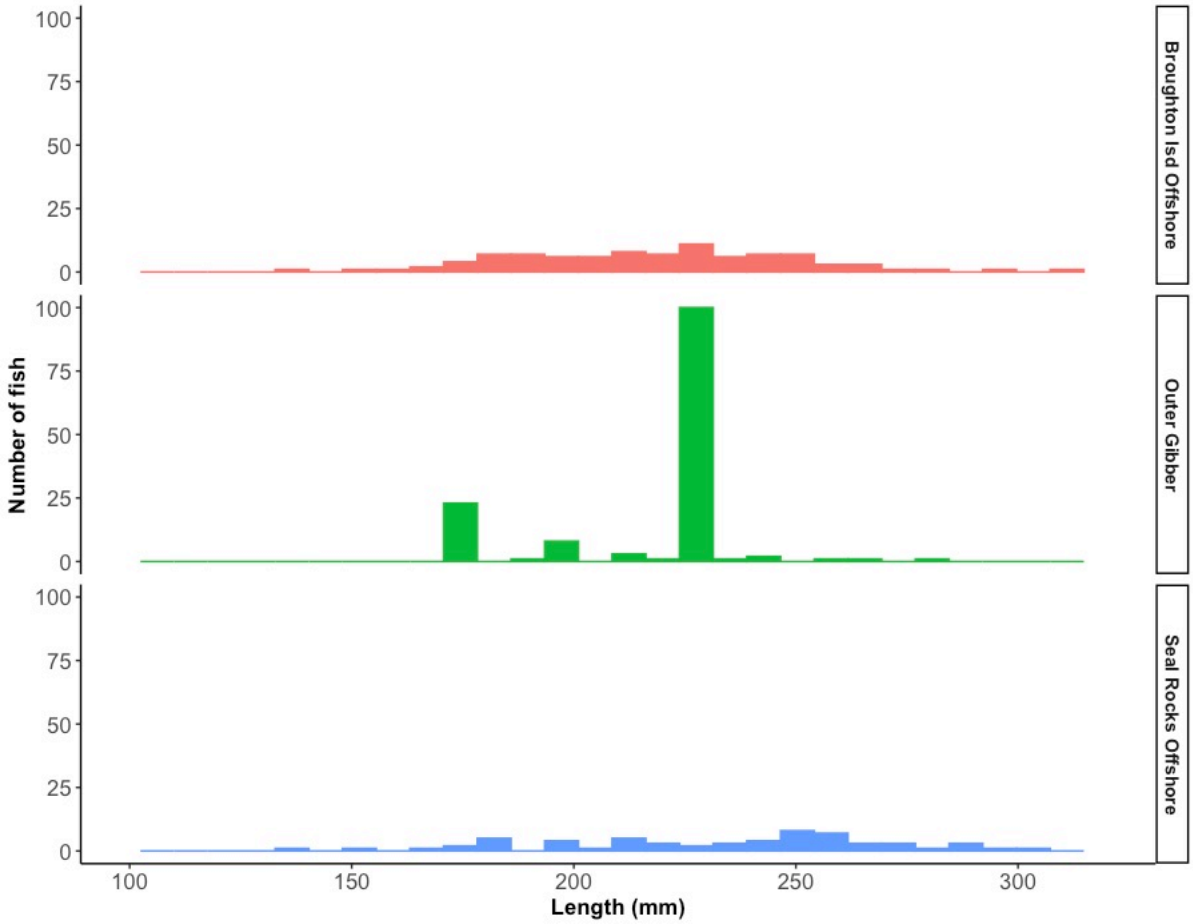


Figure 4-43. Histograms of the lengths for yellowtail scad at each of the three locations. There is no minimum legal length for retention of this species.

The lengths distribution for yellowtail scad were consistent across each location (Figure 4-43). Length of fish ranged from 120 mm to over 300 m, with a mean of 260 mm (Figure 4-43).

Velvet leatherjacket, Meuschenia scaber

Velvet leatherjacket is a common leatherjacket species in southern Australia. While they are a bycatch species in Australia there is a large commercial trawl fishery in New Zealand (Visconti et al. 2018a, 2018b). Velvet leatherjackets were ubiquitous across all three study locations and were recorded on 87% of stereo-BRUV deployments in schools of 1 to 26 fish (Figure 4-44 and Figure 4-45).

The best model for explaining the distribution of velvet leatherjacket included the factors location and interactions including aspect by location, kurtosis (25 m^2 and 105 m^2) by location (Figure 4-27 and Table 4.7). Abundances were highest at Broughton Island Offshore and Outer Gibber, and particularly on sections of reef that had highest variability in bathymetry at those locations (Figure 4-44 and Figure 4-45). Particularly, it was reef between 90 and 100 m that had the highest abundance of velvet leatherjacket (Figure 4-44 and Figure 4-45).

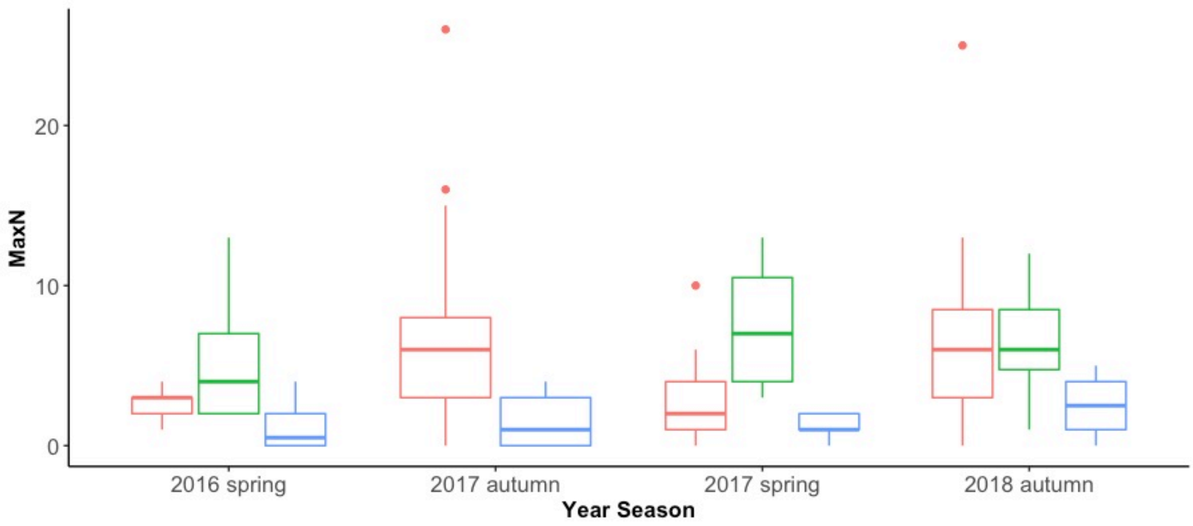


Figure 4-44. Boxplot of velvet leatherjacket relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

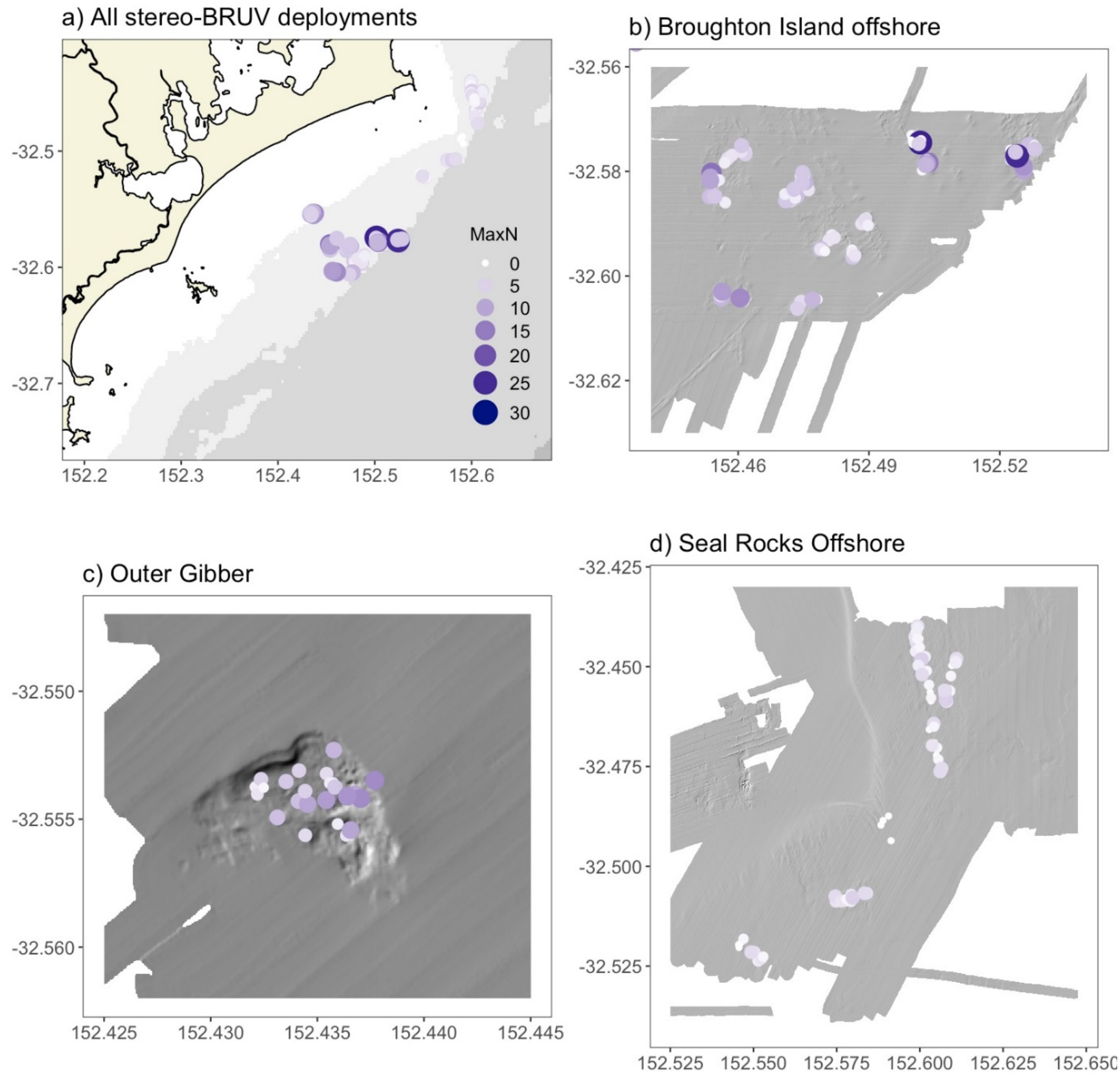


Figure 4-45. Bubble plots of velvet leatherjacket relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

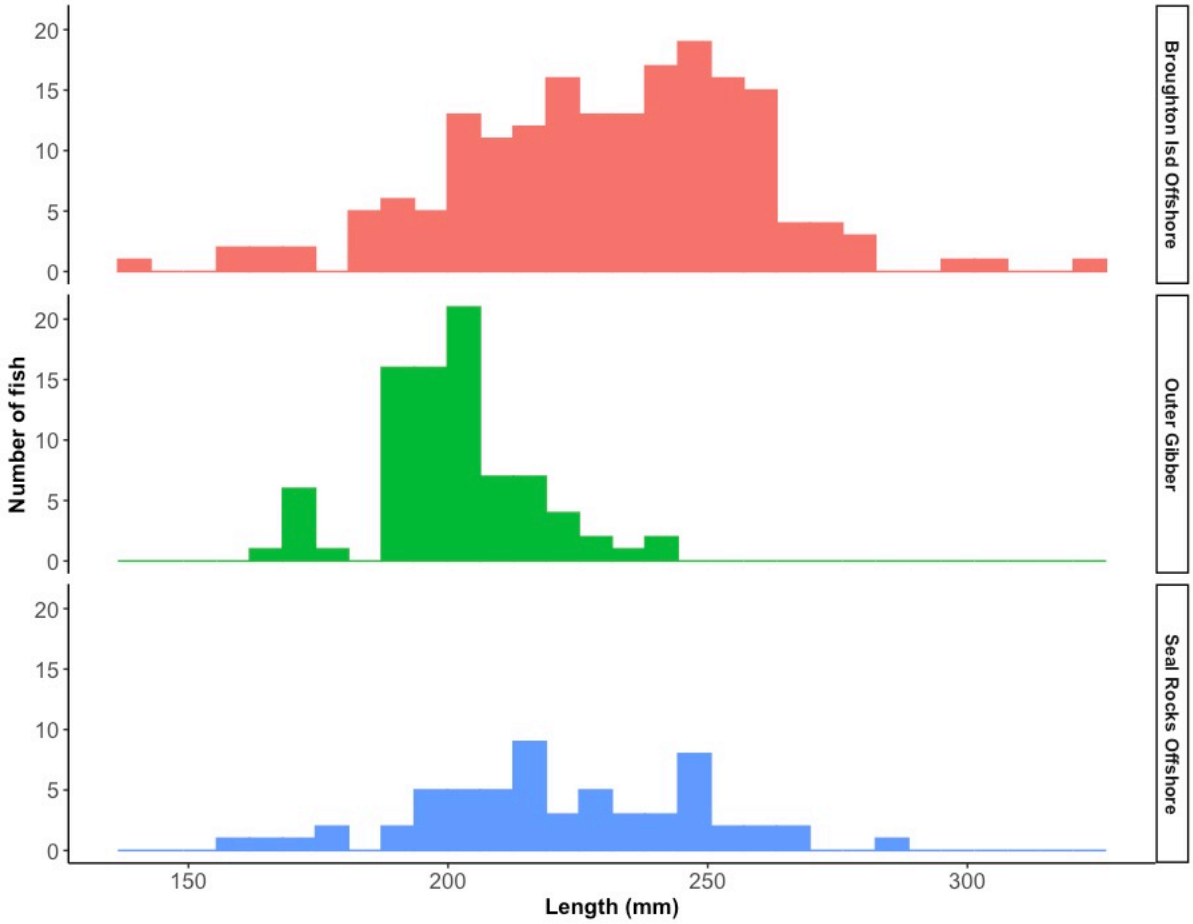


Figure 4-46. Histograms of the lengths for velvet leatherjacket at each of the three locations. There is no minimum legal length for retention of this species.

The distribution of lengths of velvet leatherjacket were very similar for the deeper location Broughton Island Offshore and Seal Rocks Offshore (Figure 4-46). Outer Gibber had a notably small size distribution (Figure 4-46). As the velvet leatherjacket isn't known to be a targeted fish for recreational fishers, it is unlikely this is a fishing effect and that it is mostly an ontogenetic shift from upper mesophotic reef to lower mesophotic reef.

Teraglin, Atractoscion aequidens

Teraglin are distributed from southern NSW to southern Queensland (Hegarty 2016) and also in the western Indian Ocean. While this species has been well studied in South Africa (Griffiths and Hecht 1995, Hutton et al. 2001, Henriques et al. 2014), very little is known about the life history and ecology in a NSW context (Hegarty 2016). Closely related to the well-known mulloway it is also targeted by recreational and commercial fishers. There is concern that stocks of teraglin have declined in NSW and the current status of this fishery is set as uncertain due to the lack of life history information (Hegarty 2016). Recent annual catches have been well below what has been previously reported (Hegarty 2016). There is also some evidence to suggest there has been range extension of this species (Hegarty 2016). Teraglin were recorded on 20% of stereo-BRUV deployments. On average, teraglin were observed in pairs but were occasionally seen in large schools of up to 25 fish.

Teraglin were most consistently observed at Outer Gibber but larger schools seemed to be more sporadic across all three locations (Figure 4-47 and Figure 4-48). The factors of season and bathymetry over 105 m^2, and interactions between aspect, latitude and season were selected in the best model for teraglin (Figure 4-27 and Table 4.7). Abundances of teraglin were slightly higher during spring cold-water period (Figure 4-47 and Figure 4-48), with teraglin often seen schooling on top of high relief reefs.

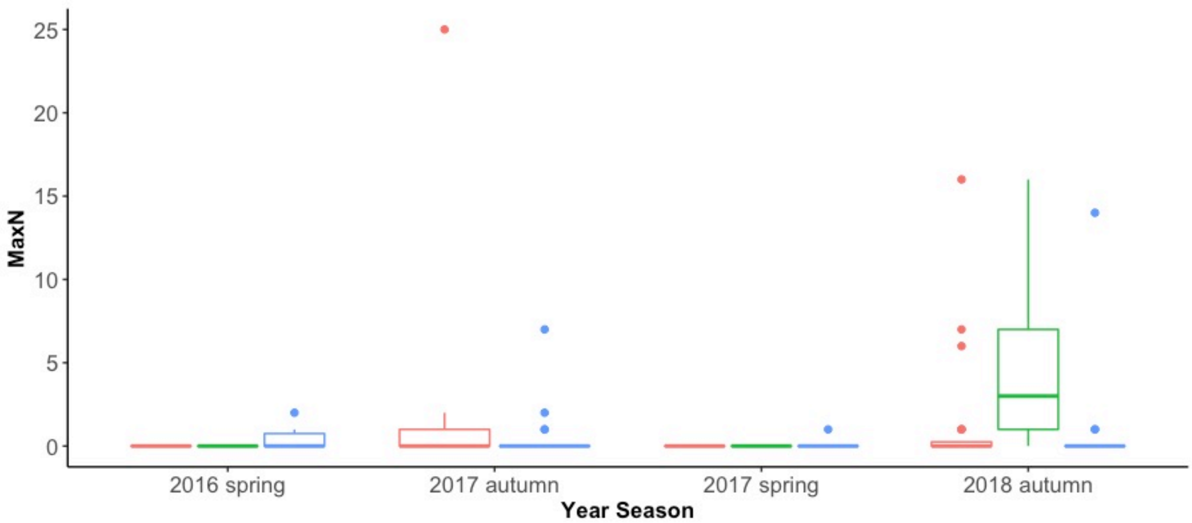


Figure 4-47. Boxplot of teraglin relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

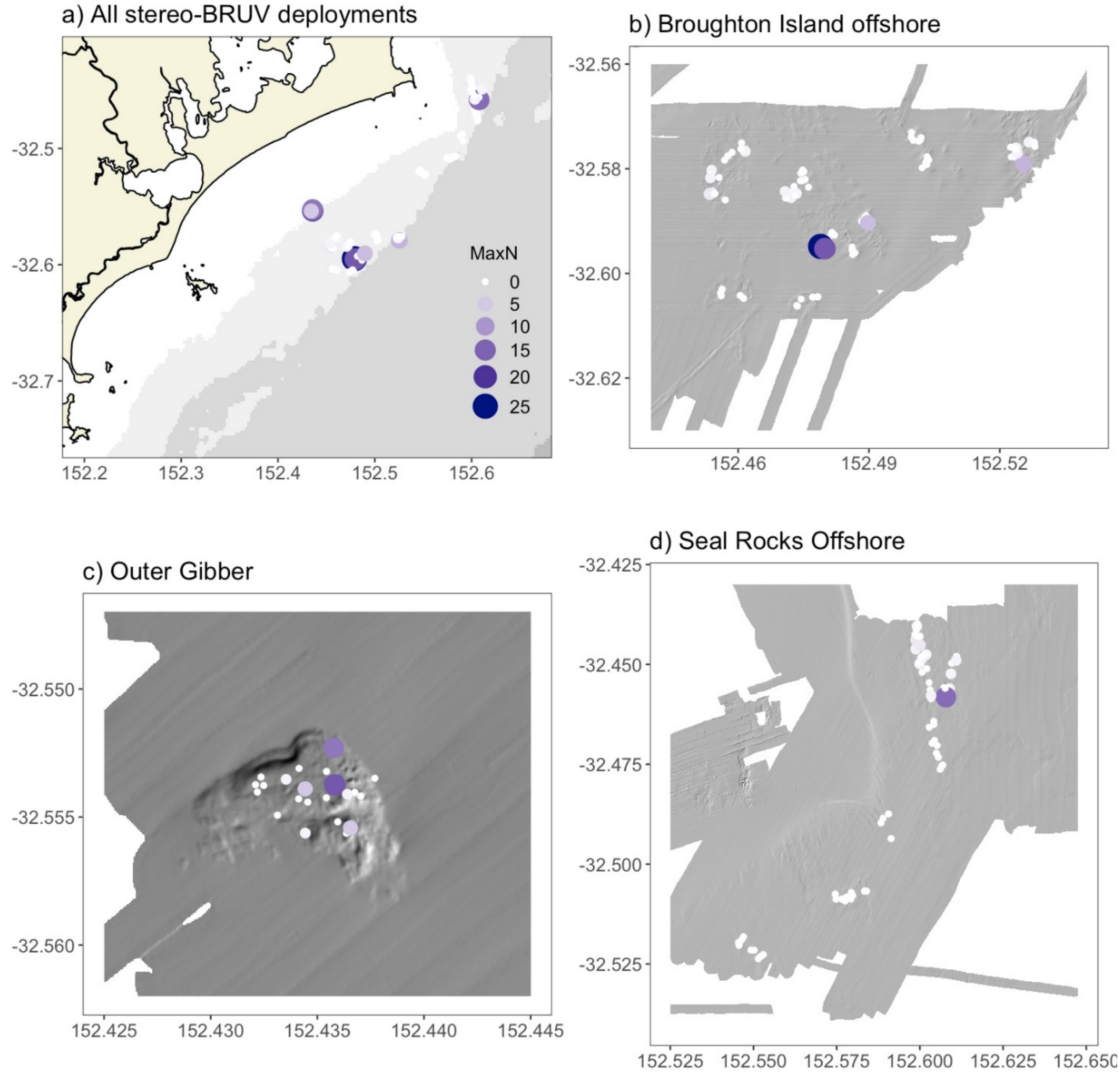


Figure 4-48. Bubble plots of teraglin relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

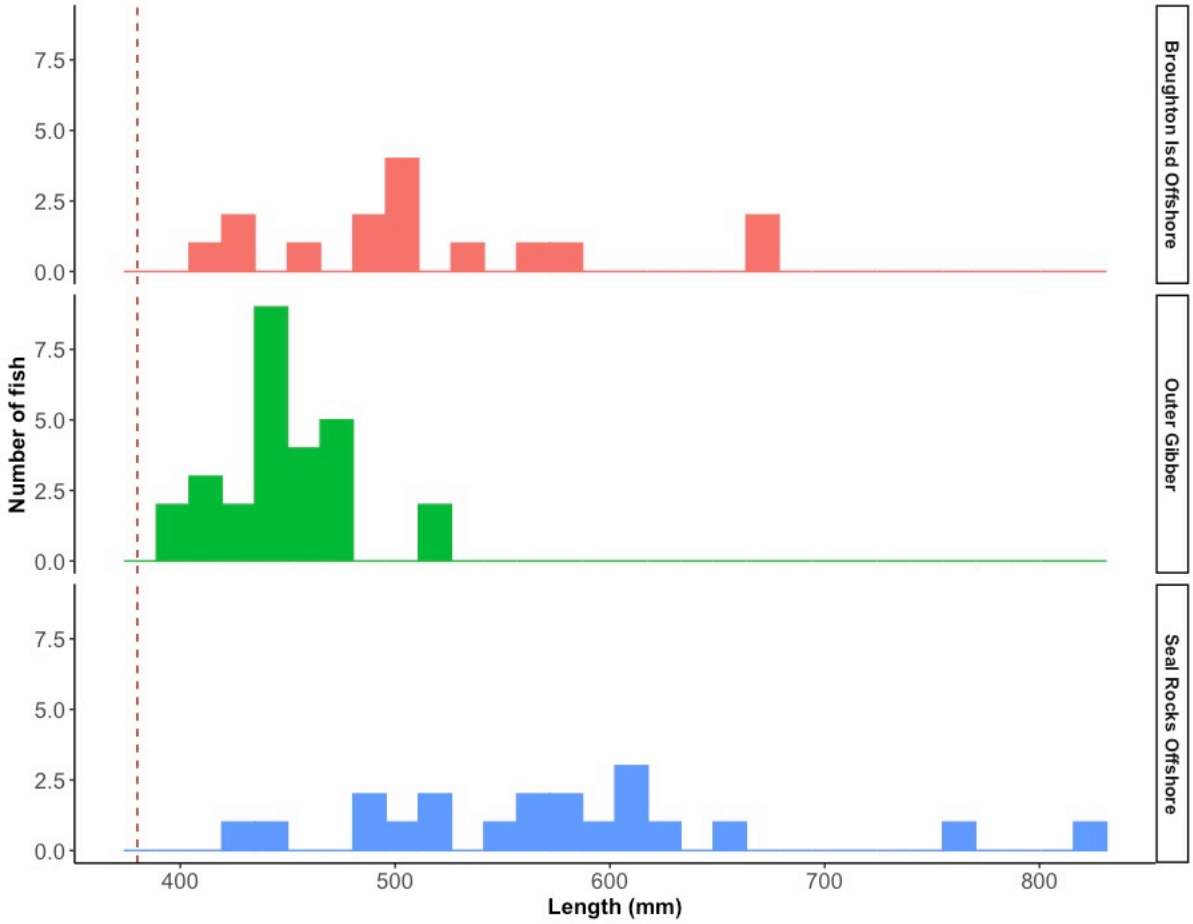


Figure 4-49. Histograms of the lengths for teraglin at each of the three locations. The dashed red line represents the minimum legal length for retaining in NSW.

All teraglin that were observed and measured during this study were above the minimum legal length (MLL; Figure 4-49). This suggest that all fish were sexually mature adults (Hegarty 2016). However, fish observed at both Broughton Island Offshore and Seal Rocks Offshore had larger fish (Figure 4-49). This was particularly the case with Seal Rocks Offshore that had several fish >600 mm in length (Figure 4-49).

Pearl perch, Glaucosoma scapulare

Pearl perch are endemic to NSW and southern Queensland (Stewart et al. 2013, Sumpton et al. 2017). They are a very popular food fish and are caught by recreational and commercial fishers. Catches of pearl perch have declined dramatically over the last couple of decades to a depleted stock (Roelofs and Stewart 2018). During this study, pearl perch were observed on 20% of stereo-BRUV deployments. They were mainly observed as 1 or 2 fish but were occasionally observed in schools of up to 9 fish (Figure 4-50 and Figure 4-51).

The best model that explained the distribution of pearl perch included the factors location and ruggedness as well as the interaction between location and northness (Figure 4-27 and Table 4.7). The location effect is primarily driven by the consistently higher abundance of Pearl Perch on reefs in the northern half of Seal Rocks Offshore (Figure 4-50 and Figure 4-51). Stereo-BRUV deployments in this region tended to be in the north aspect of the reef. There were no pearl perch recorded at the shallower Outer Gibber location (Figure 4-50 and Figure 4-51). At Seal Rocks Offshore and Broughton Island Offshore, the higher the ruggedness of the reef the higher the abundance of pearl perch.

