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South-west Corner Marine Park Survey Report

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Executive Summary

The South-west Corner Marine Park, within the South-west Network of the Australian Marine Parks, has a rich marine biodiversity with high levels of endemism that supports a range of socio-economic values including important recreation and commercial fisheries. Partnership with Wadandi Traditional Owners and Custodians for this region provided guidance through cultural maps and knowledge to inform the discovery of remarkable biodiversity across submerged ancient coastline features that document the dynamic history of the region. In addition to ancient coastline features, the tropical poleward flowing Leeuwin Current dominates the shelf waters in the marine park and provides climatic stability but is nutrient poor, this current also results in incredibly clear visibility and natural light penetration down to at least 120 m. The influence of this current, combined with the ancient coastline features has been hypothesised to shape the unique endemic biodiversity found here.

This survey of the ‘Capes region’ of the South-west Corner Marine Park was designed to increase knowledge of the biodiversity of the area, including significant seafloor features, benthic habitat extents and the fish assemblage, and inform any future biodiversity monitoring of the park. Within the National Park Zone, our survey revealed one of the best-preserved examples of submerged ancient coastlines and lowlands currently observed across the Australian Marine Park network. We found 80% more mesophotic and rariphotic rocky reef habitats within the National Park Zone than expected based on a previous national reef model, with extensive kelp, seagrass and sponge gardens out to the last interglacial paleo shoreline in ~120 m depth. This survey found the deepest seagrass and kelp recorded in the South-west Network. Beyond this were extensive sand plains with isolated reefs out to the shelf break in 220 m where again extensive sponge gardens were found. The survey only reached the shelf break, but here in 220-250 m we found aggregations of Hapuku (*Polyprion oxygeneios*), a deep-water grouper highly valued by commercial and recreational fishers, whose populations likely benefits from increased productivity along the shelf break created by nutrient rich Mentelle upwelling.

Guided by expert commercial fisher knowledge we discovered a potential aggregation of Grey Nurse Sharks (*Carcharius taurus*), a species listed as Vulnerable by the Environment Protection and Biodiversity Conservation (EPBC) Act, on isolated reefs in 140 m amongst the mid-shelf sand plains of the National Park Zone. If this aggregation was recorded over multiple years, then it would classify this as the deepest and only 2nd published aggregation of Grey Nurse Shark on the west Australian coast.

Distinct endemic fish assemblages were found to be associated with the last interglacial paleo shoreline, 20-30 thousand years before present (ka BP), in ~120 m depth and with each defined ancient shoreline in 80, 60 and 35 m respectively (15-17, 12-13 and 9-10 ka BP). Across the 9-10 thousand year old shoreline we also observed distinct ancient lowland, suggestive of coastal wetlands, and submerged granite outcrops now covered in kelp and deep water seagrass with aggregations of the iconic and endemic West Australian Dhufish (*Glaucosoma hebraicum*), a highly prized recreational and commercial fisheries species.

The broad extent of sampling coverage that was possible in this survey enabled a National Park Zone and adjacent region of the Special Purpose Zone to be characterised for seascape features, benthic habitats and fish and shark assemblages. This provides useful information to inform future management or permitting decisions. More importantly, the cultural knowledge provided through partnership with Wadandi Traditional Owners and

Custodians not only guided the discovery of remarkable biodiversity across submerged ancient coastline features but provides future guidance for managing the cultural and natural values of the marine park.

To understand the impact of management or environmental change on natural values and ecosystems across the network, within a park or between zones, it is important to identify comparable reference sampling areas across areas of interest (e.g., control areas to evaluate change in a National Park Zone) and have substantial data collected before the implementation of zoning. However, due to the design and implementation legacy of marine parks, and their constituent zones, these conditions can rarely be achieved.

Instead, we recommend research and monitoring focus on the creation of suitable national and international benchmarks to enable meaningful comparison of the status and trend of natural values. Previous global analyses, using some of the same methods used in the latest survey, have demonstrated that Australia is a leader in the sustainable management of shark and fish populations.

We recommend that comparison with synthesis benchmarks for natural values and ecosystem components should be used to give national and international context to the management of our national networks of marine parks. We provide a series of recommendations to understand the impact of management including known and emerging pressures on the status and trend of natural values and ecosystem components in local and national networks of marine parks, using potential natural value indicators and metrics from this survey of the South-west Corner Marine Park. These include the extension and establishment of national and international benchmarks for natural values and ecosystem components and the updating of existing metrics of topicalization and biodiversity, both initially designed for shallow waters (>30 m), to make them fit for the monitoring and assessment of shelf waters within the AMP network.

This survey report is structured into sections that includes:

- Background and eco-narrative of the study area within the Capes region of the South-west Corner Marine Park. This includes existing information on the natural, socio-economic, cultural values and existing pressure information in the region.
- High level aims and objectives for the latest survey, including discovery questions related to significant seafloor features, benthic habitat extents and the fish assemblage that were used to design the survey.
- Latest survey results characterising the significant seafloor features, benthic habitat extents and the fish assemblage with spatial extent predictions and presentation of draft metrics for common pressures.
- General conclusions and recommendations for future work, including guidance from Traditional Owners for future surveys.
- Supplementary Sections that include:
    - detailed survey design and sampling methods used,
    - detailed results including modelling results used to create spatial extent predictions,
    - instructions on how to use available open data from portals in web apps for data exploration and immersive exploration of imagery.
    - open-access and reproducible data analysis workflows to create models and spatial extent predictions for both benthic and fish assemblage metrics.

1. Existing knowledge

1.1 Background

The South-west Corner Marine Park is an iconic area within the South-west Network of the Australian Marine Parks, containing important fisheries and cultural values and harbouring high marine biodiversity (Figure 1). Studies of the ecological assemblages in the region have described high levels of endemism in algae, seagrass, sponge and fish assemblages (Langlois et al. 2012).

The South-west Corner Marine Park survey was designed to establish a comprehensive baseline for benthic habitats and associated demersal fish assemblages on the continental shelf within the marine park. The survey focused on the region offshore from the Cape Naturaliste to Cape Leeuwin coast (hereafter “the Capes region”) where, beyond a general and high-level understanding of the biodiversity and environmental processes of the region, the knowledge base to inform the ongoing management of the marine park is limited (Figure 1). Key data gaps include fine-scale bathymetry coverage, and the extent and distribution of benthic and fish assemblages. The data collected during this survey aimed to address these information gaps and contribute to ongoing inventory and monitoring within the South-west Marine Parks Network as part of the current 10-year management plan (Director of National Parks 2018).

Existing knowledge of the key natural values and ecosystem components in the South-west Corner Marine Park is limited, with only ~ 6% of the continental shelf area of the park sufficiently mapped prior to this study, and minimal biological sampling undertaken. Existing data suggests diverse seabed assemblages consisting of sponges, bryozoans and some octocorals may be present (J. Monk et al. 2017). The University of Western Australia previously conducted limited sampling of the fish assemblages of the South-west Corner Marine Park using baited remote underwater stereo-video systems (stereo-BRUVs) in 2010. While sampling was limited to 7 deployments in the northern-eastern end of the Special Purpose Zone (Mining exclusion), it indicated that Swallowtail (*Centroberyx lineatus*) and Silver Trevally (*Pseudocaranx* spp) were abundant (J. Monk et al. 2017).

In contrast, the adjacent Ngari Capes Marine Park established in 2019 has extensive benchmark data on fish and benthic assemblages, including baseline surveys using stereo-BRUV, Diver Operated stereo-Video (stereo-DOV) and underwater visual census of fish assemblages, diver based surveys of macroalgae and surveys of mobile invertebrates dating back to 2006 and continuing to the present (Westera et al. 2008, S. Bell Pers. Com.). These data have contributed to publications highlighting the high species richness and endemism of both fish (Langlois et al. 2012) and benthic assemblages (Smale, Kendrick, and Wernberg 2011), and the impacts of recent marine heatwaves of fish and macroalgal assemblages (Wernberg et al. 2012).

The Ngari Capes Marine Park also extends into Geographe Bay and is adjacent to the Geographe Marine Park in Commonwealth waters. The Geographe region is also relatively data rich, with extensive historical and modern marine biodiversity surveys within State waters (Westera et al. 2008, S. Bell Pers. Com.) and the Geographe Marine Park being the subject of a 2014 NERP Benchmark Survey (Lawrence et al. 2016) and a recent synthesis report for Parks Australia to optimise the monitoring of fish and benthic assemblages (Giraldo Ospina et al. 2021).

1.2 Features and values of the South-west Corner Marine Park

The South-west Corner Marine Park is one of 14 parks in the South-west Marine Parks Network (Director of National Parks 2018). The park is the largest in the network, extending from offshore Cape Naturaliste around south-west Australia to offshore Esperance, and covering an area of 271,833 km^2 (Director of National Parks 2018). The park extends across the continental shelf and upper continental slope to the limit of Australia's exclusive economic zone (Director of National Parks 2018). The South-west Corner Marine Park comprises 16 management zones that include National Park Zones (seven areas), a Habitat Protection Zone (one area), Multiple Use Zones (four areas), a Special Purpose Zone (one area) and Special Purpose Zone (Mining Exclusion; two areas).

This report and survey focused on data collection within the National Park Zone and adjacent Special Purpose Zone (Mining Exclusion) offshore from the Cape Mentelle to Cape Freycinet coastline (the 'Capes region'). The no-take Sanctuary Zone off Contos Beach within the adjacent Ngari Capes Marine Park adjoins the no-take National Park Zones within the South-west Corner Marine Park in the centre of our study region, creating the most extensive protected areas on the continental shelf within Australia's marine estate from the Leeuwin-Naturaliste National Park on the shore out to 600 m depth off the continental shelf (Figure 1).

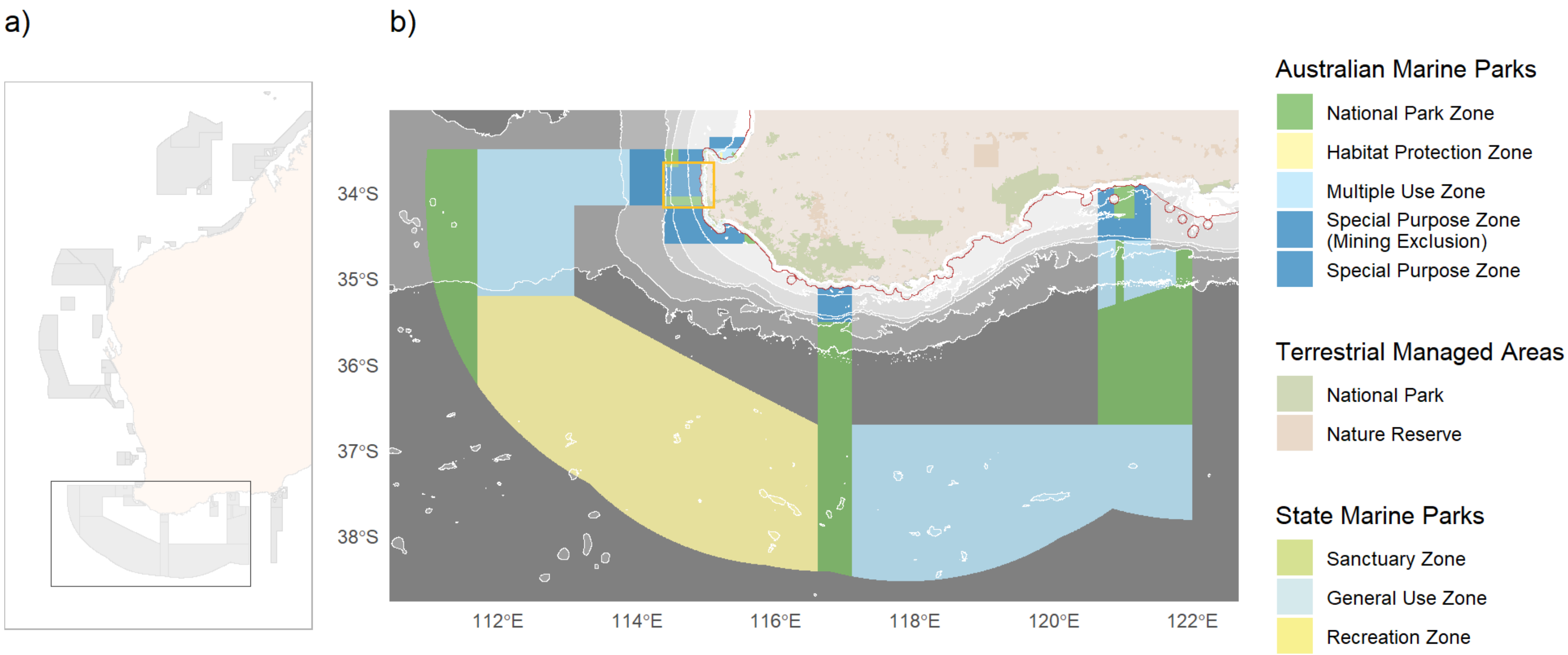


Figure 1 South-west Corner Marine Park and Capes region. a) Location of the South-west Corner Marine Park, b) South-west Corner Marine Park and the “Capes region” including adjacent state managed terrestrial and marine parks. The orange highlighted box indicates the study area presented in Figure 2 below). The red line delimits state and Commonwealth waters. The bathymetric contours shown are 30 m, 70 m, 200 m, 700 m, 2000 m and 4000 m; representing historic sea-levels and ecosystem depth contours.

Key Ecological Features used in the design of the South-west Corner Marine Park included reefs and banks on the continental shelf, submarine canyons that locally connect the shelf to the deeper waters of the continental slope, the extensive Naturaliste Plateau located beyond the continental slope, and the Diamantina Fracture Zone that reaches to depths of 6500 m (Director of National Parks 2018), Figure 1 and Table 1). Benthic biological communities within the marine park were thought to include sponges and corals associated with reefs and hard substrates, but information on these communities at the time of park design was limited. Pelagic species observed within the region also included a variety of whale species (Antarctic blue, humpback, sperm, southern right and pygmy blue), sharks and sea lions. The South-west Corner Network Management Plan (Director of National Parks 2018) also suggests this region is valued as a key habitat for the Western Rock Lobster (*Panulirus cygnus*) (Figure 2 and Table 1), however this area is at the southern range extent of this species and the majority of its fishery is restricted to north of Mandurah and south of Kalbarri (Newman et al. 2021).

Table 1 Key Ecological Features of the South-west Corner Marine Park. Environmental features summarised from the South-west Marine Parks Network Management Plan (Director of National Parks 2018).

Key Ecological Features	**Description**
Albany Canyon group and adjacent shelf break	Consisting of 32 canyons cut deeply into the steep continental shelf. The canyons are thought to be associated with small periodic upwelling that enhance productivity and aggregate marine life.
Cape Mentelle upwelling	Draws relatively nutrient-rich water from the base of the Leeuwin Current onto the inner shelf where it results in phytoplankton blooms at the surface
Diamantina Fracture Zone	A unique seafloor feature consisting of rugged, deeper water seamounts and closely spaced troughs and ridges. Ridges and seamounts can affect water dynamics and flow enhancing productivity.
Naturaliste Plateau	The combination of this unique seafloor feature’s structural complexity, mixed water dynamics and relative isolation indicates that it supports deep-water communities with high species diversity and endemism.
Demersal slope and associated fish assemblage	South-west Shelf Province marine life is diverse and influenced by the warm but oligotrophic waters of the Leeuwin Current. High levels of biodiversity and endemism.
Western rock lobster	Plays an important trophic role in many of the inshore ecosystems of the South-west Marine Region and supports a valuable fishery.
Ancient coastline between 90 m and 120 m depth	High benthic biodiversity and productivity occur where the ancient coastline forms a prominent escarpment

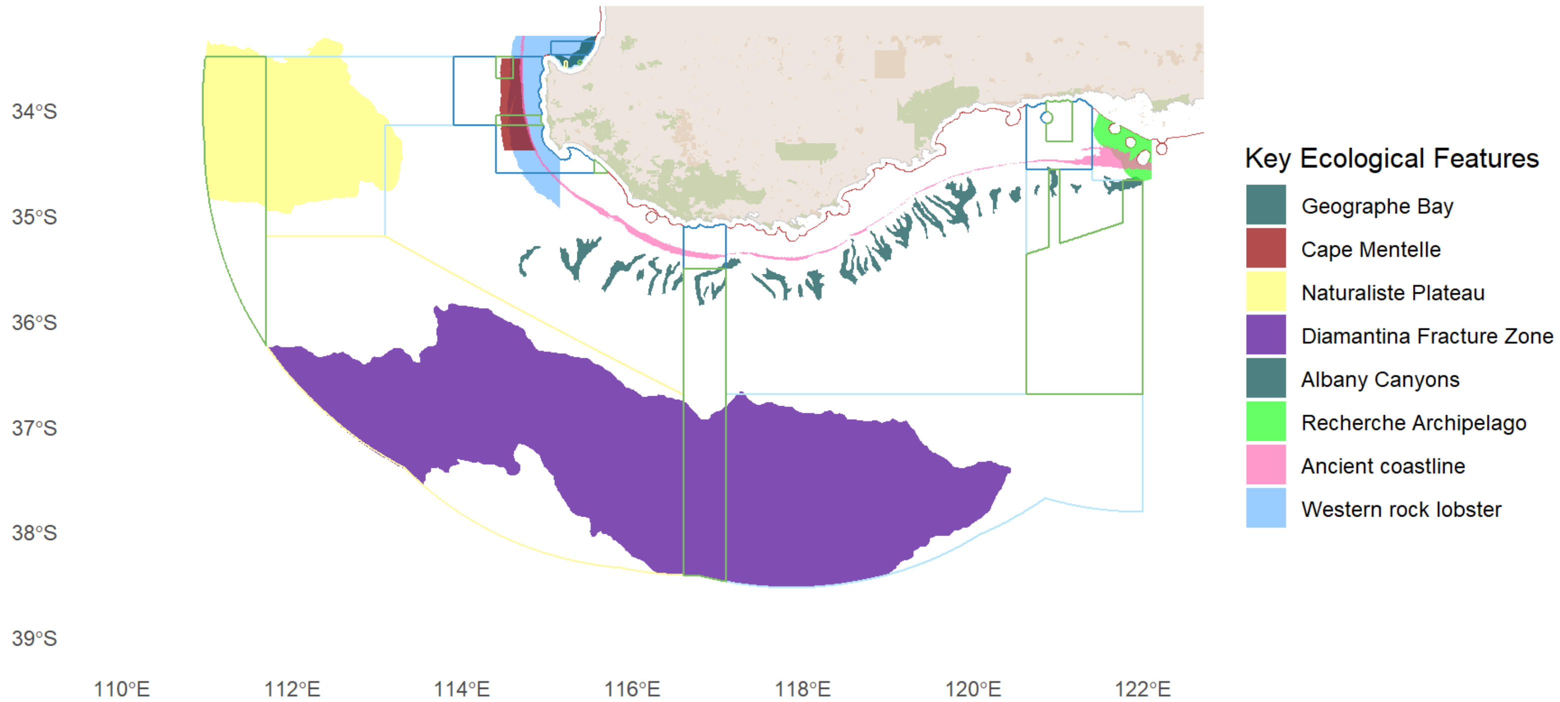


Figure 2 Key Ecological Features at the scale of the South-west Corner Marine Park. Excerpt from Marine Key Ecological Features of the Australian Marine Parks. Legend for Australian Marine Parks, Terrestrial Managed Areas and State Marine Parks can be found in Figure 1. The red line delimits state and commonwealth waters. Geographe Bay = Commonwealth marine environment within and adjacent to Geographe Bay, Cape Mentelle = Cape Mentelle upwelling, Albany Canyons = Albany Canyons group and adjacent shelf break, Recherche Archipelago = Commonwealth marine environment surrounding the Recherche Archipelago, Ancient coastline = Ancient coastline at 90-120 m depth

Key natural values and ecosystem components of the South-west Corner Marine Park are listed in Table 2. The three main values that were the focus of the latest survey (Section 3 and 4) included significant seafloor features, characterising submerged ancient coastline features, benthic values, including benthic sessile algal and invertebrate taxonomic composition and extent, and fish assemblages, including taxonomic diversity, composition, abundance and size structure.

Table 2 Draft^ Key Natural Values of the South-west Corner Marine Park. Key natural values summarised from the South-west Marine Parks Network Management Plan (Director of National Parks 2018). * Values characterised within the latest survey (Section 3 and 4). ^ These may be revised during Parks Australia's ongoing development of a Monitoring, Evaluation, Improvement and Reporting framework.

Key natural values
Mesoscale eddies
*Significant seafloor features
*Fish assemblage, endemic species and transitional zone between tropical and temperate species
*Other important benthic values (e.g. algae and sessile invertebrate assemblages), endemic species and transitional zone between tropical and temperate species
Western rock lobster
Species listed as threatened, migratory or cetacean under the EPBC Act.

Reef habitats, both temperate and tropical, have been identified as an important determinant in the location of key natural values and ecosystem components (Hayes et al. 2021), however, understanding of the distribution and extent of the reef and other seabed habitats on Australia’s continental shelf is limited. NESP Marine and Coastal Hub Project 1.3 ‘Support for Parks Australia’s Monitoring, Evaluation, Reporting and Improvement System for Australian Marine Parks’ has produced a national model of extent of seabed habitats (including reef) that provides a benchmark for the current study within the South-west Corner Marine Park (Figure 3). This existing information is derived from pre-existing national scale bathymetry data (Figure 4) and shows limited significant sea floor features (Figure 3). NESP Marine and Coastal Hub Project 1.3 also acknowledged high uncertainty in predictions of seabed habitat extent and highlighted that this is a key unknown that needs to be addressed as a priority to advance our capability to assess the efficacy of management.

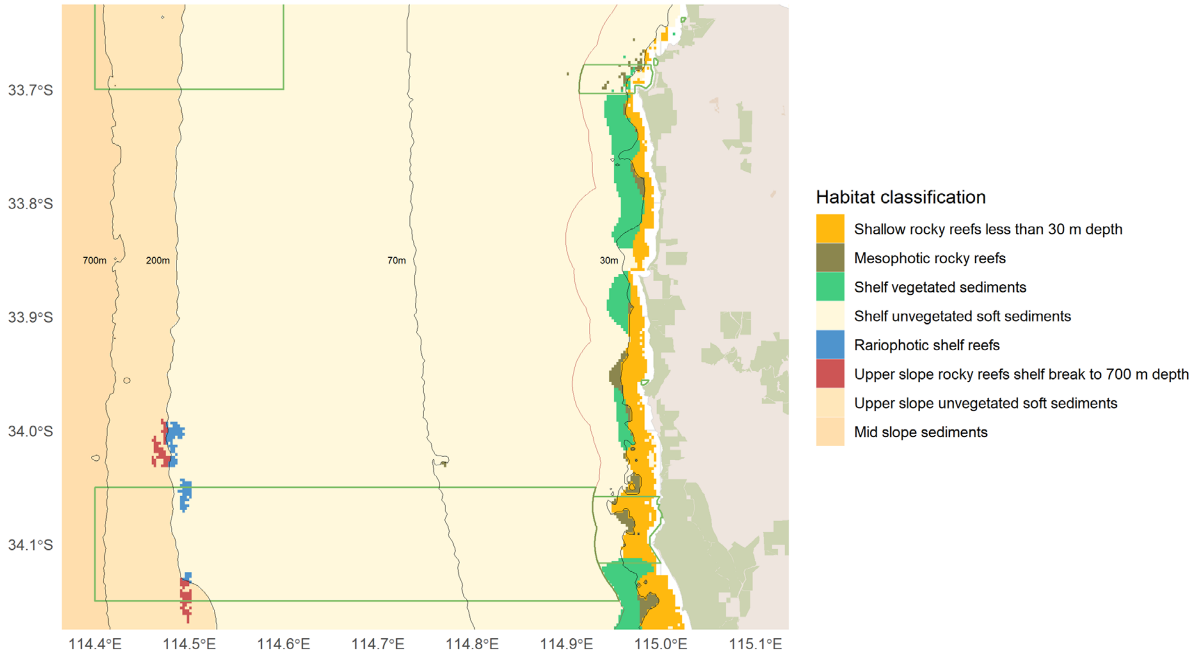


Figure 3 Pre-existing National Reef Model at the scale of the study location. Reproduced from the National benthic habitat model (J. Monk, unpublished). Australian Marine Park and State Marine Park zone boundaries are shown. The red boundary following the coast demarcates the boundary between state and commonwealth waters. The bathymetric contours shown are 30 m, 70 m, 200 m and 700 m representing ecosystem depth contours.

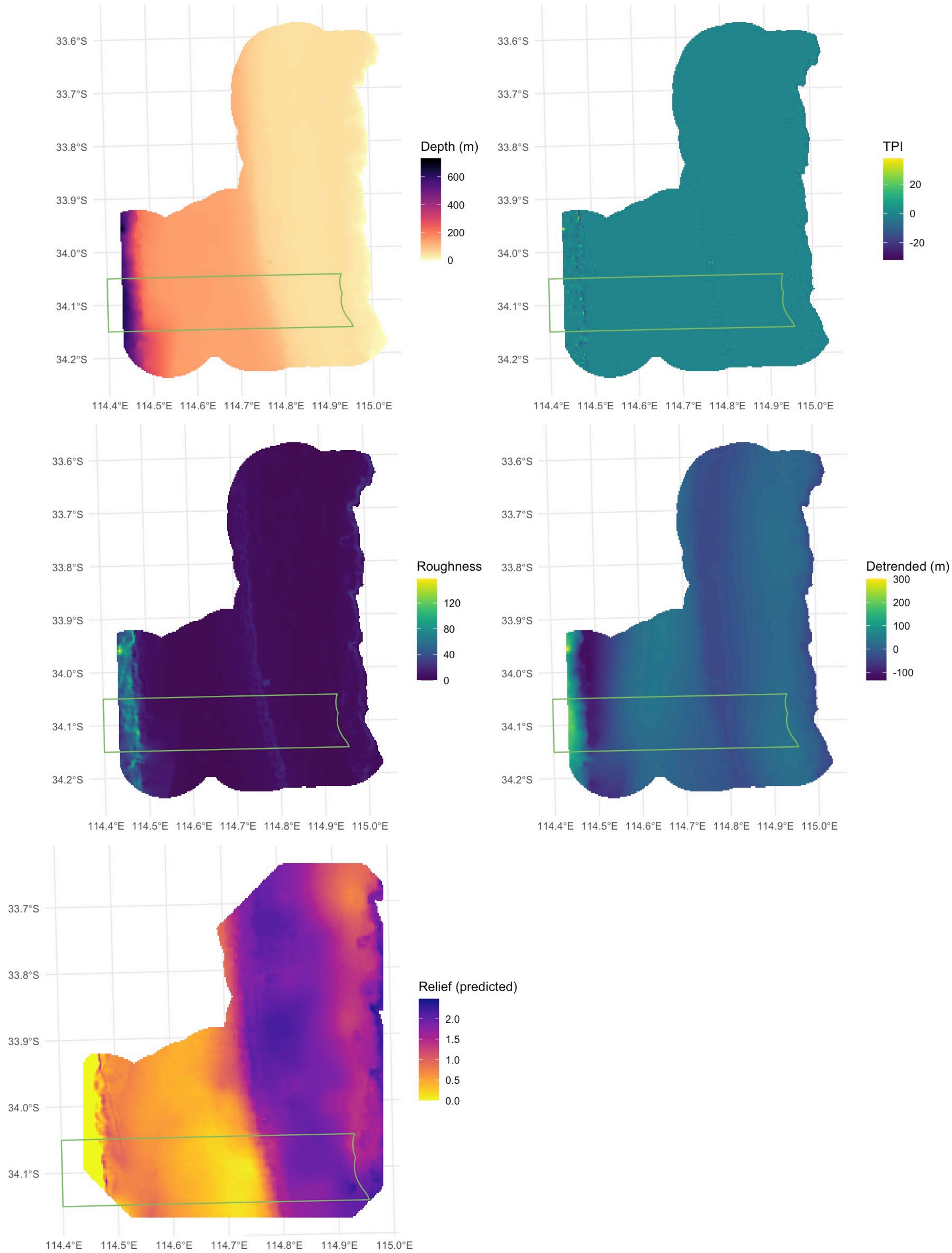


Figure 4 National scale bathymetry derived metrics for the study area. Depth, topographic point index (TPI), roughness and detrended bathymetry available nationally at a resolution of 250 x 250 m.

The cultural values of the South-west Corner Marine Park for the Wadandi region have been published in the NESP Marine Biodiversity Hub report, “The Cultural Seascape of Wadandi Boodja” (Davies et al. 2022), which, in collaboration with the Wadandi Traditional Owners, was used to direct and plan seafloor and biodiversity surveys in the latest survey (Sections 2 and 3). The cultural values presented in this report are reproduced from Davies et al. (2022) (Table 3 and Figure 5). All cultural data was provided following CARE principles (collective benefit, authority to control, responsibility and ethics), proposed by the Indigenous Data Network, and protected by an Indigenous Cultural and Intellectual Property agreement. Heritage values of the South-west Corner Marine Park have not been documented in this report (Table 4).

Table 3 Cultural values* of the South-west Corner Marine Park for the Wadandi region. *Reproduced from Davies et al. (2022) 'The Cultural Seascape of Wadandi Boodja'.

Cultural value	Description
Cowara Kwala (Purple Crown Lorikeet Songline)	The Cowara comes from inland where he breeds and comes to the coast following the gabbi kwala (freshwater songlines) during the summer for feeding. The arrival of the Cowara signals the arrival of Ngaralaang (Herring) in the ocean.
***Gortjguttuk Kwala* (Pink Snapper Songline)**	The *Gortjguttuk Kwala* (Pink Snapper Songline) starts in the *Waatu Waugal* water (Geographe Bay). They come out in the Bay in Makuru time (June/July) when it is cold and wet. They come out in the *Waarten Waugul* water (West Coast) in *Birak* time (Dec/Jan) when it is hot and dry. The *Gortjguttuk* follow the scallop line in the Bay and when they get around Cape Naturaliste, they start head-butting the shellfish, this is why they have bigger foreheads in *Waarten Waugul* water.
***Ngingaraa Kaala* (Lava flow)**	The *Ngingaraa Kaala* (Lava flow) shows us the path the lava took back when the Country shook. When the Country shook, the old people left their camp at *Yoondaddup* (Lake Jasper) and went down to *Bolghinup* (Black Rock) and fell asleep. When they went back the whole place had changed. All the hills had pushed out of the ground. This is when people left that area and spread out across the Country and sung the songs of their creation.
***Wooditj Kaarbin Kwala* (Old Man Groper Songline).**	*Wooditj Kaarbin Kwala* (Old Man Groper Songline). *Wooditj* was a powerful medicine man and could do almost anything with his magic wand. He fell in love with *Milyan*, a beautiful young woman who was betrothed to somebody else. The love-struck couple ran away together but *Milyan's* father *Ngungargoot* chased them. Wooditj used his magic wand to create a powerful river (The Margaret River) between the lovers and *Ngungargoot.* The old man couldn't cross the river but he continued to follow the runaways on the opposite bank. When they got to the mouth of the river the young couple were hungry and decided to spear some *Kaarbin* (Groper) that were plentiful on the reefs there. After a while, the rushing river slowed down and *Ngungargoot* could reach the couple, he almost seized Milyan but Wooditj struck him with his wand and turned him into a *Kaarbin* which disappeared onto the reef which is now known as Ngungargoot (Cow rock). *Milyan* was very sad at the loss of her father and *Wooditj* wished the old man would

	return to them, immediately he was restored as a man and accepted the marriage of Milyan and Wooditj.
Ngari Up (Place of the Salmon)	*Ngari Up* is the place of the *Ngari* (Salmon). The beginning of *Bunuru* time (Feb/Mar) is marked by the *Ngoolaak* (white tailed cockatoo) who sing in the *Ngari*. The cockatoos sing in a certain song and move in a certain direction to show us when to fish for *Ngari*.
Gabbi Up (Freshwater Place)	There are many important freshwater places along the Wadandi coast. In some places you can drink freshwater that comes up in the saltwater. These freshwater places show us where the water might flow out to the ancient coastline, these places would have been very important for our ancestors. The freshwater flows are important for the fish and animals that live in the saltwater. The *Gabbi Waugul* (Freshwater Serpent) drives the flow of freshwater into the sea. The *Gabbi Waugal* is in a constant battle with the *Waatern Waugal* and *Waatu Waugal* (Saltwater Serpents). When the saltwater serpent wins, it pushes seas up into the rivers and when the freshwater serpent wins the freshwater flows out to sea. This endless battle shows us the patterns of change in Wadandi Country, both daily with the tide and over long periods of time. For a long time, the saltwater serpent has been winning, which has caused the sea levels to rise.
***Mammung biddi-wah* (Whales path)**	Wadandi Boodja is an important place for *Mammung* (whales). When *Gullyung* (*Acacia Cyclops or Wattle)* flowers, the *mammung* are starting their migration. The *Gullyung* grows a bean at the time that calves are being born up in Bardi Country in the Kimberley and the seed opens up as the *mammung* come down past Wadandi Country, this seed represents the great eye of the whale. The *mammung biddi-wah* (whale path) is sometimes far offshore but they often follow a path close to shore. They come to the *Gabbi-up* places where the freshwater seeps out into the saltwater and when they beach themselves they are offering themselves back to the land where they come from. Before they entered the water, the *mammung* were more like hippos and liked to live in the shallow marshland in *Yoganup* at the foothills of *yalyal* (Whitcher Escarpment) behind what is now known as *Undalup* (Busselton). The *Yogan* (Thylacine/ wild dog) would scare the mammung into the sea. The *mammung* would come back in from *Waatu* (Geographe Bay) to land with seagrass in his mouth. Eventually the *mammung* decided the saltwater was a better place to live and so he stayed. The *Kwillan* (Dolphin) felt left behind, he saw the *mammung* in the sea and decided to follow him.

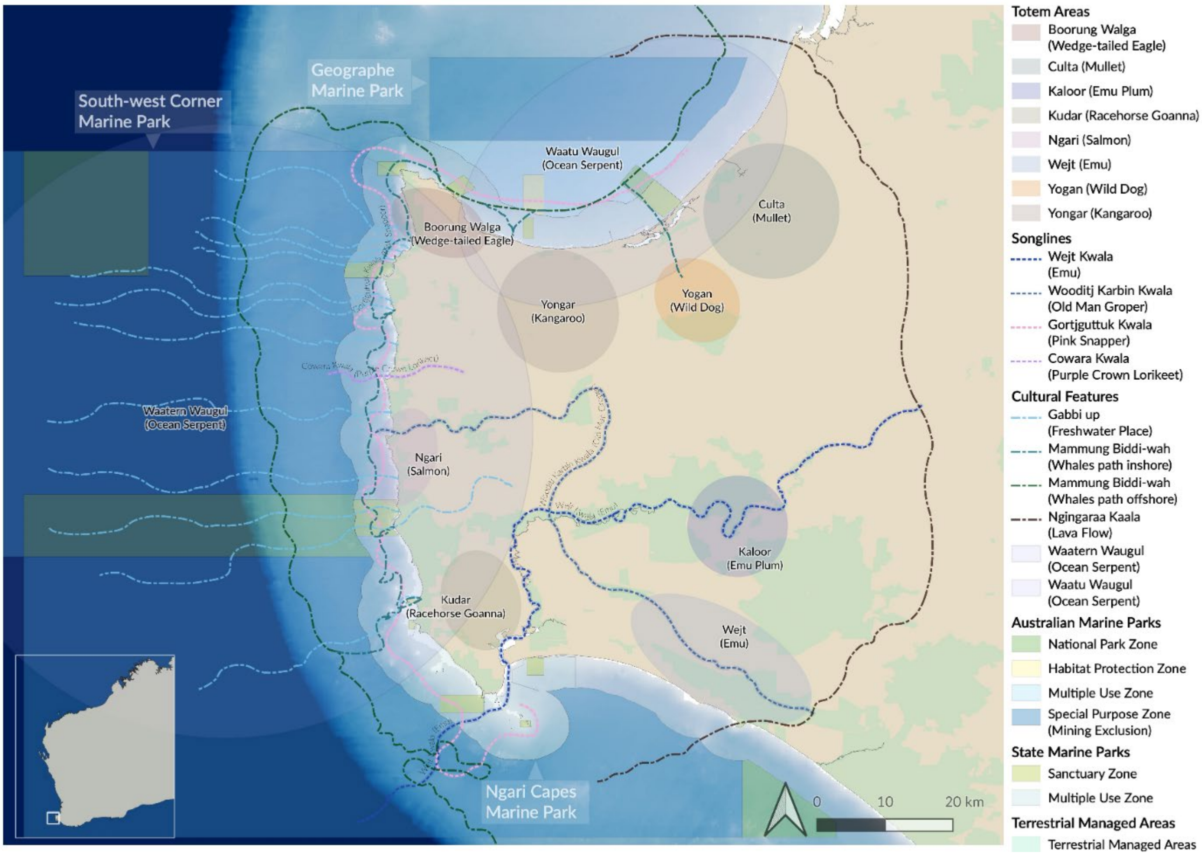


Figure 5 Map of the Wadandi Cultural Seascape. Reproduced from Davies et al. (2022) ‘The Cultural Seascape of Wadandi Boodja’.

Table 4 Heritage values* of the South-west Corner Marine Park.

