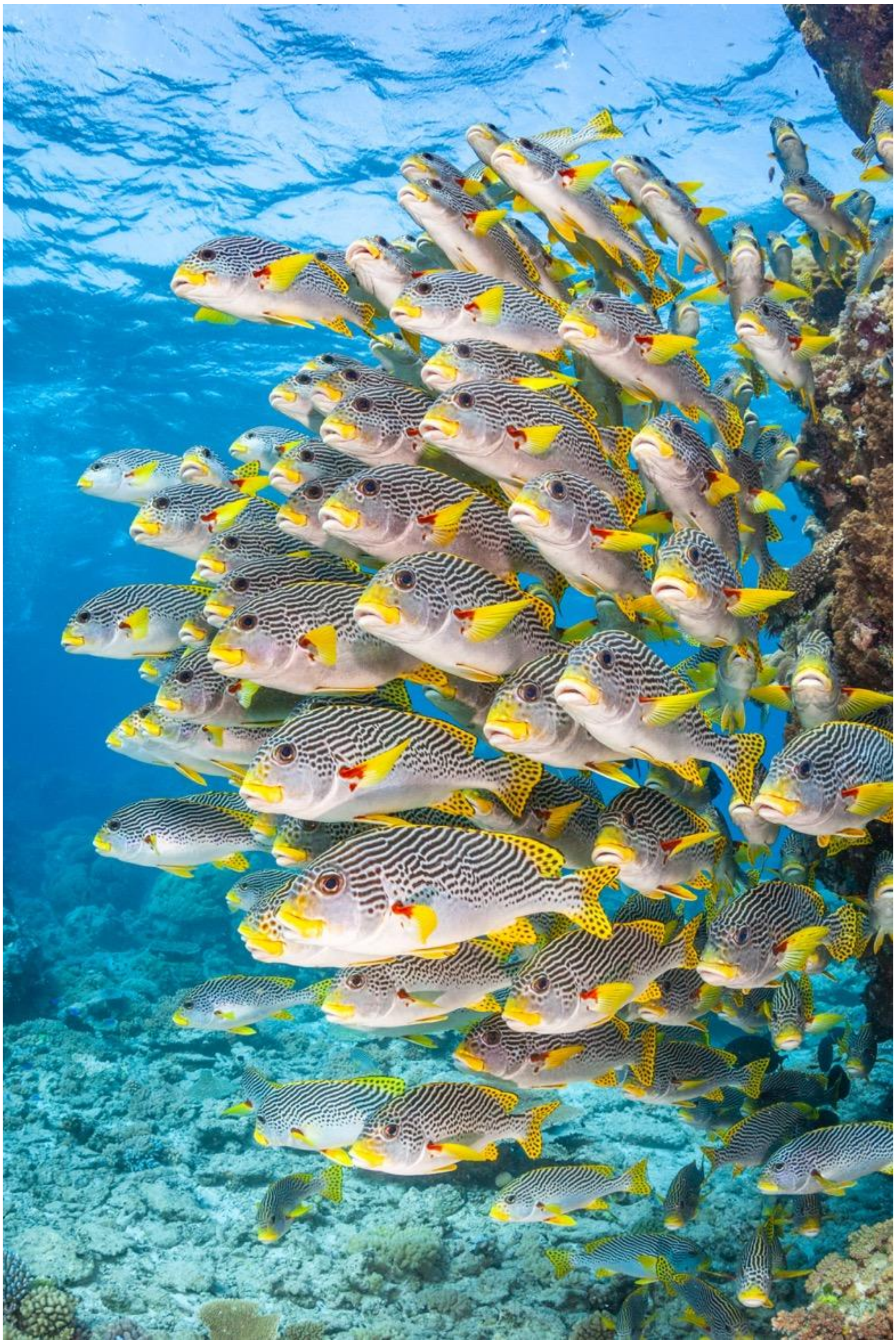

CORAL SEA MARINE PARK CORAL REEF HEALTH SURVEY

Report on reef surveys
June and October 2025

PRODUCED FOR PARKS AUSTRALIA, FEBRUARY 2026

BY JAMES COOK UNIVERSITY
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In responding to a tender from Parks Australia, a team of researchers representing the College of Science and Engineering at James Cook University (JCU) completed surveys of eleven reefs in the Coral Sea Marine Park.

On the cover – A school of oblique-banded sweetlip (*Plectorhinchus lineatus*) on Osprey Reef, November 2023. Photograph taken by Victor Huertas

Suggested citation: Hoey AS, Martin C, Garing MR, Pratchett, MS, Winding N, Huertas V (2026) Coral Sea Marine Park Coral Reef Health Survey 2025. Report on reef surveys June and Oct 2025. Report prepared for Parks Australia.

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.

Taiku Wailu from Maer Island can be seen here observing Josie Chandler (JCU) surveying coral assemblages on Ashmore Reef in March 2023. Eight members of the Meriam people joined our team during surveys of Ashmore and Boot Reefs in the far north of the Coral Sea Marine Park during Feb-Mar 2023.
Image credit: Victor Huertas

Acknowledgements

This *Coral Sea Marine Park Coral Reef Health Survey 2025* research project was jointly funded by the Director of National Parks, Australia, and the College of Science and Engineering, James Cook University. The surveys were conducted by Andrew Hoey, Victor Huertas, Madeline Garing, Cecilia Martin, and Morgan Pratchett. The report was prepared by Andrew Hoey, Cecilia Martin, Nicoline Winding and Victor Huertas. Hugo Harrison provided the R scripts and analytical pipelines used to summarise data and produce figures.

The authors wish to thank the relevant staff at Parks Australia for managing this project, with particular mention given to Fiona Hagger (Senior Marine Parks Officer, Coral Sea Marine Park), Roberta Johnson (Senior Marine Parks Officer, Coral Sea Marine Park), Martin Russell (Manager, Coral Sea Marine Park), Darren Phillips (Senior Marine Parks Officer, North-west Region) and Russell Gueho (Director, East Region).

The research presented herein was conducted with the full knowledge and support of Parks Australia, in the Australian Government Department of Climate Change, Energy, the Environment and Water. The findings and views expressed, however, are those of the authors and do not necessarily represent the views of Parks Australia, the Director of National Parks or the Australian Government.

We are indebted to the skipper and crew of *MV Strait Shooter* (June voyage) and the skipper and crew of *RV Infamis* (October voyage) for enabling this work, despite sometimes trying weather conditions.

1 Executive Summary

The Coral Sea is a critically important and significant ecosystem, which (like coral reefs globally) is increasingly threatened by changing environmental conditions, particularly ocean warming. James Cook University was commissioned by Parks Australia to assess the current condition of benthic, fish and invertebrate communities across twelve reefs within the southern and central Coral Sea Marine Park in 2025.

Key findings of the surveys conducted in June and October 2025

Changes in coral cover and community

- Total shallow water coral cover increased from 12.6% in 2023/24 to 15.1% in 2025 across the eleven reefs that were surveyed in both years, a mean increase of 20.1%.

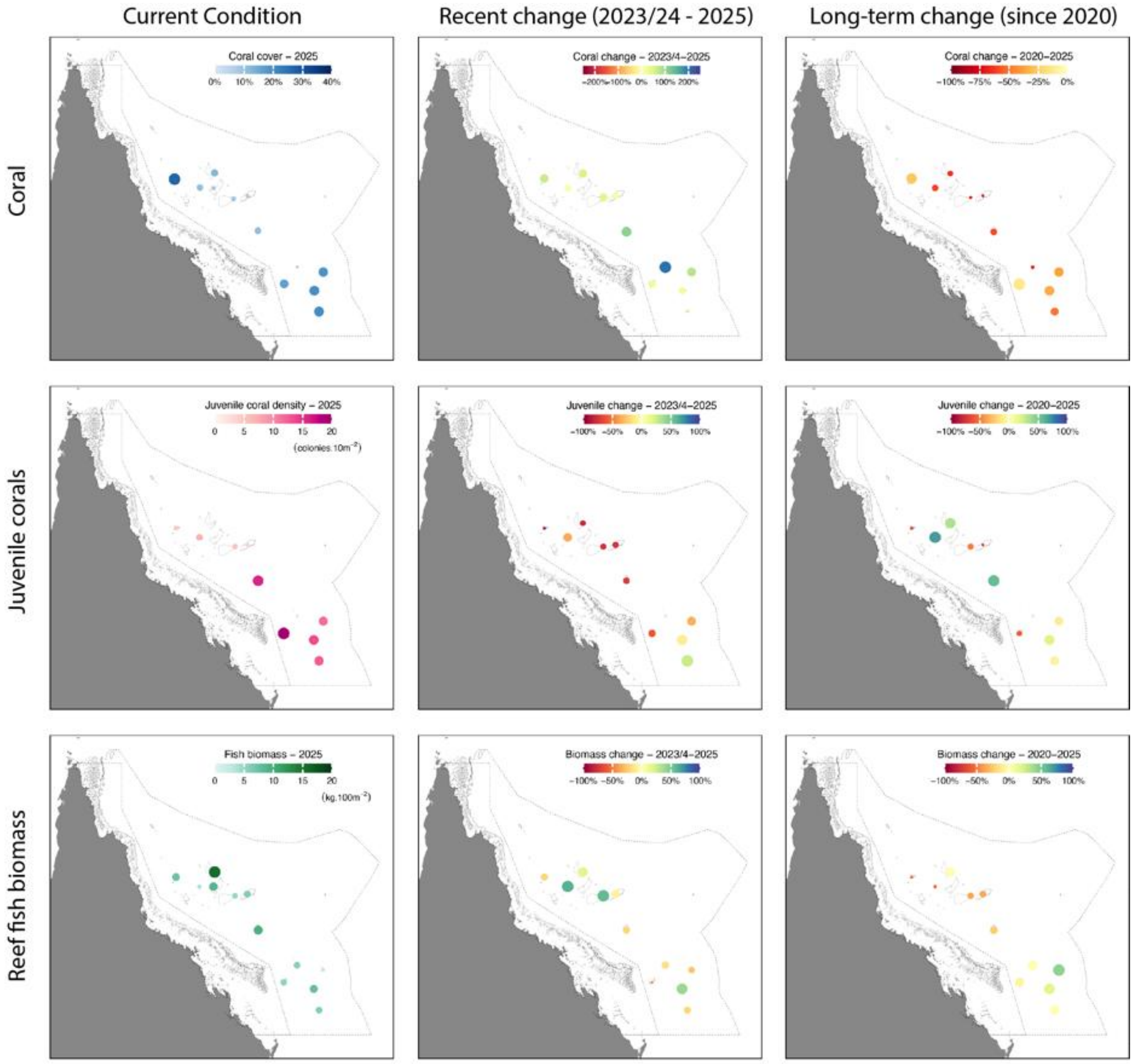

Figure 1.1. Summary of the current (2025) condition and recent and longer-term trends in coral cover, crustose coralline algae cover, and reef fish biomass across the Coral Sea Marine Park. Values are averaged across habitats and sites on each reef, and based on surveys of matching sites conducted during 2020-2024 and 2025.

- The increase in coral cover differed between the two regions, with coral cover increasing from 16.8% to 17.6% in southern CSMP and from 8.9% to 13.0% in the central CSMP from 2023/24 to 2025. The greater increase in coral cover in the central CSMP likely reflects the greater time between surveys.
- The increases in coral cover are encouraging, especially given reefs in the southern and central CSMP experienced levels of heat stress in March 2024 (>12 degree heating weeks; DHW) and in the eastern region of the central CSMP in March 2025 (>8 DHW) that are expected to cause extensive levels of bleaching and widespread mortality.

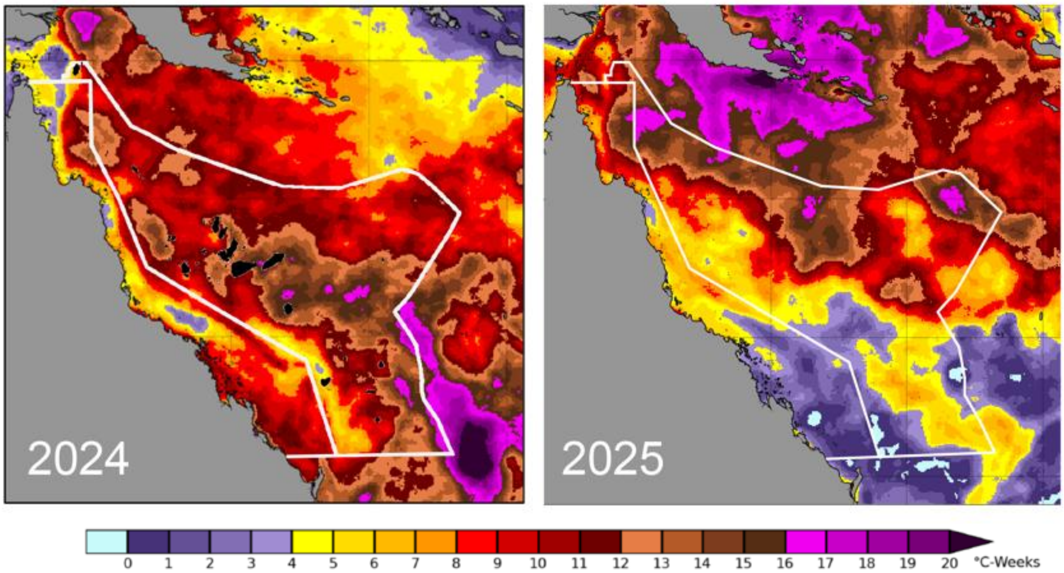

Figure 1.2 Maximum heat stress (Degree heating weeks; DHW) in the Coral Sea Marine Park for March 2024 and March 2025. Images produced using the NOAA CRW 5km product v3.1

- Cato Reef was the only reef surveyed in which coral cover was observed to have declined between 2023/24 and 2025. This likely reflects the combination of high cover of thermally-sensitive corals (e.g., *Acropora*) as Cato Reef had largely escaped the effects of previous bleaching events, and the mortality of these corals due to elevated temperatures in March-April 2024.
- Despite the increases in coral cover observed over the last 1-2 years, coral cover within the southern and central CSMP remains well below levels recorded in 2020.
- Three reefs had very low (< 10%) coral cover (southern CSMP: Frederick Reef: 7.6%; central CSMP: Lihou Reef: 8.0%; Diamond Islet: 8.3%) and another three reefs had low coral cover (Heralds Cays: 10.8%; Marion Reef: 11.8%; Willis Islets: 12.3%). Such low coral cover has been shown to disrupt key processes and have lasting consequences for the diversity and functioning of other reef systems.

<u>Decline in the density of juvenile corals</u>

- The density of juvenile corals (<5cm diameter), a key indicator of the recover potential of coral populations, declined by 66.8% (2023/24: 28.5 juvenile corals per $10m^2$; 2025: 9.5 juvenile corals per $10m^2$), with the greatest decline recorded in the central (82.2% decline) compared to the southern CSMP (36.6% decline). The cause of these declines is difficult to ascertain, although may be related to the bleaching and mortality of juvenile corals due to heat stress experienced in early 2024 and 2025, and/or the lag effects of previous bleaching events on coral broodstock and larval supply. Irrespective of the cause, these declines in juvenile corals is concerning and will inhibit the recovery of coral populations on these reefs.

Low levels of heat stress – coral bleaching

- Low levels of heat stress (4.7% of colonies surveyed were pale or bleached) were recorded across CSMP reefs during the 2025 surveys. The low levels of bleaching are likely due to the timing of the surveys (June and October), several months after the peak heat stress, and the shifted coral composition due to the effects of previous (2020, 2021 and 2022) bleaching events.

Decline in reef fish biomass

- The biomass of reef fishes (a key indicator of reef health) declined by 21.2% and 23.6% in the southern and central CSMP, respectively, from 2023/24 to 2025. These declines were primarily related to declines in corallivorous and planktivorous fishes (likely due to the loss of live coral and the structure they provide) and grazing fishes.
- The changes in biomass have been largely consistent among reefs within each region (Figures 4.22c, 4.26), and sites within each of those reefs (Figure 4.27).
- The biomass of grazing fishes on the central CSMP reefs surveyed is now only ~30% of that recorded in 2020.
- The causes of the reductions in grazing fishes are unknown though may include heat-related physiological stress and changes in food quality or availability.

Other reef taxa

- The density of other reef taxa (sharks, sea snakes, giant clams, Trochus, sea urchins, and sea cucumbers) was relatively stable between 2023/24 and 2025, however the density of sea cucumbers have declined by 20% from 2020-2021 (0.43 sea cucumbers per $100m^2$) to 2025 (0.36 sea cucumber per $100m^2$).

Comparison between zoning (Marion and Kenn Reefs)

- Comparisons between National Park Zones and Habitat Protection Zones on Kenn and Marion Reefs showed that coral cover did not differ consistently between zones. The biomass of reef fish was either similar between zones on (Kenn Reef) or greater within the NPZ than the HPZ (Marion Reef NPZ: 11.9 kg per $100m^2$; HPZ: 7.0 kg per $100m^2$).

Recommendations for future monitoring and research:

Frequency of monitoring

- Continued monitoring (annual or biennial) of reefs in the CSMP is critical, given the increasing incidence of major disturbances impacting CSMP reefs in recent years (namely six bleaching events in the past eight years), coupled with the logistical constraints of working in the CSMP (i.e., isolation and exposure).
- In the absence of any major environmental disturbances the time between recurrent surveys of individual reefs could be extended to 2-5 years, however this appears unlikely given predicted increases intensity of disturbances affecting reefs globally, and the heat stress experienced in the CSMP over recent years.

Prioritisation of monitoring locations

- Importantly, monitoring should prioritise reefs and sites that have been repeatedly surveyed since 2020. Continued monitoring of existing sites is critically important to determine any longer-term effects of the four recent bleaching events (2020, 2021, 2022 and 2024) on reef fish and other reef associated species, the potential recovery of coral assemblages, and any future disturbances that may push coral cover toward critical thresholds of collapse.
- Consideration should also be given to parallel research and monitoring on islands within the CSMP, to optimise the use of available vessel time and berths.
- With these considerations in mind, we recommend as a minimum the following 12 reefs be surveyed annually: Cato, Kenn and Saumarez Reefs in the southern CSMP; Flinders, Holmes, Lihou, Marion and Mellish Reefs, and Herald Cays in the central CSMP, and Bougainville and Osprey Reefs in the northern CSMP.
- We do not include Ashmore and Boot Reefs here given their location in the far north of the CSMP, and hence the addition travel time and cost of accessing these reefs, however given their connection to peoples of the Meriam nation (the only reefs in the CSMP with direct links to first nations people) special consideration should be given to these reefs. Monitoring and research on Ashmore and Boot Reefs would provide an important opportunity to continue engagement and capacity building with first nations people of the Meriam nation.
- Surveying and understanding the condition of all 22 CSMP reefs will be critical to informing the review of the CSMP Management Plan.

Consistency of survey methodology

- Use the same methods and sites as previous (2018-25) surveys. The consistency of survey method is critical to ensure any changes are due to changes in the ecological communities, rather than an artefact of any difference/s in the survey methods.

Focused research recommendations

- Repeat the 3-dimensional habitat mapping of sites mapped during the 2019-2020 voyages in the next 2-3 years to allow the relative contribution of live corals versus the underlying reef matrix and coralline algae in providing habitat structure to be assessed. Establishing fixed plots (i.e., with permanent markers) and mapping using high resolution photogrammetry, alongside the existing monitoring, would allow the fate and growth (or partial mortality) of individual corals to be tracked.
- As well as monitoring the current status of reefs, quantifying demographic processes of key reef taxa (e.g., recruitment, growth and mortality of corals, coralline algae and fishes) among reefs and regions within the CSMP will greatly improve our understanding of the vulnerability, recovery potential, and resilience of shallow coral reef environments in the CSMP to ongoing and future disturbances, as well as potential interactions among increasingly frequent and more intense heat stress events.
    - Given the recorded declines in juvenile corals, continued monitoring of the density of juvenile corals together with assessments of coral settlement (i.e., using settlement tiles) will be critical to understand the potential replenishment and recovery of coral populations, as well as local stock-recruitment relationships for shallow water corals within the CSMP.
    - Dedicated research and collections to quantify demographic rates (growth, mortality) for fish and identifying key settlement and nursery habitats. Ideally this would include species of grazing fish so that the likely mechanism/s for the observed declines in this group following the recent bleaching events could be identified.
- Temperature loggers and devices to quantify the settlement and calcification of CCA’s were collected and replaced across ten CSMP reefs during the 2025 voyages. Retrieving the temperature loggers and CCA devices should be a priority for future work.