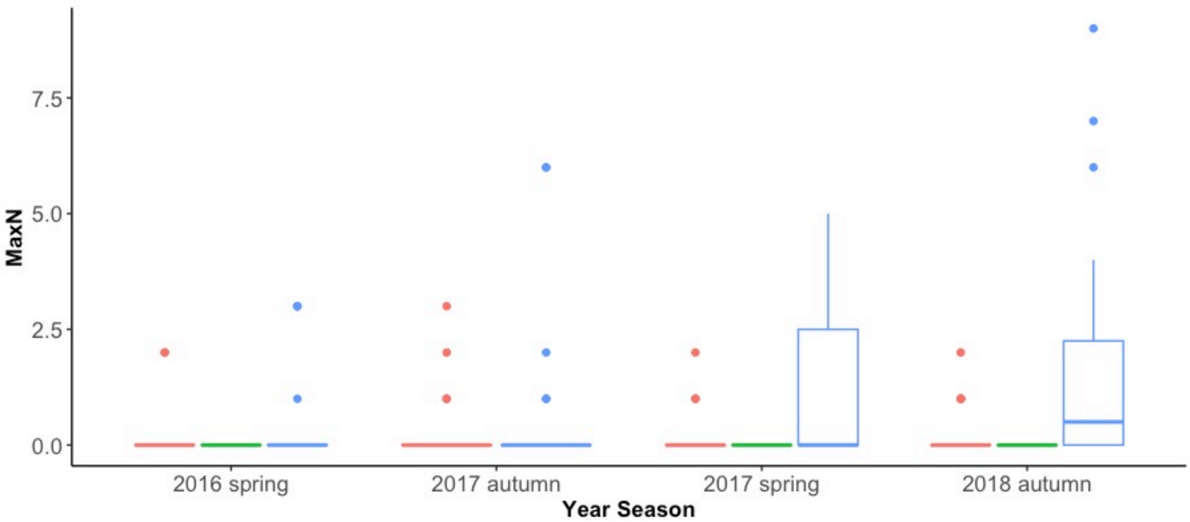


Figure 4-50. Boxplot of pearl perch relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

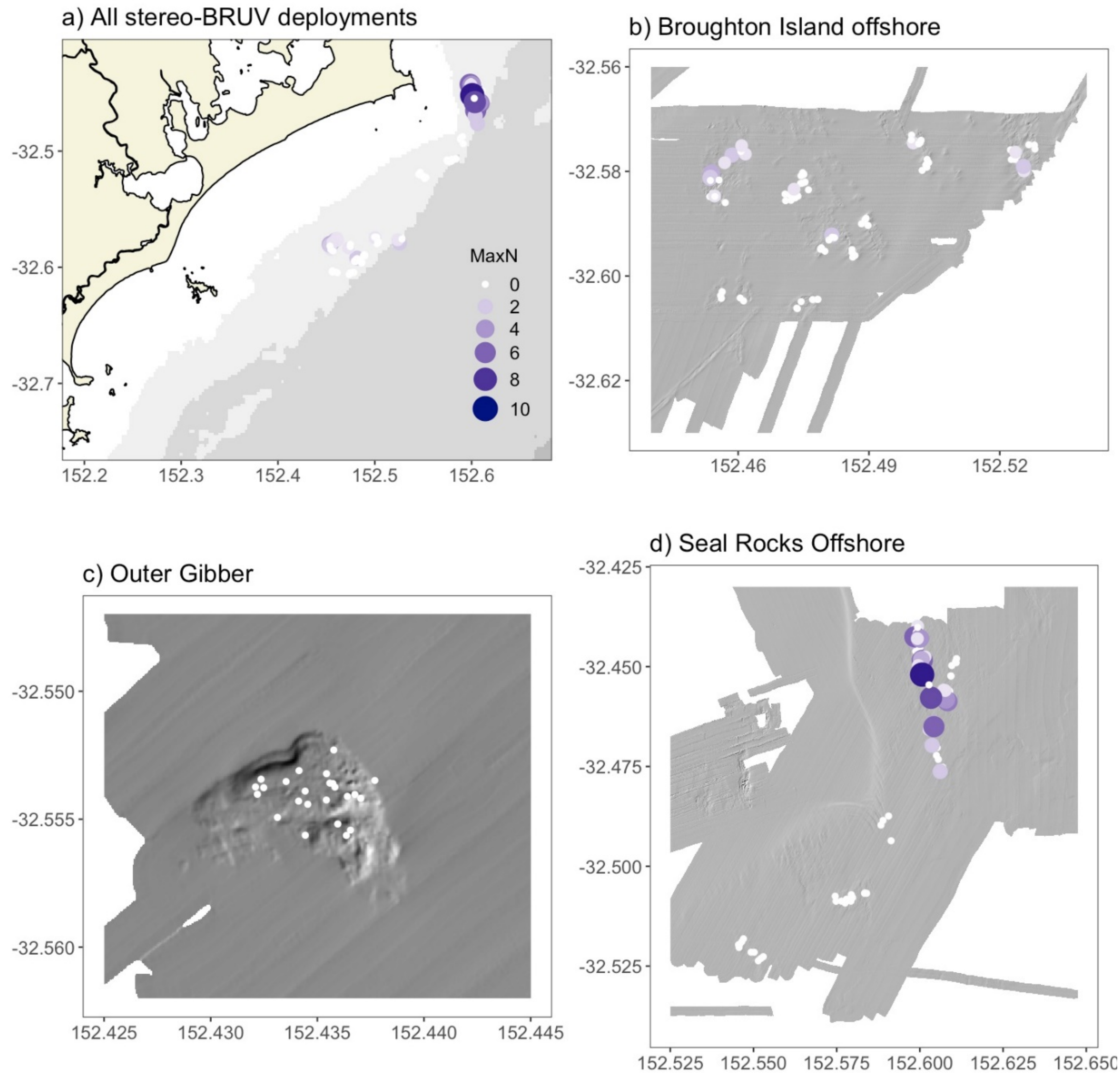


Figure 4-51. Bubble plots of pearl perch relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

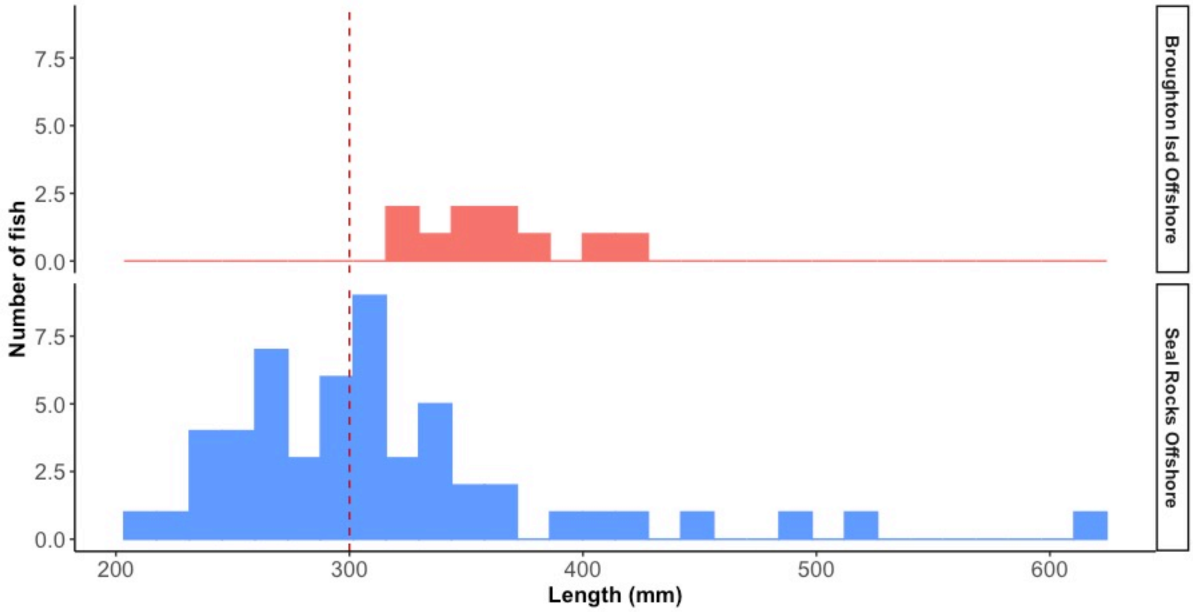
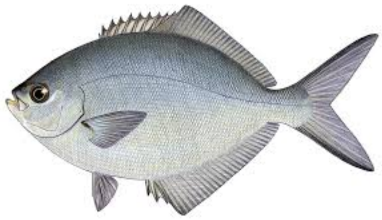


Figure 4-52. Histograms of the lengths for pearl perch at two locations (no pearl perch were observed at Outer gibber). The dashed red line represents the minimum legal length for retaining in NSW.

The majority of fish measured were above the minimum legal length (MLL) for retainment by fisheries (Figure 4-52). Therefore, the majority of these fish are considered to be sexually mature adults. All pearl perch at Outer Gibber were above the MLL.

Figure 4-53. A school of pearl perch recorded at Broughton Island Offshore in 93 m of water.

Silver sweep, Scorpis lineolata



A moderate sized schooling pelagic species that was thought to only inhabitant shallow reef (<30 m). However, during this study, Silver Sweep were observed at depths of 100 m. Silver sweep are often overlooked as they are thought to be highly abundant and common on all temperate reefs. However, they are a slow growing, long-lived fish capable of reaching ages of 50 years (Stewart and Hughes 2005). Therefore, silver sweep may respond to the removal of pressures such as fishing through spatial management (e.g. marine parks and no-take zones).

In this study, silver sweep was observed on 14% of stereo-BRUV deployments in schools varying from 1 to 25 fish (Figure 4-54 and Figure 4-55). The model that best explained the distribution of silver sweep included the factors latitude and season and the interactions between BPI and season, ruggedness and season (Figure 4-27 and Table 4.7). The highest abundance of silver sweep were recorded at Outer Gibber and the most northern deployments at Seal Rocks Offshore (Figure 4-54 and Figure 4-55). In spring, silver sweep were highly abundant on reef with high ruggedness and BPI (Appendix B).

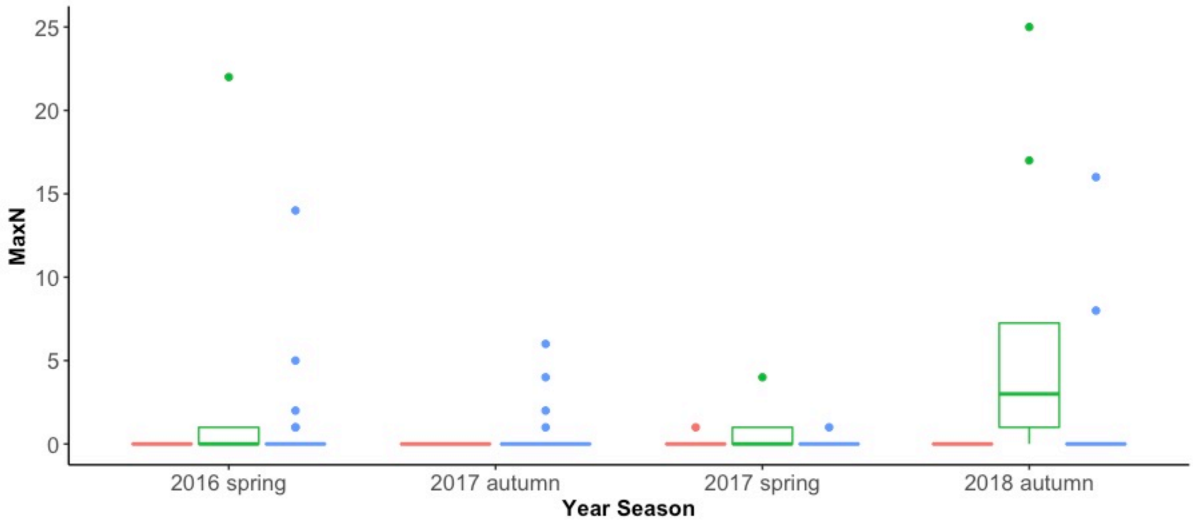


Figure 4-54. Boxplot of silver sweep relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

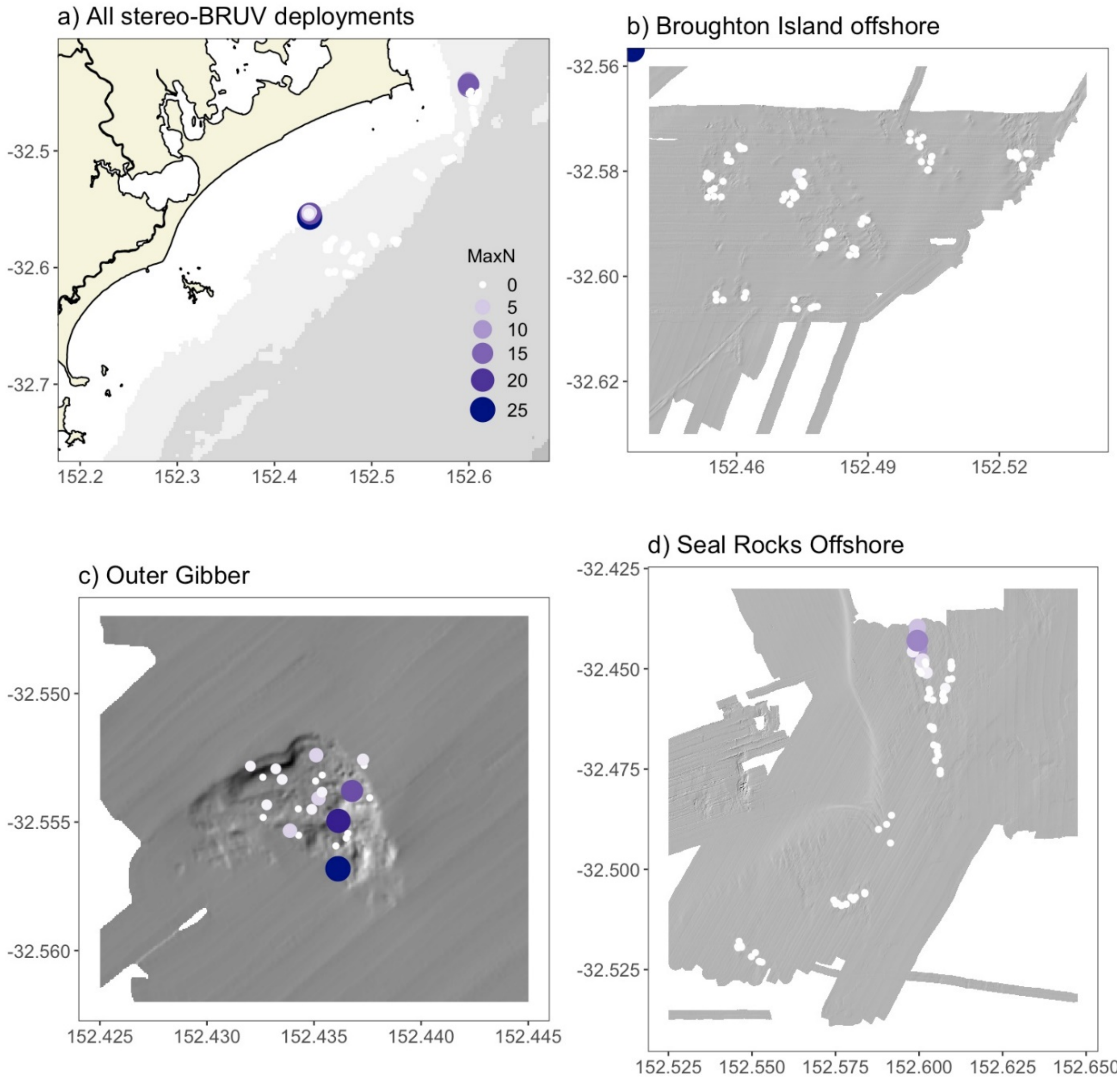


Figure 4-55. Bubble plots of silver sweep relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

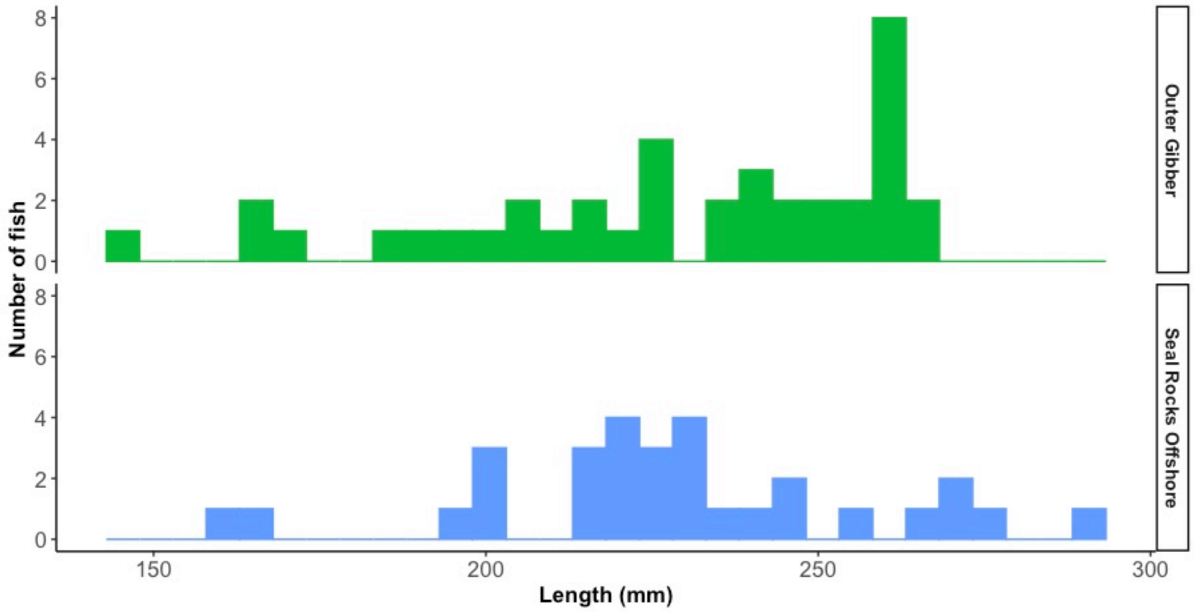


Figure 4-56. Histograms of the lengths for silver sweep at two locations (there were no length measurements for Broughton Island Offshore). There is no minimum legal length for retention of this species.

The length distribution for silver sweep were very similar between Outer Gibber and Seal Rocks Offshore (Figure 4-56). No silver sweep measurements were available for Broughton Island Offshore. There is currently no minimum legal length for retainment of silver sweep in NSW.

Reef ocean perch, Helicolenus percoides

The reef ocean perch is a relatively common species around reef in 80-350 m of water (Withell and Wankowski 1988, Seiler et al. 2012). It is a species retained by the south east trawl fishery. Reef Ocean Perch were observed on 46% of stereo-BRUV deployments during this study (Figure 4-58 and Figure 4-59). They were often observed in numbers between 1 and 7 fish.

The model that best explained the distribution for reef ocean perch included the factor location and the interactions between location and kurtosis and location by northness (Figure 4-27 and Table 4.7). The effect of location is due to the fact this is a deep reef species that was only observed at Broughton Island Offshore and Seal Rocks Offshore (Figure 4-58 and Figure 4-59). The kurtosis and northness effect were driven by ocean reef perch being observed on reef edges, often when sediment was in view.

The size distribution of reef ocean perch was very similar between both Seal Rocks Offshore and Broughton Island Offshore with length ranging from 130 to 280 mm (Figure 4-59).

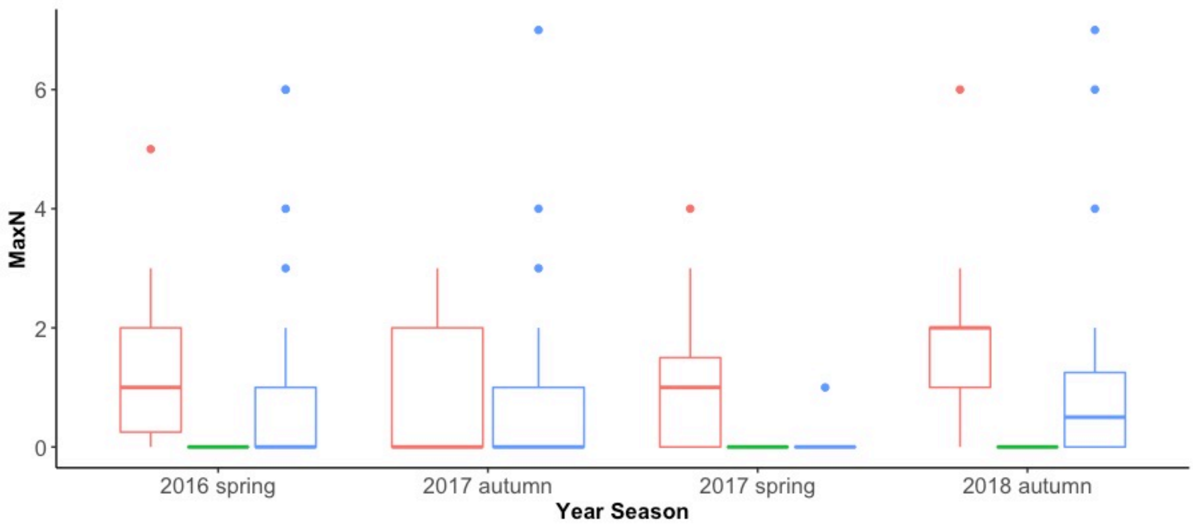


Figure 4-57. Boxplot of reef ocean perch relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

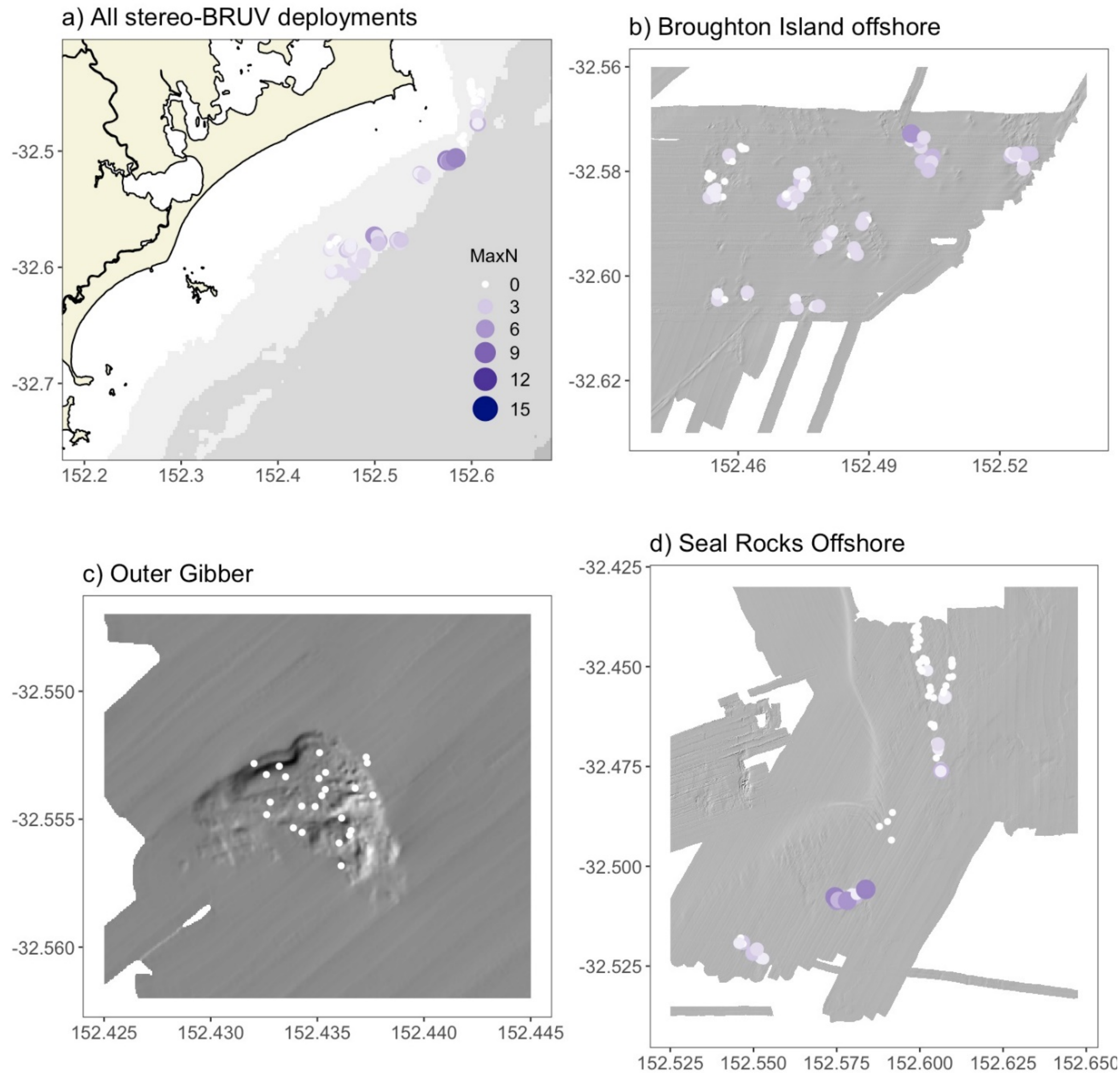


Figure 4-58. Bubble plots of reef ocean perch relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

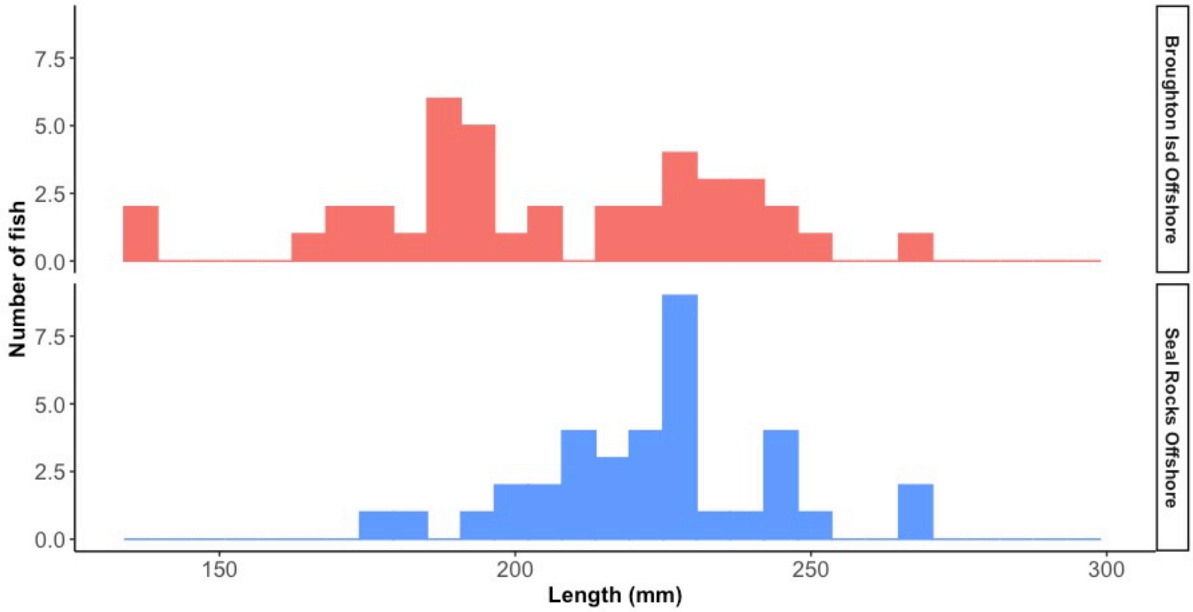


Figure 4-59. Histograms of the lengths for ocean reef perch at two locations (no ocean reef perch were observed at Outer Gibber). There is no minimum legal length for retention of this species.

Sawtooth moray, Gymnothorax prionodon

The sawtooth moray inhabits reefs in warm temperate regions of Australia, Japan, Taiwan and New Zealand (Bohlke and McCosker 2001, Malcolm 2016). Sawtooth Moray were observed on 50% of stereo-BRUV deployments, and on average recorded as single fish, but in several instances in abundances of 4 or 5 fish. Sawtooth moray were observed on every stereo-BRUV deployment at Broughton Island Offshore and the northern half of Seal Rock Offshore (Figure 4-60 and Figure 4-61). No sawtooth morays were recorded at Outer Gibber.