*Not documented in this report.

The Capes region of the South-west Corner Marine Park is a popular location for both extractive and non-extractive recreational activities (Navarro et al. 2021), and is an important area for commercial fishing (Newman et al. 2021). Metrics of the social, economic and use values of the South-west Corner Marine Park may also provide useful information on potential pressures on natural values and ecosystem components of the marine park that could be impacted by these activities. These values are presented here in draft form (Table 5) as they may be revised during Parks Australia's ongoing development of a Monitoring, Evaluation, Improvement and Reporting framework.

Previous NESP Marine Biodiversity Hub research aimed to establish national socio-economic benchmarks for the Australian Marine Park benchmarks in awareness, perception (Figure 6) and recreational fishing use (Figure 7) of the ‘Capes region’ of the South-west Corner Marine Park (Navarro, Langlois, and Burton 2020). We recommend that spatial recreational fishing use and practice data (i.e. estimated number of trips and catch) could provide a useful metric for interpreting change in natural value and ecosystem metrics for fished species in marine park monitoring (Cresswell et al. 2019; Bosch et al. 2021).

Table 5 Draft* social, economic and use values of the South-west Corner Marine Park. Key social and economic values of the South-west Corner Marine Park. Key social and economic values summarised from the South-west Marine Parks Network Management Plan (Director of National Parks 2018). * These values may be revised during Parks Australia's ongoing development of a Monitoring, Evaluation, Improvement and Reporting framework.

Key social and economic values
Tourism including charter operators
Cruise ship and large charter vessel
Commercial fishing
Recreation (extractive)
Recreation (non-extractive)
Scientific research
Knowledge of the marine park

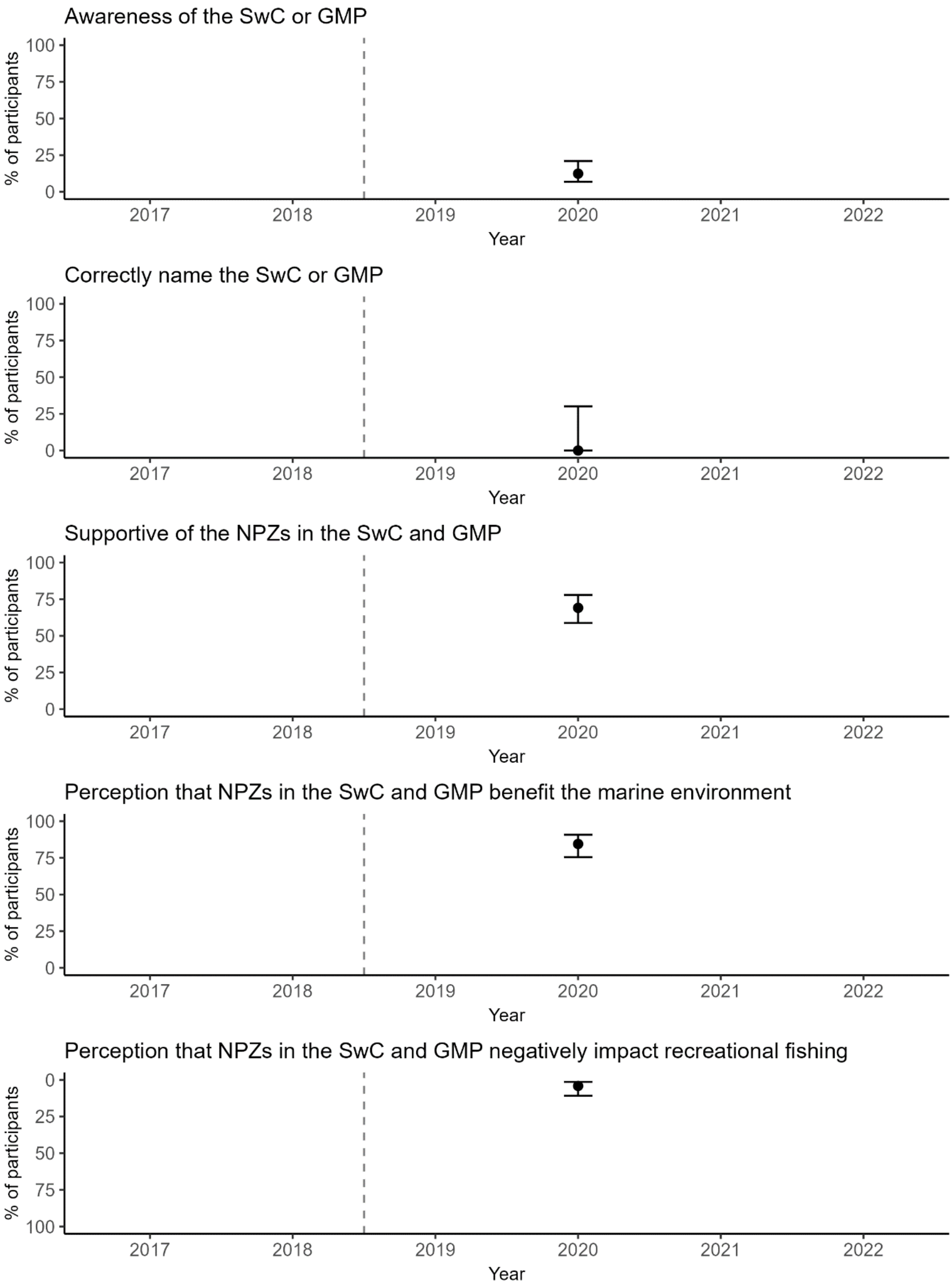


Figure 6 Awareness and perception metrics for the South-west Corner Marine Park. As reported in the national socio-economic surveys by Navarro et al. (2021). Black dots and error bars represent the mean and 95% confidence interval, and the dashed line indicates the date of establishment.

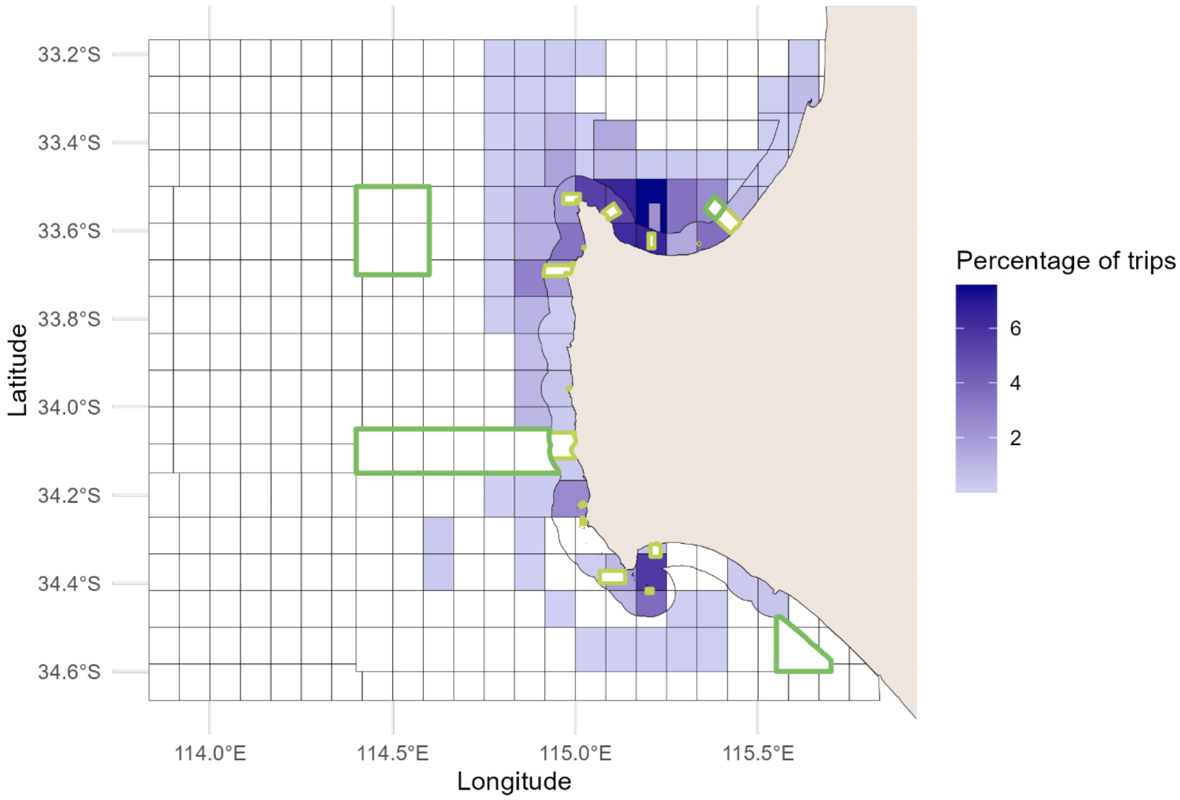


Figure 7 Recreational fishing use map. Boat ramp survey data from Augusta, Canal Rocks, Quindalup and Port Geographe boat ramps, representing the percentage of recreational fishing trips taken to areas denoted by polygons. State and Commonwealth no-take sanctuary zones are indicated by green polygons.

1.3 Pressures

Key pressures recognised for natural values and ecosystem components within the South-west Corner Marine Park (Table 6) include climatology, oceanography and climate change. Metrics of these could include indexes of ocean acidity, sea level anomaly, sea surface temperature and degree heating weeks (Figure 8 & Table 7). Degree heating weeks (DHW) (Liu et al. 2014) is a metric that can be used to characterise marine heatwave events. Sea level anomaly can also be used to characterise seasonal upwelling (Figure 9) and provides evidence of consistent seasonal changes associated with the Mentelle upwelling (Gersbach et al. 1999). Monthly annual averages of sea surface temperature characterise seasonal variation for the region (Figure 10), but DHW can be used to better characterise previous marine heatwave events. Here, we have used two maximum DHW periods to create a spatial plot of two anomalous months (Figure 11), which could be used to identify localised areas where unusual heating has occurred. All the climatology and oceanography data presented here are freely available through the Australian Ocean Data Network. This report only provides a characterisation of climatology, oceanography and climate change associated pressures (Table 7), but future analyses should attempt to provide more comprehensive accounts of the spatial and temporal variability in likely key pressures provided in Table 6 and Table 7.

Table 6 Draft* key pressures in the South-west Corner Marine Park. Key pressures likely to be acting on natural values and ecosystem components of the South-west Corner Marine Park. Key pressures are summarised from the South-west Marine Parks Network Management Plan (Director of National Parks 2018). * These pressures may be revised during Parks Australia's ongoing development of a Monitoring, Evaluation, Improvement and Reporting framework.

Key pressures
Climatology, oceanography and climate change
Changes in hydrology
Extraction of living resources
Habitat modification
Human presence
Invasive species
Marine pollution

Table 7 Potential metrics of climatology, oceanography and climate change. Examples included are indexes of ocean acidity, sea level anomaly, sea surface temperature and degree heating weeks (Figure 8 - 11). These metrics may be revised during Parks Australia's ongoing development of a Monitoring, Evaluation, Improvement and Reporting framework. Where indicated, *data was sourced from Australia's Integrated Marine Observing System (IMOS) – IMOS is enabled by the National Collaborative Research Infrastructure strategy (NCRIS).

Climatology, oceanography and climate change metrics	Description	Reference or source
Ocean acidity	Modelled product of ocean acidity, providing an indication of physiological stress for marine biota and for calcifying organisms in particular (Orr et al. 2005).	AODN*
Sea level anomaly	Satellite derived observation providing a proxy of upwelling and potential indicating areas of increased nutrient exchange and productivity (Pearce et al. 2006).	AODN*
Sea surface temperature	Satellite derived observation providing a measurement of sea surface temperature and potential indicator of physiological stress for marine biota (Caputi et al. 2009).	AODN*
Degree heating weeks	Designed to provide an indicator of potential bleaching in tropical coral reefs, this product can also be used to characterise marine heat waves globally (Liu et al. 2014).	AODN*

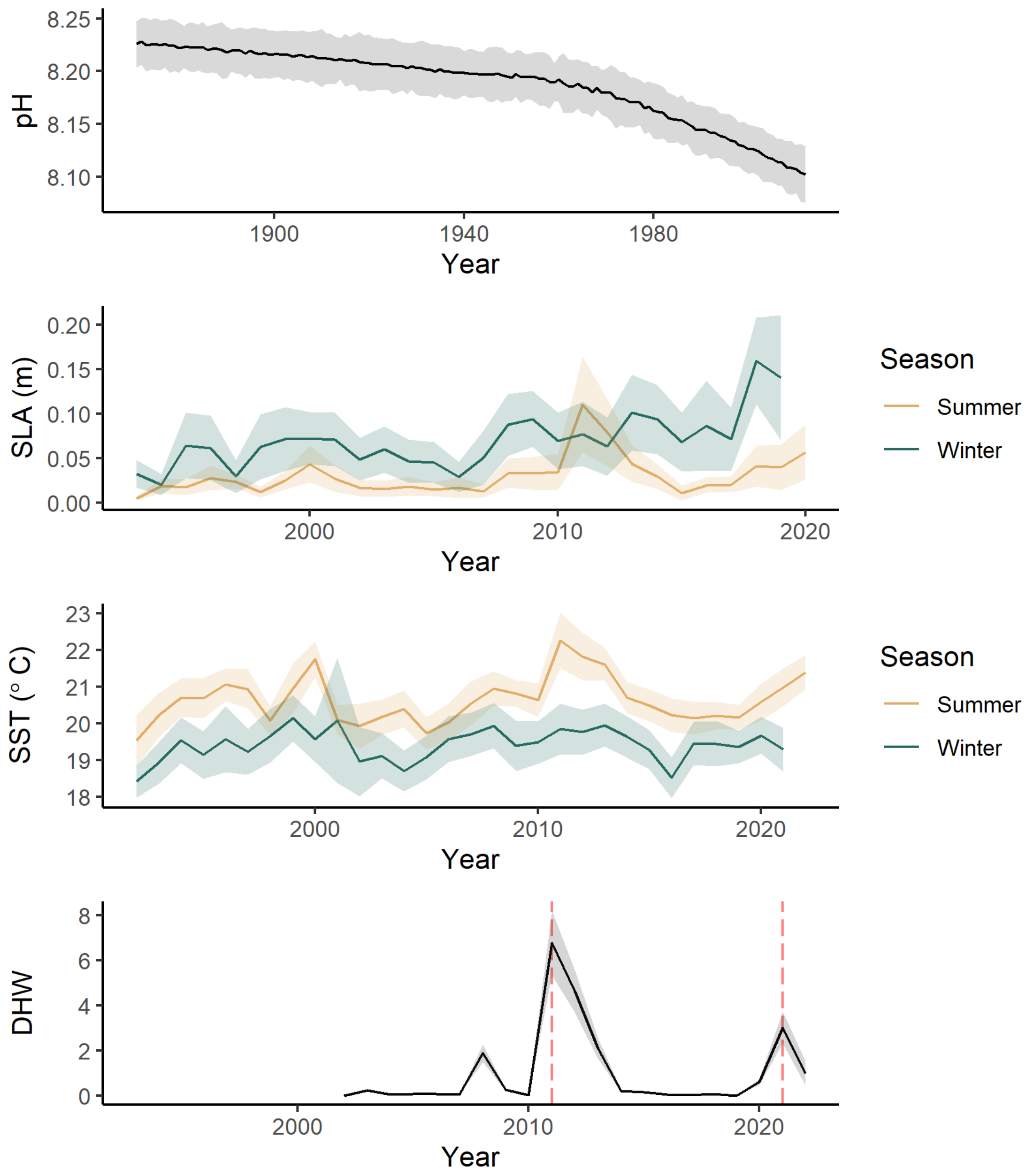


Figure 8 Characterization of the Acidification, seasonal sea level anomaly, seasonal sea surface temperature and Degree Heating Weeks at the scale of the South-west Capes region. Solid lines represent mean values for pH, sea level anomaly (SLA), sea surface temperature (SST) and Degree Heating Weeks (DHW). Confidence bounds represent standard errors. Red dashed vertical lines represent maximum DHW values that are plotted spatially in Figure 11. All data is open-access and obtained via the Australian Ocean Data Network.

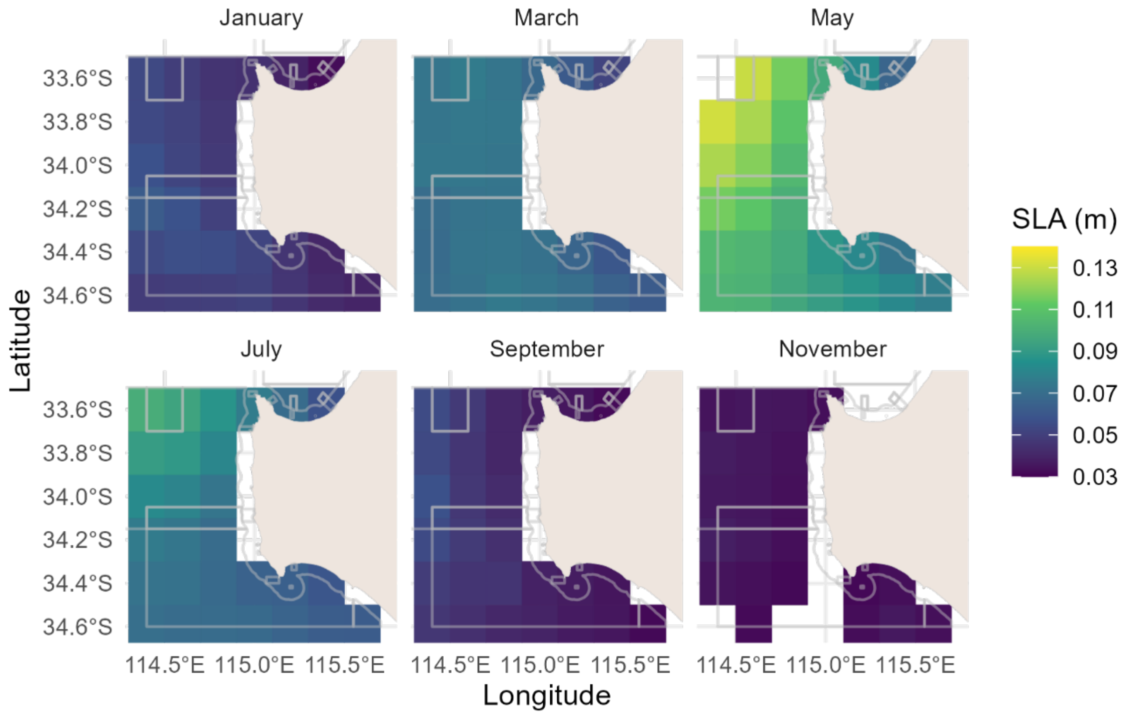


Figure 9 Sea level anomaly, as an index of upwelling, at the scale of the South-west Capes region. Heatmap values represent high (yellow) and low (blue) Sea Level Anomaly (SLA). Grey polygons represent State spatial management and Australian Marine Park boundaries. Evidence of the Mentelle upwelling can be seen in May. All data is open-access and obtained via the Australian Ocean Data Network.

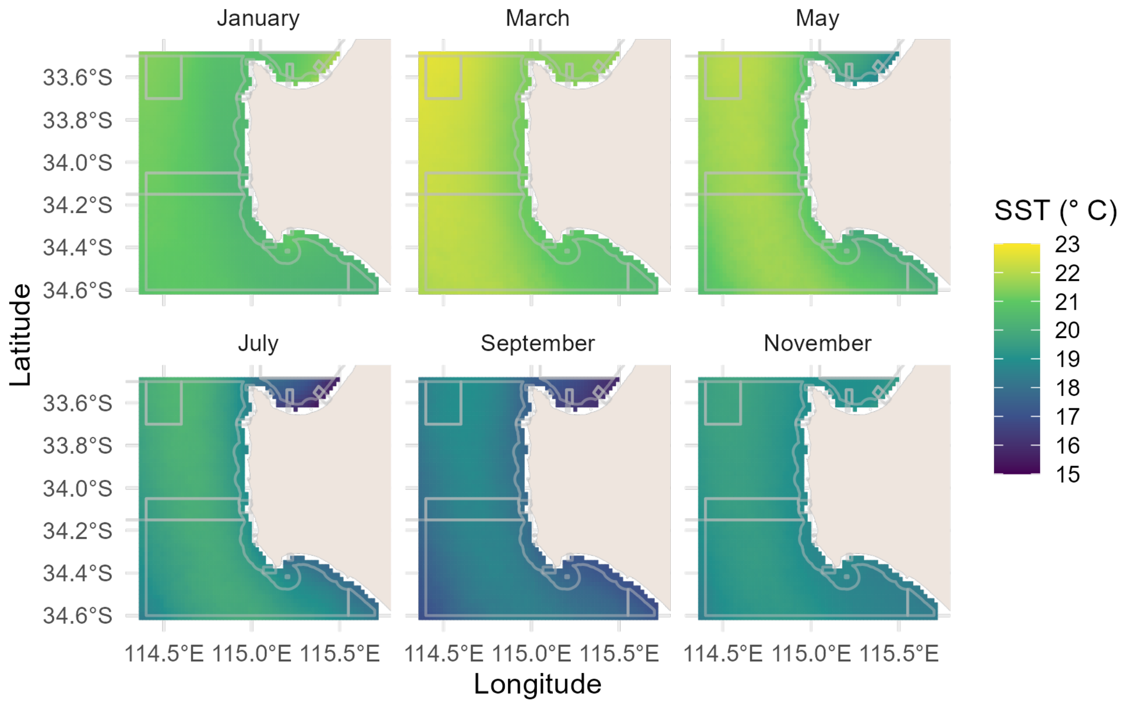


Figure 10 Sea surface temperature at the scale of the South-west Capes region. Heatmap values represent high (yellow) and low (blue) bimonthly sea surface temperature (SST). Grey polygons represent State spatial management and Australian Marine Park boundaries. All data is open-access and obtained via the Australian Ocean Data Network.

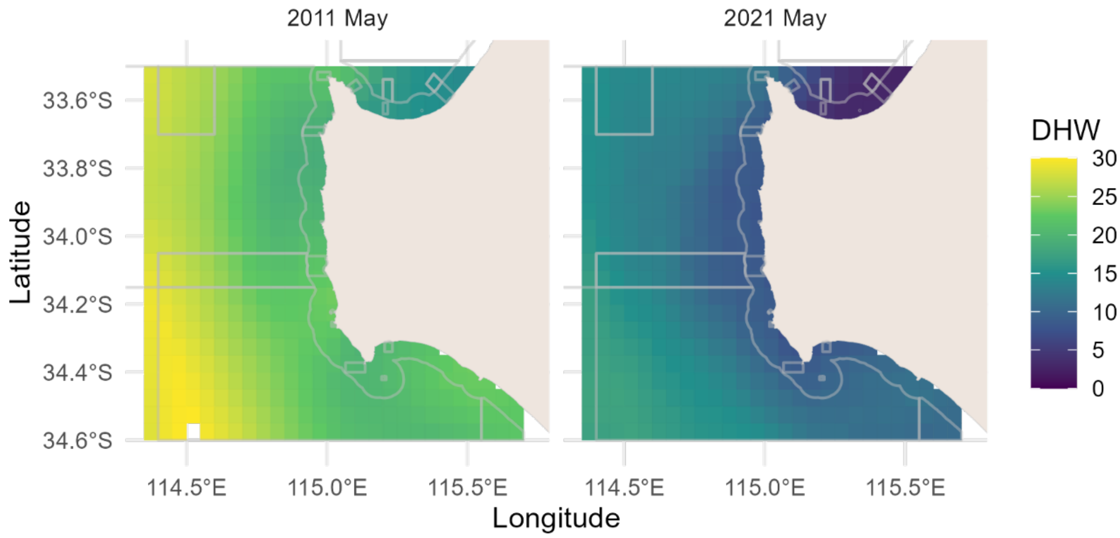


Figure 11 Degree Heating Weeks at the scale of the South-west Capes region. Heatmap values representing high (yellow) and low (blue) monthly Degree Heating Weeks (DHW). Grey polygons represent State spatial management and Australian Marine Park boundaries. All data is open-access and obtained via the Australian Ocean Data Network.

2. Latest survey aims, design and methods

2.1 Aims and objectives

The overall aim of the survey was to build baseline information for key benthic habitat and demersal fish assemblage natural values and ecosystem components within the Capes region of the South-west Corner Marine Park (see Table 2 and Table 8). Information from the survey will be used for biodiversity discovery, to support the establishment of benchmarks and to inform future assessments of the efficacy of the management plan for the South-west Corner Marine Park within the South-west Marine Parks Network through ongoing monitoring.

2.2 Discovery questions: interaction of environmental values and pressures, providing rationale for future surveys and monitoring

The Australian Marine parks network is still in the discovery phase of characterising the habitats and assemblages that exist across its parks; however this discovery can be informed by hypotheses and monitoring questions derived from existing knowledge. Based on previous studies in nearby Australian Marine Parks or Marine Parks in State waters, we proposed a series of draft discovery and monitoring questions. For this survey of the 'Capes region' of the South-west Corner Marine Park, we used this initial draft set of questions (Table 8) to inform the spatial and depth extent for the survey design.

2.3 Survey design

The latest survey (Sections 2 and 3) focused on natural values and ecosystem components, including significant seafloor features, and characterising the fish assemblage and other important benthic values, including the extent of benthic habitats (Table 2). The design of the latest survey was conducted at two different scales, a broader survey area and a detailed bathymetry area (Figure 12). The detailed survey area was designed to enable the investigation of the existence of significant seafloor features, including whether significant seafloor features would occur along contours associated with submerged ancient shorelines. The detailed survey area was designed to provide samples across a gradient in significant seafloor features to investigate co-occurrence of certain habitats and the fish assemblage. In contrast, the broader study area was designed to provide an array of samples across a larger spatial extent to characterise the potential impact of gradients in extractive use (e.g. recreational fishing) on the fish and benthic assemblage, whilst also providing a larger scale assessment of the existence of significant seafloor features, related to submerged ancient shorelines, and the variation in certain habitats and fish assemblage composition associated with significant seafloor features.

Table 8 Draft* key natural values and their draft* monitoring questions. * These values and questions may be revised during Parks Australia's ongoing development of a Monitoring, Evaluation, Improvement and Reporting framework.

Draft key natural values	Draft discovery and monitoring questions
Significant seafloor features	Will significant seafloor features occur along contours associated with submerged ancient shorelines?
Fish assemblage, endemic species and transitional zone between tropical and temperate species	i) Will the composition of fish assemblages vary with significant seafloor features and habitats? ii) What is the spatial abundance distribution and spatial extent of fish assemblages across mesophotic and rariphotic habitats across the marine park? iii) Will fish assemblages change with warming ocean temperatures? iv) Will fish assemblages change with gradients in commercial and recreational fishing pressure across zones and across use gradients? v) What is the status of fish assemblage metrics relative to national benchmarks given the location, depth and status of zones?
Other important benthic values (e.g. algae and sessile invertebrate assemblages), endemic species and transitional zone between tropical and temperate species	i) Will the extent and composition of benthic habitats vary with significant seafloor features? ii) What is the distribution and spatial extent of benthic assemblages across mesophotic and rariphotic habitats across the marine park? iii) Will benthic assemblages change with warming ocean temperatures? iv) Will benthic assemblages change with gradients in commercial and recreational fishing pressure across zones and across use gradients? v) What is the status of benthic assemblage metrics relative to national benchmarks given the location, depth and status of zones?

2.4 Survey stages

Due to interruptions caused by COVID, the survey was undertaken over six stages of data acquisition and sampling between the period March 2020 and March 2021 as given in Table 9.

Table 9 Summary of survey stages. NPZ = National Park Zone and SPZ = Special Purpose Zone (Mining Exclusion)

Stage	Dates	Methods	Objective	Area / No. samples	Sampling design
1	9 –12 March 2020	Seabed mapping	Seabed mapping within the NPZ - stopped due to COVID travel ban.	NPZ	Preferential
2	2 – 3 June 2020	Stereo-BRUV	Sampling shallow reefs up to 60 m in the NPZ	NPZ shallow reefs/ n = 31 deployments	Spatially balanced
3	12 October – 23 November 2020	Stereo-BRUV and drop camera	Stereo-BRUV and drop camera sampling in the NPZ and high use area	NPZ and high use area / n = 244 and 264 deployments	Spatially balanced
4	27 January – 17 February 2021	Seabed mapping	Continuation of seabed mapping in the NPZ and SPZ	NPZ and SPZ	Preferential
5	1 – 7 March 2021	AUV	AUV transects at key sites in the NPZ and SPZ	NPZ and SPZ / n = 15 transects	Preferential
6	8 – 11 March 2021	Drop camera	Drop camera sampling within the NPZ and SPZ	NPZ / n = 154 deployments	Spatially balanced

Sampling locations for stereo-BRUV and drop camera deployments were determined using the ‘MBHdesign’ package in R software to distribute sites across each survey area in a spatially balanced pattern, following NESP Marine Biodiversity Hub Field Manuals and following methods given in (Foster et al. 2017). Full information regarding the site selection procedures is included in Section 5.1.1.

Spatially balanced samples derived from all stereo-BRUV and drop-camera deployments were used to predict the abundance distribution and extent of fish and benthic habitat values (Figure 12).

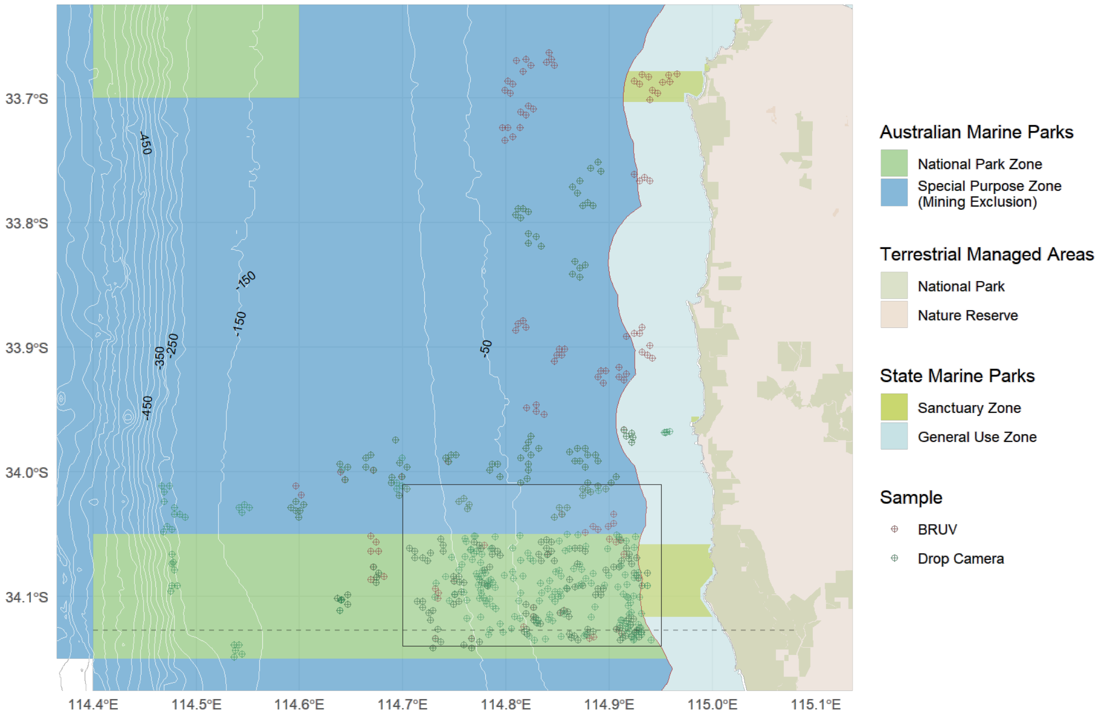


Figure 12 Sampling locations across the study area used for extent prediction of fish and benthic value metrics. Map showing sampling locations in relation to Australian Marine Parks and state managed areas. Note that in some locations both BRUV and Drop Camera methods were used and their respective icons overlap. The red line delimits state and commonwealth waters, the grey box indicates the extent of the detailed bathymetry area and the dashed line represents the location of Figure 13.

3. Latest results and discussion

3.1 Bathymetry and relief

3.1.1 Bathymetry and significant seafloor features

Within the ‘Capes region’ of the South-west Corner Marine Park, the National Park Zone represents the most extensive protected area on Australia's continental shelf, linking the Sanctuary Zone in the adjacent Ngari Capes Marine Park in Western Australian state waters with the adjacent Leeuwin-Naturaliste National Park on land (Figure 12) and extending over the continental shelf down to ~600 m depth ~55 km from the coast (Figure 13a).

Within the National Park Zone studied, our survey revealed one of the best-preserved examples of submerged ancient coastlines and wetlands yet observed across the Australian Marine Park network (Figure 13b). A distinct paleo shoreline from the last interglacial period, 20-30 thousand years before present (ka BP), was found in ~120 m depth. Further distinct paleo shorelines were apparent in 80, 60 and 35 m respectively, representing 15-17, 12-13 and 9-10 ka BP respectively. Across the 9-10 thousand year old shoreline we also observed distinct ancient coastal wetlands formations and submerged granite outcrops (Figure 13b and Figure 14). Although the detailed bathymetry collected provided greater detail on the old coastline features (Figure 13c and Figure 14), it is useful to note that in this study the pre-existing national scale bathymetry (Figure 13b) was adequate to identify all these significant submerged ancient shoreline and coastal features. However, the detailed bathymetry provided confirmation of these features and greater detail on significant seafloor features (Figure 13c and Figure 14).

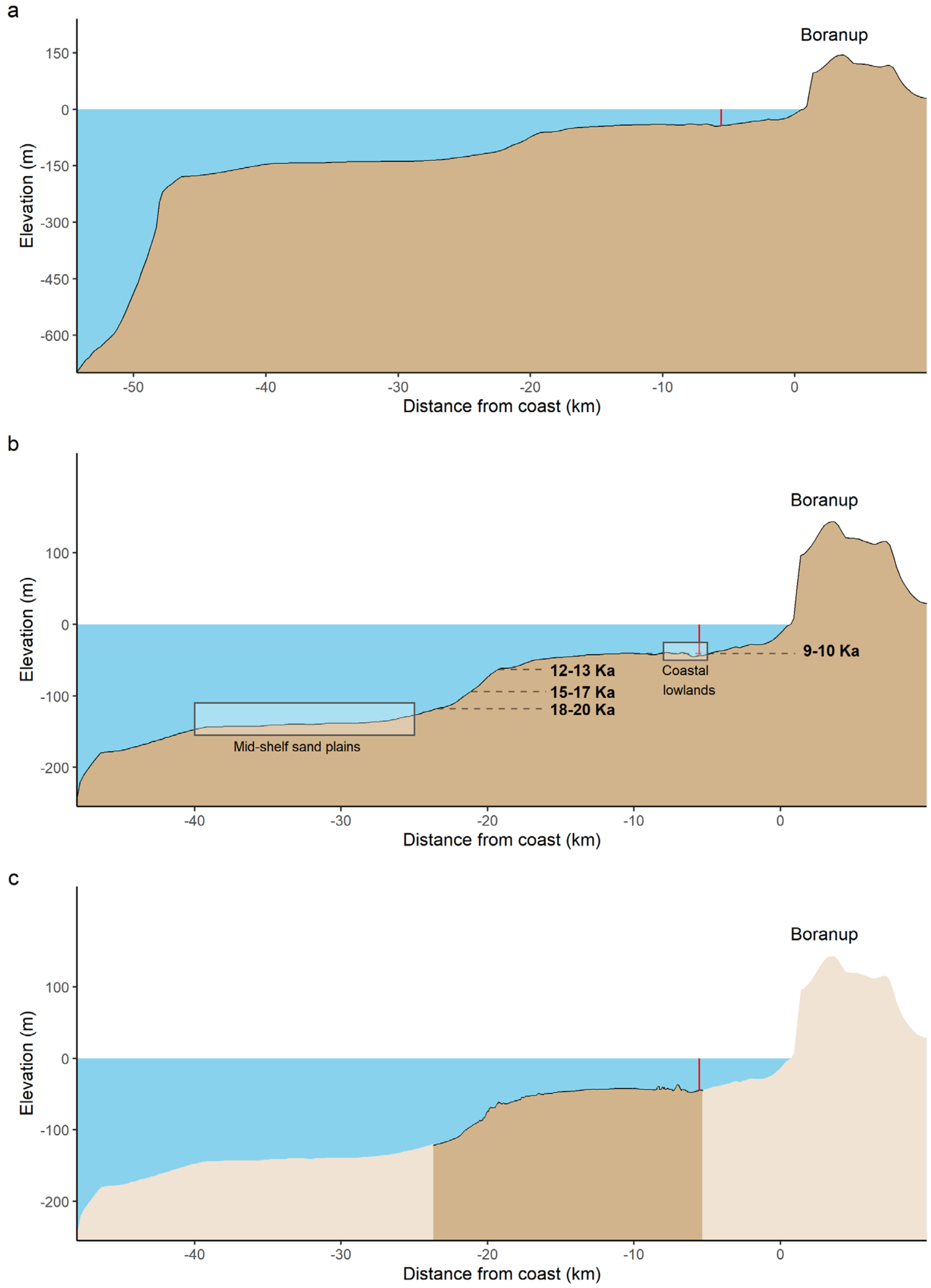


Figure 13 Significant seafloor and coastal features across marine and terrestrial protected areas. Submerged coastlines from thousands of years before present (Ka) are indicated. The red line delimits state and commonwealth waters. a) full depth and height extent across Commonwealth National Park Zone based on pre-existing national scale bathymetry; b) depth and height extent at the scale of the study area down to 250 m on the shelf break using pre-existing national scale bathymetry to identify submerged paleo shoreline features; and c) detailed bathymetry collected in the latest survey and overlaid over the study area. Distances from the coast are in km.

