THE JEWEL IN THE CORAL SEA

The cultural and ecological significance of Ashmore and Boot Reefs

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With funding opportunity from Parks Australia, through an Our Marine Parks Grant Round 3, a team of researchers from James Cook University (JCU) collaborated with people of the Meriam Nation to conduct ecological surveys of Boot and Ashmore Reefs in the Coral Sea Marine Park.

On the cover – A school of blue tangs (*Paracanthurus hepatus*) on the reef crest at Boot Reef. Image credit: Victor Huertas

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We acknowledge the traditional custodians of the sea country in which this research and monitoring was conducted and pay our respects to their elders, past, present and emerging.

Eight members of the Meriam people joined our team during surveys of Ashmore and Boot Reefs during Feb-Mar 2023. John Tabo can be seen here freediving while Josie Chandler surveys corals and other benthic substrates at Ashmore Reef. Image credit: Victor Huertas

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1 Executive Summary

Ashmore and Boot Reefs in the far north of the Coral Sea Marine Park (CSMP) have been identified through recent research as 'bright spots' within the CSMP, supporting higher cover and diversity of corals, and greater fish diversity and biomass than other CSMP reefs, and are considered the 'jewel' among Torres Strait reefs. Together with their potential ecological importance, Ashmore and Boot Reefs have cultural connections to the Meriam people. Despite the cultural and ecological significance of Ashmore and Boot Reefs our understanding of the habitats (both shallow and deep) within these reefs, the biodiversity they support, and the current status of culturally significant species is limited.

James Cook University was awarded funding through an Our Marine Parks Round 3 Grant to investigate the cultural and ecological significance of Ashmore and Boot Reefs. Specifically, the key objectives of this project were to:

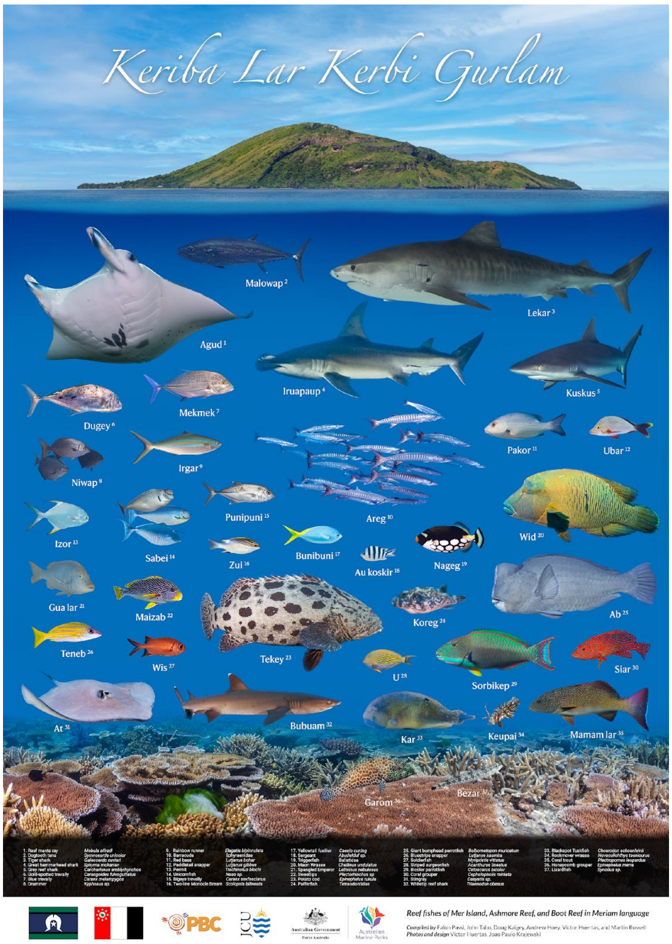
(i) engage and collaborate with, and build capacity within, the Meriam people in the conduct of ecological surveys to assess the status of shallow and deep reef habitats;

(ii) conduct extensive surveys of benthic, macro-invertebrate, and fish communities on Ashmore and Boot Reefs using a combination of diver-based and remote image-based technologies.

The project involved several engagement and capacity-building activities with the Meriam people, including a 10-day voyage to Ashmore and Boot Reefs in February – March 2023 where eight members of the Meriam people collaborated directly with our team. The project also undertook detailed surveys of benthic and fish communities in both shallow and deep habitats using diver-based surveys, and video-based surveys (i.e., remotely operated vehicles – ROV; and baited remote underwater video systems - BRUVS), respectively, across multiple sites in February-March 2023. These surveys were conducted to provide rigorous quantitative information on spatial patterns within and between reefs, and among

depths in the (i) cover, richness and composition of major benthic taxa, namely hard corals, and algae; (ii) abundance, species richness, and biomass of reef fishes, and (iii) abundance and/or biomass of culturally important fish and macro-invertebrate species.

During the 10-day voyage to Ashmore and Boot Reefs, eight representatives of the Meriam people were trained in the use of both diver-based (i.e., visual belt transects, point-intercept transects) and video-based (Remotely Operated Vehicles - ROV; Baited Remote Underwater Video systems- BRUVs; and Diver Operated Stereo Video systems – DOV) techniques for ecological surveys, and gained hands-on experience in the use of these different techniques. While this training and experience provided valuable initial capacity-building in conducting ecological surveys of coral reef habitats, ongoing training would be required to reinforce the knowledge and skills needed for any future ecological surveys. Together with the training in ecological monitoring, the representatives of the Meriam people shared their knowledge of Ashmore and Boot Reefs, and the traditional names for reef organisms. Inspired by these discussions an initiative was launched to produce an informative and educational poster for the community showcasing some of the common and charismatic fishes found on the reefs surrounding Mer Island, and Ashmore and Boot Reefs. Titled "*Keriba Lar Kerbi Gurlam"*, meaning "*Our Fishes of Our Sea*" in Meriam Mir language, this poster aims to celebrate and contribute to the preservation of the rich cultural heritage



embedded in the traditional Meriam Mir names of the fish fauna inhabiting the Meriam Sea Country.

This project surveyed 17 shallow reef sites and 9 deep reef sites across Ashmore and Boot Reefs, as well as a qualitative survey at Beva Reef (a relatively small pinnacle reef to the south of Boot Reef). The surveys revealed the cover and taxonomic richness of hard (scleractinian) corals in shallow water habitats at Ashmore and Boot Reefs was high (coral cover: Ashmore – 35.2%; Boot – 22.8%). This level of coral cover was comparable to previous surveys (2018, 2022) at these reefs and greater than most other reefs in the CSMP; the highest coral cover recorded across all CSMP reefs in 2023 was at Ashmore Reef. Unlike many other reefs within the CSMP and GBRMP that have experienced multiple severe coral bleaching events and widespread coral mortality in the past 8 years, coral cover has remained relatively stable, or increased, on Ashmore and Boot Reefs, reinforcing their status as ‘bright spot’ reefs. Moreover, the density of juvenile corals (an indicator of the replenishment potential of coral populations) recorded at Ashmore and Boot Reefs during the 2023 surveys was the highest recorded for CSMP reefs, and are directly comparable to those of more connected reef systems such as the GBRMP.

Surveys of deep reef habitats revealed that hard (scleractinian) coral cover at Ashmore Reef peaked at 31-40m (14.1%) and then declined rapidly to only 4.8% at 41-50m. after which it gradually declined to 9.3% cover at 51-60m. Whilst hard coral cover was higher at Boot Reef amongst depth bands, the decline in percentage cover followed the same pattern and was lowest at 61-70m (9.3%). This contrasts with deep habitats at other CSMP reefs where the highest coral cover was recorded at depths of 70-80m. Despite the relatively low average cover of live corals in deep reef habitats on Ashmore and Boot Reefs, there were areas of high coral cover interspersed within areas of unconsolidated substrata on both reefs. The lower coral cover at depth may, therefore, reflect the limited availability of suitable (consolidated) substrata for the recruitment and growth of corals at the sites surveyed. More extensive surveys would be required to establish the generality of these patterns of declining coral cover with depth.

The density, biomass and species richness of reef fish in shallow reef habitats was high relative to other CSMP reefs, and comparable to previous surveys at Ashmore and Boot. Of particular note is the biomass of reef fish at one site on the exposed eastern aspect of Ashmore Reef (Ashmore 16: 13,000 kg per hectare), that is one of the highest recorded throughout the CSMP during the past 6 years of monitoring, and an order of magnitude greater than estimates of unfished biomass for coral reefs globally (1,000 – 1,250 kg per hectare). The high biomass of reef fish, coupled with the abundance of sharks and relatively low level of fishing line entangled on the substratum, indicate that there is limited fishing occurring on Ashmore and Boot Reefs.

The density of reef fish displayed a similar trend with depth to that of hard coral cover, with an initial sharp decline in density followed by a gradual decline to the deepest areas surveyed. In contrast, the species richness of reef fish (i.e., number of reef fish per transect) at Ashmore Reef displayed a mid-depth peak, with 166 fish species being recorded in the mid depth band (30-60 m), decreasing at both shallower (10-30 m; 37 species) and deeper (60-80 m; 21 species) depth bands (Figure 1). 57 fish species were unique to the ROV surveys and not observed or recorded during diver-based surveys of shallow reef habitats. These depth specialist fish species included several species of tilefish (f. Malacanthidae, one of which hadn't been recorded in the CSMP previously), anthias (f. Serranidae – Anthiinae), triggerfish (f. Balistidae), and gobies (f. Gobiidae), and increase the total number of fish species recorded at Ashmore and Boot Reefs considerably.

The density of culturally important macroinvertebrates (i.e., sea cucumbers, trochus, and giant clams) was generally low, although comparable to previous surveys of Ashmore and Boot Reefs and other CSMP reefs. The low densities of sea cucumbers, trochus and giant clams may reflect the habitats surveyed (i.e., contiguous reef) that are not the preferred habitats for many of these macroinvertebrates, and/or potential effects of harvesting.

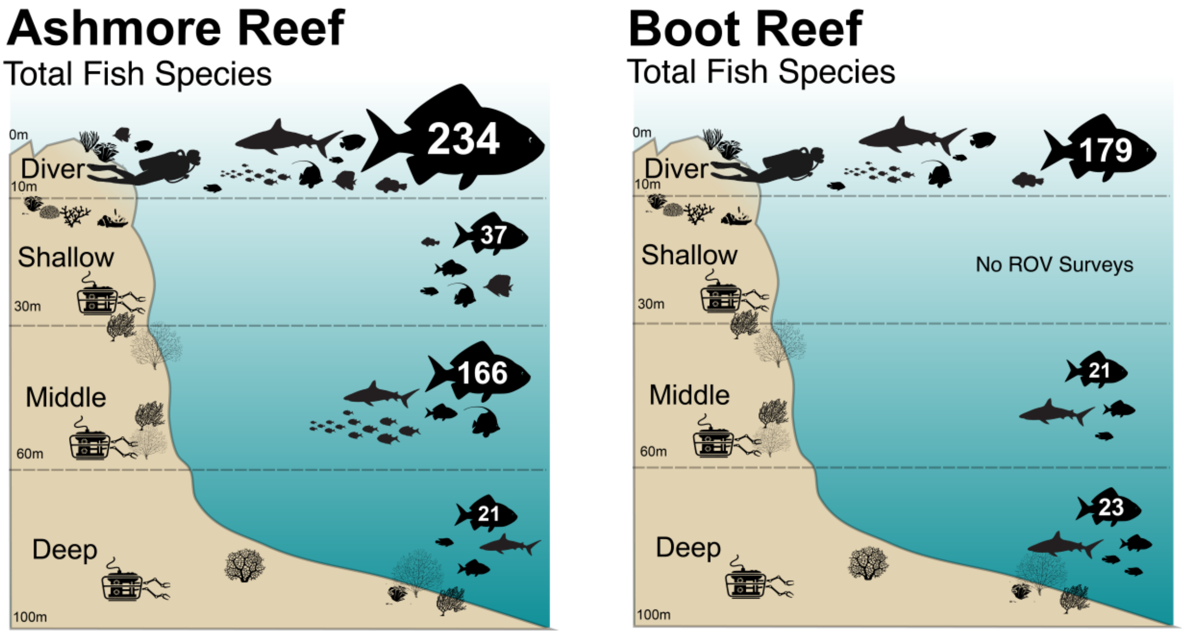


Figure 1. Infographic of the total reef fish species richness (number of species) among depth bands. The number within the fish is the total number of fish species recorded within each depth band. Note the 0-10m depth band was from diver-based surveys, and the shallow, middle and deep bands are from ROV surveys.

Recommendations:

- Continued and meaningful engagement with the Meriam people to build upon and consolidate the collaboration initiated through this project is suggested. Regular communication to be maintained with the Mer Gedkem Le, including any research or management activities relevant to Ashmore and Boot Reefs, or the broader CSMP. We recommend making at least one berth on any future research and monitoring voyages to Ashmore and Boot Reefs be made available for a member of the Meriam people.
- The distance between Mer Island and Ashmore and Boot Reefs makes these reefs largely inaccessible to the Meriam people. Partnering with other management agencies (e.g., Torres Strait Regional Authority) to provide further capacity-building and training in monitoring of coral reef ecosystems will likely provide a greater benefit and enable the Meriam people to take a more active role in the management of their local reefs and Sea Country.
- Given the increasing incidence of major disturbances impacting reefs globally, and the CSMP (including the current global bleaching event),

regular (every 2-3 years) surveys are recommended. In the absence of regular monitoring, the causes of any changes in reef communities would be largely unknown, severely limiting the capacity of managers to understand the health status of these reefs and make informed decisions.

- Increased focus on quantifying environmental conditions (e.g., temperature) and demographic rates of benthic (namely corals and crustose coralline algae; CCA) and fish taxa to better understand the replenishment and potential resilience of populations to environmental change. Temperature loggers and devices to quantify the settlement and calcification of CCA's were deployed across three sites on Ashmore Reef during the February-March 2023 voyage. The temperature loggers record water temperature every 30 mins and have a battery life of just over 2 years, and therefore should be collected in the next 12 months. Quantifying demographic rates for fish and identifying potential settlement and nursery habitats on these reefs will require dedicated research.
- Additional means for accessing Ashmore and Boot Reefs for research and monitoring should be considered. For example, Mike Ball Dive Expeditions, a dive tourism operator from Cairns visited Ashmore and Boot Reefs in November 2023, and are planning to make this an annual event, and thus could be approached to collaborate by providing vessel berths for researchers.
- Dedicate research into the connectivity of Ashmore and Boot Reefs with reefs in the Torres Strait, Eastern Fields, and adjacent reefs in PNG should be considered to better understand the ecosystem processes that support these reef areas.

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2 Background

The Coral Sea is situated off Australia's north-east coast, bounded by Papua New Guinea to the north, the Solomon Islands, Vanuatu and New Caledonia to the east, and the Tasman Sea to the south. The Coral Sea is a critically important and environmentally significant ecosystem owing to i) the extent and diversity of habitats (including many unique habitats), ii) the unique fauna these habitats support, iii) the provision of habitats for species of conservation significance and, iv) connectivity with Australia's Great Barrier Reef (GBR) and other western Pacific provinces (Ceccarelli et al. 2013; Hoey et al. 2020). Australia's marine estate within the Coral Sea is managed through the Coral Sea Marine Park (CSMP) that extends from the eastward margin of the Great Barrier Reef Marine Park (GBRMP) to the outer extent of Australia's Exclusive Economic Zone, some 1,200km offshore (Figure 2.1). The CSMP is among the world's largest and most isolated marine parks, encompassing an area of 989,836km^2.

The CSMP is one of the most isolated coral reef environments in Australian waters, with 20 widely separated shallow reef systems on top of sea mounts and extinct volcanos rising up from 100s or 1000s of metres, ranging from Ashmore and Boot Reefs adjacent to the Torres Strait in the north, to Cato Reef in the south, and Mellish Reef (>1,000 km east of Cairns) in the far east. Given the distance from the Australian mainland, and hence large human population centres, reefs within the CSMP experience limited exposure to direct human pressures (e.g., fishing, run-off) relative to more accessible coastal reefs, such as those of the Great Barrier Reef. Despite the limited direct human pressures on CSMP reefs, they are increasingly being exposed to the effects of climate change with seven major coral bleaching events recorded in the CSMP in the past two decades (2002, 2004, 2016, 2017, 2020, 2021 and 2022), with five of these bleaching events occurring in the past eight years (Oxley et al. 2004, Harrison et al. 2018, 2019, Hoey et al. 2020, 2021, 2022, 2023).

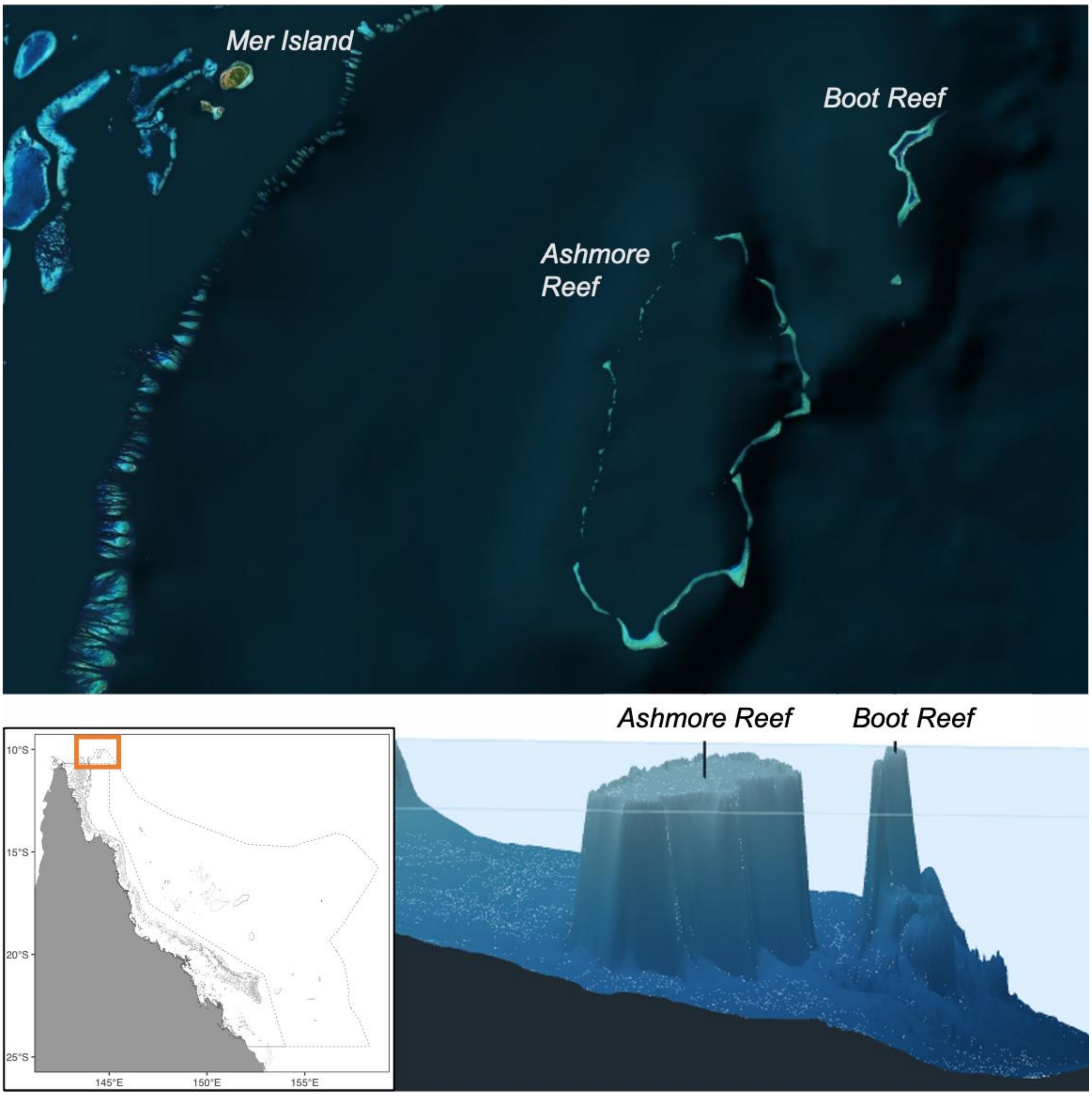


Figure 2.1. Ashmore and Boot Reefs. Top: Satellite image showing the proximity of Ashmore and Boot Reefs to Mer Island in the Torres Strait (source: eAtlas / Australian Institute of Marine Science). Bottom left: The Queensland coastline, with seaward dotted line denoting the boundary of the Coral Sea Marine Park. Orange bounding box shows the location of Ashmore and Boot Reefs. Bottom right: bathymetric map showing the three-dimensional structure of Ashmore and Boot Reefs.

These recurrent bleaching events have caused considerable declines in coral cover across CSMP reefs, although there was considerable variation in the change in coral cover among individual reefs (Hoey et al. 2021, 2022, 2023). Notably five ‘bright spot’ reefs (Ashmore, Boot, Bougainville, Mellish and Moore Reefs) were less adversely affected by recent bleaching events, and support higher coral cover, coral richness, and/or greater abundance and biomass of reef fish than other

CSMP reefs. Two of these ‘bright spot’ reefs (Ashmore and Boot Reefs) are ecological significant, and also culturally significant being the only CSMP reefs with known connections to first nations people.

Ashmore and Boot Reefs are located in the far north of the CSMP, approximately 25 nm east of the outer reefs of Torres Straits (Figure 2.1). Ashmore and Boot Reefs have historical connections to the Meriam people and are located 55-65 km east-southeast of Mer Island. Both reefs are on top of extinct underwater volcanos and have steep outer walls, dropping to >500m depth within a few hundred metres. Ashmore Reef is the larger of the two reefs (*ca.* 45 x 22 km) with an extensive and deep lagoon. Boot Reef is smaller (*ca.* 13 x 2 km) with a fully enclosed lagoon. Despite the cultural and ecological significance of Ashmore and Boot Reefs our understanding of the habitats (both shallow and deep) within these reefs, the biodiversity they support, and the status of culturally significant species is limited.

2.1 Objectives and scope

The objective of this project was two-fold: (i) to engage and collaborate with, and build capacity within, the Meriam people in the conduct of ecological surveys to assess the status of shallow and deep reef habitats; and (ii) to conduct extensive surveys of benthic, macro-invertebrate, and fish communities on Ashmore and Boot Reefs using a combination of diver-based and remote image-based technologies. In doing so, this project will provide a unique opportunity to work directly alongside the Meriam people to improve our understanding of their connections with their Sea Country and to build their capacity to participate and take an active role in the management of the CSMP.

Surveys were conducted at 17 sites across Ashmore and Boot Reefs following the methods of Hoey et al. (2020, 2021, 2022). At each site, diver-based surveys were conducted along three replicate transects within each of two habitats (reef crest: 1-3m depth; reef slope: 7-10m depth) to provide rigorous quantitative information on spatial (i.e., among reefs and regions) and temporal patterns in:

i) benthic cover and composition, including the percentage cover for hard (Scleractinian) and soft (Alcyonarian) corals, macroalgae, and other sessile organisms;
ii) size, abundance and composition of reef fish assemblages;
iii) abundance of small/ juvenile corals (<5cm diameter), as a proxy of coral recruitment and population replenishment;
iv) abundance of holothurians, urchins, clams, and other ecologically or culturally important reef-associated invertebrates; and
vi) the abundance and size of sea snakes.

Additional surveys of deeper reef habitats (up to 100m depth) were conducted at each reef using Remotely Operated Vehicles (ROV) fitted with forward-facing stereo-video systems, and side- and down-facing time lapse cameras.

As well as the objectives listed above, berths were made available on the voyage to Ashmore and Boot Reefs to Millstream Productions who were filming a documentary on Sea Country featuring the Meriam people (also funded through an Our Marine Parks Round 3 Grant).

Figure 2.2 The *MV Iron Joy* anchored off Mer Island, in the eastern Torres Straits, with the JCU research team, CSMP Manager, vessel crew, representatives of the Meriam people and cinematographers from Millstream Productions on the foredeck. Image credit: Stuart Ireland, Millstream Productions

3 Methods

3.1 Engagement and collaboration with the Meriam people

Early and regular communication and engagement with representatives of the Meriam people ensured the successful collaboration and exchange of traditional and western knowledge. Several meetings were held and presentations delivered to Meriam elders, members of the Mer Gedkem Le, and the Mer Island community prior to the voyage to Ashmore and Boot Reefs, and eight members of the Meriam people were selected by the Mer Gedkem Le to join and participate in the voyage (Table 3.1).

Date / Location	Purpose	Persons
29 July 22, Townsville	Meeting to discuss proposed project, timing and duration of the voyage to Ashmore and Boot Reefs, planned activities, and opportunity for TO participation with Chair Passi and project partners	A. Hoey (JCU), Falen Passi (Chair, Mer Gedkem Le) Moni Carlisle (TSRA) Emma Kennedy (AIMS)
11-14 Oct 22, Mer Island	Engagement with the Meriam People to obtain their permission and consent for the project. This included a presentation of the project to the Directors of the Mer Gedkem Le and community Elders on the 11th October (~20 people attended), and was followed up with a meeting with the Chair of the MGL and two Directors in the MGL office on the 12th October. Numerous informal discussions were	A. Hoey (JCU) M. Russell (PA) Mer Gedkem Le Directors, Meriam elders, Mer Isl community

	also held with the Directors of the MGL and community members over the course of the visit, and during and after a beach clean-up on the morning of the 14th Oct.	
15 Dec 22, Cairns	Meeting called by Chair Passi to discuss the draft *Cultural Heritage Agreement* (CHM) between the Mer Gedkem Le and JCU. Unfortunately, the draft CHM was not received until the 8th Feb 23, so this time was used to discuss the voyage and activities in greater detail	A. Hoey (JCU) A. Gloor (Millstream Prod) Falen Passi (Chair, Mer Gedkem Le)
25 Feb – 1 Mar 23	Ashmore and Boot Reefs voyage – leg 1 5-day voyage to Ashmore and Boot Reefs in which representatives of the Meriam people were provided with training and hands-on experience in a variety of techniques for monitoring the health of shallow and deep reef habitats and the population status of key marine species. Two berths on this leg of the voyage were made available to Millstream Productions to collect imagery for their documentary series "*Sea Country*" (funded through a separated Our Marine Parks Round 3 Grant)	A. Hoey, E. McClure, G. Galbraith, D. Burn, J. Chandler, B. Cresswell, V. Huertas (JCU), A. Gloor, S. Ireland (Millstream Prod), Falen Passi, Johnson Kaigey, Michael Salee, Nodoro Mabo (Meriam people), M. Russell (PA)
2 – 7 Mar 23	Ashmore Reef voyage – leg 2 5-day voyage to Ashmore Reef in which representatives of the Meriam people were provided with training and	A. Hoey, E. McClure, G. Galbraith, D. Burn, J. Chandler,

	hands-on experience in a variety of techniques for monitoring the health of shallow and deep reef habitats and the population status of key marine species. Were unable to access Boot Reef due to unfavorable weather	B. Cresswell, V. Huertas (JCU), Douglas Kaigey, John Tabo Jnr, Jimmy Passi, Taiku Wailu (Meriam people), M. Russell (PA)
June 24 (Planned) Mer Island	Presentation of key findings to Directors of the Mer Gedkem Le, community Elders, and the broader community. Activities to include a community lunch.	Proposed: A. Hoey, E. McClure, G. Galbraith, V. Huertas (JCU), M. Russell (PA)

3.2 Ecological surveys

Diver-based underwater visual census (UVC) of shallow reef habitats, and remote video surveys (Remotely Operated Vehicle and Baited Remote Underwater Video: ROV and BRUV, respectively) of deep reef habitats (10-80m) were conducted at Ashmore and Boot Reefs during a 10-day period from 25 Feb – 7 March 2023. The voyage to Ashmore and Boot Reefs was completed in conjunction with the CSMP 2023 Coral Sea Bright Spots Reef Health and Resilience survey (10 - 22 Feb), allowing for comparisons of Boot and Ashmore to the broader CSMP.