Dedicated invertebrate surveys

- Dedicated surveys of sea cucumber populations in reef and non-reef habitats (e.g., sandy lagoons) is recommended to understand their population status, and how this is affected by management zoning.
- Allocate sufficient time (≥3 days per reef) for sea cucumber surveys at Kenn and Marion Reef lagoons, to allow for surveys of additional reef sites and additional berths to allow for towed diver and/or towed video surveys of lagoonal habitats.

Access opportunities for researchers

- Additional means for accessing CSMP should be considered, including the continued provision of berths on the CSMP Island Health voyages, the use of berths on dive tourism vessels (e.g., Mike Ball Dive Expeditions), and conducting monitoring surveys alongside any funded research projects.

- Tourism operators (mainly Mike Ball Dive Expeditions) offer a cost-effective alternative for deploying and retrieving equipment from some of the western reefs in the CSMP (Osprey, Bougainville, Holmes and Flinders Reefs),

Regional context and connectivity

- Comparable research and monitoring in all regions within and bordering the CSMP (i.e., GBRMP, Temperate East Marine Parks Network, New Caledonia, Vanuatu, Solomon Islands and Papua New Guinea) to establish the biogeographical significance and connectivity of the CSMP.
- Support cross-jurisdictional meetings, workshops and, where possible, shared expeditions.

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2 Background

The Coral Sea Marine Park (CSMP) is among the world's largest and most isolated marine parks, encompassing an area of 989,836km^2, and together with the adjacent Parc Naturel de la Mer de Corail (Natural Park of the Coral Sea – New Caledonia) form one of the largest marine protected areas in the world (*ca.* 2.3 million km^2; Figure 2.1). The CSMP encompasses a critically important and environmentally significant ecosystem that includes a diversity of habitats (including shallow coral reefs, seamounts, plateaus and deep sea plains) and the unique associated fauna (Ceccarelli et al. 2013; Cresswell et al. 2025; Galbraith et al. 2025; Quimpo et al. 2025; Tea et al. 2025), and provide potential connectivity with Australia's Great Barrier Reef (GBR) and other western Pacific provinces (Ceccarelli et al. 2013; Hoey et al. 2020). Within the CSMP there are approximately 67 islets and cays and 34 widely separated shallow reef systems, 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. These shallow reefs systems, including Lihou Reef one of the world's largest atolls (~2,500km^2), have a combined reef area of 15,024 km^2; equating to 1.5% of the total CSMP (DNP 2018).

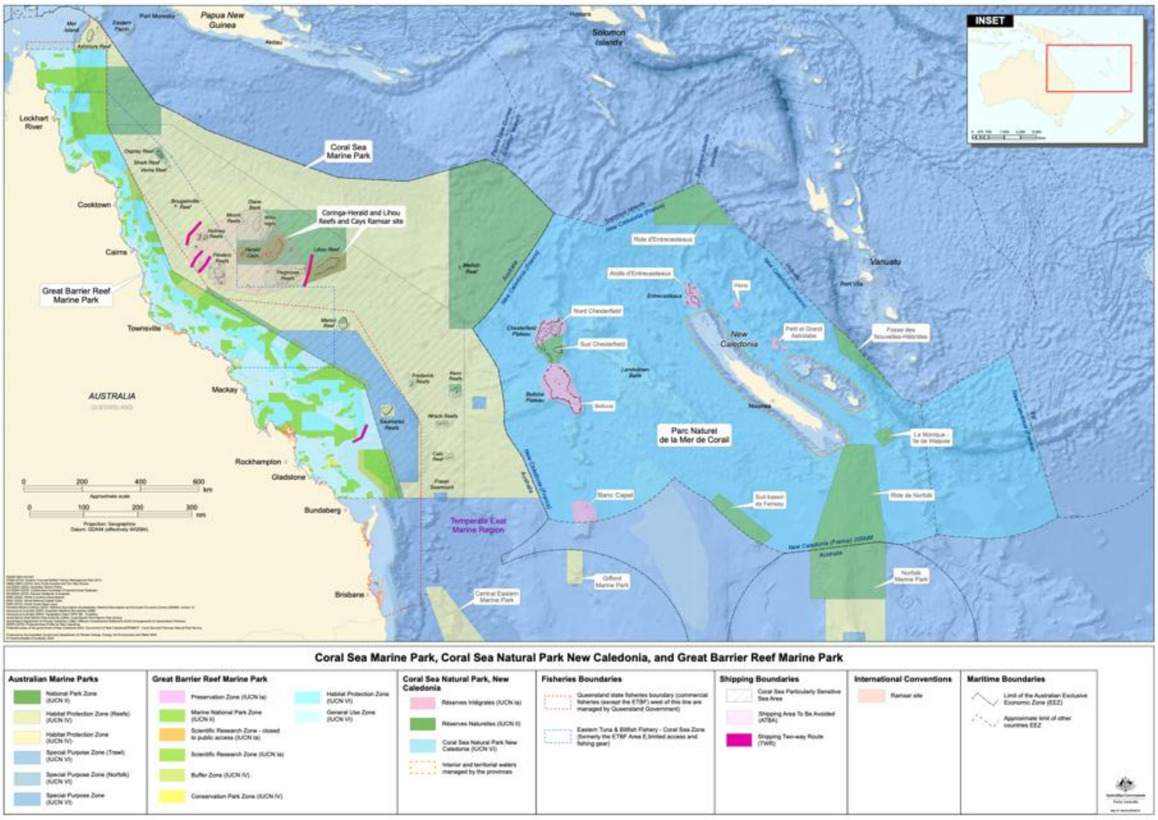


Figure 2.1. Map of the Coral Sea showing the location of the Coral Sea Marine Park and Parc Naturel de la Mer de Corail (Natural Park of the Coral Sea, New Caledonia). Together these two Marine Parks represent the world's largest marine protected area. The management zones shown were implemented in the Coral Sea Marine Park in July 2018, and in the Parc Naturel de la Mer de Corail in April 2024. (Source: parksaustralia.gov.au)

The reefs of the CSMP are fundamentally different to the more inter-connected continental shelf reefs of the GBRMP, and are largely shaped by geomorphic, oceanographic and environmental conditions of the region, and increasingly the effects of ongoing climate change. Reefs within the CSMP rise from seamounts on four major deep-water plateaus; the Eastern Plateau in the north, the Queensland Plateau in the central region, and the Marion and Kenn Plateaus in the south, such that individual reefs are separated by oceanic waters up to 4,000 m deep (Davies et al.1989; Collot et al. 2011). Given the isolation of these reefs, potential connectivity among them is likely facilitated by major ocean currents. The major oceanographic features affecting the Coral Sea are west-flowing jets of the Southern Equatorial Current (SEC), which strengthen during the summer months and bifurcate on the Australian continental shelf to form the south-flowing East Australian Current (EAC) and its eddies, and the Hiri Gyre in the Gulf of Papua to the north (Ridgway et al. 2018; Rousselet et al. 2016).

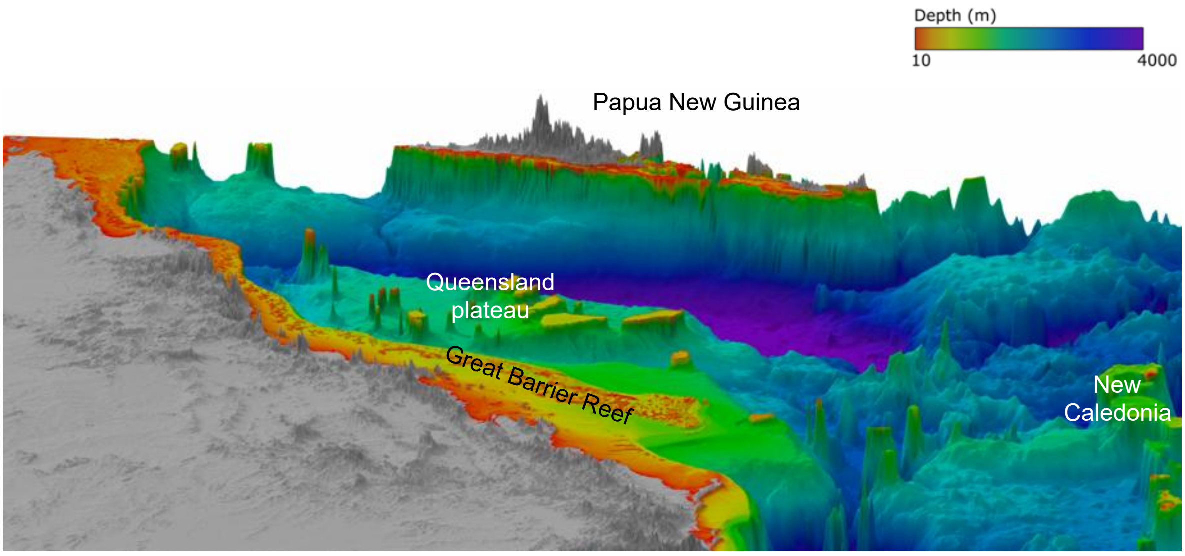


Figure 2.2. Bathymetric map of the Coral Sea showing the location of the Queensland plateau that gives rise to many of the reefs in the central and northern regions of the Coral Sea Marine Park. Three-dimensional visualization generated in R with the package Rayshader (Morgan-Wall, 2024) from a digital elevation model by Beaman (2020).

The CSMP is one of the most isolated and extensive coral reef environments in Australian waters, with limited exposure to direct human pressures (e.g., fishing, run-off) relative to more accessible coastal and continental shelf reefs. Despite this isolation, coral cover on many reefs within the CSMP, especially on some reefs in the central CSMP, has been relatively low for at least the past several decades (ca. 1-6% cover; Ayling and Ayling 1985; Oxley et al. 2003; Ceccarelli et al. 2008), with this low coral cover linked to repeated exposure to severe tropical cyclones and more recently climate-induced coral bleaching (Ceccarelli et al. 2013; Harrison et al. 2019; Hoey et al. 2020, 2021, 2022, 2024). These frequent disturbances, coupled with the general reliance on self-recruitment for the recovery of coral populations on isolated reefs (Gilmour et al. 2013; Burn et al. 2024), most likely contribute to the sustained low coral cover on these reefs.

Despite the isolation of CSMP reefs from human populations, and hence limited direct human pressures, they are increasingly being exposed to the effects of climate change. Indeed, eight major thermally-induced coral bleaching events have been recorded in the CSMP this century (2002, 2004, 2016, 2017, 2020, 2021, 2022 and 2024), with six of these bleaching events occurring in the past decade, and four in the past five years (Oxley et al. 2004, Harrison et al. 2018, 2019, Hoey et al. 2020, 2021, 2022, 2024). The four most recent bleaching events (i.e., 2020, 2021, 2022 and 2024) were the most severe and widespread, and collectively led to a 51% decline in coral cover in shallow (<15m depth) reef habitats throughout the CSMP (Hoey et al. 2024). Other thermal bleaching events may have also affected CSMP reefs but went undetected due to its isolation and infrequent scientific surveys. These bleaching events reflect the increasing frequency and intensity of marine heatwaves that are affecting coral reefs globally (van Hooidonk et al. 2016; Hughes et al. 2018; Mellin et al. 2024; Figure 2.3), with the 2024 marine heatwave within the CSMP being part of the fourth global bleaching event that impacted reefs globally (Reimer et al. 2024). These marine heatwaves and associated bleaching events are becoming a major driver of the cover and composition of coral communities on contemporary reefs, and the assemblages of reef fish and other reef-associated taxa they support (e.g., Bellwood et al. 2006a, 2012; Richardson et al. 2018). The effects of these bleaching events, and other major disturbances, may be particularly pronounced on isolated reefs such as those in the CSMP due to the reliance on self-recruitment of coral, fish and invertebrate larvae (i.e., larvae spawned from adults on the same reef rather than nearby reefs) to replenish adult populations (Gilmour et al. 2013).

The combined effects of the three recent bleaching events in the CSMP (i.e., 2020, 2021, and 2022) resulted in shallow water coral cover declining by an average of 51.2% (Hoey et al. 2024). There was, however, considerable variation in the decline in coral cover from 2020 to 2023/4 among regions, ranging from a 29.6% decline in the northern CSMP to a 50.2% and 58.6% decline in the southern and central CSMP, respectively (Hoey et al. 2024). These spatial differences in the response of coral assemblages will likely have flow-on effects to the recovery of coral populations, changes in associated assemblages of reef fish and invertebrates, and the potential resilience of the system as a whole. Future surveys are critical to assess the impacts of the marine heatwaves to which reefs of the CSMP were exposed in early 2024 and early 2025 (Figure 2.3), the potential recovery of shallow water coral assemblages following the 2020, 2021 and 2022 bleaching events, and any ongoing and delayed effects of coral loss on associated fish and invertebrate communities. It is important to note that the most recent surveys in the northern and central CSMP (i.e., 2023) occurred prior to the 2024 marine heatwave, and the most recent surveys of the southern CSMP (i.e., Feb

2024) occurred prior to the maximum heat stress recorded in March 2024. Subsequently, the effects of the 2024 marine heatwave in which much of the southern and central CSMP was exposed to 12 DHW and some areas 16 DHW, and the 2025 marine heatwave in which reef in the northern and central east of the CSMP were exposed to >12 DHW is unknown.

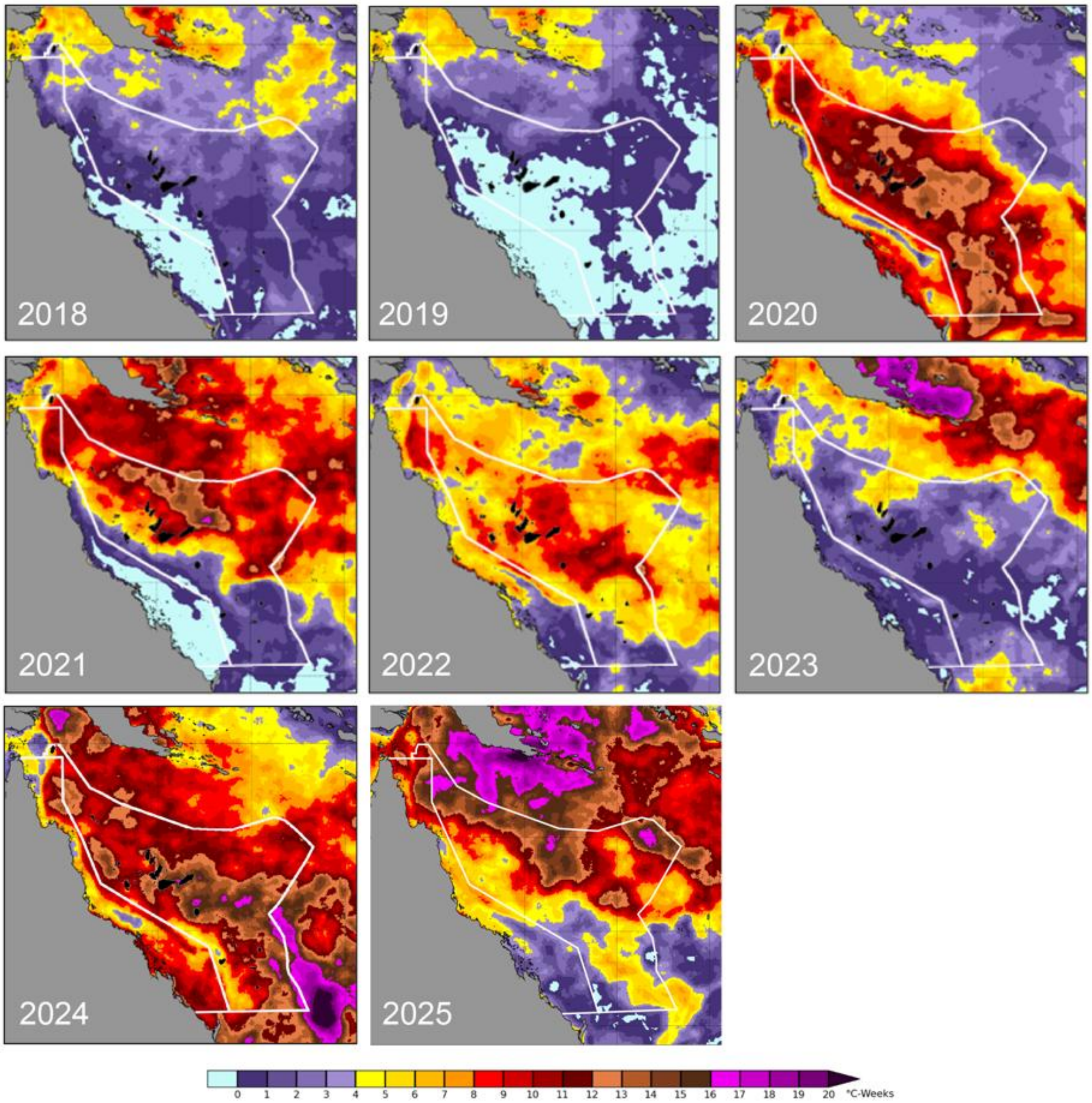


Figure 2.3 Comparison of the maximum Degree Heating Weeks (DHW) experienced throughout the Coral Sea Marine Park during the past seven years (2018-2025). Note the maximum DHW in 2021, 2022, 2024, and 2025 occurred in March of each year. Images produced using the NOAA CRW 5km product v3.1

2.1 Objectives and scope

The purpose of this study was to provide comprehensive assessments of the current condition of benthic, fish and invertebrate communities, and assess the impacts of recent thermal stress (i.e., 2020, 2021, 2022, 2023, 2024, and 2025) on these communities across twelve reefs in the central and southern CSMP.

Surveys were conducted at the twelve CSMP reefs following the methods of Hoey et al. (2020, 2021, 2022, 2024). 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) structural complexity of reef habitats;

iii) coral health and injuries caused by coral bleaching, disease, or coral predators (e.g., *Acanthaster* spp. and *Drupella* spp.);

iv) abundance of small/ juvenile corals (<5cm diameter), as a proxy of coral recruitment and population replenishment;

vi) size, abundance and composition of reef fish assemblages;

vii) abundance of holothurians, urchins and other ecologically or economically important reef-associated invertebrates; and

viii) the abundance and size of sea snakes

3 Methods

Surveys were undertaken at 16 sites across six reef systems within the central CSMP during an 11-day voyage, 4th – 14th June 2025, and 18 sites across six reef systems in the southern and central CSMP during an 11-day voyage,12th – 22nd October 2025 (Figure 3.1). The six reefs surveyed in June 2025 were Coringa, Diamond, and Willis Islets, Herald Cays, and Holmes and Lihou Reefs in the central CSMP. The six reefs surveyed in October 2025 were Cato, Frederick, Kenn, Saumarez and Wreck Reefs in the southern CSMP, and Marion Reef in the central CSMP (Appendix 1). To facilitate direct comparisons in coral health and reef condition among years we re-visited the sites that were surveyed during 2020-2024. Sites were relocated using GPS waypoints and a bearing of the direction of the transects from that waypoint.