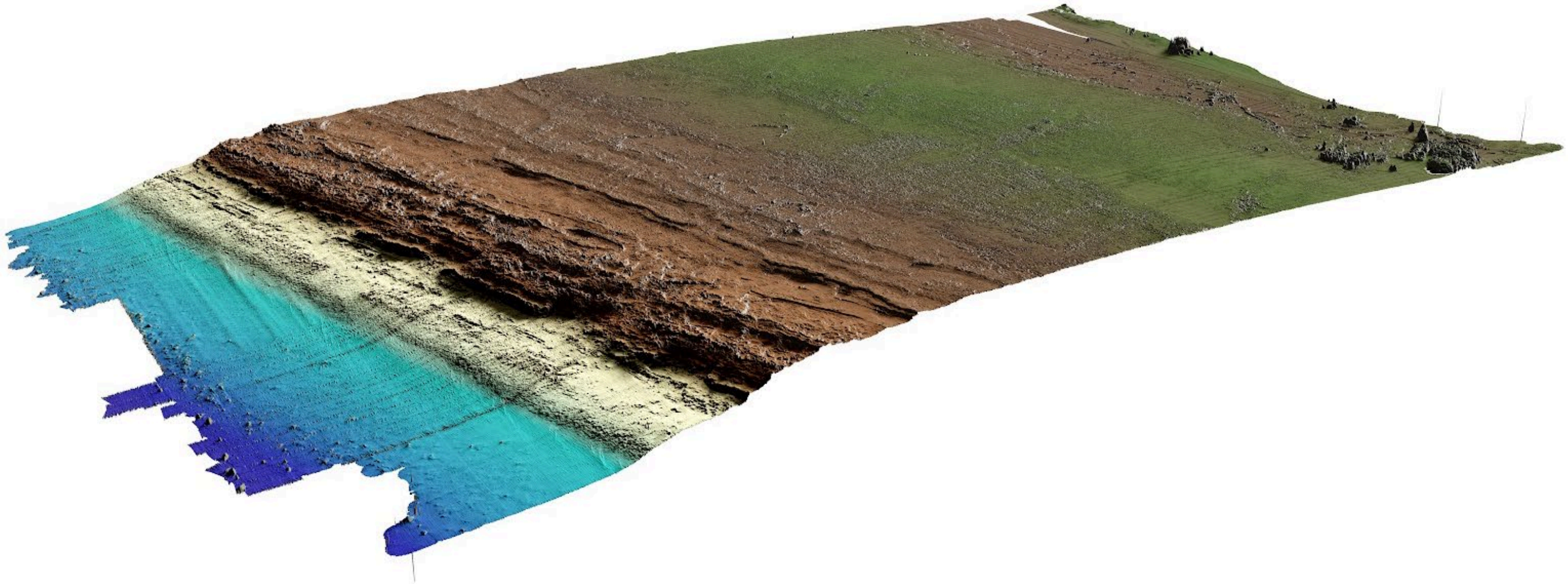


Figure 14 Three-dimensional view of the detailed resolution bathymetry region. Providing a detailed view of the significant seafloor features

3.1.2 Bathymetry and geomorphic characterisation

Seabed mapping of the continental shelf within the National Park Zone and adjacent Special Purpose Zone of the Capes region of South-west Corner Marine Park covers an area of 275 km^2 (excluding transits to/from port) between the eastern boundary of the park and the shelf break (Figure 15). The area is characterised by planar seabed with small, isolated reefs on the inner shelf (20-40 m depth) and low-profile stepped reefs (ledges) on the outer shelf (80-120 m). Classification of bathymetry data using a semi-automated method to define raised seabed features (bathymetric highs), identifies a suite of morphological types that all represent potential reef habitat. These include banks, ridges, mounds, hummocks and cones (see Dove et al. 2020 for definition of terms). Collectively, these features occupy approximately 5% (~15 km^2) of the mapped area, with the remainder classified as plane (flat seabed) (Table 10). While the area of seabed comprising raised reef features is relatively limited, they are numerous (>2400 discrete features) and introduce a degree of local complexity (mean relief up to 9 +/- 2.5 m) to the seabed. This relief, combined with the hard substrate type (granite and limestone), offers high habitat potential for epibenthic biota.

Table 10 Summary measures for raised seabed features within the mapped area of the National Park Zone and Special Purpose Zone.

Seabed feature	Area (km^2)	Area (%)	Count	Relief (m)[1]
Bank	1.24	0.4	9	9 +/- 2.5
Ridge	7.82	2.9	524	1.6 +/- 1.6
Cone	0.17	0.06	61	1.5 +/- 1.3
Mound	5.67	2.1	1694	1.0 +/- 0.8
Hummock	0.11	0.04	125	0.5 +/- 0.3
Plane[2]	259	94.5	1	N/A
Total	*274*	*100*	*2413*	*N/A*

Notes 1. Relief is shown as the mean, plus and minus one standard deviation for all instances of each feature type; 2: Plane is not a raised seabed feature but is included for completeness.

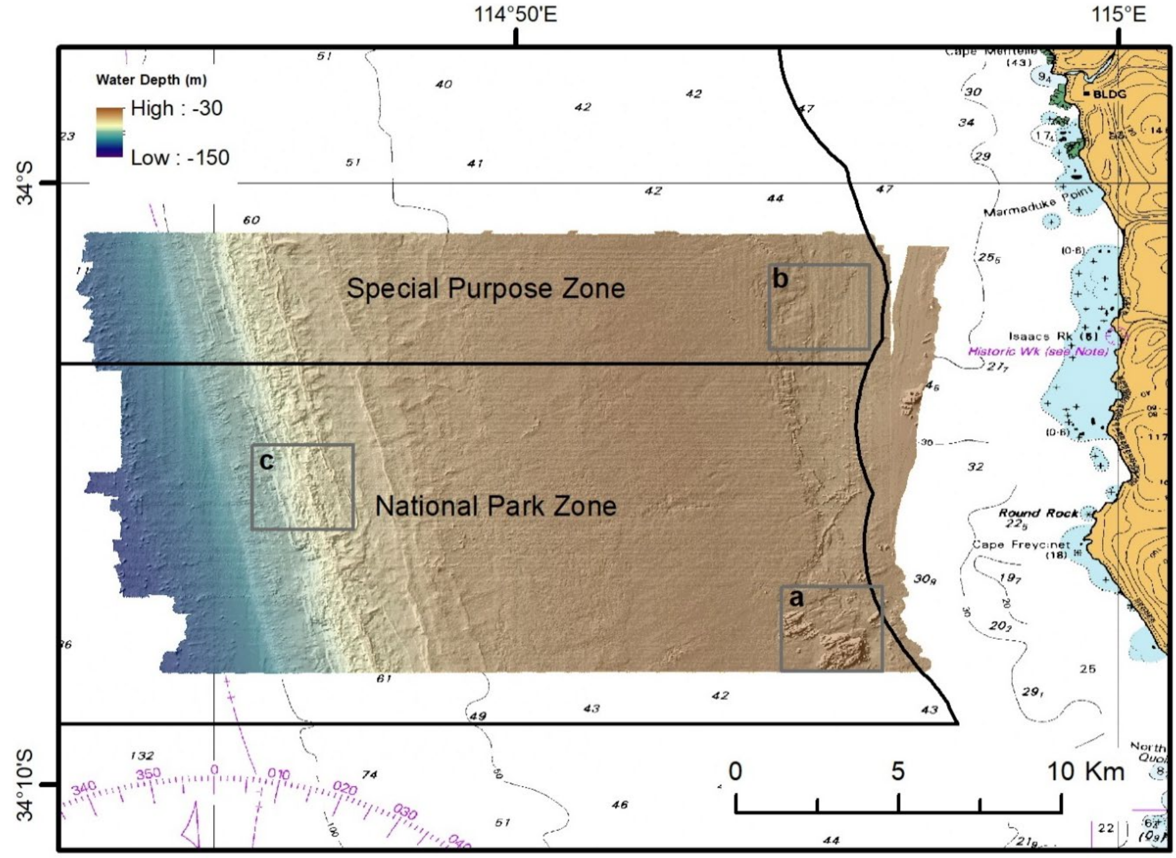


Figure 15 Bathymetry coverage within the National Park Zone and Special Purpose Zone (Mining Exclusion), South-west Corner Marine Park. Areas of interest ‘a’ and ‘c’ are described in Fig. 4.1.5 and Fig. 4.1.6 respectively.

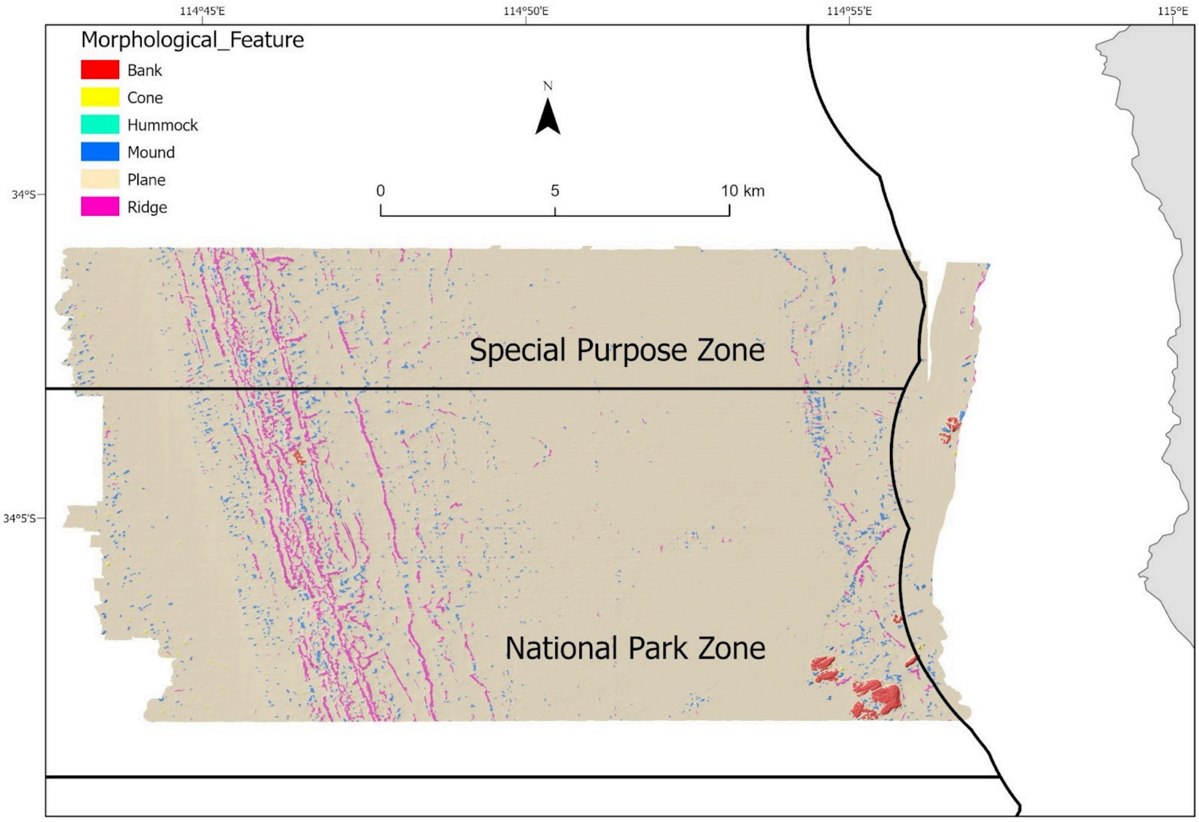


Figure 16 Seabed morphological features within the National Park Zone and Special Purpose Zone (Mining Exclusion), South-west Corner Marine Park.

The most extensive area of reef in the survey area is located within the southeast of the National Park Zone (Figure 16). Here, a cluster of flat-topped banks rises almost 12 m from a depth of 48 m and covers an area of approximately 2 km^2. Smaller isolated reefs classified as cones, hummocks, mounds and ridges are located within similar water depths nearby. The larger banks are characterised by a generally smooth surface but with linear grooves that incise up to 4 m into the reef surface. This morphology is consistent with weathered and fractured rock and is interpreted as granitic gneiss from the Leeuwin Complex that forms the headlands onshore along the Capes region coast (Wilde and Nelson 2001). This is the only example of this type of reef outcrop within the detailed bathymetry area of the marine park.

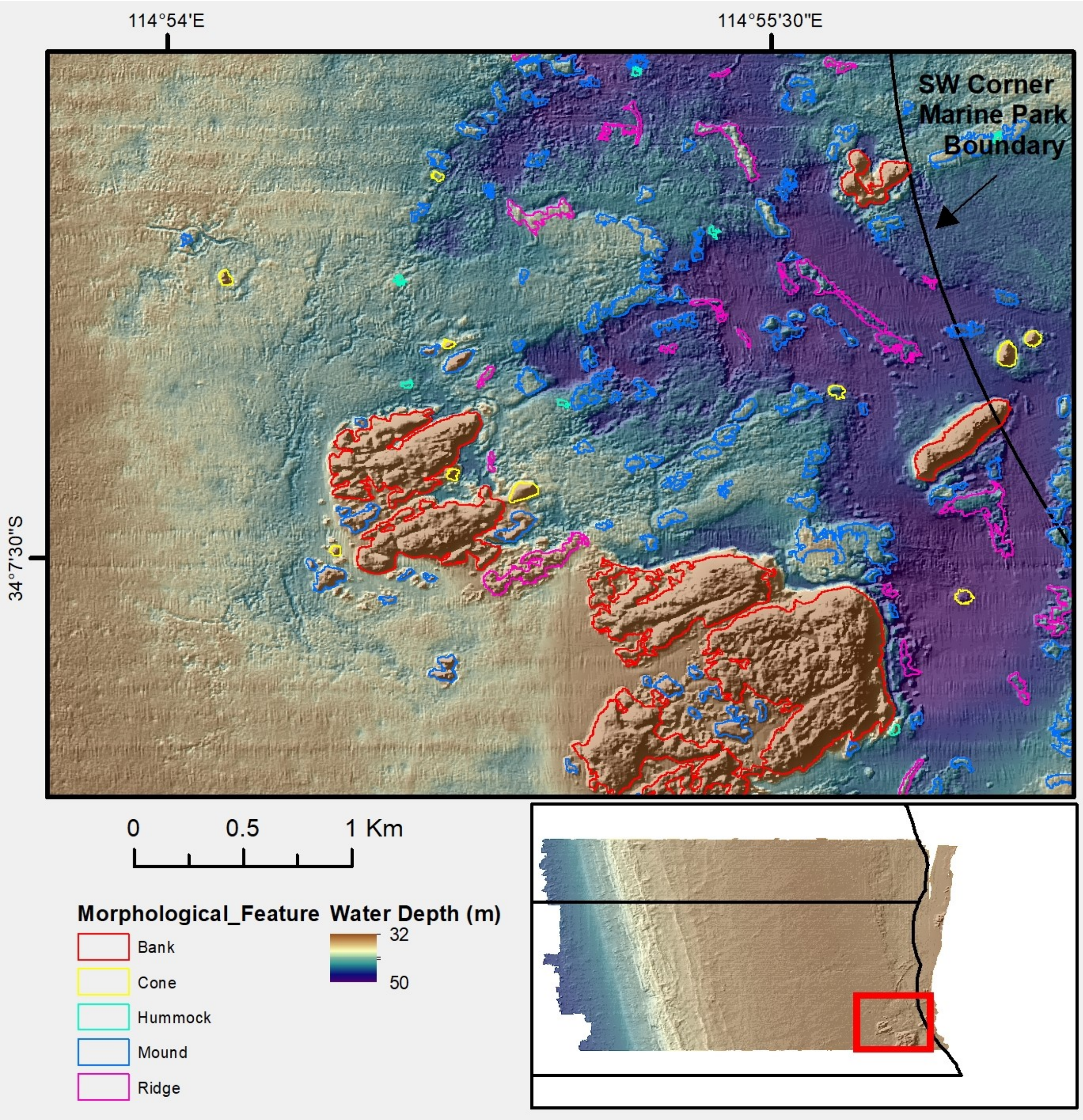


Figure 17 High resolution bathymetry and raised seabed features (reef) for an area of granite (gneiss) reef. Inset map shows the location of these features.

The outer shelf of the survey area is characterised by a series of low-profile ridges that extend north-south along the shelf as continuous features for the extent of the mapped area (~13 km) (Figure 18). These ridges are 150 - 400 m wide with steps that range in height between 5 and 8 m in water depths of 60 to 90 m. The outer shelf is also characterised by a series of discontinuous linear ridges that are ~2 m high, 10 - 20 m wide and extend up to 1 km along the shelf in water depths of ~60 m. These are potential examples of relict coastal dunes, preserved as aeolianite that define the position of an ancient coastline (likely age approximately 12,000 years; Brooke et al. 2017).

The classification of seabed features from fine scale multibeam bathymetry data within the survey area of the National Park Zone and Special Purpose Zone provides an objective and consistent measure of areas of potential reef habitat. Of note is the concentration of these raised features within the 20-40 m and 80-100 m depth ranges associated with ancient coastlines. Regardless, these areas are found to support dense sessile invertebrate communities.

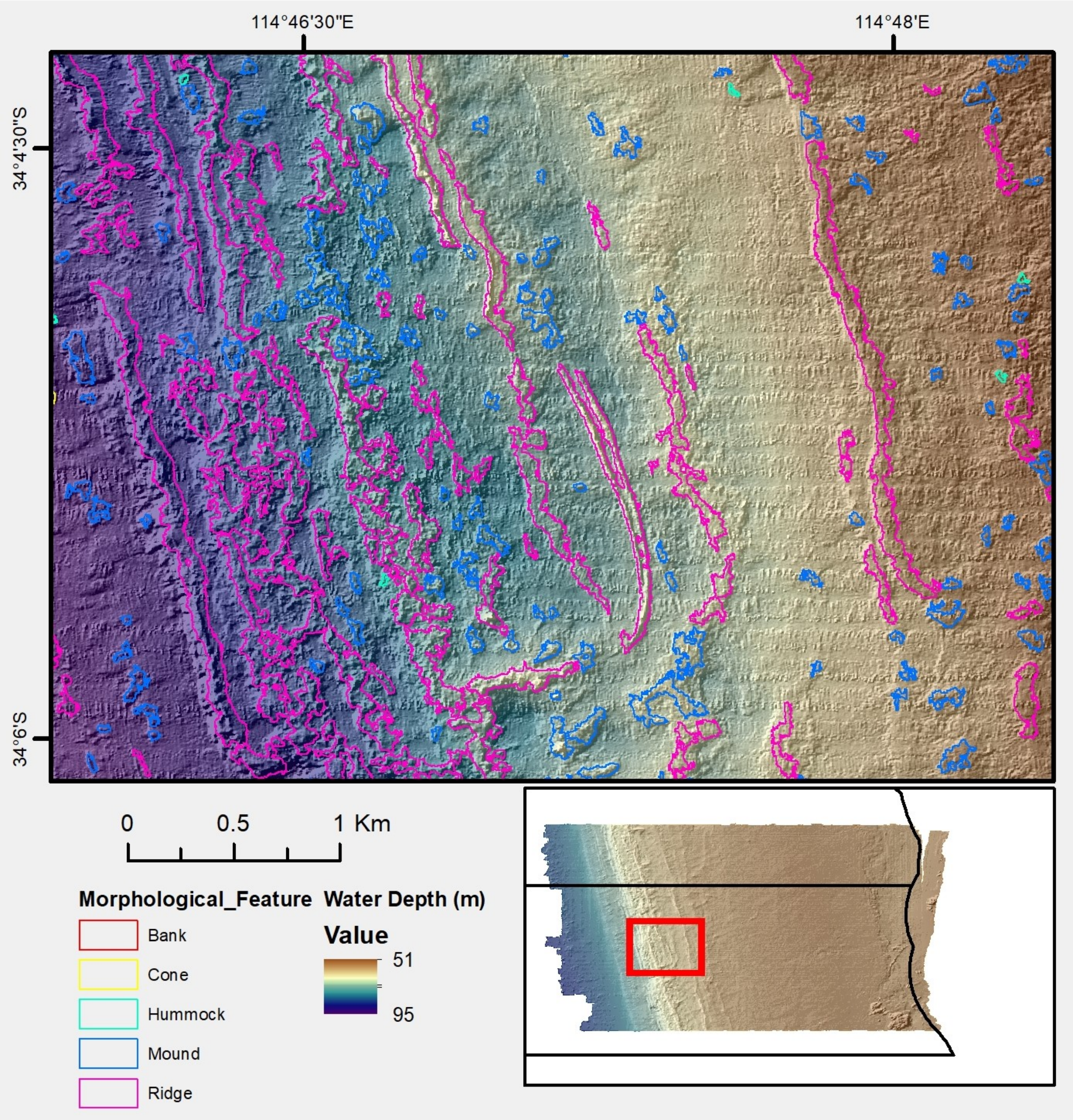


Figure 18 High resolution bathymetry and raised seabed features (reef) for an area of linear ridges and mounds on the outer shelf. Inset map shows location of the features.

3.2 Benthic biota and habitat extent

3.2.1 Distribution of dominant habitat classes

The percent habitat classes observed by BRUV and drop-camera imagery sampled across the whole study were visualised as spatial pie charts (Figure 19). This initial visualisation indicates that the current national reef model (Figure 3) substantially underestimates mesophotic reefs (30-70 m) within the marine park whereas the presence of rariphotic reefs (70-200 m) on the shelf break are broadly congruent.

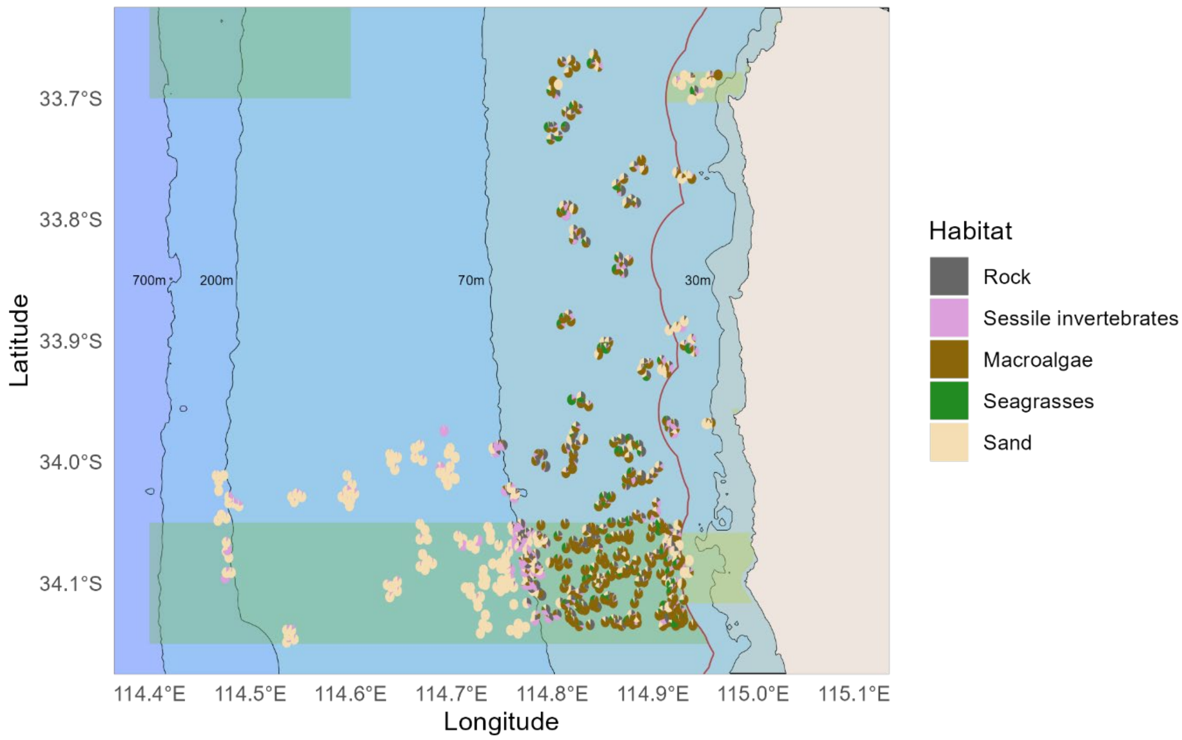


Figure 19 Habitat classes observed in benthic imagery. Habitat classes observed in spatially balanced BRUV and drop-camera imagery visualised as spatial pie charts. The red line delimits state and commonwealth waters. The bathymetric contours shown are 30 m, 70 m, 200 m and 700 m representing ecosystem depth contours.

Benthic habitat classification information was obtained over approximately 4 times the area of the detailed bathymetry collected by the multibeam survey (Figure 15). As a result, habitat extent prediction has been conducted at two scales: i) the broader scale of the study area, and benthic ground truthing imagery, and ii) at the scale of the detailed bathymetry obtained from multibeam survey. This provides an informal comparison of two different survey types, with the broader survey area only using drop camera information and detailed survey area relying on the acquisition of multibeam survey bathymetry.

3.2.2 Broader study area – habitat extent

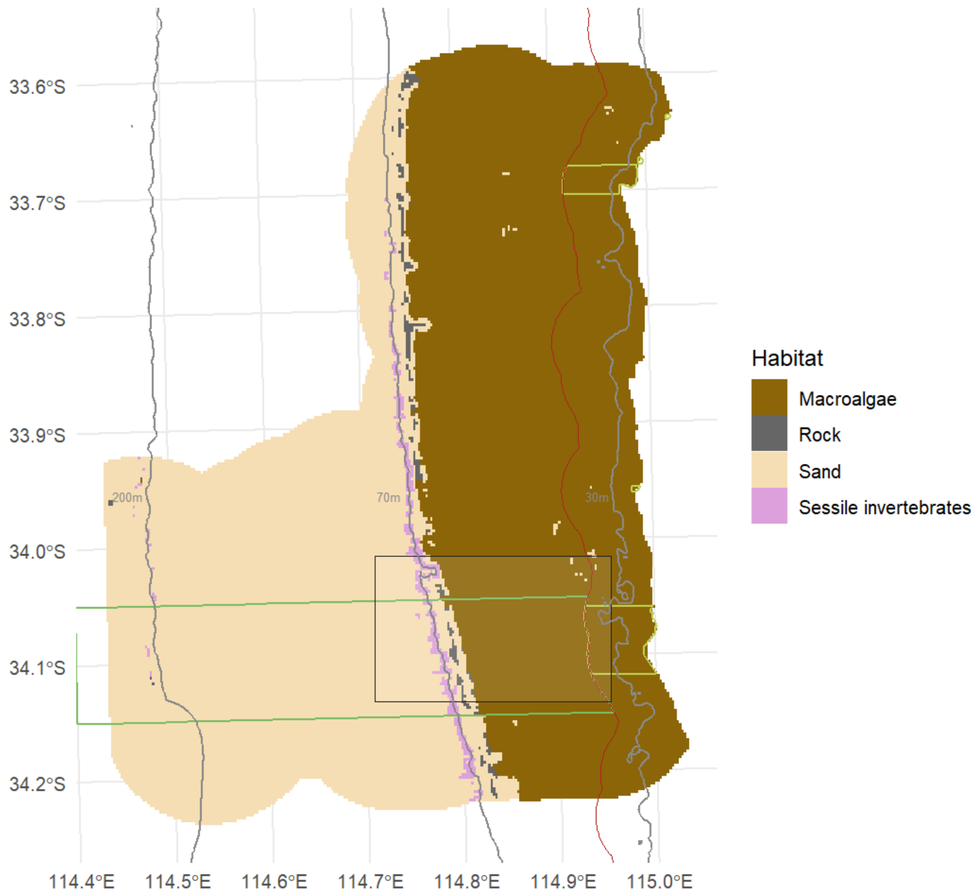


Figure 20 Predicted dominant habitat across the broader study area. The grey box indicates the extent of multibeam bathymetry. State and Commonwealth marine park boundaries are shown. The red line delimits state and commonwealth waters. The bathymetric contours shown are 30 m, 70 m, and 200 m representing ecosystem depth contours.

Spatial models of habitat extent for the broader study area (Figure 20) found macroalgae was predicted to dominate mesophotic reefs within the marine park and the National Park Zone, with sessile invertebrate dominating in a thin strip of rariphotic reef following the 80 m contour. Additionally, sand was the predominant benthic habitat in deeper areas, except at the shelf break (200 m) where rariphotic reefs with sessile invertebrates are predicted. Here, this spatial prediction of habitat extent indicates that the existing national reef model (Figure 3) substantially underestimates mesophotic reefs (30-70 m) within the marine park and National Park Zone.

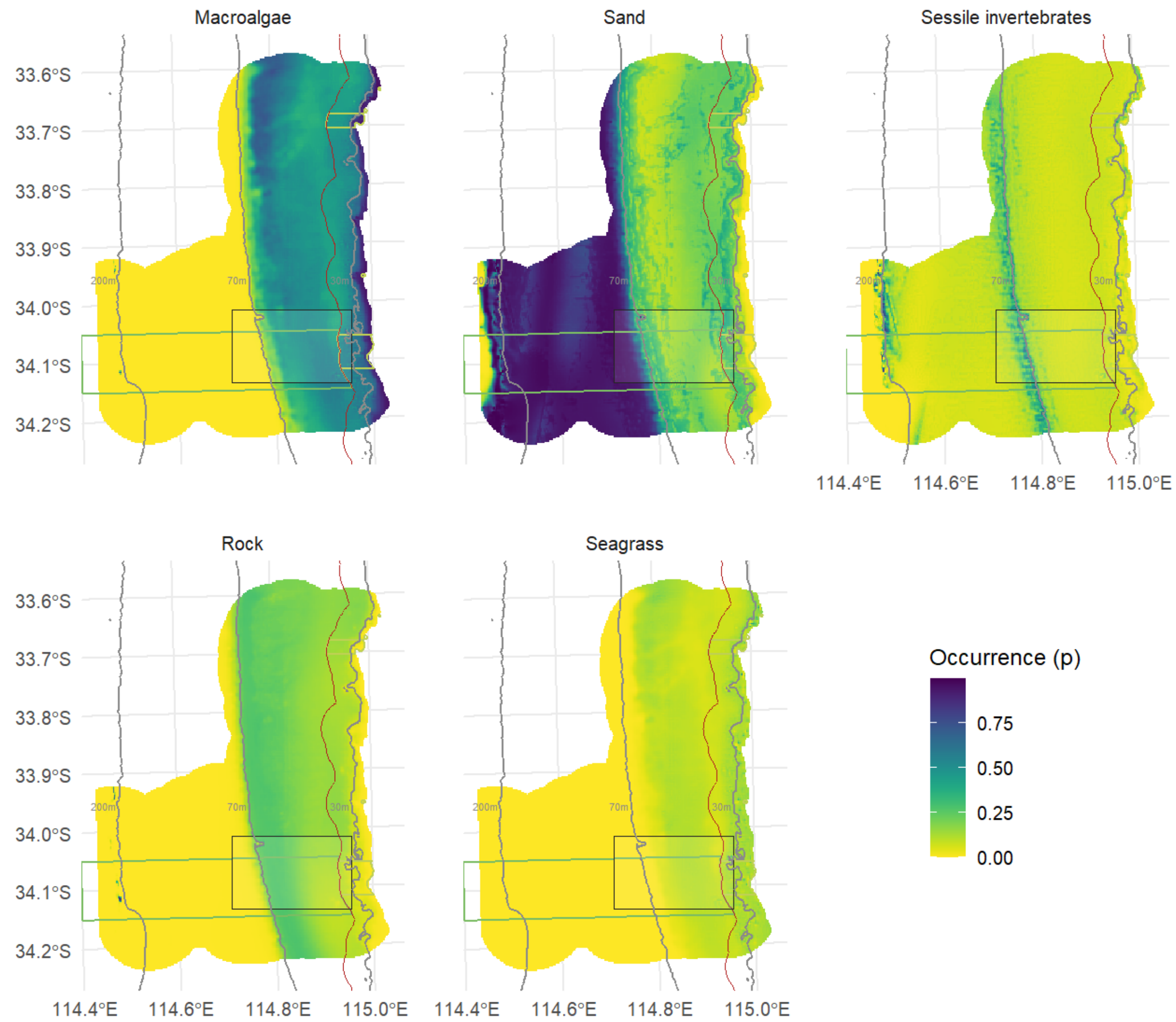


Figure 21 Predictions for individual habitat classes across the broader study area. State and Commonwealth marine park boundaries are shown. The red line delimits state and commonwealth waters. The bathymetric contours shown are 30 m, 70 m and 200 m representing ecosystem depth contours.

Spatial models of individual habitat classes for the broader study area (Figure 21) illustrate sessile invertebrates (Figure 22a) dominating a thin strip of rariphotic reef following the 70 m contour, macroalgae dominating mesophotic reefs within the National Park Zone and adjacent areas of the marine park (Figure 22b) and sand the dominant benthic habitat in deeper areas (Figure 22c). In these individual predictions (Figure 21), we can also see the relatively rare (< 50%) occurrence probability of seagrass (Figure 22d) across the mesophotic reefs.

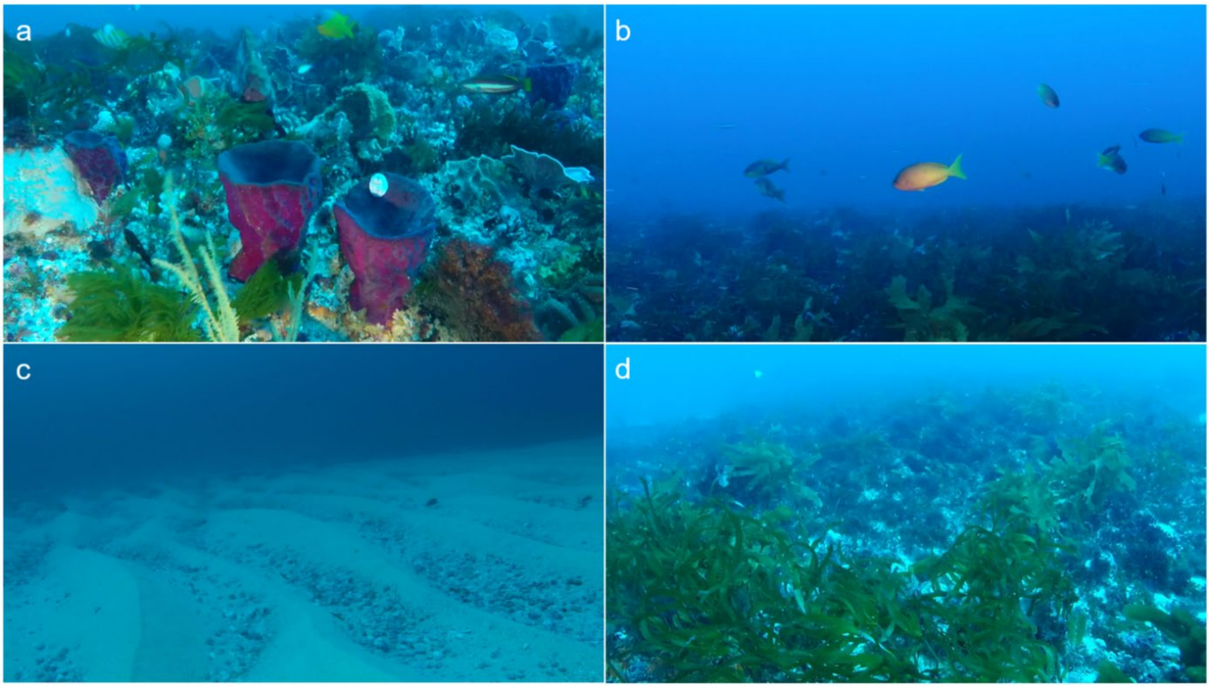


Figure 22 Examples of dominant habitat types observed on drop camera deployments as shown in Figure 20. a) Sponge garden interspersed with macroalgae and seagrass assemblages, b) Macroalgae (*Ecklonia radiata*) dominated reef habitat, c) Large sand ripples with what appears to be Rhodoliths in gutters, and d) Seagrass (*Thalassodendron pachyrhizum*) dominated low profile limestone reef.

3.2.3 Detailed bathymetry area – habitat extent

Spatial models of habitat extent for the detailed bathymetry area (Figure 23) provide a similar picture of the shallower mesophotic and rariphotic reefs found across the broader study area (Figure 20), with macroalgae dominating mesophotic reefs within the marine park and the National Park Zone and sessile invertebrate dominating in a thin strip of rariphotic reef following the 70 m contour. Again, these spatial predictions of habitat extent indicate that the existing national reef model (Figure 3) substantially underestimates mesophotic reefs (30-70 m) within the National Park Zone and adjacent areas of marine park.