Unfavorable and uncharacteristic weather (strong north-westerly winds) at the time of the voyage meant that many of the sites surveyed in previous years (i.e., protected from south-easterly winds), as well as much of the lagoon of Ashmore Reef were inaccessible. However, this did allow surveys to be conducted of both shallow and deep reef habitats on the south-eastern

10 days
17 sites – 99 transects
5 km of UVC surveys
>130 diver hours

reef aspect of both reefs. To our knowledge the diver-based and ROV surveys conducted on the south-eastern aspect of Ashmore and Boot Reefs are likely the first formal surveys of these seaward shallow and mesophotic coral reef ecosystems, respectively.

3.2.1 Shallow reef habitats – Diver-based surveys

Diver-based surveys were conducted at 17 shallow reef sites across both Ashmore and Boot Reefs (Ashmore: 12 sites; Boot: 5 sites; Figure 3.1). At each site, diver-based surveys were generally conducted within each of two habitats, i) the reef crest (approximately 1-3m depth) and ii) the reef slope (9-10m depth, where possible). The only exception to this was one site inside the lagoon at Boot Reef (Boot site 8) where there wasn't sufficient depth to differentiate the reef slope and crest habitats.

In each depth zone at each site, three replicate 50m transects were run parallel to the depth contour, with up to 10m between successive transects. Surveys were conducted by a 4-person dive team, whereby the lead diver deployed the transect tape while simultaneously recording the size and identity of all larger (>10 cm total length, TL) or motile fish species, within a 5m wide belt (following Hoey et al. 2020, 2021, 2022). Deploying the transect while simultaneously recording fishes minimises disturbance prior to censusing, thereby minimising any bias due to mobile fishes avoiding (or in some cases being attracted to) divers. The second diver along the transect recorded the size and identity of smaller, site-attached fish species within a 2m wide belt (e.g., Pomacentridae), while species with larger home ranges were recorded within a 4m wide belt (e.g., Chaetodontidae; Appendix 2). The third diver conducted a point intercept survey, providing important information on coral cover and benthic composition, by recording the sessile organisms or substratum underlying evenly spaced (50cm apart) points along the entire length of the transect. The final (fourth) diver counted abundance of juvenile corals (as a proxy of recruitment) within a 10m x 1m belt. On the return swim along the transects, one diver quantified the abundance of non-coral invertebrates (e.g., sea cucumbers, giant clams, sea urchins, *Tectus* (formerly *Trochus*), and crown-of-thorns starfish) within a 2m wide belt along the full length of each transect.

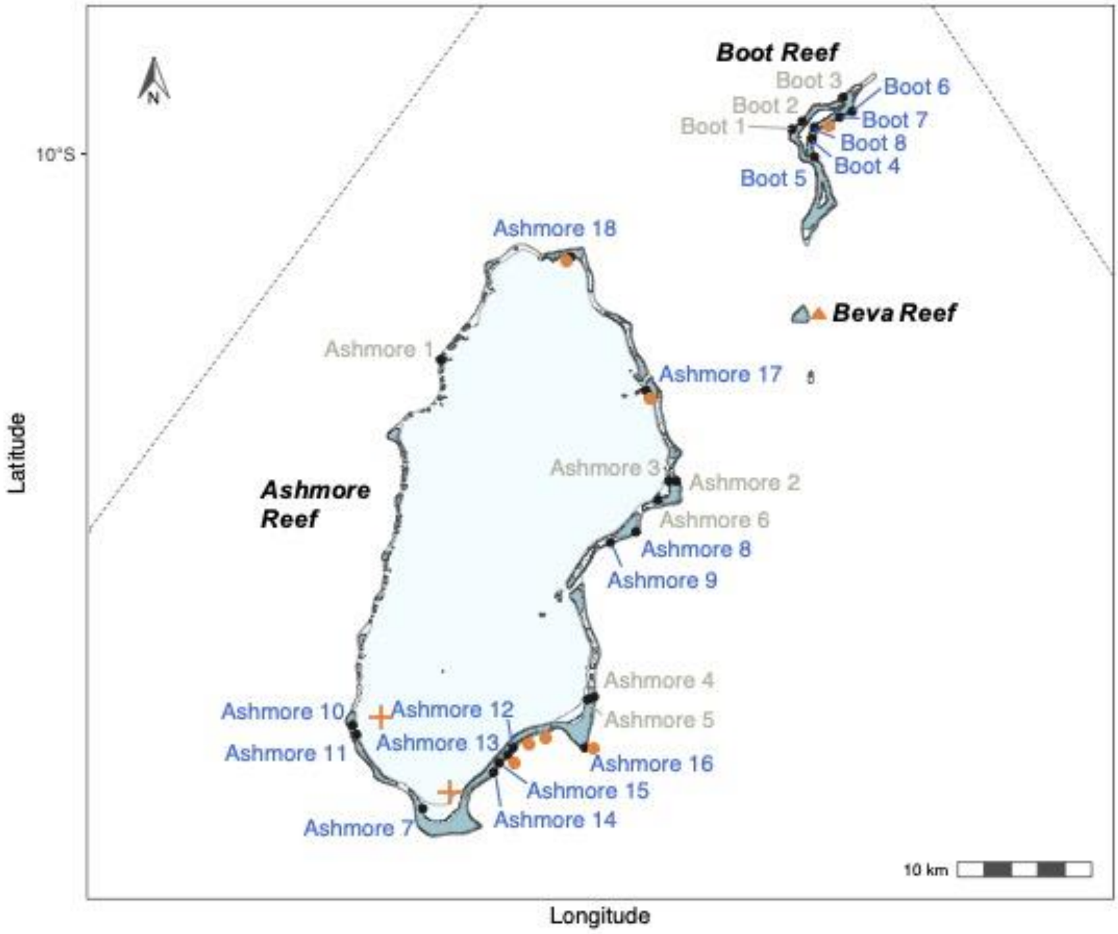


Figure 3.1 - Map of Ashmore, Boot and Beva Reefs. Black points with blue site names represent the 17 shallow reef sites surveyed by diver-based underwater visual census (UVC) during the 2023 voyage. Grey site names show sites surveyed in previous years. Orange circles show the sites of ROV surveys, orange crosses the BRUV drops, and the orange triangle the DOV survey on Beva Reef. The CSMP boundary is represented by the angled dotted lines extending from left and right to top of the map bounding box.

Benthic cover and composition – Point-intercept transects (PIT) were used to quantify benthic composition, recording the specific organisms or substratum types underlying each of 100 uniformly spaced points (50cm apart) along each transect (following Hoey et al. 2020, 2021, 2022). Corals were mostly identified to genus (using contemporary, molecular-based classifications for scleractinian corals), though some of the less abundant genera were pooled to 'other' for analyses. We also distinguished major growth forms for *Acropora* (tabular, staghorn, and other) and *Porites* (massive versus columnar or branching). Macroalgae were identified to genus. For survey points that did not intersect corals or macroalgae, the underlying substratum was categorised as either crustose coralline algae (CCA), sponge, sand/ rubble, carbonate pavement, or other (including gorgonians, hydroids, anemones).

Topographic complexity – Topographic complexity was estimated visually at the start of each transect, using the six-point scale formalised by Wilson et al. (2007), where 0 = no vertical relief (essentially flat homogenous habitat), 1 = low and sparse relief, 2 = low but widespread relief, 3 = moderately complex, 4 = very complex with numerous fissures and caves, 5 = exceptionally complex with numerous caves and overhangs.

Juvenile corals - Densities of juvenile corals (≤5 cm maximum diameter, following Rylaarsdam 1983) are increasingly used as a proxy for recovery potential of coral assemblages as opposed to quantifying the number of coral larvae that settle on experimental settlement substrata (e.g., tiles). Counting juvenile corals accounts somewhat for the high mortality rates of newly settled corals, and logistically only requires a single visit to the study site. Therefore, comprehensive counts of all juvenile colonies, including the smallest colonies that are detectable with the naked eye (approximately 1 cm diameter), enable effective comparisons of potential coral recovery among habitats, sites and reefs across the CSMP. All juvenile corals within the 10 x 1m coral health transect were recorded to genus (Figure 3.2).

Figure 3.2 Photographs of juvenile (≤5cm diameter) corals recorded within 10m^2 belt transects within the Coral Sea Marine Park. Each juvenile coral within the 10m^2 belt transects were identified to genus and recorded. Image credits: Deborah Burn

Coral reef fishes - Size (body length) and abundance of reef-associated fishes (e.g., Acanthuridae, Chaetodontidae, Labridae, Lethrinidae, Scarinae, Serranidae, and Pomacentridae) was quantified using standard underwater visual census (UVC) along replicate 50m transects (n = 3 per depth zone) at all sites. Various transect dimensions were used to account for differences in the body size, mobility, and detectability of different fishes, as well as making data more comparable to other surveys conducted within the GBRMP (e.g., Emslie et al. 2010) and other Australian Marine Parks (e.g., Hoey et al. 2018). Smaller site-attached species (Pomacentridae) were counted in a 2m wide belt ($100m^2$ per transect). Slightly larger bodied, site-attached species (e.g., Chaetodontidae, Labridae) were surveyed in a 4m wide belt ($200m^2$ per transect), while all larger and more mobile species were counted in a 5m wide belt ($250m^2$ per transect). Body size (total length) was recorded for each individual fish, and converted to biomass using published length-weight relationships for each species. Data were standardised as abundance and biomass per $100m^2$. See Appendix 2 for a comprehensive list of species surveyed.

Non-coral invertebrates – Non-coral invertebrates, including potential coral predators (e.g., crown-of-thorns starfish *Acanthaster* cf. *solaris*, pin-cushion starfish *Culcita novaeguineae*, and coral snails *Drupella* spp.) as well as ecologically and culturally important species, namely long-spined sea urchins (*Diadema* spp.) sea cucumbers (holothurians; Figure 3.3), giant clams (*Tridacna* spp.) and trochus (*Tectus* spp., formerly *Trochus* spp.), were surveyed in a 2m wide belt along each transect, giving a sample area of $100m^2$. For all crown-of-thorns starfish (*Acanthaster* cf. *solaris*) and giant clams (*Tridacna* spp.) observed, the size (diameter and length, respectively) was also recorded (to the nearest 10cm).

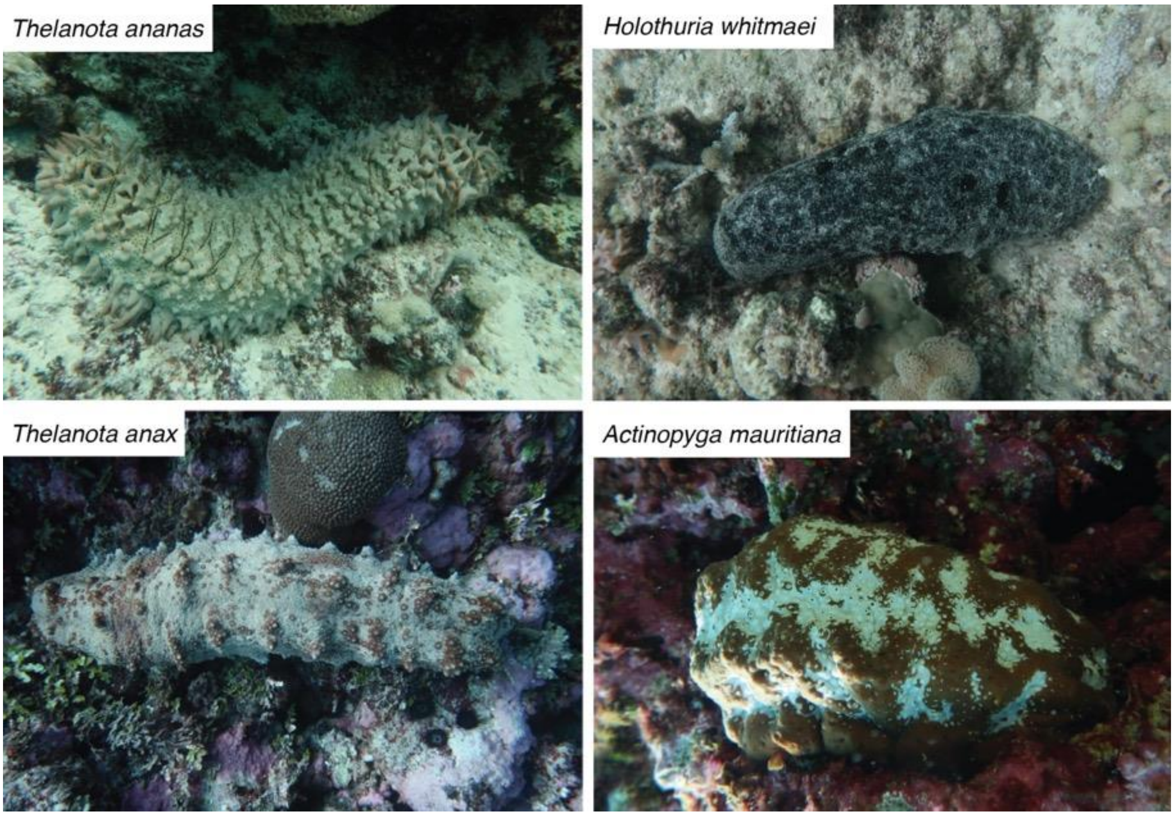


Figure 3.3 Photographs of four species of sea cucumber that are observed within the Coral Sea Marine Park; Prickly redfish, *Thelanota ananas*; Black teatfish, *Holothuria whitmaei*; Amber fish, *Thelanota anax*; and Surf redfish, *Actinopyga mauritiana*. Image credits: Deborah Burn

Coral predators are potentially important contributors to coral reef health and habitat structure, especially during periods of elevated predator densities (Pratchett et al. 2014). Population irruptions, or outbreaks, of crown-of-thorns starfish (*Acanthaster* cf. *solaris*) are a major contributor to coral loss on the Great Barrier Reef (De'ath et al. 2012) and are thought to have caused considerable coral loss on Elizabeth and Middleton Reefs in the 1980's (Hoey et al. 2018), though it is not known whether there have been population irruptions in the CSMP. Sea urchins, especially long-spined sea urchins of the genus *Diadema*, can also have a major influence on the habitat structure of coral reef environments (e.g., McClanahan and Shafir 1990; Eakin 1996). Like herbivorous fishes, larger urchin species such as *Diadema* spp. may be important in removing algae that would otherwise inhibit coral growth and/or settlement (Edmunds and Carpenter 2001). At high densities, however, intensive grazing by sea urchins may have negative effects on reef habitats, causing significant mortality of juvenile corals and loss of coral cover, thereby reducing topographic complexity of reef habitats (McClanahan and Shafir

1990), and ultimately can lead to a net erosion of the reef carbonates (Glynn et al. 1979; Eakin 1996).

Sea snakes – The abundance and size of sea snakes (including the Olive sea snake, *Aipysurus laevis*; Dubois' sea snake, *Aipysurus duboisii*; Spiny headed or Horned sea snake, *Hydrophis peronii*; Turtle-headed sea snake, *Emydocephalus annulatus*; Figure 3.4) were quantified within the same 50 x 5m belt transects used to survey large, mobile reef fishes. Only one sea snake was observed during the diver-based surveys at Ashmore and Boot Reef, and as such data on their abundances is not presented.

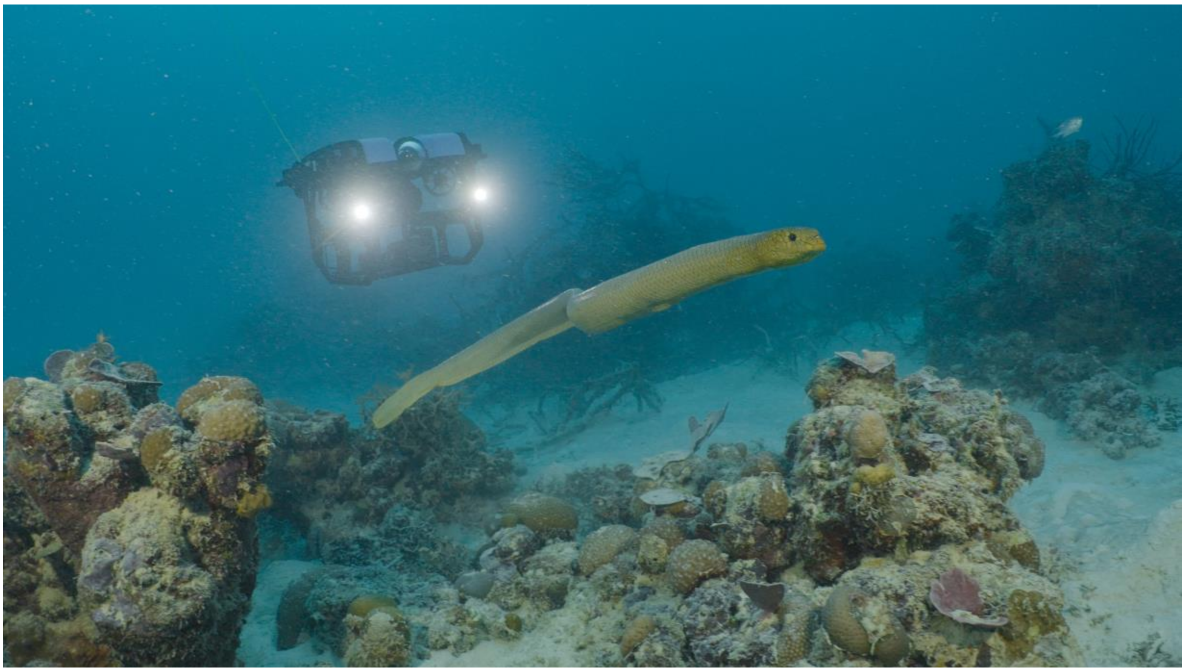


Figure 3.4 An Olive sea snake, *Aipysurus laevis* recorded in the lagoon at Ashmore Reef. The ROV piloted by one of the Meriam people can be seen in the background. Image credit: Stuart Ireland (Millstream Productions)

3.2.2 Deep reef habitats – Video-based surveys

Remotely Operated Vehicle (ROV) surveys were undertaken at six sites at Ashmore Reef and one site at Boot Reef. Overall, 14 ROV dives and 30 transects were completed between depths of 10-80m, following protocols detailed in Galbraith et al. (2022). At each reef, ROV survey sites were selected based on proximity to shallow reef monitoring sites and the feasibility of deploying, piloting and retrieving survey equipment given the prevailing sea and weather conditions.

The strong north-westerly winds prevented the safe deployment and operation of the ROV at many locations.

ROV configuration and field operation - All deep-habitat transect surveys were conducted using a BlueROV 2 high-performance underwater ROV. The ROV was constructed with an 8-thruster vectored configuration and 2 high-powered lumen Subsea lights. In addition to the onboard high-definition (1080p, 30fps), wide-angle, low-light optimized camera that was used for piloting the ROV, the ROV was fitted with a forward-facing GoPro Hero 8 housed inside a deep rated aluminum T-housing to allow fish communities to be surveyed.

Additionally, a time-lapse benthic camera system consisting of three GoPro Hero 7 action cameras inside deep rated aluminum T-housings was used. These GoPros were mounted on the left and right side of the ROV to allow the benthic communities on steep habitats (i.e., walls) to be photographed, and one GoPro mounted facing downwards on the ROV payload skid to allow the benthic assemblages on relatively flat, or horizontal, habitats to be photographed. The cameras were set to take timelapse photos resulting in an average of 35 benthic photos (range 16-60) per transect.

The ROV was deployed, piloted and retrieved from a tender launched from the *MV Iron Joy* (Figure 3.5). At each site, the ROV was deployed and descended to the maximum depth possible depending on the habitat type, sea conditions, and maximum depth rating of the ROV (i.e. 100m). Once at the target depth the ROV was positioned ~0.5m above the substratum (or alongside for vertical reef walls), and two timed transects were conducted at a constant depth. Each transect was 2.5 minutes long and by travelling at a known speed of 0.2m/s^{-1}, equating to a distance of approximately 30m. The start and end of each transect was defined by a side-to-side ‘head-shake’ movement of the ROV. Transects within each depth band were separated horizontally by 5-10m. After the second transect within a depth band, the ROV ascended by 5 -10m and two more transects were conducted at this depth in the opposite direction to the previous two transects (i.e., at the depth band immediately below). This survey pattern was repeated at ~10m depth bands until the two final transects were conducted (Figure 3.6).

Figure 3.5 Photograph showing the operation of the Remotely Operated Vehicle (ROV) from a tender to the *MV Iron Joy* in the Coral Sea Marine Park. Top: The ROV being deployed from the tender with the operator (Gemma Galbraith, standing) piloting the ROV, while an assistant manages the tether (Ben Cresswell). Image credits: Victor Huertas

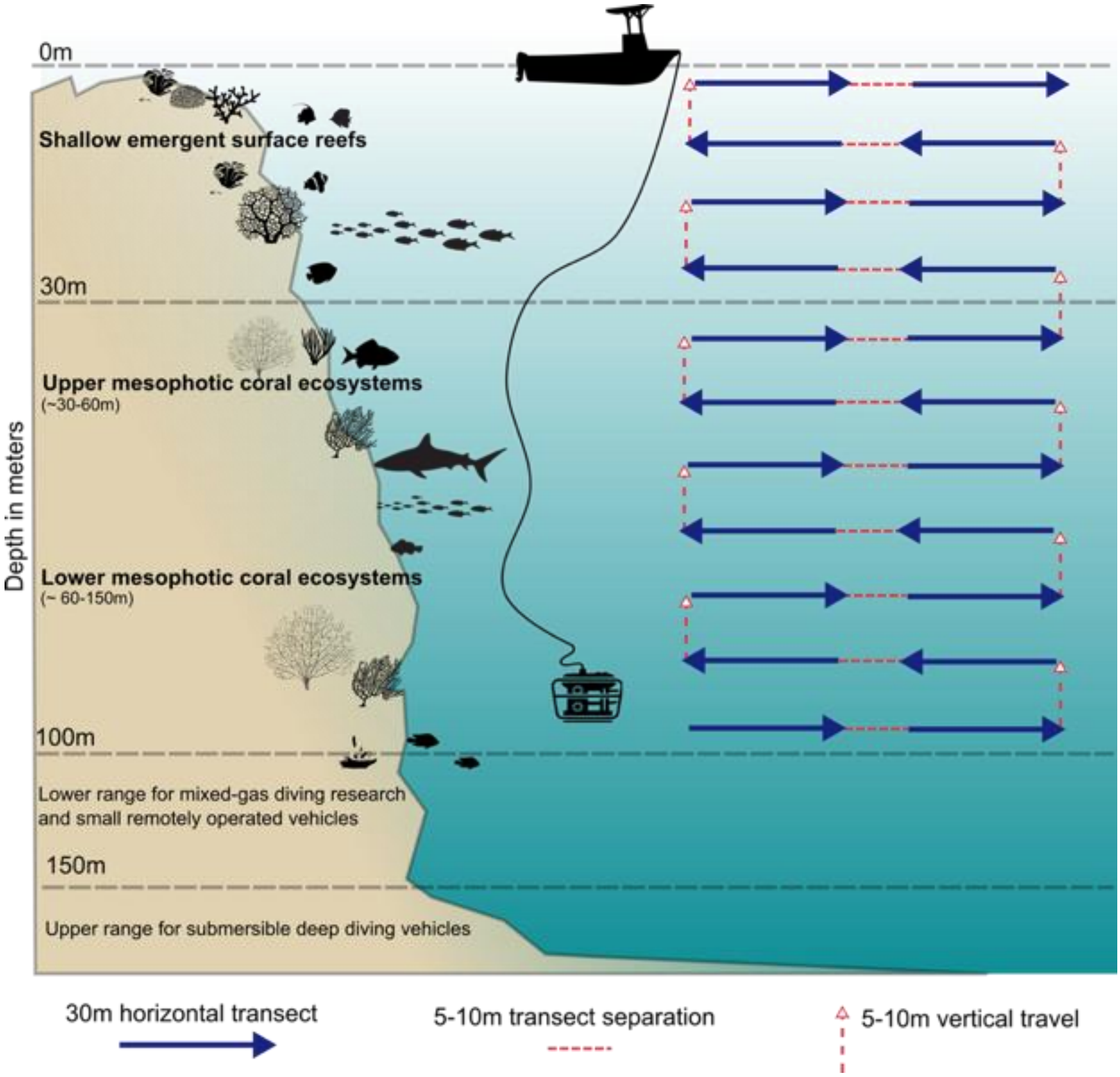
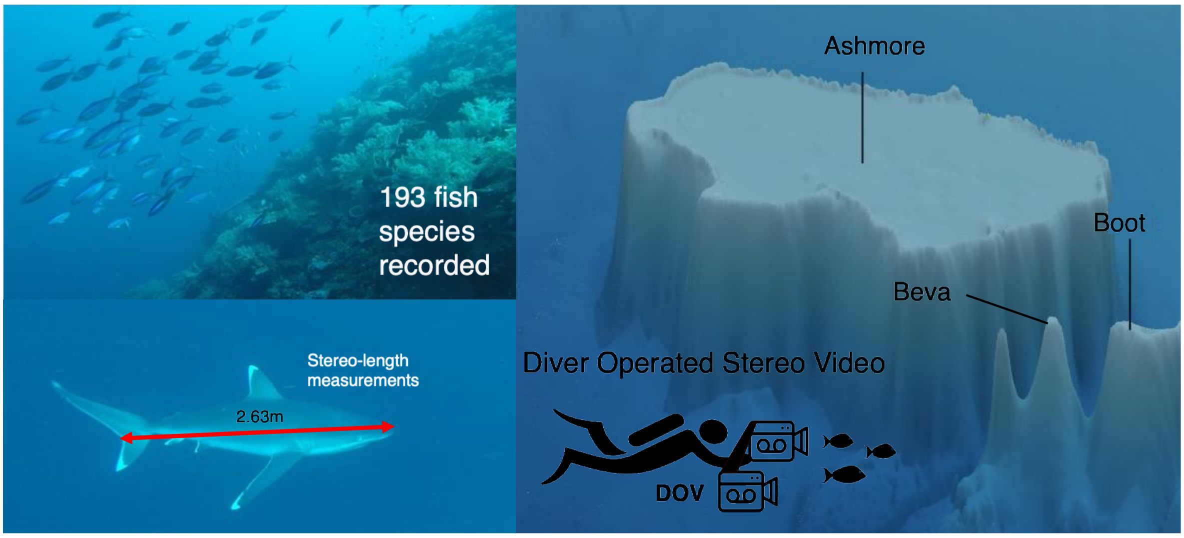


Figure 3.6 Remotely Operated Vehicle (ROV) transect survey methodology used to survey fish and benthic communities in the Coral Sea Marine Park. All ROV surveys were conducted at depths between 10 – 80m using the BlueRobotics BlueRov2.

BRUV configuration and field operation - Eight BRUV drops were conducted across two sites at Ashmore Reef within the lagoon between depths of 25-45m. No BRUV drops were possible on seaward reefs of either Ashmore or Boot Reef due to the steep walls and the prevailing wind and sea conditions at the time of the survey.