The model that best explained the distribution of sawtooth moray included the factors status and kurtosis as well as the interaction between bathymetry mean and status (Figure 4-27 and Table 4.7). This interaction is primarily driven by the numbers of sawtooth moray at shallower location in the no-take zone at Seal Rocks Offshore compared to the high abundances at the deeper sites at Broughton Island Offshore (Figure 4-60 and Figure 4-61). These are also locations with reef that has high variability in bathymetry. It is these reefs that provide cracks, crevices and ledges for morays to inhabit.

Moray eels are very difficult measure on stereo-BRUV. Therefore, there were insufficient measurements to warrant plotting and analysing.

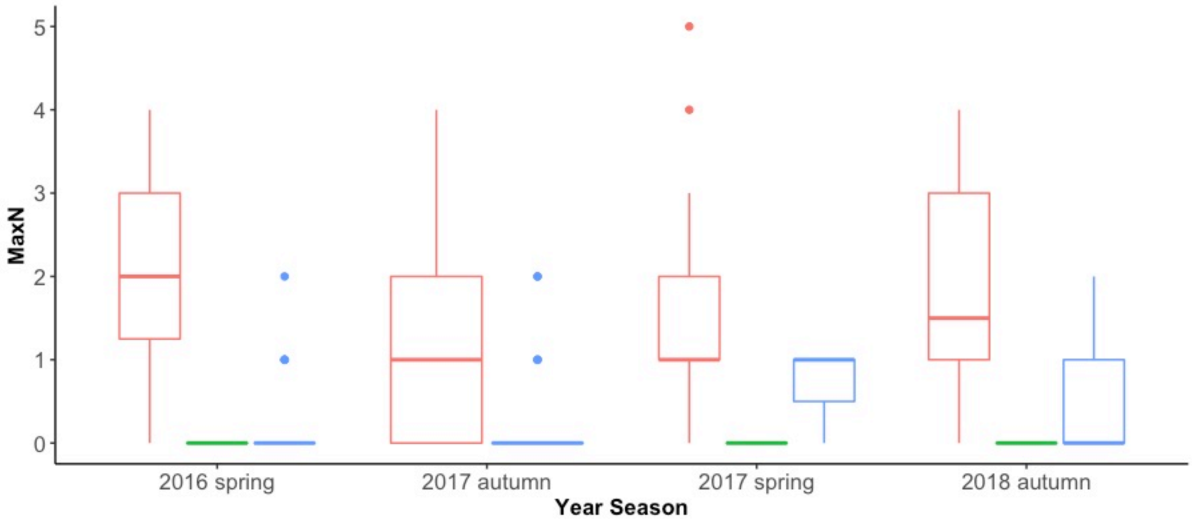


Figure 4-60. Boxplot of sawtooth moray relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

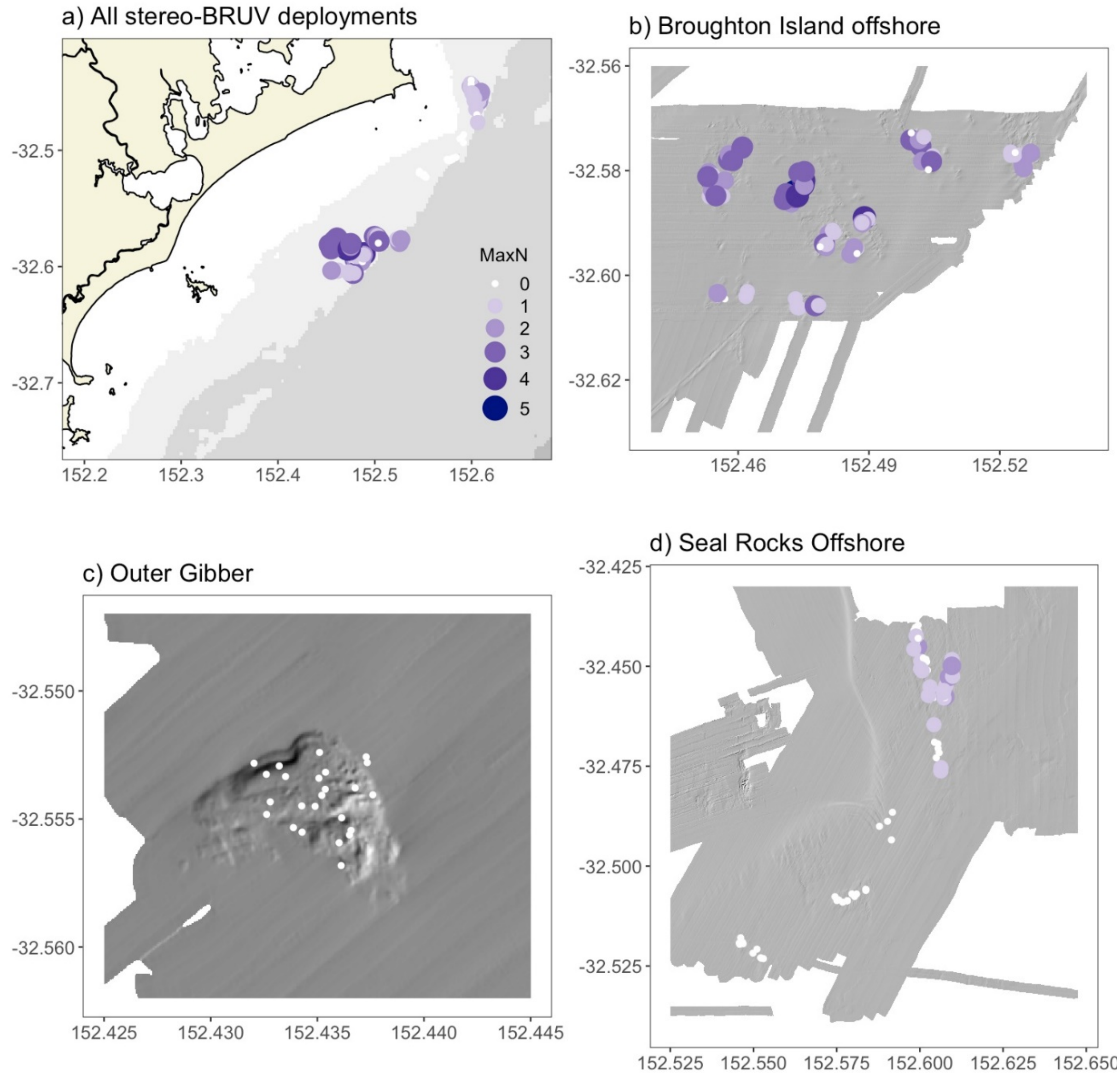


Figure 4-61. Bubble plots of sawtooth moray relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

Bluespotted flathead, Platycephalus caeruleopunctatus

Flathead species are a soft sediment dwelling, ambush predator and given that this study aimed to sample rocky reef, stereo-BRUVs are not likely the best method for sampling this species (Fetterplace et al. 2016). However, given it is the species with the highest recreational fishing retainment rate in NSW it was considered worth reporting (Lynch et al. 2020b, 2020a).

Bluespotted flathead were observed on 35% of stereo-BRUV deployments during this study (Figure 4-62 and Figure 4-63). The best model that explained the distribution of bluespotted flathead included the factors latitude, depth, kurtosis and northness (Figure 4-27 and Table 4.7). The highest abundances of bluespotted flathead were recorded at Seal Rocks on reef with low complexity or on reef edge. No bluespotted flathead were recorded at Outer Gibber. This is likely due to the fact Outer Gibber is one large rocky reef compared to Broughton Island Offshore and Seal Rocks Offshore that are fragmented reef and stereo-BRUVs would often land on reef edge.

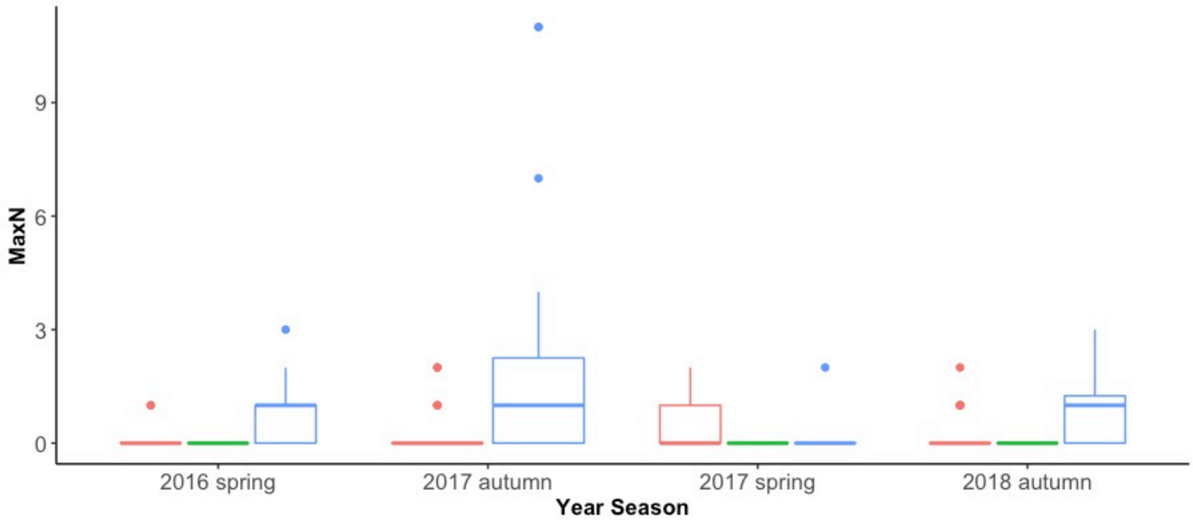


Figure 4-62. Boxplot of bluespotted flathead relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

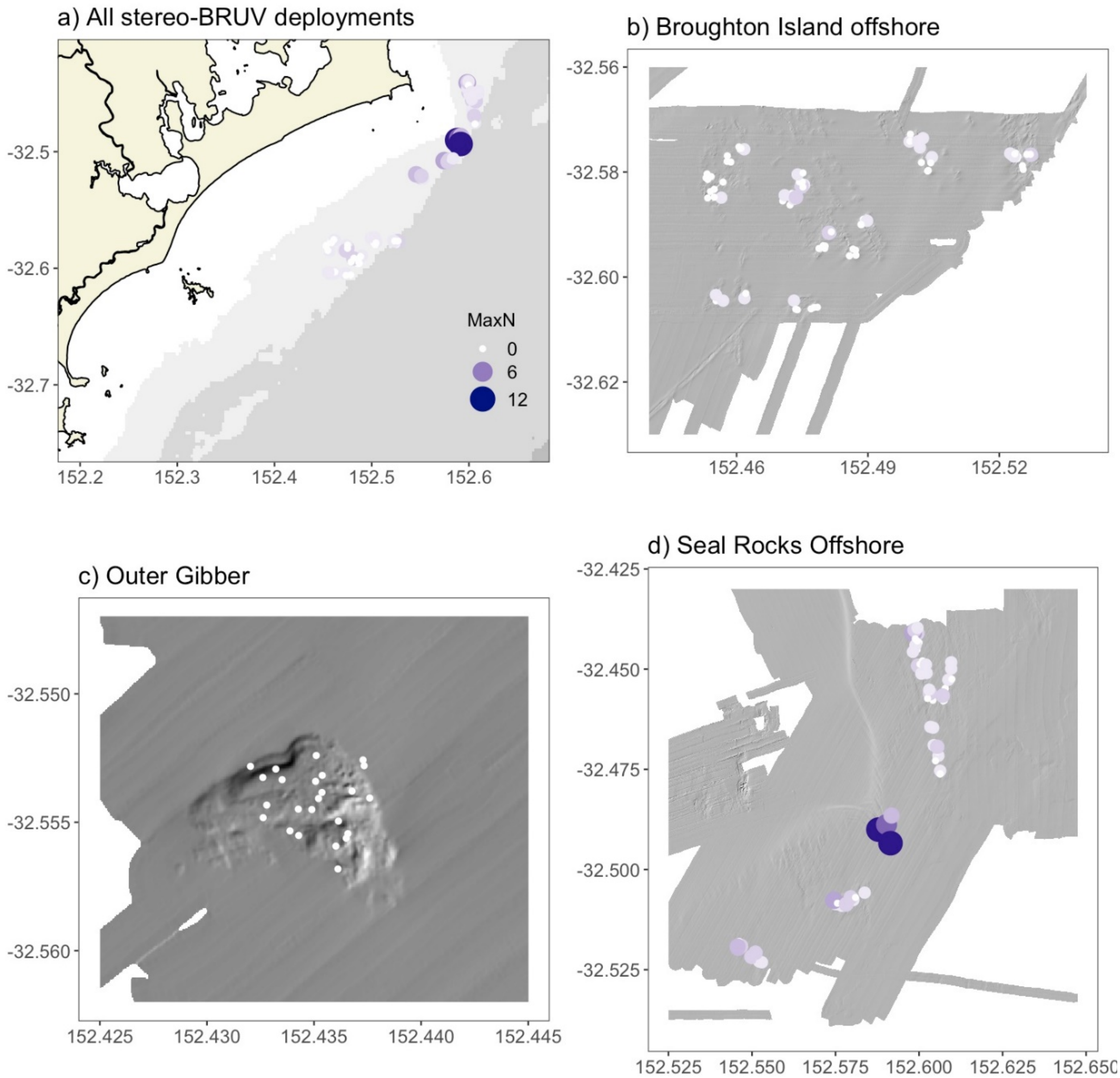


Figure 4-63. Bubble plots of bluespotted flathead relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

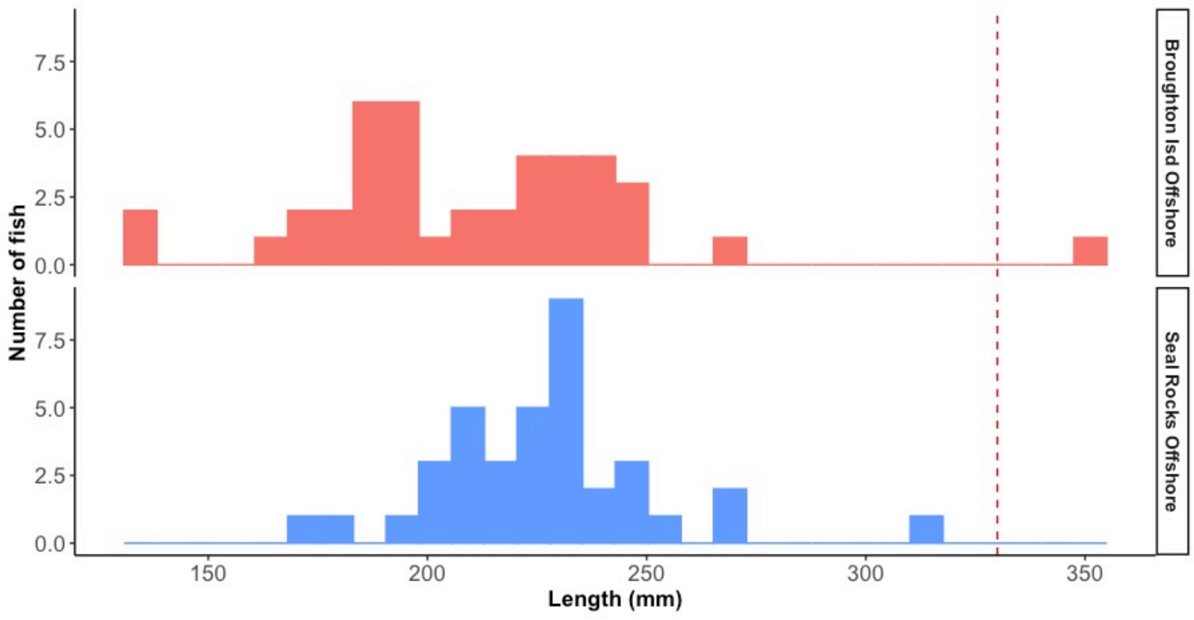


Figure 4-64. Histograms of the lengths for bluespotted flathead at two locations (no bluespotted flathead were observed at Outer gibber). The dashed red line represents the minimum legal length for retaining in NSW.

The size distribution of bluespotted flathead was very similar between locations (Figure 4-64). Interestingly, only one fish measured above the minimum legal length (MLL) for retainment. This could be either due to fishing pressure or juvenile bluespotted flathead migrate to deeper reefs to mature. Further research would be required to understand this pattern.

Eastern Pigfish, Bodianus unimaculatus

The eastern pigfish was the only Labrid species that was recorded at multiple locations. While it is not highly targeted by fishers it is still a species that is often retained. It is also a species that responds to spatial management and marine parks (Denny and Babcock 2004, Anderson and Millar 2004, Knott et al. 2020). Despite being known to be abundant on reefs in 6-60 m of water, during this study they were only recorded on reef between 80-100 m at Broughton Island Offshore and Seal Rocks Offshore (Figure 4-65 and Figure 4-66).

The best model that explained the distribution of eastern pigfish included the factors depth and BPI (Figure 4-27 and Table 4.7). Eastern pigfish were commonly observed on deeper reefs with high variability in bathymetry at both Seal Rocks Offshore and Broughton Island Offshore (Figure 4-65 and Figure 4-66)

The length distribution of eastern pigfish was very similar between the two locations (Figure 4-67). There were a few larger fish measured at Seal Rocks Offshore compared to Broughton Island Offshore.

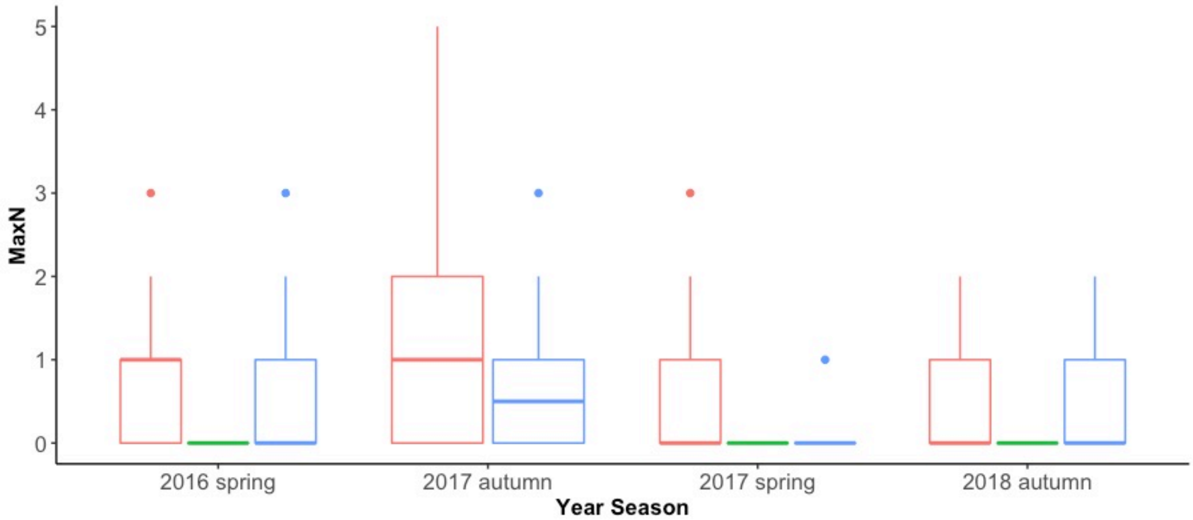


Figure 4-65. Boxplot of eastern pigfish relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

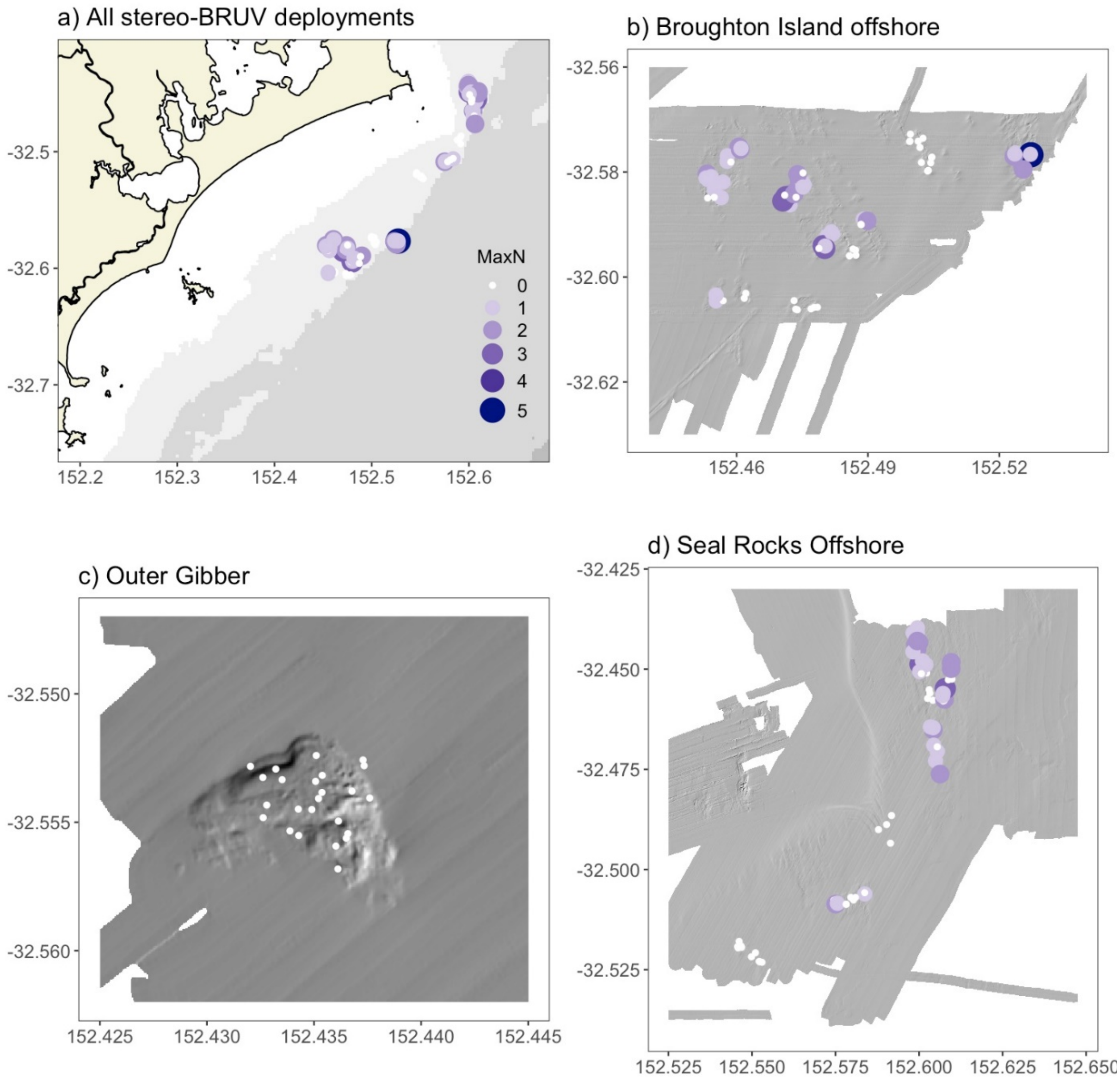


Figure 4-66. Bubble plots of eastern pigfish relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

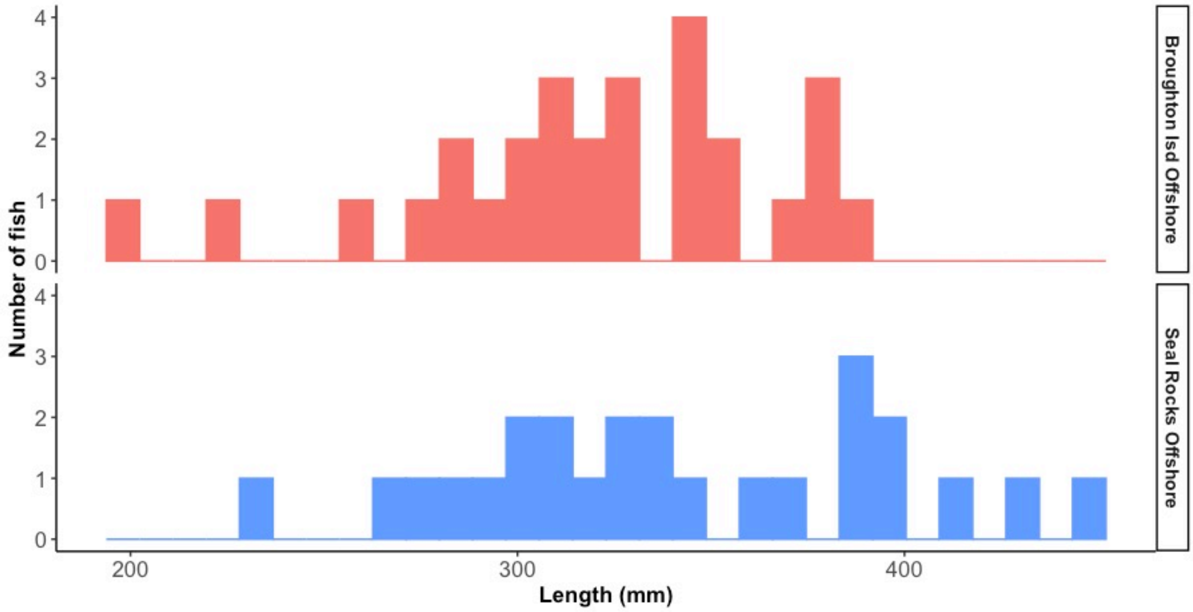
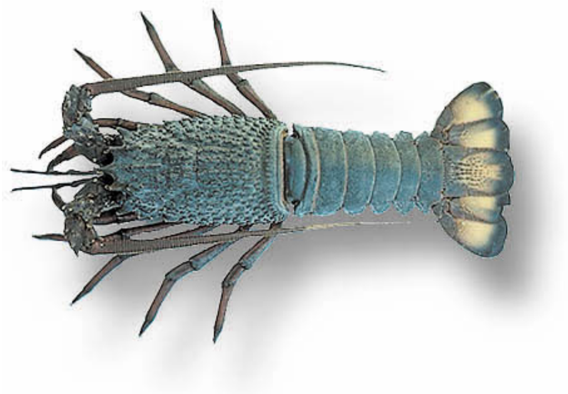


Figure 4-67. Histograms of the lengths for eastern pigfish at two locations (no eastern pigfish were observed at Outer Gibber). There is no minimum legal length for retention of this species.

Eastern rock lobster, Sagmariasus verreauxi

Eastern rock lobster are a highly valuable fishery in NSW (Liggins 2018, Liggins et al. 2018). While it was not expected that stereo-BRUV would observe lobsters, they were repeatedly recorded during this study. Interestingly, they have never been recorded on stereo-BRUVs during 10 years of Port Stephens - Great Lakes Marine Park monitoring of shallower reefs (pers comms). It is possible that lobsters are more bold or larger and bolder on deeper, darker mesophotic reef.



The Eastern Rock Lobster were recorded on 11% of stereo-BRUV deployments and only at Broughton Island Offshore and Seal Rock Offshore (Figure 4-68 and Figure 4-69). The best model for explaining the distribution of Eastern Rock Lobster included the factors status, season and the interactions between bathymetry mean and status and curvature by season (Figure 4-27 and Table 4.7). The highest abundances of Eastern Rock Lobster occurred in the no-take zone of the Port Stephens - Great Lakes Marine Park during spring (Figure 4-68 and Figure 4-69). This timing coincides with when lobsters move from the outer shelf to the inner shelf. Seal Rocks Offshore (in commonwealth water) is also a popular location for commercial trapping of eastern rock lobsters.