Spatial models of individual habitat classes for the detailed bathymetry area (Figure 24) illustrate sessile invertebrates (Figure 20a) dominating in a thin strip of rariphotic reef following the 70m contour, macroalgae dominating mesophotic reefs within the marine park and the National Park Zone (Figure 22b) and sand the dominant benthic habitat in deeper areas (Figure 22c). Again, in these individual predictions, we can also see the relatively rare (<50%) occurrence probability of seagrass (Figure 22d) across the mesophotic reefs. These results provide a similar picture of the individually predicted habitat classes of shallower mesophotic and rariphotic reefs found across the broader study area (Figure 25).

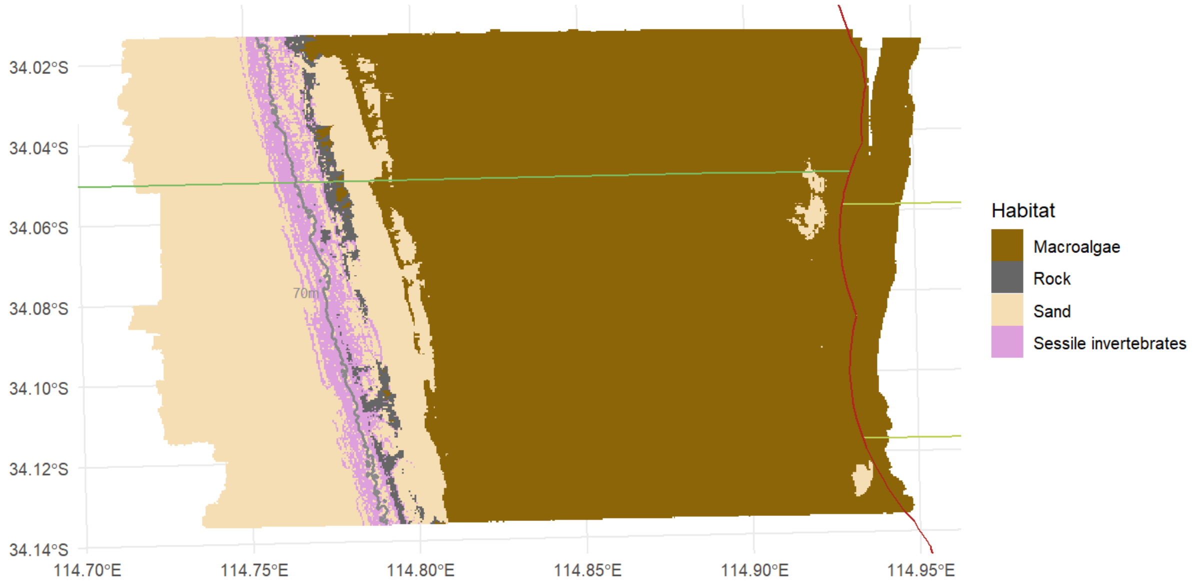


Figure 23 Predicted dominant habitat within the area of multibeam bathymetry. State and Commonwealth marine park boundaries are shown. The red line delimits state and commonwealth waters. The bathymetric contour shown is 70 m representing ecosystem depth contours, with all habitats shown greater than 30 m.

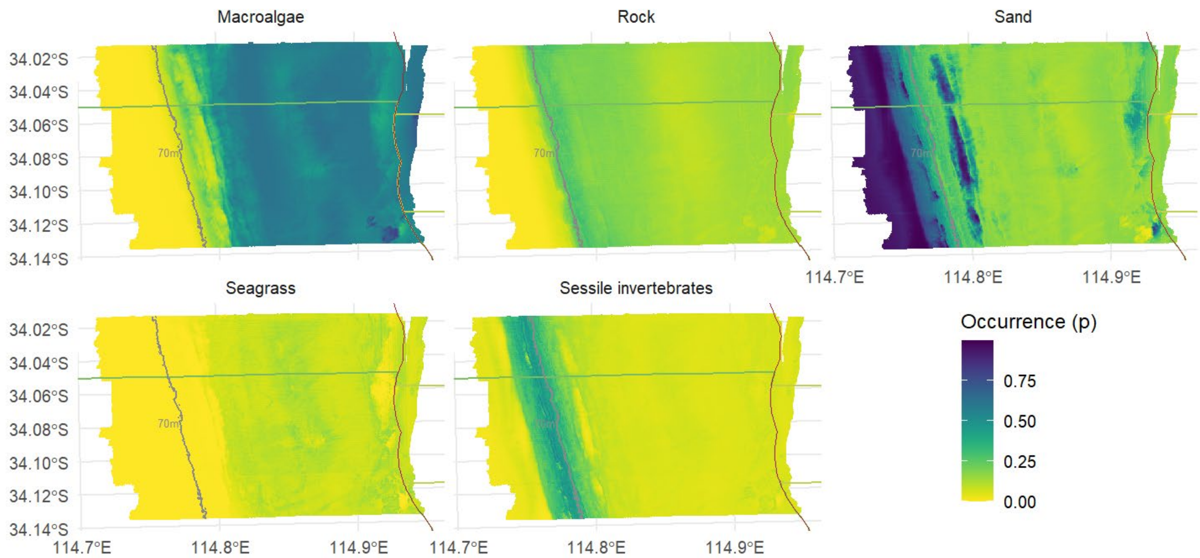


Figure 24 Predictions for individual habitat classes within the detailed bathymetry area. State and Commonwealth marine park boundaries are shown. The red line delimits state and commonwealth waters. The bathymetric contour shown is 70 m representing ecosystem depth contours, with all habitats shown greater than 30 m depth.

3.2.4 Characterization of significant seafloor features

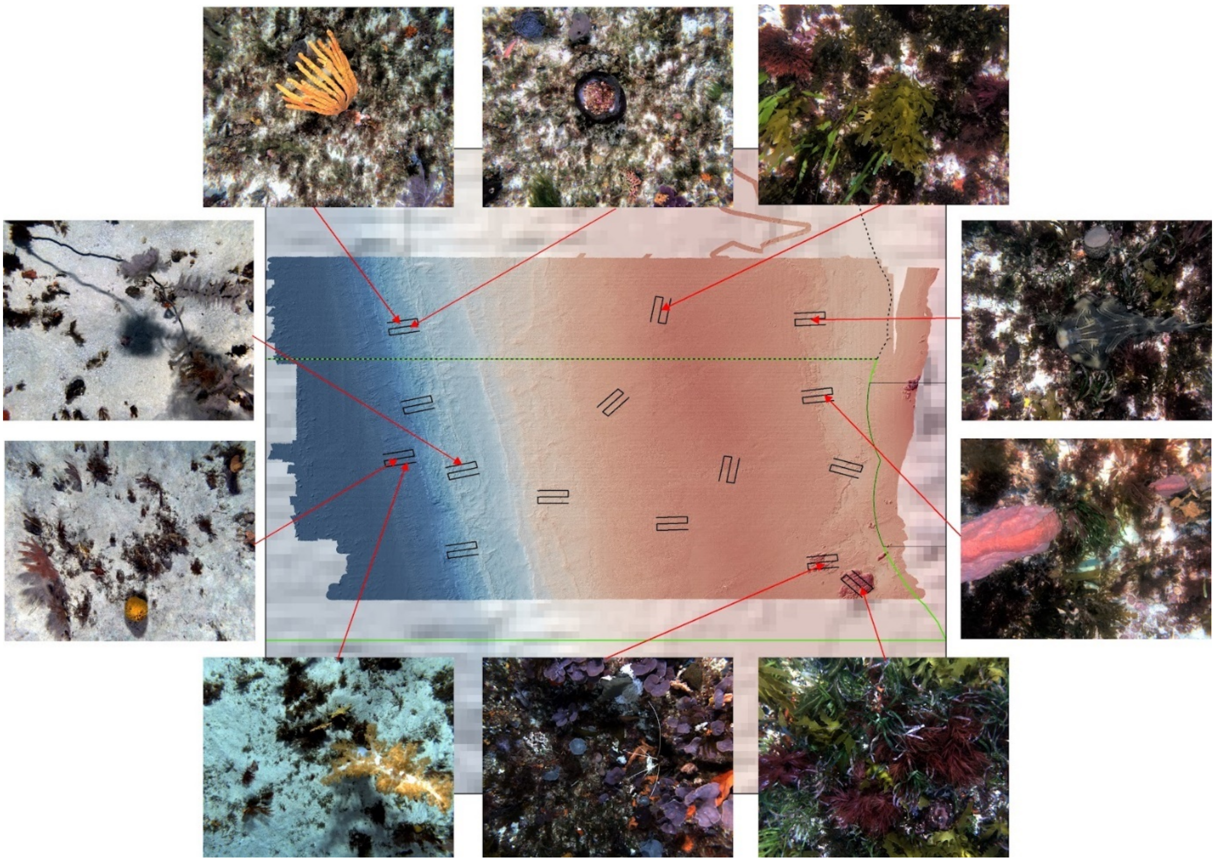


Figure 25 Habitat distribution from AUV imagery. Images highlight similar patterns in epibiota as the drop and stereo-BRUV datasets with macroalgae, stony coral and seagrass dominating shallows to the sparse sessile filter feeding epibiota beds at depth.

3.3 Fish assemblage

3.3.1 Broader study area

Given the very different areas covered by the broader study area and the detailed bathymetry (Figure 12), we have presented the fish assemblage at two different scales matching these two different resolutions of bathymetry. Fish assemblage value and metric models were undertaken at two scales: i) the broader scale of the study area, and benthic ground truthing imagery, and ii) at the scale of the detailed bathymetry obtained from multibeam survey.

At both scales five metrics were presented: (1) the total abundance of all fishes, (2) species richness, (3) abundance of targeted fishes greater than legal size, (4) abundance of target fishes smaller than legal size and (5) Community Thermal Index. Metrics 1-4 were chosen to be universal at both network and national scales, with the use of body-size abundance metrics from BRUV data previously being demonstrated to be useful at a national scale

(Bosch et al. 2021). Metric 5 was calculated from the weighted average of the thermal affinity of individual species, and has previously been demonstrated to provide a sensitive metric of the influence of climate change on fish assemblage structure and composition (Day et al. 2018; Stuart-Smith, Edgar, and Bates 2017).

Total abundance

The most parsimonious model (i.e., the most powerful but conservative model) for total abundance included mean relief as a single predictor (Figure 26), which explained 35% of its distribution (Table 20). Total abundance was positively correlated with mean relief (Figure 57), with variable importance scores indicating weak support for roughness, Topographic Position Index (TPI) and status as predictors (Figure 26). The spatial patterns in this metric reflect the positive impact of mean relief on fish biomass, with generally higher abundances along the shallower ancient coastline feature running through the east of the NPZ and SPZ, and higher abundances to the east of this feature through the shallower, macroalgae-dominated reef (Figure 27). Relief has previously been noted as a key predictor for fish abundance, with higher relief reefs supporting a greater abundance of fish in shallow reefs in south-west Western Australia (Harman, Harvey, and Kendrick 2003).

Species richness

The most parsimonious model for species richness included the percentage cover of macroalgae, detrended bathymetry and status as predictors (Figure 26), which explained 71% of its distribution (Table 20). Species richness was positively correlated with macroalgae, negatively correlated with detrended bathymetry, and was higher in the Special Purpose Zone (SPZ) than the National Park Zone (NPZ - Figure 33 and Figure 56). The spatial patterns in this metric reflect the positive impact of the percentage cover of macroalgae on species richness, while this metric was lower inside the NPZ, and on areas with high detrended bathymetry. High values for detrended bathymetry correlate with areas where water depth is greater than surrounding areas (i.e., large drop-offs and the shelf-break - Figure 4), indicating that as other national studies have found, species richness is greater on raised features (Bosch et al. 2021), such as the ancient coastline feature that runs through the NPZ and SPZ. One hundred and nineteen unique fish species were identified in the NPZ and SPZ of the South-west Corner Marine Park (Figure 28 and Figure 33), including two tropical species that have not previously been identified in this area (*Gymnocranius grandoculis* and *Naso tuberosus*). Of these 119 species, 9 were listed on the International Union of the Conservation of Nature's (IUCN) 'Red List' of Endangered Species as either 'Near Threatened' or 'Vulnerable' (Table 11). Notably was the Grey Nurse Shark (*Carcharias taurus*), which was found at a site which represents the deepest potential aggregation site and the second ever recorded aggregation site in Western Australia. The west coast population of this species is also listed on the EPBC Act List of Threatened Fauna as 'vulnerable' (Table 11). Several key demersal target species were also listed on the IUCN Red List, including the Western Blue Groper (*Achoerodus gouldii*), an iconic and slow growing wrasse species that is endemic to southern Australia (Table 11).

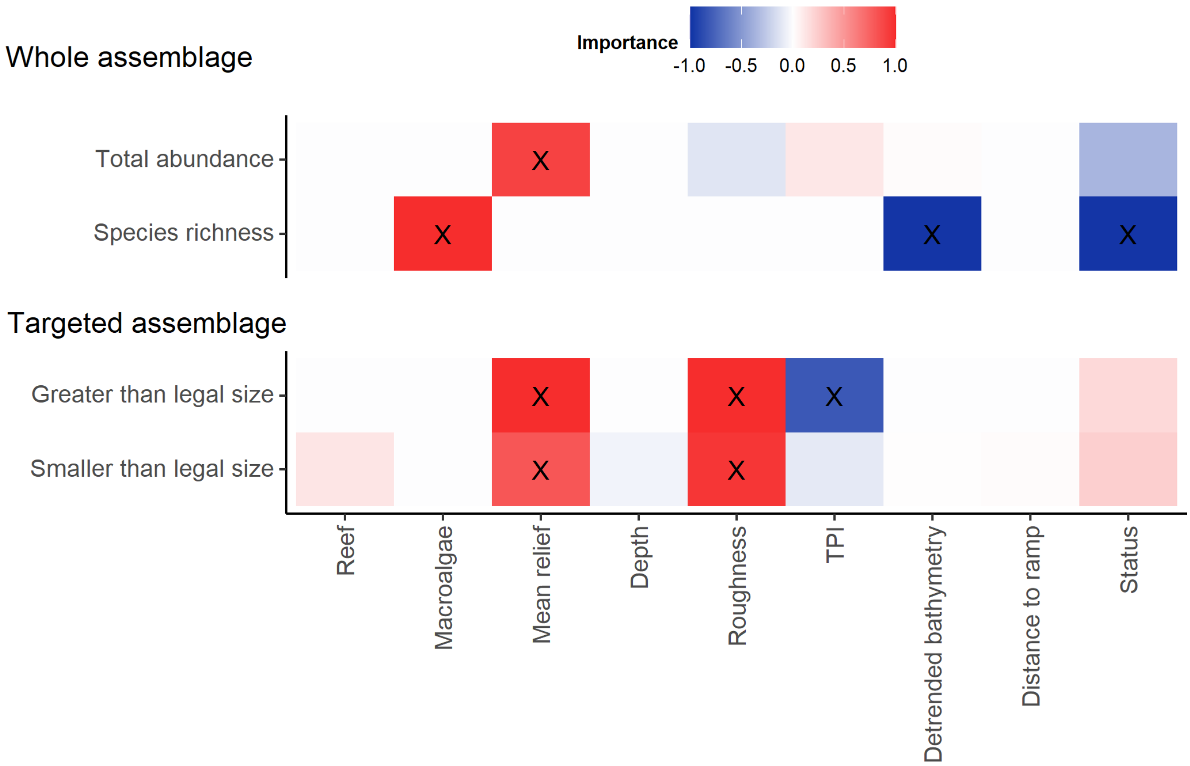


Figure 26 Model variable importance scores for whole and targeted fish assemblage metrics across the broader study area. Response variables included in the most parsimonious model are indicated by an 'X', with the colour gradient representing positive (red), none (white) and negative (blue) relationships.

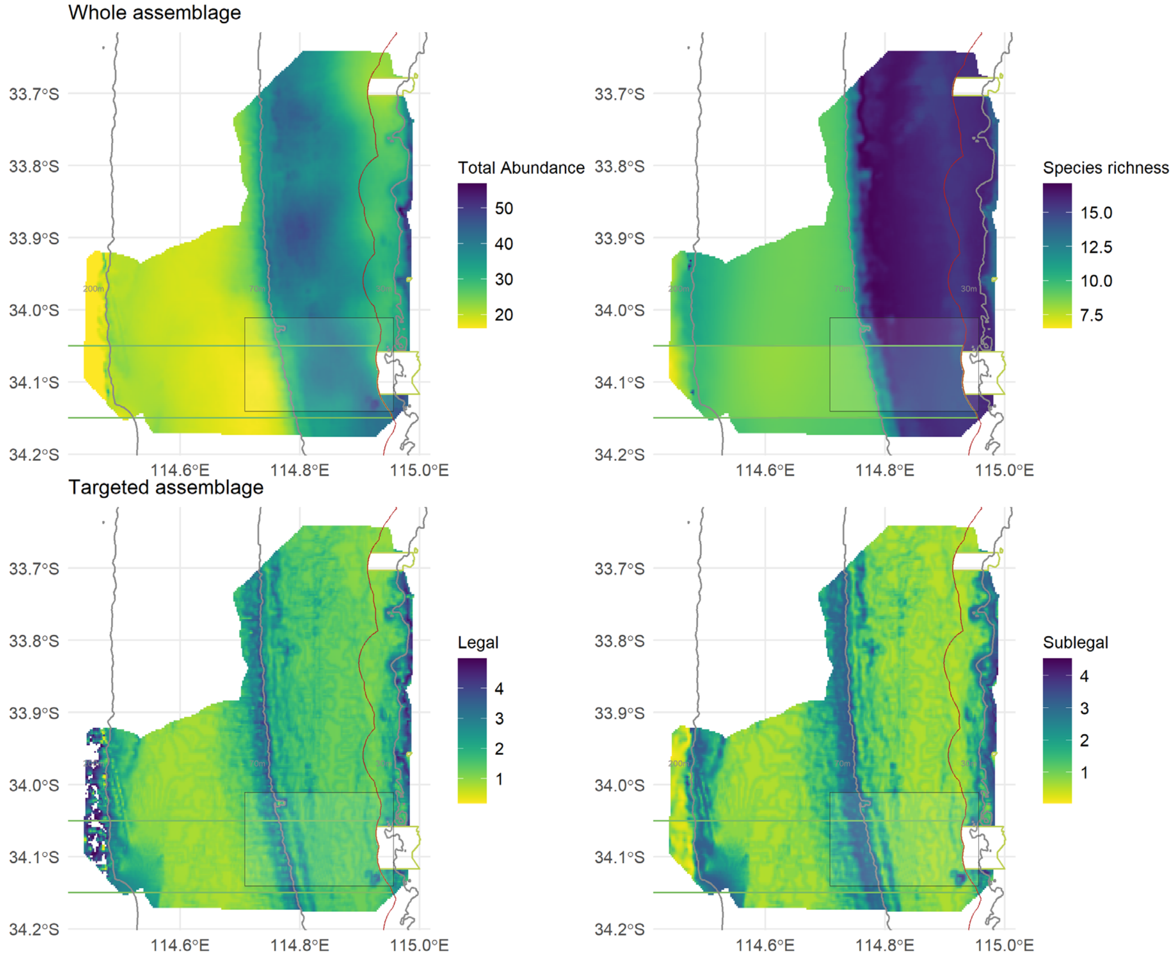


Figure 27 Spatial predictions for whole and targeted fish assemblage metrics across the broader study area. Individual heat maps represent total abundance per deployment (∑MaxN), species richness per deployment, the abundance of greater than legal size target species per deployment (legal) and the abundance of smaller than legal size target species per deployment (sublegal). State and Commonwealth marine park boundaries are shown. The red line delimits state and commonwealth waters. The bathymetric contours shown are 30 m, 70 m, 200 m and 700 m representing ecosystem depth contours. No predictions are made into State no-take Sanctuary Zones.

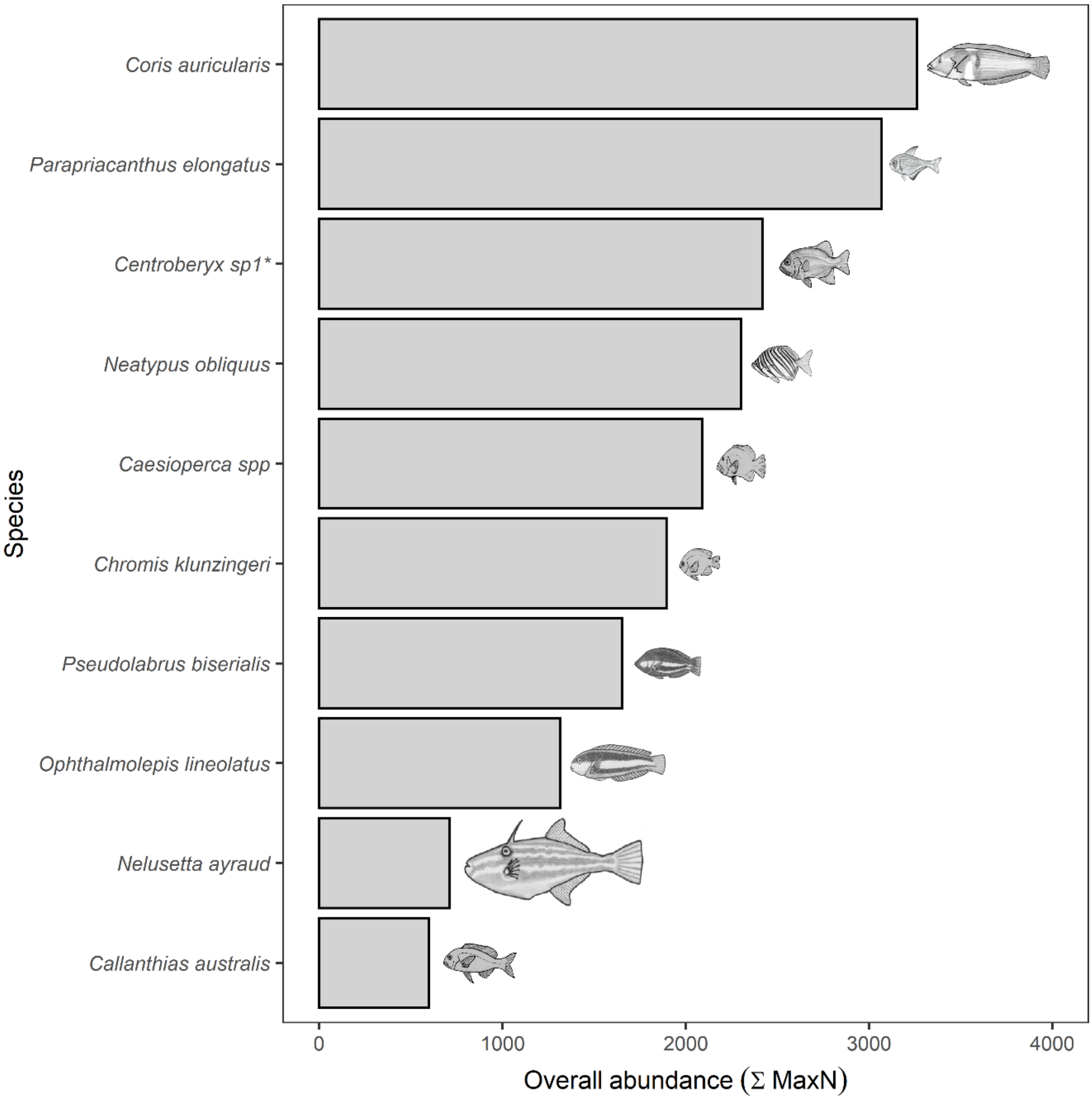


Figure 28 Top 10 most abundant species for the broader study area. Values represent the cumulative MaxN per species across all drop-camera and BRUV deployments, with * denoting recreationally and commercially targeted fish species.

Figure 29 Examples of fish, sharks, rays and other mobile fauna that were observed within the South-west Corner Marine Park. a) an endemic Horseshoe leatherjacket (*Meuschenia hippocrepis*, left) and bight redfish (*Centroberyx gerrardi*), b) Port Jackson shark (*Heterodontus portusjacksoni*, front) and pink snapper (*Chrysophrys auratus*, back), c) Smooth stingray (*Bathytoshia brevicaudata*), d) Curious cuttlefish (*Sepia* spp.), e) Harlequin fish (*Othos dentex*, front) and whiskery shark (*Furgaleus macki*, back), f) Smooth hammerhead (*Sphyrna zygaena*), listed as vulnerable by the IUCN, g) Woodward's Moray (*Gymnothorax woodwardi*) attacking the bait bag, h) a latchet (*Pterygotrigla polyommata*, right), and i) an endemic common sawshark (*Pristiophorus cirratus*, right).

Greater than legal size

The most parsimonious model for the abundance of the greater than legal size targeted species assemblage included mean relief, roughness and TPI as predictors (Figure 26), which together explained 44% of its distribution (Table 20). Greater than legal size target species were positively correlated with mean relief and roughness, and negatively correlated with TPI (Figure 56), with variable importance scores indicating weak support for status as a predictor (Figure 26). The spatial patterns in this metric reflect the positive impact of mean relief and roughness on fish biomass, with these metrics being higher on areas of higher structural complexity (Figure 27). The negative correlation between TPI and legal sized target species abundance suggests that large target species prefer areas where the substrate is lower than surrounding areas, such as smaller drop-offs and ledges on the western edge of the ancient coastline feature that runs north-south through the centre of the NPZ. The relationship between the abundance of larger target species and various measures of structural complexity (mean relief, roughness and TPI) has previously been seen in national benchmarks of this metric (Bosch et al. 2021). Thirty recreationally and commercially targeted species were identified in the South-west Corner Marine Park (Figure 30 and Table 12), including the West Australian Dhufish (*Glaucosoma hebraicum*) and Pink Snapper

(*Chrysophrys auratus*), which are key indicator species for the West Coast Demersal Scalefish Resource (Newman et al. 2021). In the broader study area, the greater depth range covered explains the relatively high abundance of deeper water species including Redfish (*Centroberyx)* species.

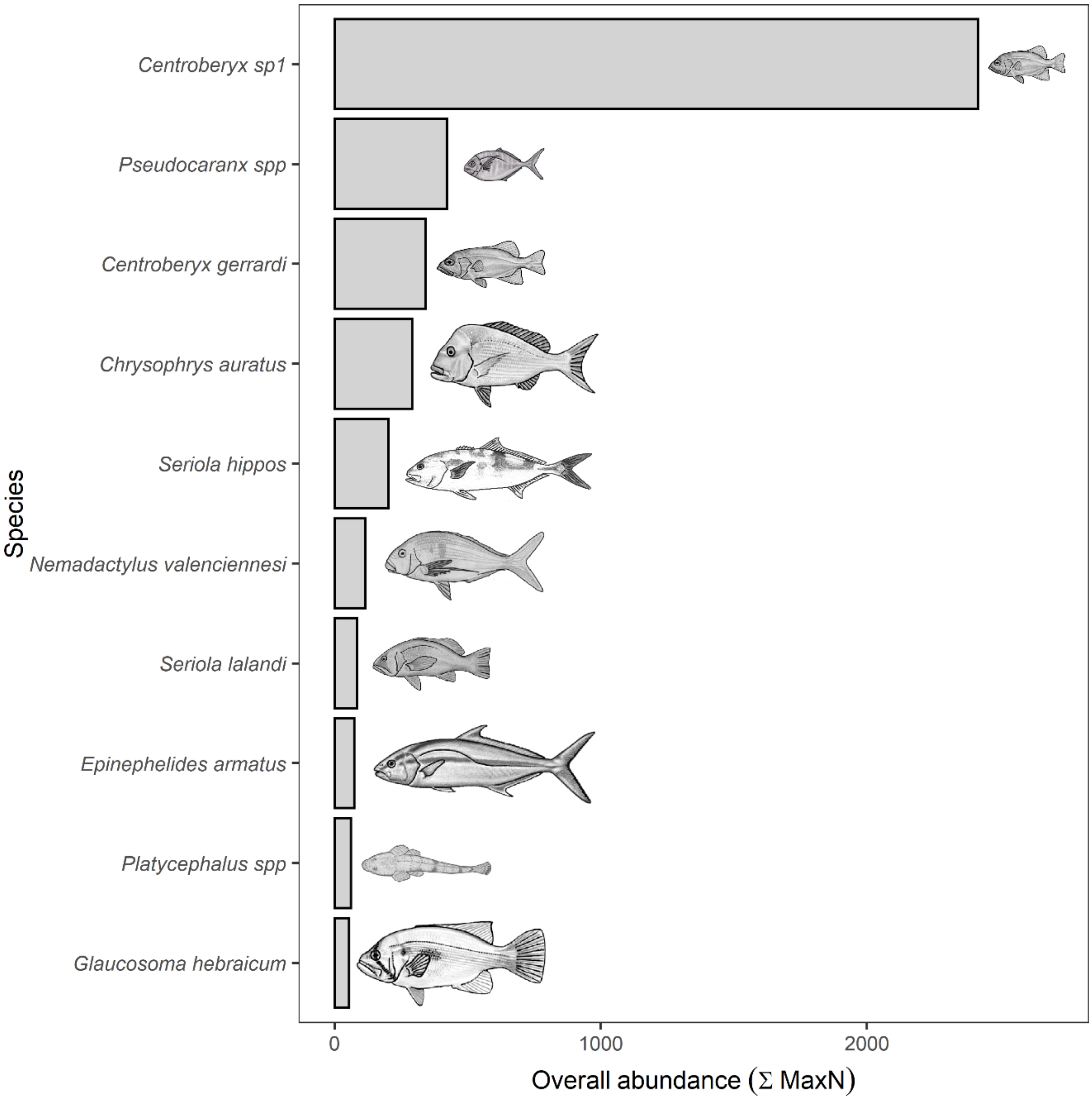


Figure 30 Top 10 most abundant targeted species for the broader study area. Values represent the cumulative MaxN per recreationally or commercially targeted species across all drop camera and BRUV deployments.

Smaller than legal size

The most parsimonious model for the abundance of smaller than legal size target species included mean relief and roughness as predictors (Figure 26), which together explained 26%

of its distribution (Table 20). Smaller than legal size target species were positively correlated with roughness and negatively correlated with depth and TPI (Figure 56), with variable importance scores indicating weak support for the percentage cover of reef and status as predictors (Figure 26). The spatial patterns in this metric represent the positive correlation between roughness and the abundance of sublegal size target species, with this metric being higher on areas of higher structural complexity, a common driver of fish abundance (Harman, Harvey, and Kendrick 2003). The negative correlation between TPI and sublegal sized target species abundance suggests that smaller target species prefer areas where the substrate is lower than surrounding areas, such as smaller drop-offs and ledges on the western edge of the ancient coastline feature that runs north-south through the centre of the NPZ (Figure 27). The negative correlation between depth and sublegal target species suggests that the smaller target species are found in shallower waters, a finding that is consistent with a national survey of data from stereo-BRUVs, where larger target species were found in deep water and away from highly populated areas (Bosch et al. 2021).

Community thermal index

For the broad study area, the community thermal index was calculated and compared to regional sea surface temperature mean and variance (Figure 31), and for both the SPZ and NPZ was found to fall within 1 standard deviation of the mean of the sea surface temperature. This metric has previously been demonstrated to provide a sensitive estimate of the influence of warming on fish assemblage structure and composition (Day et al. 2018; Stuart-Smith, Edgar, and Bates 2017).

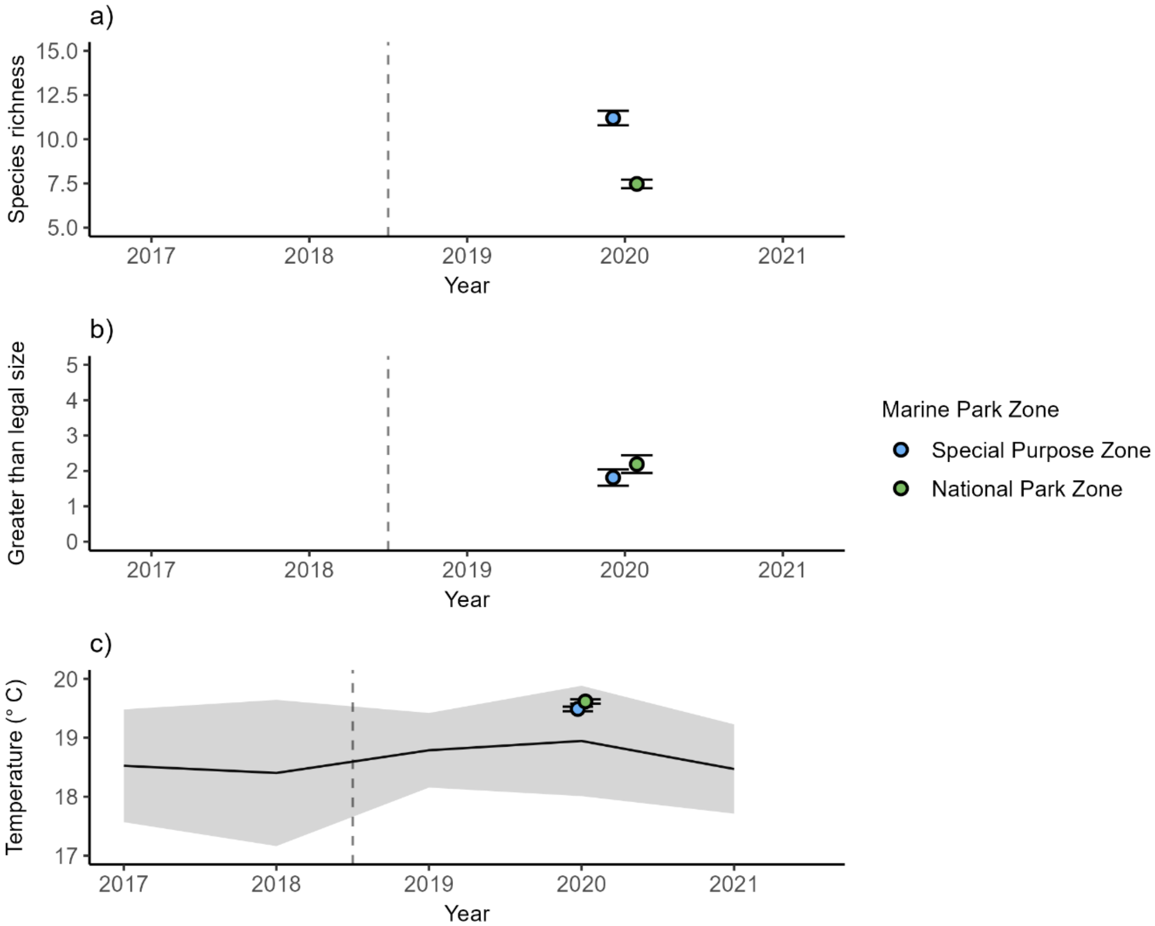


Figure 31 Draft* temporal plots for species richness, the abundance of greater than legal size targeted assemblage and community temperature index for the broader study area. Mean and standard error of metrics; a) species richness, b) abundance of targeted species greater than legal size, c) community thermal index. Black solid line and grey confidence bands on c) community temperature index indicate sea surface temperature mean and standard deviation. Dashed vertical line indicates the date of establishment of the marine park. * These metrics may be revised during Parks Australia's ongoing development of a Monitoring, Evaluation, Improvement and Reporting framework.

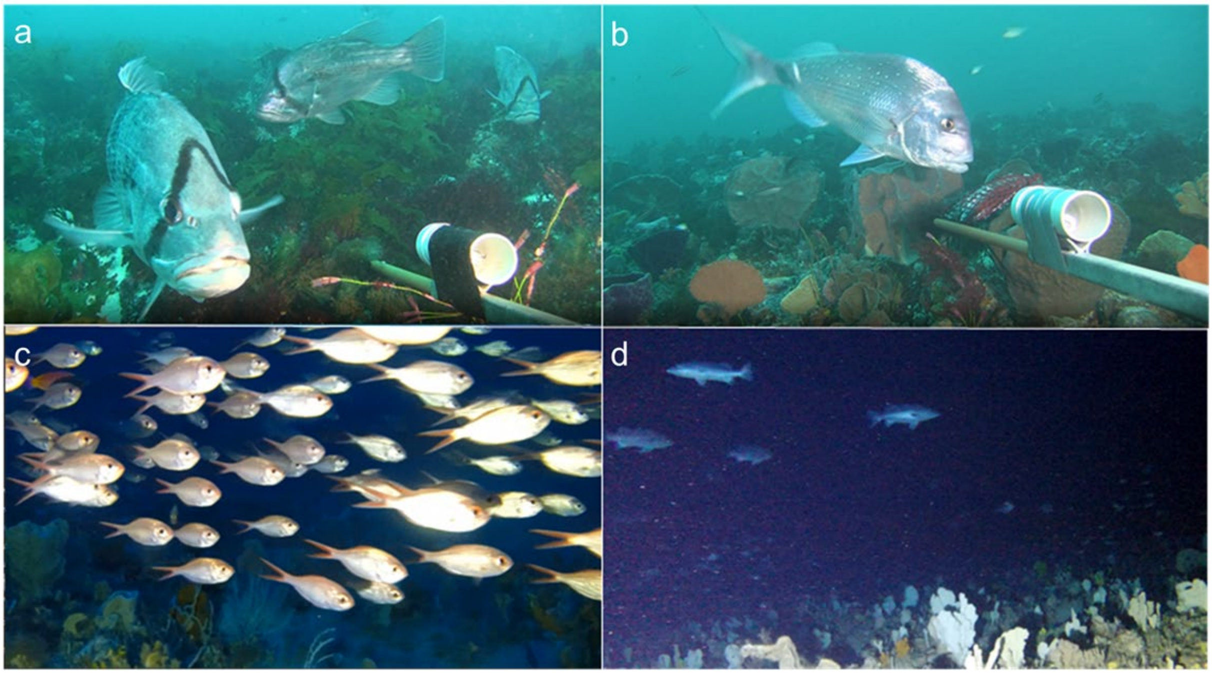


Figure 32 Examples of highly targeted species observed on stereo-BRUV (a-b) and drop camera (c-d) deployments. a) West Australian Dhufish, *Glaucosoma hebraicum* in 39 m, b) Pink Snapper, *Chrysophrys auratus* in 46 m, c) Swallowtail, *Centroberyx lineatus* and Yelloweye Redfish, *Centroberyx australis* in 129 m, and d) Hapuka, *Polyprion oxygeneios* in 250 m.