All BRUVS used in this project were constructed by SeaGis (SeaGIS Pty Ltd, Australia). Each system consisted of a weighted frame, waterproof camera housing, bait arm and bait bag. GoPro Hero7 cameras were used in each BRUV and set to 1080 resolution, 60fps and medium field of view. 1kg of frozen pilchards was used as bait for each drop. Bait was thawed and crushed prior to surveys and placed in the mesh bag positioned 1.2m from the camera by the bait arm. BRUVS were deployed from a tender to the main vessel between daylight hours of 0800 and 1600. Individual BRUV drops at a given site were separated by at least 500m to reduce the likelihood of non-independence due to individual animals being sampled by adjacent BRUV systems (Langlois et al. 2020). Each BRUV was set for at least 1hr, starting from the time the system reached the seafloor. BRUVS were recovered by hand-hauling or using a lightweight pot-hauler fitted to the tender.

Diver operated stereo video (DOV) configuration and field operation - One DOV survey of the fish community at Beva Reef was conducted along five replicate belt transects of approximately 30 m in length by 5 m in width. The survey at Beva Reef was done as part of the engagement and training aspect of this project, to introduce the Mer Island representatives to a range of technologies used in reef fish monitoring and research. Detailed protocols for using DOVs to survey fish communities are described in Goetze et al. 2019. For the Beva Reef survey, a diver swam a stereo-video system (SeaGIS Pty, Australia) housing two GoPro Hero 4 cameras pointing forwards at 0.5 m above the reef at a steady speed (approx. 20 m/min) following the reef contour. A second diver timed the swim and indicated to the diver operating the camera when the end of each transect had been reached. The start and end of each transect was defined by a side-to-side movement of the DOV system.



3.2.3 Image processing

Video analyses - Fish species and abundance data were extracted from the ROV and DOV videos using the specialised software EventMeasure (SeaGis Pty Ltd, Australia). Footage from each ROV and DOV transect was played back in EventMeasure, with each fish along the transect identified to species level and counted. From ROV surveys fish species richness, diversity (Shannon-Weiner H') and density were calculated for each transect and standardised to 150m^2.

For BRUVs, 1 hour of video footage was viewed, starting 1 minute after the BRUV system arrived on the seabed to allow the fish community to resettle after the deployment. This 60 min "soak time" has been shown to effectively sample elasmobranch species (i.e., sharks and rays) in shallow coral reef habitats (Currey-Randall et al. 2020) and is the recommended duration for BRUV deployments (Langlois et al. 2020). Every fish entering the field of view was identified to species and the maximum number of individuals observed in a single video frame for each species (MaxN) was recorded. MaxN is a widely-used estimate of relative abundance for BRUV and other stationary video surveys (Ellis and DeMartini 1995; Willis and Babcock 2000) as it avoids repeatedly counting the same individual, which may enter, exit and then re-enter the field of view. For all video methods, any individual fish that could not be identified to species level were recorded to genus or family.

Benthic image analysis - Benthic habitat data was collected from both ROV and BRUV surveys. For ROV surveys, the benthic environment on each ROV transect was categorised from still images taken parallel to the reef topography and analysed using the free cloud-based machine learning platform ReefCloud following ReefCloud's analysis protocols (AIMS 2024). Briefly, photographs were uploaded to ReefCloud, grouped at the level of Transect within each Site on each Reef. On each photo, a grid of 12 uniformly spaced points was overlayed for observer annotation, using a custom classification label set developed specifically for this project (Appendix 3). The label set was designed to reflect the classification system used in shallow water diver surveys, with modifications to account for the low light environments and lower resolution of still images taken on deep reefs (i.e., higher emphasis on morphological characteristics than taxonomic characteristics). Through annotation of 12 points per image, the user trained a model on each benthic category via machine learning. Once sufficiently trained, the model classified another 38 points per image. The ReefCloud platform includes model validation tools to check the performance of the model in classifying points. Point classifications (50 points per image) were exported as a .csv file to calculate percent cover of benthic categories of interest.

For each BRUV survey, a single image was analysed using screen shots from the forward-facing GoPro video cameras. Each still screen shot was analysed in TransectMeasure (SeaGIS Pty Ltd, Australia) following established protocols and using predefined benthic CATAMI categories commonly used for BRUV image analysis (Hill et al. 2014). Briefly, benthic categories were assigned hierarchically, starting with a ‘broad’ category, further defined by ‘morphology’ and ‘type’ where applicable (e.g., Stony [Hard] coral > branching > live; Appendix 4). Classifications of ‘open water’ and ‘unknown’ substrata (due to low light or visibility, and distance of reef from camera) were removed before calculating percent benthic cover estimates for each classification.

3.3 Data handling and analysis

All data were handled in R Version 4.3.2. (R Core Team 2023). Data were wrangled using the *tidyverse* environment (Wickham 2017) and visualised using the *ggplot2* package (Wickham 2016). Colour palettes for figures were chosen in *RColorBrewer* (Neuwirth 2014) and *viridis* (Garnier 2018), with visualisations aided by *ggrepel* (Slowikowski 2018) and *ggpubr* (Kassambara 2018). Maps of the CSMP and CSMP reef boundaries were reproduced from Australian Government shapefiles contained in *gisaimsr* (Barneche and Logan 2021) and *dataaimsr* (AIMS Datacentre 2021), data courtesy of the Great Barrier Reef Marine Park Authority, or generated by Project 3DGBR (Beaman 2012). All maps were produced in R using the package *sf* (Pebesma 2018) and *ggspatial* (Dunnington 2021) using the WGS84 coordinate system.

Shallow reef habitats: UVC data analysis – All survey data were averaged across independent transects to obtain a site average prior to summarising data at the level of reefs. For calculations of taxonomic richness, the number of species/taxa were calculated at the level of site (i.e., pooled among transects and reef zone) to give the total (not average) number of species/taxa observed at a site, prior to being summarised to the level of reefs. While the focus of this report is on Ashmore and Boot Reefs, survey data collected at other CSMP Reefs during the are used for comparison. Where data are presented as box and whisker plots, each boxplot represent the distribution of the data based on the minimum, first quartile, median, third quartile and maximum values. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the hinge to the largest value no further than 1.5 * IQR from the hinge (where IQR is the inter-quartile range, or distance between the first and third quartiles). The lower whisker extends from the hinge to the smallest value at most 1.5 * IQR of the hinge. Data beyond the end of the whiskers (i.e., outliers) are plotted individually.

Deep reef habitats: ROV and BRUV data analysis - ROV survey data were averaged across independent transects within 10m depth bins (i.e., 11-20m, 21-30m etc.) or categories (Shallow: 0-30m, Mid: 31-60m and Deep: 61-100m) to obtain a site-depth average prior to summarising at the level of reefs and/or regions. BRUV drops were treated independently and categorised as Shallow, Mid and Deep only (due to low replication), before being summarised at the level of site, reef or region. For calculations of taxonomic richness, the number of species/taxa were calculated at the level of site (i.e., pooled among transects or drops) to give the total number of species/taxa observed at a site, prior to being summarised to the level of reefs or regions. Data are presented using a combination of descriptive infographics, and box and whisker plots (i.e., box plots) for comparing density (ROV) and relative abundance (MaxN – BRUV), species richness of diversity.

4 *Findings*

4.1 Engagement and collaboration with the Meriam people

The engagement, collaboration and knowledge exchange with the Meriam people through this project was highly successful. The presentations, meetings and informal discussions with community elders, Chair and Directors of the Mer Gedkem Le, and the Mer Island community during the initial visit to Mer Island (11-14 October 2022) were well received and secured the support of the Meriam people for the project (Figure 4.1).



Figure 4.1 Photographs from the initial visit to Mer Island, 11-14 October 2022. Top left: Andrew Hoey (project lead) presenting to the Mer Gedkem Le and community Elders; top right: Community event at the beach; bottom left: Mer Gedkem Le Chair, Falen Passi (left) showing Martin Russell, Parks Australia (middle) and Andrew Hoey (JCU) around Mer Island.

During the voyage to Ashmore and Boot Reefs, eight members of the Meriam people (Falen Passi - Chair Mer Gedkem Le, Johnson Kaigey, Michael Salee, Nodoro Mabo, Douglas Kaigey, John Tabo Jnr, Jimmy Passi and Taiku Wailu) were provided training in the use of diver-based transects, Remotely Operated Vehicle (ROV), Baited Remote Underwater Video (BRUV), and Diver Operated Stereo Video (DOV), as well as video analysis, data handling and equipment maintenance. The Meriam representatives were then given the opportunity for hands-on experience in the operation and use of this equipment and survey techniques.

Figure 4.2 Training in the use of various survey methods on the back deck of the *MV Iron Joy* during the voyage to Ashmore and Boot Reefs. Top left: Andrew Hoey describing the use of transects for diver-based surveys of reef fishes; Top right: Josie Chandler describing the survey of corals and macro-invertebrates; Bottom left: Ben Cresswell explaining the deployment of BRUVs and providing a lesson in knot tying. Bottom right: Chair Falen Passi, Nodoro Mabu, and Johnson Kaigey constructing a BRUV unit ready for deployment.

Figure 4.3 Photographs of Falen Passi (Chair, Mer Gedkem Le; top left), Douglas Kaigey (top right), John Tabo Jnr (bottom left), and Taiku Wailu (bottom right) piloting the ROV while other voyage participants watch on. An X-box controller is used to control the movement of the ROV, and the footage from an onboard camera is projected on the computer screen.

Figure 4.4 Photographs of representatives of the Meriam people observing and assisting with diver-based surveys of corals and reef fish in shallow water reef habitats.

During the voyage to Ashmore and Boot Reefs, the representatives of the Meriam people (in particular Falen Passi, Douglas Kaigey, and John Tabo Jnr) shared their knowledge of these reefs and the diverse communities of animals and plants they support. Onboard the *MV Iron Joy*, our team gave a presentation to provide an overview of the underwater research activities we conduct during our surveys and the reef life we have previously documented in Ashmore and Boot Reefs and other reefs in the CSMP. This presentation sparked a lively conversation, prompting the representatives of the Meriam people to ask several questions about the surveys and share their personal experiences with some of the organisms depicted in our slides. Our team expressed a particular interest in learning the Meriam Mir language, with a focus on the traditional names for various reef organisms, including different types of corals and fish species. A collaborative effort between representatives of the Meriam people, members of our team and Martin Russell (Parks Australia) resulted in the compilation of a comprehensive list featuring over 100 traditional Meriam Mir names for reef organisms, including 78 fishes. Inspired by this exchange, an initiative was launched to produce a poster showcasing some of the most common and charismatic fishes found in the reefs surrounding Mer Island, and Ashmore and Boot Reefs. Titled "*Keriba Lar Kerbi Gurlam"*, meaning "*Our Fishes of Our Sea*" in Meriam Mir language (Figure 4.5), this poster aims to celebrate and contribute to the preservation of the rich cultural heritage embedded in the traditional Meriam Mir names of the fish fauna inhabiting the Meriam Sea Country.

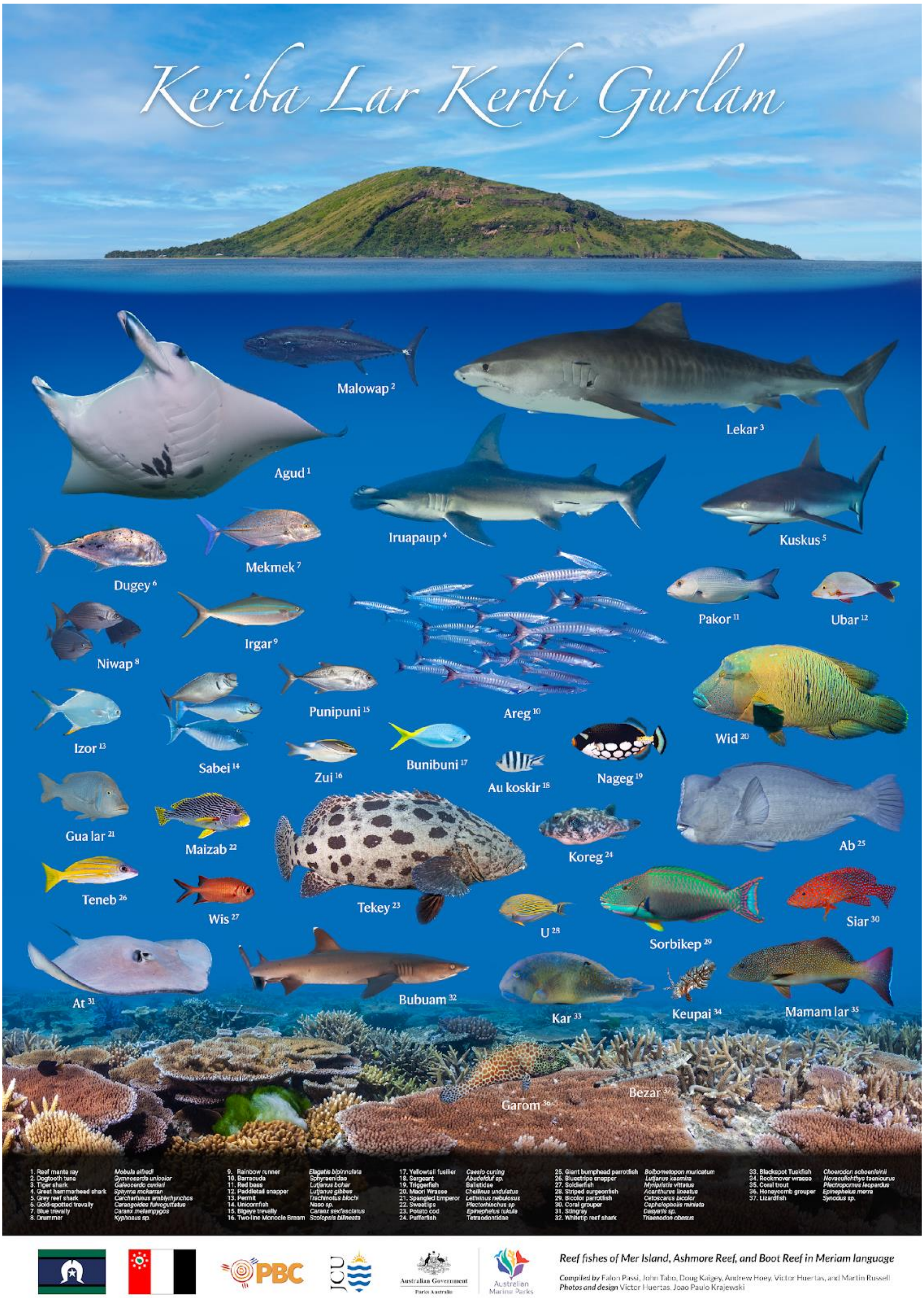


Figure 4.5 Poster titled *Keriba Lar Kerbi Gurlam* (*Our Fishes of Our Sea* in Meriam Mir) produced as an additional part of this project. The poster (one copy printed on durable paper with a UV coating, and mounted in either acrylic or aluminium, and several paper copies) will be presented to the Mer Island community during a planned visit in 2024.

4.2 Ecological surveys

4.2.1 Shallow Reef Habitats

Coral cover - The average cover of hard (scleractinian) corals recorded across the 17 sites surveyed across Ashmore and Boot Reefs in 2023 was 31.6% (±2.5 SE), ranging from 16.50% (±5.9 SE) at Ashmore 8 to 47.5% (±2.5 SE) at Ashmore 17 (Figure 4.6). While average coral cover was generally greater on Ashmore Reef (35.2%) than Boot Reef (22.8%), there was considerable variation in coral cover among sites on each reef. Coral cover varied from 16.5% (Ashmore 8) to 47.5% (Ashmore 17) on Ashmore Reef and was generally greatest on the south-east and north-east aspects of the reef (Figure 4.6). Coral cover was less variable on Boot Reef, ranging from 18.0% in the lagoon (Boot 8) to 29.0% on the exposed eastern face of the reef (Boot 7). Much of the variation in coral cover among sites was due to the large differences in coral cover on the shallow reef crests of sites on the exposed eastern faces of these reefs (Figure 4.7).

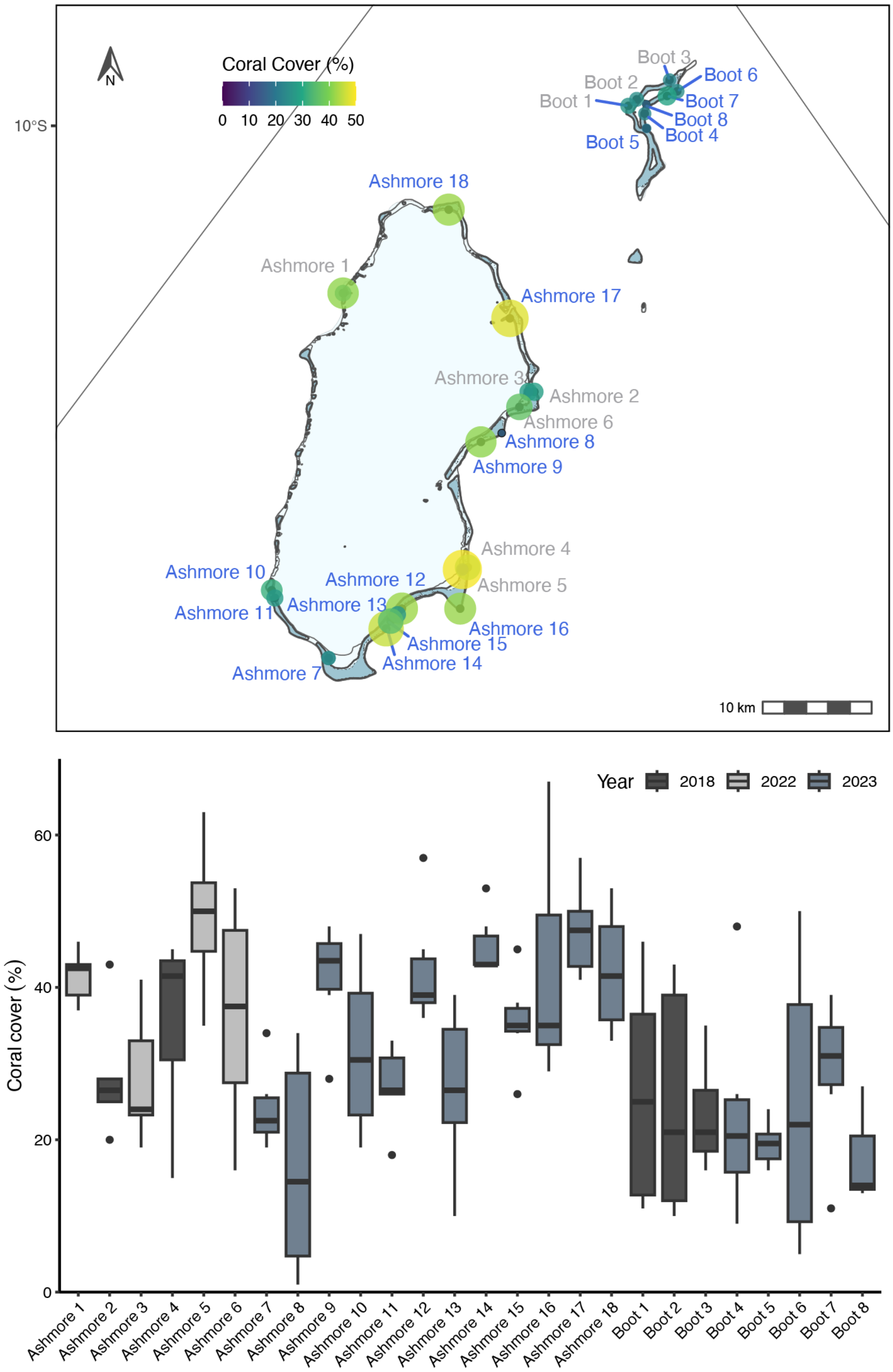


Figure 4.6 Map showing spatial variation in average coral cover across Ashmore and Boot Reefs. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the percentage of hard coral cover at each site. Data are based on replicate 50m point-intercept transects.

Figure 4.7 Photographs showing the variation in the cover and richness of corals on exposed reef crests of Ashmore and Boot Reefs. Clockwise from top: Ashmore 16, Ashmore 13, Boot 6 and Boot 7. Note the extremely low coral cover on the reef crest at Boot 6. Photos: Victor Huertas

Coral richness - The average taxonomic richness of corals across Ashmore and Boot Reefs, based on the number of hard (scleractinian) coral taxa (mostly genera) recorded using the 50m point-intercept transects at each survey site, was 17.4 taxa per site. Average taxonomic richness was relatively consistent between reefs (Ashmore: 17.0 taxa per site; Boot: 18.2 taxa per site) but displayed considerable variation among sites within each reef (Ashmore: 13-20 taxa per site; Boot: 13-22 taxa per site; Figure 4.8). The highest coral richness on both Ashmore and Boot Reefs was recorded on the north-western aspect of each reef during previous surveys (2018 and 2022; Ashmore 1: 29-32 taxa per site; Boot 2: 28 taxa per site). The lower richness recorded during the 2023 surveys likely reflects the different sites and aspects surveyed in each year, rather than a decline in coral richness.

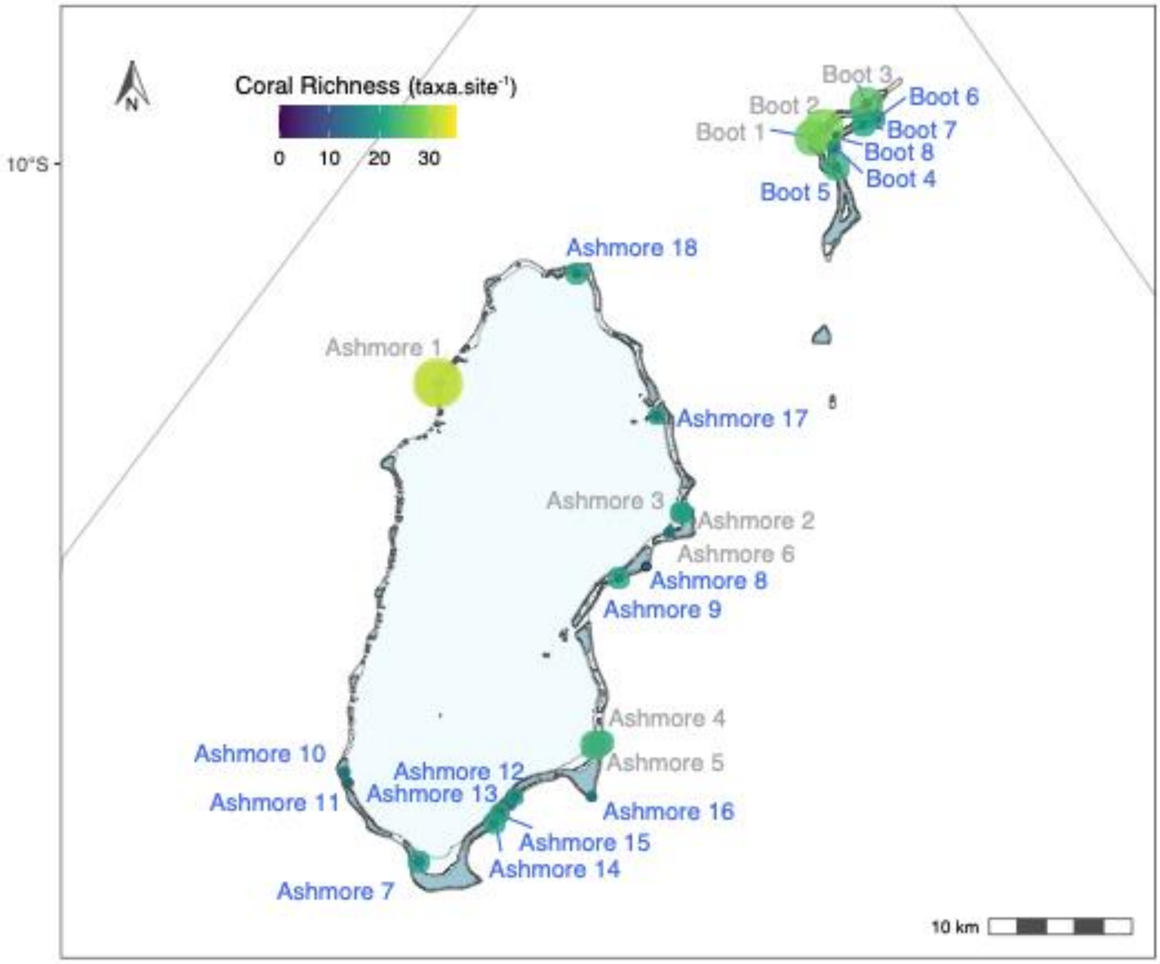


Figure 4.8 Map showing spatial variation in average taxonomic richness of corals across Ashmore and Boot Reefs. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the number of coral taxa recorded at each site.

Coral recruitment - A total of 6,912 juvenile corals (≤5cm diameter; Rylaarsdam 1983) were recorded across the 17 shallow reef sites surveyed on Ashmore and Boot Reefs in 2023, equating to a mean density of 69.8 juvenile corals per 10m^2 (Ashmore: 72.8 juvenile corals per 10m^2; Boot: 65.8 juvenile corals per 10m^2). The density of juvenile corals was highly variable among sites, ranging from 22.5 to 116.7 juvenile corals per 10m^2 at Ashmore 7 and Ashmore 14, respectively (Figure 4.9). The density of juvenile corals was generally greater on sites on the exposed eastern and south-eastern aspect of each reef, and lower in the lagoon and sheltered sites on the western aspect of each reef. The density of juvenile corals recorded on Ashmore and Boot Reefs in 2023 were the highest recorded across all CSMP reefs over the past six years (2018-2023), and directly comparable to those of more connected reef systems (e.g., mid-shelf GBR: 61-82 juvenile corals per 10 m^2, Trapon et al. 2013; New Caledonia: 20 - 116 juvenile corals per 10 m^2, Adjeroud et al. 2010).

Comparisons to other CSMP reefs surveyed in 2023 show that Ashmore and Boot Reefs have among the highest coral cover and coral richness, and the greatest density of juvenile corals recorded across all reefs (Figure 4.10).