3.1 Sampling design – diver-based surveys

At each site, diver-based surveys were generally conducted within each of two different habitats, i) the reef crest (approximately 1-3m depth) and ii) the reef slope (9-10m depth, where possible). In shallow reef environments (mainly inside lagoons or in back reef environments), where maximum depths were less than 9m, the reef slope transects were run along the deepest margin of contiguous reef habitats, avoiding extensive areas of sand or rubble. Similarly, it was not always possible to survey the reef crest, due to low tides, limited water depth, and/ or large swells, and in those cases the reef crest transects were often run just below the outermost edge of the reef crest (2-4m).

22 days
12 reefs - 34 sites
10.2 km of UVC surveys
>200 diver hours

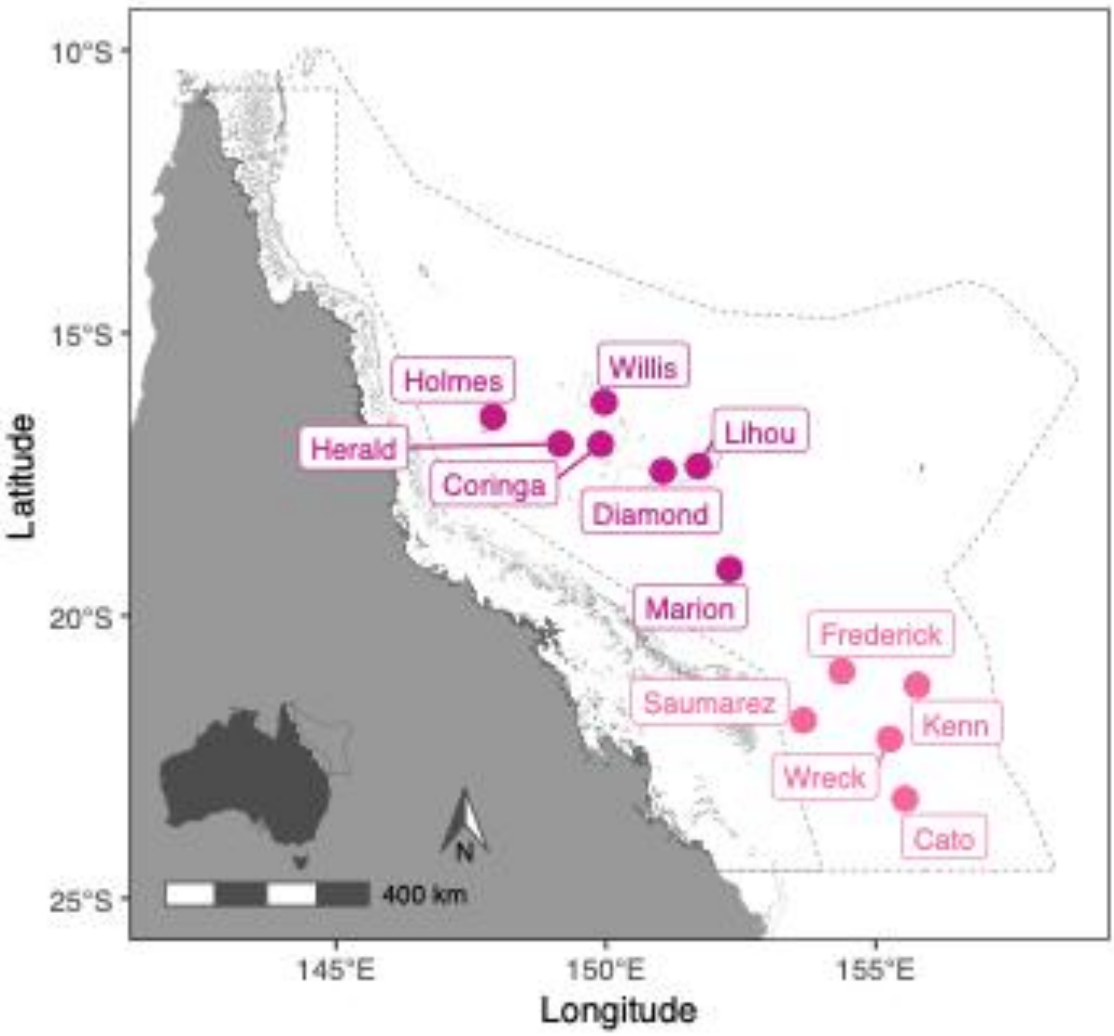


Figure 3.1 Map of the Coral Sea Marine Park (CSMP) showing the seven reefs in the central CSMP and the five reefs in the southern CSMP surveyed during the June and October 2025 voyages. Colours relate to the regional allocation of reefs in the southern (pink), and central (magenta) Coral Sea Marine Park which are used throughout the report. Regional allocation is based on our current understanding of coral and fish communities.

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 (or 5-person) dive team, whereby the lead diver deployed the transect tape while simultaneously recording the size and identity of larger (>10 cm total length, TL) and generally more motile fish species, within a 5m wide belt (following Hoey et al. 2020, 2021, 2022, 2024). 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 (Emslie et al. 2018; Hoey and Martin 2026). 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 fourth diver assessed coral health, estimated colony size, and 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.

3.1.1 Coral and reef habitats

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, 2024). 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 where possible. 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.

Coral health – The health of all coral colonies was recorded within a 10m x 1m belt on each transect (n = 3 per depth zone per site), following protocols developed by the Australian Coral Bleaching Taskforce (Hughes et al. 2017). The 10 x 1 m belt transects were generally run at the start of each 50m transect, but were relocated as required to avoid areas of sand or rubble substrata. For each colony contained wholly or mostly (>50%) within the transect area, the taxonomic identity, size and health of the colony was recorded. Corals were classified to genus and growth form (as described for PIT above), and then assigned to one of five size classes based on their maximum diameter (≤ 5cm, 6-20cm, 21-40cm, 41-60cm and >60cm). The health of each coral colony was then assigned to one of eight categories (Figure 3.2), to document the extent and severity of bleaching, as well as any other recent injuries (e.g., evidence of recent predation). Where possible, the cause of conspicuous injury was also recorded, be it due to coral predators (e.g., *Drupella* spp., crown-of-thorns starfish or parrotfish) observed within or nearby the injured colony, or coral disease.

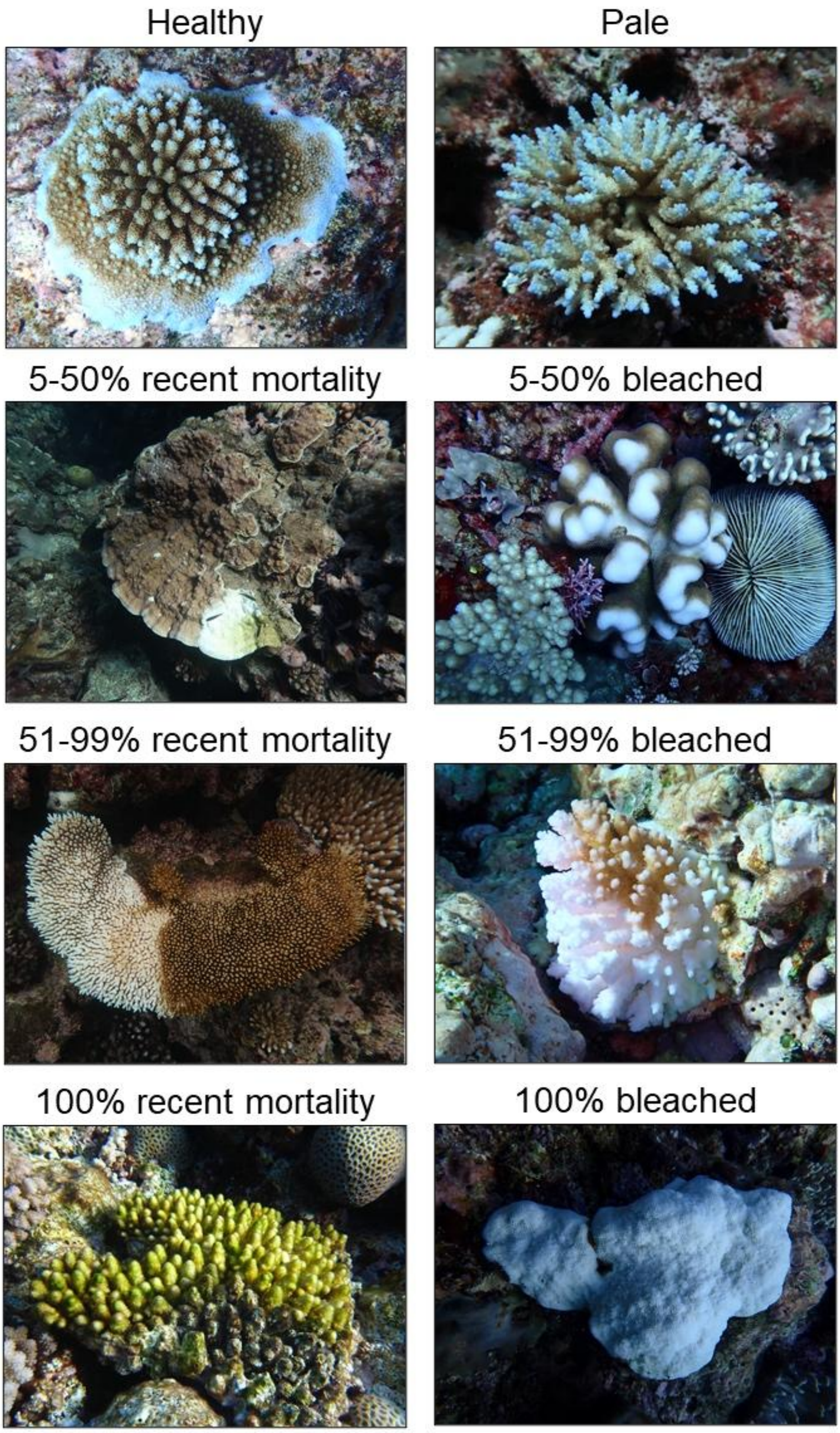


Figure 3.2 Coral health categories used for the in-water coral health assessments. Images on the left provide examples of the four injury categories, whilst images on the right are examples of the coral bleaching categories. Image credits: Deborah Burn, Morgan Pratchett

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 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 3.3).

Figure 3.3 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

Temperature loggers and Crustose Coralline Algae (CCA) devices – Temperature loggers and CCA devices deployed in Feb-Mar 2023 and Feb-Mar 2024 were retrieved and new loggers and devices deployed across 19 sites on ten reefs during the 2025 voyages (Figure 3.4). The CCA devices were deployed to quantify the settlement and growth of CCA and consisted of a length of PVC pipe (15mm diameter x 250mm length) that were attached to a steel bar (12mm diameter x 450 mm length) using cable ties (following Kennedy et al. 2017). The temperature loggers (Hobo Water Temp Pro v2) were set to record water temperature at 30-min intervals.

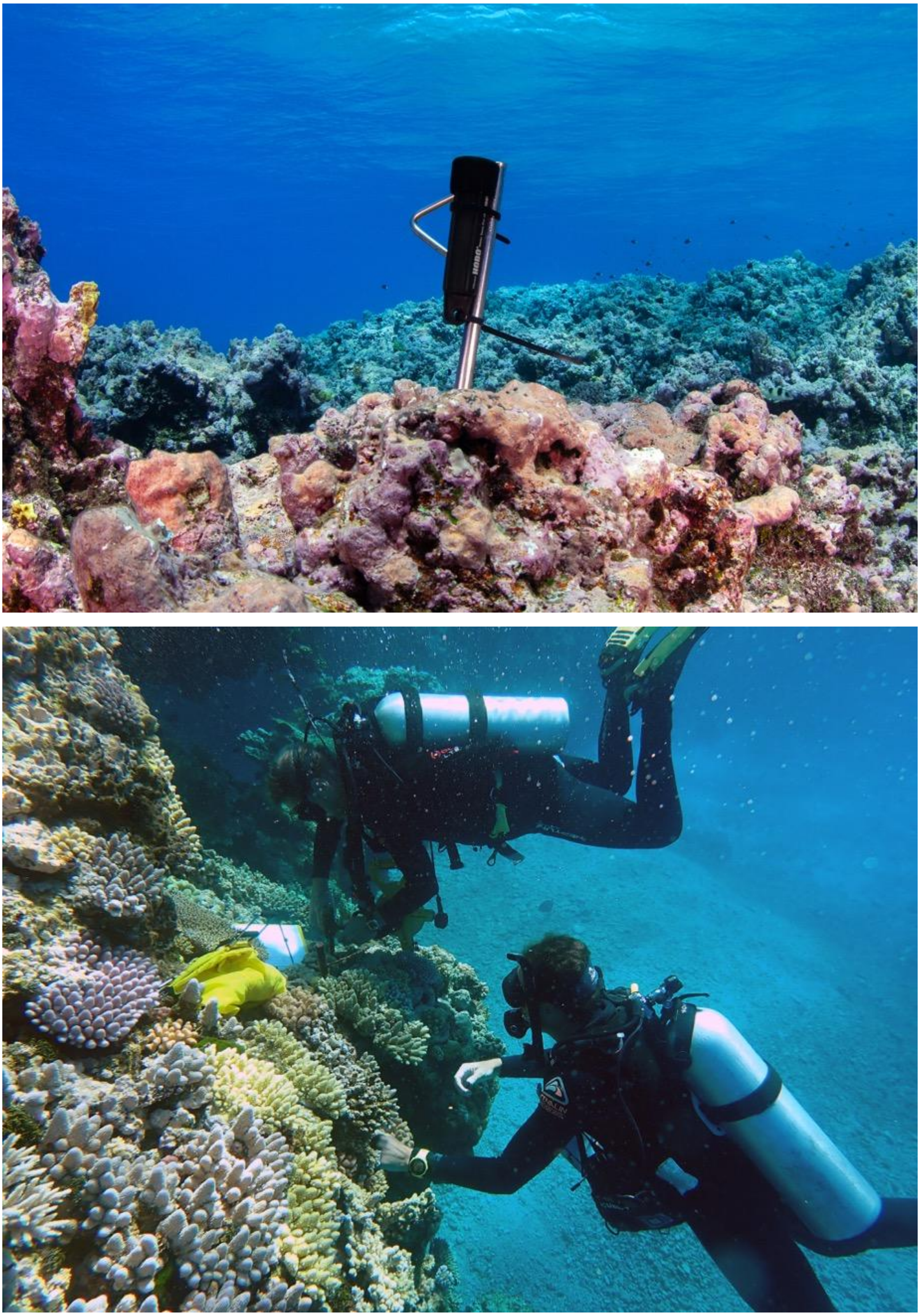


Figure 3.4 Photographs of a temperature logger deployed in Feb-Mar 2023 (top) and divers retrieving and replacing a temperature logger on Saumarez Reef in October 2025. Image credits: Victor Huertas (top), Fiona Hagger (bottom).

3.1.2 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, 2024). 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 3 for a comprehensive list of species surveyed.

3.1.3 Other reef taxa

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 3.5) were quantified within the same 50 x 5m belt transects used to survey large, mobile reef fishes. All sea snakes observed within the transect area were identified to species and their length estimated.

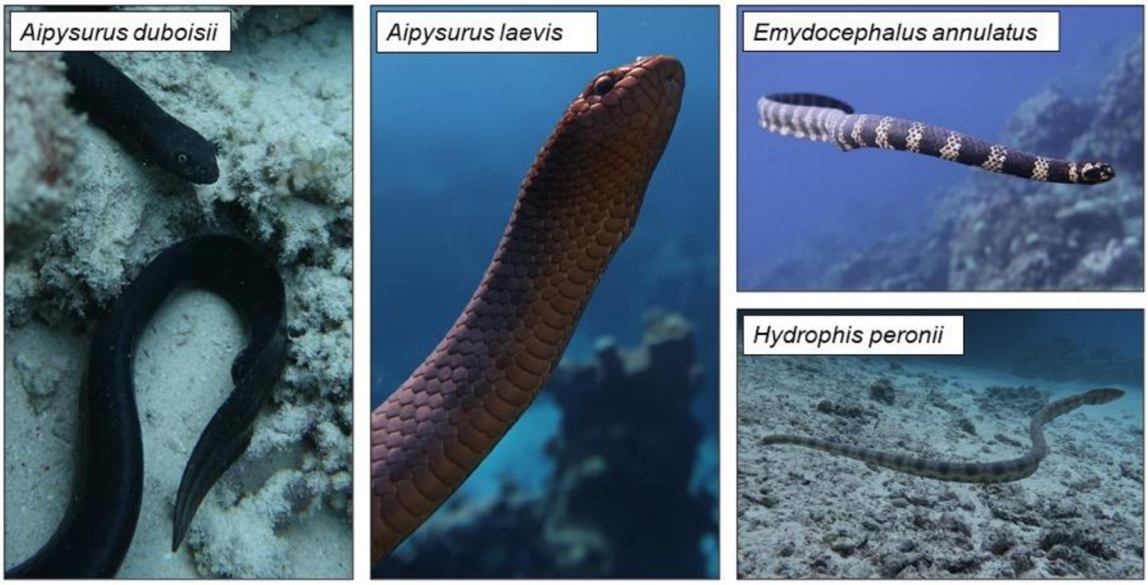


Figure 3.5 Photographs of the four species of sea snake that are commonly observed within the Coral Sea Marine Park; Dubois' sea snake, *Aipysurus duboisii*; Olive sea snake, *Aipysurus laevis*; Turtle-headed sea snake, *Emydocephalus annulatus;* Spiny headed or Horned sea snake, *Hydrophis peronii*. Image credits: Deborah Burn

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 economically important species, namely long-spined sea urchins (*Diadema* spp.) sea cucumbers (holothurians; Figure 3.6), 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).

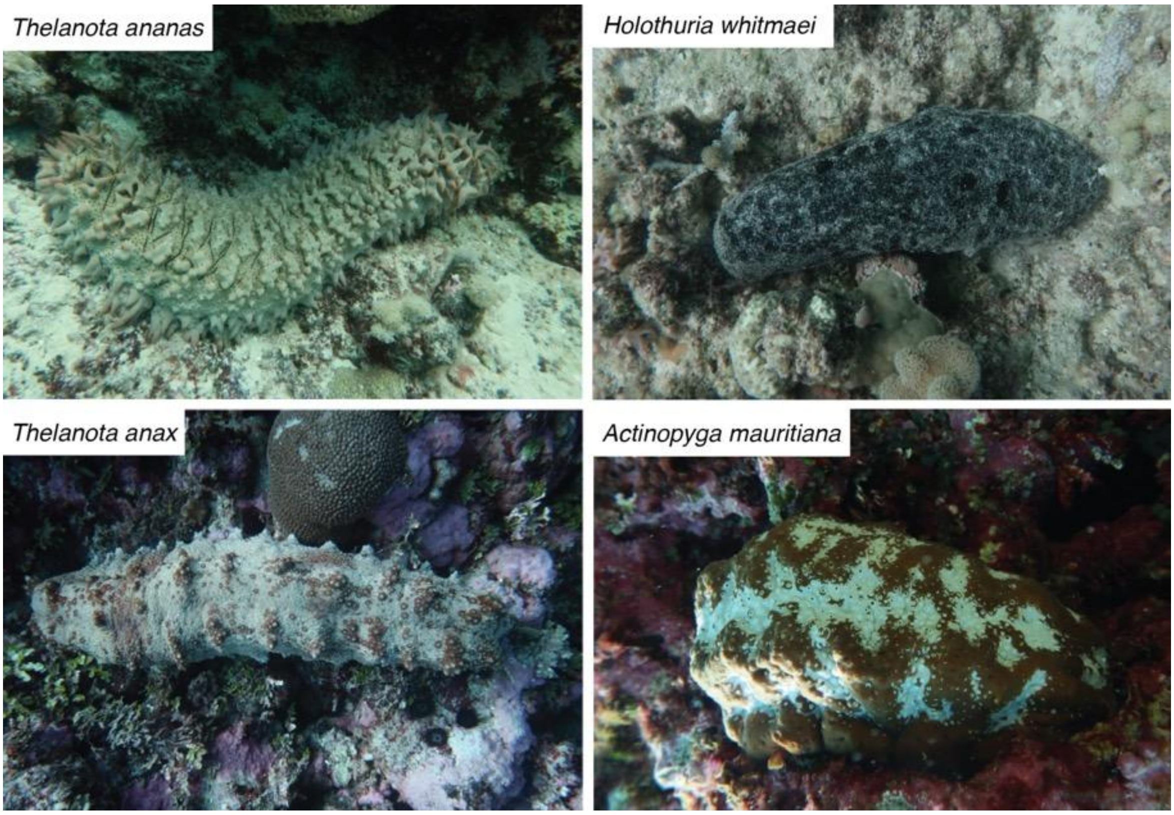


Figure 3.6 Photographs of four species of sea cucumber that are commonly observed within the Coral Sea Marine Park; Prickly redfish, *Thelanota ananas*; Black teatfish, *Holothuria whitmaei*; Amber fish, *Thelanota anax*; and Surf redfish, *Actinopyga mauritiana*. Image credits: Deborah Burn

Coral predators are potentially important contributors to coral reef health and habitat structure, especially during periods of elevated densities (Pratchett et al. 2014). Population irruptions 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).