Table 11 IUCN threatened species in the broader study area. Table of the species identified in sampling that are listed on the IUCN Red List of Threatened Species. **Carcharias taurus* and *Galeorhinus galeus* are listed on the EPBC Act List of Threatened Fauna as Vulnerable and Conservation dependent respectively.

Scientific name	Common name	IUCN ranking
Achoerodus gouldii	Western Blue Groper	Vulnerable
*Carcharias taurus**	Grey Nurse Shark	Vulnerable
Carcharhinus plumbeus	Sandbar Shark	Vulnerable
Sphyrna zygaena	Smooth Hammerhead	Vulnerable
*Galeorhinus galeus**	School Shark	Vulnerable
Bodianus frenchii	Foxfish	Near Threatened
Epinephelides armatus	Breaksea Cod	Near Threatened
Carcharhinus brevipinna	Spinner Shark	Near Threatened
Carcharhinus limbatus	Common Blacktip Shark	Near Threatened

Table 12 Targeted species observed in the broader study area. Fishing type represents; C = Commercial, R = Recreational, B = Bycatch. Fish not identified to the species level were not included in this table, however were included in the analysis when all species

Scientific	Common name	Fishing type
Centroberyx gerrardi	Bight Redfish	C/R
Seriola hippos	Samsonfish	C/R
Seriola lalandi	Yellowtail Kingfish	C/R
Nemadactylus valenciennesi	Blue Morwong	C/R
Glaucosoma hebraicum	West Australian Dhufish	C/R
Achoerodus gouldii	Western Blue Groper	R
Bodianus frenchii	Foxfish	C/R
Choerodon rubescens	Baldchin Groper	C/R
Pentaceropsis recurvirostris	Longsnout Boarfish	C/R
Polyprion oxygeneios	Hapuka	C/R
Epinephelides armatus	Breaksea Cod	C/R
Chrysophrys auratus	Pink Snapper	C/R
Centroberyx australis	Yelloweye Redfish	C/R
Centroberyx lineatus	Swallowtail	C/R
Trachurus novaezelandiae	Yellowtail Scad	B/C/R
Carcharhinus limbatus	Common Blacktip Shark	B/C
Carcharhinus plumbeus	Sandbar Shark	C
Pseudophycis barbata	Bearded Rock Cod	C/R
Parazanclistius hutchinsi	Short Boarfish	C/R
Sarda orientalis	Oriental Bonito	R
Hyporthodus octofasciatus	Eightbar Grouper	C/R
Othos dentex	Harlequin Fish	C/R
Sillaginodes punctatus	King George Whiting	C/R
Sphyrna zygaena	Smooth Hammerhead	C
Furgaleus macki	Whiskery Shark	C
Galeorhinus galeus	School Shark	C/R
Mustelus antarcticus	Gummy Shark	B/C
Chelidonichthys kumu	Red Gurnard	B/C
Pterygotrigla polyommata	Latchet	B/C

3.3.2 Detailed bathymetry area

Total abundance

The most parsimonious model for total abundance included mean relief as a single predictor (Figure 33), which explained 37% of its distribution (Table 21). Total abundance was positively correlated with mean relief (Figure 57), with variable importance scores indicating weak support for detrended bathymetry as a predictor (Figure 33). The spatial patterns in this metric reflect the positive impact of mean relief on fish abundance, with generally higher abundances along the shallower old coastline feature running through the east of the NPZ and SPZ, and higher abundances to the east of this feature through the shallower, macroalgae-dominated reef (Figure 34). The Elongate Bullseye (*Parapriacanthus elongatus*) and Western King Wrasse (*Coris auricularis*) were the most abundant species in the assemblage (Figure 35). Relief has previously been noted as a key predictor for fish abundance, with higher relief reefs supporting a greater abundance of fish on shallow reefs in south-west Western Australia (Harman, Harvey, and Kendrick 2003).

Species richness

The most parsimonious model for species richness included mean relief as a single predictor (Figure 33), which explained 63% of its distribution (Table 21). Species richness was positively correlated with mean relief (Figure 57), with variable importance scores not indicating support for any other predictors (Figure 34). Higher species richness was observed in the Special Purpose than the National Park Zone but with greater standard error (Figure 37), likely due to the smaller number of samples collected within this zone due to the much smaller proportion of this zone where bathymetry was mapped in detail (Figure 12). No IUCN threatened species also currently under assessment through the EPBC Act1999 were observed in the detailed bathymetry area (Table 13).

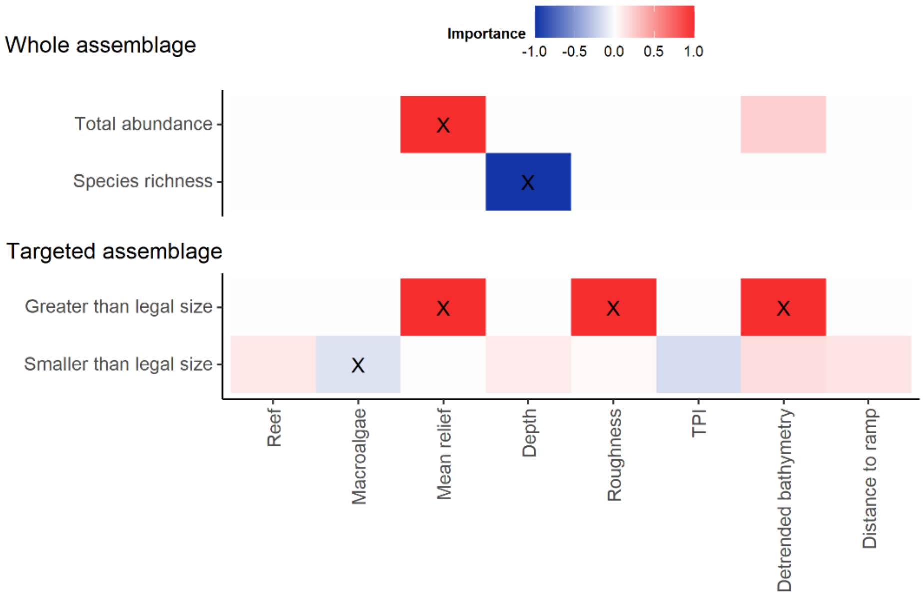


Figure 33 Model variable importance scores for whole and targeted fish assemblage metrics in the detailed bathymetry area. Response variables included in the most parsimonious top model are indicated (X), with the colour gradient representing positive (red), zero (white) and negative (blue) relationships.

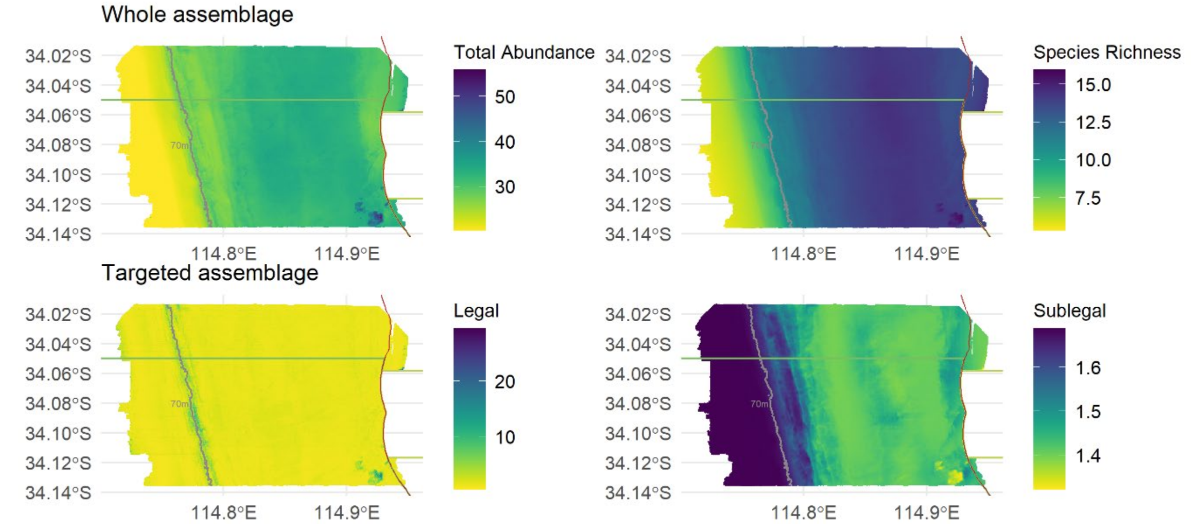


Figure 34 Spatial predictions for whole and targeted fish assemblage metrics in the detailed bathymetry area. Green polygons represent state sanctuary zones (IUCN II), blue polygons represent Commonwealth multiple use zones (IUCN VI). Individual heat maps represent total abundance per deployment (∑MaxN - top left), species richness per deployment (top right), the abundance of greater than legal size target species per deployment (legal - bottom left) and the abundance of smaller than legal size target species per deployment (sublegal - bottom right). The colour gradient represents high (blue) and low (yellow) values. Horizontal and vertical axes represent latitude and longitude respectively. State and Commonwealth marine park boundaries are shown. The red line delimits State and Commonwealth waters. The bathymetric contour shown is 70 m representing ecosystem depth contours, all habitats shown are greater than 30 m. Note that no predictions are made into State no-take Sanctuary Zones.

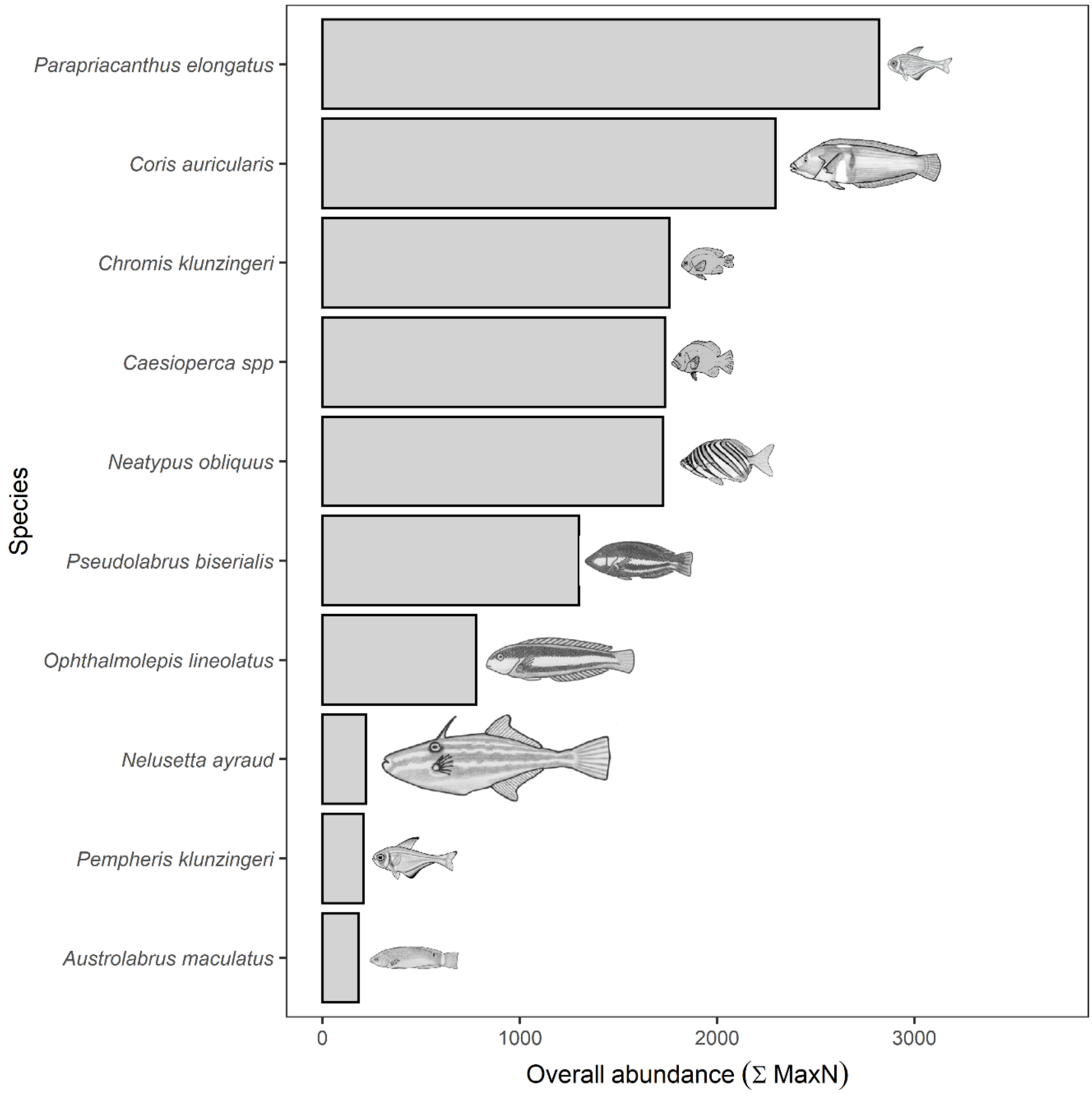


Figure 35 Top 10 most abundant species in the detailed bathymetry area. Values represent the cumulative MaxN per species across all drop-camera and BRUV deployments. None of the top 10 most abundant species in the detailed bathymetry area are recorded as recreationally or commercially targeted.

Greater than legal size

The most parsimonious model for the abundance of greater than legal size target species included the mean relief, detrended bathymetry and roughness as predictors (Figure 33), which together explained 45% of its distribution (Table 21). Greater than legal size target species were positively correlated with reef, detrended bathymetry and roughness (Figure 57), with variable importance scores not indicating support for any other predictors (Figure 33). The relationship between the abundance of larger target species and various measures of structural complexity (mean relief, roughness and TPI) has previously been seen in national benchmarks of this metric (Bosch et al. 2021). Key commercially targeted species were identified in the South-west Corner Marine Park (Figure 32, Figure 36 and Table 14), including the West Australian Dhufish (*Glaucosoma hebraicum*) and Pink Snapper (*Chrysophrys auratus*), which are key indicator species for the West Coast Demersal Scalefish Resource (Newman et al. 2021). There were no substantial differences in the abundance of greater than legal size target species between the NPZ and SPZ. In the detailed bathymetry area, the shallower depth range covered explains the relatively higher abundance of shallow and mesophotic associated species such as the Pink Snapper (*Chrysophrys auratus*, Figure 36).

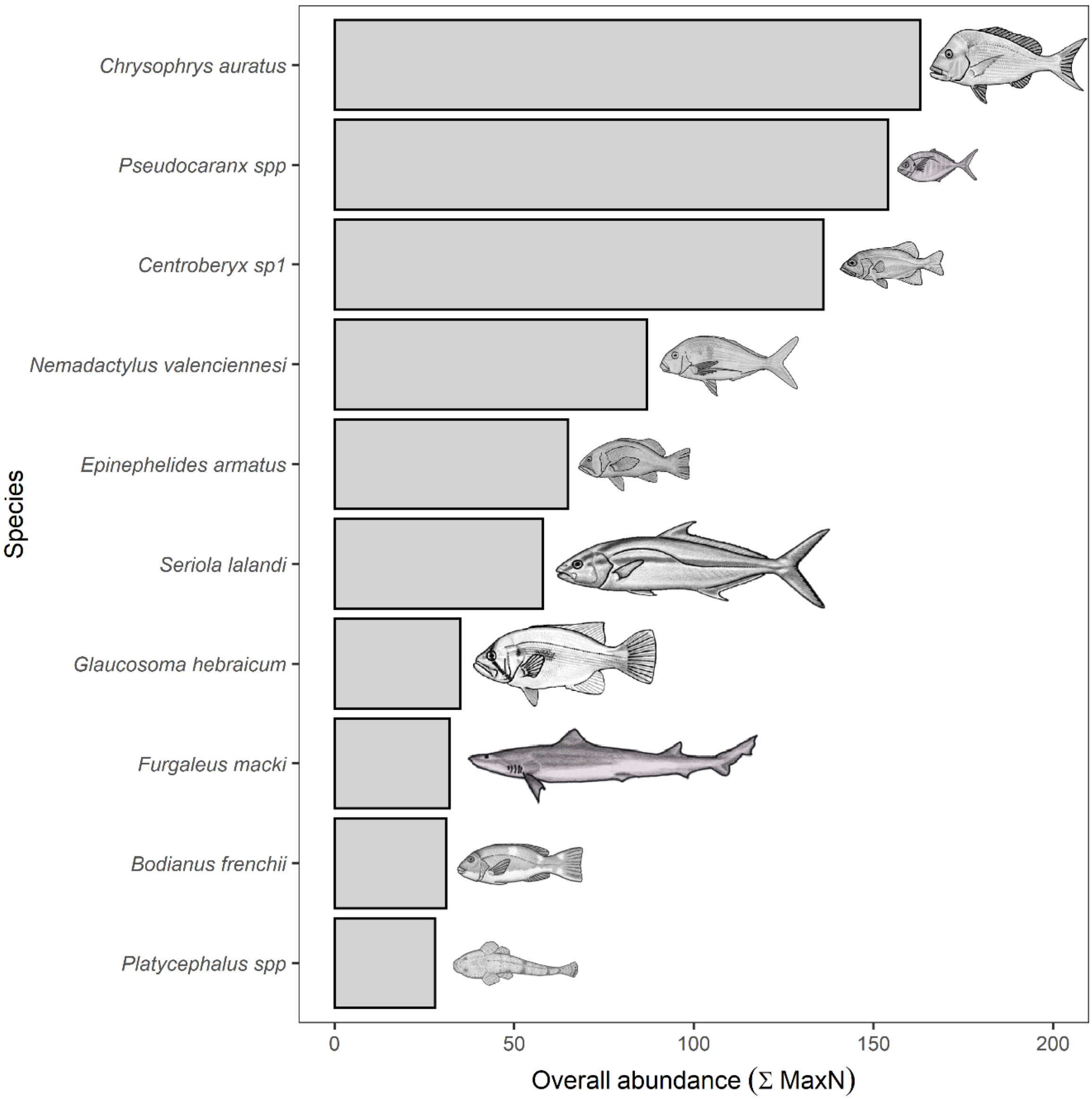


Figure 36 Top 10 most abundant targeted species in the detailed bathymetry area. Values represent the cumulative MaxN per recreationally or commercially targeted species across all drop-camera and BRUV deployments.

Smaller than legal size

The most parsimonious model for the abundance of smaller than legal size target species included the percentage cover of macroalgae as a single predictor (Figure 33), which explained 20% of its distribution (Table 21). Smaller than legal size target species were negatively correlated with macroalgae (Figure 57), with variable importance scores indicating weak support for the percentage cover of reef, depth, TPI, detrended bathymetry and distance to ramp as predictors (Figure 33).

Community thermal index

For the detailed bathymetry area, the community thermal index was calculated and compared to regional sea surface temperature mean and variance (Figure 37), and for both the SPZ and NPZ was found to fall within 1 standard deviation of the mean of the sea surface temperature. This metric has previously been demonstrated to provide a sensitive estimate of the influence of warming on fish assemblage structure and composition (Day et al. 2018; Stuart-Smith, Edgar, and Bates 2017).

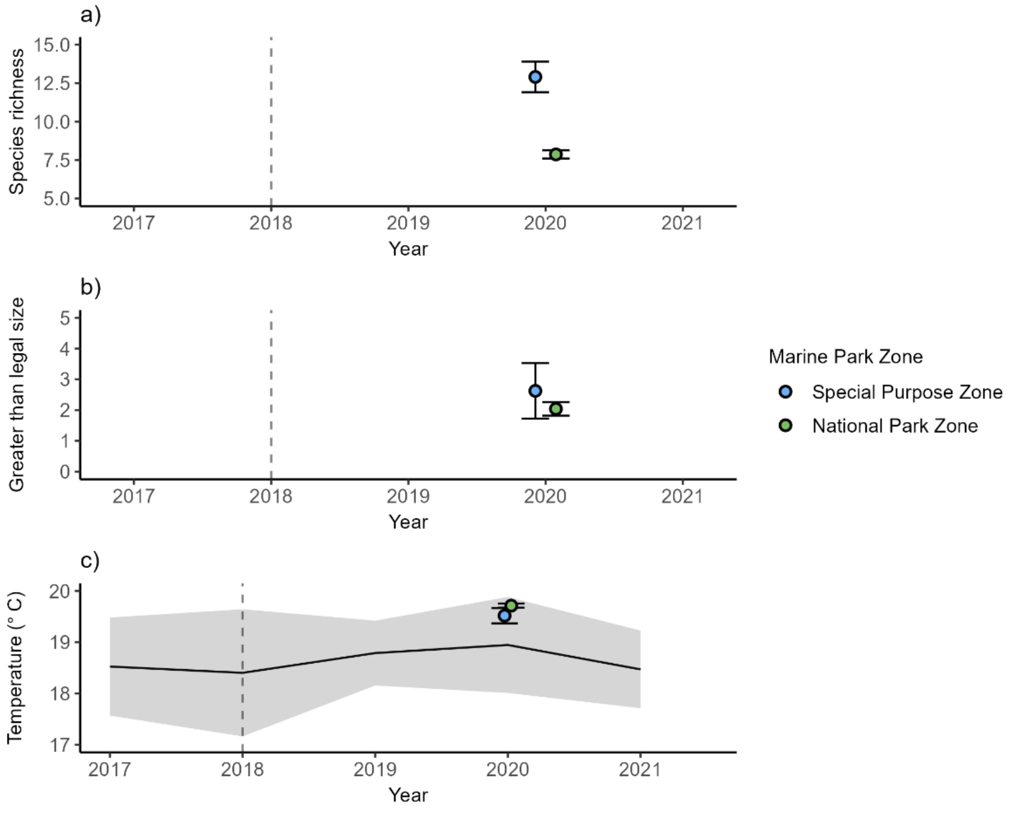


Figure 37 Draft* temporal plots for species richness, the abundance of greater than legal size target species and community temperature index for the detailed bathymetry area. Mean and standard error of metrics; a) species richness, b) abundance of targeted species greater than legal size, c) community thermal index. Black solid line and grey confidence bands on c) community temperature index indicate sea surface temperature mean and standard deviation. Dashed vertical line indicates the data of establishment of the marine park. * These values

may be revised during Parks Australia's ongoing development of a Monitoring, Evaluation, Improvement and Reporting framework.

Table 13 IUCN threatened species in the detailed bathymetry area.

Scientific	Common name	IUCN ranking
Achoerodus gouldii	Western Blue Groper	Vulnerable
Bodianus frenchii	Foxfish	Near Threatened
Epinephelides armatus	Breaksea Cod	Near Threatened
Carcharhinus brevipinna	Spinner Shark	Near Threatened
Carcharhinus limbatus	Common Blacktip Shark	Near Threatened
Carcharhinus plumbeus	Sandbar Shark	Vulnerable

Table 14 Targeted species observed in the detailed bathymetry area. Fishing type represents; C = Commercial, R = Recreational, B = Bycatch. Fish not identified to the species level were not included in this table, however were included in the analysis when all species in the genus were targeted.

Scientific	Common name	Fishing type
Centroberyx gerrardi	Bight Redfish	C/R
Seriola hippos	Samsonfish	C/R
Seriola lalandi	Yellowtail Kingfish	C/R
Nemadactylus valenciennesi	Blue Morwong	C/R
Glaucosoma hebraicum	West Australian Dhufish	C/R
Achoerodus gouldii	Western Blue Groper	R
Bodianus frenchii	Foxfish	C/R
Choerodon rubescens	Baldchin Groper	C/R
Pentaceropsis recurvirostris	Longsnout Boarfish	C/R
Epinephelides armatus	Breaksea Cod	C/R
Chrysophrys auratus	Pink Snapper	C/R
Centroberyx australis	Yelloweye Redfish	C/R
Centroberyx lineatus	Swallowtail	C/R
Carcharhinus limbatus	Common Blacktip Shark	B/C
Carcharhinus plumbeus	Sandbar Shark	C

3.3.3 Threatened species

Within the National Park Zone we observed smooth hammerhead (*Sphyrna zygaena*, Figure 29f), listed as vulnerable by the IUCN and currently under assessment through the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act), and found evidence of a potential aggregation site for grey nurse sharks (*Carcharias taurus*, Figure 38). Identification and protection of grey nurse shark aggregation sites is important for conserving this species (Lynch et al. 2013). Although the west coast population of *C. taurus* is listed as Vulnerable under the EPBC Act, the eastern Australian populations of this species are listed as Critically Endangered. Their biennial reproductive cycle and slow population growth make *C. taurus* populations vulnerable to decline (Hoschke and Whisson 2016).

We observed five individuals at one site in the National Park Zone at a depth of 137 m. To our knowledge this would represent the deepest aggregation site for *C. taurus* and would represent the second aggregation site identified in the west coast population, with the other sites located at the Navy Pier in Exmouth (Hoschke and Whisson 2016). Another aggregation site at the West End of Rottnest Island has been observed but not officially recorded in any publication. Although population estimates have been made for the eastern Australian population, there is no such information for the western population reflecting the lack of knowledge and high degree of uncertainty on the status of this subpopulation (Bradford et al. 2018). Repeat surveys of this aggregation are needed to confirm site use on a recurrent basis, and to determine whether this site is used seasonally, or year-round.

Figure 38 A Grey Nurse Shark (*Carcharias taurus*) aggregation site in the National Park Zone. Imagery taken from a drop camera deployment in 141 m.

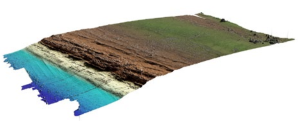
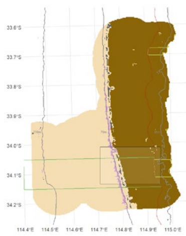
4. General conclusions and recommendations for future work

4.1 General conclusions

This was the first survey of the ‘Capes region’ of the South-west Corner Marine Park, which was designed to inform discovery and knowledge of the biodiversity within the marine park. We used targeted discovery and monitoring questions to investigate significant seafloor features, the fish assemblage, and benthic values, including the extent and distribution of benthic habitats and fish assemblages. This survey benefited from the guidance of Wadandi Traditional Owners who provided Traditional Ecological and Scientific Knowledge disseminated through meetings, a map of the Wadandi Cultural Seascape and Wadandi cultural values, provided in more culturally detailed NESP Marine Biodiversity Hub report (Davies et al. 2022). Traditional Ecological and Scientific Knowledge was used to inform the prioritisation of the location of the detailed bathymetry data collection and associated components of the survey.

The survey revealed and highlighted the presence of both special cultural and natural values or components with the study area in the South-west Corner Marine Park. These included the extensive submerged ancient coastline features in the National Park Zone, extensive mesophotic and rariphotic reefs, the occurrence of large-bodied key target species in the National Park Zone, a potential Grey Nurse Shark aggregation site in the National Park Zone and aggregations of Hapuka, a highly targeted deeper water species, on the shelf break in the National Park Zone (Table 15).

Table 15 Five special cultural or natural values and components characterising the study area of the South-west Corner Marine Park.

Special value or component	Snapshot	Description
Submerged ancient coastline features in the National Park Zone		Distinct pale shorelines from the last interglacial period 18 thousand year old (ka BP) in ~120 m depth to 9-10 ka BP ~35 m. Across the 9-10 ka BP shoreline we also observed distinct submerged lowlands and granite outcrops indicating ancient coastal wetlands
Extensive mesophotic and rariphotic reefs		Surveys revealed substantially greater extent of sessile invertebrate and macroalgae dominated mesophotic (30-70 m) and rariphotic (70-250 m) reefs.

Large-bodied key target species in the National Park Zone		Large-bodies endemic Dhu Fish and Pink Snapper were observed in the National Park Zone. These species are key target fisheries species and subject to substantial fisheries management adjustments.
Potential Grey Nurse Shark aggregation site in the National Park Zone		A potential Grey Nurse Shark (*Carcharias taurus*) aggregation site was observed in the National Park Zone in 140 m. Grey Nurse Shark are a listed species.
Aggregations of Hapuka on the shelf break in the National Park Zone		Aggregations of Hapuka (*Polyprion oxygeneios*) a key and highly targeted deeper water species in 200-250 m on the shelf break in the National Park Zone.

The design of this survey was conducted at two different scales, a broader survey area (relying on available national scale bathymetry at 250 m resolution) and detailed bathymetry area (4 m resolution). This contrasts with a typical NESP Marine Biodiversity Hub survey, which are usually restricted to detailed bathymetry extents (Carroll et al. 2021; Keesing et al. 2021). The detailed survey area revealed the existence of significant seafloor features, associated with submerged ancient shoreline features, and the strong correlation between the distribution of benthic habitat extent and the fish assemblage but was mostly restricted to the National Park Zone at the centre of the study.

The broader study area provided an array of samples across a larger spatial extent, both inside the National Park Zone and, including likely comparable areas, in the adjacent Special Purpose Zone. Using only coarse publicly available bathymetry products (250 m resolution, Figure 4), this larger survey area was able to characterise the existence of significant seafloor features, related to submerged ancient shorelines, and revealed the variability of habitats and fish assemblage composition with significant seafloor features. Further, there was no evidence of the potential impact of gradients in extractive use (e.g., recreational fishing effort using the proxy of distance to boat ramp) on the fish assemblage, including the abundance of target species greater than legal size. The existing spatial use data for the area was not used as a covariate in analysis as it came from a national benchmark study in 2020 (Navarro et al. 2021) that had only limited days of sampling in each region.

Spatial estimates of recreational extractive effort relevant to the current discovery and monitoring questions would likely be improved with additional sampling effort as the current benchmark is likely under estimating effort around access points in the Capes region (Navarro et al. 2021). To further investigate the monitoring questions relating to the potential impact of gradients in extractive use across the marine park, we recommend a more detailed collection of spatial use data for extractive recreational activities, which has previously been identified as lacking in past meta-analysis and interpretation of marine park natural value long-term monitoring (Cresswell et al. 2019).

To monitor the impacts of climate change on natural and socio-economic values, future monitoring, coupled with measurements of pressures (e.g. Figure 8) will provide a useful monitoring framework (Sagar et al. 2020; Chapman 2015). Here, we have provided a demonstration of a potential fish assemblage metric to monitor the response of the fish assemblage to warming or cooling over time (Figure 31c & Figure 37c - Community Thermal Index) and a series of recommendations for the future use of this metric (Table 16).

Table 16 Recommendations on the development of data products to inform benchmarks for metrics of fish assemblage natural values and ecosystem components for the Australian Marine Parks and national reporting.

Metric	Data product and portal to be targeted	Recommendations
Abundance of fished species by size class (i.e. sub-legal, greater than legal, large)	Bosch et al. 2021 + Australian BRUV synthesis + new mesophotic and rariophotic datasets via GlobalArchive	Build predictive national benchmark model for fish metrics; by location, depth and zone status.
Community Thermal Index	Australian BRUV synthesis + new mesophotic and rariophotic datasets via GlobalArchive	Extend Species Thermal Index collated by Stuart-Smith et al. (2017) - with additional species characteristic of deeper habitats in commonwealth waters; by depth and zone status. Build predictive national benchmark model for CTI metrics; by location, depth and zone status.

In addition, this survey has demonstrated the application of a novel panoramic drop-camera system and its use to rapidly ground truth the benthic composition of relatively large survey areas. This panoramic drop-camera is now being evaluated as a national standard for benthic composition surveys and tested further for broad-scale benthic habitat characterisation through upcoming NESP Marine and Coastal Hub projects in Research Plan 2 (www.nespmarinecoastal.edu.au/).

The two different scales used in the current survey were a product of COVID related interruptions to field work and the collection of detailed bathymetric data from the multibeam survey, however the larger scale of the broader study area led to the characterisation of a broader suite of natural values and ecosystem components both inside and outside the National Park Zone. For example, the broader study area, outside of the detailed bathymetry area, led to the inclusion of EPBC Act List of Threatened Fauna and IUCN Red List species and deep water species (e.g., Hapuka *Polyprion oxygeneios* on the shelf break, Figure 39) that would have otherwise not have been found if the survey had been limited to the spatial extent of detailed bathymetry as is typically the case in NESP Marine Biodiversity Hub surveys (Keesing et al. 2021; Carroll et al. 2021). Most of the detailed bathymetry survey was focused on the National Park Zone with only a small area of the Special Purpose Zone surveyed, meaning that any comparison of value metrics between zones using samples only from the detailed bathymetry area resulted in less certainty around estimates of metrics from within the Special Purpose Zone.

It should be acknowledged that the success of the broad scale survey to characterise ancient shorelines and associated benthic and fish assemblages has been in part due to the apparent reliability of the available national scale bathymetry (250 m resolution) in this particular location. The researchers involved in the latest survey have also observed examples around the country where the available national scale bathymetry is highly unreliable and misleading, including the Ningaloo Marine Park and Eastern Recherche Marine Park (Pers. Obs. T. Langlois). This suggests that the approach taken in the broad scale survey here will likely be most useful where the available national scale bathymetry is reliable.

Figure 39 Aggregation of Hapuka (*Polyprion oxygeneios*) on the shelf break in the broader study area. Hapuka aggregation over sponge gardens on the continental shelf break in the National Park Zone. Imagery taken from a drop-camera deployment in 201 m.

4.2 Recommendations for benchmarks and monitoring

A challenge for future monitoring of national networks of marine parks and their values, is to design surveys and benchmarks that will enable the status and trend of natural and socio-economic metrics to be robustly assessed relative to monitoring questions and provide national context. To understand the impact of management or environmental change within a park and between zones, it will be important for monitoring surveys to identify comparable reference sampling areas across zones of interest (e.g., control areas to evaluate change in a National Park Zone) and have substantial data collected before the implementation of zoning (Underwood 1995). However, due to the design and implementation legacy of marine parks, and their constituent zones, these conditions can rarely be achieved. Zones of interest frequently contain unique features that complicate the selection of reference sites (Denny, Willis, and Babcock 2004) and it is rarely possible to establish monitoring surveys to collect adequate data before the implementation of zoning regulations (Babcock et al. 2010; Goetze et al. 2021).

To evaluate the management effectiveness of national networks of marine parks and their values a complementary and alternative approach to relying on before/after control/impact comparisons would be to compare metrics from individual zones, reference areas, parks and networks to national or international benchmarks to provide context to the status of those values. This approach has recently been demonstrated by a global study of tropical reef shark populations, which has enabled countries and regions to be compared and identify management pathways that have successfully restored or ensured the sustainability of reef shark populations (MacNeil et al. 2020). This approach highlighted that Australia, for its direct top-down management of fishing and advanced governance conditions, was a management success story and global role model for approaches to sustain reef shark populations.

To establish national benchmarks for natural values and ecosystem components useful to evaluate the management impact of the Australian Marine Park network will require the synthesis and maintenance of national-scale data sets of the appropriate breadth and scope (e.g., depth extents) for metrics that can be compared across networks and relevant and robust for comparisons across bioregions. An example of a potential national synthesis dataset that has already been used to start creating such benchmarks is the Australian national BRUV synthesis (Harvey et al. 2021) maintained through GlobalArchive.org. This synthesis product has already produced a national model of the abundance distribution of body-size classes of target and non-target fishes (Bosch et al. 2021) and an evaluation of contributing factors to observed differences between no-take and fished reference areas for marine parks nationally (Goetze et al. 2021). This data product should be built upon and repurposed to create a predictive national model for fish metrics. Such a model could provide locale specific predicted benchmarks for a zone of a particular marine park, accounting for bioregion and depth variation, for a range of standardised condition categories (e.g., Good, Good with some concerns, Significant concern, Poor) to evaluate management success.

The existing Australian BRUV synthesis has a useful coverage of shallow (0-30 m) and mesophotic (30-70 m) habitats nationally, with some notable exceptions including the Great Barrier Reef Marine Park. The current synthesis contains stereo-BRUV data up to 2016, since this time there has been an increase in the number of stereo-BRUV surveys conducted in deeper waters, in part through investment by the NESP Hub and Parks Australia. By including these newer datasets into an updated national synthesis, it would be feasible to extend national benchmarks to include rariphotic depths (70-200 m) where important fish assemblages may occur within the Australian Marine Park network (Figure 15).

The current study within the South-west Corner Marine Park has used metrics developed during the Australian BRUV synthesis [i.e. Figure 31 & Figure 37, the abundance of target species greater than legal size, (Bosch et al. 2021)]. Establishing a benchmark with condition categories (i.e., Good, Good with some concerns, Significant concern, Poor) could be investigated through an extension of the existing Australian national BRUV synthesis, including additional datasets. Such an extension could be used to develop locale and depth range (e.g. for mesophotic or rariphotic habitats) specific benchmark category predictions for a variety of metrics, including extending the Species and Community Thermal Index for shallow reefs proposed by Stuart-Smith et al. (2017) with the additional species characteristic of deeper habitats across commonwealth waters and the Australian Marine Parks (Table 16).