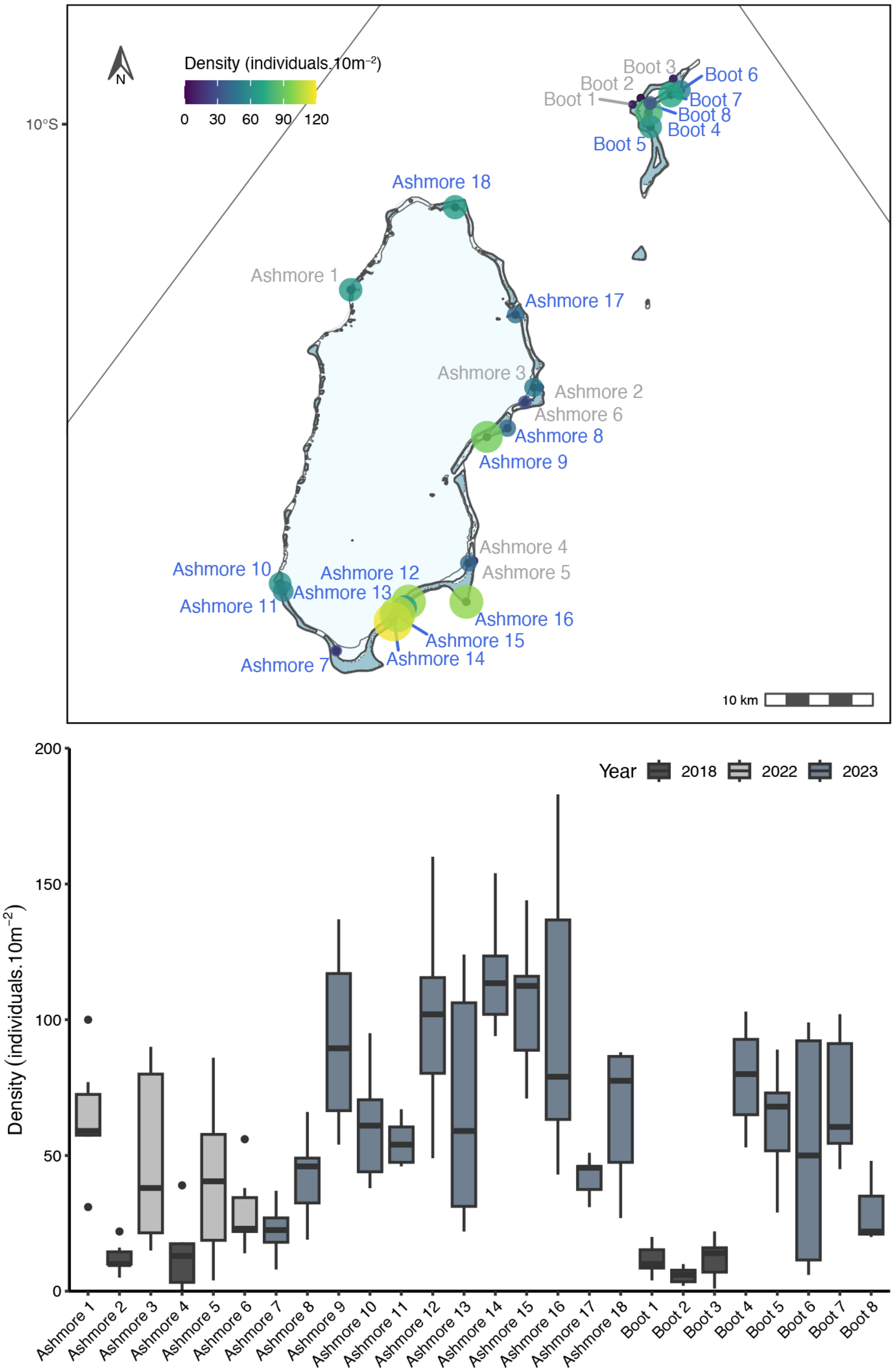


Figure 4.9 Spatial variation in the density of juvenile corals across Ashmore and Boot Reefs. *Top*: Map showing spatial variation in the density of juvenile corals among sites. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the number of coral taxa recorded at each site. *Bottom*: Box plot showing differences in the density of juvenile corals among sites.

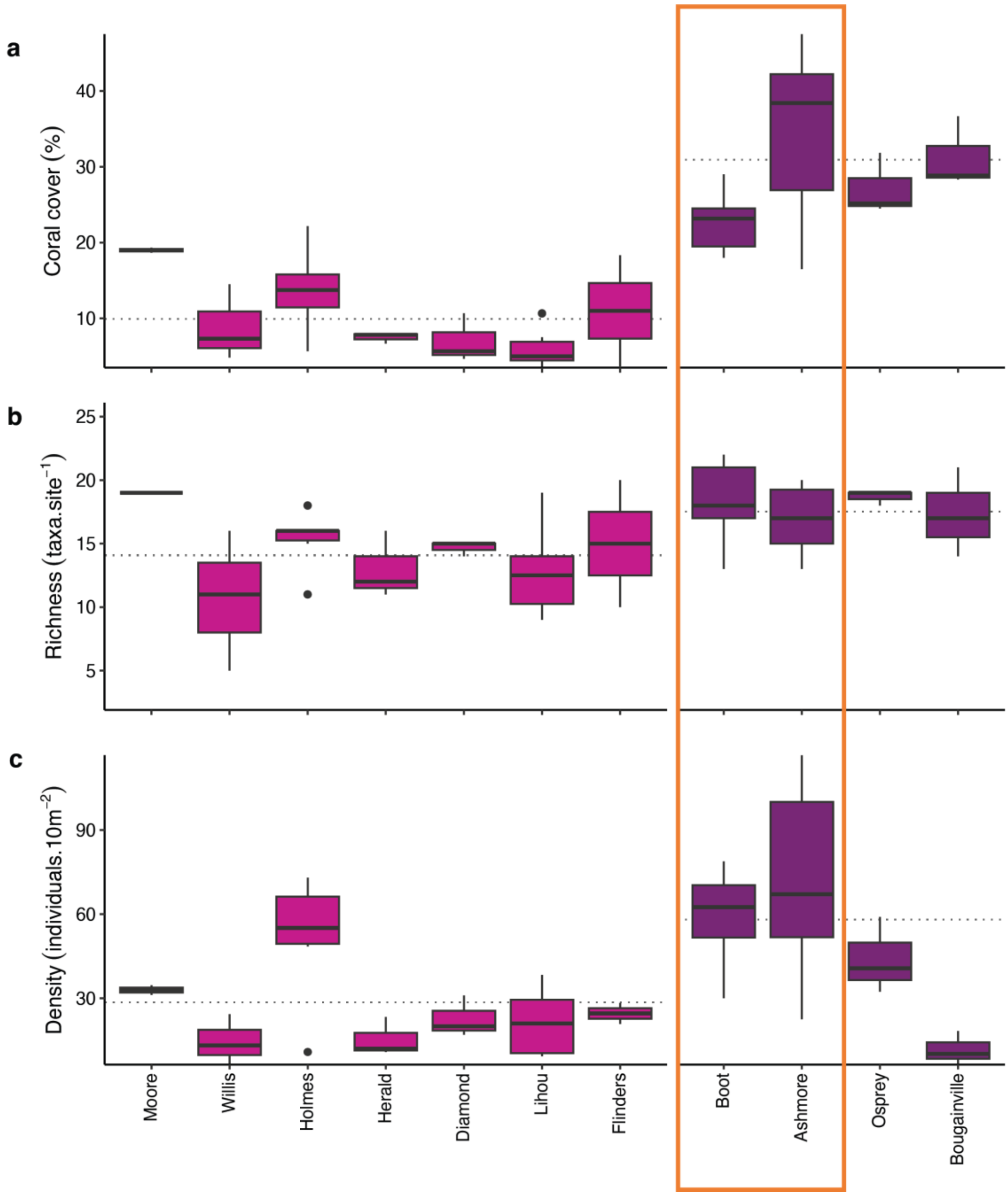


Figure 4.10 Variation in (a) coral cover, (b) coral richness, and (c) juvenile coral densities among 11 reefs in the Coral Sea Marine Park (CSMP) in 2023. Coral cover and richness data are based on the 50m point-intercept transects, with data for richness based on the number of coral taxa recorded at each site (i.e., pooled across transects and slope and crest habitats). Juvenile coral data are based on the 10 x 1m belt transects. Reefs are arranged into the central and northern CSMP and coloured by *a priori* regional assignments. Dotted lines represent regional averages.

Crustose coralline algae (CCA) – The average cover of crustose coralline algae (CCA) recorded across the 17 sites at Ashmore and Boot Reefs was 18.1% (Ashmore Reef:19.6%; Boot Reef: 13.9%), and lower than other reefs in the northern CSMP (Bougainville: 23.5%; Osprey: 35.6%) and reefs in the central

CSMP (33.3%; Figure 4.11). While CCA's are generally viewed as a critical component of healthy coral reef ecosystems, contributing to reef calcification, cementing and infilling (e.g., Teichert et al. 2020; Cornwall et al. 2023), inducing the settlement of coral larvae (e.g., Harrington et al. 2004; Abdul Wahab et al. 2023), and potentially the provision of 3-dimensional structure for reef associated species (Hoey et al. 2022), the lower levels of CCA at Ashmore and Boot Reef likely reflect the higher cover of live coral on these reefs.

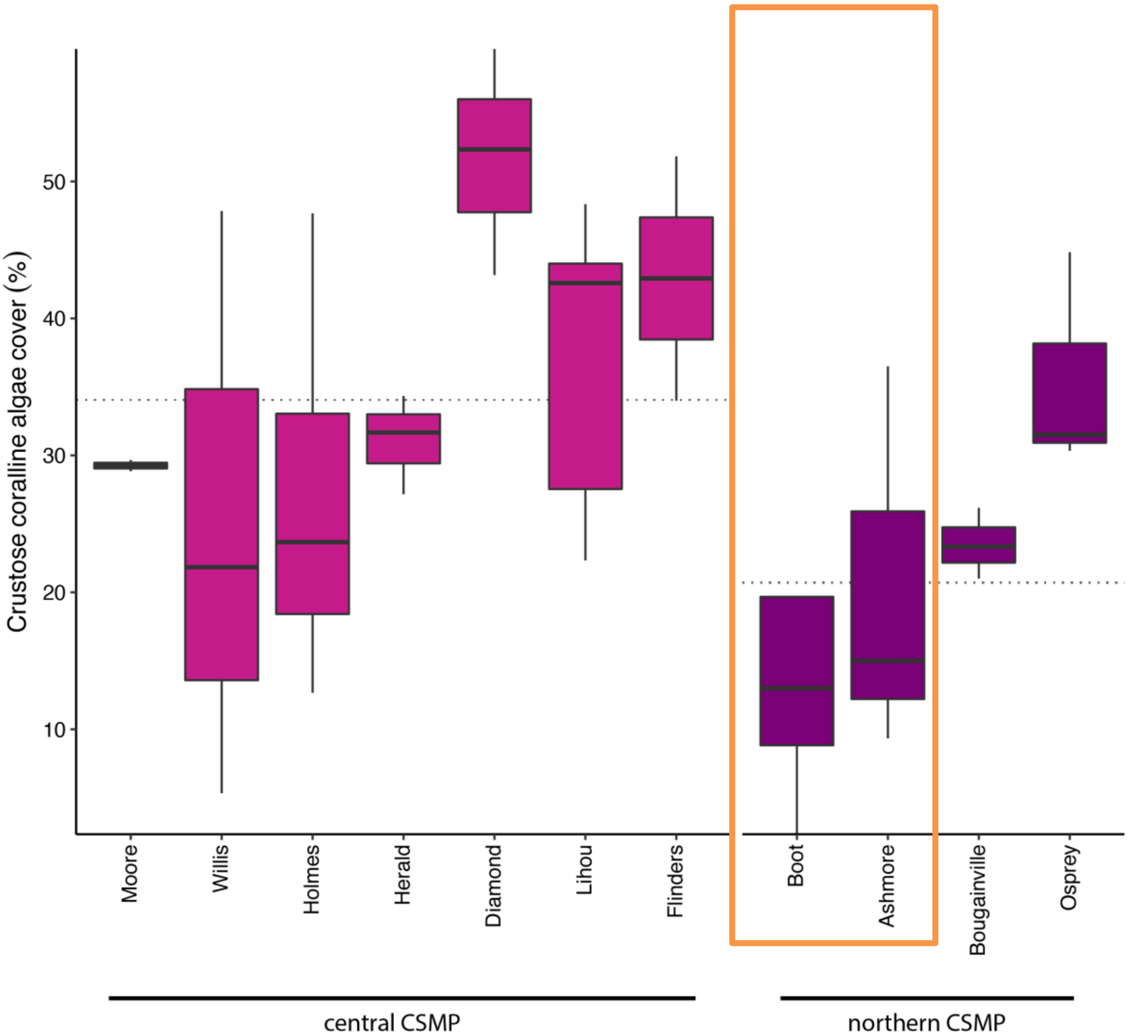


Figure 4.11 Variation in the cover of crustose coralline algae among 11 reefs in the Coral Sea Marine Park (CSMP) in 2023. Data are based on the 50m point-intercept transects. Reefs are arranged into the central and northern CSMP and coloured by *a priori* regional assignments (following Hoey et al. 2020). Dotted lines represent regional averages.

Coral reef fish

The abundance, richness and biomass of coral reef fish assemblages is tightly linked to the composition and structure of benthic communities. In particular, the cover and composition of live corals is a major determinant of reef fish assemblages with approximately 75% of reef fish species using live coral at some stage during their life cycle (e.g., as a settlement or juvenile habitat; Coker et al. 2014). Given the high cover and taxonomic richness of coral assemblages on Ashmore and Boot Reefs, it is not surprising that these reefs support abundant and diverse reef fish assemblages.

A total of 32,797 fishes were recorded across the 17 sites surveyed across Boot and Ashmore Reefs in 2023. Eleven fish species (*Chromis richardsoni, Cirrhilabrus* sp., *Epinephelus spilotoceps, Lutjanus biguttatus, Naso lopezi, Naso minor, Naso thynnoides, Pentapodus aureofasciatus, Pycnochromis lineatus, Scarus festivus,* and *Sphyraena qenie*) that had not been recorded during surveys or observations of shallow reef habitats of these reefs or the broader CSMP on the previous voyages (2018-2022) were recorded during the 2023 surveys. Three of these species (*N. lopezi, N. minor,* and *P. aureofasciatus*) have been previously recorded in deeper (>40m) reef habitats in the CSMP using baited remote underwater video systems (BRUVs; Galbraith et al. 2022), and the remaining eight species were new records for the CSMP. These new observations take the total fish species recorded in shallow reef habitats on Ashmore and Boot Reefs to 331 species, and >650 species across the CSMP during the past seven years of surveys.

The species richness of reef fishes at Ashmore and Boot Reefs was generally high (average = 88 species per site) and relatively consistent among sites, ranging from 71 species per site at Ashmore 14 to 111 species at Boot 5 (Figure 4.12). These estimates of fish species richness were, however, generally lower than those recorded during previous surveys at these reefs (i.e., 2018 and 2022), and likely reflect the different habitats and aspects surveyed in each year.

The mean density and biomass of reef fish across Ashmore and Boot Reefs was 200.8 individuals per $100m^2$ and 12.7 kg per $100m^2$, respectively. There was, however, considerable variation in reef fish density and biomass among sites, with reef fish density varying 4.5-fold, from 127 (Ashmore 8) to 567 individuals per $100m^2$ (Ashmore 16), and reef fish biomass varying 27.7-fold, from 4.7 (Ashmore 13) to 130.4 kg per $100m^2$ (Ashmore 16; Figures 4.13, 4.14). Notably, the density and biomass of reef fish at Ashmore 16 was one of the highest, if not the highest, recorded across all CSMP reefs in the past 6 years, with large schools of trevally and midnight snapper distributed along the reef edge (Figure 4.15). The estimated biomass of reef fish at Ashmore 16 is an order of magnitude greater that estimates of unfished biomass for coral reefs globally (10 – 12.5 kg per $100m^2$; MacNeil et al. 2015; McClanahan 2018). This site was on a promontory (or point) on the exposed eastern aspect of Ashmore Reef, and experiences strong water flow (even during slack tides when our surveys were conducted), and it is likely that the strong water flow and mixing of currents makes this a highly productive area for reef fishes. Reef fish biomass was also particularly high on the reef slope at Boot 5, with large schools of paddletail snapper, bumphead parrotfish, and unicornfish.

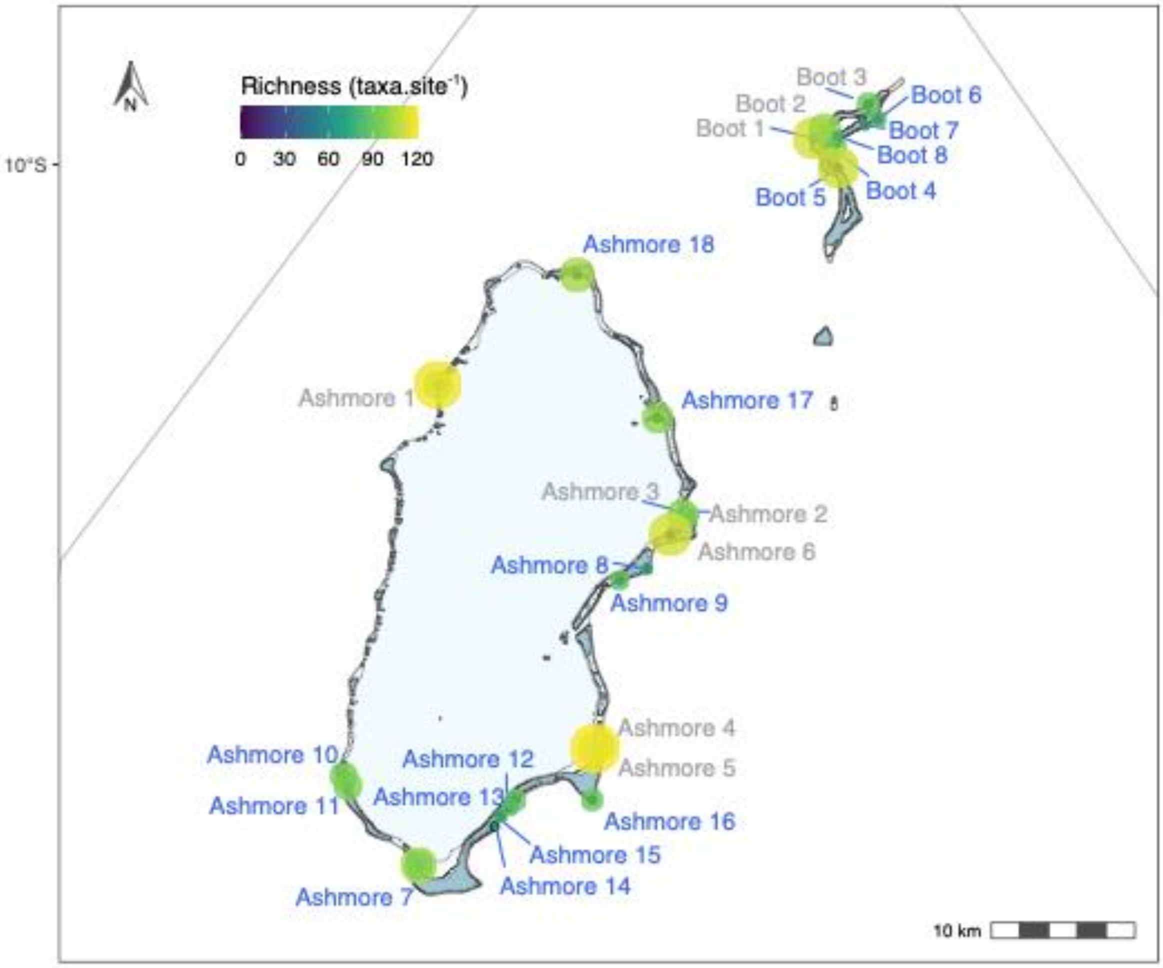
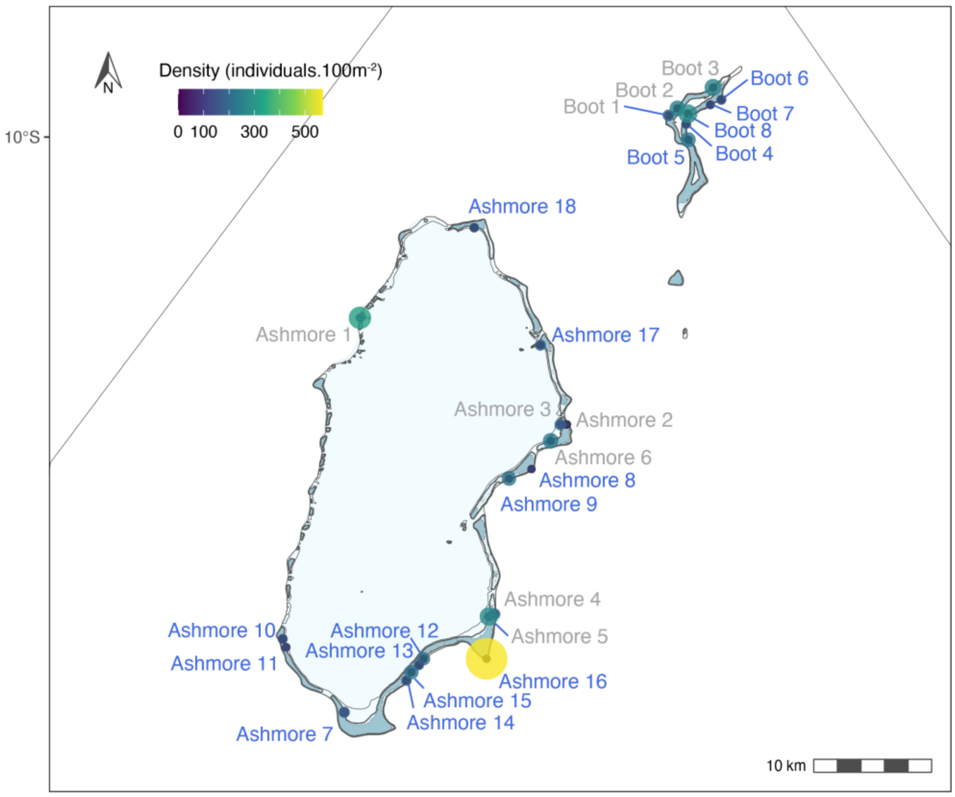


Figure 4.12 Map showing spatial variation in average taxonomic richness of reef fish across Ashmore and Boot Reefs. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the number of fish species recorded at each site.

Reef fish density



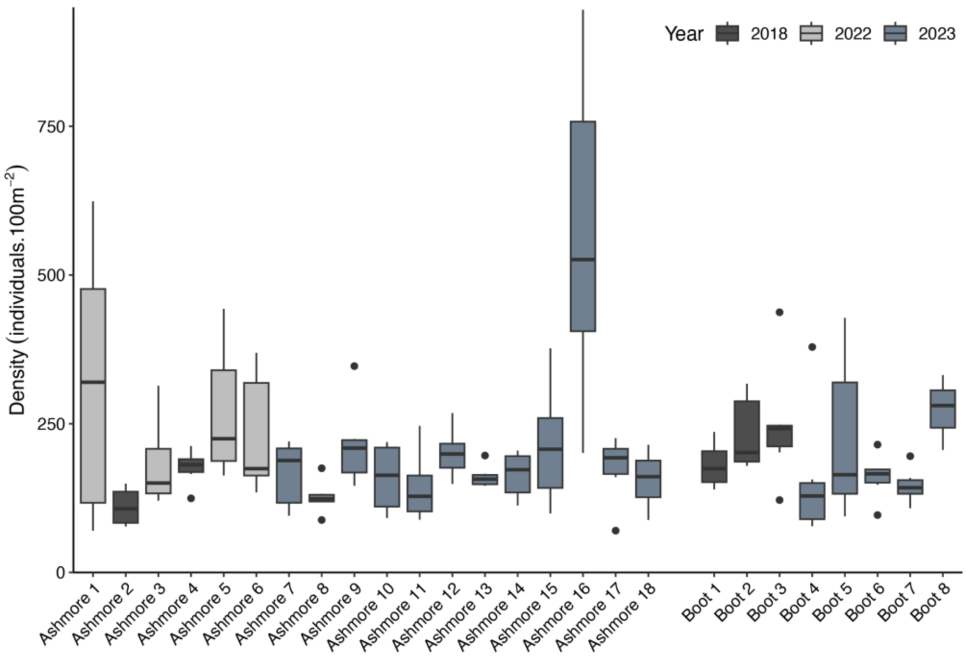


Figure 4.13 Spatial variation in the density of reef fish across Ashmore and Boot Reefs. *Top*: Map showing spatial variation in the density of reef fish among sites. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the number of coral taxa recorded at each site. *Bottom*: Box plot showing differences in the density of reef fishes among sites

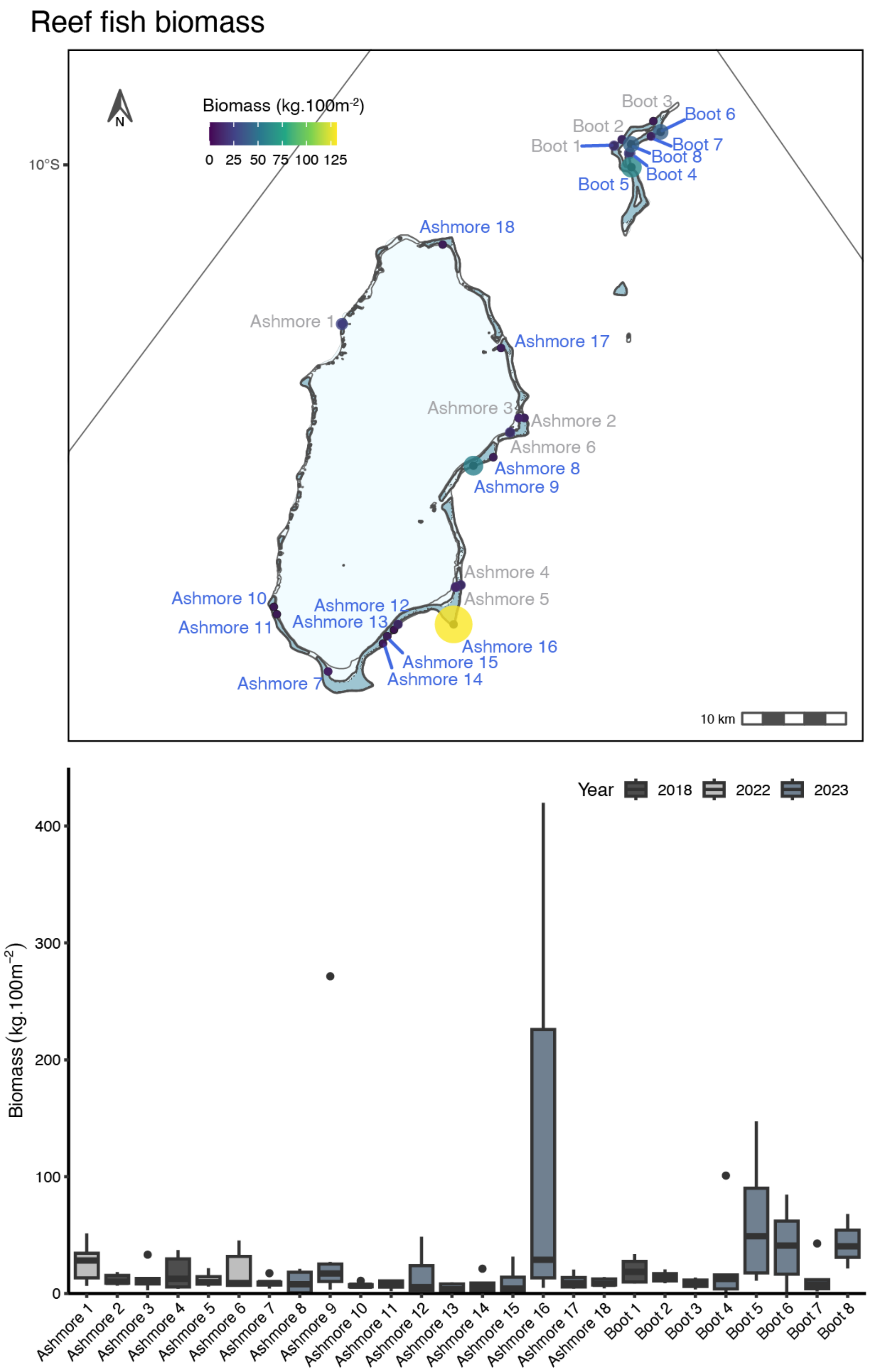


Figure 4.14 Spatial variation in the biomass of reef fish across Ashmore and Boot Reefs. *Top*: Map showing spatial variation in the biomass of reef fish among sites. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the number of coral taxa recorded at each site. *Bottom*: Box plot showing differences in the biomass of reef fishes among sites

Photographs of abundant and high biomass fish communities at Boot site 5 on the exposed aspect of Boot Reef, northern Coral Sea Marine Park. Top: Large school of bumphead parrotfish (*Bolbometopon muricatum*) on the shallow reef crest. Each individual is 80-100cm long. Bottom: School of paddletail snapper (*Lutjanus gibbus*) closely associated with the benthos at 12m on the reef slope. Note the difference in the benthic communities between habitats. Image credits: Andrew Hoey

Figure 4.15 Photographs of abundant and high biomass fish communities at Ashmore site 16 on the exposed aspect of Ashmore Reef, northern Coral Sea Marine Park. Top: Schools of small planktivorous fish on the shallow reef crest. Bottom: School of trevally at 12m on the reef slope. Image credits: Victor Huertas (top), Eva McClure (bottom)

Overall, the taxonomic richness of reef fishes at Ashmore and Boot Reef were comparable to the other northern CSMP reefs surveyed in 2023, however the density of reef fishes at Boot Reef, and the density and biomass of reef fishes at Ashmore Reef were lower than those of the other two reefs in the northern CSMP (Figure 4.16). The lower estimates of reef fish density and biomass compared to other CSMP reefs, and the lower estimates of reef fish richness, density and biomass compared to previous surveys at Ashmore and Boot Reefs in 2018 and 2020 likely reflect the lower coral cover and structural complexity of sites surveyed on the exposed eastern aspect of both reefs in 2023. Previous sites that had been surveyed of the sheltered western aspect of each reef, and several sites within the lagoon at Ashmore Reefs were inaccessible due to unfavourable weather conditions at the time of the surveys.