3.2 Data handling and analysis

Data from the June 2025 and October 2025 surveys were combined with those of the previous voyages (2018-2024) into a single database and analysed using R version 4.3.2 with RStudio interface version 2023.09.1+494 (R Core Team 2021). 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 GBRMP and marine park boundaries were reproduced from shapefiles contained in the data package *gisaimsr* (Barneche and Logan 2021) and *dataaimsr* (AIMS Datacentre 2021), with datasets courtesy of the Great Barrier Reef Marine Park Authority and Geoscience Australia. Two-dimensional maps of CSMP reefs and reef boundaries were reproduced from shapefiles generated by Project 3DGBR (Beaman 2012). These maps were produced in R using the package *sf* (Pebesma 2018) and *ggspatial* (Dunnington 2021) using the GDA2020 coordinate system. Data for the three-dimensional digital elevation model (i.e., Figure 2.2) came from Project 3DGBR Version 6 (Beaman 2020), rendered in R using the *rayshader* package (Morgan-Wall 2024).

All survey data were averaged across independent transects to obtain a site, or where appropriate a zone (i.e., crest, slope) average prior to summarising data at the level of reefs or regions. 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 number of species/taxa observed at a site, prior to being summarised to the level of reefs or regions. For temporal comparisons (i.e., among years), 30 sites were identified that were surveyed in June or October 2025 that had been surveyed at least once between 2020-2024 (Appendix 1). These sites form the basis of all temporal comparisons.

Data are generally presented using box and whisker plots (i.e., box plots). The box plots 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.

Non-metric multi-dimensional scaling (nMDS) was used to identify similarities in coral and fish assemblages among reefs in *a priori* defined regions (i.e., southern, central, and northern CSMP) and between years. The objective of nMDS is to summarise all available information on the presence and abundance of species, or taxa, into a simple dissimilarity matrix. In the visual representations that follow, objects (i.e., sites or reefs) that are closer to one another are likely to be more similar than those further apart. Data were square-root transformed to reduce the relative influence of the most frequent and variable taxa, which otherwise will tend to dominate the dissimilarity matrix. For the analysis of coral composition rare taxa were grouped as 'other Scleractinia' to reduce the influence of these rare taxa in the dissimilarity matrix. The data were then standardised following a Wisconsin double standardisation, which removes the effect of absolute species abundance and also abundance between sites, so the comparison between sites becomes relative. Distances between points were determined with the *metaMDS* function using the Bray-Curtis dissimilarity matrix. All data were analysed in the *vegan* package (Oksanen et al. 2020) using the statistical software package R version 4.1.1.

4 Findings

4.1 Coral communities

The recent marine heatwaves and associated bleaching events in the CSMP (2020, 2021, and 2022) were severe and widespread, and collectively have resulted in a 51.2% decline in shallow water coral cover from 2020 to 2023/2024 (Hoey et al. 2024). There was, however, considerable variation in the change in coral cover among regions, with the greatest decrease in coral cover occurring on reefs in the central CSMP (2020 – 2023/24: 58.6% decline) compared to reefs in the southern and northern CSMP (50.2% and 29.6% declines, respectively). Understanding the ongoing impacts of, and the potential recovery from, these and subsequent (i.e., 2024) bleaching events on the cover and composition of coral assemblages, and the associated fish and invertebrate communities, is critical in assessing the current health and predicted future trajectories of reefs in the CSMP under ongoing climate change.

4.1.1 Coral cover and richness

The average cover of hard (scleractinian) corals recorded across the 34 sites surveyed in 2025 was 14.3% (±1.2 SE), ranging from 7.6% (±2.8) at Frederick Reef in the southern CSMP up to 27.0% (±1.5) at Holmes Reef in the central CSMP (Figure 4.1a). Average coral cover was approximately 1.5-fold greater on reefs in the southern CSMP (averaging 17.6 ± 1.7 %), compared to the central CSMP reefs (12.1 ± 1.6 %). With the exception of Frederick Reef (7.6% cover) in the southern CSMP and Holmes Reef (27.0% cover) in the central CSMP, average coral cover was relatively consistent among reefs within each region (southern CSMP: 16.3-20.3%; central CSMP: 7.8 – 12.3%; Figure 4.1a).

The average taxonomic richness of corals across the 34 sites, based on the number of hard (Scleractinian) coral taxa (mostly genera) recorded using the 50m point-intercept transects at each survey site, was 15.9 taxa per site and ranged from 6.0 taxa per site at Coringa Islet in the central CSMP to 20.7 taxa per site (± 0.3 SE) at Holmes Reef also in the central CSMP (Figure 4.1b). Only a single site was surveyed at Coringa Islet and hence there is no estimate of the variability among sites. Coral richness, like coral cover, tended to be greater in the southern CSMP (16.9 taxa per site) than the central CSMP (15.3 taxa per site), although there was considerable variation among reefs within each region (southern CSMP: 12.5 – 20.3 taxa per site; central CSMP: 6.0 to 20.6 taxa per site; Figure 4.1b).

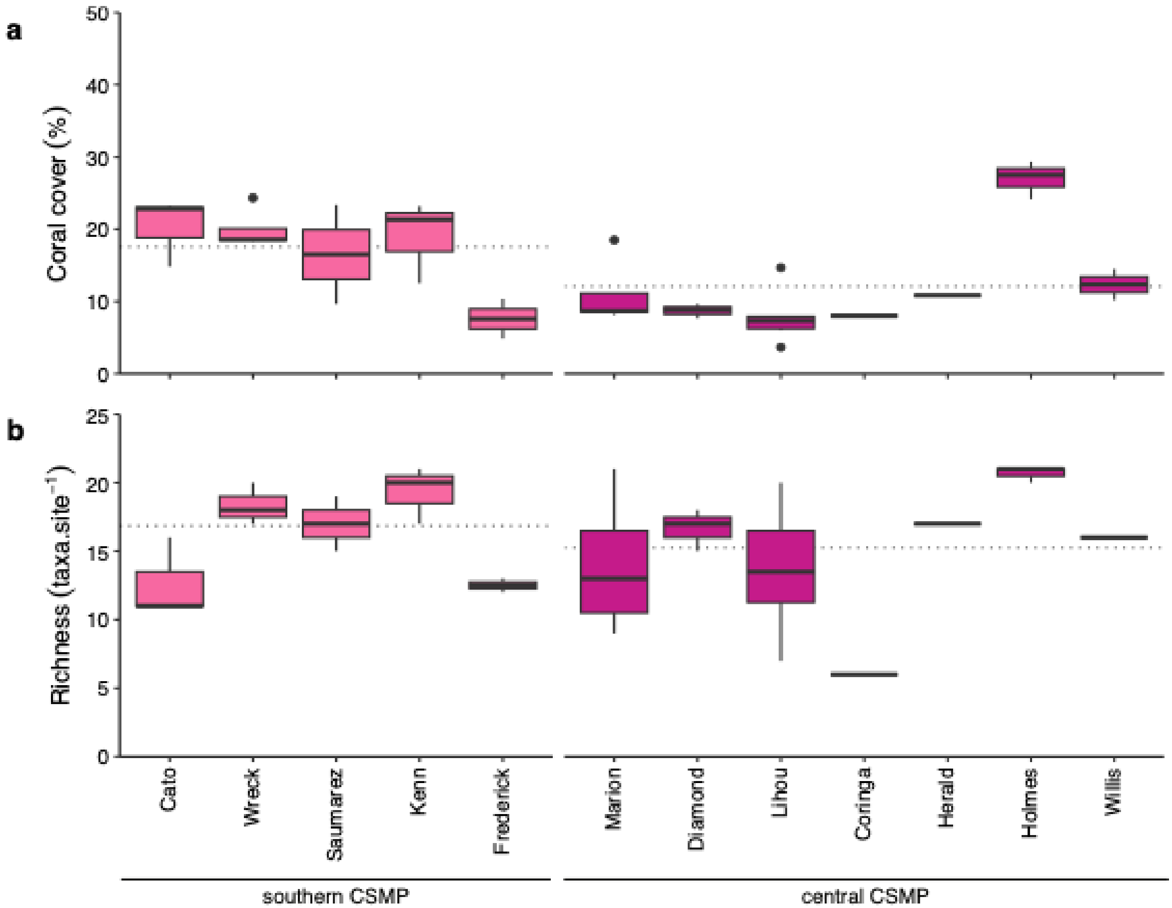


Figure 4.1 Variation in coral cover and coral richness among twelve reefs in the Coral Sea Marine Park (CSMP) in 2025. Data are based on the 50m point-intercept transects, with data for richness based on the number of coral taxa recorded at each of the 34 sites (i.e., pooled across transects and slope and crest habitats). Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Dotted lines represent regional averages. Diamond, Coringa and Willis Islets, Lihou and Holmes Reefs, and Herald Cays were surveyed in June 2025, and Cato, Wreck, Saumarez, Kenn, Frederick, and Marion Reefs were surveyed in October 2025.

4.1.2 Temporal changes in coral cover and richness

Coral cover - Comparisons of coral cover in shallow reef habitats across the eleven reefs that were surveyed in 2020-24 and 2025 (i.e., excluding Coringa Islet) revealed some differences in the temporal patterns in coral cover between the two CSMP regions (Figure 4.2). While coral cover declined in both the central and southern CSMP from 2020 to 2022 (i.e., following the 2020 and 2021 coral bleaching events; Hoey et al. 2021, 2022), coral cover continued to decline between 2022 and 2023/24 in the central CSMP (2022: 11.4%; 2023: 8.9%) yet increased in the southern CSMP (2022: 14.8%; 2024: 16.8 %; Figure 4.2). This difference may reflect differences in the timing of the surveys in 2023/24 with the central CSMP reefs (except Marion Reef) being surveyed in 2023 and the southern CSMP reefs being surveyed in 2024. Importantly, coral cover increased from 2023/24 to 2025 in both southern (2023/24: 16.8%; 2025: 17.6%; an absolute increase of 0.8%) and central CSMP (2023/24: 8.9%; 2025: 13.0%; an absolute increase of 4.1%). These changes in coral cover from 2023/24 to 2025 were relatively consistent between habitats (i.e., the reef crest: 1-3m depth; reef slope: 7-10m) in the southern and central CSMP (Figure 4.3).

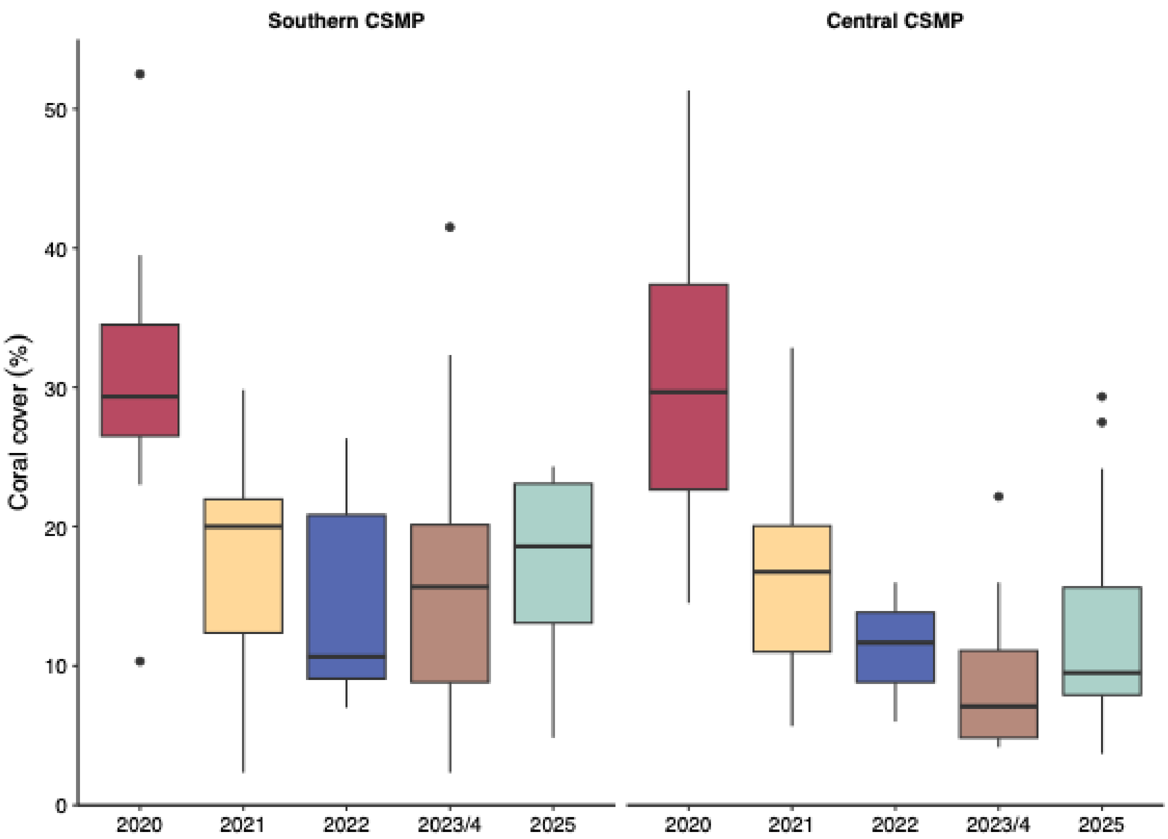


Figure 4.2 Temporal (2020-2025) variation in coral cover within the two regions of the Coral Sea Marine Park. Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at once during 2020-24, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays). Data are averaged across sites and habitats (reef slope and reef crest).

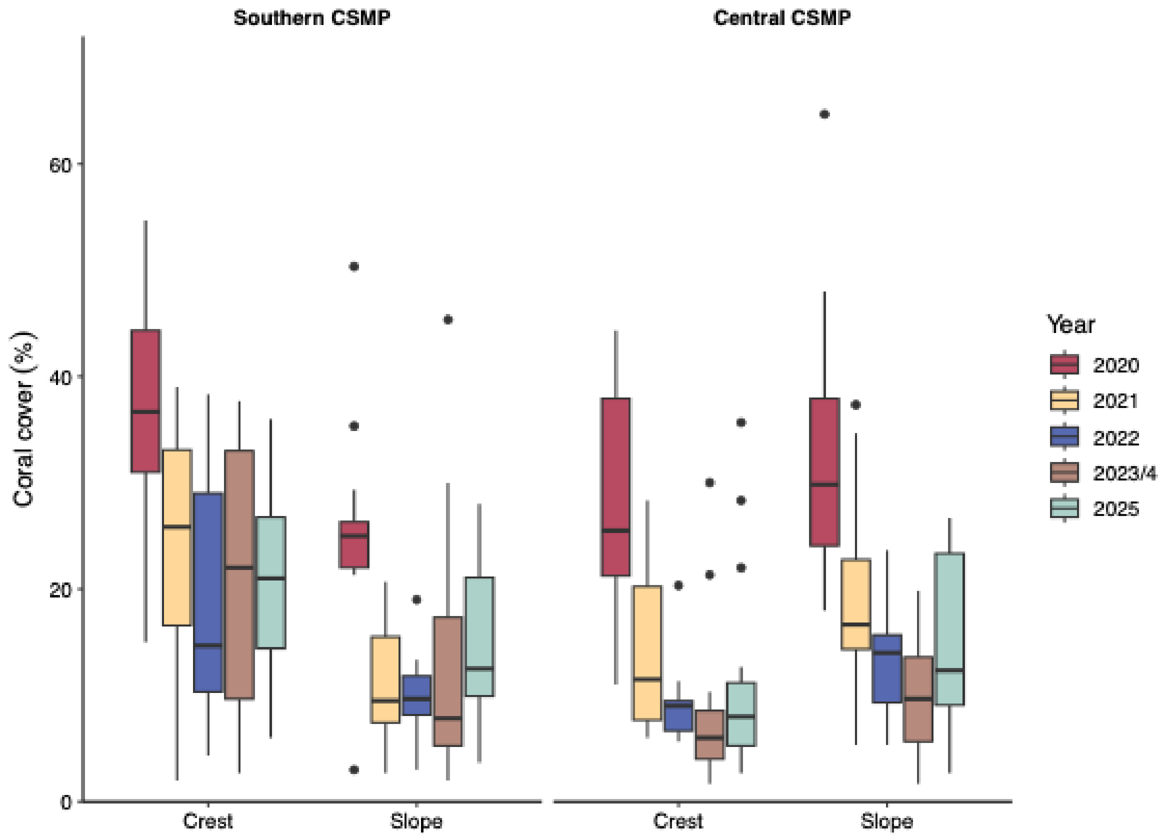


Figure 4.3 Temporal (2020-2025) variation in coral cover between shallow reef habitats (reef crest and reef slope) within the southern and central regions of the Coral Sea Marine Park. Data are based on 30 sites from eleven reefs that were surveyed at least once in 2020-24 and again in 2025.

Changes in coral cover varied among reefs within each region, yet were relatively consistent among sites within each reef between 2022 and 2023/24 (Figures 4.4 and 4.5). In the southern CSMP changes in coral cover between 2023/24 and 2025 ranged from a decline of 13.4% at Cato Reef (2024: 33.7%; 2025: 20.3%) to a 7.6% increase at Kenn Reefs (2024: 11.3%; 2025: 19.0%; Figures 4.5). Importantly, Cato Reef was the only reef surveyed in which coral cover was observed to have declined between 2023/24 and 2025. Despite the decline in coral cover at Cato Reef, and increases in coral cover at the other four reefs in the southern CSMP, coral cover at Cato Reef (20.3%) remains the highest in the southern CSMP. Coral cover increased across all central CSMP reefs from 2023/24 to 2025 ranging from an increase of 0.7% at Herald Cays (2023: 10.1%; 2025: 10.8%) to 10.2% at Holmes Reef (2024: 16.8%; 2025: 27.0%; Figure 4.5).

The cause/s of the decline in coral cover at Cato Reef when coral cover at all other reefs remained relative stable is difficult to determine, however it is likely related to the heat stress experienced in the southern CSMP in March 2024 (Figure 4.6) coupled with the high cover of bleaching-sensitive corals (namely branching and tabular *Acropora*) at Cato Reef in 2024 (Hoey et al. 2024). Interestingly, the increases in coral cover recorded at ten of the eleven reefs (all except Cato Reef), although relatively small, are somewhat surprising given the heat stress to which these reefs were exposed in March 2024 and March 2025 (Figure 2.3). Most reefs in the southern and central CSMP experienced levels of heat stress in March 2024 (>12 DHW) and in the eastern region of the Queensland Plateau in March 2025 (>8 DHW; Figure 2.3) that are expected to cause extensive levels of bleaching and widespread mortality. The recorded increase in coral cover suggests there was little, if any, coral mortality related to these marine heatwaves.