Similarly, national benchmarks for metrics of benthic habitat natural values and ecosystem components could be created through a similar national syntheses enabled by recent advances in benthic image annotation management, such as the IMOS Understanding Marine Imagery (UMI) facility (Table 17). This work could also be built upon recent synthesis work on seagrass and macroalgal extent around Australia (e.g. NESP Marine and Coastal Hub Project 1.13 Synthesising three decades of seagrass spatial data from Torres Strait and Gulf of Carpentaria).

Table 17 Recommendations on data products to inform benchmarks for metrics of benthic natural values and ecosystem components for the Australian Marine Parks and national reporting.

Metric	Data product and portal to be targeted	Recommendations
Seagrass extent and condition	IMOS AUV + Australian BRUV synthesis (habitat data) + new datasets via UMI	Build predictive national benchmark model for benthic cover; by location, depth and zone status.
Macroalgae extent and condition (e.g. kelp)	IMOS AUV + Australian BRUV synthesis (habitat data) + new datasets via UMI	Build predictive national benchmark model for benthic cover; by location, depth and zone status.
Sessile invertebrate extent and condition	IMOS AUV + Australian BRUV synthesis (habitat data) + new datasets via UMI	Build predictive national benchmark model for benthic cover; by location, depth and zone status.

4.3 Guidance for future studies and surveys

Wadandi, People of the Sea, are the Custodians for the far southwest region of this continent. With obligations to protect, manage and monitor their Sea Country, a partnership was developed between the Wadandi-led project team, Parks Australia and the NESP

Marine Biodiversity Hub and Marine and Coastal Hub survey team to use mapped cultural values (Davies et al. 2022) to guide biodiversity discovery surveys in the established Australian Marine Parks.

The partnership used cultural maps and knowledge to guide the discovery of remarkable biodiversity across submerged ancient coastline features that document the dynamic history of the region, indicate how these features shape the biodiversity, and provide a benchmark for managing the cultural and both natural values and ecosystem components of the marine parks into the future.

4.3.1 Submerged wetlands

The Wadandi-led team recognise how these surveys have shown us the submerged wetlands that would have existed along and behind the ancient shorelines. These wetlands would have been where the old people camped, and freshwater springs would have been located within them. Future surveys should visit these areas and identify the freshwater springs so they can be better understood and protected.

4.3.2 Following the animal prints

Outside of the current survey area, the submerged ancient softlands and wetlands have shown us animal prints. The Wadandi project team proposes that future surveys will follow these animal prints to find the old country that is now submerged in the Australian Marine Parks.

4.3.3 Bolghinup

Bolghinup (Black Rock) lies on the Ngingaraa Kaala (Lava flow). Bolghinup means the shaking or rumbling of the land as it moved and rose. After the shaking, this is where the people went out from and is the source of different languages. There is now a National Park Zone offshore from Bolghinup in the South-west Corner Marine Park. This area is shallow and will hold submerged coastal areas that would have been frequently visited by our ancestors and should be a place for future surveys to be led in collaboration with the Wadandi project team.

5. Supplementary Materials

5.1 Detailed survey design and sampling methods

5.1.1 Detailed survey design

Sampling designs for stereo-BRUV and drop camera deployments were determined with a spatially balanced design using the ‘MBHdesign’ package in R software (Foster 2021). Spatially balanced designs allow for the use of unequal inclusion probabilities, which increase the efficiency of designs by increasing sampling effort for environmental conditions that are likely to have higher variance (Foster 2021).

Survey designs for the National Park Zone (NPZ) were based on slope and depth, since areas of high slope often reflect regions with reef structure with abundant fish and benthic assemblages, with depth known to be a driver of changes to fish and benthic assemblages. Slope for each area was calculated and then used to divide the area into four categories based on the 0-10%, 10-50%, 50-95% and 95-100% quantiles of slope values. The resulting slope categories were used to calculate inclusion probabilities for each zone based on the number of stereo-BRUVs and drop camera deployments planned. Sampling in the South-west Corner NPZ and adjacent areas in the Special Purpose Zone (SPZ) was conducted during three different sampling periods, separated into four ‘Campaign IDs’ (Table 9).

5.1.2 Bathymetry

Broad bathymetry was downloaded from Geoscience Australia’s publicly available dataset, the ‘Australia Bathymetry and Topography Grid (2009)’. Detailed bathymetry and acoustic backscatter data were acquired within the National Park Zone and Special Purpose Zone using a Kongsberg EM2040C multibeam echo-sounder (MBES). The system was configured to operate using a single sonar transducer mounted in the moon-pool of FV Santosha and operating in dual-ping mode at vessel speeds of 7-9 knots (Figure 40). Vessel navigation and data acquisition used the Kongsberg Seabed Information System (SIS) software, with vessel motion data collected using an Applanix POS MV motion referencing system (Figure 40). Survey lines for seabed mapping were run in an east-west direction and were designed to provide 100 percent bathymetry and backscatter coverage of the survey area, with a minimum of 10 percent overlap between survey lines. To improve survey efficiency in deeper water and on days of high winds and seas, some survey lines were oriented north-south. The total area mapped for the study area covered approximately 330 km^2 in water depths ranging between 34 m and 130 m (Figure 41).

Figure 40 Multibeam sonar acquisition workstation on board FV Santosha.

Data processing of bathymetry data was completed using the Caris HIPS & SIPS suite v.11.3.8. Raw sounding data was corrected for ship motion (pitch, roll and heave), navigation and sound velocity. The data was reduced to the ellipsoid using real time ellipsoid heights. True heave and real time RMS (root mean square error) values were imported from Applanix 000 files and used in the final computed solution and to calculate Total Propagated Uncertainty for each individual sounding. Bathymetry surfaces were gridded using the CUBE algorithm at a spatial (horizontal) resolution of 4 m. Outliers were removed using a combination and surface filters and visual outlier removal. Shifting the ellipsoid referenced soundings to MSL was done by subtracting the earth gravitational model (EGM2008).

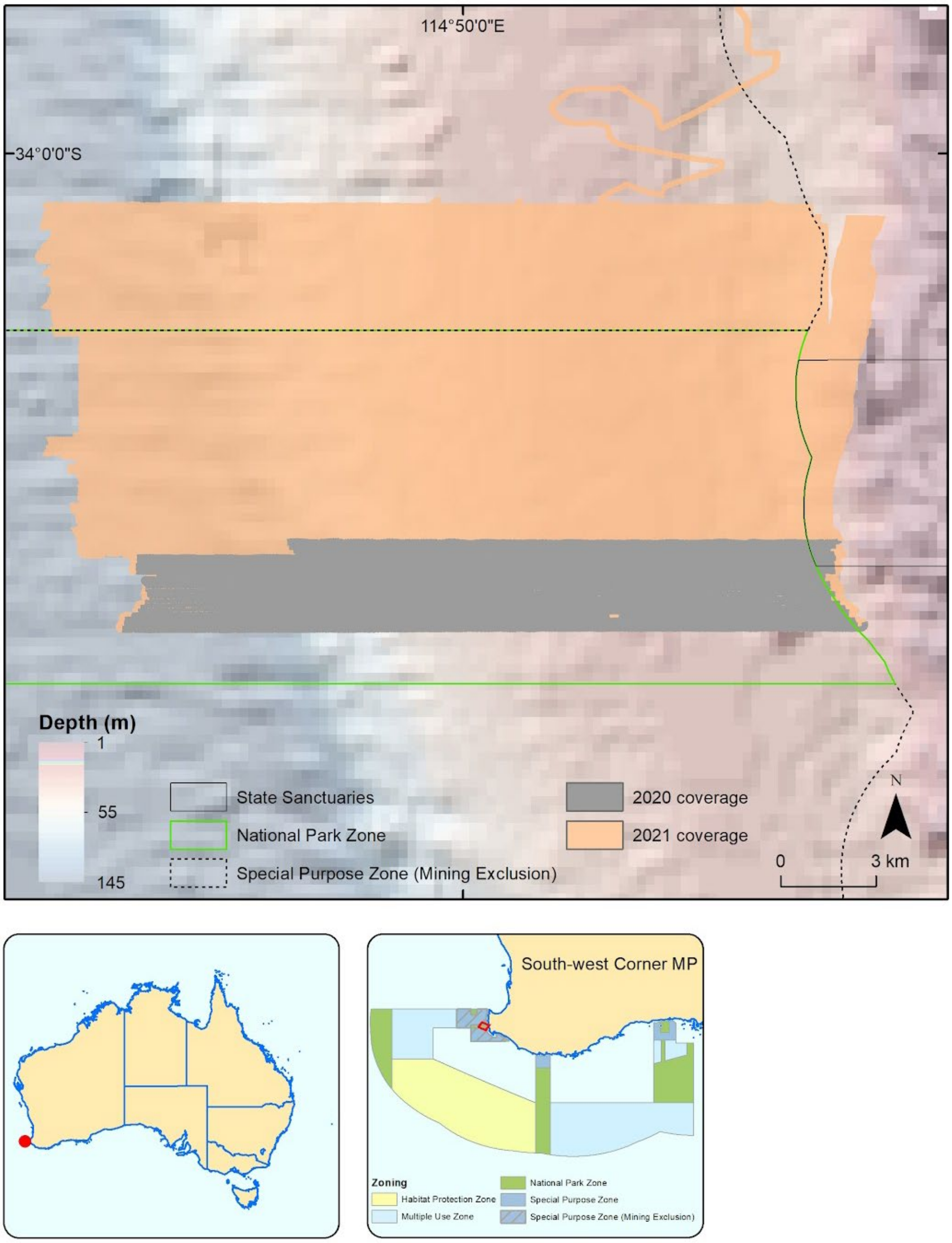


Figure 41 Extent of the multibeam survey. Data collected during 2020 for Stage 1 (grey) and 2021 for Stage 4 (orange).

5.1.3 Seabed morphology mapping

We applied a semi-automatic method to map seabed morphological features, in this case the bathymetric high features according to Dove et al (2020), from the multibeam bathymetry data acquired within the National Park Zone and Special Purpose Zone of the AMP. The semi-automatic method involves three steps. First, we mapped the boundaries of individual seabed morphological features using a GIS tool based on a Topographic Position Index (TPI) approach (Weiss 2001). Here we used two TPI scales (100 and 25 cells in the bathymetry grid) to capture broad-scale bathymetric high features (e.g., banks) and fine-scale bathymetric high features (e.g, ridges, hummocks, etc), respectively. The broad and fine scales features were then merged to form the final map of bathymetric high features. In the second step, we calculated a range of attributes for each bathymetric high feature. These attributes are broadly divided into three groups: those based on the planform shape of the feature, those based on the topography of the feature and those based on the cross-sectional profile of the feature. Finally, we used a subset of these attributes to classify and calculate statistics for each seabed bathymetric high feature into one of the morphological feature types following the definitions of Dove et al (2020). For this study, these features included banks, ridges, mounds, hummocks, cones and planes.

5.1.4 Benthic and demersal assemblage observations

Stereo-BRUVs

Observations of demersal fish communities within the survey area were undertaken using stereo-BRUV units (Figure 42). Each stereo-BRUV comprises a pair of either Canon Legria HF-G25 video cameras, set to a focus point of three metres (to prevent them from focusing on individual fish) and set to record at 1080p resolution at a rate of 25 frames per second, GoPro Hero 7 Black cameras, set at 1080p resolution and a wide field of view, at a rate of 30 frames per second, or Sony FDR-X3000 cameras, set at resolution of 1080p and a medium field of view, at a rate of 60 frames per second. The cameras are separated by 650 mm and each inwardly converged at 7º to provide an overlapping field of view and allow for the accurate identification and stereo-photogrammetric measurement of individual fish from 0.5 to 8 m in front of the stereo-BRUVs. To maximise calibration stability, the cameras and housings were mounted on a base bar to eliminate camera movement within the housing and between the cameras. The stereo-video systems were calibrated in a pool to synchronise the cameras prior to and post deployment in the field. In addition to the pair of stereo cameras, a single rearward facing GoPro Hero 7 Black habitat camera was mounted facing the opposing direction to the stereo pair of cameras. This camera was set to record still photographs at 1 minute intervals at a resolution of 1080p. Further information on the design and calibration of these systems can be found in Harvey and Shortis (1995).

Figure 42 stereo-BRUV sampling equipment. Assembly on deck prior to deployment.

Each stereo-BRUV was baited with approximately ~1 kg of crushed pilchards (*Sardinops spp.)* held within a plastic-coated wire mesh basket, attached to a stainless steel and conduit bait arm and positioned 1.2 m in front of the cameras (Figure 42). Each system was deployed for at least 60 minutes on the seafloor. Neighbouring deployments were separated by at least 400 m to reduce the likelihood of fish swimming between neighbouring stereo-BRUV deployments. Forward and rearward white LED lights were also attached to the base bar to illuminate the field of view in front of the forward-facing stereo cameras and rearward facing habitat camera.

60 minutes of the left camera of each video was analysed using EventMeasure™ software (SeaGIS 2011). During analysis all fish were identified to their lowest possible taxonomic level, with a number of species grouped to higher taxonomic rankings due to difficulties in identification in video footage. The maximum number of individuals of a single species in one frame (MaxN) was recorded, and the fork length of all distinct individuals were also measured at this point. Habitat composition was obtained from video footage at the time the stereo-BRUVs landed on the seabed and analysed using TransectMeasure™ (SeaGIS 2011). Annotation of each image consisted of 20 randomly positioned points per image (Figure 43), using a modified version of the CATAMI habitat classification scheme (Althaus et al. 2015). Given the propensity for the top half of images to contain open water or biota too far away to confidently classify, points were only positioned in the lower 50% of each image (Figure 43). Relief complexity was visually estimated on a scale of 0 - 5 using a 5 x 4 grid over the entirety of the image (Wilson, Graham, and Polunin 2007).

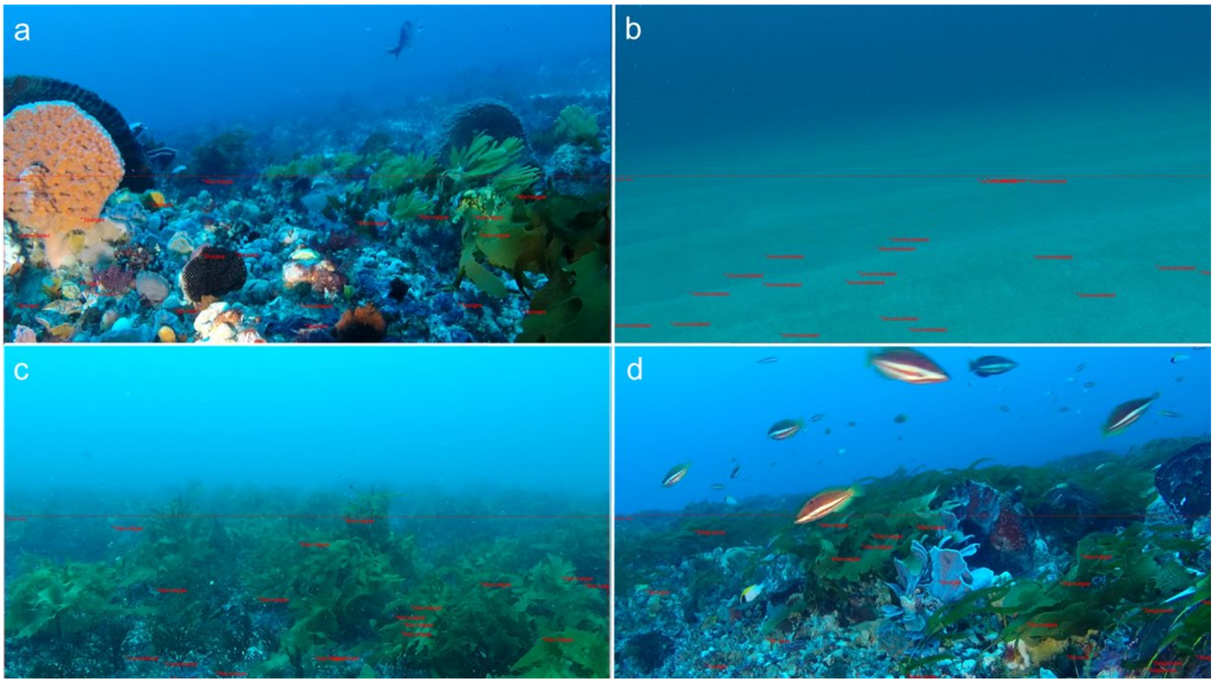


Figure 43 Example habitat images with assigned annotation points. (a) Sponges, macroalgae and bryozoans (b) unconsolidated/sand (c) macroalgae and (d) macroalgae, sponges and seagrasses.

Drop camera

Detailed observations of benthic habitat within the survey area were undertaken using a panoramic drop camera system (Figure 44). In addition to benthic habitat annotation, observations of demersal fish communities were taken using the drop camera system. This system consisted of synchronised pairs of either Sony FDR-X3000 or Go Hero 3+ Silver camera units in waterproof housings facing in four directions, to give a more complete picture of habitat and fishes at a given point and provide a 270^{o} field of view. Each pair of cameras was vertically separated by 500 mm with the top camera tilted downward at 8$_{o}$. Habitat images were taken at the same timecode for each camera to ensure no overlap of images. The system also had a downwards facing camera to collect fine-scale downwards facing imagery, and an LED light in a waterproof housing was positioned to provide lighting for all 5 directions of sampling.

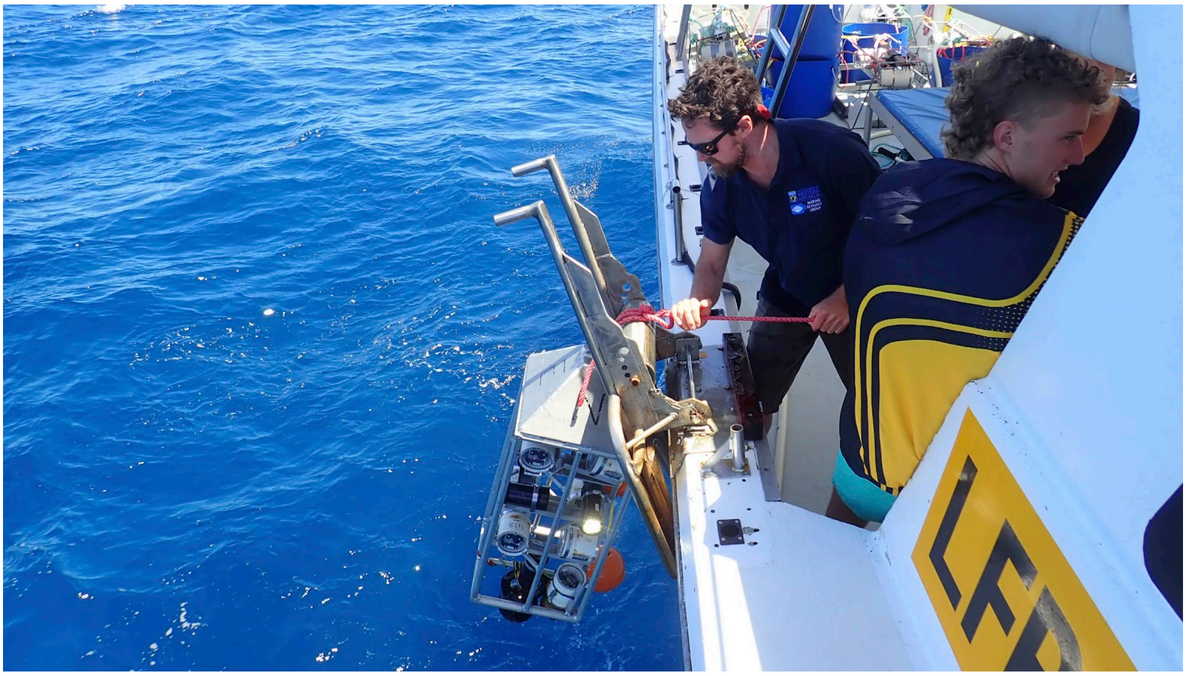


Figure 44 Drop camera system. Tim Langlois deploying a drop camera system from FV Santosha.

The top four horizontally facing videos were analysed using EventMeasure™ software and spliced together into a single composite image using VidComp™ software (SeaGIS 2011). Each deployment was analysed for a period of three minutes on the seafloor per drop. During analysis all fish were identified to their lowest possible taxonomic level. The maximum number of individuals of a single species in one frame (MaxN) was recorded, and the fork length of all distinct individuals were also measured at this point. For each deployment, the top four horizontally facing camera images were analysed using Transect Measure™ software (SeaGIS 2011) for the point composition of benthic habitat. Annotation of each image consisted of 20 randomly positioned points per image, using a modified version of the CATAMI habitat classification scheme (Althaus et al. 2015). Given the propensity for the top half of images to contain open water or biota too far away to confidently classify, points were only positioned in the lower 50% of each image (Figure 43). Relief complexity was visually estimated on a scale of 0 - 5 using a 5 x 4 grid over the entirety of the image (Wilson, Graham, and Polunin 2007). Downwards facing imagery from the drop camera was analysed using the same habitat classification scheme, however using 25 randomly positioned points over the entire extent of the image. Relief complexity was not analysed for the downwards facing imagery.

5.1.5 Autonomous Underwater Vehicle transections

A benthic survey of the National Park Zone and Special Purpose zone was conducted using the IMOS autonomous underwater vehicle (AUV) ‘Nimbus’ (Figure 45). The AUV is equipped with a calibrated pair of downward looking 9 MP machine cameras illuminated with synchronised strobes. The transect path and associated imagery is precisely georeferenced using an Ultra Short Baseline Acoustic positioning system (USBL) and post-processed detailed in the NESP AUV field manual (Jacquomo Monk et al. 2020).

Each AUV deployment consisted of a broad grid of three 1km parallel transects separated by 250 m (Figure 46). The location of the grids was selected to survey geomorphological features identified from the multibeam bathymetry data, and areas with mixed benthic communities of macroalgae, seagrass and sponges that were identified through previous drop-camera surveys (Stage 3). A total of 12 grids in the NPZ and three in the SPZ were surveyed (Figure 46).

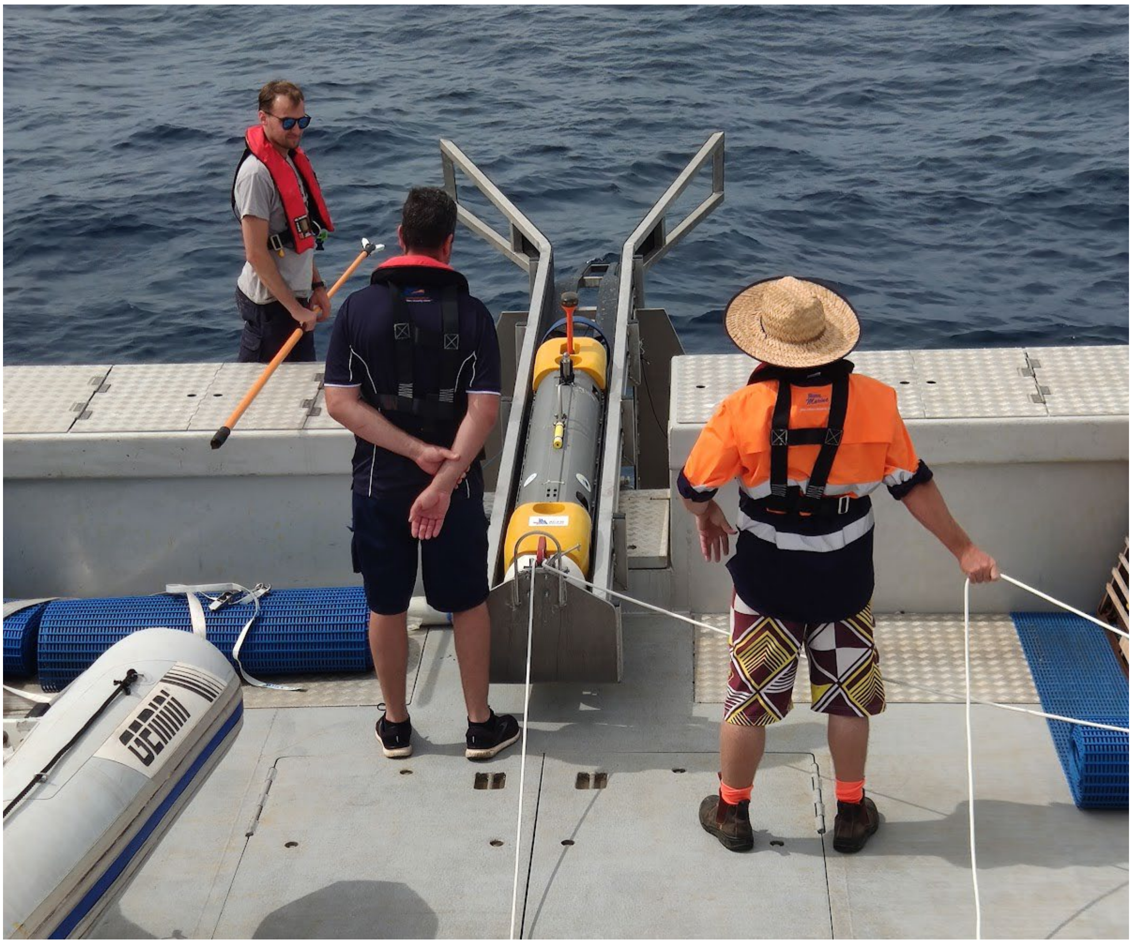
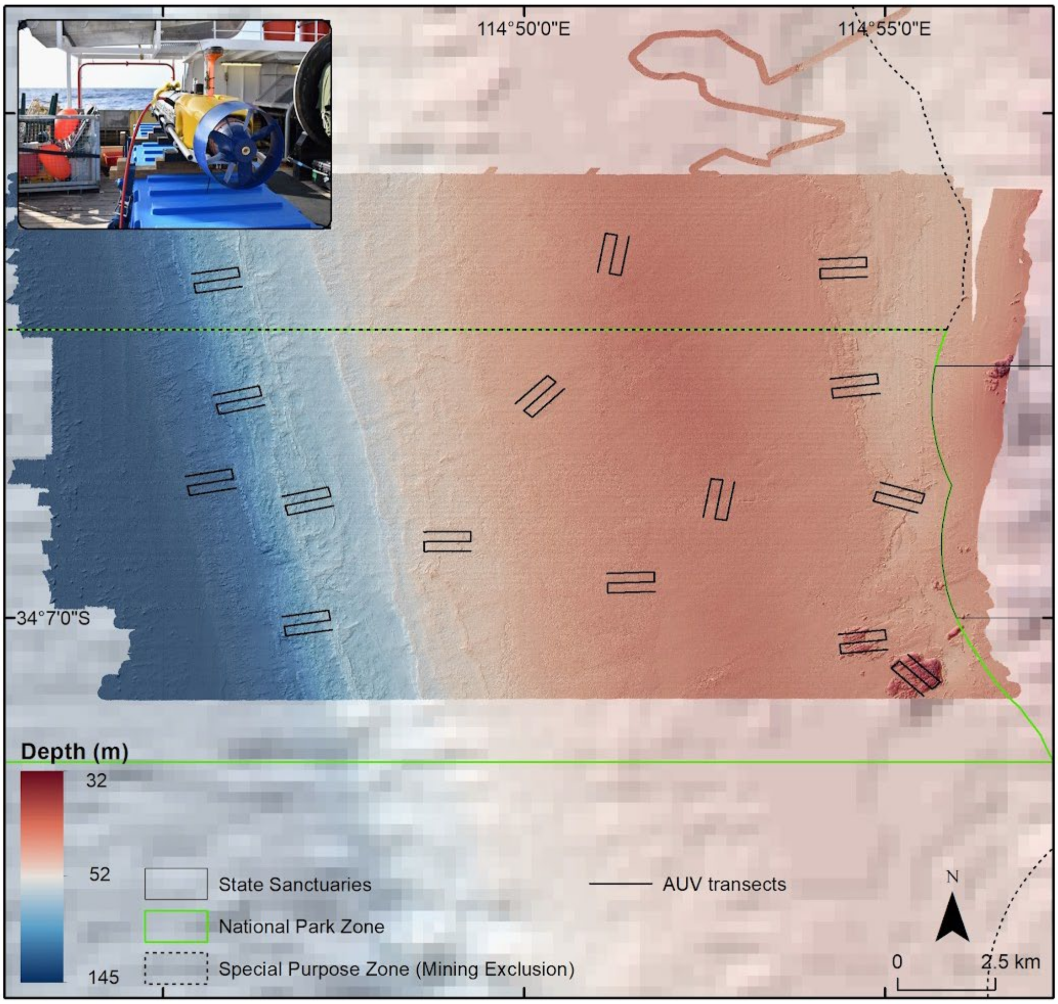
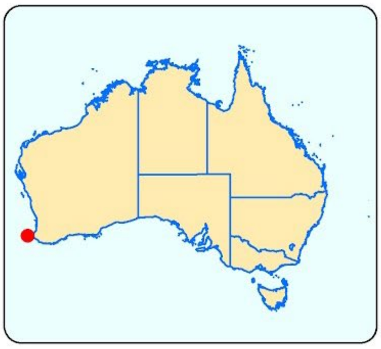


Figure 45 IMOS Autonomous Underwater Vehicle ‘Nimbus’. AUV mounted on the launch and recovery system on the vessel.





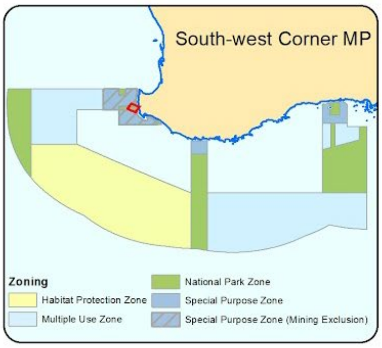


Figure 46 Location of the 15 Autonomous Underwater Vehicle (AUV) transects. Sites were chosen to represent features identified by stereo-BRUV and drop camera samples during earlier sampling.

5.1.6 Statistical analysis

Relief modelling and prediction

Local relief can be an influential driver of fish communities. To account for the influence of relief over the study area, observed relief scores were modelled and predicted independently from benthic habitat. Data were collated and a range of variables calculated from the bathymetry (slope, aspect, roughness, TPI, detrended bathymetry). A full-subsets generalised additive modelling approach was used to select the most parsimonious set of covariates based on the Akaike Information Criteria corrected for small sample size (AICc, (Akaike 1973)), using the 'fssgam' package in R (Fisher et al. 2018). The final model was then fit including an additional component that used stochastic partial differential equations to account for the spatial effect of the sampling regime and underlying autocorrelation in relief, estimated using the Integrated Nested Laplace Approximation approach with the 'INLA' package in R (Lindgren and Rue 2015). The overall predictive performance of this model was evaluated using k-fold cross-validation (k = 5) and the Bayesian r-squared equivalent. Predicting relief across the study areas enabled us to account for its relationship with fish species distribution in later analysis.

Habitat distribution modelling

To map habitats across the National Park Zones (NPZ) and assess the influence of habitat on the fish community, we modelled the spatial distribution of four key classes of habitat: macroalgae, bare rock, sand and sessile invertebrates. Habitat observations were combined with the suite of bathymetry-derived covariates at each sampling location as per the analysis of relief in the previous section. The most parsimonious model that explained the distribution of each key habitat was selected using the full-subset generalised additive modelling approach using the 'fssgam' package in R (Fisher et al. 2018), evaluated using the Akaike Information Criteria (AIC). The models used the binomial family with logit link function. The models were then used to predict each species occurrence (p) across the study areas, within a 10km of sampling points. The map of dominant habitats was generated by selecting the habitat of highest likelihood of occurrence within each cell (cell size was approximately 250 x 250m for the full sample area and 4 x 4m for the multibeam area, as determined by the resolution of available bathymetry).

Fish assemblage abundance distribution modelling

The data were initially summarised, with all predictor variables being visually inspected to determine if any data transformations were necessary. Recreationally and commercially targeted species were determined using data extracted from FishBase (Froese and Pauly 2019). The correlations between predictor variables were assessed, in order to exclude highly correlated variables (>0.90). Predictor and response variables with more than 90% zeros were also excluded. Generalised Additive Models (GAMs) with a full subset model selection were used to determine if any of the included predictor variables best explained the variance in the abundance for the chosen predictors of interest (Fisher et al. 2018). In order to avoid problems with overfitting and collinearity, variables with correlations greater than 0.28 were excluded from individual models (Graham 2003). All data were modelled using a tweedie distribution, with the number of knots (*k*) and the number of predictor variables included in GAMs limited to three. Model selection was based on Akaike's Information Criterion (Akaike 1973) adjusted for small sample sizes (AICc) (Hurvich and Tsai 1989), with the most parsimonious or 'top' model being chosen as the model with the least terms within two AICc units of the model with the lowest AICc. The variable importance scores were calculated from the sum of the AICc weights of each model that each variable occurred within (Burnham and Anderson 2003), and these scores were then plotted to visualise the relative importance of all predictor variables across the various responses. Spatial predictions were then made for each response metric based on the relationships with covariates established in the top model.

5.2 Detailed results

5.2.1 Bathymetry and relief

Broader study area

The bathymetry and derived metrics provided proxies for the geomorphic information summarised in Section 3.1.2. The key reef features of interest are visibly revealed in the bathymetry, roughness, and detrended bathymetry layers (Figure 4). The modelling and prediction of relief was possible using these three variables, with an acceptable fit (r = 0.646) obtained using the modelling approach (Figure 47). Relief was positively associated with roughness, negatively associated with depth, and was generally negatively associated with detrended bathymetry though this effect was unclear. The resulting predictions showed higher relief was associated with the shallowest areas of the survey and declined rapidly beyond approximately 90 m depth. An estimate of the spatial random effect is provided (Figure 48) to demonstrate how autocorrelation varied among sampling clusters.

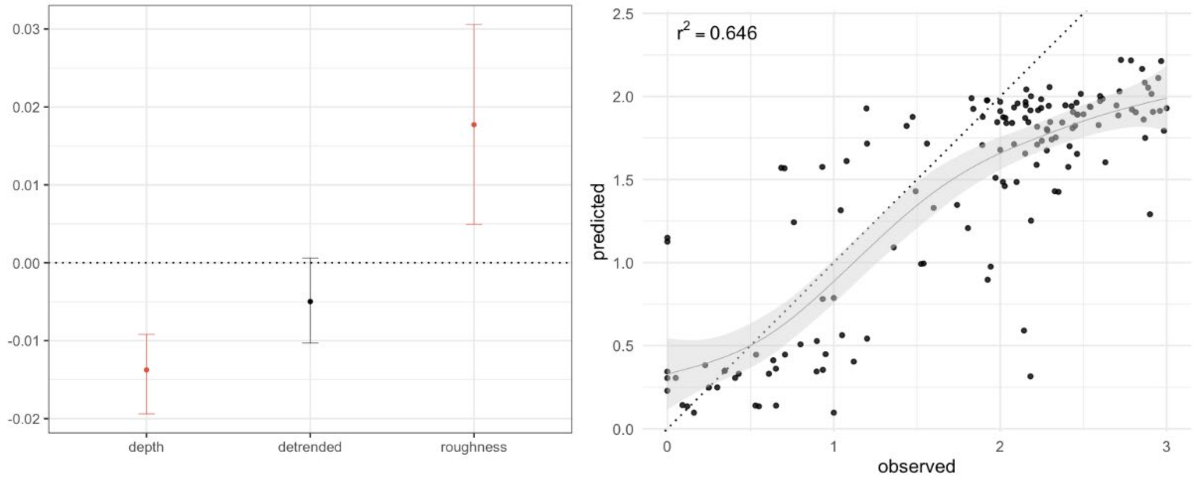


Figure 47 Relief model diagnostics for entire project area. Left: model estimates and credible intervals (95 % c.i.), Right: prediction accuracy and Bayesian r² equivalent

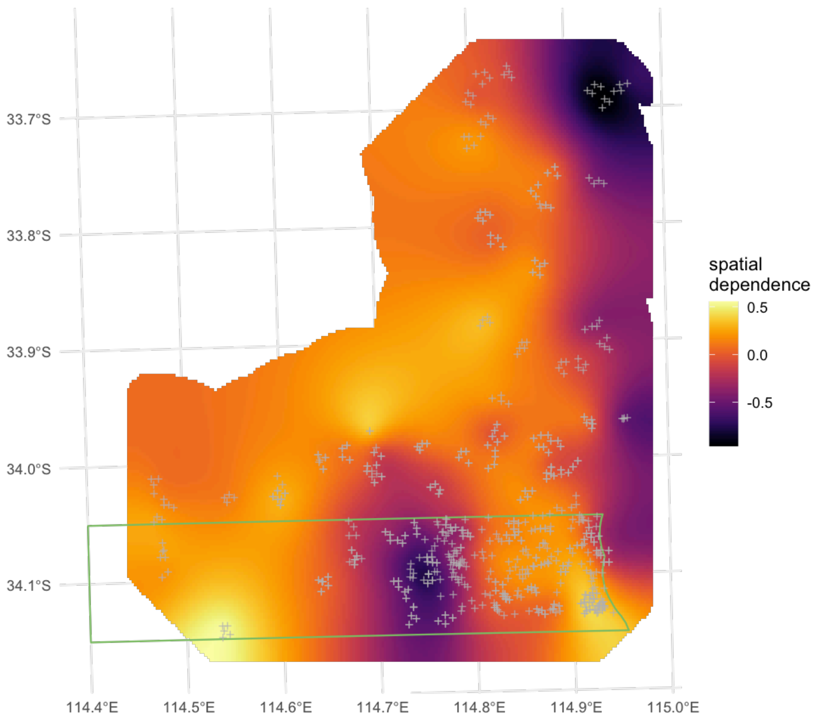


Figure 48 Spatial autocorrelation in relief.