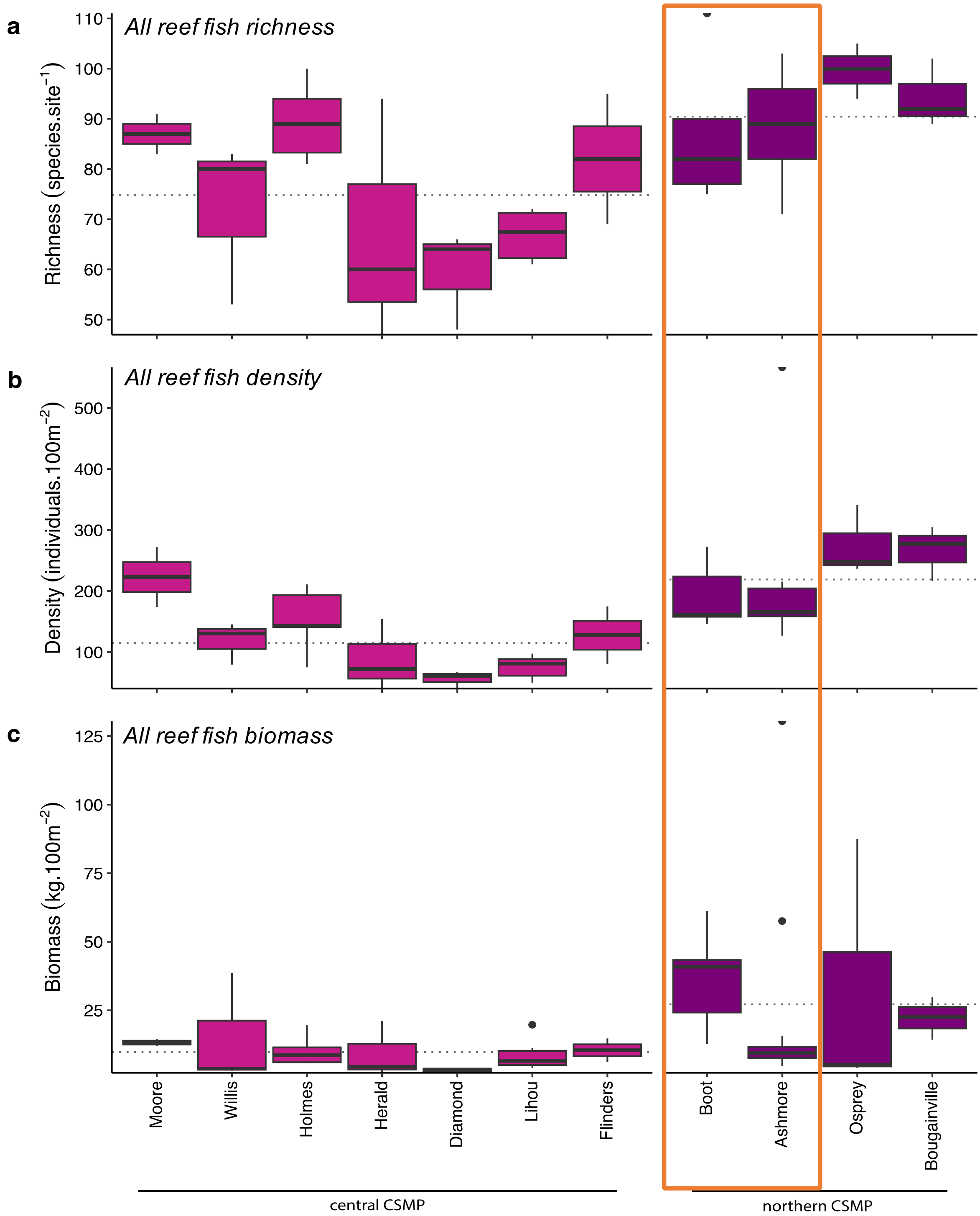


Figure 4.16 Spatial variation in the **(a)** species richness, **(b)** abundance, and **(c)** biomass of coral reef fishes and sharks among the 11 reefs surveyed in the Coral Sea Marine Park during 2023. Data are based on the 50m belt transects, with data for richness based on the number of fish species recorded at each site (i.e., pooled across transects and slope and crest habitats). Reefs are arranged into the central and northern CSMP and coloured by *a priori* regional assignments (following Hoey 2020). Dotted lines represent regional averages.

Species of potential cultural importance

The Mer Gedkem Le and members of the Mer Island community (in particular fishers and divers) were consulted regarding species and/or areas on Ashmore and Boot Reefs that were culturally important during a visit to Mer Island (11-14 October 2022) by the Project Lead (Prof Andrew Hoey) and CSMP Manager (Martin Russell). From these discussions it became apparent that the very few, if any, of the Meriam People had visited Ashmore and Boot Reefs, and as such their knowledge of these reefs was limited. No specific areas on these reefs were identified as culturally important, and the species identified as being of importance aligned with previous discussions held with the Meriam People in October-November 2018. The species identified were primarily those of subsistence and economic importance (sea cucumbers, giant clams, trochus, coral trout, humphead Maori wrasse, barramundi cod, sharks). Humphead Maori wrasse and barramundi cod were rarely observed on the transects and so are not present here.

Giant clams – Overall, 64 giant clams (*Tridacna* spp.) were recorded across the 17 sites on Ashmore and Boot Reefs in 2023, with the vast majority (57 individuals, 89.1%) being *Tridacna maxima* and *Tridacna squamosa.* The other species recorded were *Tridacna derasa* (2 individuals, 3.1%) and *Tridacna gigas* (4 individuals, 6.3%). The average density of giant clams (*Tridacna* spp.) across all sites was low (0.6 clams per 100m^2) compared to other Indo-Pacific reefs (e.g., French Polynesia: 291-771 clams per 100m^2 Gilbert et al. 2006; Malaysia: 1-5 clams per 100m^2, Tan et al. 1998; Palau: 16.2 clams per 100m^2, Hardy and Hardy 1969), but comparable to previous studies of the CSMP and GBRMP (e.g., Hoey et al. 2020). There was, however, considerable variation among sites, ranging from 0 clams per 100m^2 on many of the sites on the exposed eastern aspect of both reefs to 2.2 clams per 100m^2 within the lagoon at Ashmore Reef (Ashmore 7 and Ashmore 10; Figure 4.17). Importantly, four large *T. gigas* were recorded in the lagoon at Ashmore Reef, yet this species is extremely rare or absent on other CSMP reefs (Hoey et al. 2020, 2021, 2022).

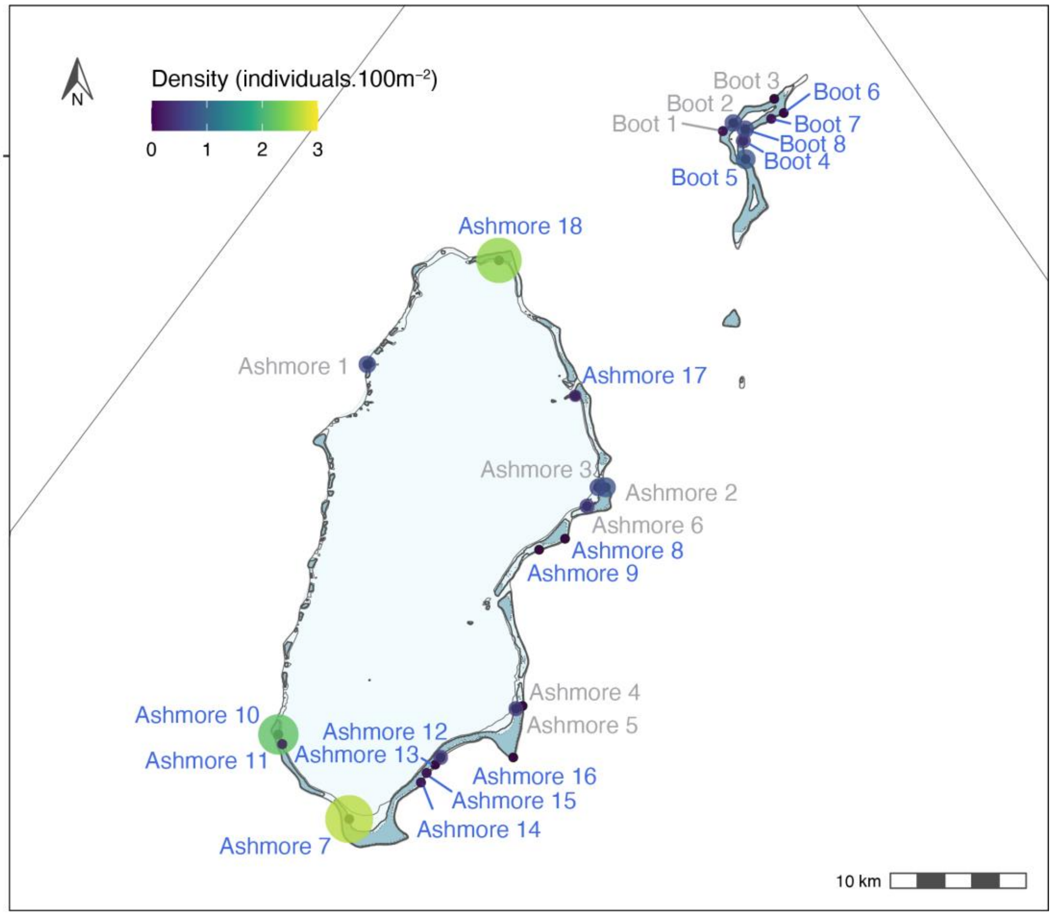


Figure 4.17 Spatial variation in the density of clams (*Tridacna* spp.) across Ashmore and Boot Reefs. *Top*: Map showing spatial variation in the density of clams among sites. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the density of clams recorded at each site. *Bottom*: Photograph of *Tridacna gigas* in the lagoon at Ashmore 10. Image credit: Andrew Hoey

Trochus –*Tectus* spp. (formerly *Trochus*) were relatively rare across the sites surveyed on Ashmore and Boot Reefs, with 13 individuals recorded across the 17 sites, equating to mean density of 0.13 individuals per 100m^2 (Figure 4.18). The density of *Trochus* tended to be greater at lagoon sites in the south of Ashmore Reef, however given the low and variable densities across all sites (0-2 individuals per 100m^2, with *Trochus* being not recorded at many sites) it is difficult to determine if these differences are ecologically meaningful. The estimates of *Trochus* density were, however, higher than those of previous studies in the CSMP and GBRMP (<0.002 individuals per 100m^2; Hoey et al. 2020), comparable to those of Ashmore Reef, Western Australia (0.2-0.4 individuals per 100m^2; Ceccarelli et al. 2010), and lower than those from Guam (up to 100 individuals per 100m^2; Smith 1987).

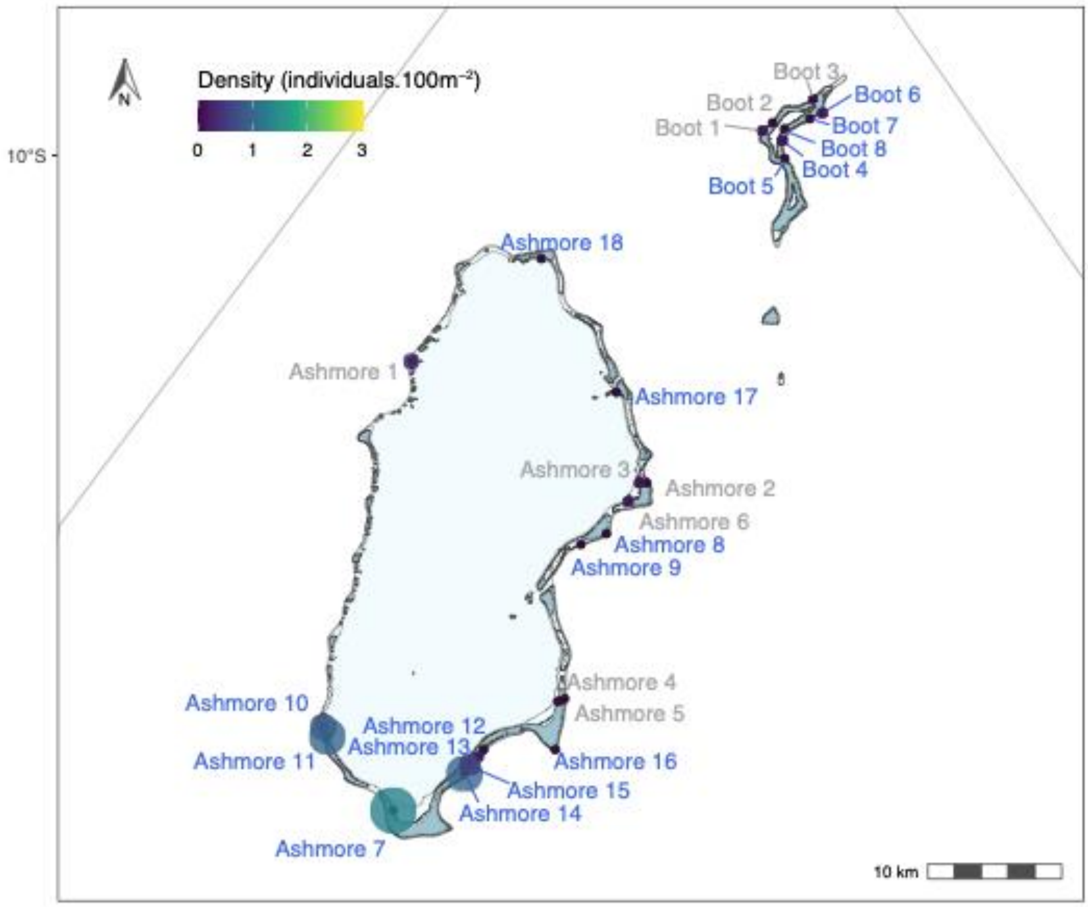


Figure 4.17 Map showing the spatial variation in the density of *Trochus* spp. across Ashmore and Boot Reefs. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the density of *Trochus* recorded at each site.

Sea cucumbers – A total of 32 sea cucumbers (Holothuroidea) from 8 species were recorded across the 17 sites on Ashmore and Boot Reefs in 2023, equating to an average of 0.36 individuals per 100m^2. These estimates of sea cucumber density were comparable to those of previous studies of similar habitats in the CSMP (e.g., 0.38 individuals per 100m^2; Hoey et al. 2020), but lower than those from the GBRMP (*ca.* 1-2 individuals per 100m^2; Hoey et al. 2020), and lagoonal habitats within the CSMP (1.33 individuals per 100m^2; Skewes and Persson 2017). Interestingly, the highest density of sea cucumbers was recorded at Boot 8 (1.7 individuals per 100m^2). Boot 8 is within the enclosed lagoon at Boot Reef (Figure 4.19) and can only be accessed by small vessels at high tide (i.e., when there is sufficient water to navigate over the shallow reef flat). The higher densities of sea cucumber at this site may reflect lower fishing pressure and warrants further investigation.

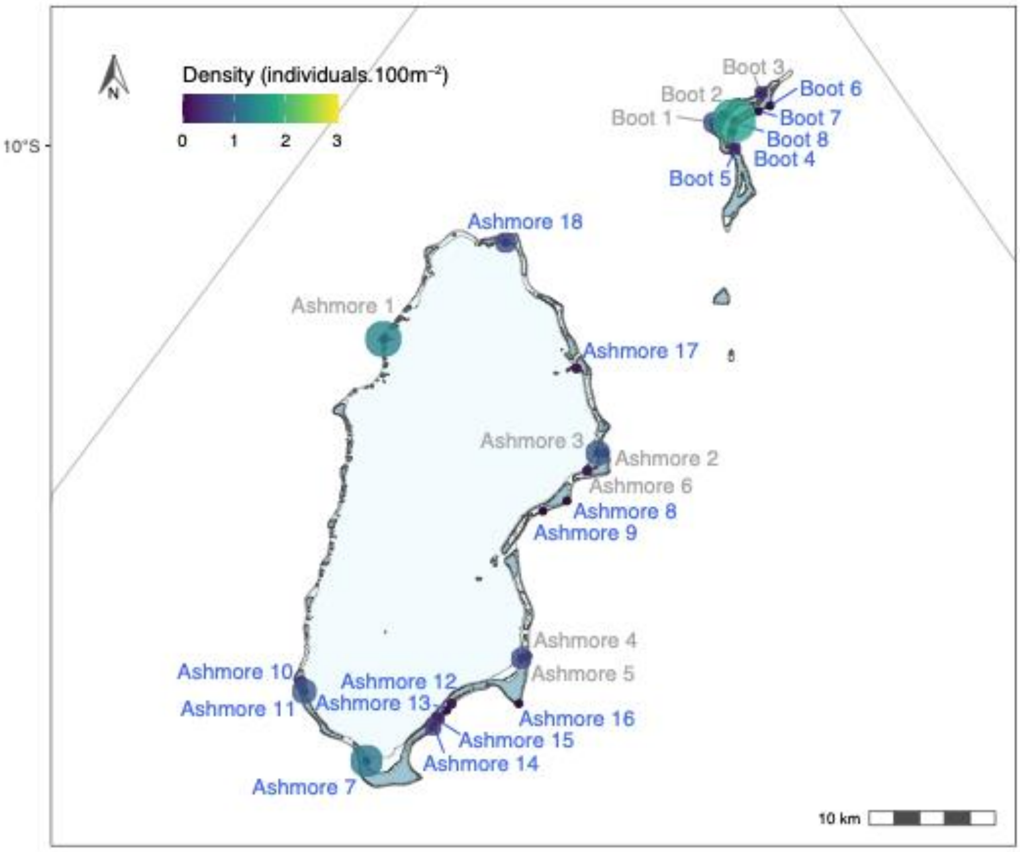


Figure 4.18 Map showing the spatial variation in the density of sea cucumbers (Holothuroidea) across Ashmore and Boot Reefs. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the density of sea cucumbers recorded at each site.

Figure 4.19 Aerial photograph of the enclosed lagoon at Boot Reef. Image credit: Stuart Ireland, Millstream Productions

When interpreting the density estimates of these macroinvertebrates (i.e., giant clams, trochus and sea cucumbers), and the species composition of giant clams and sea cucumbers across the CSMP, consideration needs to be given to the sampling design, and in particular the habitats surveyed. Our surveys were designed primarily to provide robust estimates of coral and associated reef fish assemblages, and as such were conducted on areas of contiguous reef with a defined reef crest adjacent to a reef slope. These are not the preferred habitats for many of these macroinvertebrates. For example, most giant clam (*Tridacna*) species, and *T. gigas* in particular, are most abundant in lagoonal and shallow reef flat habitats (e.g., Braley 1987), and would require dedicated surveys in these habitats to assess spatial and temporal changes in their populations. Similarly, and as noted previously (e.g., Hoey et al. 2020), the density estimates of sea cucumbers provided herein are substantially lower than those of previous dedicated sea cucumber surveys in the central CSMP (average of 1.33 individuals per 100m^2 for all species combined; 1.06 individuals per 100m^2 for *H. atra*; Skewes and Persson 2017). These differences likely reflect differences in the habitats surveyed, rather than significant changes in sea cucumber populations. Although we had planned to conduct more detailed surveys of lagoon habitats during this voyage, unfavourable weather made these areas unworkable. The surveys conducted on consolidated reef habitat do, however, provide valuable information of the abundance of these macro-invertebrates that are directly comparable to previous surveys of reefs within the CSMP and GBRMP (e.g. Hoey et al. 2020, 2021, 2022, 2023), as well as the broader Indo-Pacific (e.g., sea cucumbers: Eriksson et al. 2005; Ceccarelli et al. 2011; *Tridacna*: Gilbert et al. 2006; Van Wynsberge et al. 2015; Rossbach et al. 2021)

Coral trout – Coral trout (*Plectropomus* spp.) and coronation trout (*Variola* spp.) were common, although not abundant across Ashmore and Boot Reefs at the time of our surveys (average density: 0.1 individual per 100m^2; Figure 4.20). This low density of coral trout may reflect the habitats and sites surveyed in 2023 (predominantly on the exposed eastern aspect of the reefs) and the low structural complexity at the sites, potential fishing activities on these reefs, or movement of individuals to spawning aggregations at the time of our surveys.

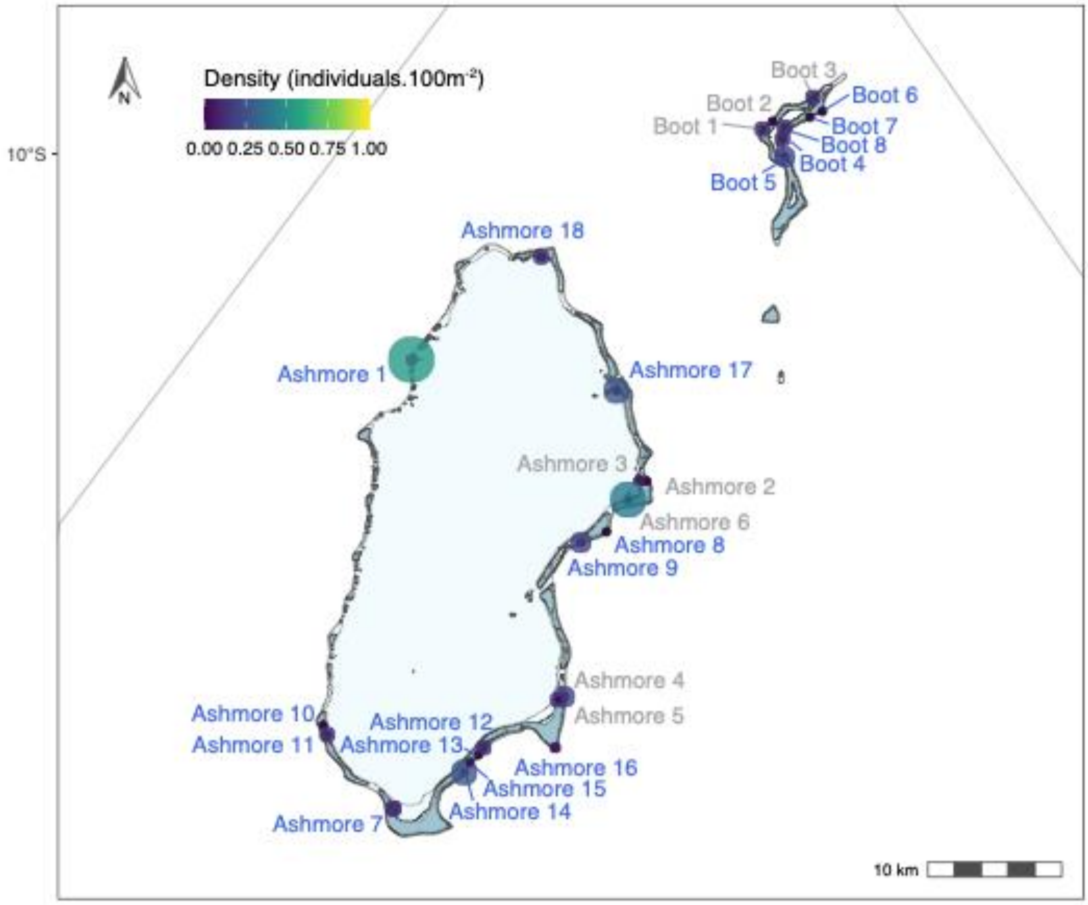


Figure 4.20 Map showing the spatial variation in the density of coral trout (*Plectropomus* spp and *Variola* spp) across Ashmore and Boot Reefs. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the density of coral trout recorded at each site.

Sharks – Sharks (predominantly grey reef sharks *Carcharinus amblyrhynchos,* and silvertip sharks *Carcharinus albimarginatus*) were relatively common across Ashmore and Boot Reefs (average density: 0.1 individual per 100m^2; average biomass 7.8 kg per 100m^2). Sharks were generally more abundant on the exposed eastern aspect of both reefs, compared to the lagoon or sheltered western aspects (Figure 4.21). The relatively high abundance of sharks is indicative of low or limited fishing on these reefs.

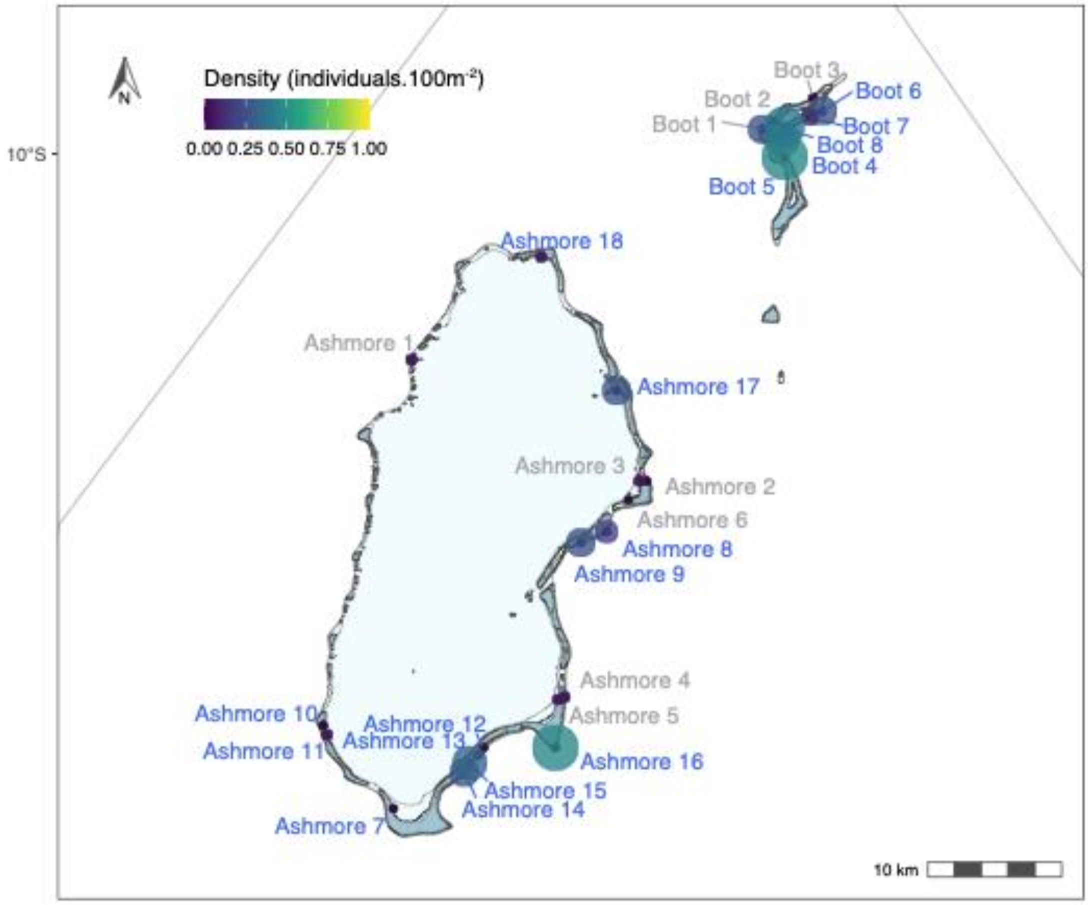


Figure 4.21 Map showing the spatial variation in the density of sharks across Ashmore and Boot Reefs. Sites surveyed during the 2023 voyage are shown in blue text, and sites surveyed during previous voyages (2018 and 2022) are shown in grey text. The size and colour of the circle relates to the density of sharks recorded at each site. There was similar spatial variation in the biomass of sharks among sites.