Despite the small increases in coral cover observed over the last 1-2 years, coral cover within the southern and central CSMP remains well below levels recorded in 2020. Overall, coral cover has declined by 50.7% across the southern and central CSMP from 2020 (30.7%) to 2025 (15.1%) with the central CSMP (2020: 30.6%; 2025: 13.0%; a relative decline of 57.4%) experiencing a greater decline than the southern CSMP (2020: 30.9%; 2025: 17.6%; a relative decline of 43.1%).

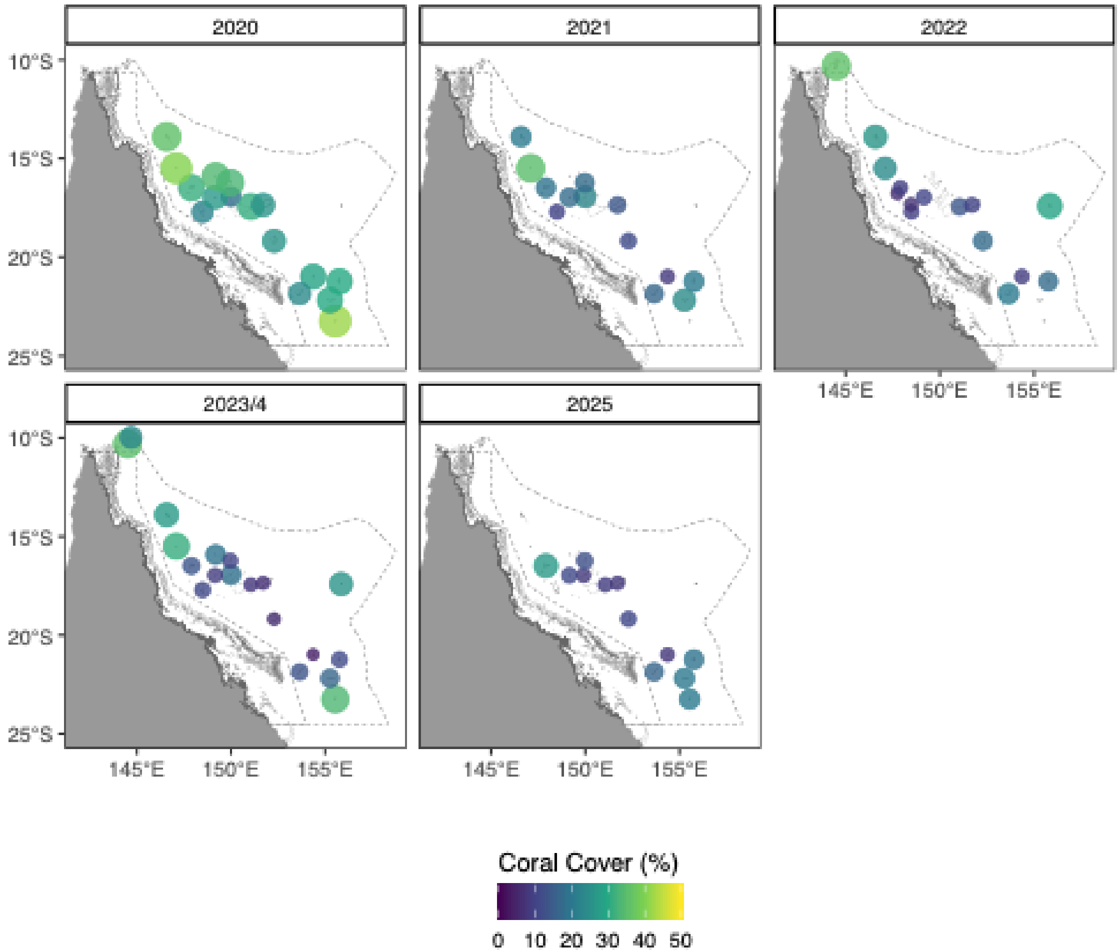
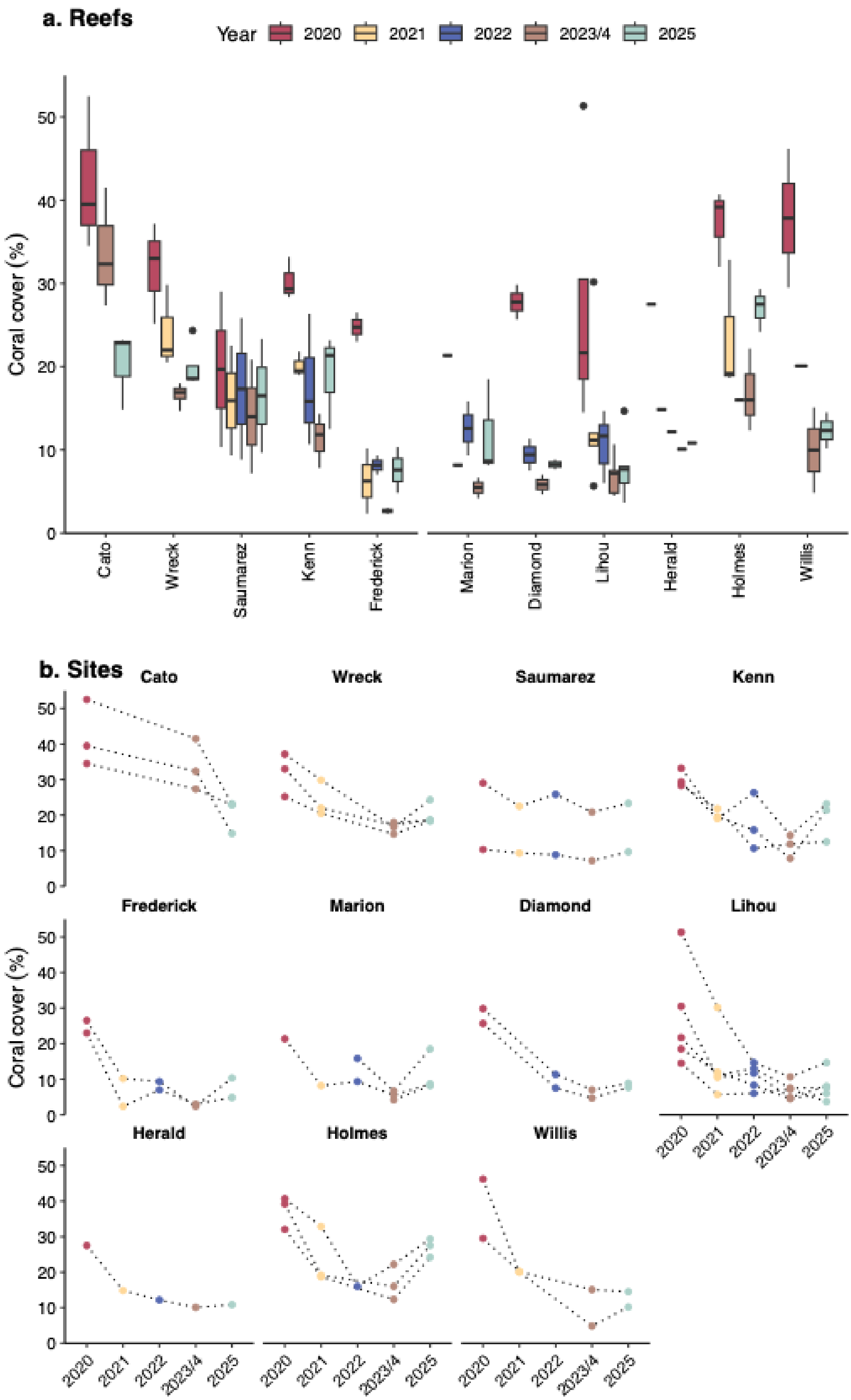


Figure 4.4 Spatial and temporal (2020-2025) variation in the cover of live hard (scleractinian) corals on shallow reef habitats (reef crest and reef slope) across 22 reef systems in the Coral Sea Marine Park. The size of individual points is proportional to the cover of live coral at each reef.



a. Reefs
Year
2020
2021
2022
2023/4
2025
Coral cover (%)
0
10
20
30
40
50
Cato
Wreck
Saumarez
Kenn
Frederick
Marion
Diamond
Lihou
Herald
Holmes
Willis
b. Sites
Cato
Wreck
Saumarez
Kenn
Frederick
Marion
Diamond
Lihou
Herald
Holmes
Willis
Coral cover (%)
2020
2021
2022
2023/4
2025

Figure 4.5 Temporal variation in coral cover among **(a)** seventeen reefs, and **(b)** 58 sites in the Coral Sea Marine Park that were surveyed at least once in 2020-22 and again in 2023/24. Data are based on surveys of matching sites in each year and pooled between habitats (reef slope and reef crest) within each site.

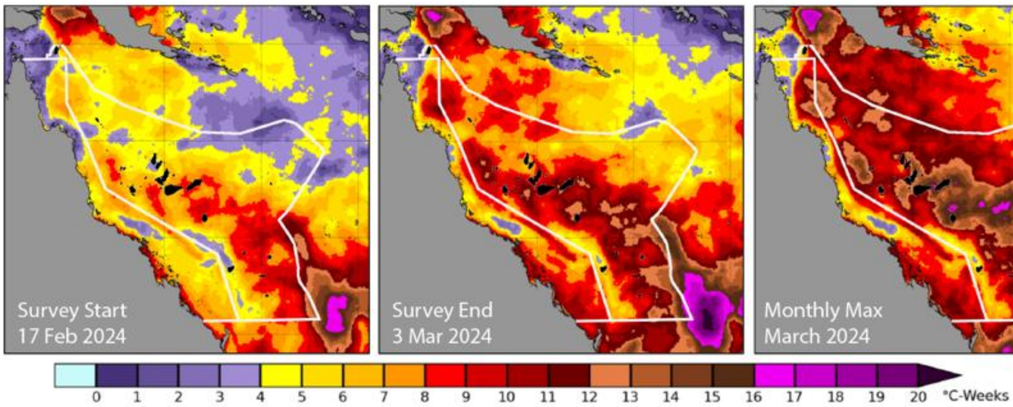


Figure 4.6 Heat stress (shown as degree heating weeks, DHW) experienced in the Coral Sea Marine Park during February – March 2024. The maps show the progression of heat stress from the start (17th February) to the end of the 2024 surveys (3rd March), and the monthly maximum heat stress for March 2024. Importantly the maximum heat stress experienced occurred several weeks after the completion of the 2024 surveys. Images produced using the NOAA CRW 5km product v3.1

Coral richness – Temporal variation in coral richness displayed broadly similar patterns to that of coral cover, although the magnitude of the changes was lower. Overall, coral richness increased across both CSMP regions from 2023/24 to 2025 (Figures 4.7, 4.8). Average coral richness increased from 14.0 to 16.9 taxa per site on southern CSMP reefs, and from 15.3 to 16.6 taxa per site on central CSMP reefs (Figure 4.7). These increases were generally consistent among reefs in each region, the only exception being Cato Reef in the southern CSMP where average coral richness decreased from 15.0 to 12.7 taxa per site from 2024 to 2025 (Figure 4.8). Overall, the average taxonomic richness remains below that recorded in 2020 for both the southern (2020: 18.6 taxa per site; 2025 16.9 taxa per site) and central CSMP (2020: 18.6 taxa per site; 2025 16.6 taxa per site).

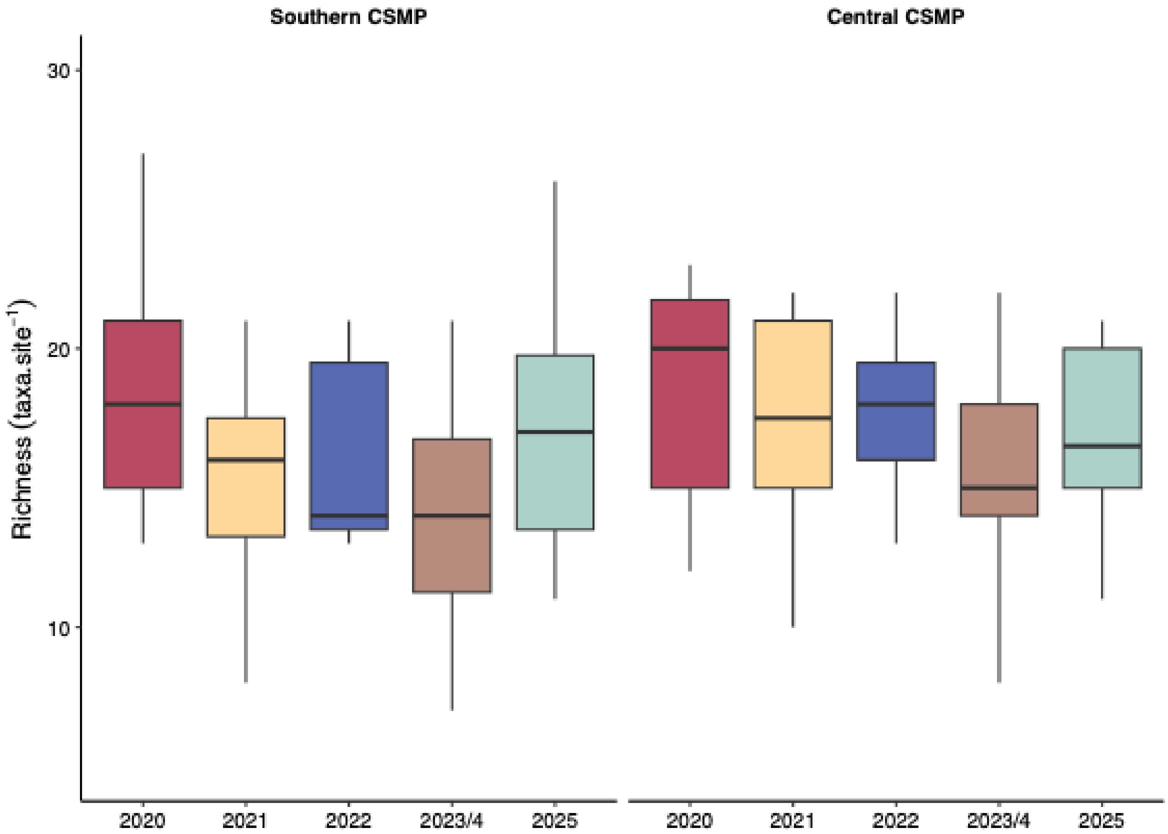


Figure 4.7 Temporal (2020-2025) variation in coral richness among the two regions in the Coral Sea Marine Park. Data are based on surveys of 30 sites across eleven reefs that were surveyed at least once in 2020-24 and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays). Data are based on the number of coral taxa recorded at each of 30 sites (i.e., pooled across slope and crest habitats).

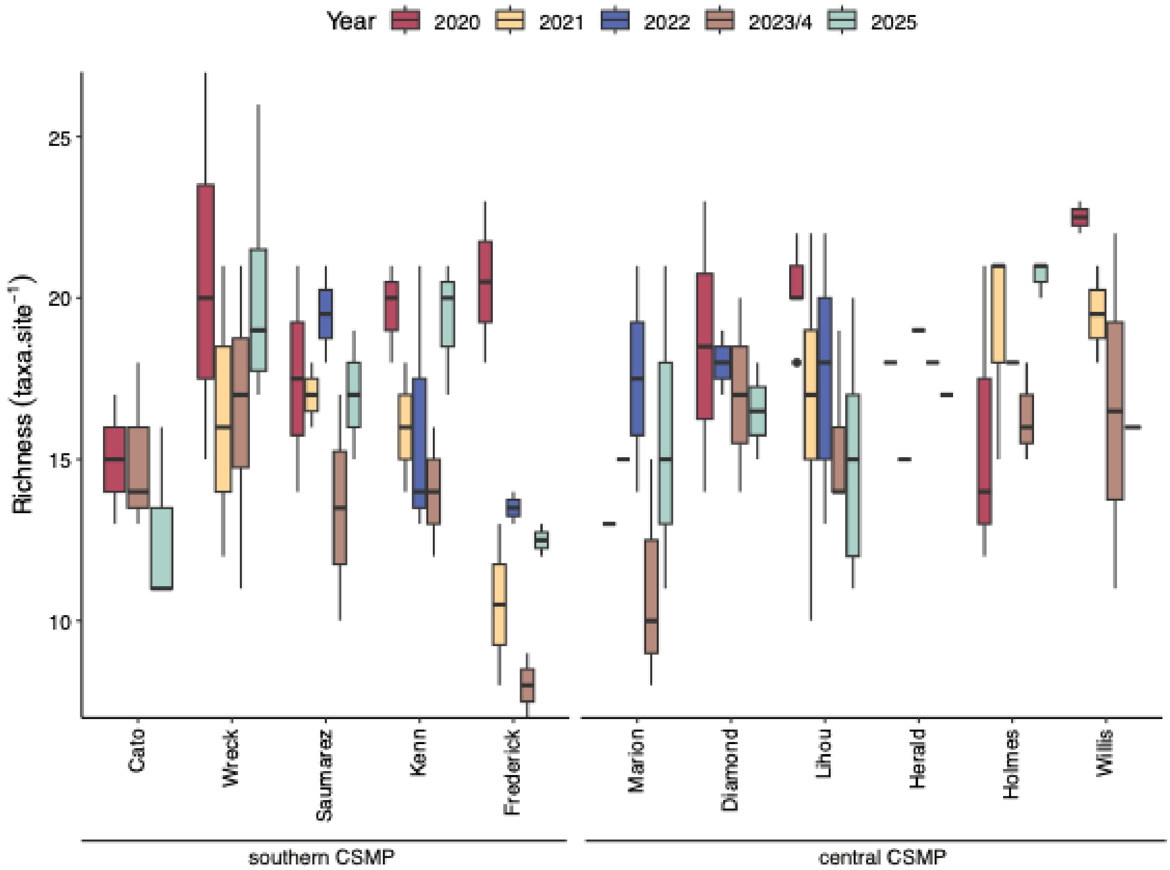


Figure 4.8 Temporal (2020-2025) change in coral richness among eleven reefs in the Coral Sea Marine Park from 2020 to 2025. Data are based on the number of coral taxa recorded at each of 30 sites (i.e., pooled across slope and crest habitats). One to five sites were surveyed at each reef.

4.1.3 Coral composition

The composition of shallow water coral assemblages in the CSMP varied both spatially (between regions) and temporally (among years; Figure 4.9). Coral assemblages within the southern CSMP were generally positioned on the left-hand side of the nMDS space and were characterised by a higher cover of tabular and 'other' *Acropora,* and *Isopora*, while coral assemblages within the central CSMP were positioned on the right-hand side of the nMDS space and were characterised by a higher cover of branching *Goniastrea, Pocillopora* and 'other' Scleractinia (Figure 4.9 a,b).