Detailed bathymetry area

As with the broad coarse bathymetric dataset, the derived metrics performed well for the multibeam area. The geomorphic information is summarised in Section 3.1.2. When compared with the coarse bathymetry, the multibeam-derived metrics display much more detail and as a result are more difficult to interpret visually in some cases (e.g. Roughness and TPI). This effect represents the scale-dependency of these metrics - reducing the spatial resolution will also reduce the scale of the derived metrics. The key reef features of interest are most visible in the detrended bathymetry layers (Figure 49). Predicting relief was less reliable (r = 0.405) using the multibeam dataset than for the broad bathymetry (Figure 50). Relief was negatively associated with depth, positively associated with detrended bathymetry, and had no clear relationship to roughness (Figure 51).

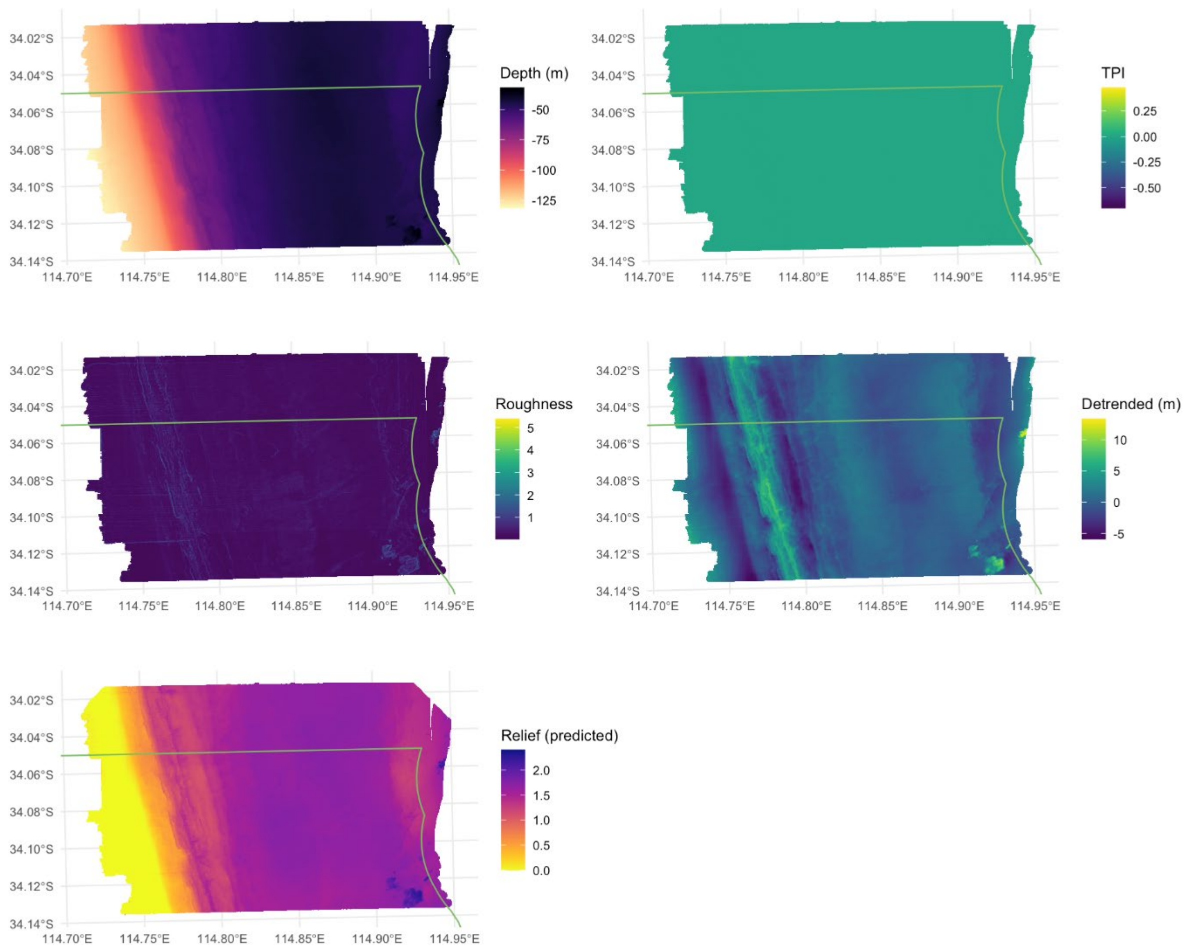


Figure 49 Bathymetry derived metrics and predicted relief for across with multibeam area.

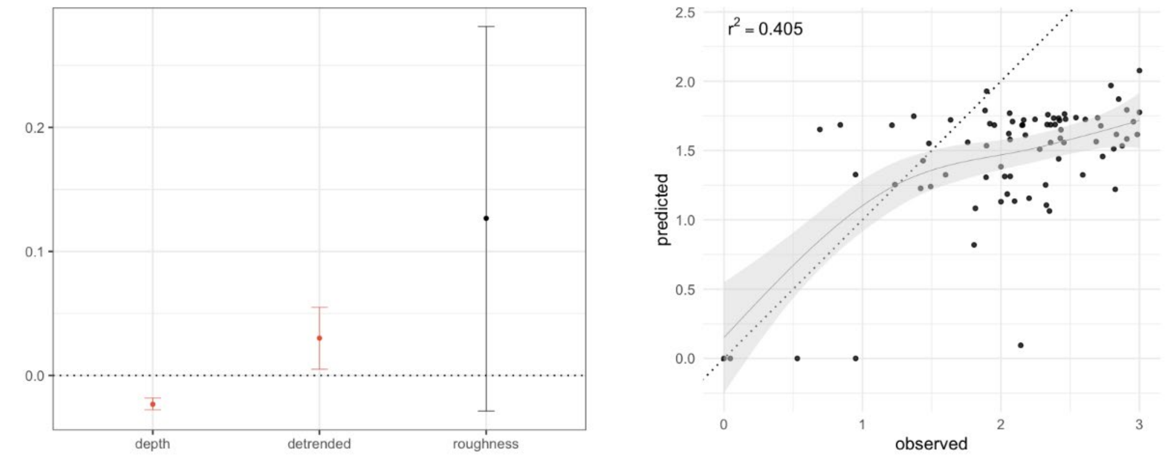


Figure 50 Relief model diagnostics for the area with multibeam data. Left: model estimates and credible intervals (95 % c.i.), Right: prediction accuracy and Bayesian r^2 equivalent

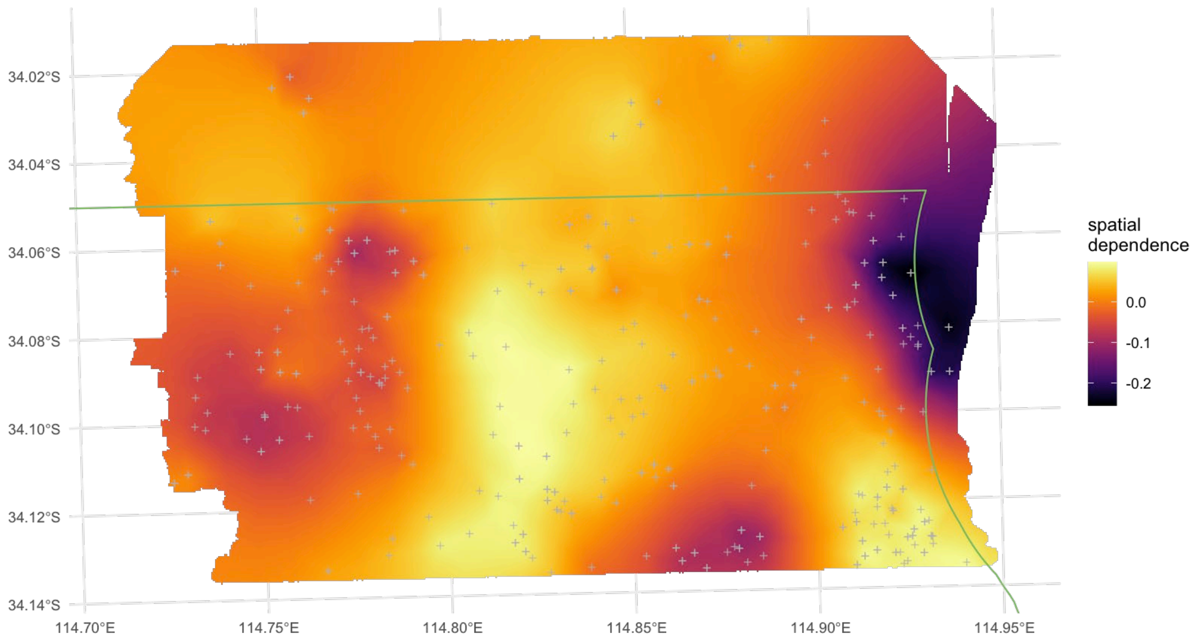


Figure 51 Spatial autocorrelation in relief across the multibeam area.

5.2.2 Habitat

Broader study area

Table 18 Habitat model selection results. Top generalised additive models (GAMs) for predicting the probability of occurrence of key habitats from full subset analyses. Differences between the lowest reported corrected Akaike Information Criterion (ΔAICc), AICc weight (ωAICc), variance explained (R^2) and effective degrees of freedom (EDF) are reported for model comparison. Model selection was based on the most parsimonious model (fewest variables - shown in bold) within two units of the lowest AICc. The predictor variables included are; depth, roughness, Topographic Position Index (tpi) and detrended bathymetry (detrended).

Response	Model	Δ AICc	ω AICc	R^2	EDF
Biogenic reef	**depth+detrended+ roughness**	**0**	**1**	**0.25685**	**12.32**
Consolidated (rock)	**depth+detrended+ roughness**	**0**	**1**	**0.27903**	**12.88**
Invertebrate complex	**depth+detrended+tpi**	**0**	**0.56**	**0.21144**	**12.73**
	depth+detrended+ roughness	0.482	0.44	0.21087	10.57
Macroalgae	**depth+detrended+tpi**	**0**	**1**	**0.39868**	**11.95**
Seagrasses	**depth+detrended+tpi**	**0**	**0.62**	**0.09874**	**11.14**
	depth+detrended+ roughness	0.976	0.38	0.08956	12.49
Sponges	**depth+detrended+ roughness**	**0**	**1**	**0.19089**	**12.06**
Unconsolidated (sand)	**depth+detrended+ roughness**	**0**	**1**	**0.61221**	**12.91**

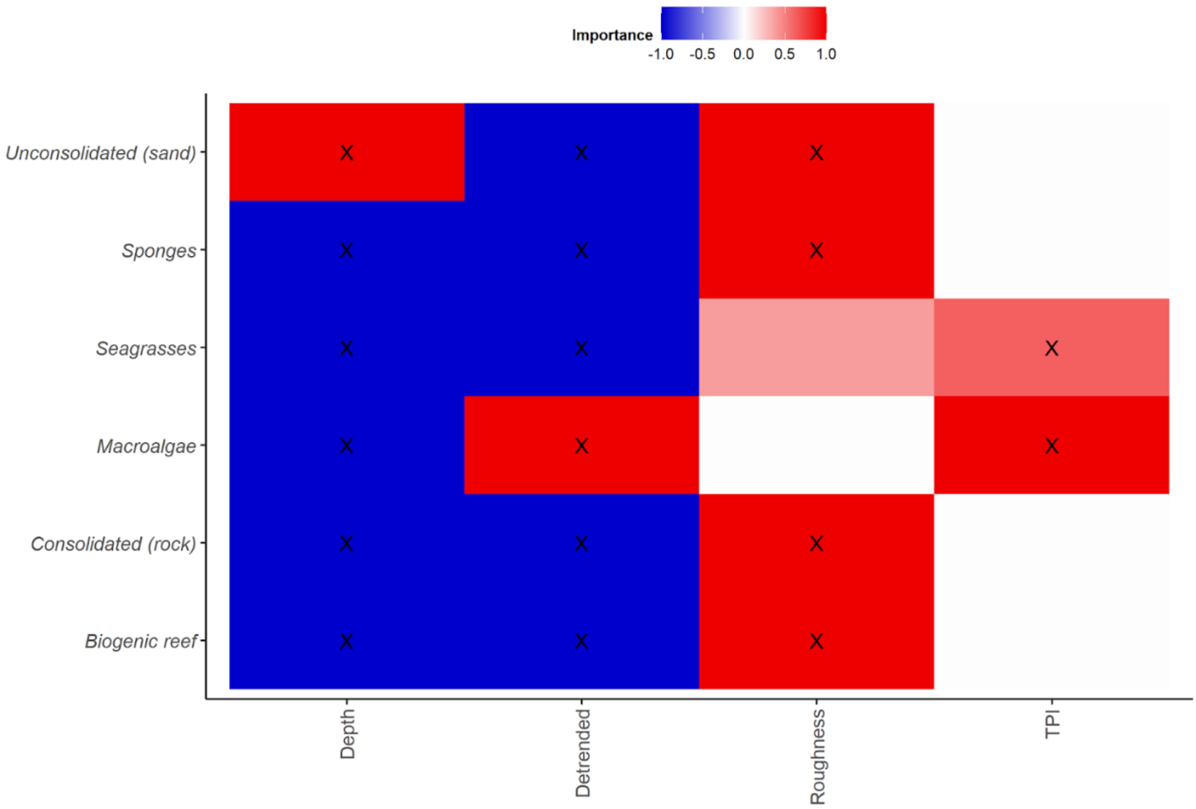


Figure 52 Variable importance scores for predicting the probability of occurrence of key habitats. Response variables included in the most parsimonious top model are indicated (X), with the colour gradient representing positive (red), zero (white) and negative (blue) relationships.

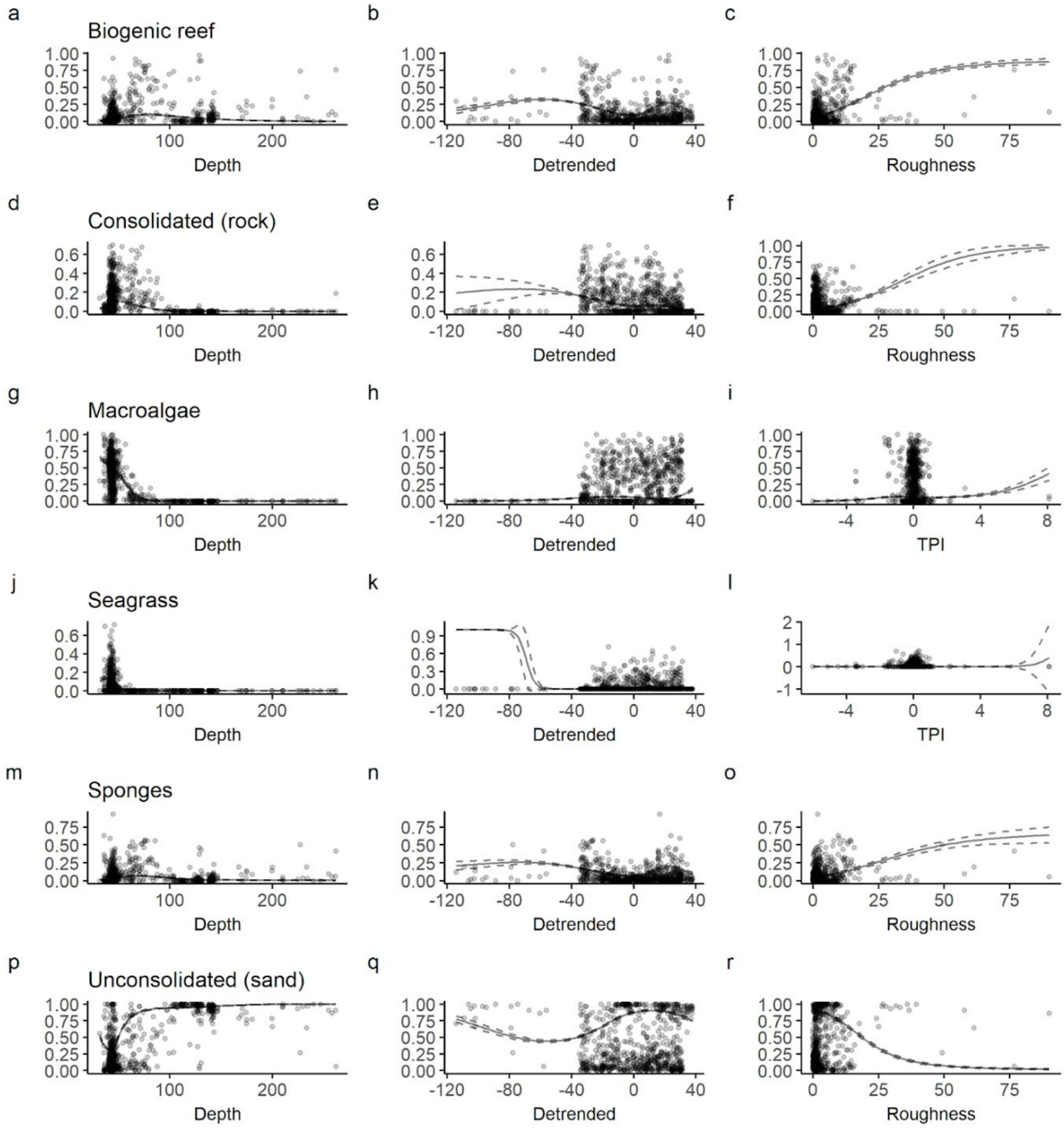


Figure 53 Plots of the most parsimonious model found to predict the probability of occurrence key habitat types. Individual panes display the predicted relationships between model covariates and consolidated substrate (rock - a-d), unconsolidated substrate (sand - e-h), invertebrate reef (i-l) and macroalgae/coral reef (m-o) occurrence. Solid lines represent predicted Generalized Additive Model (GAM) fits with other variables held constant at their mean value. Dashed lines represent upper and lower standard error bounds around the prediction, and points represent the observed data. The predictor variables included are; depth, roughness, Topographic Position Index (tpi) and detrended bathymetry (detrended).

Detailed bathymetry area

Table 19 Habitat model selection results. Top generalised additive models (GAMs) for predicting the probability of occurrence of key habitats from full subset analyses. Differences between the lowest reported corrected Akaike Information Criterion (ΔAICc), AICc weight (ωAICc), variance explained (R^2) and effective degrees of freedom (EDF) are reported for model comparison. Model selection was based on the most parsimonious model (fewest variables - shown in bold) within two units of the lowest AICc. The predictor variables included are depth, roughness, Topographic Position Index (tpi) and detrended bathymetry (detrended).

Response	Model	Δ AICc	ω AICc	R^2	EDF
Biogenic reef	**depth+roughness+tpi**	**0**	**1**	**0.35409**	**12.22**
Consolidated (rock)	**depth+detrended+ roughness**	**0**	**0.998**	**0.16342**	**12.13**
Macroalgae	**depth+detrended+tpi**	**0**	**1**	**0.42287**	**12.14**
Seagrasses	**depth+detrended+ roughness**	**0**	**1**	**0.09316**	**11.04**
Sponges	**depth+roughness+tpi**	**0**	**1**	**0.21942**	**11.43**
Unconsolidated (sand)	**depth+detrended+ roughness**	**0**	**1**	**0.52942**	**12.88**

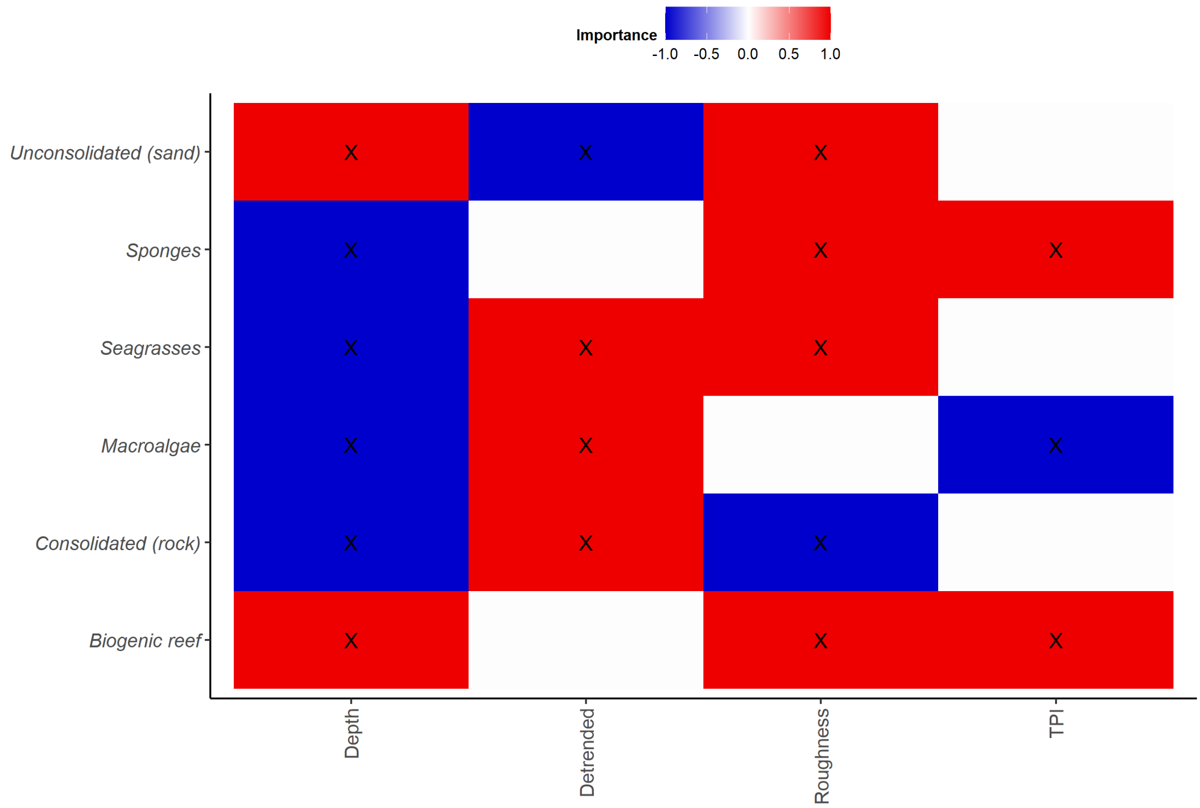


Figure 54 Plots of the most parsimonious model found to predict the probability of occurrence key habitat types. Individual panes display the predicted relationships between model covariates and consolidated substrate (rock - a-d), unconsolidated substrate (sand - e-h), invertebrate reef (i-l) and macroalgae/coral reef (m-o) occurrence. Solid lines represent predicted Generalized Additive Model (GAM) fits with other variables held constant at their mean value. Dashed lines represent upper and lower standard error bounds around the prediction, and points represent the observed data. The predictor variables included are; depth, roughness, Topographic Position Index (tpi) and detrended bathymetry (detrended).

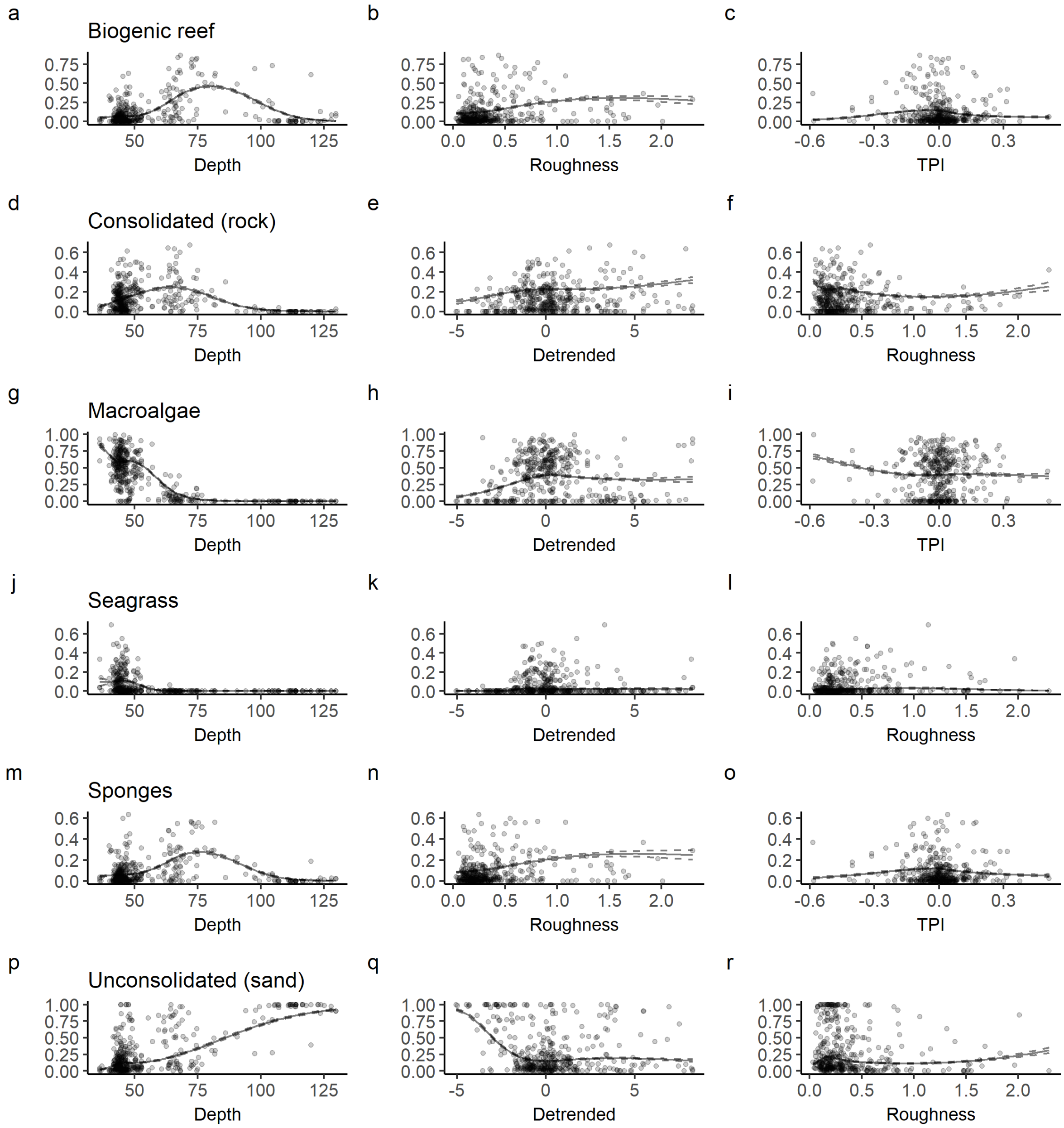


Figure 55 Variable importance scores for predicting the probability of occurrence of key habitats. Response variables included in the most parsimonious top model are indicated (X), with the colour gradient representing positive (red), zero (white) and negative (blue) relationships.

5.2.3 Fish assemblage

Broader study area

Table 20 Fish model selection results for the broader study area. Top generalised additive models (GAMs) for predicting the abundance distribution of metrics and species of interest from full subset analyses. Differences between the lowest reported corrected Akaike Information Criterion (ΔAICc), AICc weight (ωAICc), variance explained (R^2) and effective degrees of freedom (EDF) are reported for model comparison. Model selection was based on the most parsimonious model (fewest variables - shown in bold) within two units of the lowest AICc. The predictor variables included are; depth, mean relief, percentage cover of reef (broad.reef), percentage cover of macroalgae (broad.macroalgae), Topographic Position Index (tpi), roughness, detrended bathymetry (detrended) and fishing status.

Response	Model	Δ AICc	ω AICc	R^2	EDF
Total abundance	**mean.relief**	**0**	**0.473**	**0.34715**	**195.49**
	mean.relief+status	1.093	0.274	0.34356	197.03
Species richness	**broad.macroalgae+detrended+ status**	**0**	**1**	**0.71009**	**62.75**
Greater than legal size	**mean.relief+roughness+tpi**	**0**	**0.819**	**0.44201**	**43.34**
Smaller than legal size	**mean.relief+roughness**	**0**	**0.522**	**0.25905**	**34.76**

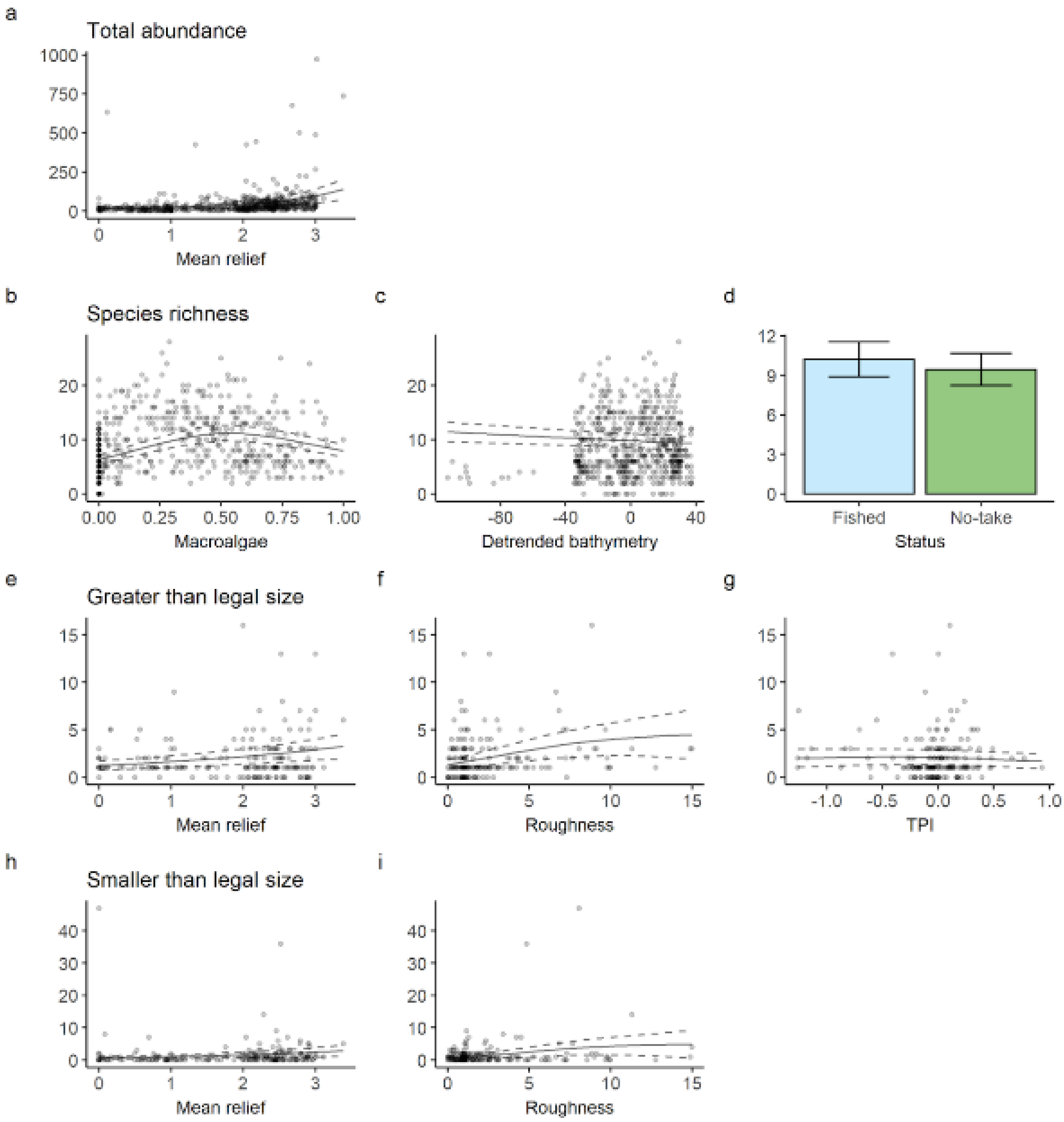


Figure 56 Plots of the most parsimonious model found to predict the probability of occurrence of key fish groups. Individual panes display the predicted relationships between model covariates and the abundance of all species (total abundance - a-b), the number of unique species (species richness - c-e), the abundance of greater than legal size target species (f-h) and the abundance and smaller than legal size target species (i-k). Solid lines represent predicted Generalized Additive Model (GAM) fits with other variables held constant at their mean value. Dashed lines represent upper and lower standard error bounds around the prediction, and points represent the observed data. The predictor variables included are; depth, mean relief, percentage cover of reef (broad.reef), percentage cover of macroalgae (broad.macroalgae), Topographic Position Index (tpi), roughness, detrended bathymetry (detrended) and fishing status.

Detailed bathymetry area

Table 21 Fish model selection results for the detailed bathymetry area. Top generalised additive models (GAMs) for predicting the abundance distribution of metrics and species of interest from full subset analyses. Differences between the lowest reported corrected Akaike Information Criterion (ΔAICc), AICc weight (ωAICc), variance explained (R2) and effective degrees of freedom (EDF) are reported for model comparison. Model selection was based on the most parsimonious model (fewest variables - shown in bold) within two units of the lowest AICc. The predictor variables included are; depth, mean relief, percentage cover of reef (broad.reef), percentage cover of macroalgae (broad.macroalgae), Topographic Position Index (tpi), roughness, detrended bathymetry (detrended) and fishing status.

Response	Model	Δ AICc	ω AICc	R^2	EDF
Total abundance	**mean.relief**	**0**	**0.779**	**0.36805**	**144.94**
Species richness	**depth**	**0**	**1**	**0.63381**	**15.57**
Greater than legal size	**mean.relief + detrended + roughness**	**0**	**1**	**0.45248**	**12.56**
Smaller than legal size	**broad.macroalgae**	**0**	**0.088**	**0.20175**	**12.95**
	tpi	0.1034	0.084	0.2	13.06
	distance.to.ramp	0.104	0.08	0.2005	13
	detrended	0.0562	0.077	0.19385	13.54
	broad.reef	0.3023	0.067	0.19754	13.29
	depth	0.1603	0.061	0.20088	13.03

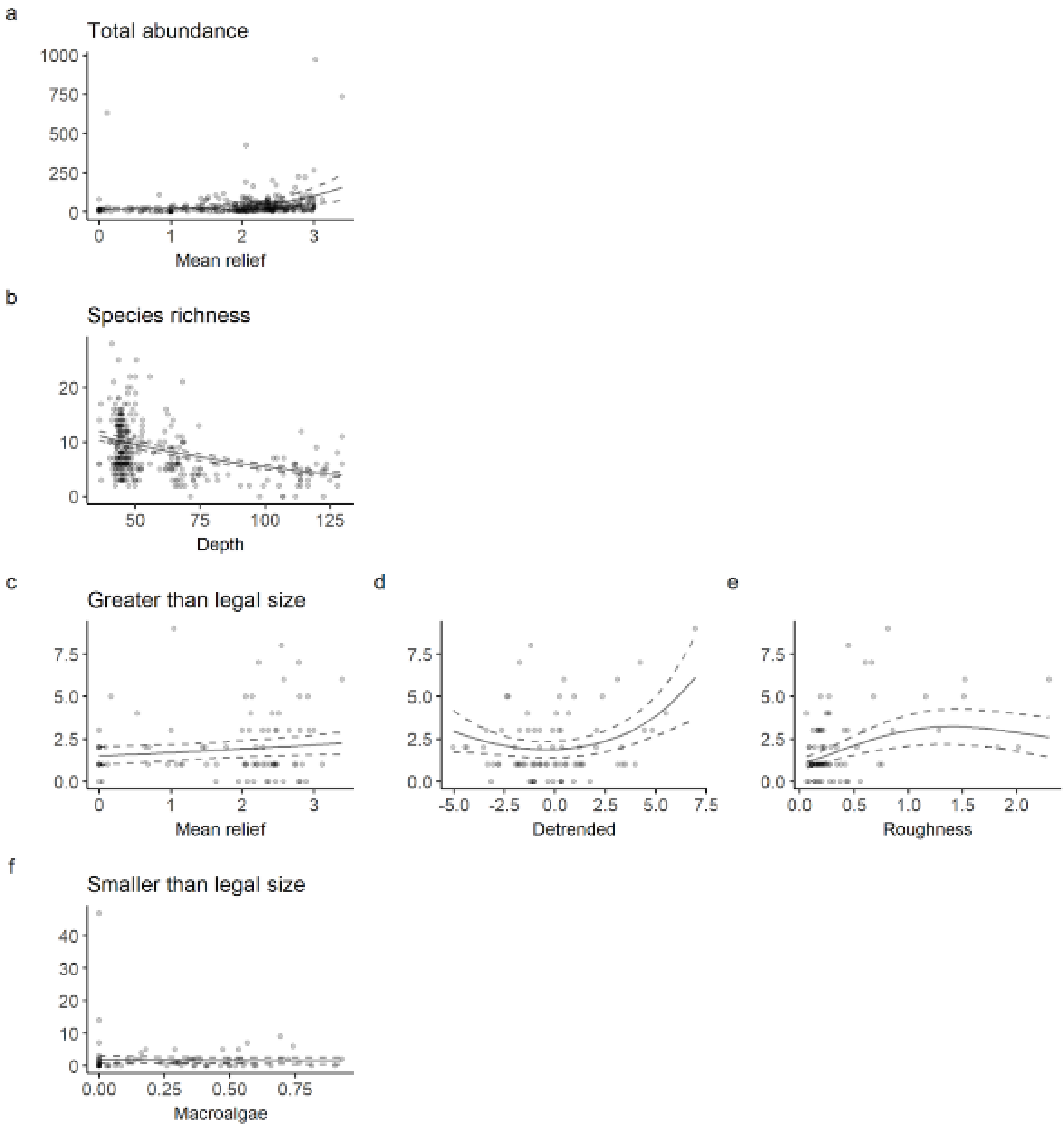


Figure 57 Plots of the most parsimonious model found to predict the probability of occurrence of key fish groups. Individual panes display the predicted relationships between model covariates and the abundance of all species (total abundance - a), the number of unique species (species richness - b), the abundance of greater than legal size target species (c-e) and the abundance and smaller than legal size target species (f). Solid lines represent predicted Generalised Additive Model (GAM) fits with other variables held constant at their mean value. Dashed lines represent upper and lower standard error bounds around the prediction, and points represent the observed data. The predictor variables included are; depth, mean relief, percentage cover of reef (broad.reef), percentage cover of macroalgae (broad.macroalgae), Topographic Position Index (tpi), roughness, detrended bathymetry (detrended) and fishing status.