4.2.2 Deep Reef Habitats

Despite unfavourable weather 14 ROV dives and 30 transects were conducted across 7 sites (Ashmore: 6 sites; Boot: 1 site; Figure 2.1), and at depths from 11m to 80m.

Coral cover – Coral cover on Ashmore Reef was greatest in the 11-20m and 31-40m depth band (13.2% and 14.1% respectively) and declined markedly to 9.3% in the 41-50m depth band (Figure 4.22). Coral cover then declined gradually with increasing depth to 2.5% in the 61-70m depth band, before increasingly slightly to 6.1% in the 71-80m depth band. Coral cover was generally higher within the respective depth bands on Boot Reef, with average coral cover declining from 20.3% at 41-50m, to 13.0% at 51-60m and 9.3% at 61-70m (Figure 4.22). It should be noted, however, that estimates of coral cover at Boot Reef are based on a single site and cannot be assumed to be representative of the reef as a whole.

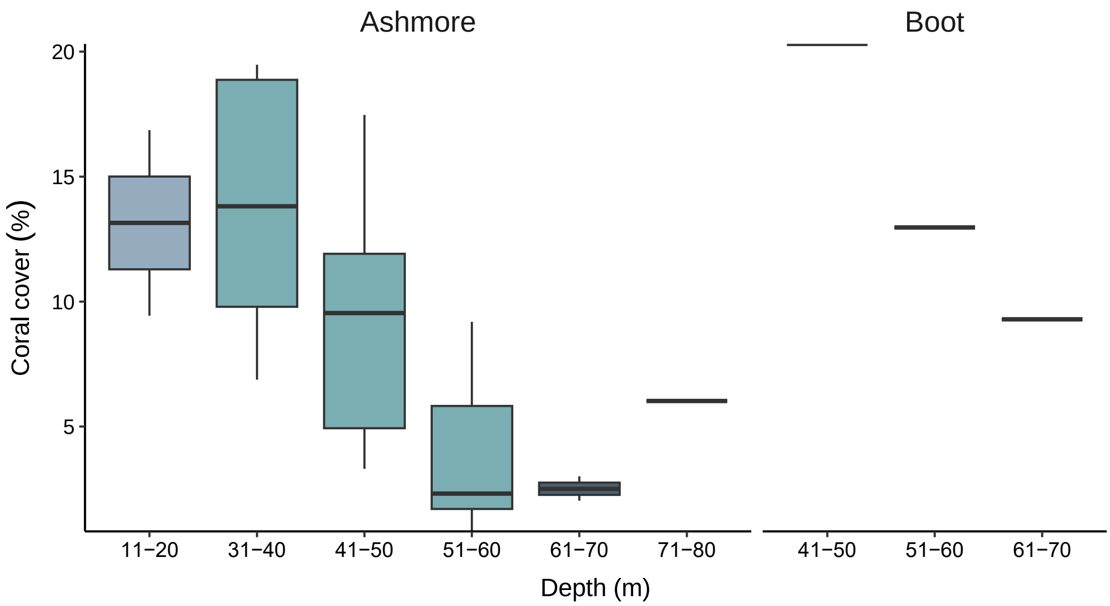


Figure 4.22 Variation in coral cover among depth bands on Ashmore (11-80m) and Boot (41-70m) Reefs. Coral cover is based on two ROV transects in each depth at each of six sites at Ashmore Reef and one site at Boot Reef.

Together with the decline in live coral cover with increasing depth on Ashmore Reef, the cover of the green calcified macroalga *Halimeda* was highest at 11-20m (51.9%), before gradually declining to 3.5%% at 61-70m (Figure 4.23). The cover of reef pavement also declined in cover with depth, from 19.4% at 11-20m to 13.8% at 61-70m, while the cover of unconsolidated substrata (i.e., sand and rubble) increased from 2.5% at 11-20m to be the dominant substratum at depths below 40m (53.9 - 86.5%; Figure 4.23).

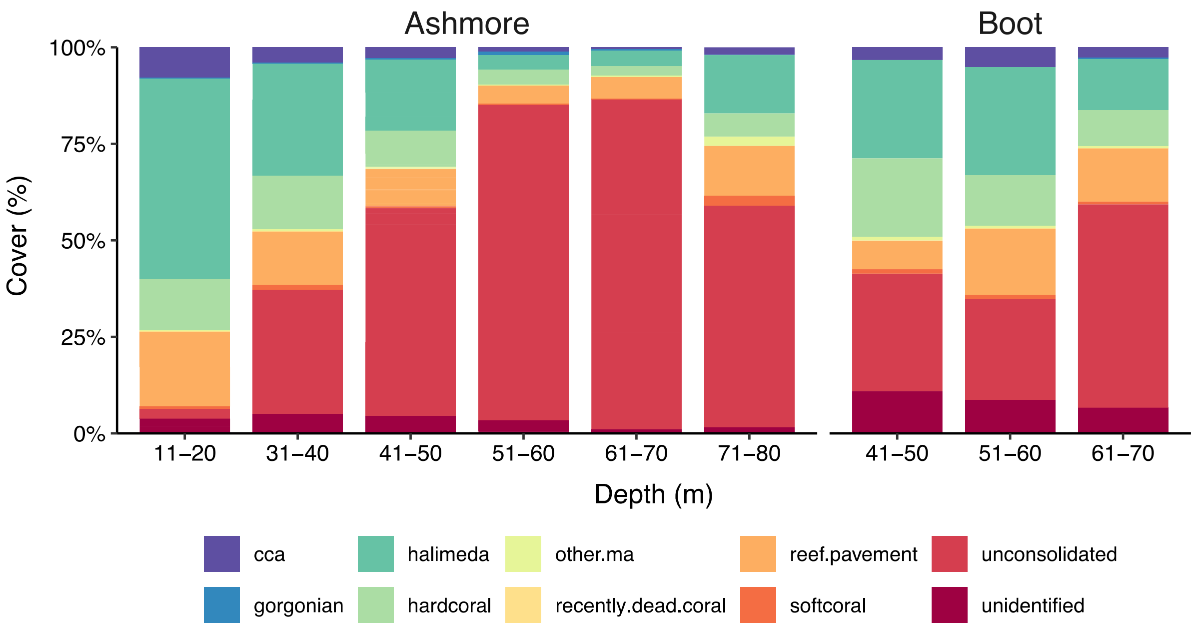


Figure 4.23 Variation in benthic community composition among depth bands on Ashmore (0-80m) and Boot (41-70m) Reefs. Coral cover is based on two ROV transects in each depth at each of six sites at Ashmore Reef and one site at Boot Reef.

Despite the relatively low average cover of live corals in deep reef habitats on Ashmore and Boot Reefs, there were areas of high coral cover interspersed within areas of unconsolidated substrata on both reefs (Figure 4.24).

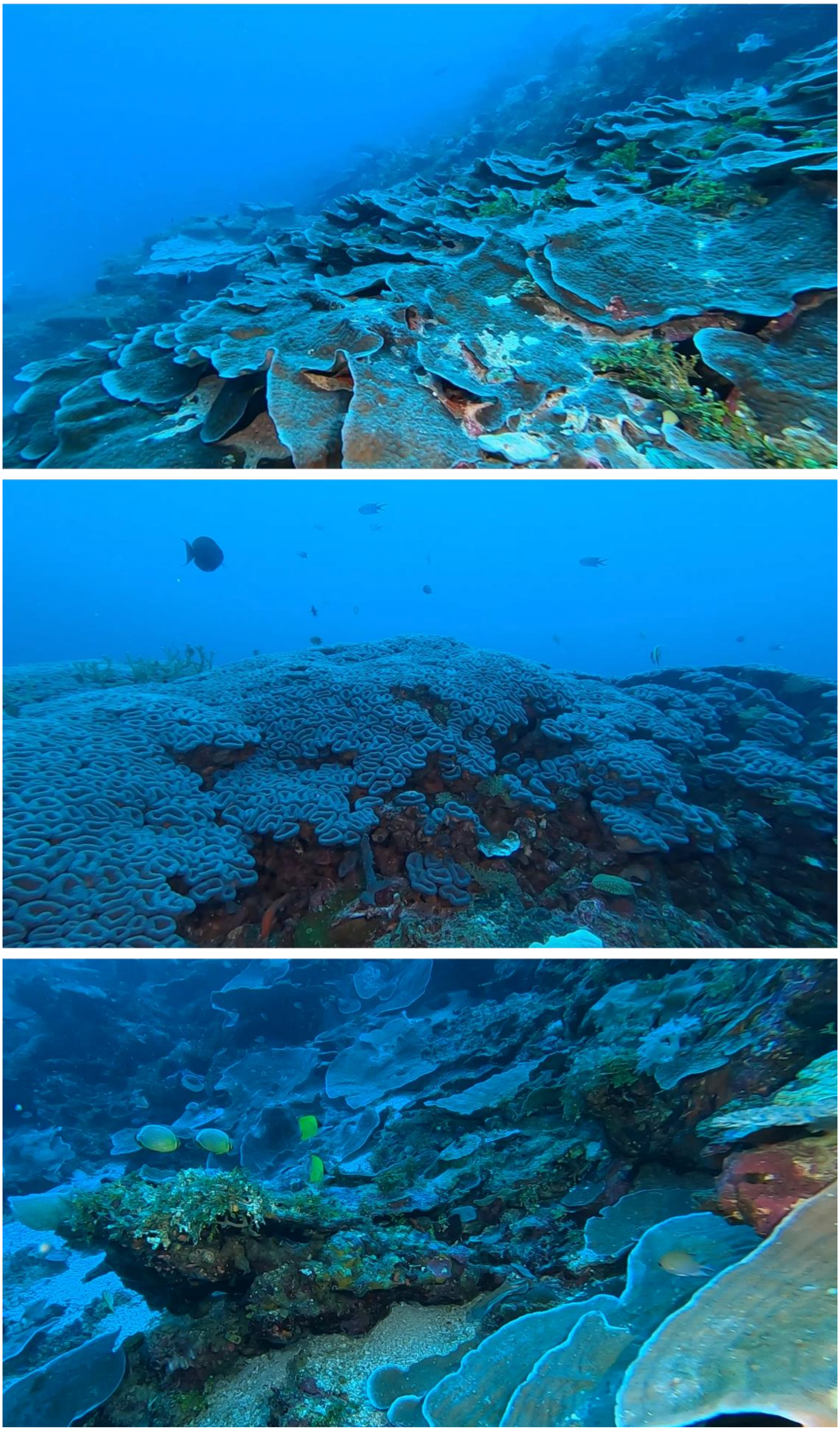


Figure 4.24 Mesophotic Coral Ecosystems at Ashmore Reef (top and middle) and Boot Reef (bottom) surveyed using an ROV at depths between 50-70m

Coral reef fish – In total 159 fish species were recorded across the 30 ROV transects, with 57 species being unique to the ROV surveys and not observed or recorded during diver-based surveys of shallow reef habitats (Appendix 5). These depth specialist fish species included several species of tilefish (f. Malacanthidae), anthias (f. Serranidae – Anthiinae), triggerfish (f. Balistidae), and gobies (f. Gobiidae). Notably, ROV surveys conducted on this voyage confirmed the presence of Randall's tilefish (*Hoplolatilus randalli*) at Ashmore and Boot Reefs, as well as at Lihou Reef and East Diamond Islets. A total of eight individuals have now been recorded at reefs spanning the northern and central CSMP (Ashmore, Boot and Lihou Reefs and East Diamond Islet), all at depths below 50m. These observations by ROV in the CSMP represent the southernmost occurrence records for the species and expand the known extent of occurrence for *H. randalli* by almost 10 degrees of latitude (Galbraith et al. 2024; Figure 4.25).

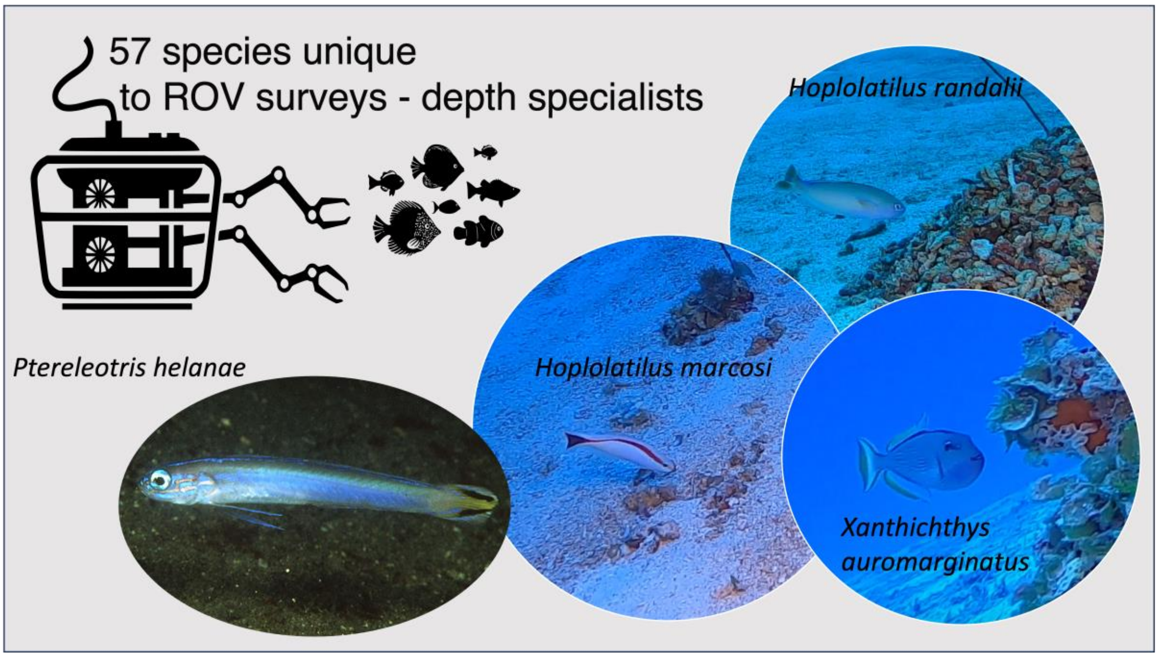


Figure 4.24 Infographic showing photographs of four of the depth specialist fish species recorded during the ROV surveys at Ashmore and Boot Reefs.

The density of reef fish displayed a similar pattern among depth bands to that of hard coral cover, with the average density of fish being greatest in the 11-20m depth band (271 individuals per 150m^2), decreasing markedly to 107 individuals per 150m^2 in the 31-40m depth band, and then gradually declining to 55 individuals per 150m^2 in the 61-70m depth band (Figure 4.25). The density of reef fish at the one site surveyed using the ROV at Boot Reef, showed fish density increased from 7 individuals per 150m^2 at 41-50m to 48 individuals per 150m^2 at 61-70m.

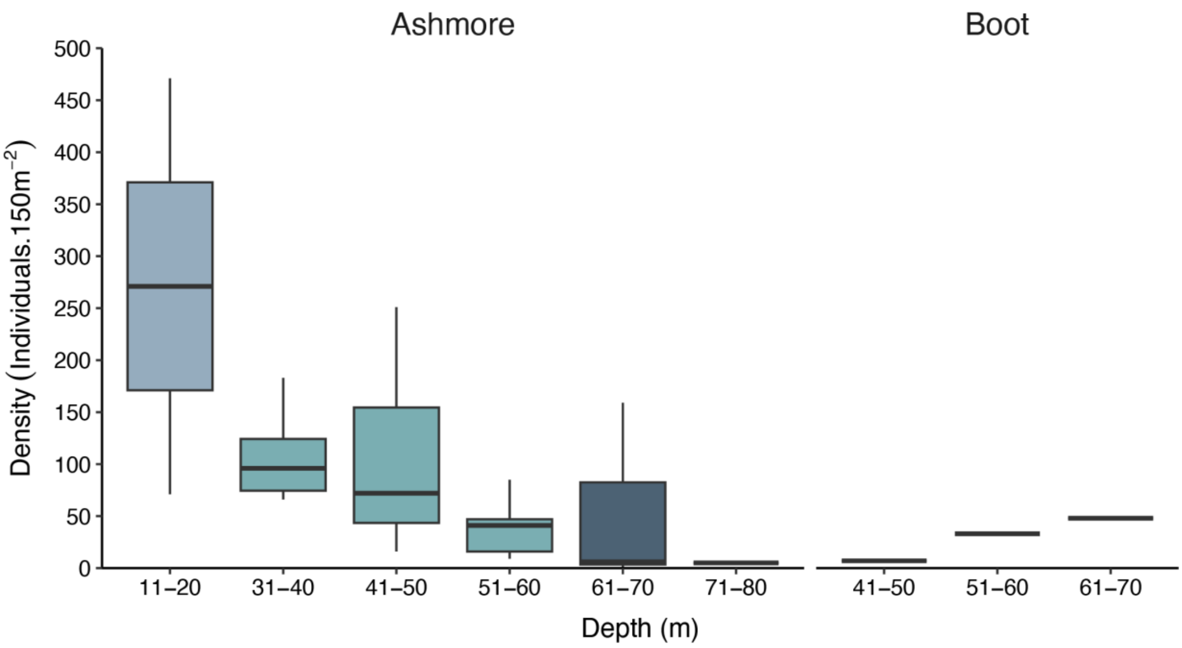


Figure 4.25 Variation in the density of reef fish among depth bands on Ashmore (0-80m) and Boot (41-70m) Reefs. Data are based on two ROV transects in each depth at each of six sites at Ashmore Reef and one site at Boot Reef.

In contrast to the density of reef fish, the species richness of reef fish (i.e., number of reef fish per transect) at Ashmore Reef was greatest at intermediate depths (36 species per 150m^2 at 31-40m) and declined in both shallower (24 species per 150m^2 at 11-20m) and deeper transects (5 species per 150m^2 at 71-80m; Figure 4.26).

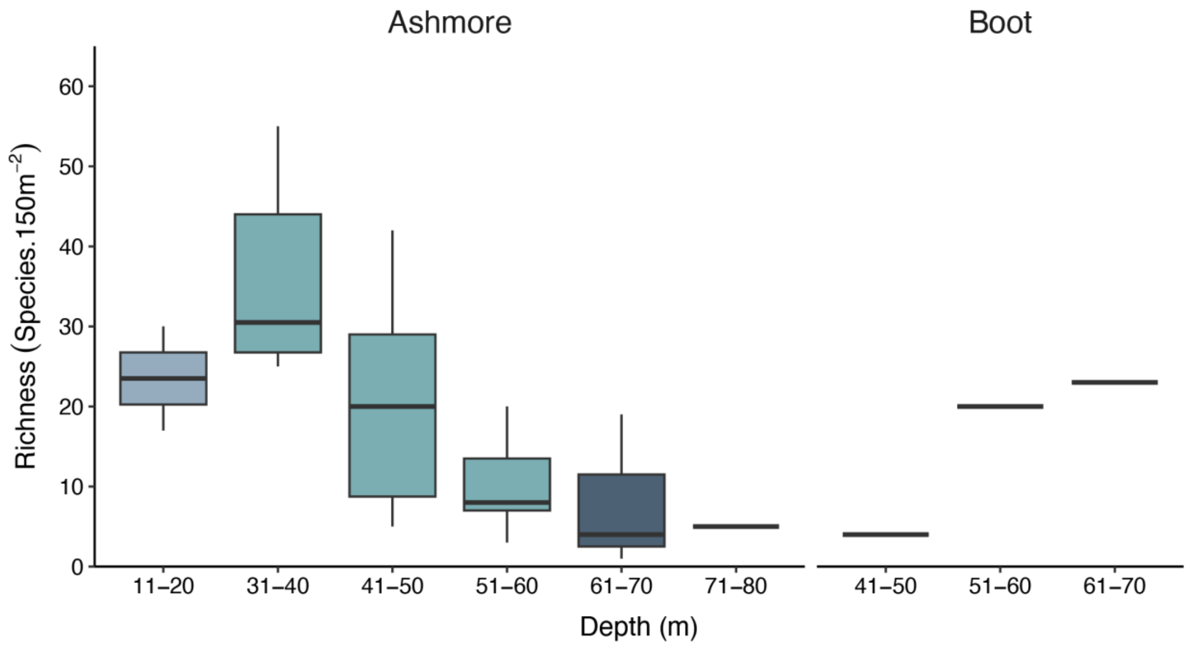


Figure 4.26 Variation in the species richness of reef fish among depth bands on Ashmore (0-80m) and Boot (41-70m) Reefs. Data are based on two ROV transects in each depth at each of six sites at Ashmore Reef and one site at Boot Reef.

The density and species richness of reef fish recorded on the eight BRUV drops within the lagoon at Ashmore Reef displayed broadly similar patterns, with the density and species richness of reef fish being 2- to 3-fold greater in the shallow areas (20-25m) than the deeper areas (32-44m; Figure 4.27).

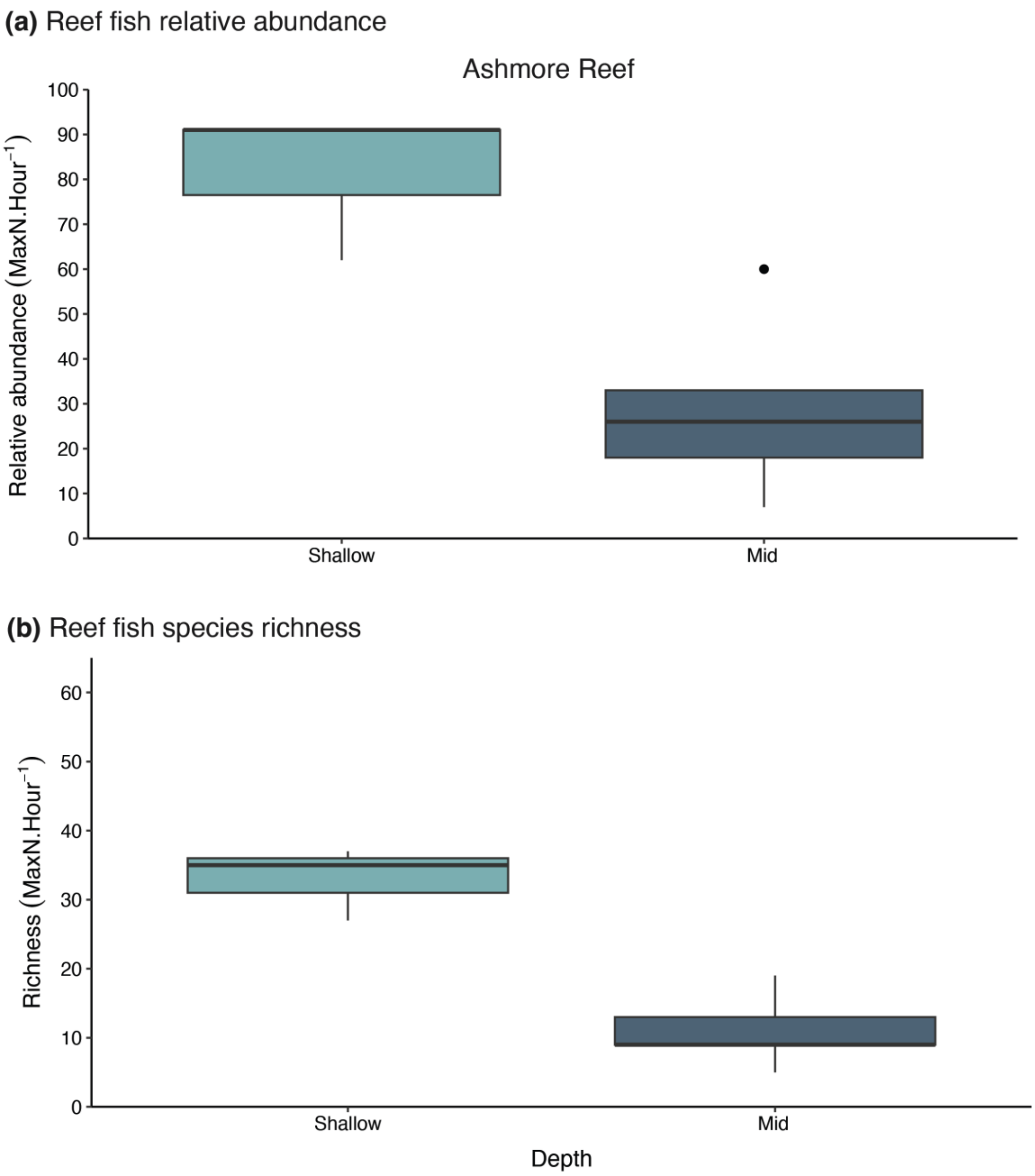


Figure 4.27 Differences in the **(a)** relative abundance, and **(b)** species richness of reef fishes between shallow (20-25m) and mid (32-44m) depth Baited Remote Underwater Video (BRUV) drops in the lagoon at Ashmore Reef. Depths and locations of each drop are given in Appendix 1.

5 Conclusions

This project was successful both in terms of engagement, collaboration, and capacity-building within the Meriam people, and the ecological surveys of shallow and deep reef habitats on Ashmore and Boot Reefs. This was despite unfavourable weather conditions throughout the 10-day voyage (strong north-westerly winds) that limited access to the extensive lagoon at Ashmore Reef, and previously surveyed sites on the typically sheltered western and north-western aspects of both reefs.

During the 10-day voyage to Ashmore and Boot Reefs eight representatives of the Meriam people were trained in the use of diver-based (i.e., visual transects) and video-based (Remotely Operated Vehicles - ROV; Baited Remote Underwater Video systems- BRUVs; and Diver Operated Stereo Video systems – DOV) survey techniques, and gained hands-on experience in the use of these different techniques. The majority of the participants were engaged, enthusiastic, and comfortable and competent snorkelling and operating out of small boats. While this training and experience provided some initial capacity-building in conducting ecological surveys of coral reef habitats, further training and considerable resources would be required to enable the Meriam people to actively monitor the health and status of Ashmore and Boot Reefs. Prior to and during the voyage it became apparent that very few Meriam people had been to Ashmore and Boot Reefs, with only two of the eight voyage participants having been to these reefs previously (one of these was on a previous research voyage in 2018). This is likely due to the greater distance separating Ashmore and Boot Reefs from Mer Island (~60 km) compared to the numerous reefs that are directly adjacent to Mer Island.