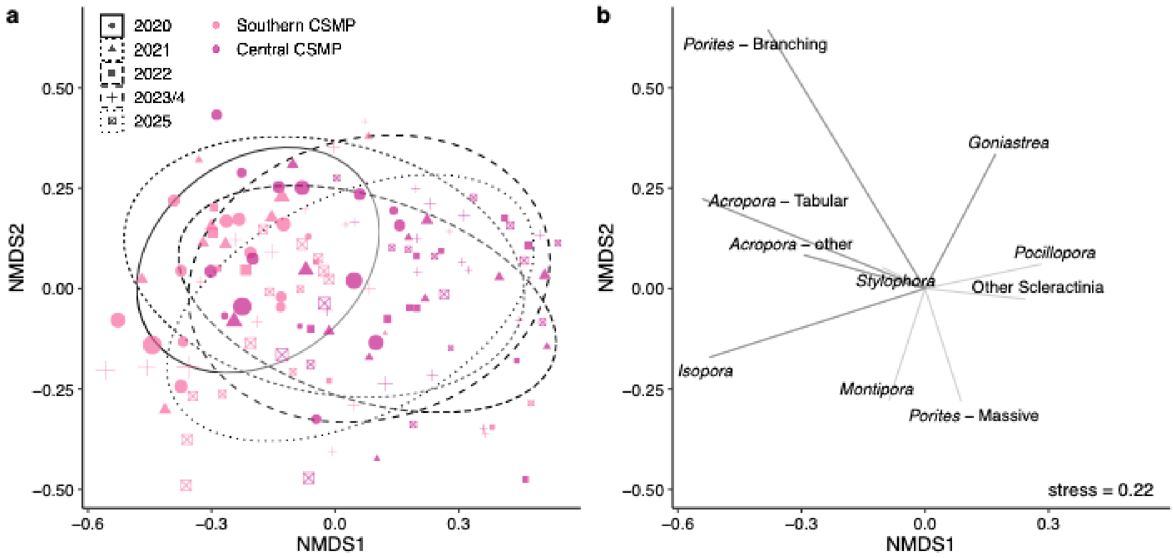


Figure 4.9 Regional and temporal (2020-2025) variation in the composition of shallow water coral assemblages within the Coral Sea Marine Park. Non-metric multidimensional scaling (nMDS) plot showing the variation in coral composition among years for the two regions of the Coral Sea Marine Park. Analyses are based on data from 30 sites that were surveyed at least once in 2020-2024, and again in 2025. The size of individual points is proportional to the cover of live coral at each site. Vectors in the right-hand side plot indicate key taxa that account for the variation in coral composition displayed in the corresponding left-hand side plot.

Together with differences in coral composition between the southern and central CSMP reefs, there has been a shift in the composition of coral assemblages from 2020 to 2025 (Figure 4.9). Temporal shift in the composition of coral assemblages were most pronounced in the central CSMP (from left to right in the nMDS space) where the relative cover of thermally sensitive taxa (namely tabular and 'other' *Acropora, Isopora* and *Stylophora*) decreased, and the relative cover of thermally tolerant taxa (i.e., *Goniastrea* and 'other' Scleractinia) increased (Figure 4.10a,b). This shift in coral composition was less evident in the southern CSMP, where coral assemblages tended to become more variable among sites from 2020 to 2023/24 (as indicated by the larger ellipses; Figure 4.10c).

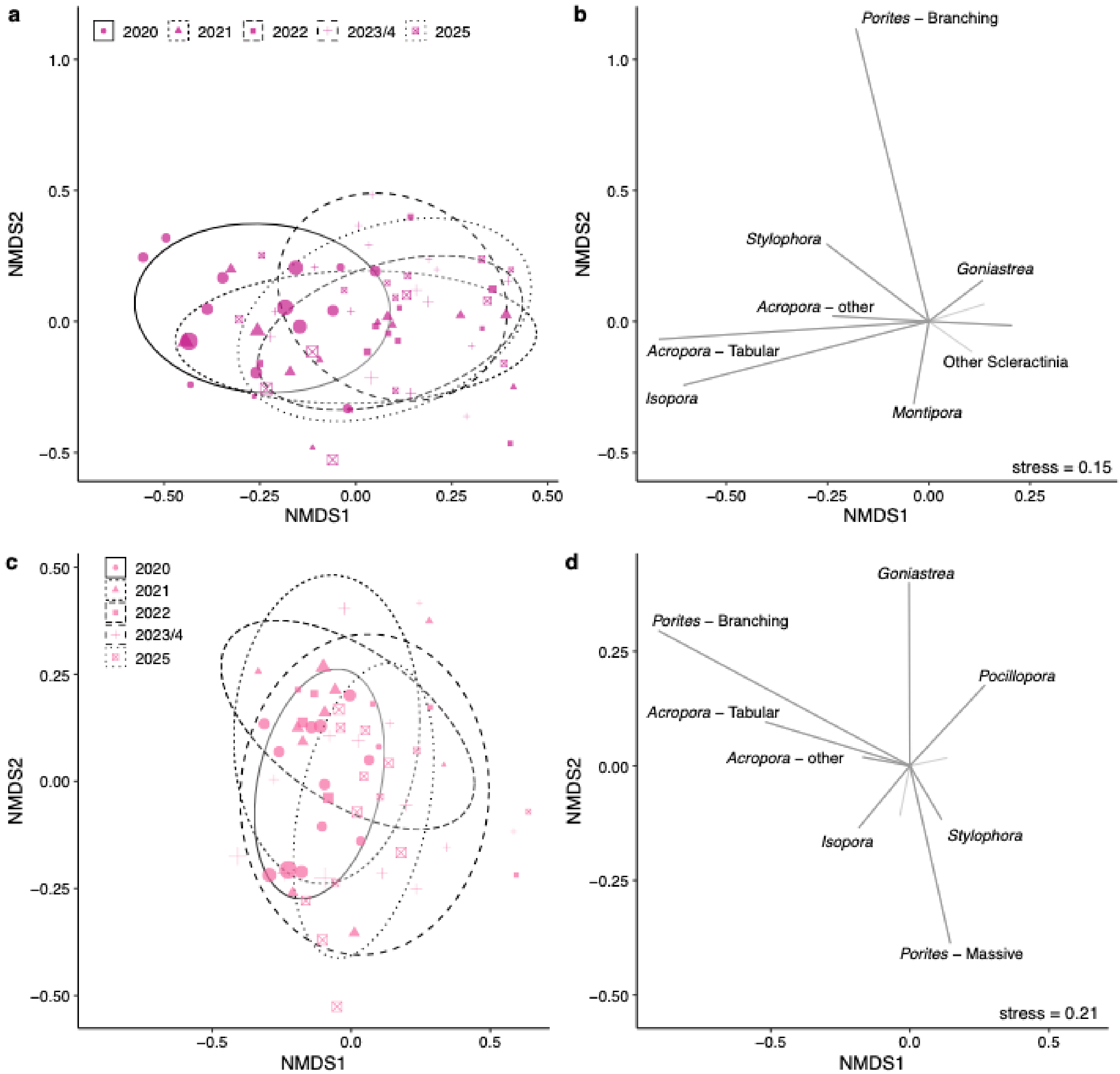


Figure 4.10 Non-metric multidimensional scaling (nMDS) plots showing the temporal variation (2020-2025) in shallow water coral composition among reefs in the **(a,b)** central, and **(c,d)** southern Coral Sea Marine Park. Analyses are based on data from 30 sites that were surveyed at least once in 2020-24 and again in 2025 (central: 16 sites; southern: 14 sites). The size of individual points is proportional to the cover of live coral at each site. Vectors in the right-hand side plot indicate key taxa that account for variation in coral composition displayed in the corresponding left-hand side plot.

Figure 4.11 Photographs of low coral cover reef crest habitat at Lihou Reef (top; June 2025) and high coral cover at Saumarez Reef (bottom; October 2025) within the Coral Sea Marine Park. Note the high cover of crustose coralline algae in the top image. Image credits: Morgan Pratchett (top), Fiona Hagger (bottom).

4.2 Algal communities

4.2.1 Fleshy macroalgae

The cover of macroalgae across the twelve CSMP reefs surveyed in 2025 was moderate, with total macroalgal cover averaging 18.4%. Macroalgal cover was 3.1-fold greater on reefs in the central CSMP (25.7%) than the southern CSMP (8.2%; Figure 4.12). Macroalgal cover also varied among reefs within each region, ranging from 0.1% on Cato Reef to 23.8% on Saumarez Reef in the southern CSMP, and from 14.2% on Holmes Reefs to 46.7% on Coringa Islets in the central CSMP (Figure 4.12). Macroalgae assemblages were dominated by the green calcareous alga *Halimeda* that accounted for 86.5% and 59.8% of all macroalgae recorded in the central and southern CSMP, respectively CSMP (Figure 4.12). Other macroalgae that were commonly observed included the chlorophytes *Caulerpa, Udotea and Rhipiliopsis.*

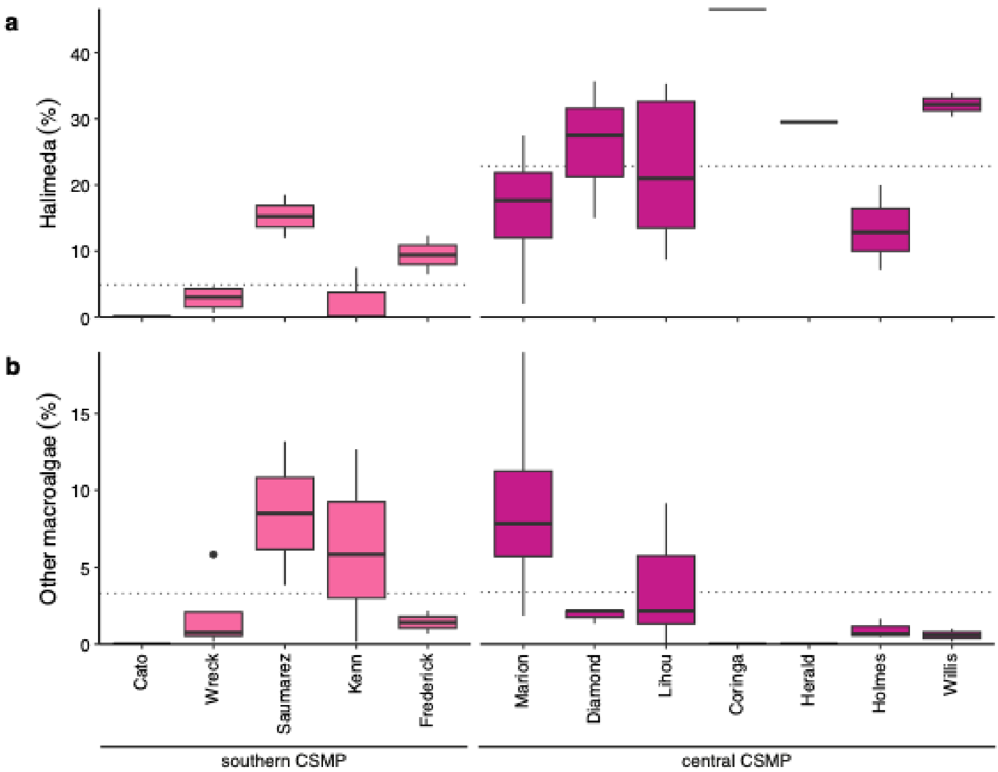


Figure 4.12 Variation in the cover of **(a)** *Halimeda* and **(b)** 'other' macroalgae among twelve reefs in the Coral Sea Marine Park (CSMP) in 2025. Data are based on the 50m point-intercept transects at each of the 34 sites (i.e., averaged across transects, habitats - slope and crest, and sites). Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Dotted lines represent regional averages.

Comparisons of macroalgal cover in shallow reef habitats across the eleven reefs that were surveyed at least once during 2020-24 and again in 2025 revealed a marked difference in macroalgal cover between the two CSMP regions (Figure 4.13). Despite macroalgal cover steadily increasing from 2020 to 2025 in the southern CSMP, total macroalgal cover has remained below 10% cover (2020: 2.9%; 2025: 8.2%). In contrast, macroalgal cover in the central CSMP decreased from 8.1% in 2020 to 3.1% in 2022, before increasing 8-fold to 25.7% in 2025 (Figure 4.13).

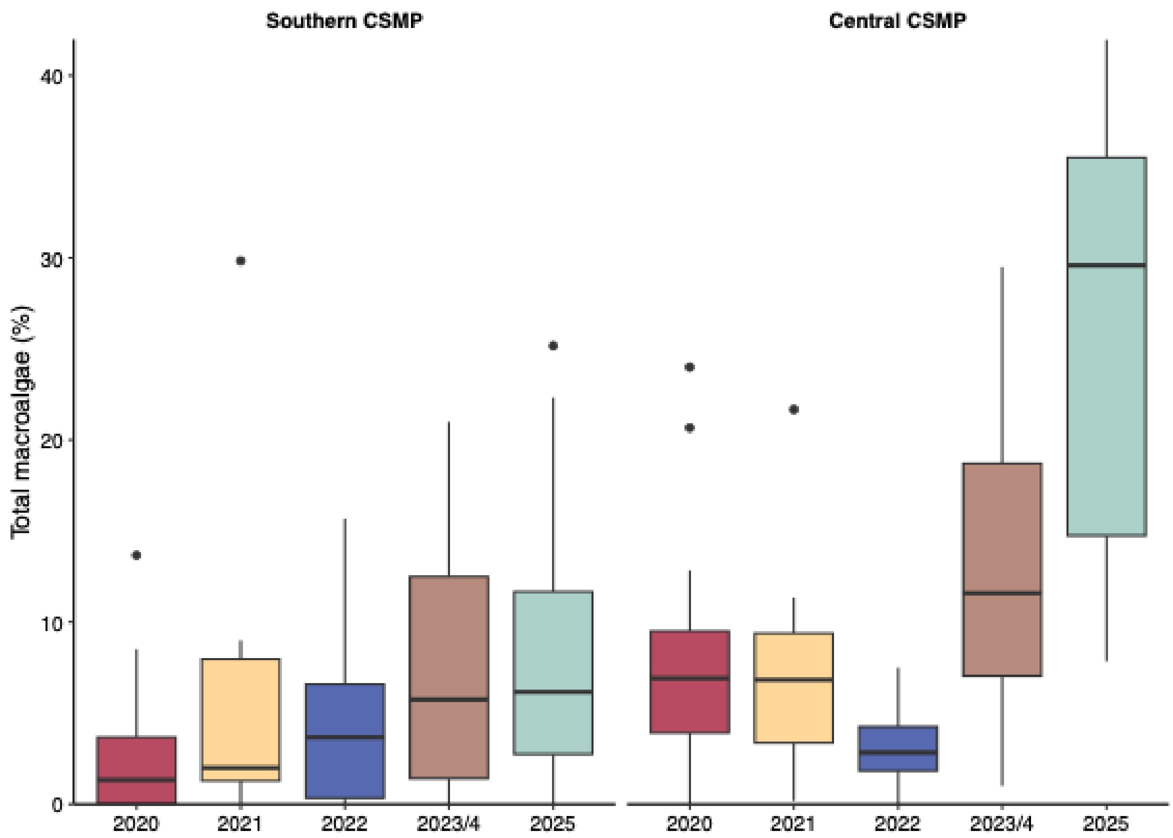


Figure 4.13 Temporal (2020-2025) variation in total macroalgae cover within the two regions of the Coral Sea Marine Park. Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at least once during 2020-24, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays).

Consistent with previous surveys of shallow reef habitats within the CSMP, the green calcified macroalga *Halimeda* spp. accounted for >80% of all macroalgae recorded across all sites in 2025 and changes in total macroalgal cover were largely reflective of changes in the cover of *Halimeda*. The cover of *Halimeda* increased 2-fold on reefs in the central CSMP from 2023/24 (11.6%) to 2025 (22.1%) yet decreased on reefs in the southern CSMP over the same period (2023/4: 6.0%; 2025: 4.9%; Figure 4.14). *Halimeda* is a common feature of oceanic reefs where it often forms thick curtains on steep slopes and overhangs and is an important contributor to calcification and production of reef sediments (Drew 1983). Increases in, or high cover of *Halimeda* is not considered to be symptomatic of reef degradation. The average cover of 'other' macroalgae was low (<5% cover) within both the southern (3.3%) and central CSMP (3.6%) in 2025 (Figure 4.14). There was, however, considerable variation in the cover of 'other' macroalgae among reefs in both regions. In the central CSMP, the cover of 'other' macroalgae ranged from 0.0% at Herald Cays to 4.0% (primarily *Laurencia* and *Rhipiliopsis*) at Lihou Reef and 9.8% (primarily *Rhipiliopsis*) at Marion Reef (Figure 4.15). Similarly in the southern CSMP the cover of 'other' macroalgae ranged from 0.0% at Cato Reef to 6.2% (primarily an unidentified alga) at Kenn Reef and 8.5% (primarily *Caulerpa*) at Saumarez Reef.

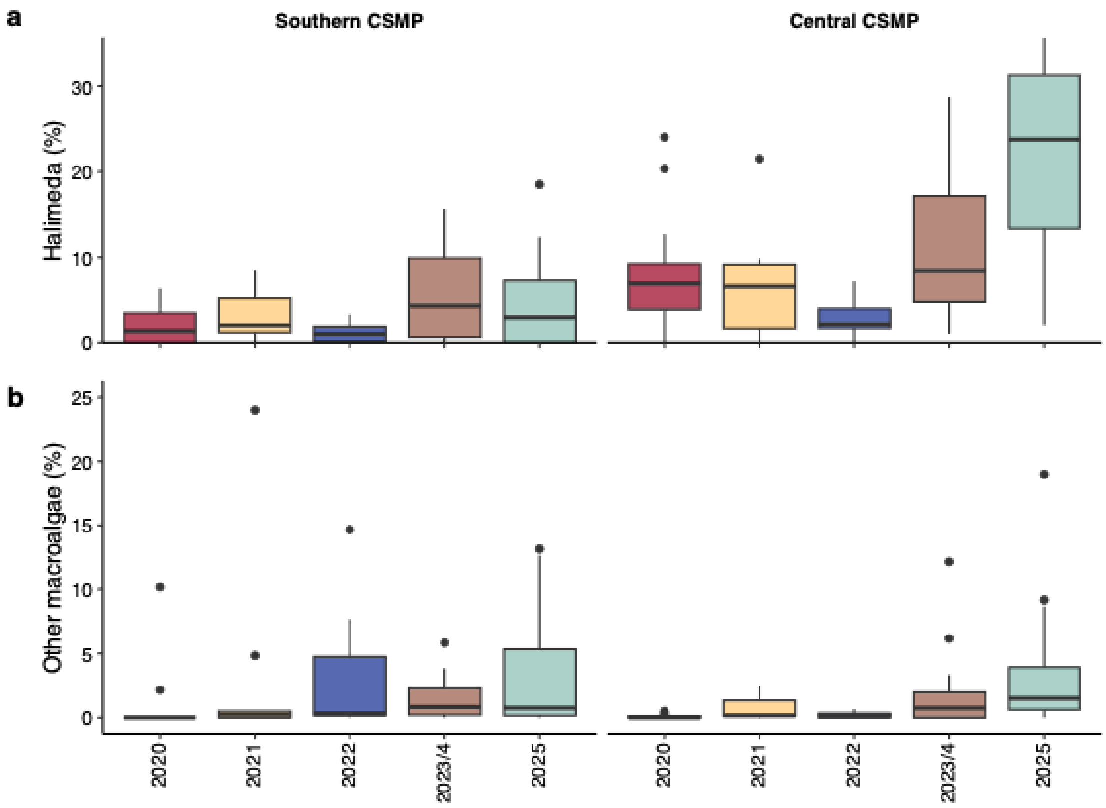


Figure 4.14 Temporal (2020-2025) variation in the cover of **(a)** *Halimeda* spp. and **(b)** 'other' macroalgae within the two regions of the Coral Sea Marine Park. Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at least once during 2020-24, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays).