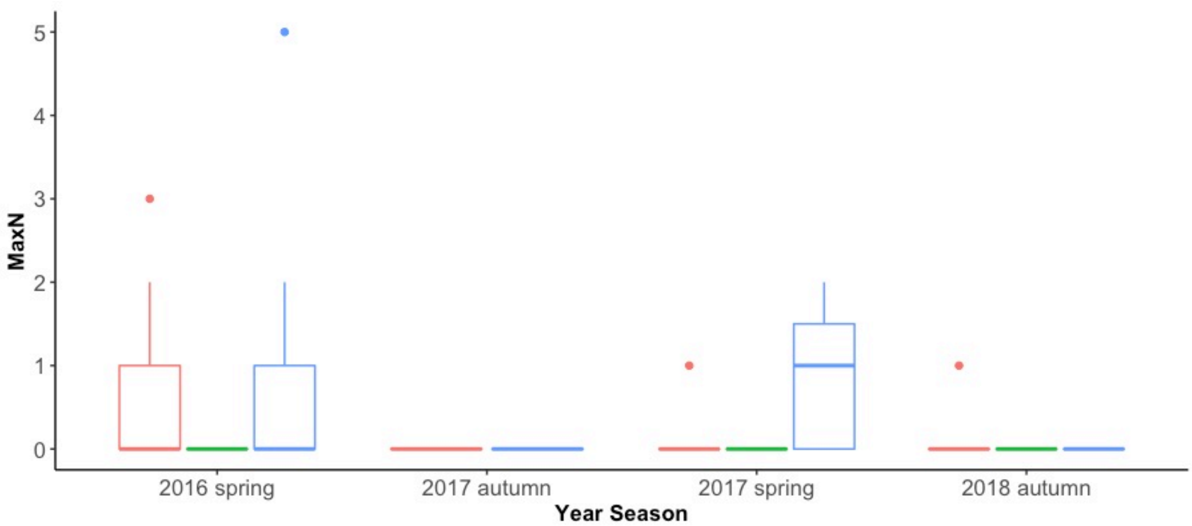


Figure 4-68. Boxplot of eastern rock lobster relative abundance (MaxN) for each year, season and location (■ Broughton Island Offshore, ■ Outer Gibber and ■ Seal Rocks Offshore). The boxes represent the interquartile range of the data, the bottom line is the 25th percentile, top line is the 75th percentile and the bold middle line represent the median data point for that group. The whiskers or vertical line coming out of the box represent smallest and largest values with 1.5 times above or below the interquartile range. The dots represent outliers.

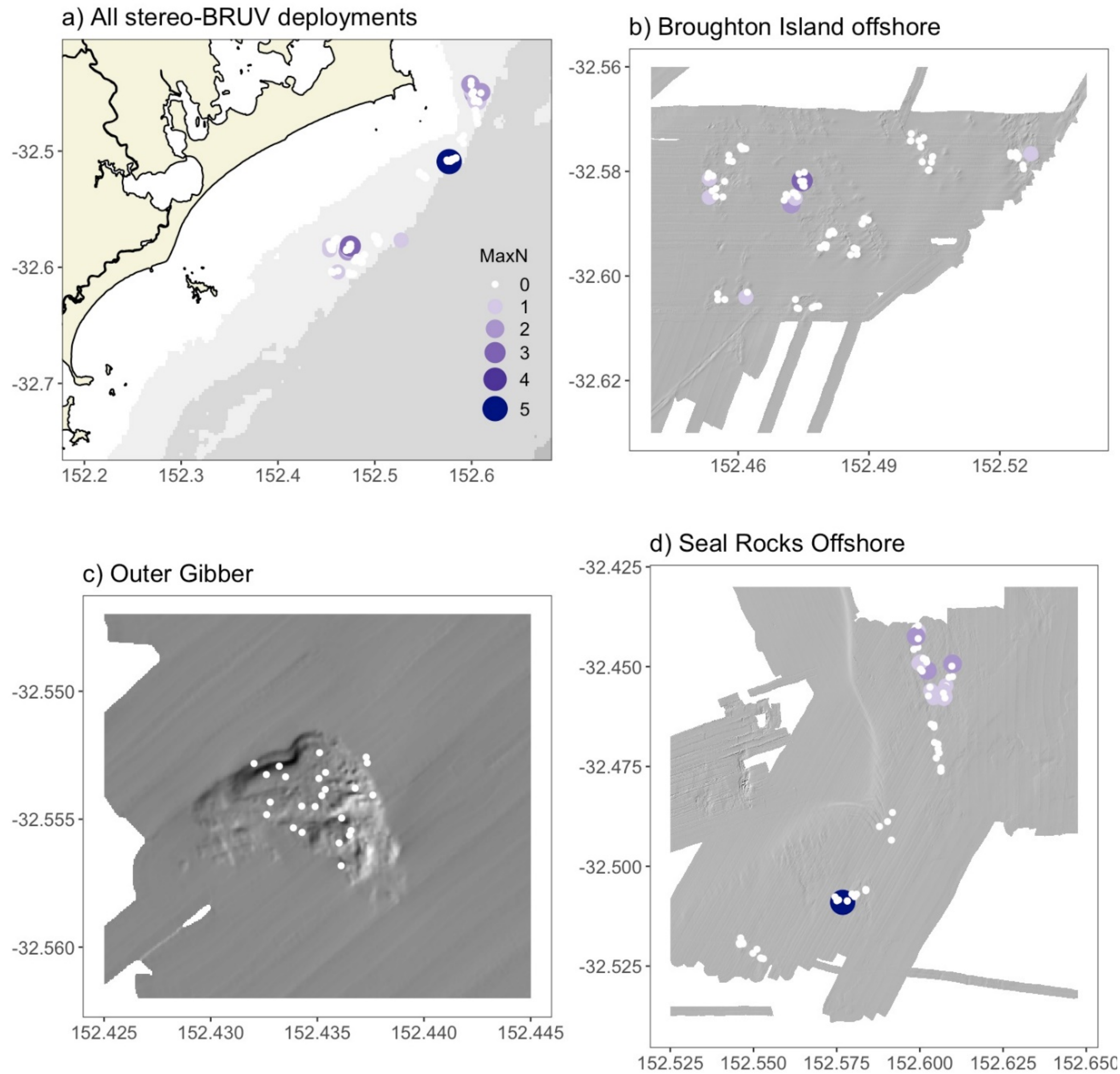


Figure 4-69. Bubble plots of eastern rock lobster relative abundance (MaxN) at individual stereo-BRUV deployments. The larger the bubble and darker blue, the higher the relative abundance recorded on a stereo-BRUV deployment.

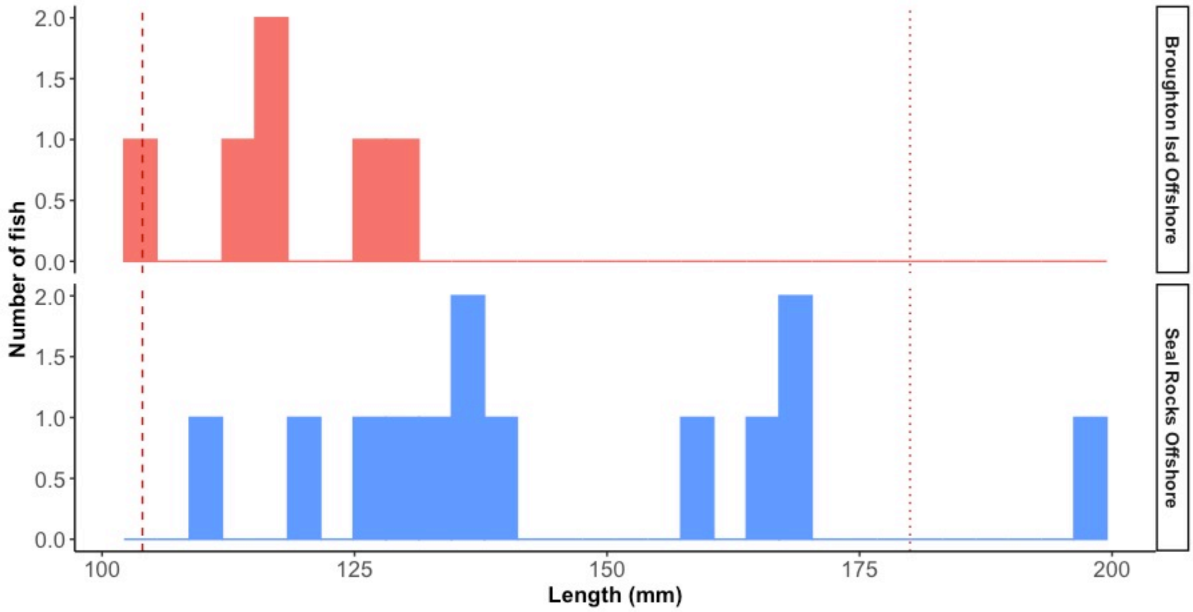


Figure 4-70. Histograms of the lengths for Eastern Rock Lobster at each of the three locations (no Eastern Rock Lobster were observed at Outer Gibber). The dashed red line represents the minimum legal length for retaining in NSW and the dotted line represent the maximum size for retaining.

All eastern rock lobsters that were measured (carapace length) during this study were within the legal-size limits, except one that measured 190 mm and was above the maximum size for retainment (Figure 4-70).

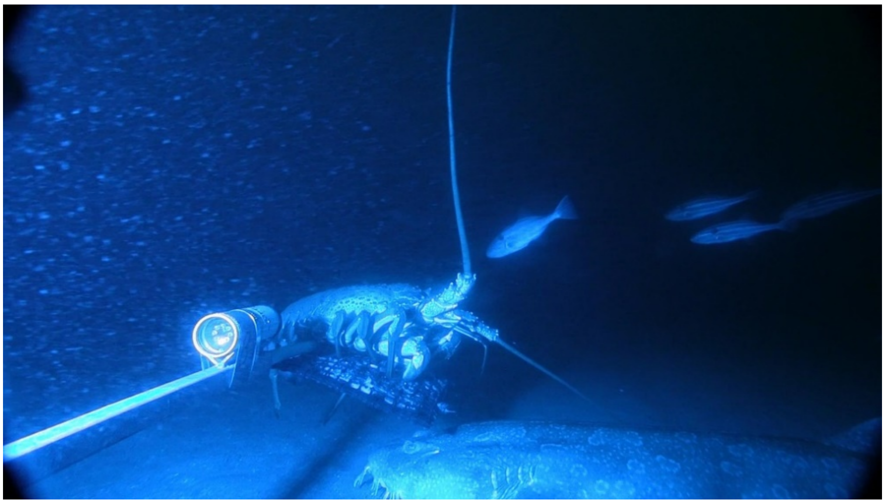


Figure 4-71. A large eastern rock lobster feeding on the bait at Seal Rocks Offshore.

4.3.6 Threatened and Protected Species

The critically endangered grey nurse shark, *Carcharias taurus* was observed on five separate stereo-BRUV deployments, with a total of seven sharks recorded. Sharks were seen on each survey at Outer Gibber and on two surveys at Broughton Island Offshore.

The vulnerable white shark, *Carcharias* was observed on a single occasion at Seal Rocks Offshore. This shark was measured at 1.8 m, which is near the estimated birth size of white sharks suggesting this individual was pupped nearby.

A species of pipefish *Solegnathus* sp, most likely spiny pipehorse, *Solegnathus spinosissimus* was observed on four stereo-BRUV deployments in Broughton Offshore location. This species is protected by the NSW Fisheries Management Act.

Marine mammals were also regularly observed during survey work in the Hunter Marine Park. A humpack whale and fur seal were observed during a towed video survey. Humpack whales were often observed from the surface daily during the stereo-BRUV surveys.

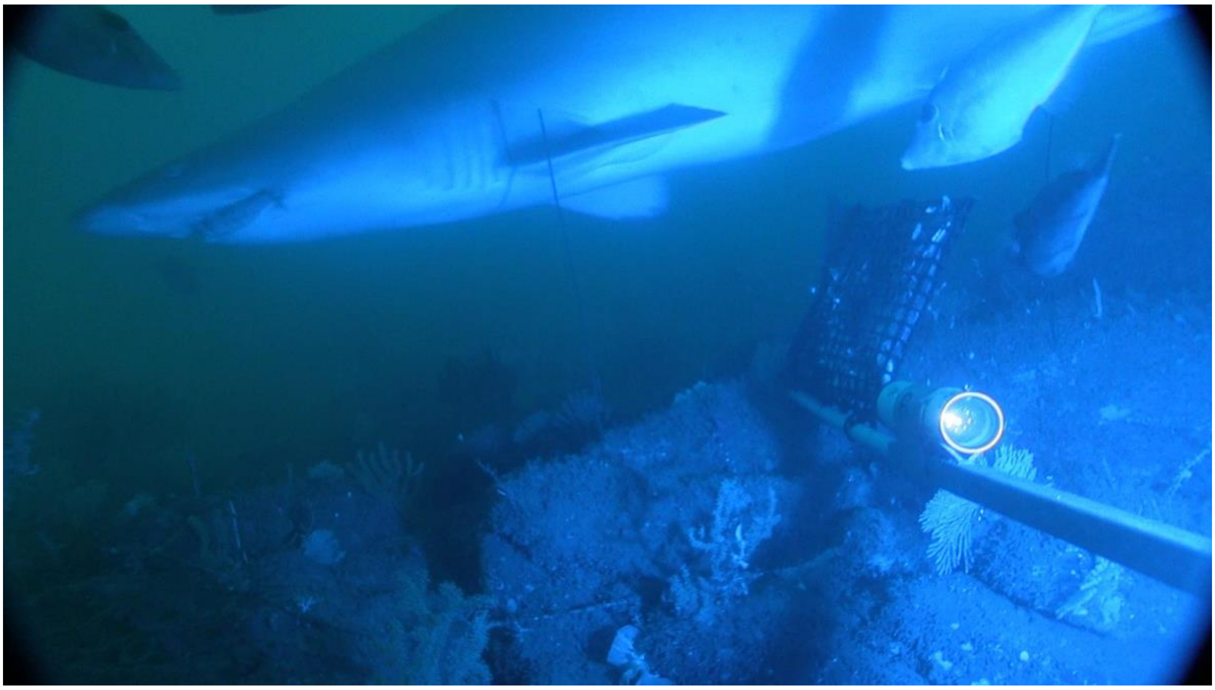


Figure 4-72. A 3 m long male critically endangered grey nurse shark, *Carcharias taurus* observed at Broughton Island Offshore in 90 m of water.

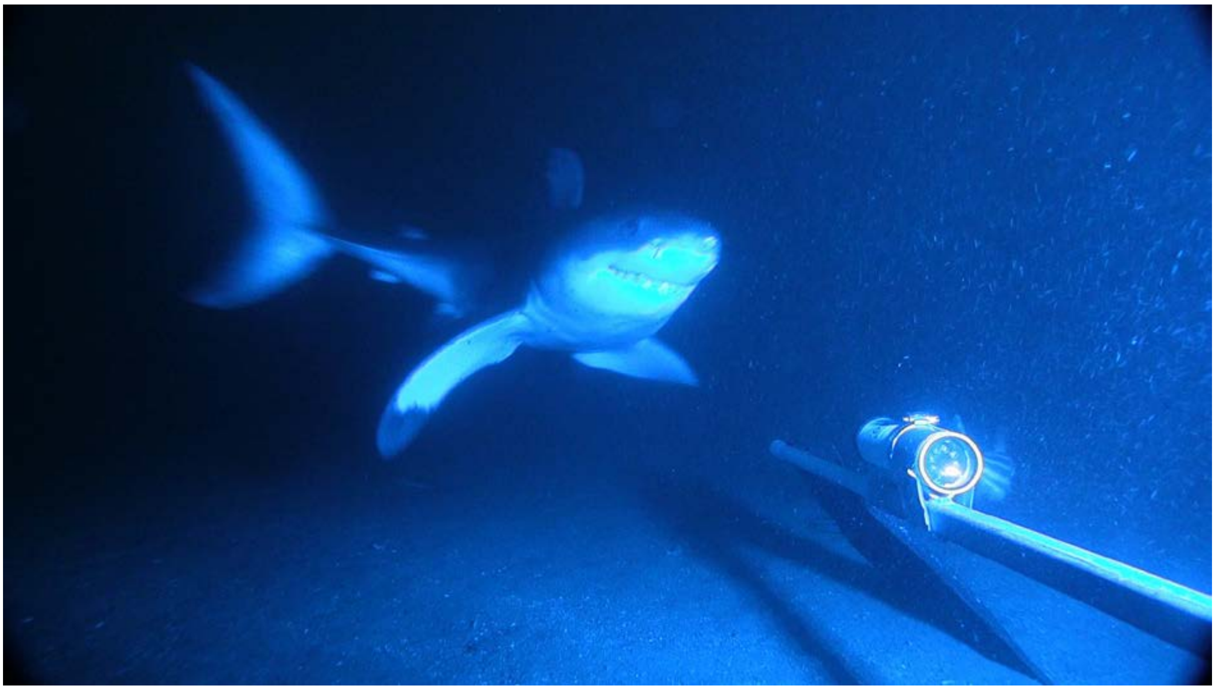


Figure 4-73. A newly born 1.8 m long white shark, *Carcharias* observed at Seal Rocks Offshore in 100m of water.

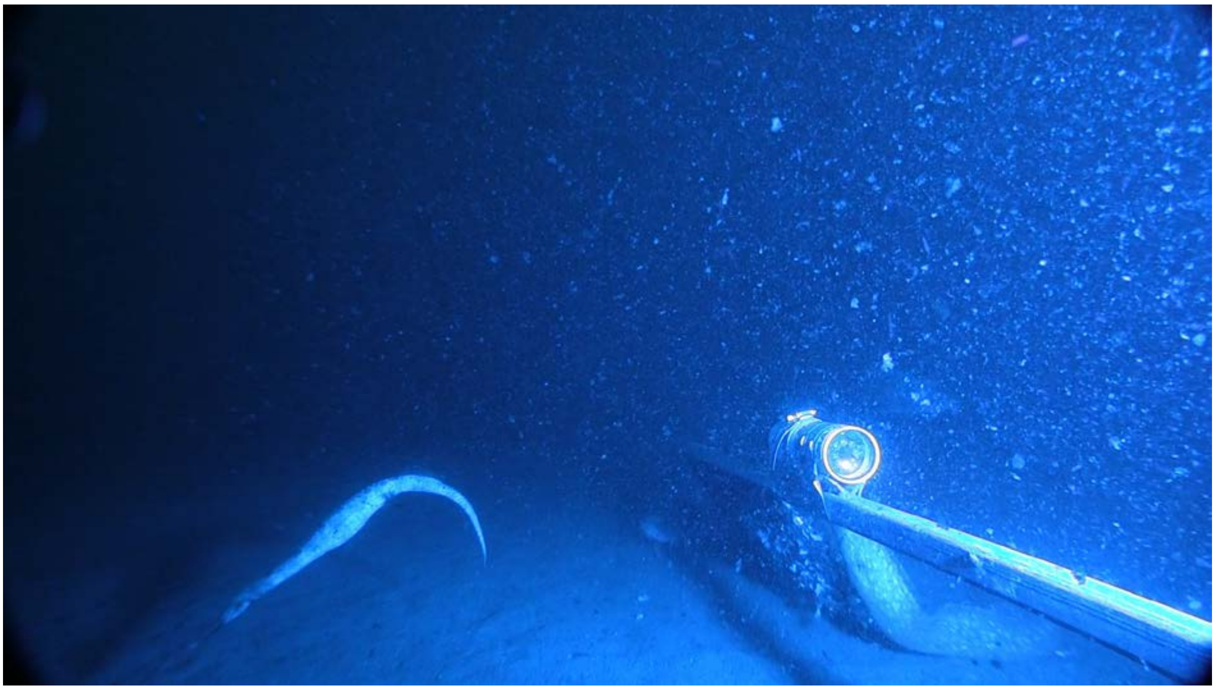


Figure 4-74. A *Solegnathus* sp, most likely spiny pipehorse, *Solegnathus spinosissimus* observed at Broughton Island Offshore.

4.3.7 Other Species of Interest

Common sawshark, Pristiophorus cirratus

The common sawshark is endemic to southern Australia and ranges from Coffs Harbour in NSW through to Jurien Bay in Western Australia. They are a small bodied benthic species that inhabit depths from 40-700 m. They are most commonly caught as bycatch in the NSW trawl and south east Australia trawl fishery.

Very little is known on the biology of this species despite large numbers being caught and retained in trawl fisheries. The large-scale movements of this species are also relatively unknown. Current research is trying to elucidate continental scale movements of this species using satellite pop-up tags. However, much more research is needed to better understand the ecology and biology of this species to enable better management.

During this study, 12 individuals were recorded on 12 drops across Broughton Island Offshore and Seal Rocks Offshore, in depths ranging from 87 to 100 m.

Banded rockcod, Hyporthodus ergastularius

The banded rockcod is an Australian endemic species that mostly inhabits deep reefs (100 to 400 m) from Dunk Island Queensland to Eden in NSW, including Lord Howe Island. It is a popular recreationally targeted species and is also retained by commercial fishers. There is anecdotal evidence that this species is being increasingly targeted by recreational fishers that are fishing offshore targeting deep reefs with new sonar technology. The largest banded rockcod to be caught was 157 cm, however it is very rare to see a fish larger than 100 cm. Data from the commercial trap and line fishery suggested there has been a decline in the number of banded rockcod caught (New South Wales Department of Primary Industries 2017a). Very little is known about the biology of this species, but it is believed to be a long-lived slow growing species.

During this current study, seven individuals were observed. Six of these were observed in pairs within the Seal Rock Port Stephens - Great Lakes Marine Park sanctuary zone in 90 m of water. While an individual was observed at Brought Island Offshore in 100m of water. Conversations with recreational anglers suggest there are greater number on reef near the continental shelf break.

This is a species that is worthy of further monitoring and research to understand how spatial management and marine parks could benefit this species.

4.3.8 Power Analyses for Species of Interest

The power analyses indicated that in for all species of interest and scenarios, revisiting the same approximate stereo-BRUV locations required the least number of stereo-BRUV deployments (Figure 4-75. Power analysis of the key fish species selected as potential candidate indicators for monitoring the Hunter Marine Park. The dashed horizontal line represents 150 stereo-BRUV deployments, the number deemed the maximum number of realistically achievable deployments during a single survey period. Interpretation of these figures is relatively straight forward. For example, for pink snapper (*C. auratus*) at Boughton Island Offshore (red bars), it would require ~80 deployments to detect a 50% increase in mean abundance when sampling at new locations, while ~45 stereo-BRUV deployments would be required for resampling sites. To detect a 100% change in mean abundance of pink snapper at Broughton Island would require ~20 and ~30 deployments for revisiting or new sites, respectively.). As the magnitude of the mean abundance increased, the number samples required to detect a difference decreased substantially. Considerable variation between species and locations was observed (Figure 4-75. Power analysis of the key fish species selected as potential candidate indicators for monitoring the Hunter Marine Park. The dashed horizontal line represents 150 stereo-BRUV deployments, the number deemed the maximum number of realistically achievable deployments during a single survey period. Interpretation of these figures is relatively straight forward. For example, for pink snapper (*C. auratus*) at Boughton Island Offshore (red bars), it would require ~80 deployments to detect a 50% increase in mean abundance when sampling at new locations, while ~45 stereo-BRUV deployments would be required for resampling sites. To detect a 100% change in mean abundance of pink snapper at Broughton Island would require ~20 and ~30 deployments for revisiting or new sites, respectively.). Overall, it would not be practically achievable (>150 deployments), irrespective of location, to detection a 50% increase in mean abundance for some species (such as *A. aequidens, C. affinis, G. scapulare, S. verreauxi, S. lineolata* and *T. novaezelandiae*), but could be achievable for *B. unimaculatus, C. auratus* and M*. scaber*. A 100%, and even more so a 200%, increase in mean abundance could be detected with a modest amount of sampling effort (nominally < 150 stereo-BRUV deployments at each sampling event; Figure 4-75. Power analysis of the key fish species selected as potential candidate indicators for monitoring the Hunter Marine Park. The dashed horizontal line represents 150 stereo-BRUV deployments, the number deemed the maximum number of realistically achievable deployments during a single survey period. Interpretation of these figures is relatively straight forward. For example, for pink snapper (*C. auratus*) at Boughton Island Offshore (red bars), it would require ~80 deployments to detect a 50% increase in mean abundance when sampling at new locations, while ~45 stereo-BRUV deployments would be required for resampling sites. To detect a 100% change in mean abundance of pink snapper at Broughton Island would require ~20 and ~30 deployments for revisiting or new sites, respectively.). It is noted that the number of samples could potentially be reduced further if new sites were selected based on species-specific optimal habitat. However, focusing monitoring on just core habitat for a particular focal species may result in hyperstability whereby sampling may not adequately detect changes in abundances until the fish population changes drastically.

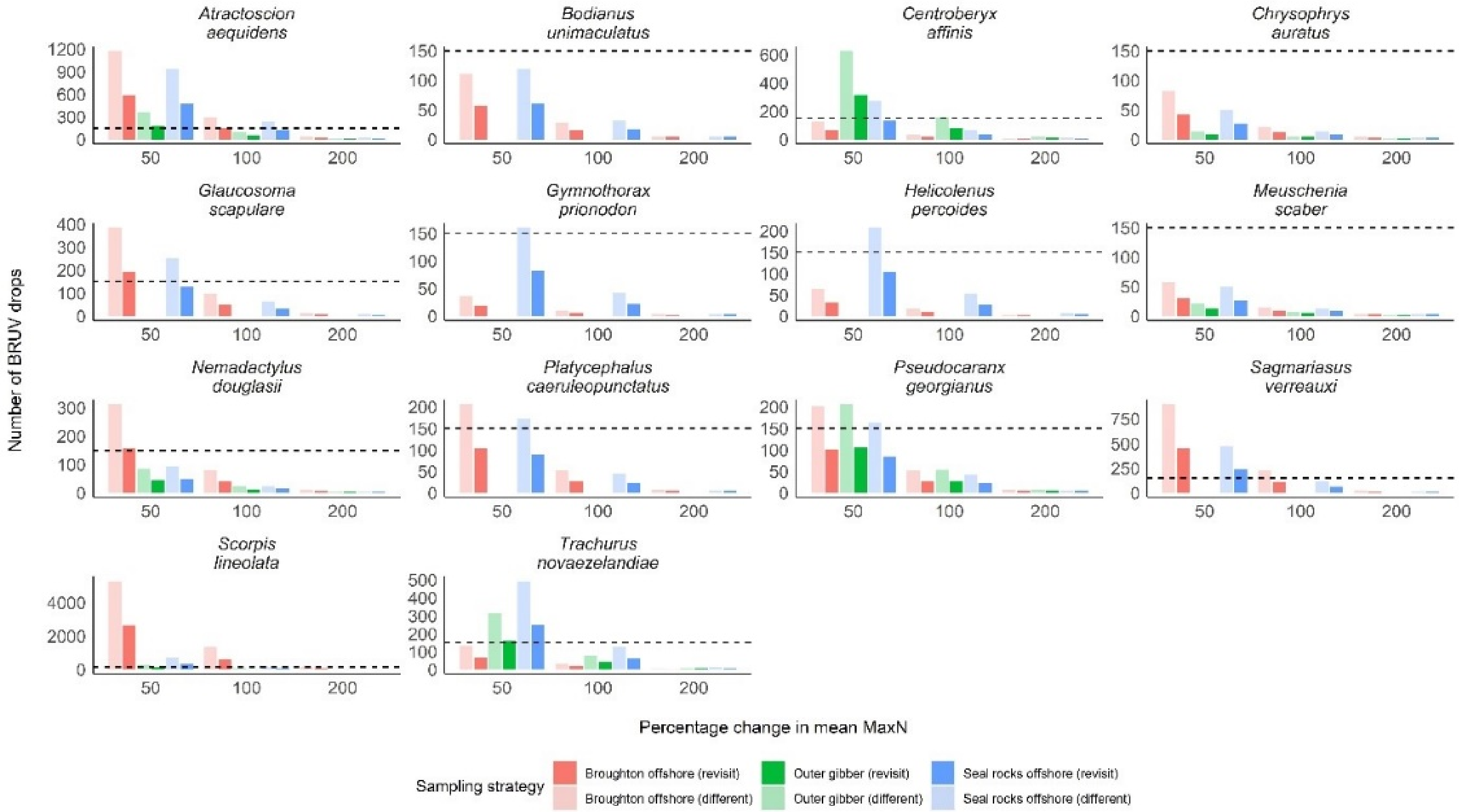


Figure 4-75. Power analysis of the key fish species selected as potential candidate indicators for monitoring the Hunter Marine Park. The dashed horizontal line represents 150 stereo-BRUV deployments, the number deemed the maximum number of realistically achievable deployments during a single survey period. Interpretation of these figures is relatively straight forward. For example, for pink snapper (*C. auratus*) at Boughton Island Offshore (red bars), it would require ~80 deployments to detect a 50% increase in mean abundance when sampling at new locations, while ~45 stereo-BRUV deployments would be required for resampling sites. To detect a 100% change in mean abundance of pink snapper at Broughton Island would require ~20 and ~30 deployments for revisiting or new sites, respectively.