Several of the Meriam people we spoke with (both on the voyage and on island) were experienced divers and had detailed knowledge of the health and condition of reefs adjacent to Mer Island, and expressed concerns regarding recent changes they had seen on these reefs. While continued engagement and capacity-building is suggested, future efforts will likely be more effective if focusing on more accessible reefs (i.e., adjacent to Mer Island) and partnering with the appropriate management agencies (e.g., Torres Strait Regional Authority).

The ecological surveys conducted through this project are the most comprehensive surveys of shallow and deep reef habitats on Ashmore and Boot Reefs to date. Although the unfavourable and atypical weather limited access to lagoon and sites on the western and north-western aspects of both reefs, it provided an unprecedented opportunity to survey shallow and deep sites on the eastern and south-eastern aspects of these reefs. These likely represent the first rigorous and quantitative surveys in the habitats. Collectively these surveys identified eleven fish species that hadn't been recorded during previous surveys of shallow reef habitats at Ashmore and Boot Reefs, and 57 previously unrecorded fish species in deep habitats, including several new records for the CSMP (Galbraith et al. 2024).

The cover and taxonomic richness of corals at Ashmore and Boot Reefs was high (coral cover: Ashmore – 35.2%; Boot – 22.8%) relative to other reefs in the CSMP (Hoey et al. 2023), reinforcing their designation as 'bright spot' reefs. Unlike many other reefs within the CSMP and GBRMP that have experienced multiple severe coral bleaching events and widespread coral mortality in the past 8 years (e.g., Hughes et al. 2017, 2019; Hoey et al. 2023), coral cover has remained relatively stable, or increased, on Ashmore and Boot Reefs.

Coral reefs across the world's oceans are being increasingly exposed to the effects of climate change, with climate-induced coral bleaching now recognised as the foremost threat to coral reefs globally (Hughes et al. 2017). The severity and frequency of marine heatwaves, and associated bleaching of corals, have increased over recent decades, with the likelihood of mass-coral bleaching events occurring in any given year now being three-fold higher than prior to 2000 (Hughes et al. 2018). Indeed the 4th global bleaching event was announced by the National Oceanic and Atmospheric Administration (NOAA) on 15 April 2024, with >50% of the reef areas in the global ocean experiencing bleaching-level heat stress consistent with coral bleaching (NOAA 2024). The reason/s why Ashmore and Boot Reefs have largely escaped the effects of recent bleaching-level heat stress events is unknown, but may be related to the upwelling of cooler deeper waters around these reefs, the tolerance of local coral populations to heat stress, and/or their proximity to the reefs of adjacent areas (e.g., Eastern Fields, Torres Strait) that may aid in the replenishment of populations through the supply of coral, fish and invertebrate larvae to Ashmore and Boot Reefs. Temperature loggers deployed at several sites around Ashmore Reef during this voyage (as part of another project funded by Parks Australia: *Coral Sea Marine Park Coral Reef Health Survey*) will provide some insight into the potential for the upwelling of cooler waters in dampening the heating of surface waters. These loggers are recording water temperature every 30 mins with a battery life of just over 2 years, and therefore should be collected prior to April-May 2025.

Understanding the potential connectivity between Ashmore and Boot Reefs and the reefs of the Torres Strait and Papua New Guinea would require a dedicated research project. While some inferences could be drawn based on predominant wind and current directions, the connectivity among reefs is also influenced by the biology and behaviour of individual species. That said, the density of juvenile corals (an indicator of the replenishment potential of coral populations) recorded at Ashmore and Boot Reefs during the 2023 surveys was the highest recorded for CSMP reefs over the past 6 years (Hoey et al. 2020, 2021, 2022, 2023), and are directly comparable to those of more connected reef systems (e.g., mid-shelf GBR: Trapon et al. 2013; New Caledonia: Adjeroud et al. 2010).

Interestingly, the low coral cover within deep habitats (30-80m) at Ashmore and Boot Reef is counter to surveys of deep habitats on other CSMP reefs where the highest coral cover was recorded at depths of 70-80m (Galbraith et al. 2022). Further ROV surveys are required to determine whether low coral cover in deep habitats is widespread at Ashmore and Boot Reefs or restricted to the sites surveyed on the exposed eastern aspect. It should be noted, however, that deploying and piloting the ROV from a small tender during periods of strong winds and swell proved extremely difficult and largely unworkable. While further surveys of deeper habitats would lead to a greater understanding of the reef ecosystem as a whole, and likely identify additional fish species and areas of high coral cover, they should be viewed as an optional, rather than an essential, component of any future research activities.

The density and biomass of reef fishes recorded on Ashmore and Boot Reef during the 2023 surveys was comparable to previous surveys (2018, 2022). Reef fish biomass was particularly high on the reef slope (9-10 m depth) of many of the sites along the exposed eastern aspect of the reef, but low on the corresponding reef crest (2-3 m depth). The abundance, biomass and richness of reef fishes is closely linked to the cover of hard corals and physical structure of the habitat (e.g., Pratchett et al. 2011, 2014; Hoey et al. 2016). Many of the exposed reef crests on the eastern aspect of both reefs had low coral cover with a scoured pavement, characteristic of shallow reef habitats in high wave energy environments. Further, the majority of corals in these habitats had encrusting or robust prostrate growth forms, offering little structural complexity for reef fishes. Moreover, the relatively high abundance of sharks and relatively low level of discarded fishing line observed on reef indicates that fishing pressure may be limited.

The density of culturally important macroinvertebrates (i.e., sea cucumbers, trochus, and giant clams) was generally low compared to estimates from the GBRMP (Hoey et al. 2020) and other Indo-Pacific locations (e.g., sea cucumber: Eriksson et al. 2005; Ceccarelli et al. 2011; *Tridacna*: Gilbert et al. 2006; Rossbach et al. 2021), although comparable to estimates from other CSMP reefs (Hoey et al. 2023). The density estimates from the current study, although providing a useful indicator when compared across studies of similar habitats, may not be representative of the broader populations across these reefs as the habitats surveyed (i.e., contiguous reef) are not the preferred habitats for many of these macroinvertebrates (e.g., Van Wynsberge et al. 2015). Given there is an active sea cucumber fishery operating in the Torres Strait, a detailed assessment of the population status of sea cucumbers that incorporates their preferred habitats, together with clams and trochus, is recommended.

Climate change and associated disturbances are increasingly shaping the composition and state of coral reefs globally (e.g., Hughes et al. 2017, 2018; Pratchett et al. 2020), and it is becoming increasingly important to understand the patterns of disturbance, as well as the responses, recovery and resilience of individual reefs and reef systems. Reefs in the CSMP have experienced five major coral bleaching events over the past 7 years (i.e., 2016, 2017, 2020, 2021, 2022), and a sixth event is likely occurring in 2024. While previous research has highlighted the importance of reef geomorphology, reef size, habitat type, habitat complexity, and connectivity in shaping the status and health of reef communities in the CSMP (Ceccarelli et al. 2013), it will be increasingly important to understand how interactions between these contemporary factors and ongoing and future effects of climate change shape these unique reefs into the future.

5.1 Recommendations

Continued and meaningful engagement with the Meriam people is essential to strengthen and consolidate the collaboration initiated through this project. Gaining community support and trust for this project was a considerable undertaking and the relationships established should be nurtured through regular communication of any research or management activities relevant to Ashmore and Boot Reefs, or the broader CSMP. We recommend making at least one berth on any future voyages to Ashmore and Boot Reefs be made available for a member of the Meriam people.

The distance between Mer Island and Ashmore and Boot Reefs makes these reefs largely inaccessible to the Meriam people, and this is unlikely to change without significant investment (i.e., boats capable of making the journey). Partnering with other management agencies (e.g., TSRA) to provide further capacity-building and training in monitoring coral reef ecosystems will likely provide a greater benefit and enable the Meriam people to take a more active role in the management of these reefs.

Regular (every 2-3 years) comprehensive monitoring of reef and non-reef (i.e., lagoon) environments at Ashmore and Boot Reefs, and the CSMP more broadly, is essential to understand their structure and function, ecological significance, and changing health and condition. This is particularly important in the wake of the increasing incidence of heat stress events, including the 2024 global bleaching event. Annual monitoring of CSMP reefs since 2018 has greatly improved our understanding of the unique nature of these reefs, and importantly identified drivers of change (i.e., major bleaching events). In the absence of regular monitoring, the causes of such changes would be largely unknown, severely limiting the capacity of managers to make informed decisions. As well as monitoring the current status of reefs (i.e., coral cover and population sizes of fishes and non-coral invertebrates), quantifying demographic processes of key reef taxa (e.g., recruitment, growth and mortality of corals, coralline algae and fishes) on Ashmore and Boot Reefs will greatly improve our understanding of the vulnerability, recovery potential, and resilience of these reefs to ongoing and future disturbances, and identify the reasons why these reefs have largely escaped the effects of recent marine heatwaves. Temperature loggers deployed during the 2023 voyage will provide some insight into the potential role of upwelling in dampening the heating of surface seawater on Ashmore and Boot Reefs.

Dedicated monitoring of deep reef and non-reef (i.e., soft-bottom, macroalgae beds, seagrass) habitats using remotely operated underwater vehicles (ROVs) should be considered an optional, rather than essential, component of future activities. While the ROV surveys have yielded valuable new insights into the composition and structure of deeper habitats, the ROV cannot always be reliably deployed. Recent voyages have highlighted the difficulties in deploying and piloting the ROV when conditions are not favourable, thereby limiting the cost-effectiveness of these surveys. The use of alternate technologies (e.g., towed videos) may provide a viable alternative to the ROV, especially if surveying deeper lagoon habitats within limited structure (e.g., for seagrass, macroalgae beds and/or sea cucumbers).

The maintenance and replenishment of populations, and the resilience of reef systems is largely dependent on the supply of larvae. Understanding the connectivity of Ashmore and Boot Reefs with adjacent reefs in Papua New Guinea and Torres Strait will require dedicated collections and genetic analyses of animal and plant tissues. We recommend focusing on several fish taxa that vary in their dispersal potential (i.e., reproductive mode, pelagic larval duration, body size), as well as species of cultural importance (e.g., sea cucumber, *Tridacna* clams).

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6 APPENDIX 1 – Sites surveyed

List of sites surveyed across Ashmore and Boot Reefs in February - March 2023.

Reef	Site	Date	Survey Method	Habitat	Depth	Latitude	Longitude
Boot	4	25/2/2023	UVC	Eastern/exposed face	3-9m	-9.98998	144.69431
Boot	5	25/2/2023	UVC	Eastern/exposed face	3-9m	-10.00210	144.69582
Boot	6	26/2/2023	UVC	Eastern/exposed face	3-9m	-9.97152	144.72154
Boot	7	26/2/2023	UVC	Eastern/exposed face	3-9m	-9.97534	144.71307
Boot	8	26/2/2023	UVC	lagoon	3-9m	-9.98221	144.69560
Ashmore	7	28/2/2023	UVC	7 (south lagoon)	3-9m	-10.43908	144.42902
Ashmore	8	27/2/2023	UVC	Eastern/exposed face	3-9m	-10.25345	144.57431
Ashmore	9	27/2/2023	UVC	Eastern/exposed face	3-9m	-10.26073	144.55684
Ashmore	10	3/3/2023	UVC	Lagoon - western	3-9m	-10.38310	144.38130
Ashmore	11	3/3/2023	UVC	Lagoon - western	3-9m	-10.38948	144.38394
Ashmore	12	4/3/2023	UVC	Eastern/exposed face	3-9m	-10.39825	144.49052
Ashmore	13	4/3/2023	UVC	Eastern/exposed face	3-9m	-10.40306	144.48694
Ashmore	14	5/3/2023	UVC	Eastern/exposed face	3-9m	-10.41489	144.47729
Ashmore	15	5/3/2023	UVC	Eastern/exposed face	3-9m	-10.40854	144.48111
Ashmore	16	6/3/2023	UVC	Eastern/exposed face	3-9m	-10.39828	144.53943
Ashmore	17	7/3/2023	UVC	Lagoon- eastern	3-9m	-10.15881	144.58116
Ashmore	18	7/3/2023	UVC	Lagoon- northern	3-9m	-10.06913	144.52982
Ashmore	1R	4/3/2023	ROV	Outer	31-65m	-10.40495	144.486252
Ashmore	2R	5/3/2023	ROV	Outer	37-68m	-10.39245	144.499753
Ashmore	3R	5/3/2023	ROV	Outer	65-70m	-10.38878	144.511377
Ashmore	4R	6/3/2023	ROV	Outer	1-52m	-10.39746	144.539925
Ashmore	5R	7/3/2023	ROV	Inner/Lagoon	10m	-10.15894	144.581192
Ashmore	6R	7/3/2023	ROV	Inner/Lagoon	10m	-10.06913	144.52982
Boot	1R	26/2/2023	ROV	Outer	47-67m	-9.984974	144.698166
Beva	1D		DOV	Outer	30m		
Ashmore	1B	27/2/2023	BRUV	lagoon	20m	10.434167	144.4322
Ashmore	1B	28/2/2023	BRUV	lagoon	24m	10.43316	144.43227
Ashmore	1B	28/2/2023	BRUV	lagoon	36m	10.42955	144.43382
Ashmore	1B	28/2/2023	BRUV	lagoon	32m	10.43115	144.43724
Ashmore	1B	28/2/2023	BRUV	lagoon	25m	10.434251	144.437563
Ashmore	2B	3/3/2023	BRUV	lagoon	38m	10.40105	144.39197
Ashmore	2B	3/3/2023	BRUV	lagoon	40m	10.39812	144.38928
Ashmore	2B	3/3/2023	BRUV	lagoon	44m	10.38503	144.38340

7 APPENDIX 2 – Fish species surveyed

List of fish species recorded within the CSMP (2018-2023) and the area in which fish are counted in each transect.

Species	Transect area	Species	Transect area
Abudefduf sexfasciatus	50 x 2	*Acanthurus olivaceus*	50 x 5
Abudefduf vaigiensis	50 x 2	*Acanthurus pyroferus*	50 x 5
Abudefduf whitleyi	50 x 2	*Acanthurus thompsoni*	50 x 5
Acanthochromis polyacanthus	50 x 2	*Acanthurus triostegus*	50 x 5
Amblyglyphidodon aureus	50 x 2	*Acanthurus xanthopterus*	50 x 5
Amblyglyphidodon curacao	50 x 2	*Anyperodon leucogrammicus*	50 x 5
Amblyglyphidodon leucogaster	50 x 2	*Aphareus furca*	50 x 5
Amphiprion akindynos	50 x 2	*Aprion virescens*	50 x 5
Amphiprion chrysopterus	50 x 2	*Balistapus undulatus*	50 x 5
Amphiprion clarkii	50 x 2	*Balistoides conspicillum*	50 x 5
Amphiprion melanopus	50 x 2	*Balistoides viridescens*	50 x 5
Amphiprion perideraion	50 x 2	*Bolbometopon muricatum*	50 x 5
Chromis agilis	50 x 2	*Caesio cuning*	50 x 5
Chromis alpha	50 x 2	*Caesio lunaris*	50 x 5
Chromis amboinensis	50 x 2	*Calotomus carolinus*	50 x 5
Chromis atripectoralis	50 x 2	*Carangoides bajad*	50 x 5
Chromis atripes	50 x 2	*Carangoides ferdau*	50 x 5
Chromis chrysura	50 x 2	*Carangoides fulvoguttatus*	50 x 5
Chromis flavomaculata	50 x 2	*Carangoides orthogrammus*	50 x 5
Chromis iomelas	50 x 2	*Caranx ignobilis*	50 x 5
Chromis lepidolepis	50 x 2	*Caranx lugubris*	50 x 5
Chromis margaritifer	50 x 2	*Caranx melampygus*	50 x 5
Chromis retrofasciata	50 x 2	*Caranx sexfasciatus*	50 x 5
Chromis ternatensis	50 x 2	*Caranx sp.*	50 x 5
Chromis vanderbilti	50 x 2	*Carcharhinus albimarginatus*	50 x 5
Chromis viridis	50 x 2	*Carcharhinus amblyrhynchos*	50 x 5
Chromis weberi	50 x 2	*Cephalopholis argus*	50 x 5
Chromis xanthochira	50 x 2	*Cephalopholis cyanostigma*	50 x 5
Chromis xanthura	50 x 2	*Cephalopholis leopardus*	50 x 5
Chrysiptera biocellata	50 x 2	*Cephalopholis miniata*	50 x 5
Chrysiptera brownriggii	50 x 2	*Cephalopholis spiloparea*	50 x 5
Chrysiptera flavipinnis	50 x 2	*Cephalopholis urodeta*	50 x 5
Chrysiptera glauca	50 x 2	*Cetoscarus ocellatus*	50 x 5
Chrysiptera rex	50 x 2	*Cheilinus chlorourus*	50 x 5
Chrysiptera rollandi	50 x 2	*Cheilinus fasciatus*	50 x 5
Chrysiptera talboti	50 x 2	*Cheilinus oxycephalus*	50 x 5
Chrysiptera taupou	50 x 2	*Cheilinus trilobatus*	50 x 5
Dascyllus aruanus	50 x 2	*Cheilinus undulatus*	50 x 5
Dascyllus reticulatus	50 x 2	*Chlorurus bleekeri*	50 x 5
Dascyllus trimaculatus	50 x 2	*Chlorurus frontalis*	50 x 5
Dischistodus melanotus	50 x 2	*Chlorurus japanensis*	50 x 5
Dischistodus pseudochrysopoecilus	50 x 2	*Chlorurus microrhinos*	50 x 5
Hemiglyphidodon plagiometopon	50 x 2	*Chlorurus spilurus*	50 x 5
Lepidozygus tapeinosoma	50 x 2	*Choerodon cyanodus*	50 x 5
Neoglyphidodon melas	50 x 2	*Choerodon fasciatus*	50 x 5
Neoglyphidodon nigroris	50 x 2	*Choerodon graphicus*	50 x 5
Neopomacentrus asyzron	50 x 2	*Cromileptes altivelis*	50 x 5
Neopomacentrus cf cyanomos	50 x 2	*Ctenochaetus binotatus*	50 x 5
Plectroglyphidodon dickii	50 x 2	*Ctenochaetus cyanocheilus*	50 x 5
Plectroglyphidodon imparipennis	50 x 2	*Ctenochaetus striatus*	50 x 5
Plectroglyphidodon johnstonianus	50 x 2	*Diploprion bifasciatum*	50 x 5
Plectroglyphidodon lacrymatus	50 x 2	*Elagatis bipinnulatus*	50 x 5
Plectroglyphidodon leucozonus	50 x 2	*Epibulus insidiator*	50 x 5

Plectroglyphidodon phoenixensis	50 x 2	*Epinephelus coeruleopunctatus*	50 x 5
Pomacentrus adelus	50 x 2	*Epinephelus coioides*	50 x 5
Pomacentrus amboinensis	50 x 2	*Epinephelus fasciatus*	50 x 5
Pomacentrus bankanensis	50 x 2	*Epinephelus fuscoguttatus*	50 x 5
Pomacentrus brachialis	50 x 2	*Epinephelus hexagonatus*	50 x 5
Pomacentrus chrysurus	50 x 2	*Epinephelus howlandensis*	50 x 5
Pomacentrus coelestis	50 x 2	*Epinephelus lanceolatus*	50 x 5
Pomacentrus grammorhynchus	50 x 2	*Epinephelus merra*	50 x 5
Pomacentrus imitator	50 x 2	*Epinephelus polyphekadion*	50 x 5
Pomacentrus lepidogenys	50 x 2	*Epinephelus quoyanus*	50 x 5
Pomacentrus moluccensis	50 x 2	*Epinephelus tukula*	50 x 5
Pomacentrus nagasakiensis	50 x 2	*Gnathodentex aureolineatus*	50 x 5
Pomacentrus pavo	50 x 2	*Gracilla albomarginata*	50 x 5
Pomacentrus philippinus	50 x 2	*Gymnocranius euanus*	50 x 5
Pomacentrus vaiuli	50 x 2	*Gymnocranius microdon*	50 x 5
Pomacentrus wardi	50 x 2	*Hemigymnus fasciatus*	50 x 5
Pomachromis richardsoni	50 x 2	*Hemigymnus melapterus*	50 x 5
Stegastes apicalis	50 x 2	*Hipposcarus longiceps*	50 x 5
Stegastes fasciolatus	50 x 2	*Hologymnosus annulatus*	50 x 5
Stegastes gascoynei	50 x 2	*Hologymnosus doliatus*	50 x 5
Stegastes nigricans	50 x 2	*Kyphosus cinerascens*	50 x 5
Anampses caeruleopunctatus	50 x 4	*Kyphosus vaigiensis*	50 x 5
Anampses femininus	50 x 4	*Lethrinus atkinsoni*	50 x 5
Anampses meleagrides	50 x 4	*Lethrinus erythracanthus*	50 x 5
Anampses neoguinaicus	50 x 4	*Lethrinus miniatus*	50 x 5
Anampses twistii	50 x 4	*Lethrinus nebulosus*	50 x 5
Apolemichthys trimaculatus	50 x 4	*Lethrinus obsoletus*	50 x 5
Bodianus axillaris	50 x 4	*Lethrinus olivaceus*	50 x 5
Bodianus dictynna	50 x 4	*Lethrinus sp. 1*	50 x 5
Bodianus loxozonus	50 x 4	*Lethrinus xanthocheilus*	50 x 5
Bodianus mesothorax	50 x 4	*Lutjanus argentimaculatus*	50 x 5
Bodianus perditio	50 x 4	*Lutjanus bohar*	50 x 5
Centropyge bicolor	50 x 4	*Lutjanus carponotatus*	50 x 5
Centropyge bispinosus	50 x 4	*Lutjanus fulviflamma*	50 x 5
Centropyge fisheri	50 x 4	*Lutjanus fulvus*	50 x 5
Centropyge flavissimus	50 x 4	*Lutjanus gibbus*	50 x 5
Centropyge heraldi	50 x 4	*Lutjanus kasmira*	50 x 5
Centropyge loricula	50 x 4	*Lutjanus monostigma*	50 x 5
Centropyge smokey	50 x 4	*Lutjanus rivulatus*	50 x 5
Centropyge tibicen	50 x 4	*Lutjanus semicinctus*	50 x 5
Centropyge vrolikii	50 x 4	*Luzonichthys sp*	50 x 5
Chaetodon auriga	50 x 4	*Macolor macularis*	50 x 5
Chaetodon baronessa	50 x 4	*Macolor niger*	50 x 5
Chaetodon bennetti	50 x 4	*Melichthys vidua*	50 x 5
Chaetodon citrinellus	50 x 4	*Monotaxis grandoculis*	50 x 5
Chaetodon ephippium	50 x 4	*Monotaxis heterodon*	50 x 5
Chaetodon flavirostris	50 x 4	*Mulloidichthys flavolineatus*	50 x 5
Chaetodon kleinii	50 x 4	*Mulloidichthys vanicolensis*	50 x 5
Chaetodon lineolatus	50 x 4	*Naso annulatus*	50 x 5
Chaetodon lunula	50 x 4	*Naso brachycentron*	50 x 5
Chaetodon lunulatus	50 x 4	*Naso brevirostris*	50 x 5
Chaetodon melannotus	50 x 4	*Naso caesius*	50 x 5
Chaetodon mertensii	50 x 4	*Naso hexacanthus*	50 x 5
Chaetodon meyeri	50 x 4	*Naso lituratus*	50 x 5
Chaetodon ocellicaudus	50 x 4	*Naso tonganus*	50 x 5
Chaetodon ornatissimus	50 x 4	*Naso unicornis*	50 x 5
Chaetodon oxycephalus	50 x 4	*Naso vlamingii*	50 x 5
Chaetodon pelewensis	50 x 4	*Odonus niger*	50 x 5
Chaetodon plebeius	50 x 4	*Oxycheilinus digramma*	50 x 5
Chaetodon punctatofasciatus	50 x 4	*Oxycheilinus orientalis*	50 x 5

Chaetodon rafflesi	50 x 4	*Oxycheilinus oxycephalus*	50 x 5
Chaetodon rainfordi	50 x 4	*Oxycheilinus unifasciatus*	50 x 5
Chaetodon reticulatus	50 x 4	*Paracanthurus hepatus*	50 x 5
Chaetodon semeion	50 x 4	*Parupeneus barberinoides*	50 x 5
Chaetodon speculum	50 x 4	*Parupeneus barberinus*	50 x 5
Chaetodon trifascialis	50 x 4	*Parupeneus ciliatus*	50 x 5
Chaetodon ulietensis	50 x 4	*Parupeneus crassilabris*	50 x 5
Chaetodon unimaculatus	50 x 4	*Parupeneus cyclostomus*	50 x 5
Chaetodon vagabundus	50 x 4	*Parupeneus multifasciatus*	50 x 5
Chaetodontoplus meredithi	50 x 4	*Parupeneus pleurostigma*	50 x 5
Chelmon rostratus	50 x 4	*Platax pinnatus*	50 x 5
Cirrhilabrus exquisitus	50 x 4	*Plectorhinchus albovittatus*	50 x 5
Cirrhilabrus laboutei	50 x 4	*Plectorhinchus chaetodontoides*	50 x 5
Cirrhilabrus lineatus	50 x 4	*Plectorhinchus lessoni*	50 x 5
Cirrhilabrus punctatus	50 x 4	*Plectorhinchus lineatus*	50 x 5
Cirrhilabrus scottorum	50 x 4	*Plectorhinchus picus*	50 x 5
Coris aygula	50 x 4	*Plectropomus areolatus*	50 x 5
Coris batuensis	50 x 4	*Plectropomus laevis*	50 x 5
Coris dorsomacula	50 x 4	*Plectropomus leopardus*	50 x 5
Coris gaimard	50 x 4	*Pomacanthus imperator*	50 x 5
Diproctacanthus xanthurus	50 x 4	*Pomacanthus semicirculatus*	50 x 5
Forcipiger flavissimus	50 x 4	*Pomacanthus sexstriatus*	50 x 5
Forcipiger longirostris	50 x 4	*Pomacanthus xanthometopon*	50 x 5
Gomphosus varius	50 x 4	*Prionurus maculatus*	50 x 5
Halichoeres biocellatus	50 x 4	*Pseudanthias cooperi*	50 x 5
Halichoeres hortulanus	50 x 4	*Pseudanthias pascalus*	50 x 5
Halichoeres margaritaceus	50 x 4	*Pseudanthias pleurotaenia*	50 x 5
Halichoeres marginatus	50 x 4	*Pseudanthias squamipinnis*	50 x 5
Halichoeres melanurus	50 x 4	*Pseudanthias tuka*	50 x 5
Halichoeres ornatissimus	50 x 4	*Pseudobalistes flavimarginatus*	50 x 5
Halichoeres prosopeion	50 x 4	*Pseudobalistes fuscus*	50 x 5
Halichoeres trimaculatus	50 x 4	*Pterocaesio digramma*	50 x 5
Hemitaurichthys polylepis	50 x 4	*Pterocaesio tile*	50 x 5
Heniochus acuminatus	50 x 4	*Pterocaesio trilineata*	50 x 5
Heniochus chrysostomus	50 x 4	*Rhinecanthus rectangulus*	50 x 5
Heniochus monoceros	50 x 4	*Scarus altipinnis*	50 x 5
Heniochus varius	50 x 4	*Scarus chameleon*	50 x 5
Labrichthys unilineatus	50 x 4	*Scarus dimidiatus*	50 x 5
Labroides bicolor	50 x 4	*Scarus flavipectoralis*	50 x 5
Labroides dimidiatus	50 x 4	*Scarus forsteni*	50 x 5
Labroides pectoralis	50 x 4	*Scarus frenatus*	50 x 5
Labropsis australis	50 x 4	*Scarus ghobban*	50 x 5
Labropsis xanthonota	50 x 4	*Scarus globiceps*	50 x 5
Macropharyngodon choati	50 x 4	*Scarus longipinnis*	50 x 5
Macropharyngodon kuiteri	50 x 4	*Scarus niger*	50 x 5
Macropharyngodon meleagris	50 x 4	*Scarus oviceps*	50 x 5
Macropharyngodon negrosensis	50 x 4	*Scarus psittacus*	50 x 5
Paracentropyge multifasciata	50 x 4	*Scarus rivulatus*	50 x 5
Pseudocheilinus evanidus	50 x 4	*Scarus rubroviolaceus*	50 x 5
Pseudocheilinus hexataenia	50 x 4	*Scarus schlegeli*	50 x 5
Pseudocoris yamashiroi	50 x 4	*Scarus spinus*	50 x 5
Pseudodax moluccanus	50 x 4	*Scarus viridifucatus*	50 x 5
Pteragogus sp.	50 x 4	*Scarus xanthopleura*	50 x 5
Pygoplites diacanthus	50 x 4	*Scolopsis bilineatus*	50 x 5
Stethojulis bandanensis	50 x 4	*Scomberoides lysan*	50 x 5
Stethojulis interrupta	50 x 4	*Scomberoides sp*	50 x 5
Stethojulis strigiventer	50 x 4	*Serranocirrhites latus*	50 x 5
Thalassoma amblycephalum	50 x 4	*Siganus argenteus*	50 x 5
Thalassoma hardwicke	50 x 4	*Siganus corallinus*	50 x 5