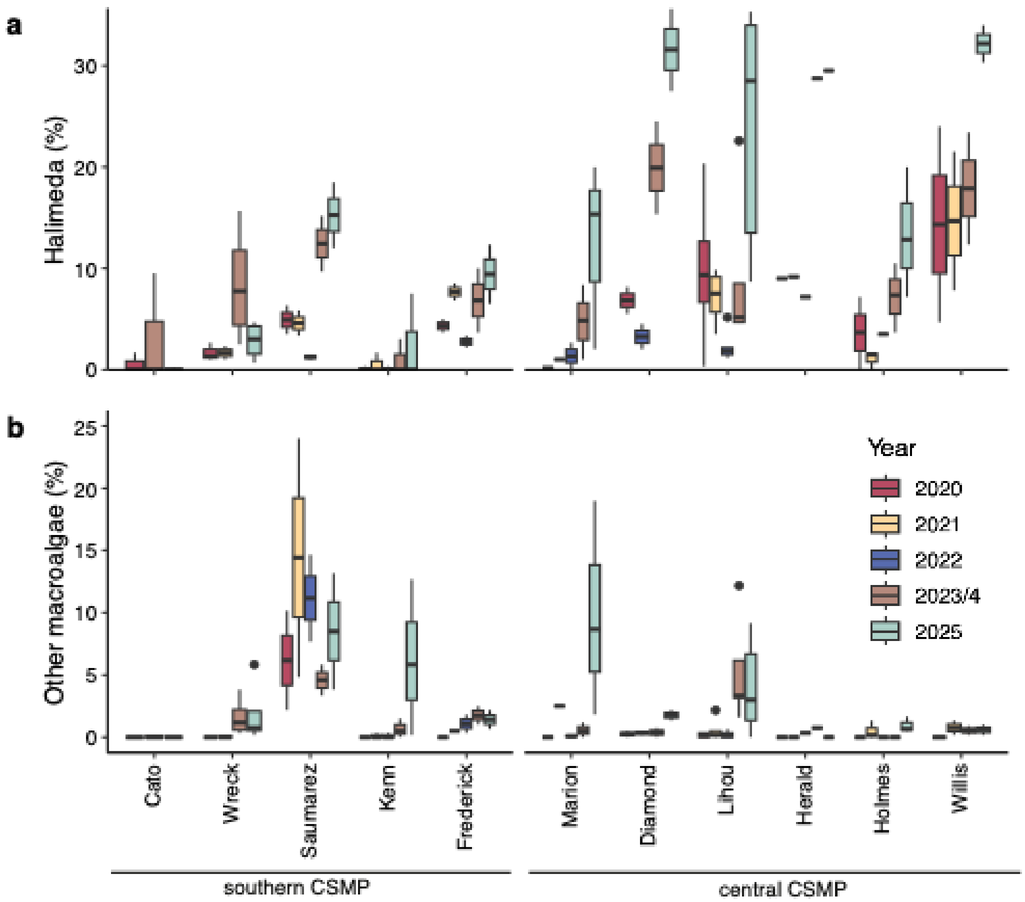


Figure 4.15 Temporal (2020-2025) variation in the cover of **(a)** *Halimeda* spp. and **(b)** 'other' macroalgae among eleven reefs in the Coral Sea Marine Park. Data are based on surveys of 30 matching sites that were surveyed at least once during 2020-24, and again in 2024. One to five sites were surveyed per reef.

4.2.2 Crustose coralline algae (CCA)

Crustose coralline algae (CCA) 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 average cover of crustose coralline algae recorded across the 34 CSMP sites surveyed in 2025 was 29.1% (±1.3 SE) (Figure 4.16). Average CCA cover was generally greater on reefs in the southern CSMP reefs (32.3 ± 2.2%) compared to the central CSMP (26.9 ± 1.5%), although there was considerable variation among reefs within each region. Average CCA cover varied 2-fold from

20.0% (Cato Reef) to 41.2% (Kenn Reef) in the southern CSMP, and similarly from 14.4% (Holmes Reefs) to 38.7% (Herald Cays) in the central CSMP (Figure 4.16).

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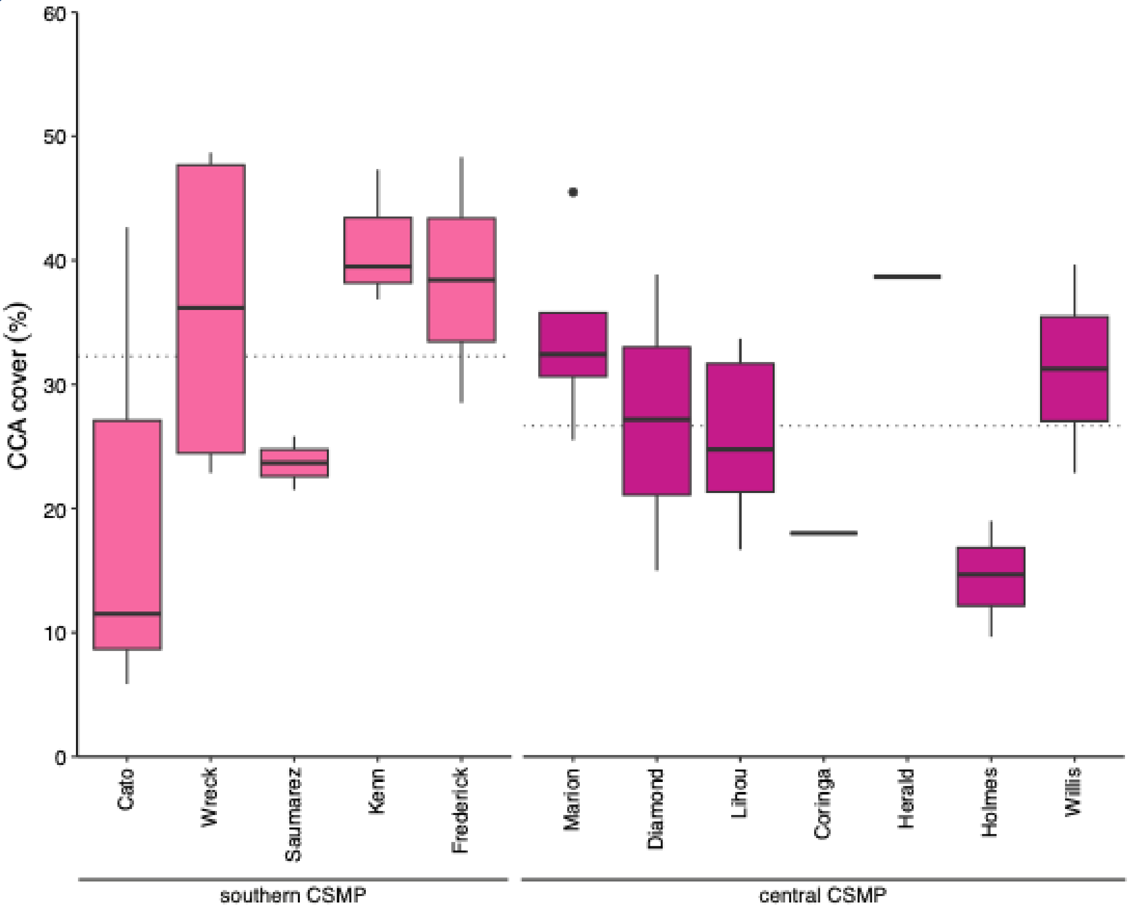

Figure 4.16 Variation in the cover of crustose coralline algae (CCA) among twelve reefs in the Coral Sea Marine Park (CSMP) in 2025. Data are based on the 50m point-intercept transects at each of the 34 sites. Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Dotted lines represent regional averages. Diamond, Coringa and Willis Islets, Lihou and Holmes Reefs, and Herald Cays were surveyed in June 2025, and Cato, Wreck, Saumarez, Kenn, Frederick, and Marion Reefs were surveyed in October 2025.

Comparisons of CCA cover in shallow reef habitats across the eleven reefs that were surveyed at least once in 2020-24 and again in 2025 revealed broadly similar trends from 2020 to 2024; increasing from 2020 to 2022 and then declining in 2023/24 (Figure 4.17). However, changes in CCA cover from 2023/24 to 2025 diverged between regions, with CCA cover continuing to increase in the southern CSMP (2023/24: 24.3%; 2025: 32.3%) but decrease in the central CSMP (2023/24: 31.1%; 2025: 28.6%; Figure 4.17). These changes in CCA cover were generally consistent among reefs within each region, the only exceptions being Marion Reef and Herald Cays in the central CSMP which experienced an increase in CCA cover from 2023/24 to 2025 (Figure 4.18, 4.19).

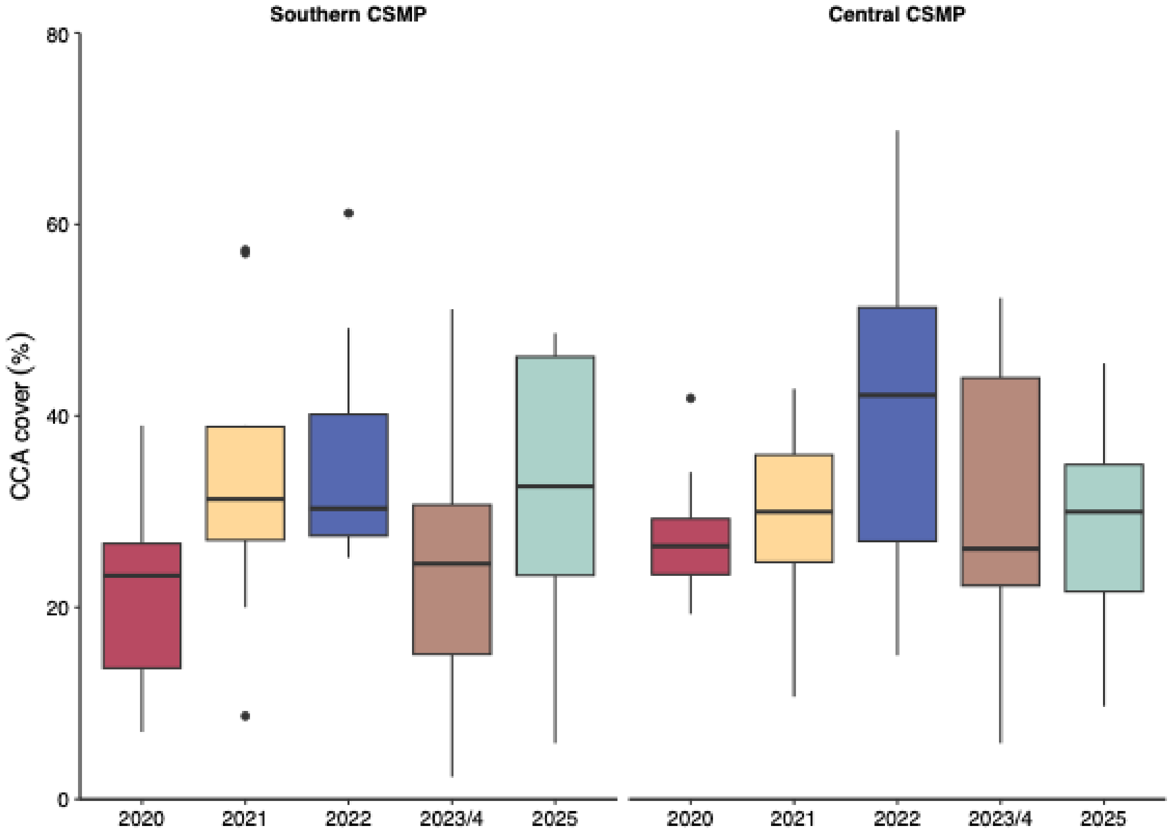

Figure 4.17 Temporal (2020-2025) variation in the cover of Crustose Coralline Algae (CCA) within the two regions of the Coral Sea Marine Park. Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at least once during 2020-24 and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays).

Images of the green calcified alga *Halimeda* (top) and the siphonous green alga *Caulerpa* (bottom) in the central Coral Sea Marine Park, June 2025. Image credits: Fiona Hagger (top), Morgan Pratchett (bottom).

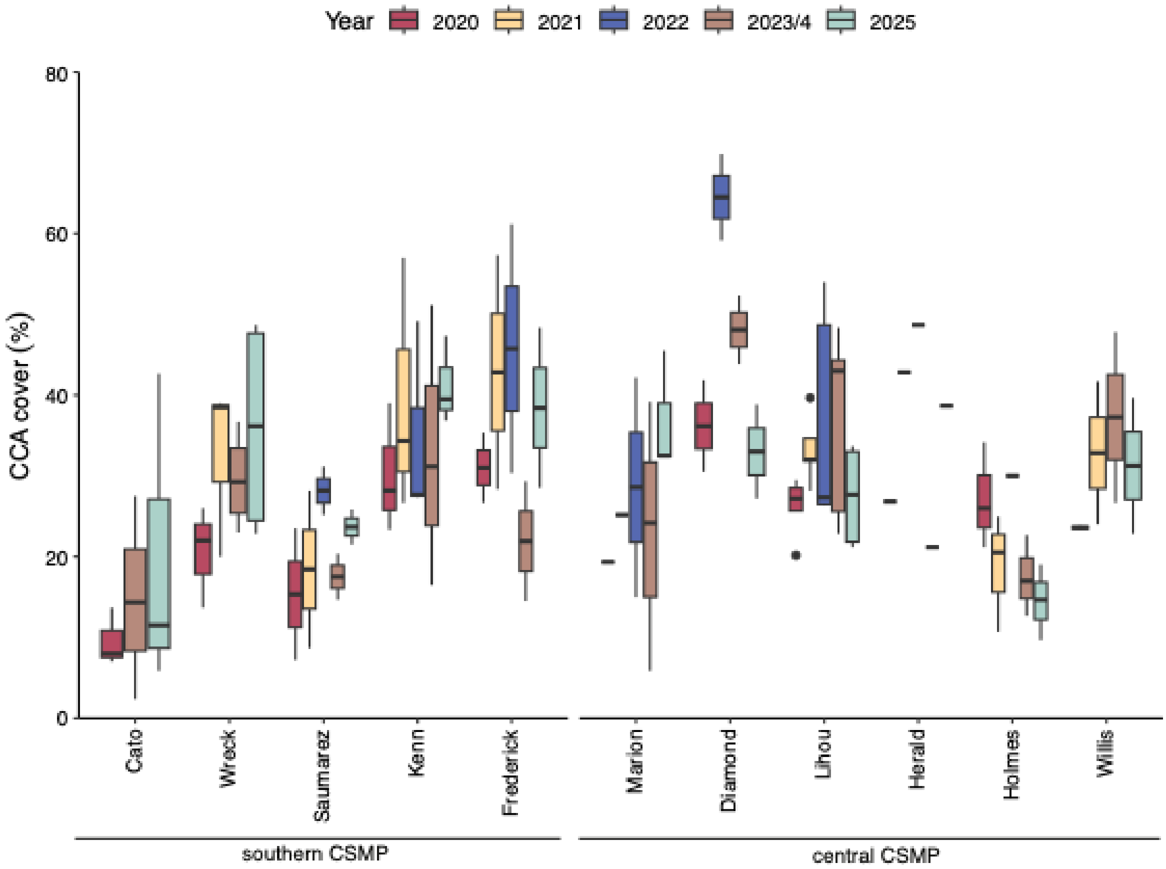

Figure 4.18 Temporal (2020-2025) variation in the cover of Crustose Coralline Algae (CCA) among eleven reefs in the Coral Sea Marine Park. Data are based on surveys of 30 matching sites that were surveyed at least once during 2020-24 and again in 2025. One to five sites were surveyed per reef.

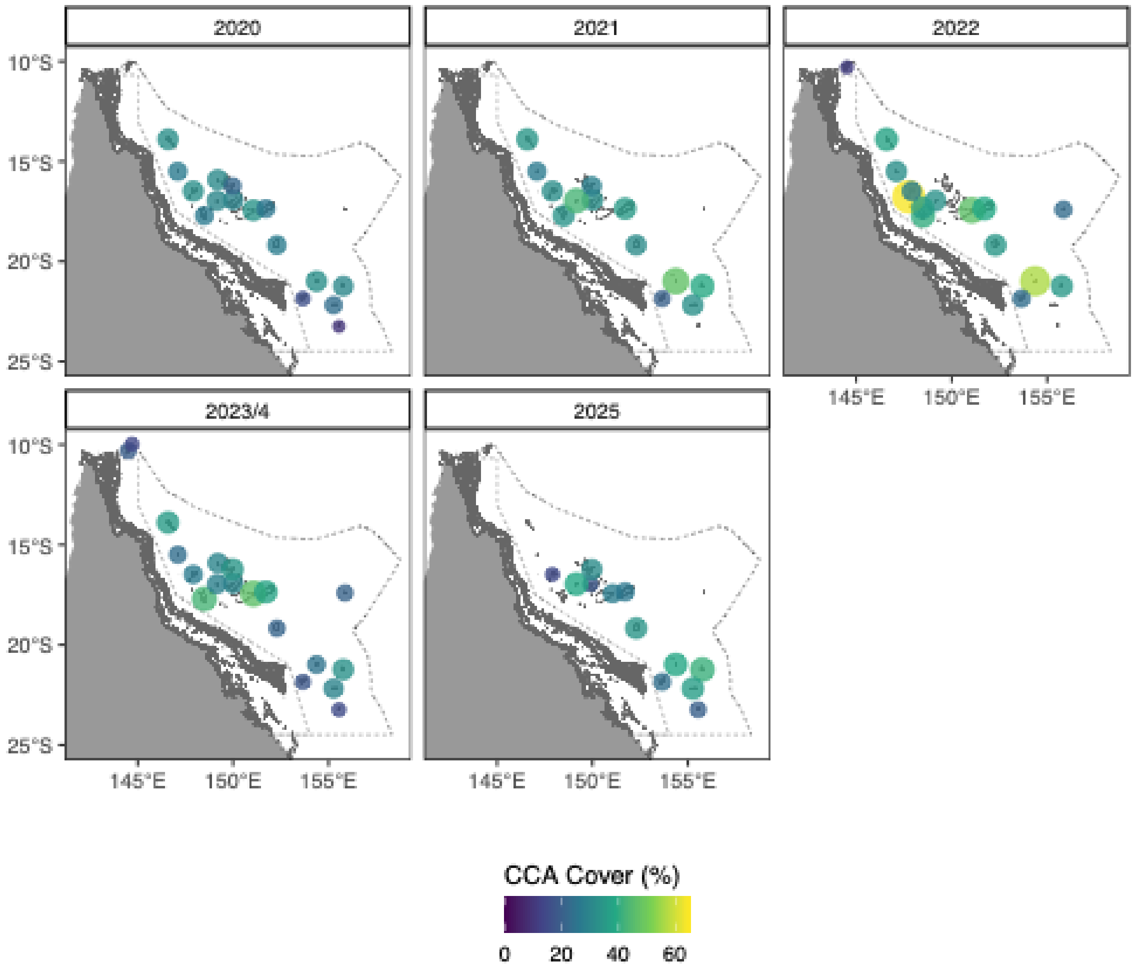

Figure 4.19 Spatial and temporal (2020-2025) variation in crustose coralline algae (CCA) cover on shallow reef habitats (reef crest and reef slope) across 22 reef systems in the Coral Sea Marine Park. The size of individual points is proportional to CCA cover at each reef.

4.3 Reef Fish Assemblages

Reef fishes are a critical component of coral reef ecosystems, contributing to numerous ecological processes (e.g., herbivory) and the provision of ecosystem goods and services (Brandl et al. 2019; Woodhead et al. 2019, Hoey and Johansen 2026). The abundance, biomass and composition of reef fishes is influenced by both extractive activities (i.e., fishing) and habitat changes. Notably declines in the cover of live corals and concomitant increases in other benthic taxa that rapidly colonise dead coral skeletons (namely algae), and subsequent reductions in the structural complexity of reef habitats can influence the structure of reef fish assemblages (Pratchett et al 2014; Hoey et al. 2016).

4.3.1 Richness, density and biomass of reef fishes

A total of 19,920 fishes from 244 species were recorded across the 34 sites and twelve reefs surveyed in 2025. Overall, the species richness, density, and biomass of reef fishes were generally lower on reefs in the southern CSMP than those in the central CSMP, although there was considerable variation among reefs in each region (Figure 4.20). Regional species richness of reef fishes ranged from an average of 59 species per site in the southern CSMP to 67 species per site in the central CSMP, and from 36 species (Coringa Islets) to 84 species per site (Holmes Reefs) among individual reefs (Figure 4.20a). Although there was considerable variation among reefs within each region (southern CSMP: 52 – 65 species per site; central CSMP: 36 to 84 species per site), the higher species richness of reef fishes in the central CSMP is consistent with established latitudinal gradients in the diversity of marine species (Hillebrand 2004; Bellwood and Hughes 2001).