5. FISH ASSEMBLAGE: ROV

In 2019, researchers from NSW Department of Fisheries trialled the use of a small, affordable observation class remotely operated vehicle (ROV). The ROV used was a BlueRobotics ROV (www.bluerobotics.com) fitted with a heavy upgrade kit and four 1,000 lumen lights on 300 m of umbilical cable. At a cost of AUD$14,000, this current setup is capable of diving to 100 m and with a small upgrade this can be expanded to 300 m.

The current setup was tested in the Hunter Marine Park by completing 14 x 7 minute transects (the equivalent of ~200m transects). Timed swims were used as there was no position system (USBL) available at that time. However, transects were done by swimming the ROV at a randomly selected compass baring. The majority of reef sampled was low relief (i.e. <10 m depth range). However, Outer Gibber is a high relief reef and transects often had a depth of >10 m (often swimming 45-30 m depth). Two GoPro 8s housed in deep water housing were attached to the front of the ROV to record 2.5k video footage and allow for 3d measurements using the same techniques as the stereo-BRUVs.

The video footage provides the first high definition views of the reefs structure inside the Hunter Marine Park. The video was analysed to describe the habitat types and fish assemblages.

The small ROV performed remarkably well, although, it was limited to low current and wind conditions. The main advantage of this setup is that it is battery powered and can be used of small boats.

During these transects, a number of interesting features were observed:

- Large patches of sea whips and fan octocorals on low relief reef (Figure 5-1.).
- Areas of gorgonian fan corals and other diverse octocoral structures on high relief reef (Figure 5-2.).
- Large boulder or blocks of reef estimated to be 5 m tall (Figure 5-3.).
- Several species of fish were observed in a more natural state (no bait compared to stereo-BRUV). Species observed included reef ocean perch, redfish, velvet leatherjacket, long-fin boarfish, banded seaperch (Figure 5-4.).
- Extensive invertebrate assemblages and evidence of litter in 100 m of water (Figure 5-5).

Figure 5-1. Large patches of Seawhips (octocorals) in 90 m of water.

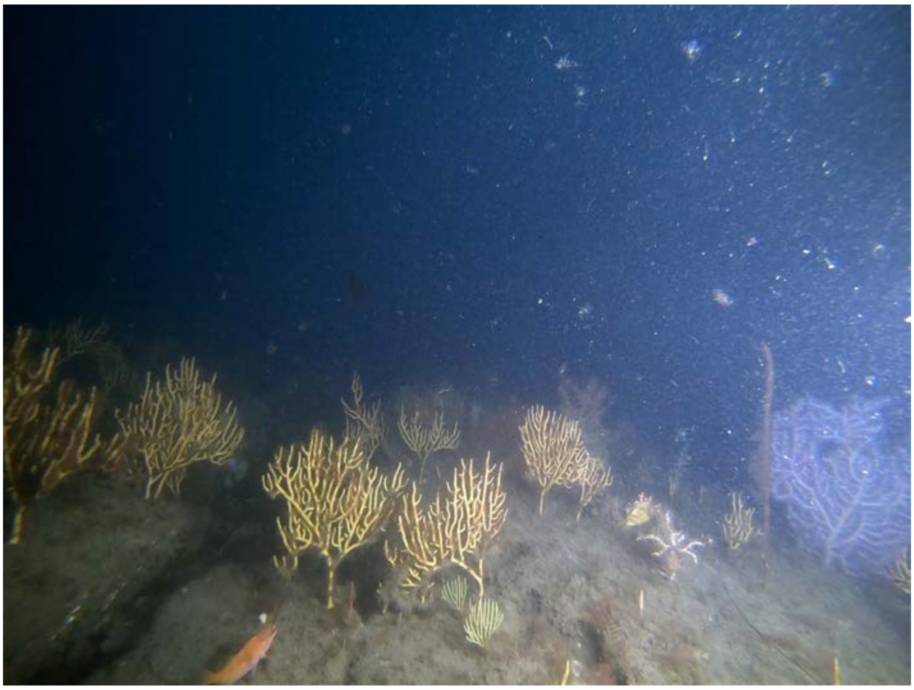


Figure 5-2. Diverse sessile invertebrate assemblages and a *Hypoplectrodes* sp.

Figure 5-3. Several large boulder or block shaped reef structures, estimated to be at least 5 m tall and covered in sessile invertebrates.

Figure 5-4. Low relief sediment covered reef with branching octocorals and an Ocean Reef Perch

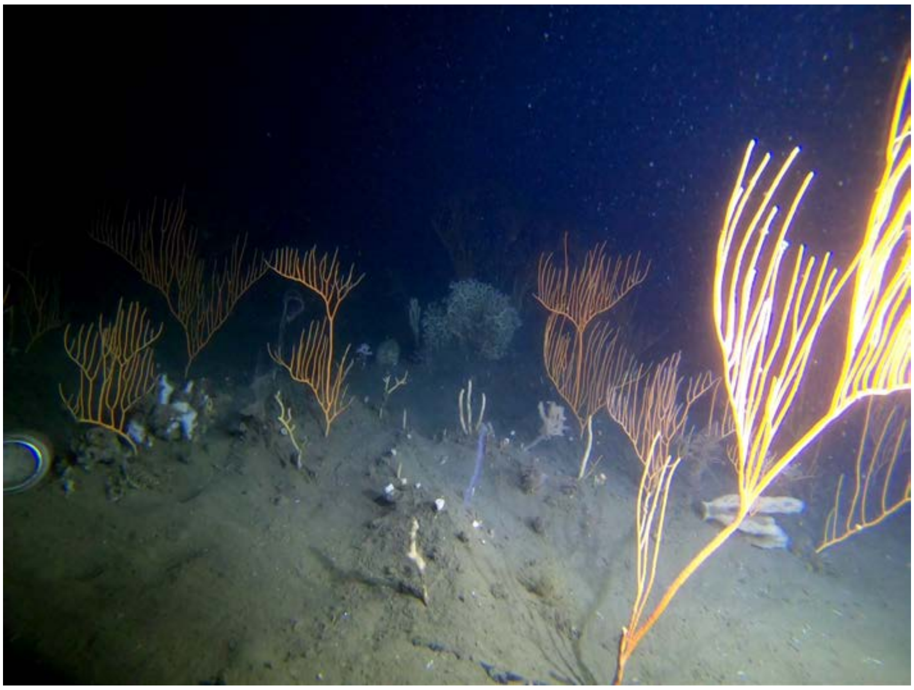


Figure 5-5. Evidence of litter with a can observed in 100 m of water. Note the beer can on the left of the image.

6. CONCLUSIONS

- The NESP Field Manual was used to design surveys that incorporated multibeam echo sounder (MBES), towed video, stereo baited remote underwater video (stereo-BRUVs) and remotely operated vehicle (ROV) to collect baseline data for the Hunter Marine Park.
- 30% of the on-shelf (< 200m water depth) component of the Hunter Marine Park's Special Purpose Zone (Trawl) has been mapped in high resolution multibeam.
- It is estimated that reefs cover only 5.5 km^2 of the currently mapped area of which 91% (5.0 km^2) of NESP mapped reef is in depths 80-115 m (lower mesophotic). An analysis of more recent (~2017-20) Marine National Facility multibeam transit data and earlier multibeam data captured over the shelf-break have not been examined here and may identify additional reef within the Special Purpose Zone (Trawl).
- Towed video revealed a wide range of benthic invertebrates and mobile species occupy the seafloor across surveyed areas of the Hunter Marine Park. Shallower areas (<50 m water depth) of unconsolidated seabed are characterised by relatively variable sediment types with bedforms, while deeper areas are largely uniform and, in some areas, are dominated by fine sands/silts with burrows and/or tube worms. Reefs in shallower water (<50-60 m water depth) are relatively large and high profile and dominated by algae (i.e. kelp), ascidians and sponges. Reefs at depth (>80 m water depth) are, by comparison, relatively 'patchy', with a relief of less than 2-3 m and characterised by sponges, sea-whips and gorgonians.
- Stereo-BRUVs were used as a cost-effective method of sampling the mesophotic reef fish assemblage in the Hunter Marine Park. The use of stereo-BRUVs enables a large sample size to be collected, sufficient to detect changes in abundance of key species of interest, with maximum spatial coverage.
- This report focused on three regions within the Special Purpose Zone (Trawl), these included: Outer Gibber, Broughton Island Offshore and Seal Rock Offshore. Site selection was based on available mapping data from 2016. The sites within Seal Rock Offshore were immediately inside (along the boundary) state coastal waters of a no-take sanctuary zone. The depths at these sites were comparable to Broughton Offshore and allowed for a fished versus no-take comparison. The fish assemblages were notably different between the two regions; however, this is most likely due to Seal Rocks having greater reef structure. Recent mapping work has revealed reef within the Hunter Marine Park directly adjacent to the Seal Rock Offshore sites. Sampling these newly mapped reefs would provide greater insight into the effectiveness of no-take zones for mesophotic reef.
- There are some interesting reef assemblages supporting a diverse fish assemblage, with 112 species of fish identified from stereo-BRUV alone. It was demonstrated that the three locations samples had statistically unique fish assemblage that were best differentiated by depth, season, reef kurtosis and reef aspect.

- It was demonstrated that many species of interest listed in the report would be suitable indicator species for monitoring. This is because they occurred in abundances that were sufficient to detect changes through time. Furthermore, there is a good mix of targeted and non-targeted species, including eastern rock lobster a highly valuable fishery in this region.
- Metrics derived from the bathymetry data were highly valuable in explaining the spatial distribution of several key species of interest.
- There were no large temporal variations in the species assemblages between autumn and spring. However, some species including teraglin, blue morwong and eastern rock lobster, demonstrated clear spatial patterns that are most likely attributed to life history stages.
- There is evidence of fishing pressure influencing the population size structure of some species including pink snapper and teraglin. Larger fish were observed in the state managed no-take zone at Seal Rocks Offshore. This was especially the case when comparing length with Outer Gibber, a highly popular recreational fishing site.
- Several threatened and protected species were observed in the Hunter Marine Park. These included, white shark, grey nurse shark, pipefish, humpback whale and fur seals.
- A small-ROV was tested as an additional tool for mapping and monitoring fish assemblages and habitat. The compact nature of the ROV meant that it could be deployed off any vessel. The other advantage of the ROV is that it is possible to obtain large samples sizes that are adequate for monitoring programs.
- All stereo-BRUV data has been made freely available and downloadable from the GlobalArchive website. Metadata has also been upload to the University of Tasmania meta-database.

7. RECOMMENDATIONS

- From the NESP funded surveys presented here, it is apparent that additional reef is likely to occur adjacent to the existing coverage over the inner shelf. A further 180 km^2 (3 areas) of MBES surveys (Figure 7-1) would provide a more complete picture of inner shelf reef extent with an additional 100 km^2 over an area of the mid shelf to identify reef and other seabed landform features over the mid-shelf.
- Anecdotal evidence suggest that additional reef is also expected in deeper water (depths of 150-180 m) and closer to the shelf edge (J. Williams pers comms). This includes a feature known as Allmark Mountain, a popular fishing location for recreational anglers to target yellowtail kingfish and banded rock cod. A transit survey or Ships-of-Opportunity survey by the MNF or AusSeabed partner could potentially cover this deeper offshore area (400 km^2) in coming years.
- Mapping these reefs would also allow for biological surveys such as towed video, AUV, stereo-BRUV and ROV. Knowing the locations of reef simplified the ability to design a spatially balanced random sampling survey as outlined in the NESP Field Manuals. The data from the multibeam surveys also provides statistics used to described and predict the distribution, abundance and biomass of species of interest.
- Further towed video and/or AUV data collection will be required in the future to 1) characterise the composition and distribution of seabed communities in MBES surveyed areas for which imagery has not yet been obtained (MNF mapped areas) or new areas to be mapped as proposed above, and 2) repeat surveys at a sub-set of already surveyed locations. Towed imagery is currently concentrated on the inner shelf and imagery from new areas will provide a more spatially balanced understanding of both along-shore and across-shore (depth) related variability in community composition and abundance over the continental shelf. With greater spatial coverage, we can start to examine relationships between distributions of benthic organisms and environmental variables with anthropogenic pressures within the park. Repeat surveys (i.e every 1-2 years for 5-6 years) at a sub-set of sites would provide a temporal understanding of inter-annual variability in seabed communities for the park, and potentially allow us to build models to predict how communities might change over even longer time scales. Time frames for longer-term monitoring would then be re-assessed based on the results of this initial monitoring period and modelling.
- It is recommended that further stereo-BRUV baseline data be collected from reefs that were mapped during the 2018-19 MBES surveys. This would offer greater spatial coverage that provides for a more representative baseline dataset for fish assemblages of the inner shelf region of the Special Purpose Zone (Trawl). It would also be recommended to collect baseline data from the shelf edge at locations that are known to be popular recreational fishing sites. This would allow researchers to monitor how fish assemblages change at sites that are influence by fishing effort and climate change. Little is known about the distribution and habitat association of these deeper reef fish species. Many of these species are large slow growing species that are potentially exposed to over exploitation and warming oceans.

- It is recommended that an ROV based monitoring program be established to complement the stereo-BRUV component of any future work. This is because the ROV observes species that are not commonly observed by stereo-BRUV sampling. ROV imagery also provides higher quality habitat data that can be used to quantify habitat types and ground truth multibeam coverage. The newly published NESP Field Manual for ROV surveys provides details on how to design a spatially balanced random survey that is consistent with what is being done in other Australian Marine Parks. This tool will provide a greater insight into the biodiversity value of the Hunter Marine Park.
- It has also been suggested by researchers at the Australian Museum that there are number of undescribed species of fish and invertebrates that are potentially inhabiting these mesophotic reefs inside the Hunter Marine Park. ROV surveys may assist in the describing and collection of such species.
- Given the highly dynamic nature of the oceanography of the Hunter Marine, and the fact that NSW coastal waters are warming at some of the fastest rates in the world, it would be worth investigating how changes in the timing and intensity of the East Australian Current are likely to influence fish and habitat assemblages within the Hunter Marine Park.
- Future sampling should incorporate the use of light and temperature loggers to provide a better understanding of how much light reaches these reefs and how the temperatures change on both short and long-term scales. This would be particularly important for assessing the impacts of climate change.
- Several species, including barred rockcod and common sawshark, were observed in very low abundances. This is mostly likely due to sampling methodology bias but given these species have been recorded within the Hunter Marine Park and are exposed to pressures such as recreational and commercial fishing and climate change, there is reason for further research to better understand their life histories and movement patterns.
- A monitoring program incorporating multiple methods MBES, towed video, AUV, stereo-BRUV and ROV could be designed to detect changes in abundances and distribution over long-term period. Surveys would need to incorporate a temporal component (i.e. survey both warm and cold-water periods) and could easily be completed every 2-4 years. With a reassessment of the required frequency of sampling to detect patterns of change to be done after multiple years of data have been collected.
- It is worth noting that the close proximity of the Hunter Marine Park to Port Stephens and research vessel and equipment from both DPI and DPIE means that surveys can be done, and data can be collected at any time of the year and with relatively short time lines (i.e. no need to for large survey vessel time or the associated costs).

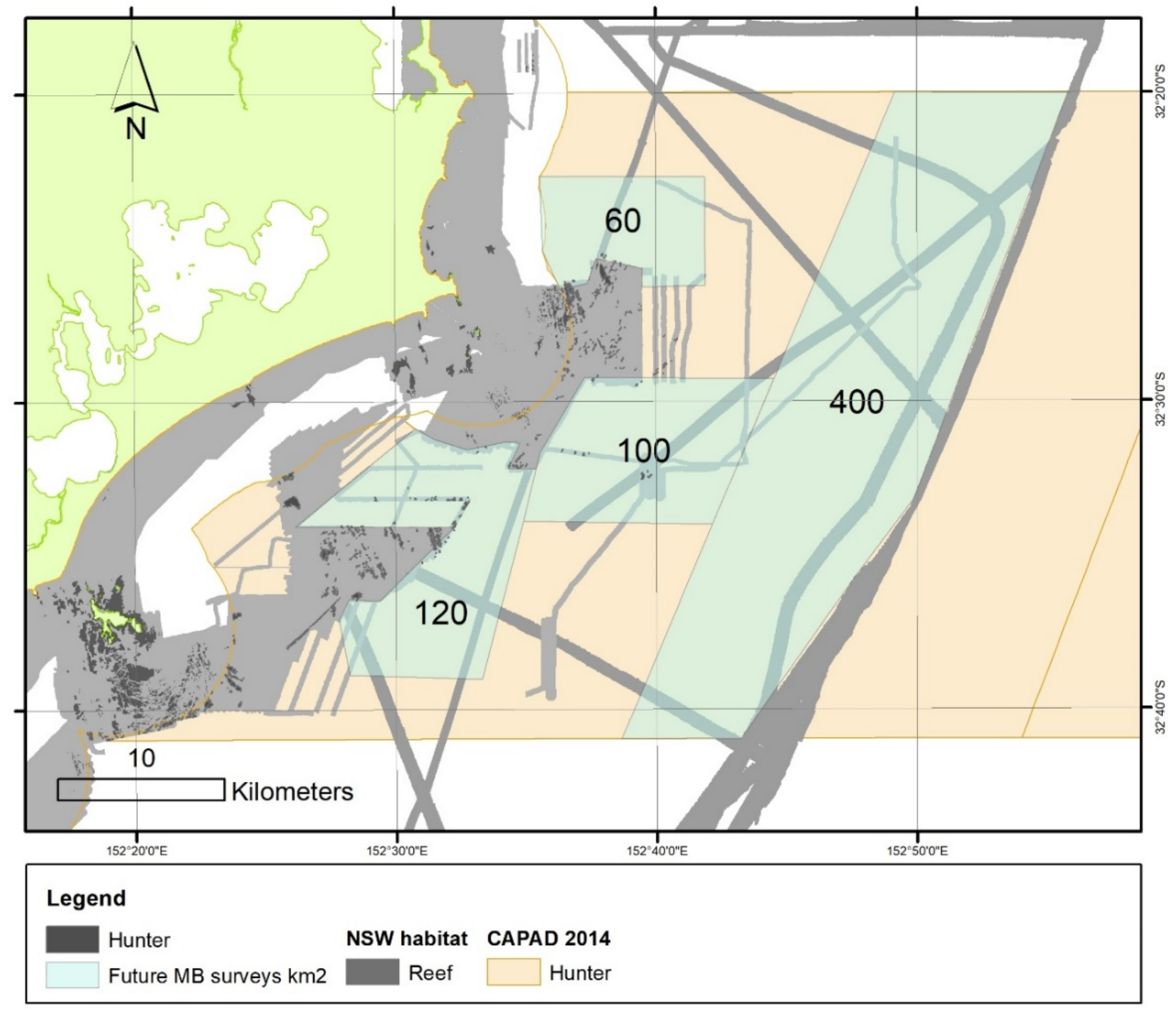


Figure 7-1. Proposed future MBES survey areas across the shelf and Hunter Marine Park Special Purpose Zone

METADATA AND DATA STORAGE

MBES data will be made freely available: 1) as data packages (multiple gridded and image formats; metadata) on the Australian Oceanographic Data Network and 2) as geotif on AusSeabed (with survey report). Towed video imagery will be made available on the NSW Environmental Data Portal - Sharing and Enabling Environmental Data (SEED)'s Amazon Web Service and accessible for annotation in Squidle+. Both MBES and towed video imagery are backed up on the NSW Department of Planning Industry and Environment Internal Assets Register with full metadata statements. All stereo-BRUVs metadata is stored on the IMAS metadata catalogue.

MBES:

https://portal.aodn.net.au

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

https://iar.environment.nsw.gov.au/dataset

Towed Video Imagery:

https://squidle.org/

https://iar.environment.nsw.gov.au/dataset/nesp-biodiversity-hub-nsw-dpie-hunter-marine-park-towed-video-imagery)

All stereo-BRUVs data is stored on GlobalArchive:

https://globalarchive.org/geodata/explore/?filters={%22deployment_campaign_list%22:[966]}

https://globalarchive.org/geodata/explore/?filters={%22deployment_campaign_list%22:[963]}

https://globalarchive.org/geodata/explore/?filters={%22deployment_campaign_list%22:[958]}

https://globalarchive.org/geodata/explore/?filters={%22deployment_campaign_list%22:[171]}

OUTREACH

This project featured on the Marine Biodiversity Hub webpage as a story and was shared on both Twitter and Facebook. The story can be read at : https://www.nespmarine.edu.au/news/mapping-life-mesophotic.

To date there has been one scientific peer-reviewed article published that demonstrates the unique fish assemblage of the Hunter Marine Park. J Williams announced the publication of this article on twitter acknowledging the NESP MBH and Parks Australia. This tweet was viewed 6,328 time with 120 people visiting the article. A second peer-reviewed article will be published focussing on the results from this report.

J Williams consistently ‘tweeted’ images and videos from fieldwork to promote this research and the Hunter Marine Park. These tweets were highly viewed and ‘retweeted’.

The results from this study have also been presented at a number of conferences to diverse audience. This included a keynote presentation at the Australian Society of Fish Biology conference in Melbourne 2018. Note that funding to attend conferences was provided outside of the NESP MBH.

- Williams J, Jordan A, Harasti D, Doyle F, Ingleton T, Davies P, Barrett N, Lynch T and Devine C (2019). Temperate Mesophotic Ecosystems: What fish are down there and are people trying to catch them. Australian Marine Sciences Association. Fremantle, Western Australia, Australia.

- Williams J, Jordan A, Harasti D Doyle F, Ingleton T, Davies P, Barrett N, Lynch T and Devine C (2018 Plenary). Science into Practice, Practice into Science: Looking a little deeper. Australian Society of Fish Biology, Melbourne, Victoria, Australia.

- Williams J, Jordan A, Harasti D and Davies P (2017). Taking a deeper look: Quantifying the differences in fish assemblages between shallow and mesophotic temperate rocky reefs. 10th Indo-Pacific Fish Conference. Papeete, French Polynesia.

- Williams J, Jordan A, Harasti D and Davies P (2018). Taking a deeper look: Quantifying the differences in fish assemblages between shallow and mesophotic temperate rocky reefs. Australian Marine Sciences Association. Adelaide, South Australia, Australia.

A short video highlighting the amazing reef features and fish assemblages from the data collected during this study is currently being produce and will upload to YouTube.

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REFERENCES

Anderson, M. J., and R. B. Millar. 2004. Spatial variation and effects of habitat on temperate reef fish assemblages in northeastern New Zealand. Journal of experimental marine biology and ecology 305:191–221.

Andradi-Brown, D. A., E. Gress, G. Wright, D. A. Exton, and A. D. Rogers. 2016. Reef Fish Community Biomass and Trophic Structure Changes across Shallow to Upper-Mesophotic Reefs in the Mesoamerican Barrier Reef, Caribbean. PloS one 11:e0156641.

Armstrong, R. A., and H. Singh. 2012. 24 - Mesophotic Coral Reefs of the Puerto Rico Shelf. Pages 365–374 *in* P. T. Harris and E. K. Baker, editors. Seafloor Geomorphology as Benthic Habitat. Elsevier, London.

Baker, E. K., K. A. Puglise, and P. T. Harris. 2016. Mesophotic coral ecosystems — A lifeboat for coral reefs? The United Nations Environment Programme and GRID-Arendal, Nairobi and Arendal.

Bax, N. J., and A. Williams. 2001. Seabed habitat on the south-eastern Australian continental shelf: context, vulnerability and monitoring. Marine and Freshwater Research 52:491–512.

Bax, N., R. Kloser, A. Williams, K. Gowlett-Holmes, and T. Ryan. 1999. Seafloor habitat definition for spatial management in fisheries: A case study on the continental shelf of southeast Australia. Oceanologica Acta 22:705–720.

Beck, M. W. 2000. Separating the elements of habitat structure: independent effects of habitat complexity and structural components on rocky intertidal gastropods. Journal of experimental marine biology and ecology 249:29–49.

Bejarano, I., R. S. Appeldoorn, and M. Nemeth. 2014. Fishes associated with mesophotic coral ecosystems in La Parguera, Puerto Rico. Coral reefs 33:313–328.

Bo, M., S. Bava, S. Canese, M. Angiolillo, R. Cattaneo-Vietti, and G. Bavestrello. 2014. Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. Biological conservation 171:167–176.

Bohlke, E. B., and J. E. McCosker. 2001. The moray eels of Australia and New Zealand, with the description of two new species (Anguilliformes: Muraenidae). Records-Australian Museum 53:71–102.

Booth, D. J., W. F. Figueira, M. A. Gregson, L. Brown, and G. Beretta. 2007. Occurrence of tropical fishes in temperate southeastern Australia: Role of the East Australian Current. Estuarine, coastal and shelf science 72:102–114.

Borcard, D., F. Gillet, and P. Legendre. 2018. Numerical Ecology with R. Springer.

Bridge, T., T. J. Done, A. Friedman, and R. J. Beaman. 2011. Variability in mesophotic coral reef communities along the Great Barrier Reef, Australia. Ecology Progress Series.

Brokovich, E., S. Einbinder, N. Shashar, M. Kiflawi, and S. Kark. 2008. Descending to the twilight-zone: changes in coral reef fish assemblages along a depth gradient down to 65 m. Vol. 371:253–262.

Cameron, M. J., V. Lucieer, N. S. Barrett, C. R. Johnson, and G. J. Edgar. 2014. Understanding community-habitat associations of temperate reef fishes using fine-resolution bathymetric measures of physical structure. Marine ecology progress series 506:213–229.

Cappo, M., E. Harvey, and M. Shortis. 2007. Counting and measuring fish with baited video techniques - an overview. Pages 101–114 *in* J. Lyle, D. M. Furlani, and C. D. Buxton, editors. Proceedings of the 2006 Australian Society of Fish Biology conference and workshop cutting edge technologies in fish and fisheries science. ASFB.

Cappo, M., P. Speare, and G. De'ath. 2004. Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. Journal of experimental marine biology and ecology 302:123–152.

Carroll, A., F. Althaus, R. Beaman, A. Friedman, D. Ierodiaconou, T. Ingleton, A. Jordan, M. Linklater, J. Monk, A. Post, R. Przeslawski, Smith J., M. Stowar, M. Tran, and A. Tyndall. 2020. Marine sampling field manual for towed underwater camera systems. In Field Manuals for Marine Sampling to Monitor Australian Waters, Version 2. Page (R. Przeslawski and S. Foster, Eds.). National Environmental Science Programme (NESP).

Champely, S., C. Ekstrom, P. Dalgaard, and J. Gill. 2020. pwr: Basic functions for power analysis. R package version 1:665.