6. Immersive visualisations and data access

6.1 Validate and explore the data

6.1.1 GlobalArchive to archive and share annotations

'GlobalArchive' is an online portal developed to archive, share and synthesise fish imagery annotation (Figure 58). GlobalArchive is a map-based portal that acts as a repository and database to share, combine and download fish imagery annotation, with more information on GlobalArchive available in the user guide.

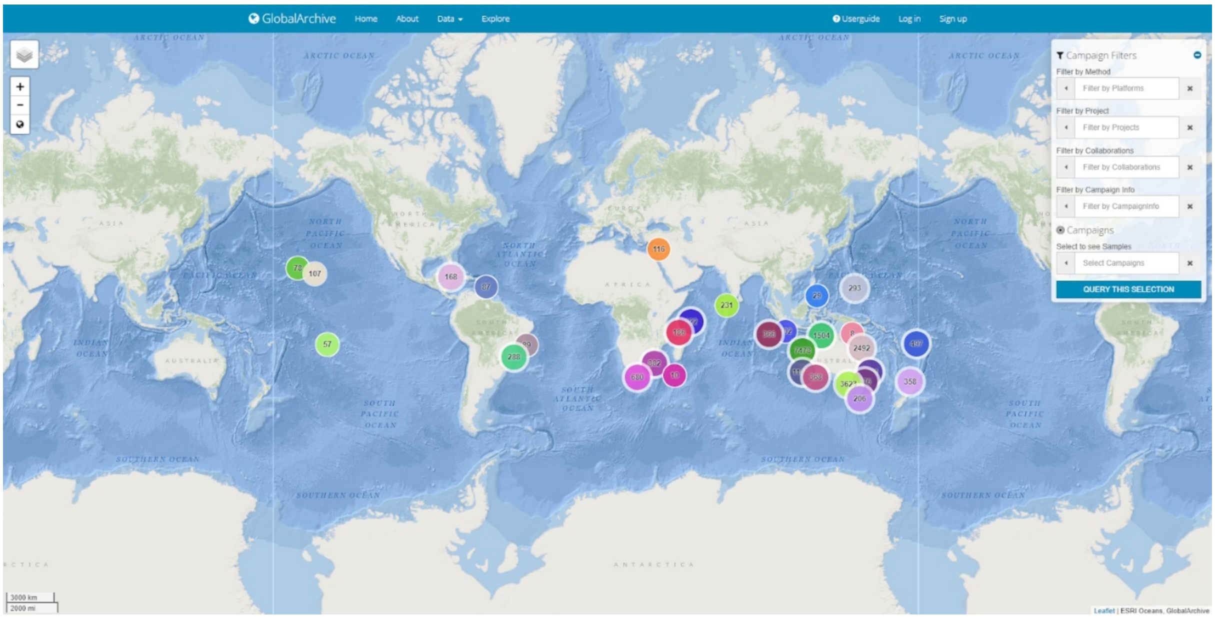


Figure 58 GlobalArchive map portal displaying stereo video campaigns.

6.1.2 CheckEM to validate annotations

'CheckEM' (Langlois, Gibbons, and Monk 2021) is a Shiny app (Chang et al. 2019) developed for validation and quality control in biodiversity data (Figure 59). Data are checked against life-history information based on the Codes for Australian Aquatic Biota (CAAB), including length-weight relationships, expected spatial distribution and body-size of fishes and sharks and suggestions of species name changes where species names have been changed historically. In addition, CheckEM plots data by marine park zone type by joining the metadata with Australian marine spatial planning shapefiles. CheckEM also converts annotation data into summarised data (e.g. the count and the length data by species) suitable for biodiversity reporting or for use in data exploration tools such as the 'Visualiser' (Langlois, Gibbons, and Monk 2021). CheckEM can be easily operated using the instructions available on the landing page and user guide, with further instructions available in Langlois et al. (2021).

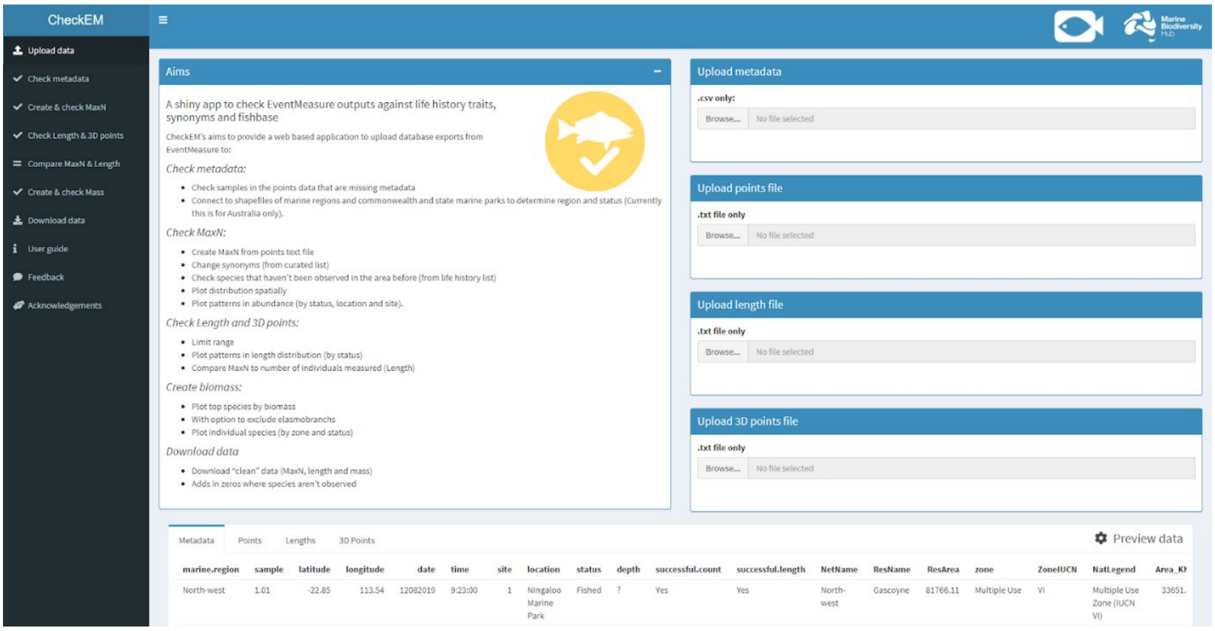


Figure 59 CheckEM landing page highlighting app instructions and example metadata.

6.1.3 Visualiser to visualise annotations

The 'Visualiser' component of GlobalArchive was developed to explore fish and shark image annotation data (Figure 60). Visualiser serves to rapidly create plots from data available on GlobalArchive and is operated using .fst files that are downloadable from GlobalArchive. Visualiser can create a variety of different plots and figures, including spatial count metrics, length frequency distributions and mass metrics, and can highlight relationships in data such as the effect of fishing status on the abundance of key species. Instructions on how to use Visualiser are available on the landing page, with further information available in Langlois et al. (2021).

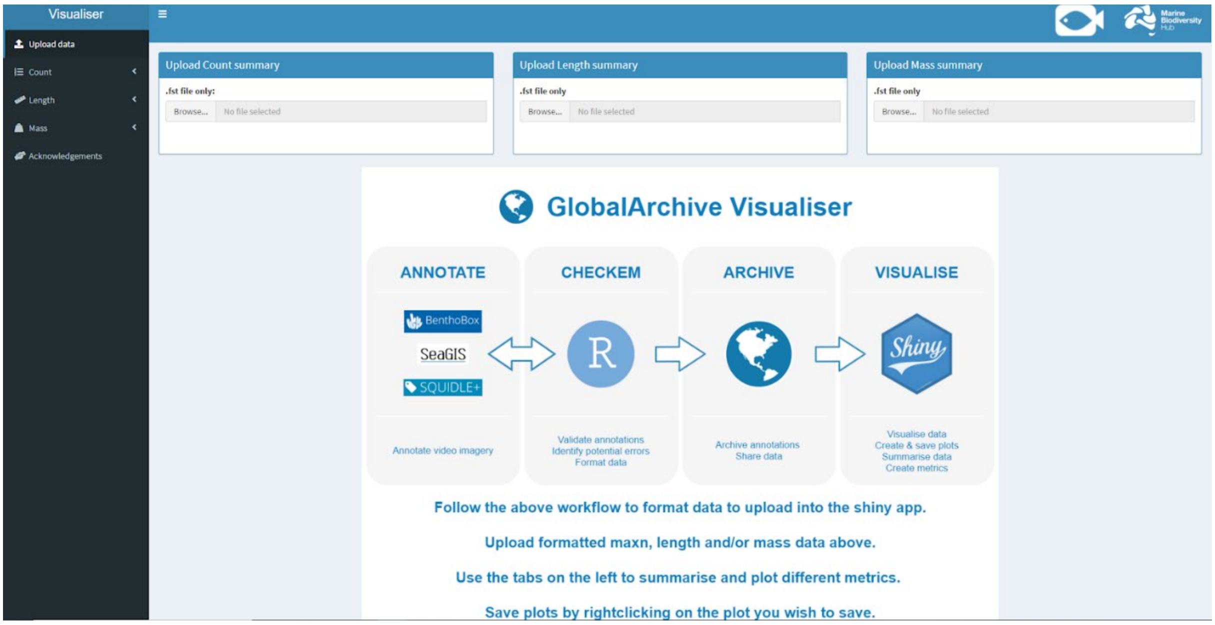


Figure 60 Visualiser landing page with workflow instructions.

6.1.4 FishNClips to explore imagery

'FishNClips' is an interactive web-service developed to showcase marine imagery collected to benchmark Australia's marine biodiversity (Figure 61). FishNClips currently displays benthic habitat imagery, fish highlights and 3D models collected within the Geographe Marine Park, the Capes and Abrolhos regions of the South-west Corner Marine Park and the Ningaloo Marine Park (Commonwealth) from existing baited remote underwater stereo-video (stereo-BRUV), panoramic drop camera, Autonomous Underwater Vehicle (AUV), and towed-video surveys. FishNClips is an easily navigable interface that is operated by selecting from the various marine parks and data formats available on the landing page, with more detailed instructions available in Langlois et al. (2021).

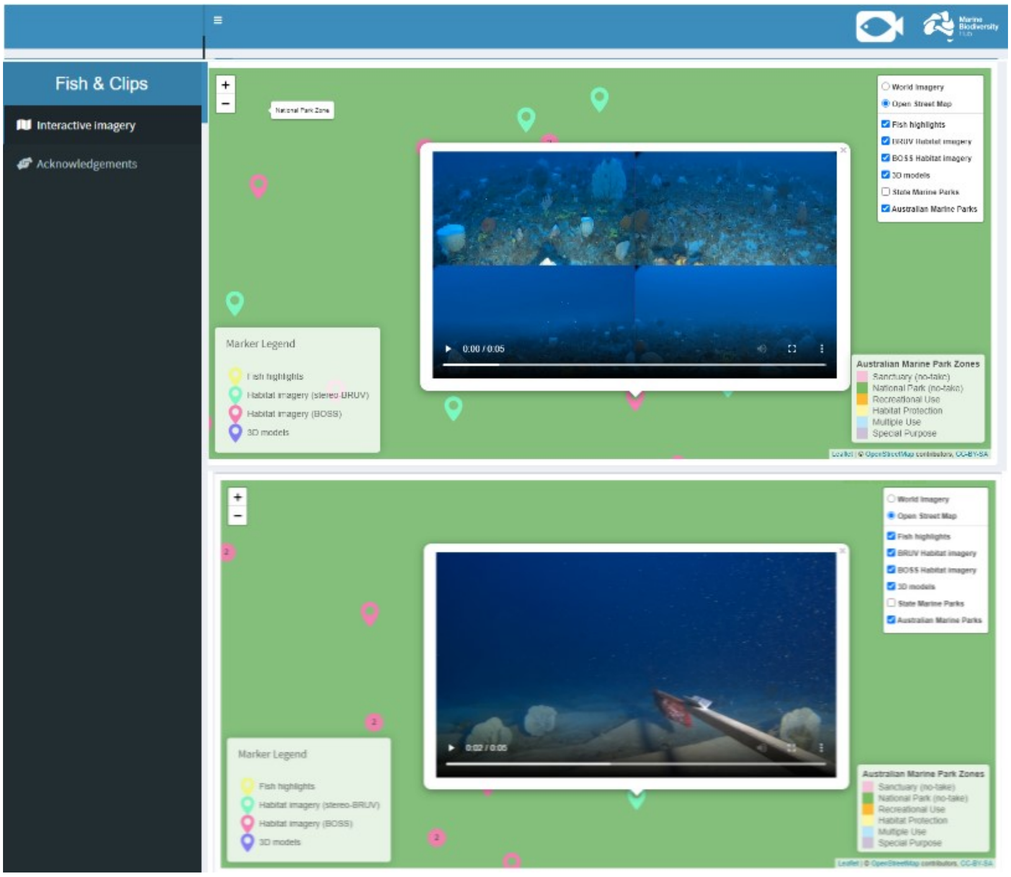


Figure 61 BRUV and Drop camera imagery from the South-west Corner Marine Park displayed on FishNClips.

6.1.5 Published Datasets on the AODN catalogue and SeaMapAustralia

Data sets are publicly available on the Australian Ocean Data Network (AODN) catalogue, for fish and benthos annotations and predicted habitat maps.

Habitat predictions, for the broader survey areas, can also be viewed on SeaMapAustralia.

7. Reproducible data analysis and plotting workflows

7.1 Data repository

A reproducible data analysis and plotting workflow for the latest survey was built using git, a free and open source distributed version control system, and hosted on github, as a public repository within the UWA Marine Ecology Group project github organisation to demonstrate the utility of FAIR (findable, accessible, interoperable, reusable) data principles (Wilkinson et al. 2016). The repository used a standard template to organise the reproducible workflow (Figure 62). Access to the benthic and fish imagery annotation data is available through the Australian Ocean Data Network.

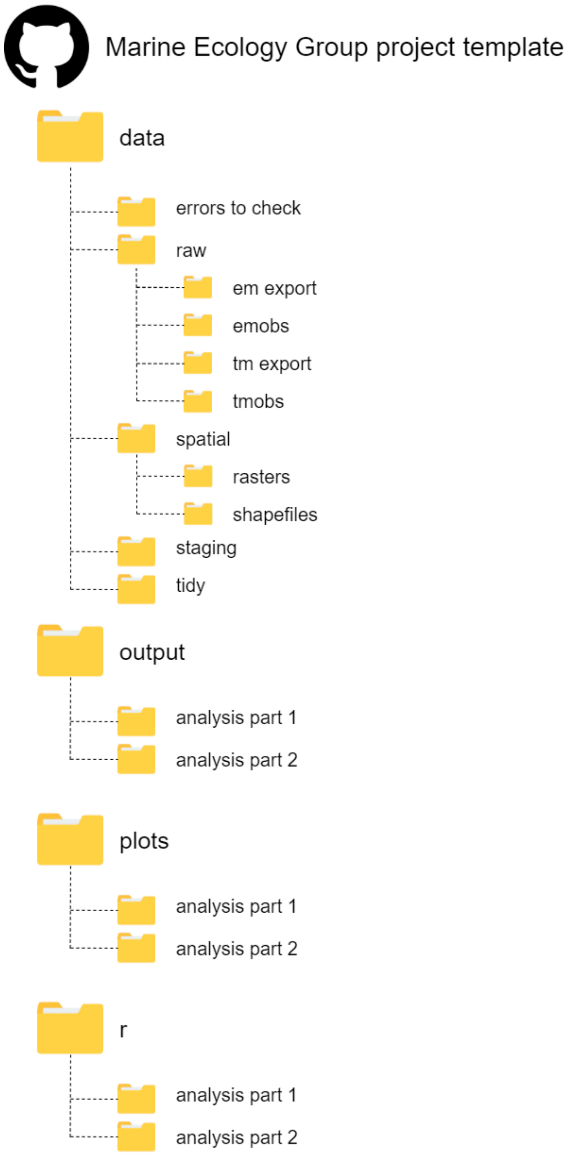


Figure 62 Project template used to create reproducible analysis of fish and benthic image annotation, including spatial and metric analyses including plotting.

7.2 Contributors

This public repository provides all code used to summarise and validate fish annotation, made using EventMeasure, and benthic annotation, made using TransectMeasure, from open data held on GlobalArchive and validated using CheckEM workflows. The public repository also includes all metric and spatial modelling, including all scripts to re-create plots. The largest contributor to the repository was Claude Spencer, followed by Kingsley Griffin (Figure 63).

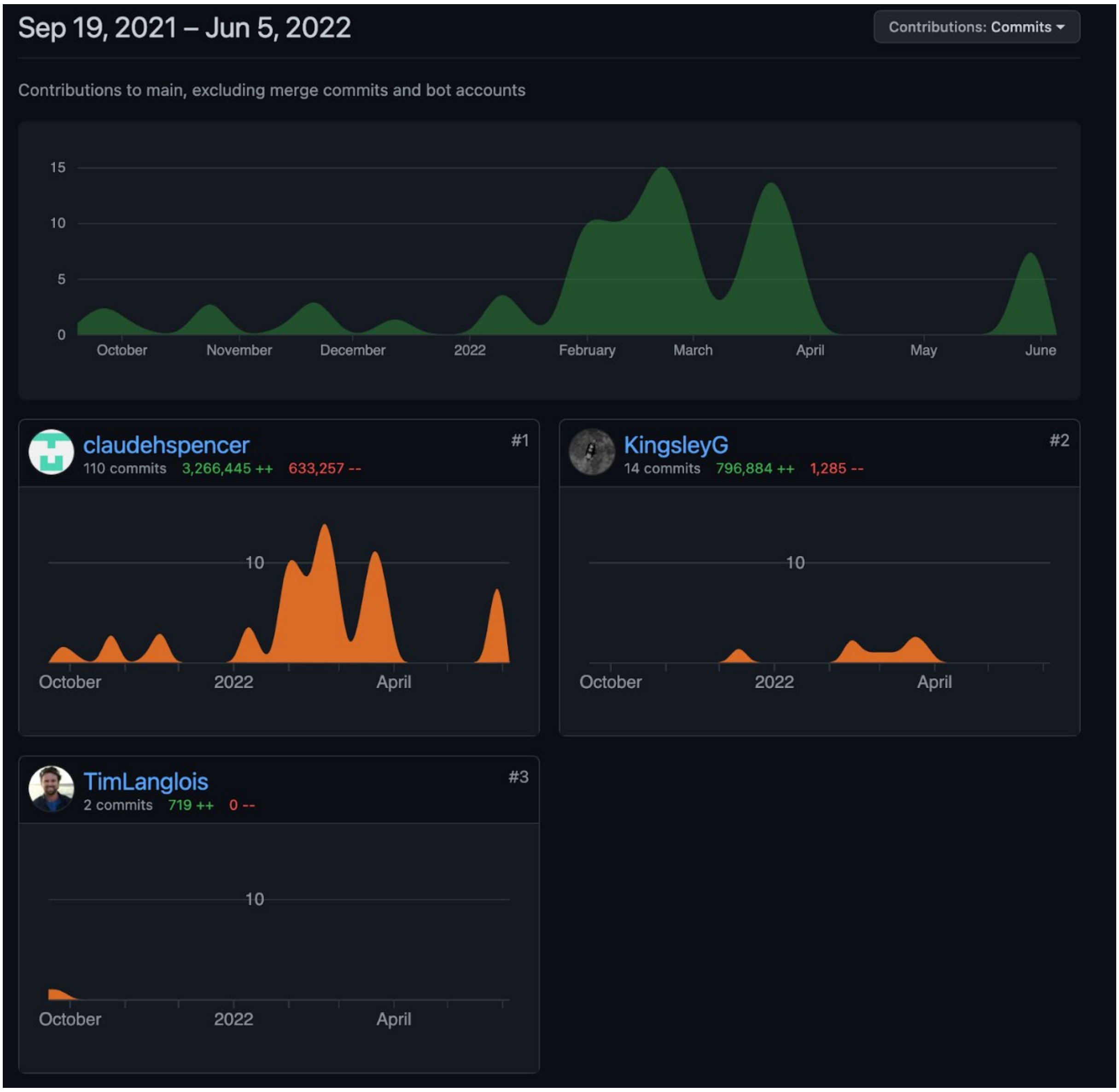


Figure 63 Contributions to reproducible analysis.

8. References

Akaike, H. 1973. “Information Theory as an Extension of the Maximum Likelihood Principle.” In *2nd International Symposium on Information Theory*, 267–81. Budapest, Akademiai Kiado.

Althaus, Franziska, Nicole Hill, Renata Ferrari, Luke Edwards, Rachel Przeslawski, Christine H. L. Schönberg, Rick Stuart-Smith, et al. 2015. “A Standardised Vocabulary for Identifying Benthic Biota and Substrata from Underwater Imagery: The CATAMI Classification Scheme.” *PloS One* 10 (10): e0141039.

Babcock, R. C., N. T. Shears, A. C. Alcala, N. S. Barrett, G. J. Edgar, K. D. Lafferty, T. R. McClanahan, and G. R. Russ. 2010. “Decadal Trends in Marine Reserves Reveal Differential Rates of Change in Direct and Indirect Effects.” *Proceedings of the National Academy of Sciences of the United States of America* 107: 18256–61.

Bosch, Nestor E., Jacquomo Monk, Jordan Goetze, Shaun Wilson, Russell C. Babcock, Neville Barrett, Jock Clough, et al. 2021. “Effects of Human Footprint and Biophysical Factors on the Body-Size Structure of Fished Marine Species.” *Conservation Biology: The Journal of the Society for Conservation Biology*, July. https://doi.org/10.1111/cobi.13807.

Bradford, R., R. Thomson, M. Bravington, D. Foote, R. M. Gunasekera, B. Bruce, D. Harasti, N. Otway, and P. Feutry. 2018. “A Close-Kin Mark-Recapture Estimate of the Population Size and Trend of East Coast Grey Nurse Shark. Report to the National Environmental Science Program, Marine Biodiversity Hub.” CSIRO Oceans & Atmosphere, Hobart, Tasmania. available at: https://www ….

Brooke, Brendan P., Scott L. Nichol, Zhi Huang, and Robin J. Beaman. 2017. “Palaeoshorelines on the Australian Continental Shelf: Morphology, Sea-Level Relationship and Applications to Environmental Management and Archaeology.” *Continental Shelf Research* 134 (February): 26–38.

Burnham, Kenneth P., and David R. Anderson. 2003. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. Springer Science & Business Media.

Carroll, A. G., J. Monk, N. Barrett, S. Nichol, S. J. Dalton, N. Dando, J. Siwabessy, et al. 2021. “Elizabeth and Middleton Reefs, Lord Howe Marine Park, Post Survey Report.” http://ecite.utas.edu.au/145637/.

Chang, Winston, Joe Cheng, J. J. Allaire, Yihui Xie, and Jonathan McPherson. 2019. “Shiny: Web Application Framework for R. R Package Version 1.4.0. Https://cran.r-project.org/package=shiny.”

Chapman, Peter M. 2015. “Climate Change Must Be Considered in Short- and Long-Term Monitoring and Assessment.” *Marine Pollution Bulletin*. https://doi.org/10.1016/j.marpolbul.2015.11.050.

Cresswell, A. K., T. J. Langlois, S. K. Wilson, J. Claudet, D. P. Thomson, M. Renton, C. J. Fulton, et al. 2019. “Disentangling the Response of Fishes to Recreational Fishing over 30 Years within a Fringing Coral Reef Reserve Network.” *Biological Conservation* 237 (September): 514–24.

Davies, H. N., W. Webb, I. Webb, T. Webb, D. Guilfoyle, S. Clohessy, and T. Langlois. 2022. “The Cultural Seascape of Wadandi Boodja.” The University of Western Australia.

Day, Paul B., Rick D. Stuart-Smith, Graham J. Edgar, and Amanda E. Bates. 2018. “Species’ Thermal Ranges Predict Changes in Reef Fish Community Structure during 8 Years of Extreme Temperature Variation.” Edited by David Schoeman. *Diversity & Distributions* 14 (April): 677.

Denny, C. M., T. J. Willis, and R. C. Babcock. 2004. “Rapid Recolonisation of Snapper Pagrus Auratus: Sparidae within an Offshore Island Marine Reserve after Implementation of No-Take Status.” *Marine Ecology Progress Series* 272: 183–90.

Director of National Parks. 2018. “South-West Marine Parks Network Management Plan 2018.” Attorney-General’s Department. https://www.legislation.gov.au/Details/F2018L00326.

Dove, D., R. Nanson, L. R. Bjarnadóttir, J. Guinan, J. Gafeira, A. Post, M. F. J. Dolan, H. Stewart, R. Arosio, and G. Scott. 2020. “A Two-Part Seabed Geomorphology Classification Scheme: (V.2) PART 1: MORPHOLOGY FEATURES GLOSSARY.” Open Report prepared by the MIM-GA geomorphology working group. https://www.researchgate.net/profile/Dayton-Dove/publication/344649872_A_two-part_seabed_geomorphology_classification_scheme_v2_Part_1_morphology_features_glossary/links/5f86d489299bf1b53e26402d/A-two-part-seabed-geomorphology-classification-scheme-v2-Part-1-morphology-features-glossary.pdf.

Fisher, Rebecca, Shaun K. Wilson, Tsai M. Sin, Ai C. Lee, and Tim J. Langlois. 2018. “A Simple Function for Full-Subsets Multiple Regression in Ecology with R.” *Ecology and Evolution* 8 (12): 6104–13.

Foster, Scott D. 2021. “MBHdesign: An R-package for Efficient Spatial Survey Designs.” *Methods in Ecology and Evolution / British Ecological Society* 12 (3): 415–20.

Foster, Scott D., Geoffrey R. Hosack, Emma Lawrence, Rachel Przeslawski, Paul Hedge, M. Julian Caley, Neville S. Barrett, et al. 2017. “Spatially Balanced Designs That Incorporate Legacy Sites.” *Methods in Ecology and Evolution / British Ecological Society* 8 (11): 1433–42.

Froese, R., and D. Pauly. 2019. *FishBase*. www.fishbase.org, last accessed 31/03/2019.

Gersbach, Guy H., Charitha B. Pattiaratchi, Gregory N. Ivey, and George R. Cresswell. 1999. “Upwelling on the South-West Coast of Australia—Source of the Capes Current?” *Continental Shelf Research* 19 (3): 363–400.

Giraldo Ospina, A., T. Langlois, S. Hickey, B. Radford, R. Hovey, J. Monk, K. Adams, et al. 2021. “Optimisation of Monitoring for Detecting Change in Benthic Habitats and Fish of Geographe Marine Park.” University of Western Australia.

Goetze, Jordan S., Shaun Wilson, Ben Radford, Rebecca Fisher, Tim J. Langlois, Jacquomo Monk, Nathan A. Knott, et al. 2021. “Increased Connectivity and Depth Improve the Effectiveness of Marine Reserves.” *Global Change Biology* 27 (15): 3432–47.

Graham, Michael H. 2003. “Confronting Multicollinearity in Ecological Multiple Regression.” *Ecology* 84 (11): 2809–15.

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: 177–84.

Harvey, Euan, Dianne L. McLean, Jordan S. Goetze, Benjamin J. Saunders, Tim J. Langlois, Jacquomo Monk, Neville Barrett, et al. 2021. “The BRUVs Workshop – An Australia-Wide Synthesis of Baited Remote Underwater Video Data to Answer Broad-Scale Ecological Questions about Fish, Sharks and Rays.” *Marine Policy*. https://doi.org/10.1016/j.marpol.2021.104430.

Harvey, Euan, and Mark Shortis. 1995. “A System for Stereo-Video Measurement of Sub-Tidal Organisms.” *Marine Technology Society Journal* 29: 10–22.

Hoschke, Alexandra M., and Glen J. Whisson. 2016. “First Aggregation of Grey Nurse Sharks (Carcharias Taurus) Confirmed in Western Australia.” *Marine Biodiversity Records* 9 (1): 17.

Hurvich, Clifford M., and Chih-Ling Tsai. 1989. “Regression and Time Series Model Selection in Small Samples.” *Biometrika* 76 (2): 297–307.

Keesing, J., A. Donavan, S. Collings, T. Langlois, E. Lawrence, and R. Babcock. 2021. “Initial Baseline Survey of Deepwater Fish in the Ningaloo Marine Park (Commonwealth Waters).” CSIRO.

Langlois, T., B. Gibbons, and J. Monk. 2021. “Enhancement, Connectivity and Interoperability of Spatial Portals: Linking of Science Communication Products to Spatial Metadata Records.” 1. Report to the National Environmental Science Program, Marine Biodiversity Hub. The University of Western Australia.

Langlois, T., B. Gibbons, J. Monk, and V. Lucieer. 2021. “Quality Control and Interoperability of Fish Annotation Data: Case Study of GlobalArchive-CheckEM Service for Validating Stereo-BRUV Annotations.” 1. Report to the National Environmental Science Program, Marine Biodiversity Hub. The University of Western Australia.

Langlois, T., B. Radford, K. P. Van Niel, J. J. Meeuwig, A. Pearce, C. S. G. Rousseaux, G. A. Kendrick, and E. S. Harvey. 2012. “Consistent Abundance Distributions of Marine Fishes in an Old, Climatically Buffered, Infertile Seascape.” *Global Ecology and Biogeography: A Journal of Macroecology* 21: 886–97.

Lawrence, Emma, Renae Hovey, Euan Harvey, Gary Kendrick, Keith Hayes, and Stefan Williams. 2016. “Application of NERP Biodiversity Hub Survey Methodology to Geographe Commonwealth Marine Reserve.” NERP Marine Biodiversity Hub. https://www.nespmarine.edu.au/system/files/Lawrence%20et%20al%20Application%20of%20NERP%20Marine%20Hub%20survey%20methodolody%20to%20Geographe%20Bay%20CMR_Final%20report%20v11_Dec2016.pdf.

Lindgren, Finn, and Håvard Rue. 2015. “Bayesian Spatial Modelling with R-INLA.” *Journal of Statistical Software* 63 (1): 1–25.

Liu, Gang, Scott F. Heron, C. Mark Eakin, Frank E. Muller-Karger, Maria Vega-Rodriguez, Liane S. Guild, Jacqueline L. De La Cour, et al. 2014. “Reef-Scale Thermal Stress Monitoring of Coral Ecosystems: New 5-Km Global Products from NOAA Coral Reef Watch.” *Remote Sensing* 6 (11): 11579–606.

Lynch, Tim P., Robert Harcourt, Graham Edgar, and Neville Barrett. 2013. “Conservation of the Critically Endangered Eastern Australian Population of the Grey Nurse Shark (Carcharias Taurus) through Cross-Jurisdictional Management of a Network of Marine-Protected Areas.” *Environmental Management* 52 (6): 1341–54.

MacNeil, M. Aaron, Demian D. Chapman, Michelle Heupel, Colin A. Simpfendorfer, Michael Heithaus, Mark Meekan, Euan Harvey, et al. 2020. “Global Status and Conservation Potential of Reef Sharks.” *Nature* 583 (7818): 801–6.

Monk, J., J. Williams, N. Barrett, A. Jordan, V. Lucieer, F. S. Althaus, and H. Nichol. 2017. “Biological and Habitat Feature Descriptions for the Continental Shelves of Australia’s Temperate-Water Marine Parks- Including Collation of Existing Mapping in All AMPs.” Report to the National Environmental Science Programme, Marine Biodiversity Hub. Institute of Marine and Antarctic Studies, University of Tasmania.

Monk, Jacquomo, Neville Barrett, Tom Bridge, Andrew Carroll, Ariell Friedman, Nicole Hill, Daniel Ierodiaconou, Alan Jordan, Gary Kendrick, and Vanessa Lucieer. 2020. “Marine Sampling Field Manual For AUVS.” In *Field Manuals for Marine Sampling to Monitor Australian Waters, Version 2*, edited by Foster S. Przeslawski R. National Environmental Science Program (NESP).

Navarro, Langlois, and Burton. 2020. “Measures for Social and Economic Monitoring of the Australian Marine Parks.” *Of Western Australia*. https://www.nespmarine.edu.au/system/files/Navarro_D6_Measures%20for%20Social%20and%20Economic%20Monitoring%20of%20the%20Australian%20Marine%20Parks.pdf.

Navarro, M., T. J. Langlois, M. Burton, A. Hegarty, C. Aston, M. E. Kragt, and A. Rogers. 2021. “Social and Economic Benchmarks of the Australian Marine Parks. Report to the National Environmental Science Program, Marine Biodiversity Hub. The University of Western Australia,” 66.

Newman, S. J., B. S. Wise, K. G. Santoro, and D. J. Gaughan. 2021. “Status Reports of the Fisheries and Aquatic Resources of Western Australia 2020/21: The State of the Fisheries.” Department of Primary Industries and Regional Development.

Sagar, Falkner, Dekker, and Huang. 2020. “Earth Observation for Monitoring of Australian Marine Parks and Other Off-Shore Marine Protected Areas.” *Report to The*. https://www.nespmarine.edu.au/system/files/Przeslawski_2019_D2_M28_Earth%20Obeservation%20for%20MPAs%20_Report.pdf.

SeaGIS. 2011. “Three-Dimensional Stereo Measurements in Visual Sampling of Fish Populations.” 2011. https://www.seagis.com.au/.

Smale, Dan A., Gary A. Kendrick, and Thomas Wernberg. 2011. “Subtidal Macroalgal Richness, Diversity and Turnover, at Multiple Spatial Scales, along the Southwestern Australian Coastline.” *Estuarine, Coastal and Shelf Science* 91 (2): 224–31.

Stuart-Smith, Rick D., Graham J. Edgar, and Amanda E. Bates. 2017. “Thermal Limits to the Geographic Distributions of Shallow-Water Marine Species.” *Nature Ecology & Evolution* 1 (12): 1846–52.

Underwood, A. J. 1995. “Ecological Research and (and Research into) Environmental Management.” *Ecological Applications: A Publication of the Ecological Society of America* 5: 232–47.

Weiss. 2001. “Topographic Position and Landforms Analysis.” *Poster Presentation, ESRI User Conference, San Diego*. http://www.jennessent.com/downloads/TPI-poster-TNC_18x22.pdf.

Wernberg, Thomas, Dan A. Smale, Fernando Tuya, Mads S. Thomsen, Timothy J. Langlois, Thibaut de Bettignies, Scott Bennett, and Cecile S. Rousseaux. 2012. “An Extreme Climatic Event Alters Marine Ecosystem Structure in a Global Biodiversity Hotspot.” *Nature Climate Change* 3 (July): 78.

Westera, M. B., E. S. Harvey, G. A. Kendrick, and P. Barnes. 2008. “Benchmark Study on Marine Communities of the South West (Capes) Region for Long-Term Monitoring Including the Proposed Capes Marine Park.” University of Western Australia, School of Plant Biology. : Report to the South West Catchments Council.

Wilde, S. A., and D. R. Nelson. 2001. “Geology of the Western Yilgarn Craton and Leeuwin Complex, Western Australia — a Field Guide.” Record 2001/15. http://www.geochron.com.au/wp-content/uploads/2016/11/99.-Wilde-and-Nelson-2001_15.pdf.

Wilkinson, Mark D., Michel Dumontier, I. Jsbrand Jan Aalbersberg, Gabrielle Appleton, Myles Axton, Arie Baak, Niklas Blomberg, et al. 2016. “The FAIR Guiding Principles for Scientific Data Management and Stewardship.” *Scientific Data* 3 (March): 160018.

Wilson, S. K., N. A. J. Graham, and N. V. C. Polunin. 2007. “Appraisal of Visual Assessments of Habitat Complexity and Benthic Composition on Coral Reefs.” *Marine Biology* 151 (3): 1069–76.

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