Thalassoma lunare	50 x 4	*Siganus doliatus*	50 x 5
Thalassoma lutescens	50 x 4	*Siganus puellus*	50 x 5
Thalassoma nigrofasciatum	50 x 4	*Siganus punctatissimus*	50 x 5
Thalassoma purpureum	50 x 4	*Siganus punctatus*	50 x 5
Thalassoma quinquevittatum	50 x 4	*Siganus vulpinus*	50 x 5
Acanthurus albipectoralis	50 x 5	*Siganus woodlandi*	50 x 5
Acanthurus blochii	50 x 5	*Stegostoma fasciatum*	50 x 5
Acanthurus dussumieri	50 x 5	*Sufflamen bursa*	50 x 5
Acanthurus grammoptilus	50 x 5	*Sufflamen chrysopterus*	50 x 5
Acanthurus guttatus	50 x 5	*Trachinotus blochii*	50 x 5
Acanthurus lineatus	50 x 5	*Triaenodon obesus*	50 x 5
Acanthurus mata	50 x 5	*Variola louti*	50 x 5
Acanthurus nigricans	50 x 5	*Zanclus cornutus*	50 x 5
Acanthurus nigricauda	50 x 5	*Zebrasoma scopas*	50 x 5
Acanthurus nigrofuscus	50 x 5	*Zebrasoma veliferum*	50 x 5
Acanthurus nigroris	50 x 5		

8 APPENDIX 3 –ReefCloud Label Set

Custom label set used for benthic classification of ROV still images in ReefCloud

Code	Description	Functional Group	Keyboard Shortcut Code
AL_FLE_CAUL	Caulerpa (fleshy)	Algae (AL)	caul
AL_ENC_CCA	Crustose coralline algae (encrusting)	Algae (AL)	cca-enc
AL_COL_CCA	Crustose coralline algae (uprights and columns)	Algae (AL)	cca-col
AL_FI_CYA	Cyanobacteria (filamentous)	Algae (AL)	cyan
AL_CA_HALI	Halimeda (calcified)	Algae (AL)	hali
AL_FI_LTURF	Long turf algae	Algae (AL)	long turf
AL_FLE_OTH	Other fleshy algae	Algae (AL)	algae-oth
AL_FLE_B	Other fleshy brown macroalgae	Algae (AL)	brown
AL_FLE_GR	Other fleshy green macroalgae	Algae (AL)	green
AL_FI_TURF	Turf algae on hard substrate	Algae (AL)	turf
HC_OTH_ACR	Acropora (digitate-caespit-corymb)	Hard coral (HC)	ac-oth
HC_ST_ACR	Acropora (Staghorn)	Hard coral (HC)	ac-st
HC_TAB_ACR	Acropora (Tabular)	Hard coral (HC)	ac-tab
HC_MAS_DIPL	Diploastrea (Massive)	Hard coral (HC)	diplo
HC_MAS_DIPS	Dipsastraea (Massive)	Hard coral (HC)	dips
HC_LAM_ECH	Echinopora (laminar)	Hard coral (HC)	
HC_MAS_FAV	Favites (Massive)	Hard coral (HC)	fav
HC_FL_FUN	Fungiidae (Free living)	Hard coral (HC)	fung-fl
HC_SUB_GAL	Galaxea (Submassive)	Hard coral (HC)	gal-sub
HC_MAS_GONIA	Goniastrea (Massive)	Hard coral (HC)	gonias
HC_MAS_GONIO	Goniopora (Massive)	Hard coral (HC)	goniop
HC_COL_ISO	Isopora (Columnar)	Hard coral (HC)	iso-col
HC_ENC_ISO	Isopora (Encrusting)	Hard coral (HC)	iso-enc
HC_MAS_LOBA	Lobophyllia (massive)	Hard coral (HC)	lob-mas
HC_BR_MON	Montipora (Branching)	Hard coral (HC)	mon-br
HC_ENC_MON	Montipora (Encrusting)	Hard coral (HC)	mon-enc
HC_FOL_MON	Montipora (Foliose)	Hard coral (HC)	mon-fol
HC_LAM_MON	Montipora (Laminar - horizontal plate)	Hard coral (HC)	mon-lam
HC_FOL_MYC	Mycedium (Foliose)	Hard coral (HC)	myc-fol
HC_LAM_MYC	Mycedium (laminar)	Hard coral (HC)	

HC_ENC_PAC	Pachyseris (Encrusting)	Hard coral (HC)	pac-enc
HC_FOL_PAC	Pachyseris (Foliose)	Hard coral (HC)	pac-fol
HC_LAM_PAC	Pachyseris (Laminar)	Hard coral (HC)	pac-lam
HC_MAS_PLAT	Platygyra	Hard coral (HC)	plat
HC_BR_POC	Pocillopora (Branching)	Hard coral (HC)	poc
HC_BR_POR	Porites (Branching)	Hard coral (HC)	por-br
HC_EWU_POR	Porites (Encrusting with uprights)	Hard coral (HC)	por-ewu
HC_MAS_POR	Porites (Massive)	Hard coral (HC)	por-mas
HC_BR_SER	Seriatopora (branching)	Hard coral (HC)	
HC_FOL_TUR	Turbinaria (Foliose)	Hard coral (HC)	tur-fol
HC_BR_OTH	Unidentified branching hard coral	Hard coral (HC)	hc-br
HC_COL_OTH	Unidentified columnar hard coral	Hard coral (HC)	hc-col
HC_ENC_OTH	Unidentified encrusting hard coral	Hard coral (HC)	hc-enc
HC_FOL_OTH	Unidentified foliose hard coral	Hard coral (HC)	hc-fol
HC_FL_OTH	Unidentified free living hard coral	Hard coral (HC)	hc-fl
HC_LAM_OTH	Unidentified laminar hard coral	Hard coral (HC)	hc-lam
HC_MAS_OTH	Unidentified massive hard coral	Hard coral (HC)	hc-mas
HC_SUB_OTH	Unidentified submassive hard coral	Hard coral (HC)	hc-sub
OTH_DARK	Darkness	Other (OTH)	dark
OTH_TAPE	Transect Tape	Other (OTH)	tape
OTH_TRASH	Trash	Other (OTH)	trash
OTH_UNKN	Unknown	Other (OTH)	unknown
OTH_WATER	Water	Other (OTH)	water
OI_SE_ANEM	Anemone (sessile)	Other Invertebrates (OI)	anem
OI_SE_ASC	Ascidian (sessile)	Other Invertebrates (OI)	asc
OI_SE_BIV	Bivalve (sessile_except giant clams)	Other Invertebrates (OI)	biv
OI_MO_COTS	Crown of Thorns Starfish (Motile)	Other Invertebrates (OI)	cots
OI_MO_CUC	Cucumber (motile)	Other Invertebrates (OI)	cuc
OI_SE_CLAM	Giant Clam Species (sessile)	Other Invertebrates (OI)	clam

OI_BR_MIL	Millepora (Branching)	Other Invertebrates (OI)	mil-br
OI_ENC_MIL	Millepora (Encrusting)	Other Invertebrates (OI)	mil-enc
OI_MO_OTH	Other motile invertebrates	Other Invertebrates (OI)	other mot invert
OI_SE_OTH	Other sessile invertebrates	Other Invertebrates (OI)	other ses invert
OI_BAR_SPON	Sponge (Barrel)	Other Invertebrates (OI)	sponge-bar
OI_BR_SPON	Sponge (Branching)	Other Invertebrates (OI)	sponge-br
OI_ENC_SPON	Sponge (encrusting)	Other Invertebrates (OI)	sponge-enc
OI_MO_URCH	Urchin (motile)	Other Invertebrates (OI)	urch
OI_SE_ZOAN	Zoanthid (sessile)	Other Invertebrates (OI)	zoan
SEAG_BL_SEAG	Seagrass	Seagrass (SEAG)	seagrass
SC_BR_ISIS	Isis (Branching gorgonian)	Soft coral (SC)	isis
SC_LOBM	Lobophytum	Soft coral (SC)	lobophyt
SC_BR_NEPH	Nephthea	Soft coral (SC)	neph
SC_ENC_OTH	Other encrusting soft coral (Briaria_Rhytisma)	Soft coral (SC)	sc-enc
SC_SAR	Sarcophyton	Soft coral (SC)	sarc
SC_SIN	Sinularia	Soft coral (SC)	sinu
SC_FAN_GOR	Unidentified Sea Fan (Gorgonian)	Soft coral (SC)	fan
SC_OTH	Unidentified soft coral	Soft coral (SC)	sc-oth
SC_XEN	Xenia	Soft coral (SC)	xen
SUB_OTH	Indiscernible consolidated substrate	Substrate (SUB)	sub-con
SUB_CON_PAV	Pavement (bare or turf)	Substrate (SUB)	pav
SUB_CON_RDC	Recently dead coral (gross morphology or skeletal features intact)	Substrate (SUB)	rdc
SUB_UN_RUB	Unconsolidated rubble	Substrate (SUB)	rub
SUB_UN_SAND	Unconsolidated sand	Substrate (SUB)	sand

9 APPENDIX 4 – Pre-defined TransectMeasure Categories

Pre-defined TransectMeasure hierarchical benthic categories and groupings used for data summaries.

TransectMeasure Hierarchical Categories	Grouped Categories
Biota: Consolidated: Boulder: Turf mat	
Biota: Consolidated: Rock: Turf mat	Turf algae
Biota: Consolidated: Cobbles: Turf mat	
Biota: Consolidated: Boulder: Veneer	
Biota: Consolidated: Cobbles: Veneer	Rock
Biota: Consolidated: Rock: Veneer	
Biota: Hydrocoral: Branching	Hydrocoral
Biota: Hydrocoral: Sub-massive/encrusting	
Biota: Macroalgae: Articulated calcareous	Halimeda
Biota: Macroalgae: Encrusting: Unknown	CCA
Biota: Macroalgae: Filamentous and filiform	
Biota: Macroalgae: Laminate	Macroalgae
Biota: Macroalgae: Small mixed	
Biota: Octocoral/Black: Branching (3D)	Complex Octocoral
Biota: Octocoral/Black: Fan (2D)	
Biota: Octocoral/Black: Pipe organ coral	
Biota: Octocoral/Black: Massive soft corals	
Biota: Octocoral/Black: Small mixed	Other Octocoral
Biota: Octocoral/Black: Whip	
Biota: Seagrasses: Elliptical leaves	Seagrass
Biota: Sponges: Crusts	
Biota: Sponges: Erect forms	Sponge
Biota: Sponges: Small mixed	
Biota: Stony corals: Branching: Live	
Biota: Stony corals: Corymbose: Live	Complex Hard Coral
Biota: Stony corals: Staghorn: Live	
Biota: Stony corals: Bottlebrush: Live	
Biota: Stony corals: Corymbose: Bleached	
Biota: Stony corals: Branching: Bleached	
Biota: Stony corals: Small mixed: Bleached	Bleached Hard Coral
Biota: Stony corals: Tabulate: Dead	
Biota: Stony corals: Foliose / plate: Dead	
Biota: Stony corals: Tabulate: Dead	
Biota: Stony corals: Corymbose: Dead	Dead Coral
Biota: Stony corals: Encrusting: Live	Encrusting Hard Coral
Biota: Stony corals: Tabulate: Live	Plate Hard Coral
Biota: Stony corals: Foliose / plate: Live	
Biota: Stony corals: Small mixed: Live	Other Hard Coral
Biota: Stony corals: Massive: Live	Massive and Sub-Massive Hard Coral
Biota: Stony corals: Sub-massive: Live	
Biota: Unconsolidated: Pebble / gravel (biogenic)	
Biota: Unconsolidated: Sand / mud (coarse sand)	Unconsolidated substrate
Biota: Unconsolidated: Sand / mud (fine sand)	
Biota: Unconsolidated: Sand / mud (mud/silt)	

10 APPENDIX 5 – Fish species records

List of reef fish species recorded during diver-based surveys (UVC) and video-based (ROV) surveys of belt transects on Ashmore and Boot Reefs during Feb-Mar 2023.

	Species	UVC	ROV
1	*Abudefduf sexfasciatus*	1	
2	*Abudefduf vaigiensis*	1	
3	*Acanthochromis polyacanthus*	1	1
4	*Acanthurus blochii*	1	
5	*Acanthurus dussumieri*	1	
6	*Acanthurus lineatus*	1	
7	*Acanthurus mata*	1	
8	*Acanthurus nigricans*	1	
9	*Acanthurus nigricauda*	1	
10	*Acanthurus nigrofuscus*	1	1
11	*Acanthurus olivaceus*	1	
12	*Acanthurus pyroferus*	1	1
13	*Acanthurus thompsoni*	1	1
14	*Acanthurus triostegus*	1	
15	*Acanthurus xanthopterus*	1	
16	*Amblyglyphidodon aureus*	1	1
17	*Amblyglyphidodon leucogaster*	1	1
18	*Amphiprion chrysopterus*	1	
19	*Amphiprion clarkii*		1
20	*Amphiprion melanopus*	1	
21	*Amphiprion perideraion*	1	
22	*Anampses caeruleopunctatus*	1	
23	*Anampses geographicus*		1
24	*Anampses melanurus*		1
25	*Anampses neoguinaicus*	1	1
26	*Anampses twistii*		1
27	*Anyperodon leucogrammicus*	1	
28	*Aphareus furca*	1	
29	*Apolemichthys trimaculatus*	1	1
30	*Aprion virescens*	1	
31	*Arothron nigropunctatus*	1	1
32	*Balistapus undulatus*	1	1
33	*Balistoides conspicillum*	1	1
34	*Balistoides viridescens*	1	1
35	*Bodianus anthioides*		1
36	*Bodianus axillaris*	1	
37	*Bodianus dictynna*	1	1
38	*Bodianus loxozonus*	1	
39	*Bodianus mesothorax*	1	1
40	*Bolbometopon muricatum*	1	
41	*Caesio cuning*	1	
42	*Calotomus carolinus*	1	
43	*Cantherhines dumerilii*		1
44	*Canthigaster epilampra*		1
45	*Carangoides fulvoguttatus*	1	
46	*Caranx ignobilis*	1	
47	*Caranx melampygus*	1	
48	*Caranx papuensis*		1
49	*Caranx sexfasciatus*	1	
50	*Carcharhinus albimarginatus*	1	1
51	*Carcharhinus amblyrhynchos*	1	1
52	*Centropyge bicolor*	1	1

53	*Centropyge bispinosa*	1	1
54	*Centropyge heraldi*		1
55	*Centropyge vrolikii*	1	1
56	*Cephalopholis argus*	1	
57	*Cephalopholis cyanostigma*	1	
58	*Cephalopholis leopardus*	1	1
59	*Cephalopholis miniata*	1	1
60	*Cephalopholis urodeta*	1	1
61	*Cetoscarus ocellatus*	1	1
62	*Chaetodon auriga*	1	
63	*Chaetodon baronessa*	1	
64	*Chaetodon citrinellus*	1	1
65	*Chaetodon ephippium*	1	
66	*Chaetodon kleinii*	1	1
67	*Chaetodon lunulatus*	1	1
68	*Chaetodon mertensii*	1	1
69	*Chaetodon ornatissimus*	1	
70	*Chaetodon pelewensis*	1	1
71	*Chaetodon plebeius*	1	1
72	*Chaetodon rafflesi*	1	
73	*Chaetodon semeion*	1	
74	*Chaetodon trifascialis*	1	
75	*Chaetodon ulietensis*	1	
76	*Chaetodon unimaculatus*	1	
77	*Chaetodon vagabundus*	1	
78	*Cheilinus chlorourus*	1	
79	*Cheilinus oxycephalus*	1	1
80	*Cheilinus trilobatus*	1	1
81	*Cheilinus undulatus*	1	
82	*Cheilodipterus macrodon*		1
83	*Chlorurus bleekeri*	1	
84	*Chlorurus japanensis*	1	
85	*Chlorurus microrhinos*	1	1
86	*Choerodon jordani*		1
87	*Chromis alpha*	1	1
88	*Chromis amboinensis*	1	1
89	*Chromis atripectoralis*	1	
90	*Chromis atripes*	1	1
91	*Chromis delta*		1
92	*Chromis iomelas*	1	1
93	*Chromis lepidolepis*	1	1
94	*Chromis margaritifer*	1	1
95	*Chromis retrofasciata*	1	1
96	*Chromis ternatensis*	1	1
97	*Chromis vanderbilti*	1	
98	*Chromis viridis*	1	
99	*Chromis weberi*	1	1
100	*Chromis xanthochira*	1	1
101	*Chromis xanthura*	1	1
102	*Chrysiptera brownriggii*	1	
103	*Chrysiptera rex*	1	
104	*Chrysiptera talboti*	1	
105	*Chrysiptera taupou*		1
106	*Cirrhilabrus exquisitus*	1	
107	*Cirrhilabrus lineatus*		1
108	*Cirrhilabrus punctatus*	1	1
109	*Cirrhilabrus scottorum*	1	
110	*Cirrhitichthys falco*	1	1
111	*Coris gaimard*	1	
112	*Ctenochaetus binotatus*	1	1

113	*Ctenochaetus cyanocheilus*	1	
114	*Ctenochaetus striatus*	1	1
115	*Cyprinocirrhites polyactis*		1
116	*Dascyllus aruanus*	1	
117	*Dascyllus reticulatus*	1	1
118	*Dascyllus trimaculatus*	1	1
119	*Dischistodus melanotus*	1	
120	*Dischistodus pseudochrysopoecilus*	1	
121	*Elagatis bipinnulatus*	1	
122	*Epibulus insidiator*	1	1
123	*Epinephelus hexagonatus*	1	
124	*Epinephelus merra*	1	
125	*Epinephelus polyphekadion*	1	
126	*Forcipiger flavissimus*	1	1
127	*Forcipiger longirostris*		1
128	*Genicanthus melanospilos*		1
129	*Gnathodentex aureolineatus*	1	
130	*Gomphosus varius*	1	
131	*Gymnocranius euanus*	1	
132	*Halichoeres biocellatus*	1	1
133	*Halichoeres chrysus*		1
134	*Halichoeres hartzfeldii*		1
135	*Halichoeres hortulanus*	1	
136	*Halichoeres margaritaceus*	1	
137	*Halichoeres marginatus*	1	
138	*Halichoeres melanurus*	1	
139	*Halichoeres prosopeion*	1	1
140	*Halichoeres trimaculatus*	1	
141	*Halichoeres zeylonicus*		1
142	*Hemigymnus fasciatus*	1	
143	*Hemitaurichthys polylepis*	1	1
144	*Heniochus acuminatus*	1	1
145	*Heniochus chrysostomus*	1	1
146	*Heniochus varius*	1	1
147	*Heteroconga polyzona*		1
148	*Hipposcarus longiceps*	1	
149	*Hologymnosus annulatus*	1	
150	*Hologymnosus longipes*		1
151	*Hoplolatilus cuniculus*		1
152	*Hoplolatilus marcosi*		1
153	*Hoplolatilus randalli*		1
154	*Hoplolatilus starcki*		1
155	*Labrichthys unilineatus*	1	1
156	*Labroides bicolor*	1	1
157	*Labroides dimidiatus*	1	1
158	*Labropsis australis*	1	
159	*Labropsis xanthonota*	1	
160	*Lepidozygus tapeinosoma*	1	
161	*Lethrinus xanthocheilus*	1	
162	*Lutjanus biguttatus*	1	
163	*Lutjanus bohar*	1	1
164	*Lutjanus gibbus*	1	
165	*Lutjanus kasmira*	1	1
166	*Lutjanus rivulatus*	1	
167	*Macolor macularis*	1	1
168	*Macolor niger*	1	1
169	*Macropharyngodon meleagris*	1	
170	*Macropharyngodon negrosensis*	1	1
171	*Malacanthus brevirostris*		1
172	*Meiacanthus atrodorsalis*		1

173	*Meiacanthus grammistes*		1
174	*Melichthys vidua*	1	1
175	*Monotaxis grandoculis*	1	1
176	*Mulloidichthys flavolineatus*	1	
177	*Mulloidichthys vanicolensis*	1	1
178	*Myripristis kuntee*		1
179	*Naso annulatus*	1	
180	*Naso brachycentron*	1	
181	*Naso brevirostris*	1	
182	*Naso caesius*	1	
183	*Naso hexacanthus*	1	1
184	*Naso lituratus*	1	1
185	*Naso lopezi*	1	
186	*Naso minor*	1	1
187	*Naso thynnoides*	1	
188	*Naso tonganus*	1	
189	*Naso unicornis*	1	
190	*Naso vlamingii*	1	1
191	*Nemateleotris decora*		1
192	*Nemateleotris magnifica*		1
193	*Neoglyphidodon nigroris*	1	
194	*Neoniphon aureolineatus*		1
195	*Neoniphon sammara*		1
196	*Novaculichthys taeniourus*	1	1
197	*Odonus niger*	1	1
198	*Oxycheilinus digramma*	1	1
199	*Oxycheilinus orientalis*		1
200	*Oxycheilinus unifasciatus*	1	
201	*Oxymonacanthus longirostris*	1	
202	*Paracanthurus hepatus*	1	
203	*Paracentropyge multifasciata*		1
204	*Paracirrhites arcatus*	1	1
205	*Paracirrhites forsteri*	1	
206	*Paracirrhites hemistictus*	1	
207	*Parupeneus barberinus*	1	1
208	*Parupeneus crassilabris*	1	
209	*Parupeneus cyclostomus*	1	1
210	*Parupeneus multifasciatus*	1	1
211	*Parupeneus pleurostigma*	1	1
212	*Pentapodus aureofasciatus*	1	1
213	*Pictichromis paccagnellae*		1
214	*Plagiotremus rhinorhynchos*		1
215	*Platax pinnatus*	1	
216	*Plectorhinchus lineatus*	1	
217	*Plectorhinchus picus*	1	
218	*Plectroglyphidodon dickii*	1	
219	*Plectroglyphidodon imparipennis*	1	
220	*Plectroglyphidodon johnstonianus*	1	
221	*Plectroglyphidodon lacrymatus*	1	
222	*Plectroglyphidodon leucozonus*	1	
223	*Plectropomus laevis*	1	
224	*Plectropomus leopardus*	1	
225	*Plotosus lineatus*	1	
226	*Pomacanthus imperator*	1	1
227	*Pomacentrus amboinensis*	1	
228	*Pomacentrus bankanensis*	1	
229	*Pomacentrus brachialis*	1	1
230	*Pomacentrus coelestis*	1	
231	*Pomacentrus imitator*	1	
232	*Pomacentrus lepidogenys*	1	

233	*Pomacentrus moluccensis*	1	
234	*Pomacentrus philippinus*	1	
235	*Pomacentrus reidi*		1
236	*Pomacentrus vaiuli*	1	
237	*Priacanthus hamrur*		1
238	*Pseudanthias cooperi*		1
239	*Pseudanthias dispar*	1	
240	*Pseudanthias engelhardi*		1
241	*Pseudanthias huchtii*		1
242	*Pseudanthias pleurotaenia*		1
243	*Pseudanthias rubrizonatus*		1
244	*Pseudanthias squamipinnis*	1	1
245	*Pseudanthias tuka*	1	1
246	*Pseudobalistes fuscus*		1
247	*Pseudocheilinus evanidus*	1	1
248	*Pseudocheilinus hexataenia*	1	
249	*Pseudocoris yamashiroi*		1
250	*Pseudodax moluccanus*	1	
251	*Ptereleotris heteroptera*		1
252	*Ptereleotris uroditaenia*		1
253	*Pterocaesio digramma*	1	
254	*Pterocaesio tile*	1	
255	*Pycnochromis leucurus*		1
256	*Pycnochromis lineatus*	1	
257	*Pygoplites diacanthus*	1	1
258	*Remora remora*		1
259	*Rhinecanthus rectangulus*	1	
260	*Scarus altipinnis*	1	
261	*Scarus chameleon*	1	1
262	*Scarus festivus*	1	
263	*Scarus forsteni*	1	1
264	*Scarus frenatus*	1	1
265	*Scarus globiceps*	1	
266	*Scarus longipinnis*		1
267	*Scarus niger*	1	1
268	*Scarus oviceps*	1	1
269	*Scarus psittacus*	1	
270	*Scarus rivulatus*	1	
271	*Scarus rubroviolaceus*	1	
272	*Scarus schlegeli*	1	1
273	*Scolopsis bilineatus*	1	1
274	*Scomberoides lysan*	1	
275	*Serranocirrhitus latus*		1
276	*Siganus argenteus*	1	
277	*Siganus corallinus*	1	
278	*Siganus doliatus*	1	
279	*Siganus punctatus*	1	
280	*Siganus vulpinus*	1	
281	*Sphyraena qenie*	1	
282	*Stegastes fasciolatus*	1	
283	*Stegastes gascoynei*	1	
284	*Stegastes nigricans*	1	
285	*Stegastes nigricans*	1	
286	*Stethojulis bandanensis*	1	
287	*Sufflamen bursa*	1	1
288	*Sufflamen chrysopterum*	1	1
289	*Sufflamen fraenatum*		1
290	*Thalassoma amblycephalum*	1	1
291	*Thalassoma hardwicke*	1	
292	*Thalassoma lunare*	1	1

293	*Thalassoma lutescens*	1	
294	*Thalassoma nigrofasciatum*	1	
295	*Thalassoma quinquevittatum*	1	
296	*Triaenodon obesus*	1	
297	*Valenciennea helsdingenii*		1
298	*Variola albimarginata*		1
299	*Variola louti*	1	1
300	*Xanthichthys auromarginatus*		1
301	*Zanclus cornutus*	1	1
302	*Zebrasoma scopas*	1	1
303	*Zebrasoma velifer*	1	1