Chen, Y., G. W. Liggins, K. J. Graham, and S. J. Kennelly. 1997. Modelling the length-dependent offshore distribution of redfish, Centroberyx affinis. Fisheries research 29:39–54.

Chick, R., A. Roelofs, C. Green, D. V. Fairclough, J. Stewart, L. Georgeson, and T. Emery. 2018. SILVER TREVALLIES (2018). Pseudocaranx georgianus, Pseudocaranx sp. "dentex" & Pseudocaranx wrighti, Pseudocaranx dinjerra. https://www.fish.gov.au/report/219-Silver-Trevally-2018.

Collins, D. L., T. J. Langlois, T. Bond, T. H. Holmes, E. S. Harvey, R. Fisher, and D. L. McLean. 2017. A novel stereo-video method to investigate fish–habitat relationships. Methods in ecology and evolution / British Ecological Society 8:116–125.

Connell, S. D., and M. J. Kingsford. 1998. Spatial, temporal and habitat-related variation in the abundance of large predatory fish at One Tree Reef, Australia. Coral reefs 17:49–57.

Davies, P., T. Ingleton, A. Jordan, and N. Barrett. 2016. Mapping shelf rocky reef habitats in the Hunter Commonwealth Marine Reserve. Marine Biodiversity Hub, Office of Environment and Heritage NSW.

Denny, C. M., and R. C. Babcock. 2004. Do partial marine reserves protect reef fish assemblages? Biological conservation 116:119–129.

Director of National Parks. 2018. Draft Temperate East Marine Parks Network Management Plan 2018. Director of National Parks 2018.

Dove, D., T. Bradwell, G. Carter, C. Cotterill, J. Gafeira Goncalves, S. Green, M. Krabbendam, M. C. Stevenson A., and H. Stewart. 2016. Seabed Geomorphology: A Two-Part Classification System. British Geological Survey: Edinburgh, UK.

Englebert, N., P. Bongaerts, P. R. Muir, K. B. Hay, M. Pichon, and O. Hoegh-Guldberg. 2017. Lower Mesophotic Coral Communities (60-125 m Depth) of the Northern Great Barrier Reef and Coral Sea. PloS one 12:e0170336.

Ferland, M. 1990. Shelf Sand Bodies in Eastern Australia.

Ferreira, C. E. L., J. E. A. Goncçalves, and R. Coutinho. 2001. Community Structure of Fishes and Habitat Complexity on a Tropical Rocky Shore. Environmental biology of fishes 61:353–369.

Fetterplace, L. C., A. R. Davis, J. M. Neilson, and M. D. Taylor. 2016. … sediment fishes can show site attachment: a preliminary assessment of the movement patterns of the blue-spotted flathead (Platycephalus caeruleopunctatus …. Animal: an international journal of animal bioscience.

Fisher, R., S. K. Wilson, T. M. Sin, A. C. Lee, and T. J. Langlois. 2018. A simple function for full-subsets multiple regression in ecology with R. Ecology and evolution 8:6104–6113.

Fitzpatrick, C., D. McLean, and E. S. Harvey. 2013. Using artificial illumination to survey nocturnal reef fish. Fisheries research 146:41–50.

Foster, S. D., J. Monk, E. Lawrence, K. R. Hayes, G. R. Hosack, T. Langlois, G. Hooper, and R. Przeslawski. 2020. Statistical considerations for monitoring and sampling. In Field Manuals for Marine Sampling to Monitor Australian Waters,Version 2. Page (R. Przeslawski and S. Foster, Eds.). National Environmental Science Program (NESP).

Fowler, A. M., R. C. Chick, and J. Stewart. 2018. Patterns and drivers of movement for a coastal benthopelagic fish, Pseudocaranx georgianus, on Australia's southeast coast. Scientific reports 8:16738.

Froese, R., and D. Pauly. 2019. FishBase. https://www.fishbase.de/.

Grey Morwong, Status of Fisheries Resources in NSW 2008/09. 2010. . http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/375900/Grey-Morwong.pdf.

Griffiths, M. H., and T. Hecht. 1995. On the life-history of Atractoscion aequidens, a migratory sciaenid off the east coast of southern Africa. Journal of fish biology 47:962–985.

Harasti, D., K. A. Lee, C. Gallen, J. M. Hughes, and J. Stewart. 2015. Movements, Home Range and Site Fidelity of Snapper (Chrysophrys auratus) within a Temperate Marine Protected Area. PloS one 10:e0142454.

Harasti, D., J. Williams, E. Mitchell, S. Lindfield, and A. Jordan. 2018. Increase in Relative Abundance and Size of Snapper Chrysophrys auratus Within Partially-Protected and No-Take Areas in a Temperate Marine Protected Area. Frontiers in Marine Science 5:208.

Harman, N., E. S. Harvey, and G. A. Kendrick. 2003. Differences in fish assemblages from different reef habitats at Hamelin Bay, south-western Australia. Marine and Freshwater Research 54:177–184.

Harris, P. T., A. D. Heap, J. F. Marshall, and M. McCulloch. 2008. A new coral reef province in the Gulf of Carpentaria, Australia: Colonisation, growth and submergence during the early Holocene. Marine geology 251:85–97.

Harvey, E. S., M. Cappo, G. A. Kendrick, and D. L. McLean. 2013. Coastal fish assemblages reflect geological and oceanographic gradients within an Australian zootone. PloS one 8:e80955.

Hastie, T., and R. Tibshirani. 1986. Generalized Additive Models. Statistical science: a review journal of the Institute of Mathematical Statistics 1:297–310.

Hegarty, A.-M. L. 2016. Life history characteristics and fishery of teraglin, Atractoscion aequidens in New South Wales, Australia. opus.lib.uts.edu.au.

Henriques, R., W. M. Potts, C. V. Santos, W. H. H. Sauer, and P. W. Shaw. 2014. Population connectivity and phylogeography of a coastal fish, Atractoscion aequidens (Sciaenidae), across the Benguela Current region: evidence of an ancient vicariant event. PloS one 9:e87907.

Heyns-Veale, E. R., A. T. F. Bernard, N. B. Richoux, D. Parker, T. J. Langlois, E. S. Harvey, and A. Götz. 2016. Depth and habitat determine assemblage structure of South Africa's warm-temperate reef fish. Marine biology 163:158.

Hill, N. A., N. Barrett, E. Lawrence, J. Hulls, J. M. Dambacher, S. Nichol, A. Williams, and K. R. Hayes. 2014. Quantifying Fish Assemblages in Large, Offshore Marine Protected Areas: An Australian Case Study. PloS one 9:e110831.

Hinderstein, L. M., J. C. A. Marr, F. A. Martinez, M. J. Dowgiallo, K. A. Puglise, R. L. Pyle, D. G. Zawada, and R. Appeldoorn. 2010. Theme section on "Mesophotic Coral Ecosystems: Characterization, Ecology, and Management." Coral reefs 29:247–251.

Hutton, T., M. H. Griffiths, U. R. Sumaila, and T. J. Pitcher. 2001. Cooperative versus non-cooperative management of shared linefish stocks in South Africa: an assessment of alternative management strategies for geelbek (Atractoscion aequidens). Fisheries research 51:53–68.

Ingleton, T., B. Morris, K. Allen, S. Holtznagel, and D. Hanslow. 2019. SeabedNSW: Standard Operating procedures for multibeam surveying. New South Wales Office of Environment and Heritage (NSW DPIE) .

Ingleton, T., J. Neilson, P. Davies, E. Foulsham, M. Linklater, D. Hanslow, and A. Jordan. 2020. Chapter 28 - Temperate rocky reef on the southeast Australian continental shelf. Pages 487–502 *in* P. T. Harris and E. Baker, editors. Seafloor Geomorphology as Benthic Habitat (Second Edition). Elsevier.

Jordan, A., P. Davies, T. Ingleton, E. Foulsham, J. Neilson, and T. Pritchard. 2010. Seabed habitat mapping of the continental shelf of NSW. NSW Office of Environment and Heritage.

Kahng, S. E., J. R. Garcia-Sais, H. L. Spalding, E. Brokovich, D. Wagner, E. Weil, L. Hinderstein, and R. J. Toonen. 2010. Community ecology of mesophotic coral reef ecosystems. Coral reefs 29:255–275.

Knott, N. A., J. Williams, D. Harasti, H. A. Malcolm, M. A. Coleman, Kelaher, B. P. Rees, M. J. Shulz, D. A. Collins, and A. Jordan. 2020. Coherent, representative and large-scale marine protected area network shows consistent change in rocky fish assemblages through time (In Review). Ecological applications: a publication of the Ecological Society of America.

Langlois, T., J. Williams, J. Monk, P. Bouchet, L. Currey, J. Goetze, D. Harasti, C. Huveneers, D. Ierodiaconou, H. Malcolm, and S. Whitmarsh. 2018. Marine Sampling Field Manual for Benthic Stereo BRUVS (Baited Remote Underwater Videos) [Version 1].

Lecours, V., R. Devillers, D. C. Schneider, V. L. Lucieer, C. J. Brown, and E. N. Edinger. 2015. Spatial scale and geographic context in benthic habitat mapping: review and future directions. Marine ecology progress series 535:259–284.

Liggins, G. 2018. Eastern Rock Lobster. https://www.fish.gov.au/report/175-Eastern-Rock-Lobster-2018.

Liggins, G. W., M. E. Miller, and G. Ballinger. 2018. Resource assessment—lobster: prepared for the total allowable catch setting and Review Committee process for the determination for the total allowable commercial catch of NSW lobster for the 2018/19 season. NSW Department of Primary Inudstries.

Lindfield, S. J., E. S. Harvey, A. R. Halford, and J. L. McIlwain. 2016. Mesophotic depths as refuge areas for fishery-targeted species on coral reefs. Coral reefs 35:125–137.

Linklater, M., A. G. Carroll, and S. M. Hamylton. 2016. High coral cover on a mesophotic, subtropical island platform at the limits of coral reef growth. Continental shelf research.

Linklater, M., T. C. Ingleton, M. A. Kinsela, and B. D. Morris. 2019. Techniques for classifying seabed morphology and composition on a subtropical-temperate continental shelf. Geosciences Journal.

Loya, Y., G. Eyal, T. Treibitz, M. P. Lesser, and R. Appeldoorn. 2016. Theme section on mesophotic coral ecosystems: advances in knowledge and future perspectives. Coral reefs 35:1–9.

Lucieer, V., N. Barrett, C. Butler, E. Flukes, D. Ierodiaconou, T. Ingleton, A. Jordan, J. Monk, J. Meeuwig, R. Porter-Smith, N. Smit, P. Walsh, A. Wright, and C. Johnson. 2019. A seafloor habitat map for the Australian continental shelf. Scientific data 6:120.

Lucieer, V., R. Porter-Smith, S. Nichol, J. Monk, and N. Barrett. 2016. Collation of existing shelf reef mapping data and gap identification: Phase 1 Final Report - Shelf reef key ecological features. Marine Biodiversity Hub, University of Tasmania.

Lynch, T. P., C. B. Smallwood, F. A. Ochwada-Doyle, J. Lyle, J. Williams, K. L. Ryan, C. Devine, B. Gibson, and A. Jordan. 2020a. A cross continental scale comparison of Australian offshore recreational fisheries research and its applications to Marine Park and fisheries management. ICES journal of marine science: journal du conseil 77:1190–1205.

Lynch, T. P., C. Smallwood, F. Ochwada-Doyle, J. Williams, K. Ryan, C. Devine, B. Gibson, M. Burton, A. Hegarty, J. Lyle, S. Foster, and A. Jordan. 2019. Recreational fishing in Commonwealth waters. NESP Marine Biodiversity Hub.

Lynch, T. P., C. Smallwood, J. Williams, F. Ochwada-Doyle, and C. Devine. 2020b. A cross continental scale comparison of Australian offshore charter boat recreational fisheries research and its applications to Marine Park and fisheries management,. NESP Marine Biodiversity Hub.

MacDonald, C., T. Bridge, and G. P. Jones. 2016. Depth, bay position and habitat structure as determinants of coral reef fish distributions: Are deep reefs a potential refuge? Marine ecology progress series 561:217–231.

Malcolm, H. A. 2016. A moray's many knots: knot tying behaviour around bait in two species of Gymnothorax moray eel. Environmental biology of fishes 99:939–947.

Malcolm, H. A., J. Williams, A. L. Schultz, J. Neilson, N. Johnstone, N. A. Knott, D. Harasti, M. A. Coleman, and A. Jordan. 2018. Targeted fishes are larger and more abundant in 'no-take' areas in a subtropical marine park. Estuarine, coastal and shelf science 212:118–127.

McLean, D. L., T. J. Langlois, S. J. Newman, T. H. Holmes, M. J. Birt, K. R. Bornt, T. Bond, D. L. Collins, S. N. Evans, M. J. Travers, C. B. Wakefield, R. C. Babcock, and R. Fisher. 2016. Distribution, abundance, diversity and habitat associations of fishes across a bioregion experiencing rapid coastal development. Estuarine, coastal and shelf science 178:36–47.

Monk, J., J. Williams, N. S. Barrett, A. R. Jordan, and V. L. Lucieer. 2017. Biological and habitat feature descriptions for the continental shelves of Australia's temperate-water marine parks-including collation of existing mapping in all …. NESP Marine Biodiversity Hub.

Morison, A. K., and K. R. Rowling. 2001. Age, growth and mortality of redfish Centroberyx affinis. Marine and Freshwater Research 52:637–649.

New South Wales Department of Primary Industries. 2017a. Assessment of the NSW Ocean Trap and Line Fishery; Prepared for the Department of the Environment and Energy for the purpose of assessment under Part 13 and 13(A) of the Environment Protection and Biodiversity Act 1999. NSW Department of Primary Industries.

New South Wales Department of Primary Industries. 2017b. Assessment of the NSW Ocean Trawl Fishery; Prepared for the Department of the Environment and Energy for the purpose of assessment under Part 13 and 13(A) of the Environment Protection and Biodiversity Act 1999. NSW Department of Primary Industries.

Nichol, S., Z. Huang, F. Howard, R. Porter-Smith, V. Lucieer, and N. Barrett. 2016. Geomorphological classification of reefs - Draft Framework for an Australian Standard. Marine Biodiversity Hub, GeoScience Australia.

de Oliveira Soares, M., M. Davis, C. C. de Paiva, and P. B. de Macêdo Carneiro. 2016. Mesophotic ecosystems: coral and fish assemblages in a tropical marginal reef (northeastern Brazil). Marine biodiversity: a journal of the Senckenberg Research Institute / Senckenberg Forschungsinstitut und Naturmudeum:1–6.

Picard, K., K. Austine, N. Bergersen, R. Cullen, N. Dando, D. Donohue, S. Edwards, T. Ingleton, A. Jordan, V. Lucieer, I. Parnum, J. Siwabessy, M. Spinoccia, R. Talbot-Smith, C. Waterson, N. Barrett, R. Beaman, D. Bergersen, M. Boyd, B. Brace, B. Brooke, O. Cantrill, M. Case, J. Daniell, S. Dunne, M. Fellows, U. Harris, D. Ierodiaconou, E. Johnstone, P. Kennedy, A. Leplastrier, A. Lewis, S. Lytton, K. Mackay, S. McLennan, C. Mitchell, J. Monk, S. Nichol, A. Post, A. Price, R. Przeslawski, L. Pugsley, N. Quadros, J. Smith, W. Stewart, S. J., N. Townsend, M. Tran, and T. Whiteway. 2018. Australian Multibeam Guidelines. Geoscience Australia.

Pittman, S. J., and K. A. Brown. 2011. Multi-Scale Approach for Predicting Fish Species Distributions across Coral Reef Seascapes. PloS one 6:e20583.

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/.

Raphael, C. 2016. Unpublished report on MNF Southern Surveyor surveys for Temperate East, CSIRO MNF for NESP Marine Biodiversity Hub.

Rees, M. J., N. A. Knott, J. Neilson, M. Linklater, I. Osterloh, A. Jordan, and A. R. Davis. 2018. Accounting for habitat structural complexity improves the assessment of performance in no-take marine reserves. Biological conservation 224:100–110.

Roelofs, A., and J. Stewart. 2018. Pearl Perch. https://www.fish.gov.au/report/208-Pearl-Perch-2018.

Rooney, J., E. Donham, A. Montgomery, H. Spalding, F. Parrish, R. Boland, D. Fenner, J. Gove, and O. Vetter. 2010. Mesophotic coral ecosystems in the Hawaiian Archipelago. Coral reefs 29:361–367.

Schilling, H. T., J. D. Everett, J. A. Smith, J. Stewart, J. M. Hughes, M. Roughan, C. Kerry, and I. M. Suthers. 2020. Multiple spawning events promote increased larval dispersal of a predatory fish in a western boundary current. Fisheries Oceanography 2019:1.

Seiler, J., A. Williams, and N. Barrett. 2012. Assessing size, abundance and habitat preferences of the Ocean Perch Helicolenus percoides using a AUV-borne stereo camera system. Fisheries research 129–130:64–72.

Sih, T. L., M. Cappo, and M. Kingsford. 2017. Deep-reef fish assemblages of the Great Barrier Reef shelf-break (Australia). Scientific reports 7:10886.

Stewart, J., and D. J. Ferrell. 2001. Age, growth, and commercial landings of yellowtail scad (Trachurus novaezelandiae) and blue mackerel (Scomber australasicus) off the coast of New South Wales, Australia. New Zealand journal of marine and freshwater research 35:541–551.

Stewart, J., and J. M. Hughes. 2005. Longevity, growth, reproduction and a description of the fishery for silver sweep Scorpis lineolatus off New South Wales, Australia. New Zealand journal of marine and freshwater research 39:827–838.

Stewart, J., and J. M. Hughes. 2009. Biological and fishery characteristics of rubberlip morwong Nemadactylus douglasii (Hector, 1875) in eastern Australia. Fisheries research 96:267–274.

Stewart, J., K. Rowling, A. Hegarty, and A. Nuttall. 2010. Size and age at sexual maturity of snapper *Pagrus auratus* in NSW 2008/09. Industry and Investment NSW.

Stewart, J., W. Sumpton, M. Lockett, and J. M. Hughes. 2013. Age-based demographics of the pearl perch G laucosoma scapulare (Ramsay, 1881). Zeitschrift fur angewandte Ichthyologie = Journal of applied ichthyology 29:801–807.

Sumpton, W., M. F. O'Neill, M. Campbell, M. McLennan, A. Campbell, and J. Stewart. 2017. Stock assessment of the Queensland and New South Wales pearl perch (Glaucosoma scapulare) fishery:87.

Suthers, I. M., J. W. Young, M. E. Baird, M. Roughan, J. D. Everett, G. B. Brassington, M. Byrne, S. A. Condie, J. R. Hartog, C. S. Hassler, A. J. Hobday, N. J. Holbrook, H. A. Malcolm, P. R. Oke, P. A. Thompson, and K. Ridgway. 2011. The strengthening East Australian Current, its eddies and biological effects — an introduction and overview. Deep-sea research. Part II, Topical studies in oceanography 58:538–546.

Tamir, R., G. Eyal, N. Kramer, J. H. Laverick, and Y. Loya. 2019. Light environment drives the shallow-to-mesophotic coral community transition. Ecosphere .

Thomas, C. J., T. C. L. Bridge, J. Figueiredo, E. Deleersnijder, and E. Hanert. 2015. Connectivity between submerged and near-sea-surface coral reefs: can submerged reef populations act as refuges? Diversity and Distributions 21:1254–1266.

Trembanis, A. C., A. L. Forrest, B. M. Keller, and M. R. Patterson. 2017. Mesophotic Coral Ecosystems: A Geoacoustically Derived Proxy for Habitat and Relative Diversity for the Leeward Shelf of Bonaire, Dutch Caribbean. Frontiers in Marine Science 4:51.

Turner, J. A., D. A. Andradi-Brown, and A. Gori. 2019. Key questions for research and conservation of mesophotic coral ecosystems and temperate mesophotic ecosystems. Mesophotic coral.

Turner, J. A., R. C. Babcock, R. Hovey, G. A. Kendrick, and S. Degraer. 2017. Deep thinking: a systematic review of mesophotic coral ecosystems. ICES journal of marine science: journal du conseil 74:2309–2320.

Vergés, A., C. Doropoulos, H. A. Malcolm, M. Skye, M. Garcia-Pizá, E. M. Marzinelli, A. H. Campbell, E. Ballesteros, A. S. Hoey, A. Vila-Concejo, Y.-M. Bozec, and P. D. Steinberg. 2016. Long-term empirical evidence of ocean warming leading to tropicalization of fish communities, increased herbivory, and loss of kelp. Proceedings of the National Academy of Sciences of the United States of America 113:13791–13796.

Visconti, V., E. D. L. Trip, M. H. Griffiths, and K. D. Clements. 2018a. Reproductive biology of the leatherjacket, Meuschenia scaber (Monacanthidae) (Forster 1801) in the Hauraki Gulf, New Zealand. New Zealand journal of marine and freshwater research 52:82–99.

Visconti, V., E. D. L. Trip, M. H. Griffiths, and K. D. Clements. 2018b. Life-history traits of the leatherjacket Meuschenia scaber, a long-lived monacanthid. Journal of fish biology 92:470–486.

Walbridge, S., N. Slocum, M. Pobuda, and D. J. Wright. 2018. Unified Geomorphological Analysis Workflows with Benthic Terrain Modeler. Geosciences Journal 8:94.

Whitmarsh, S. K., P. G. Fairweather, and C. Huveneers. 2017. What is Big BRUVver up to? Methods and uses of baited underwater video. Reviews in fish biology and fisheries 27:53–73.

Williams, A., and N. J. Bax. 2001. Delineating fish-habitat associations for spatially based management: an example from the south-eastern Australian continental shelf. Marine and Freshwater Research 52:513–536.

Williams, J., A. Jordan, D. Harasti, P. Davies, and T. Ingleton. 2019. Taking a deeper look: Quantifying the differences in fish assemblages between shallow and mesophotic temperate rocky reefs. PloS one 14:e0206778.

Withell, A. F., and J. W. Wankowski. 1988. Estimates of age and growth of ocean perch, Helicolenus percoides Richardson, in south-eastern Australian waters. Marine and Freshwater Research 39:441–457.

Wood, S. N. 2017. Generalized additive models: an introduction with R. Chapman and Hall/CRC.

Zuur, A., J. M. Hilbe, and E. I. Ieno. 2012. A beginner's guide to GLM and GLMM with R. Highland Statistics LTD.

APPENDIX A – FISH SPECIES LIST

All species recorded from stereo-BRUV deployments during this study at each location. In alphabetical order by Family.

Family	Genus species	Broughton Island Offshore	Outer Gibber	Seal Rocks Offshore
Acanthuridae	*Acanthurus dussumieri*	0	2	0
Acanthuridae	*Prionurus microlepidotus*	0	17	0
Aplodactylidae	*Aplodactylus lophodon*	0	1	0
Aracanidae	*Anoplocapros inermis*	1	1	1
Aulopidae	*Latropiscis purpurissatus*	35	12	18
Aulostomidae	*Aulostomus chinensis*	0	1	0
Berycidae	*Centroberyx affinis*	917	5	531
Blenniidae	*Xiphasia sp*	1	0	0
Callanthiidae	*Callanthias australis*	36	6	6
Carangidae	*Carangoides ferdau*	0	1	0
Carangidae	*Pseudocaranx georgianus*	168	88	365
Carangidae	*Seriola hippos*	0	3	0
Carangidae	*Seriola lalandi*	0	48	0
Carangidae	*Seriola rivoliana*	0	16	0
Carangidae	*Trachurus novaezelandiae*	1137	252	723
Carcharhinidae	*Carcharhinus sp*	0	1	0
Carcharhinidae	*Galeocerdo cuvier*	0	0	1
Centrolophidae	*Seriolella brama*	1	0	0
Chaetodontidae	*Amphichaetodon howensis*	11	3	2
Chaetodontidae	*Chelmonops truncatus*	0	8	0
Cheilodactylidae	*Cheilodactylus fuscus*	0	33	5
Cheilodactylidae	*Nemadactylus douglasii*	157	22	117
Chironemidae	*Chironemus marmoratus*	0	1	0
Congridae	*Conger verreauxi*	1	0	0
Congridae	*Conger wilsoni*	1	0	0
Cyttidae	*Cyttus australis*	7	0	1
Dasyatidae	*Bathytoshia brevicaudata*	2	6	5
Dinolestidae	*Dinolestes lewini*	190	10	34

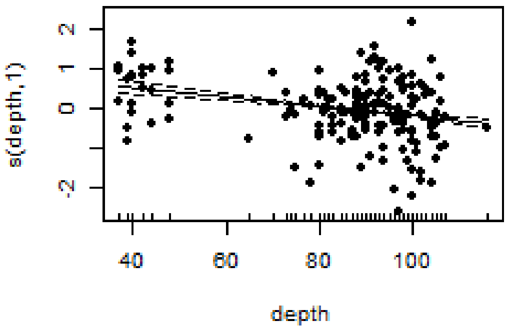
Enoplosidae	*Enoplosus armatus*	5	24	9
Gempylidae	*Thyrsites atun*	40	41	6
Glaucosomatidae	*Glaucosoma scapulare*	21	0	72
Heterodontidae	*Heterodontus galeatus*	0	2	0
Heterodontidae	*Heterodontus portusjacksoni*	42	16	23
Hypnidae	*Hypnos monopterygius*	0	0	3
Kyphosidae	*Atypichthys strigatus*	0	1125	1389
Kyphosidae	*Girella elevata*	0	4	0
Kyphosidae	*Microcanthus strigatus*	0	0	1
Labridae	*Achoerodus viridis*	0	15	0
Labridae	*Anampses elegans*	0	2	0
Labridae	*Bodianus frenchii*	0	1	0
Labridae	*Bodianus unimaculatus*	63	0	44
Labridae	*Coris picta*	0	38	0
Labridae	*Coris sandeyeri*	0	1	0
Labridae	*Notolabrus gymnogenis*	0	22	0
Labridae	*Ophthalmolepis lineolatus*	0	85	0
Labridae	*Pseudolabrus luculentus*	0	6	0
Lamnidae	*Carcharodon carcharias*	0	0	1
Latridae	*Latridopsis forsteri*	2	0	3
Monacanthidae	*Eubalichthys bucephalus*	0	2	0
Monacanthidae	*Eubalichthys mosaicus*	0	6	0
Monacanthidae	*Meuschenia freycineti*	0	19	1
Monacanthidae	*Meuschenia scaber*	417	152	130
Monacanthidae	*Meuschenia trachylepis*	0	13	0
Monacanthidae	*Meuschenia venusta*	0	2	0
Monacanthidae	*Nelusetta ayraud*	80	4	294
Moridae	*Lotella rhacina*	28	4	27
Mullidae	*Parupeneus sp*	1	0	0
Mullidae	*Parupeneus spilurus*	4	120	3
Mullidae	*Upeneichthys lineatus*	1	3	5
Mullidae	*Upeneichthys sp*	1	0	0
Muraenidae	*Gymnothorax prasinus*	9	26	18
Muraenidae	*Gymnothorax prionodon*	139	0	27

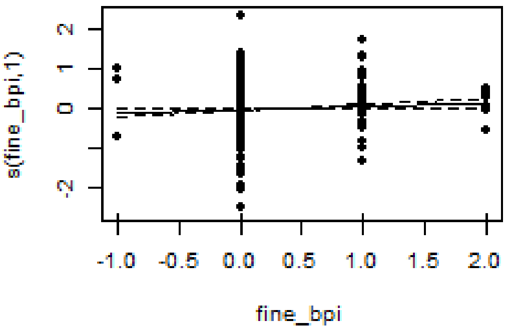
Myliobatidae	*Myliobatis tenuicaudatus*	0	4	0
Odontaspididae	*Carcharias taurus*	2	1	0
Orectolobidae	*Orectolobus maculatus*	1	11	6
Orectolobidae	*Orectolobus ornatus*	9	2	26
Palinuridae	*Sagmariasus verreauxi*	10	0	20
Paralichthyidae	*Unknown sp*	0	0	1
Parascylliidae	*Parascyllium collare*	9	0	4
Pempherididae	*Pempheris affinis*	4	0	0
Pentacerotidae	*Zanclistius elevatus*	3	0	0
Pinguipedidae	*Parapercis binivirgata*	6	0	1
Platycephalidae	*Platycephalus caeruleopunctatus*	26	0	91
Platycephalidae	*Platycephalus grandispinis*	0	0	1
Platycephalidae	*Platycephalus richardsoni*	0	0	1
Platycephalidae	*Platycephalus sp*	0	0	1
Pomacentridae	*Chromis hypsilepis*	0	47	1
Pomacentridae	*Mecaenichthys immaculatus*	0	7	3
Pomacentridae	*Parma microlepis*	0	16	0
Pomacentridae	*Parma unifasciata*	0	3	0
Pristiophoridae	*Pristiophorus cirratus*	2	0	3
Rhinobatidae	*Aptychotrema rostrata*	29	0	23
Rhinobatidae	*Trygonorrhina fasciata*	23	3	23
Sciaenidae	*Atractoscion aequidens*	65	42	35
Scombridae	*Scomber australasicus*	0	0	9
Scombridae	*Thunnus sp*	1	0	0
Scorpaenidae	*Scorpaena cardinalis*	9	9	3
Scorpaenidae	*Scorpaena jacksoniensis*	8	11	9
Scorpididae	*Scorpis lineolata*	1	84	61
Scyliorhinidae	*Asymbolus analis*	1	0	1
Sebastidae	*Helicolenus percoides*	104	0	72
Serranidae	*Acanthistius ocellatus*	40	10	50
Serranidae	*Caesioperca lepidoptera*	5	0	8
Serranidae	*Epinephelus ergastularius*	1	0	2
Serranidae	*Epinephelus undulatostriatus*	0	1	0

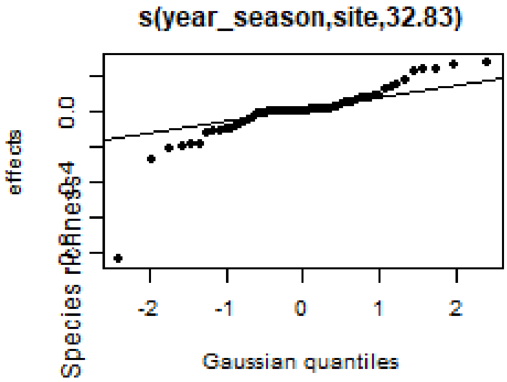
Serranidae	*Hypoplectrodes annulatus*	0	5	0
Serranidae	*Hypoplectrodes maccullochi*	11	8	16
Serranidae	*Lepidoperca pulchella*	14	0	1
Serranidae	*Lepidoperca sp*	1	0	0
Sillaginidae	*Sillaginodes sp*	7	0	1
Sillaginidae	*Sillago flindersi*	2	0	2
Sillaginidae	*Unknown spp*	0	0	3
Sparidae	*Chrysophrys auratus*	110	128	161
Sparidae	*Rhabdosargus sarba*	0	58	1
Syngnathidae	*Solegnathus sp*	2	0	0
Tetraodontidae	*Canthigaster callisterna*	0	0	1
Triakidae	*Mustelus antarcticus*	26	0	12
Triglidae	*Chelidonichthys kumu*	8	0	3
Triglidae	*Pterygotrigla polyommata*	1	0	2
Urolophidae	*Trygonoptera testacea*	1	0	0
Urolophidae	*Unknown sp*	1	0	0
Urolophidae	*Urolophus kapalensis*	0	0	2
Zeidae	*Zeus faber*	1	0	2

APPENDIX B – FULL SUBSET GAMM PARTIAL PLOTS

Species Richness







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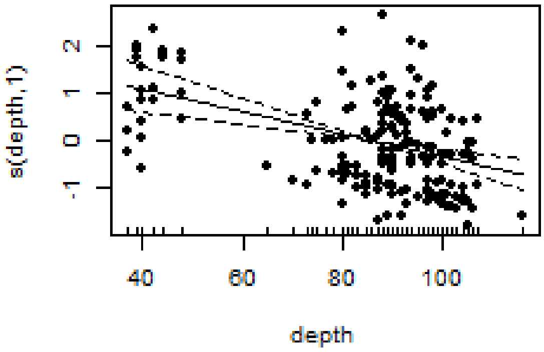
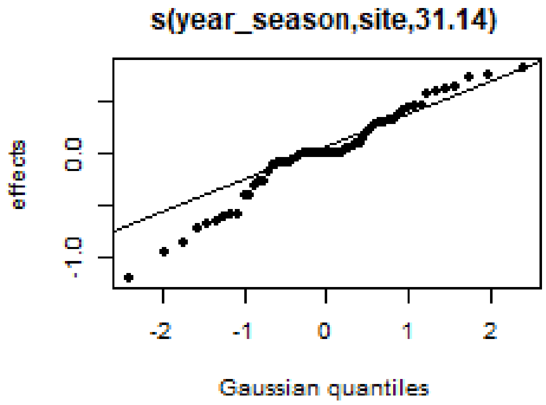
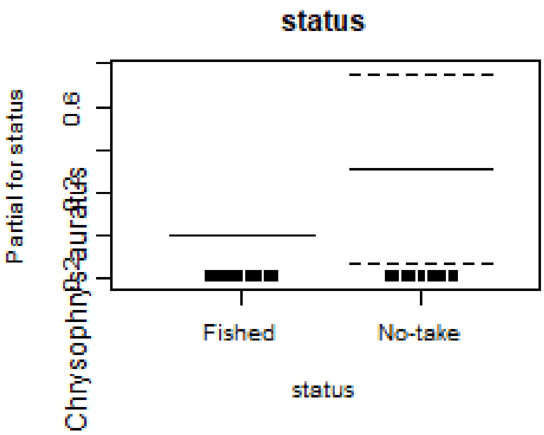
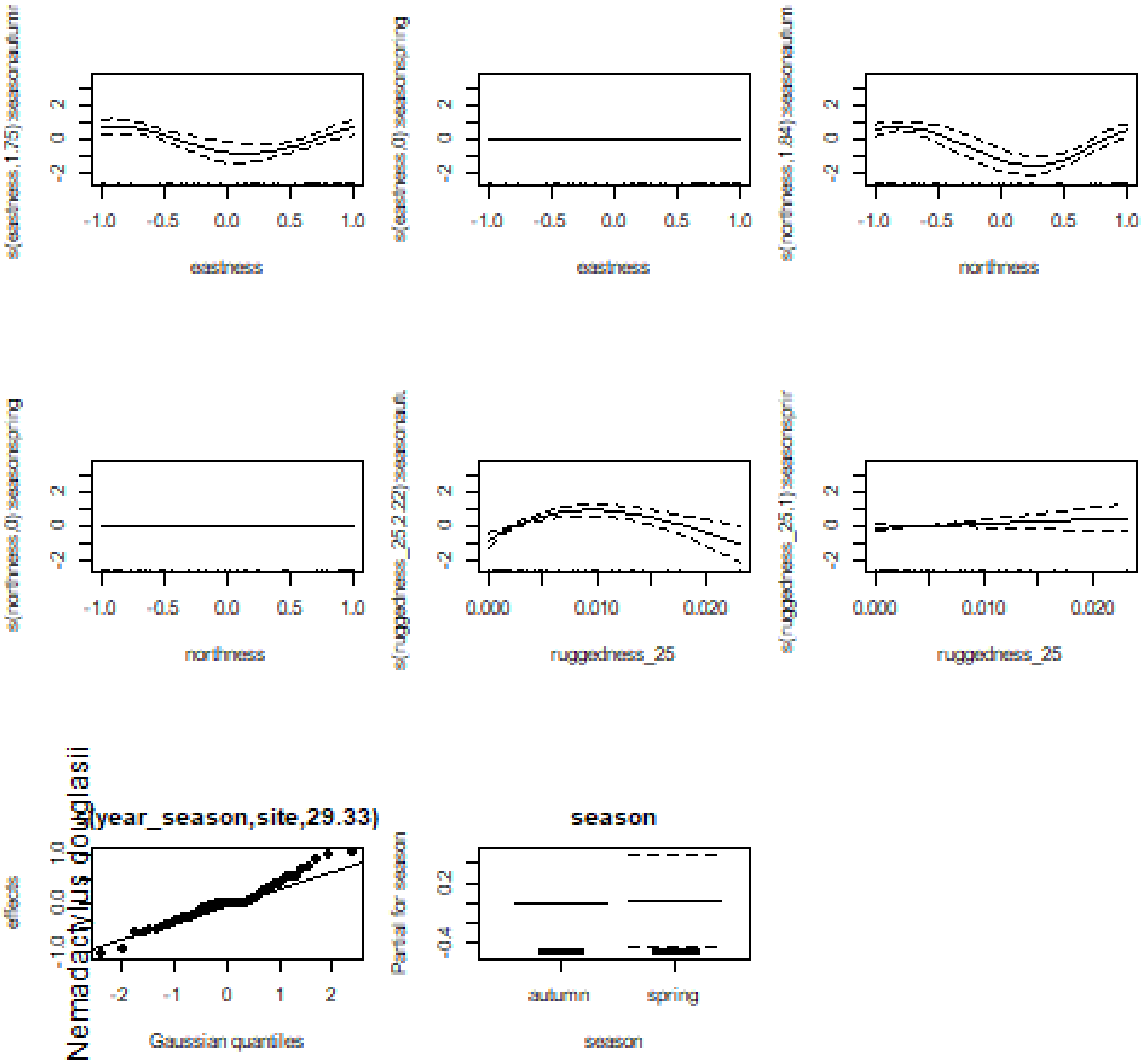


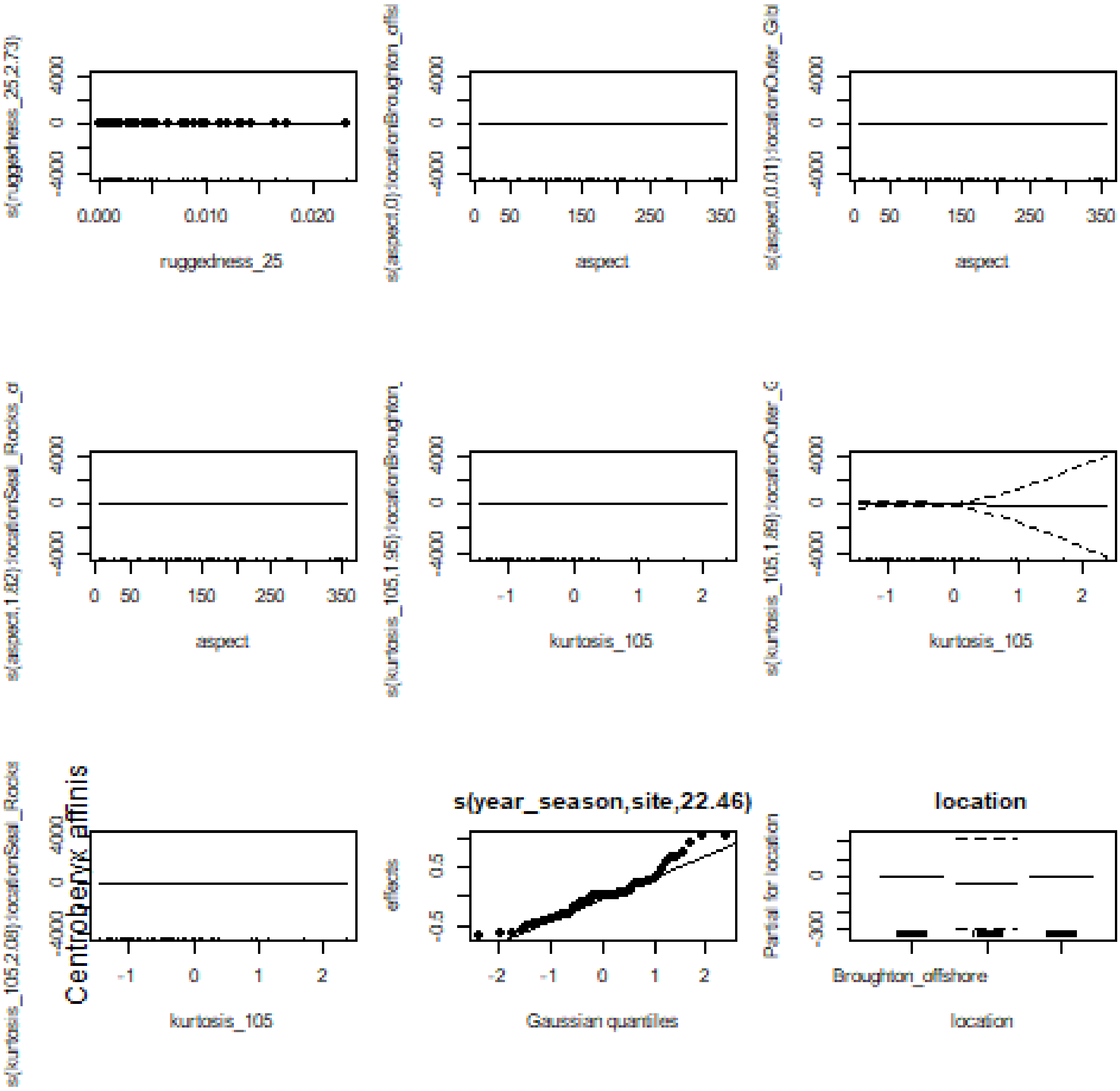




Blue Morwong



Redfish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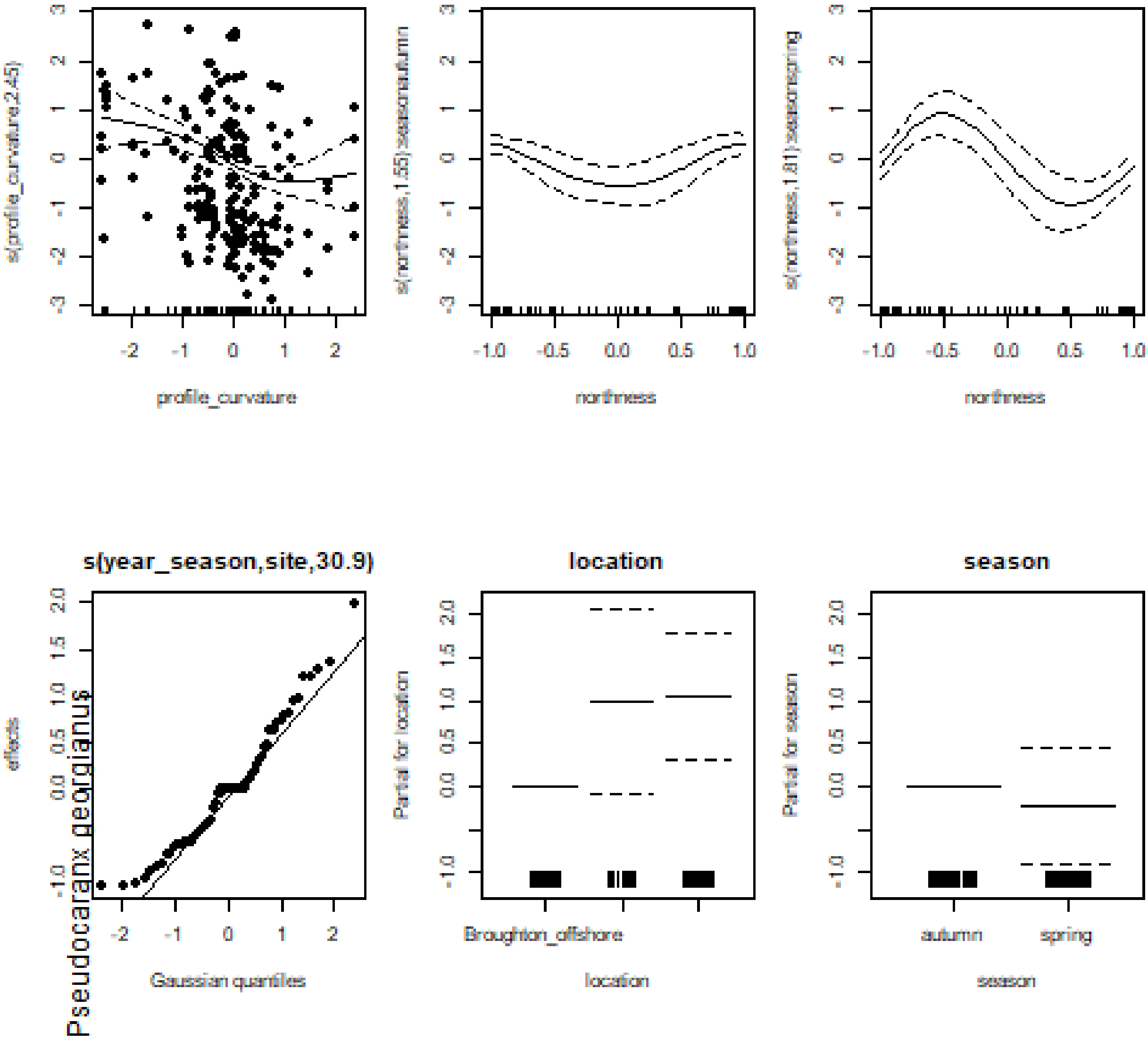
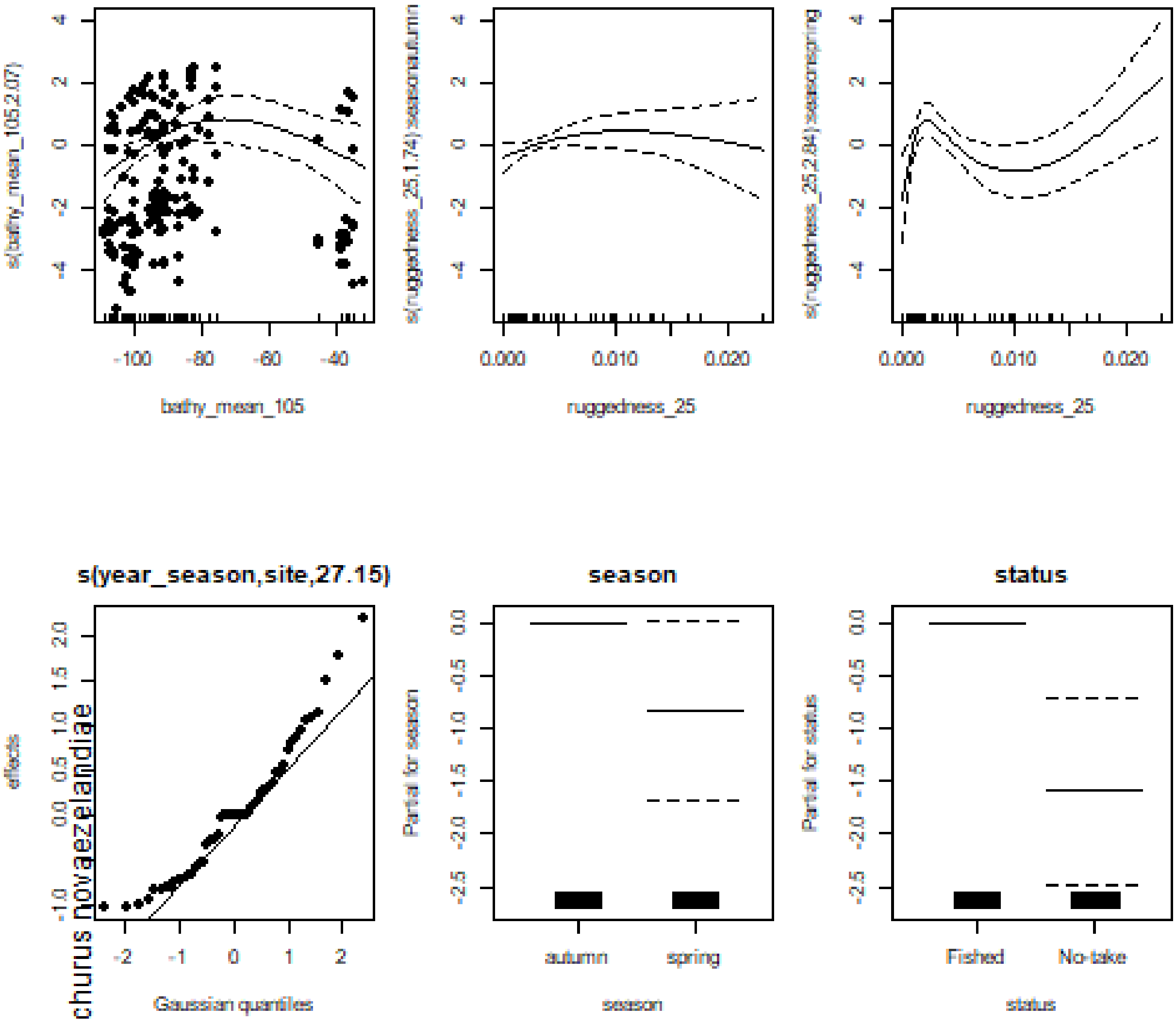
aspect
s(aspect,0.01):locationOuter_Gbl
aspect
s(aspect,1.82):locationSeal_Rocks_o
aspect
s(kurtosis_105,1.95):locationBroughton_
kurtosis_105
s(kurtosis_105,1.89):locationOuter_G
kurtosis_105
s(kurtosis_105,2.08):locationSeal_Rocks
Centroberyx affinis
kurtosis_105
s(year_season,site,22.46)
effects
Gaussian quantiles
location
Partial for location
Broughton_offshore
location

Silver Trevally

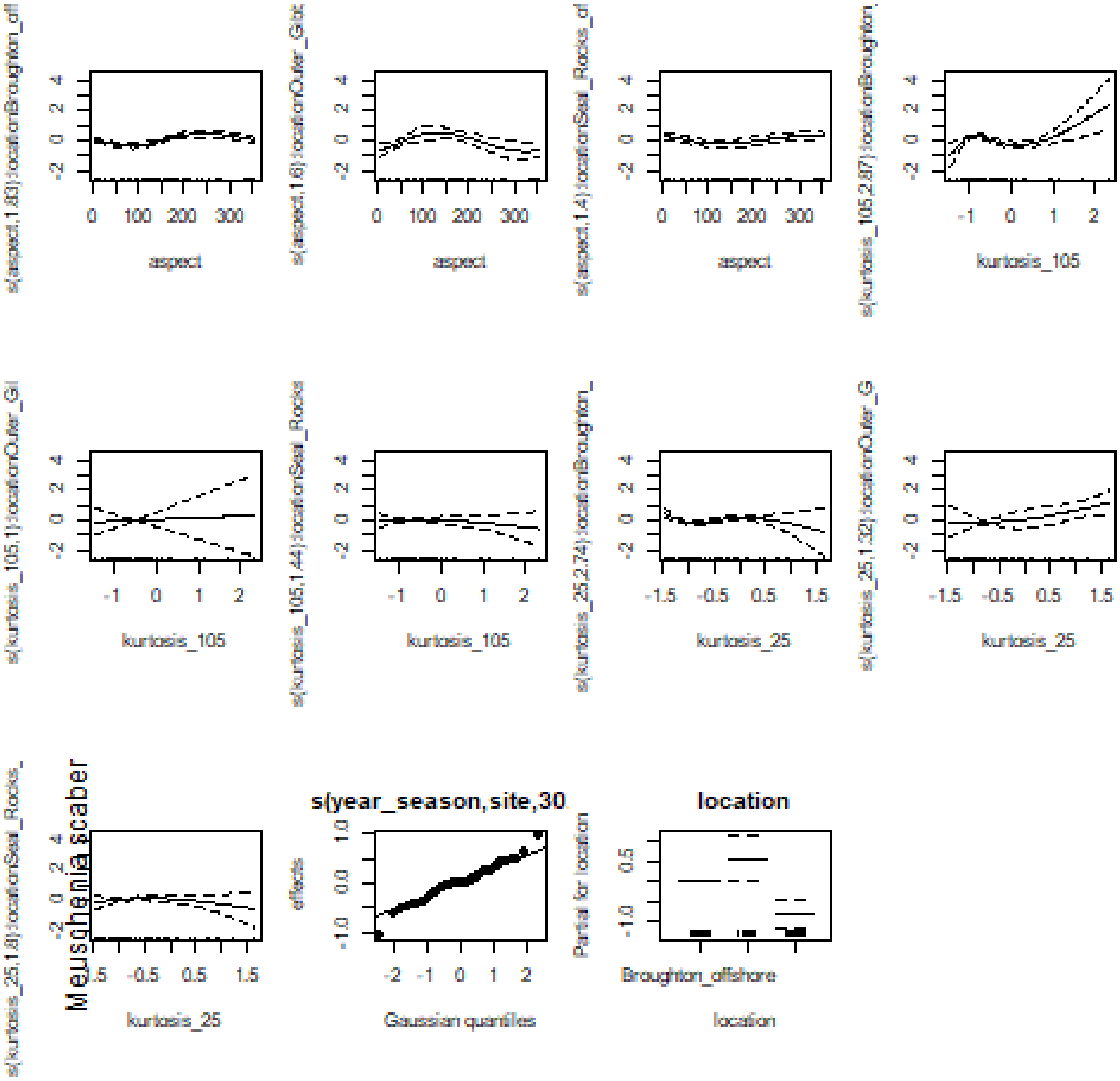


Yellowtail Scad

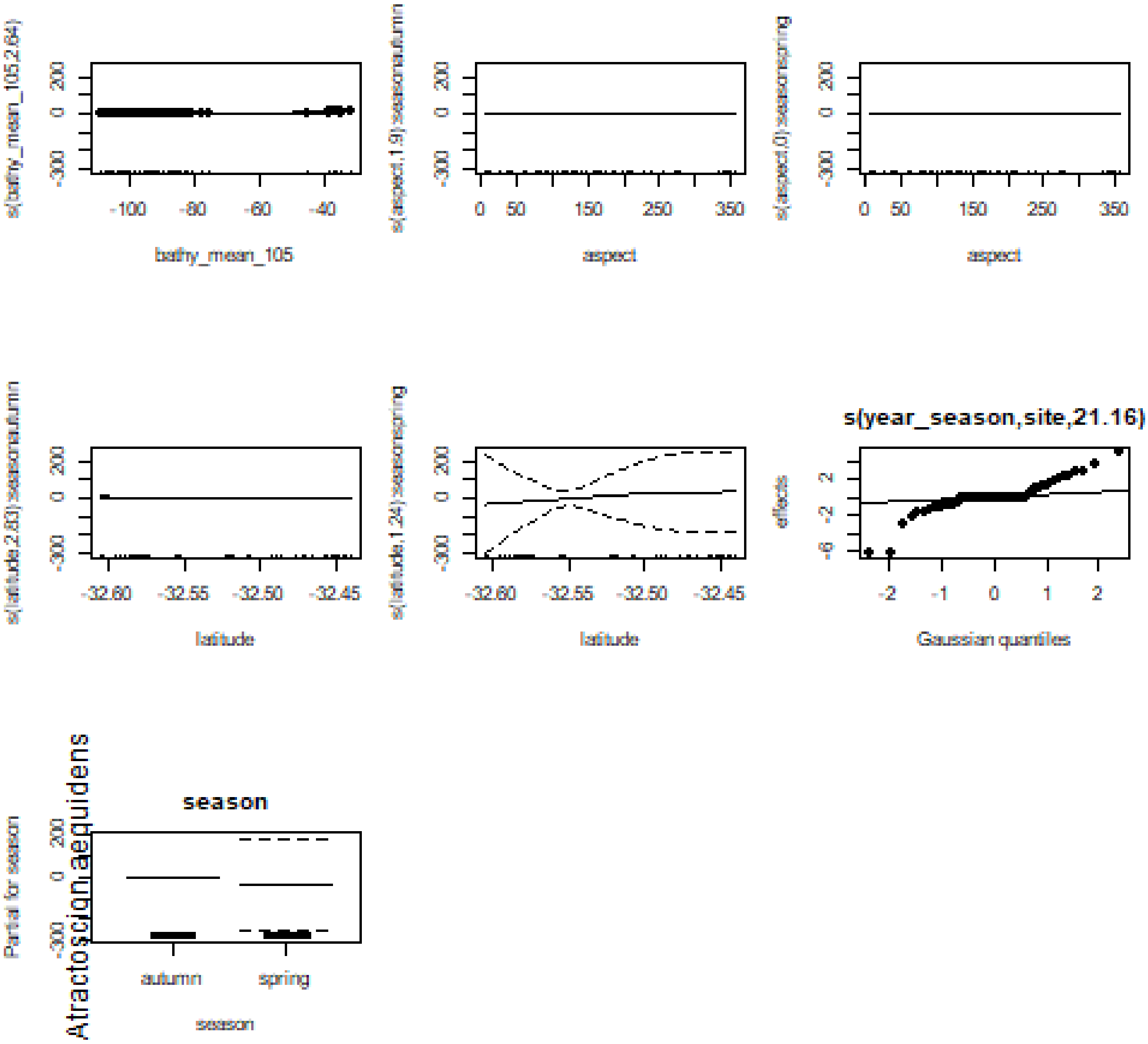


Trachurus novaezelandiae

Velvet Leatherjacket



Teraglin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aspect
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latitude
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latitude
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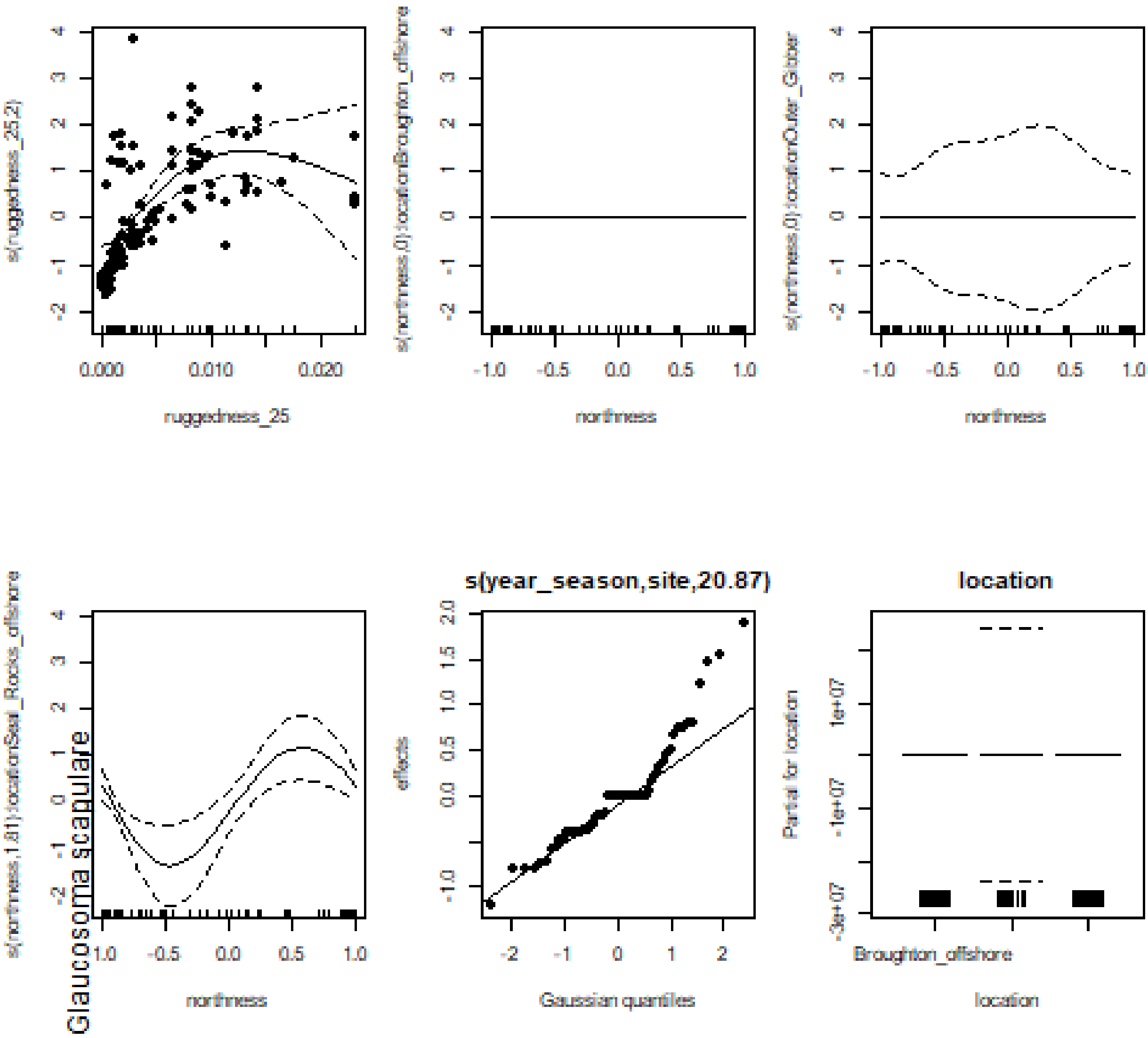
Gaussian quantiles
season
Partial for season
autumn
spring
season
Atractoscion aequidens

Pearl Perch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Glaucosoma scapulare
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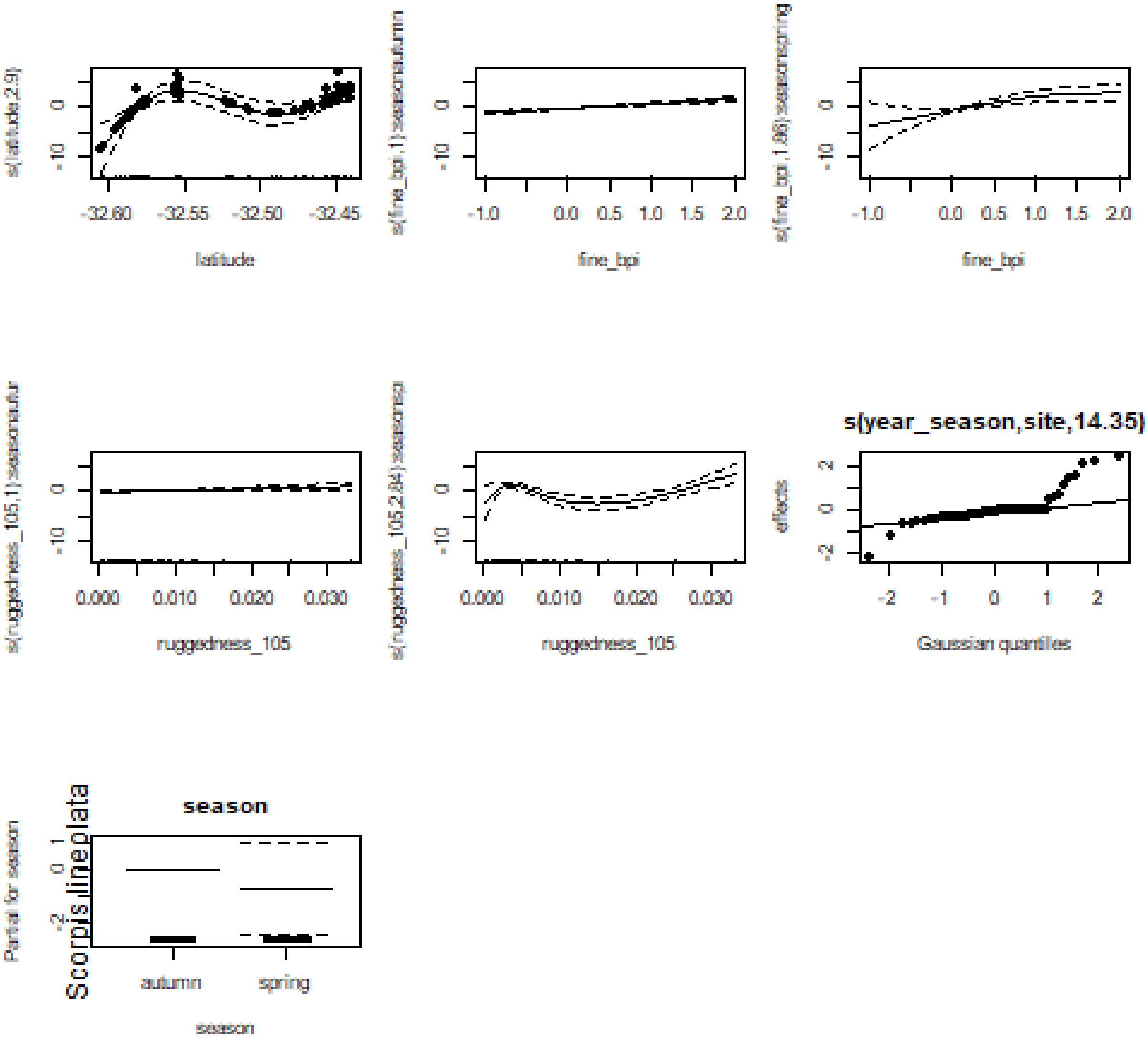
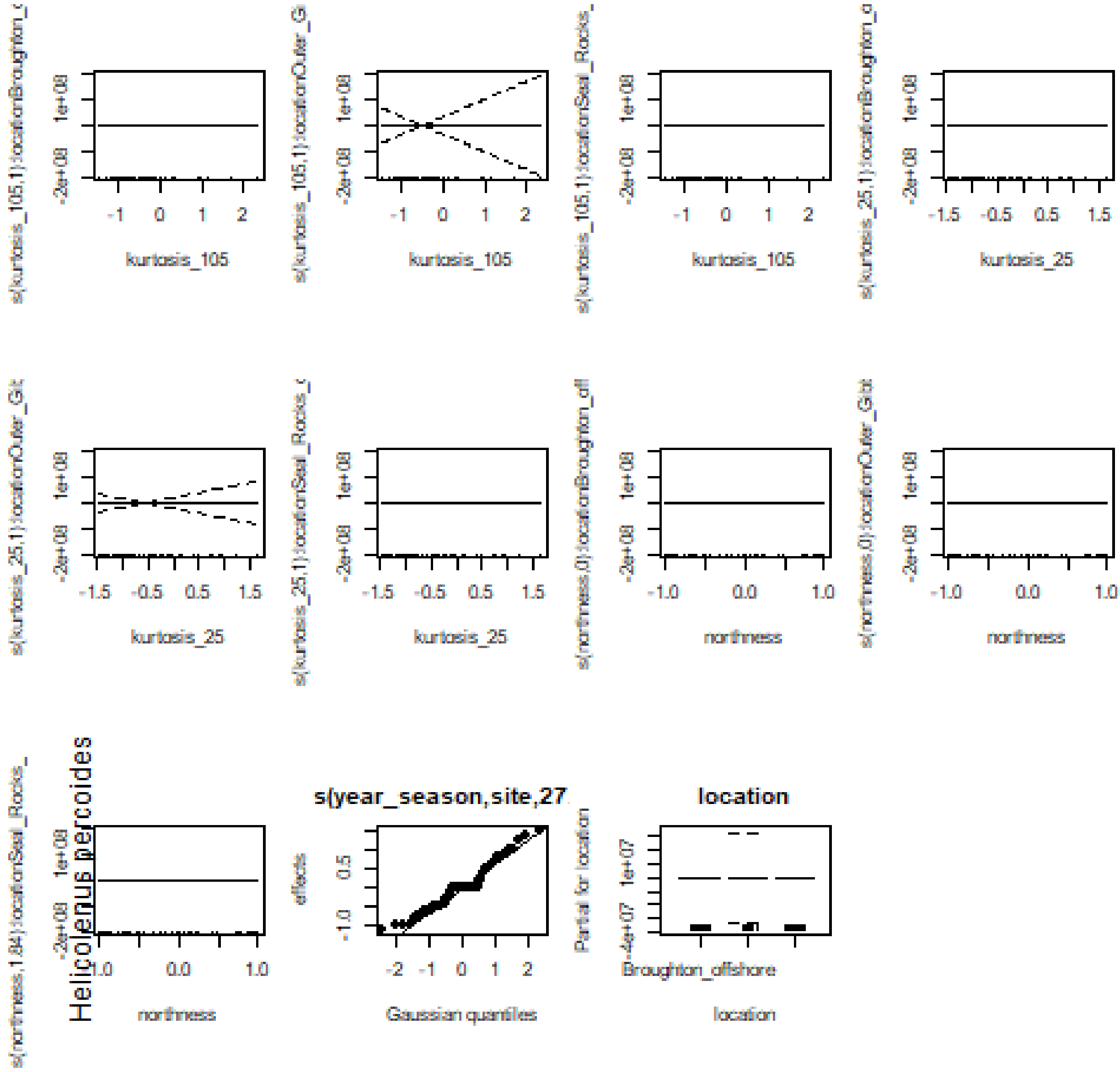
Gaussian quantiles
location
Partial for location
Broughton_offshore
location

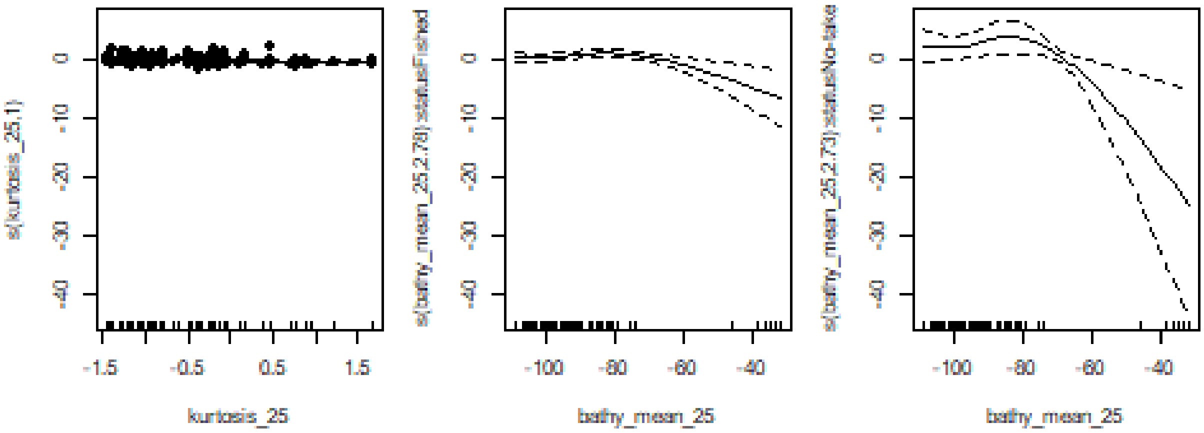
Silver Sweep

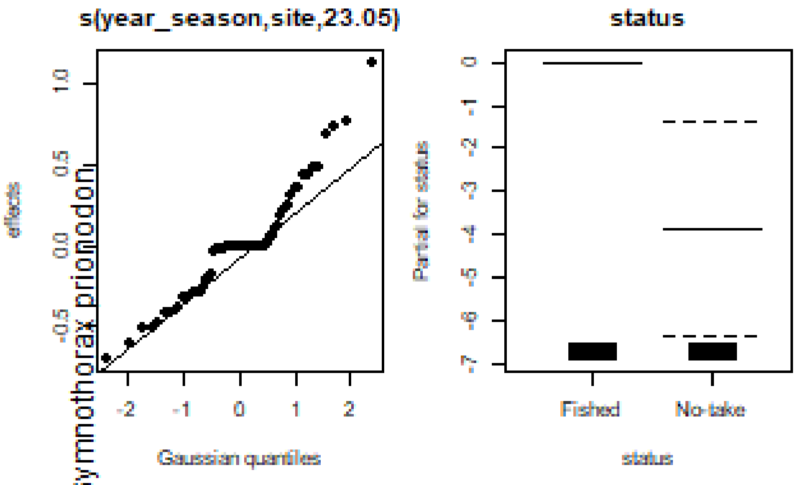


Reef Ocean Perch



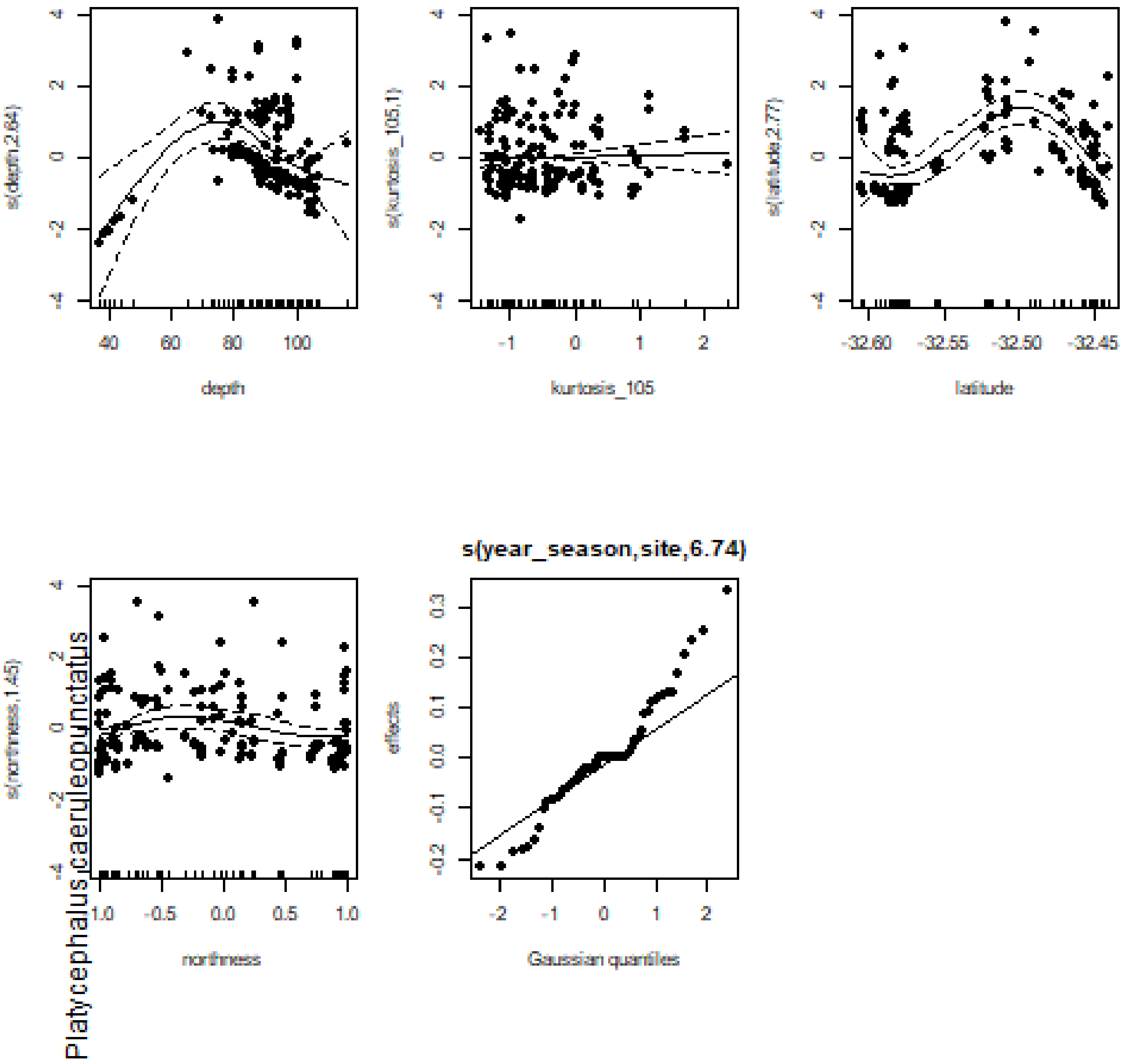
Sawtooth Moray



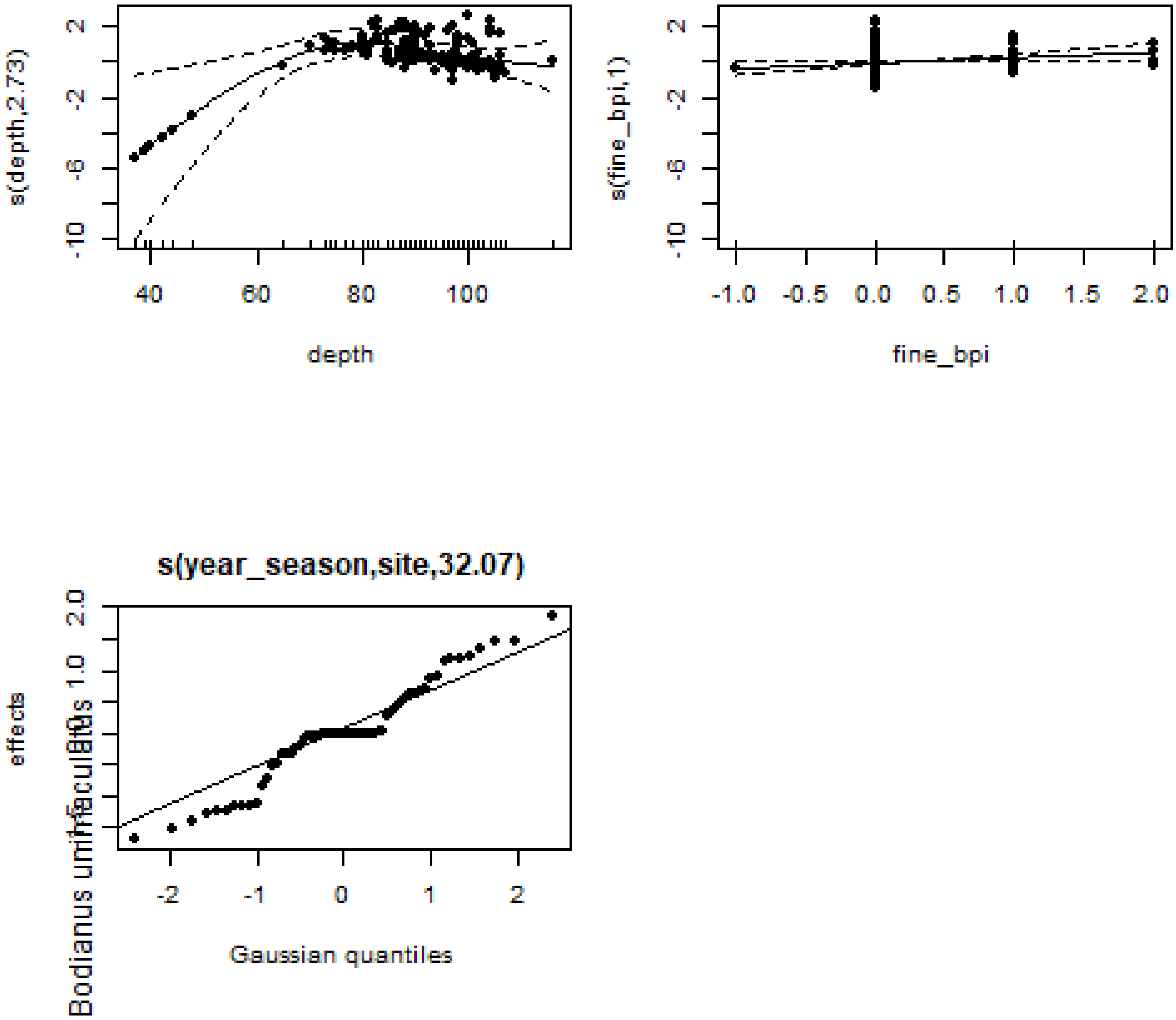


Gymnothorax prionodon

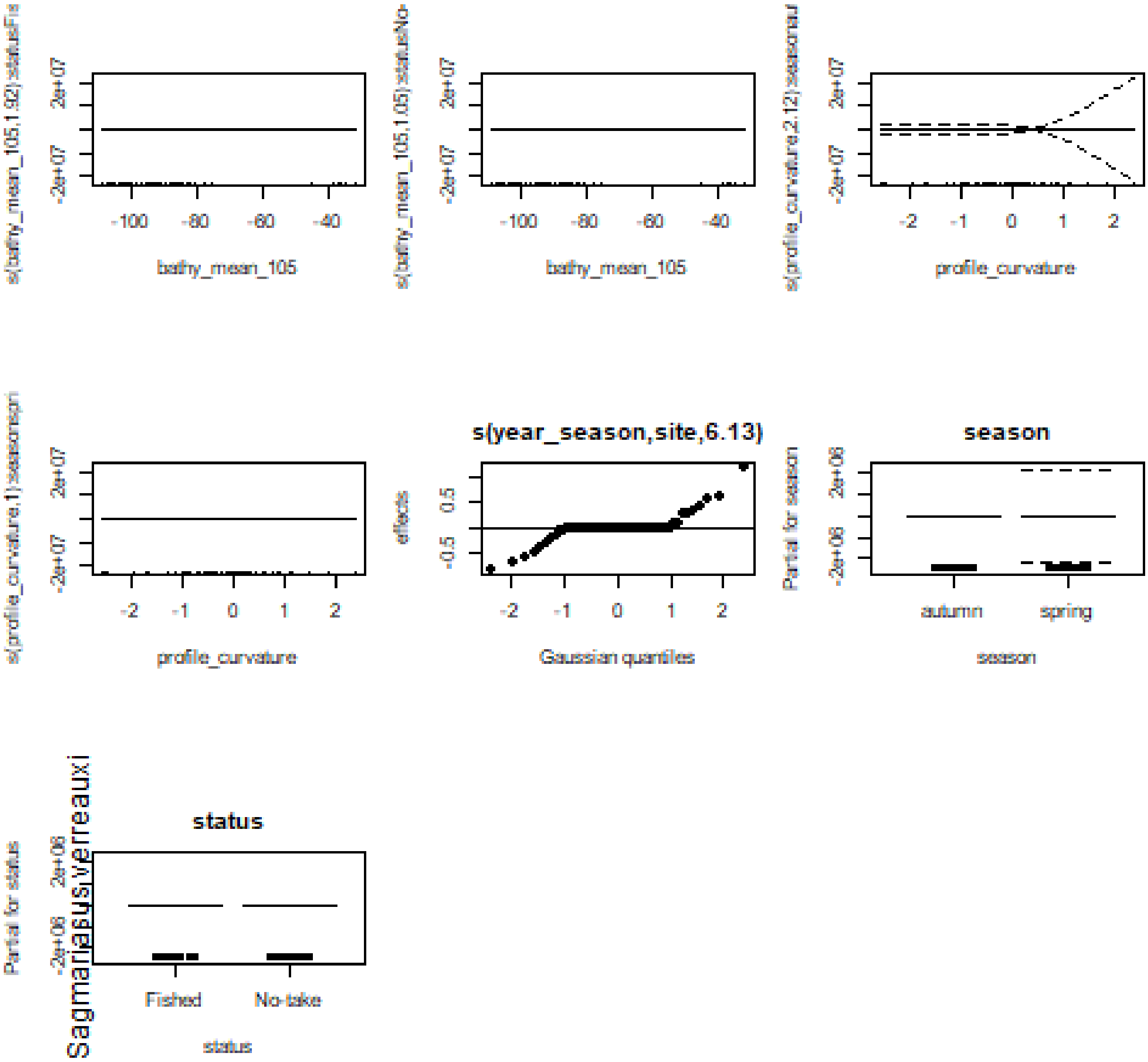
Bluespot Flathead



Eastern Pigfish



Eastern Rock Lobster



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