In 2025 regional averages in fish densities were approximately 1.7-fold higher in the central CSMP (79.1 individuals per 100 m^2) compared to the southern CSMP (47.4 individuals per 100 m^2; Figure 4.20b). Similar to species richness there was considerable variation in the density of reef fish recorded among reefs within each region, varying 5-fold among reefs in the central CSMP (30.1 to 148.5 individuals per 100 m^2 at Coringa Islets and Holmes Reefs, respectively) and 2-fold among reefs in the southern CSMP: 28.3 to 65.1 individuals per 100 m^2 at Kenn and Wreck Reefs, respectively; Figure 4.20b).

Regional patterns in reef fish biomass were similar to those of fish species richness and density, with mean reef fish biomass being greater in the central (7.7 kg per 100m^2) than the southern CSMP (5.8 kg per 100m^2; Figure 4.20c). With the exception of Kenn Reef (3.5 kg per 100 m^2), reef fish biomass was relatively consistent among reefs in the southern CSMP (5.3 – 7.8 kg per 100 m^2), while reef fish biomass was more variable among the seven central CSMP reefs (3.8 – 15.3 kg per 100 m^2; Figure 4.20c). It is important to note that only one reef (Cato Reef) surveyed during 2025 is considered a ‘bright spot’ reef. The remaining five ‘bright spot’ reefs (i.e., Mellish, Moore, Bougainville, Ashmore and Boot Reefs; Hoey et al. 2020, 2024) were not surveyed in 2025.

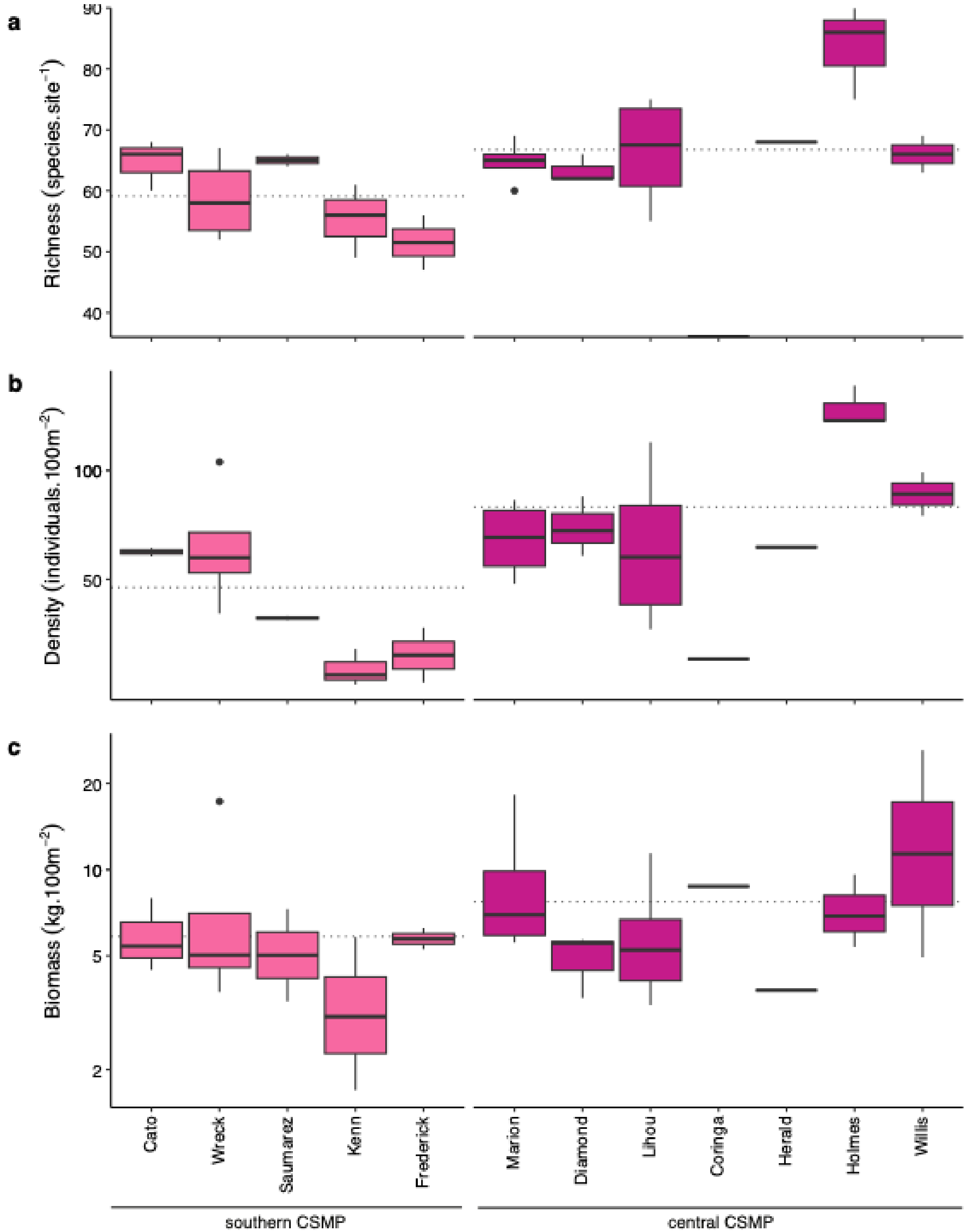

Figure 4.20 Spatial variation in the **(a)** species richness, **(b)** abundance, and **(c)** biomass of coral reef fishes among the twelve reefs surveyed in the Coral Sea Marine Park during 2025. Data are based on the 50m belt transects, with data for richness based on the number of fish species recorded at each of the 34 sites (i.e., pooled across transects and slope and crest habitats). Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Dotted lines represent regional averages. Note: the data for (b) density, and (c) biomass are presented on a $\log_{10}$-scale.

4.3.2 Temporal changes in reef fish richness, density and biomass

Richness – On the eleven reefs that were surveyed in at least once during 2020-2024 and again in 2025, the number of fish species recorded per site has declined slightly but consistently in the central CSMP (2020: 79 species per site; 2025: 69 species per site; Figure 4.21a). Species richness of reef fishes has shown greater variation among years in the southern CSMP, however has not exhibited any directional change with the average species richness recorded in 2025 (59 species per site) being similar to that recorded in 2020 (60 species per site). Temporal changes in species richness were relatively consistent among reefs and sites in each region (Figures 4.23, 4.25).

Density – The average regional density of reef fishes showed a similar temporal pattern to that of fish species richness, although recorded changes were more pronounced (Figure 4.21). The density of reef fish has declined steadily in the central CSMP from 165.8 individuals per 100m^2 in 2020 to 87.8 individuals per 100m^2 in 2025, an overall decline of 47% and a 14% decline from 2023/24 (Figure 4.21b). The average density of reef fishes was more variable within the southern CSMP; decreasing from 72.5 individuals per 100m^2 in 2020 to 34.4 individuals per 100m^2 in 2022, before increasing to 68.9 individuals per 100m^2 in 2023/24 and decreasing again to 47.4 individuals per 100m^2 in 2025 (Figure 4.21b). While the low regional density recorded in 2022 may be partly attributed to two reefs with generally high fish density not being surveyed (Cato and Wreck Reefs), the overall decline in density from 2020 to 2025 is based on the surveys of the same sites and reefs. Changes in mean density of reef fish from 2023/24 to 2025 were reasonably consistent among reefs in the southern CSMP with decreases in density being observed at all reefs, however there was considerable variation among reefs in the central CSMP (Figure 4.22b). In the central CSMP, changes in reef fish density from 2023/24 to 2025 ranged from a 37.1% decline at Willis Islets to a 50.1% increase at Diamond Islets (Figures 4.22b, 4.25).

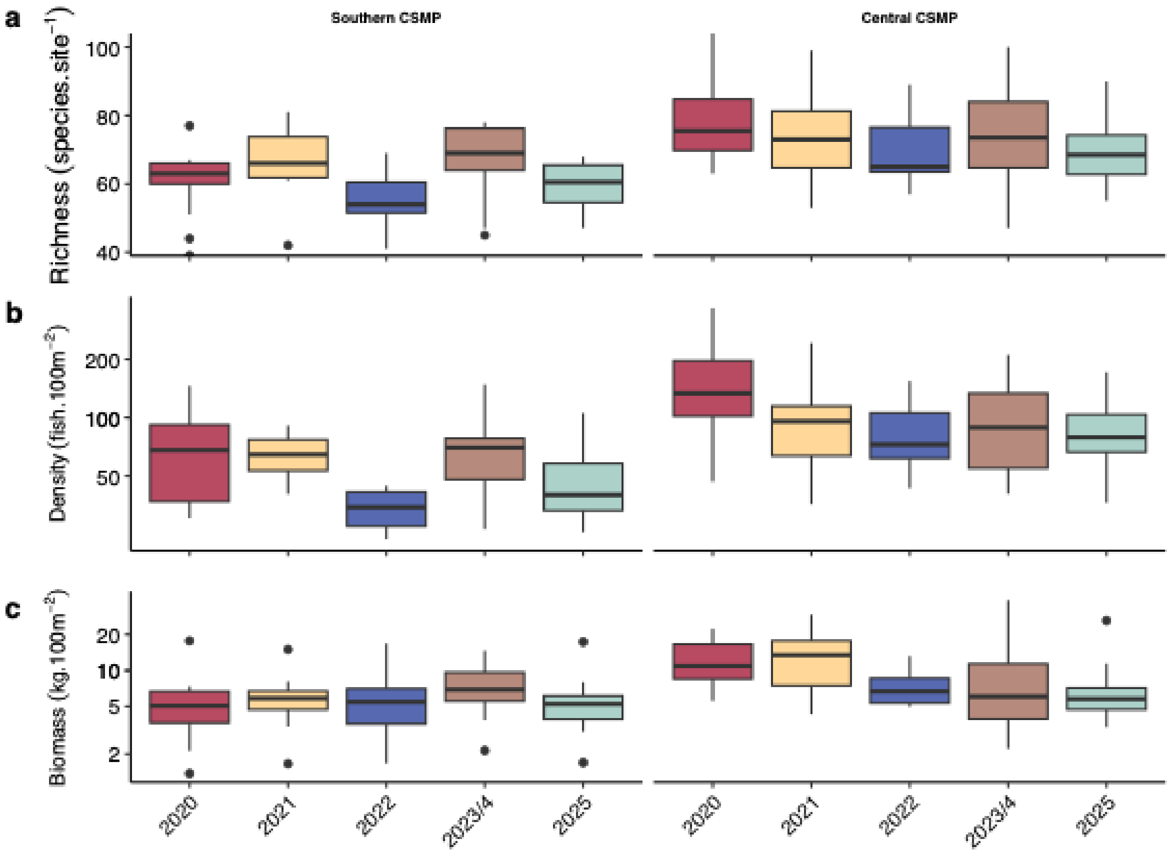

Figure 4.21 Temporal (2020-2025) variation in the **(a)** species richness, **(b)** density, and **(c)** biomass of reef fish assemblages among the two regions of the Coral Sea Marine Park. Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at once during 2020-24, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays). Note: the data for **(b)** density, and **(c)** biomass are presented on a $\log_{10}$-scale.

Biomass – Changes in reef fish biomass from 2020 to 2025 resembled those of reef fish richness and density (Figure 4.21c). Average reef fish biomass displayed consistent declines in both the southern (21.2% decline) and central CSMP (23.6% decline) from 2023/24 to 2025. This decline was largely offset by previous increases in biomass in the southern CSMP such that there was negligible change between 2020 (5.7 kg per 100m^2) and 2025 (5.8 kg per 100m^2). In contrast, the most recent decline in reef fish biomass in the central CSMP compounds on previous declines such that there was a 40.1% decline in reef fish biomass between 2020 (12.4 kg per 100m^2) and 2025 (7.4 kg per 100m^2; Figure 4.21c). The changes in biomass have been largely consistent among reefs within each region (Figures 4.22c, 4.26), and sites within each of those reefs (Figure 4.27).

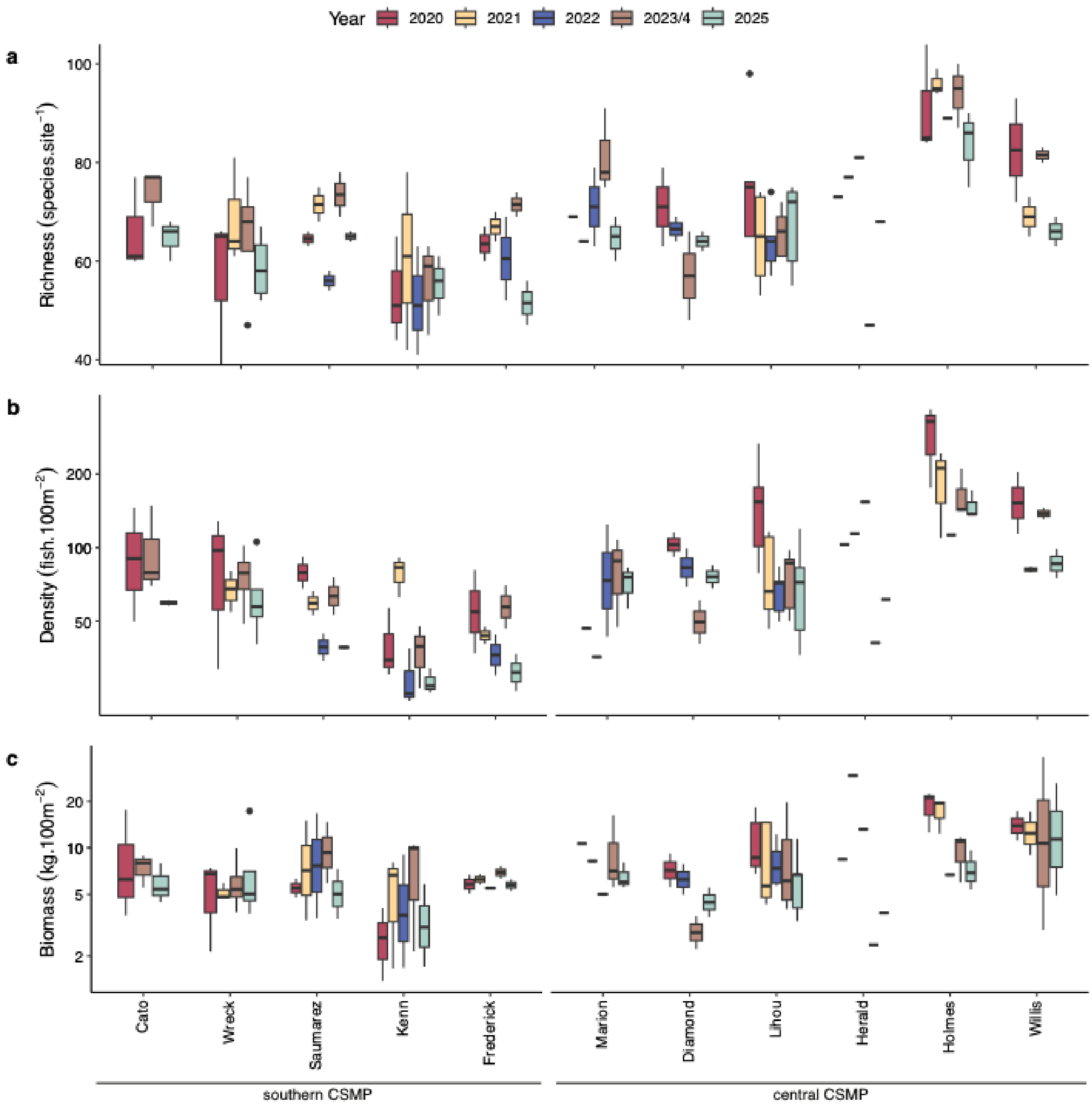

Figure 4.22 Temporal (2020-2025) variation in the **(a)** species richness, **(b)** density, and **(c)** biomass of reef fish assemblages among eleven reefs in the Coral Sea Marine Park. Data are based on surveys of 30 matching sites (n = 1 to 5 sites per reef) that were surveyed at once during 2020-2024, and again in 2025. Note: the data for **(b)** density, and **(c)** biomass are presented on a $\log_{10}$-scale.

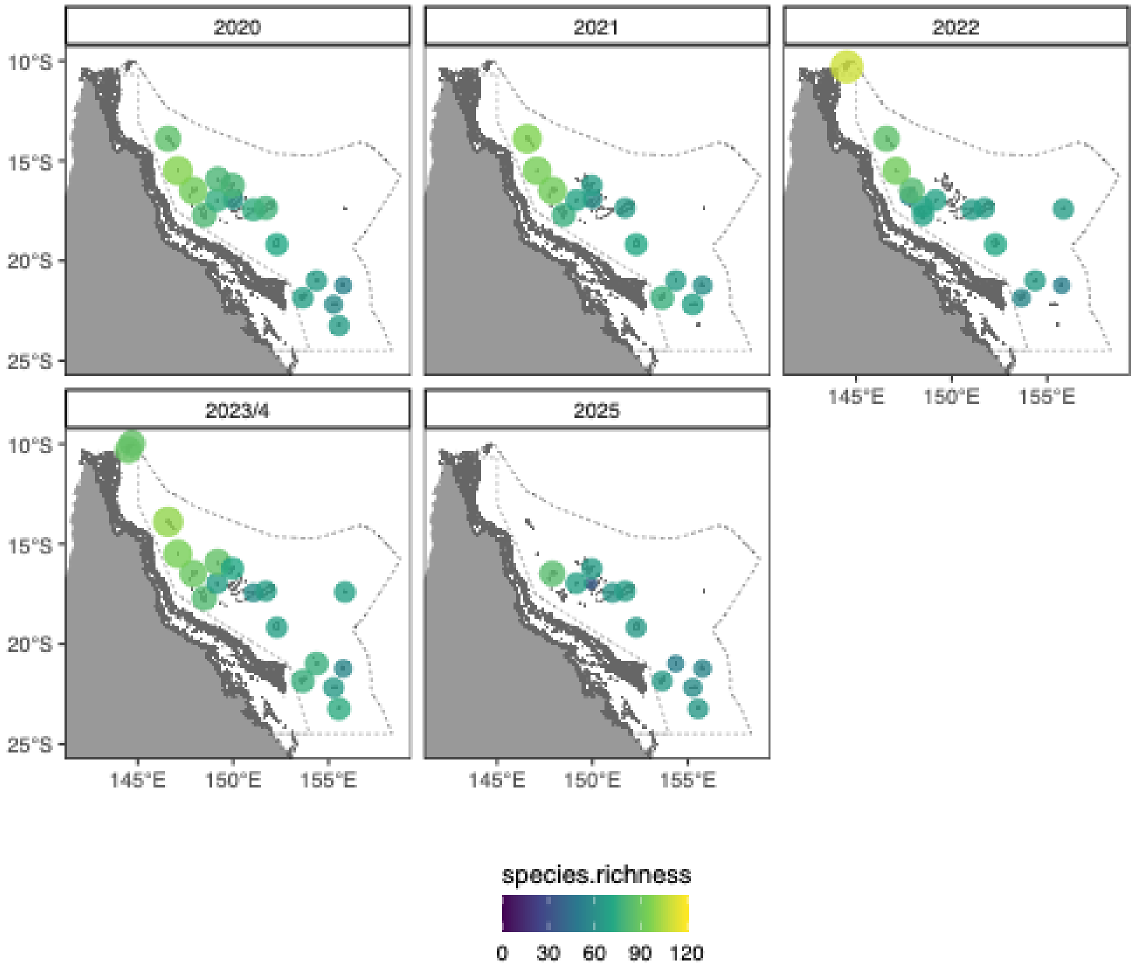

Figure 4.23 Spatial and temporal variation in the species richness of reef fish and sharks on shallow reef habitats (reef crest and reef slope) across 22 reef systems in the Coral Sea Marine Park (2018-2025). The size of individual points is proportional to the number of fish species recorded at each reef.

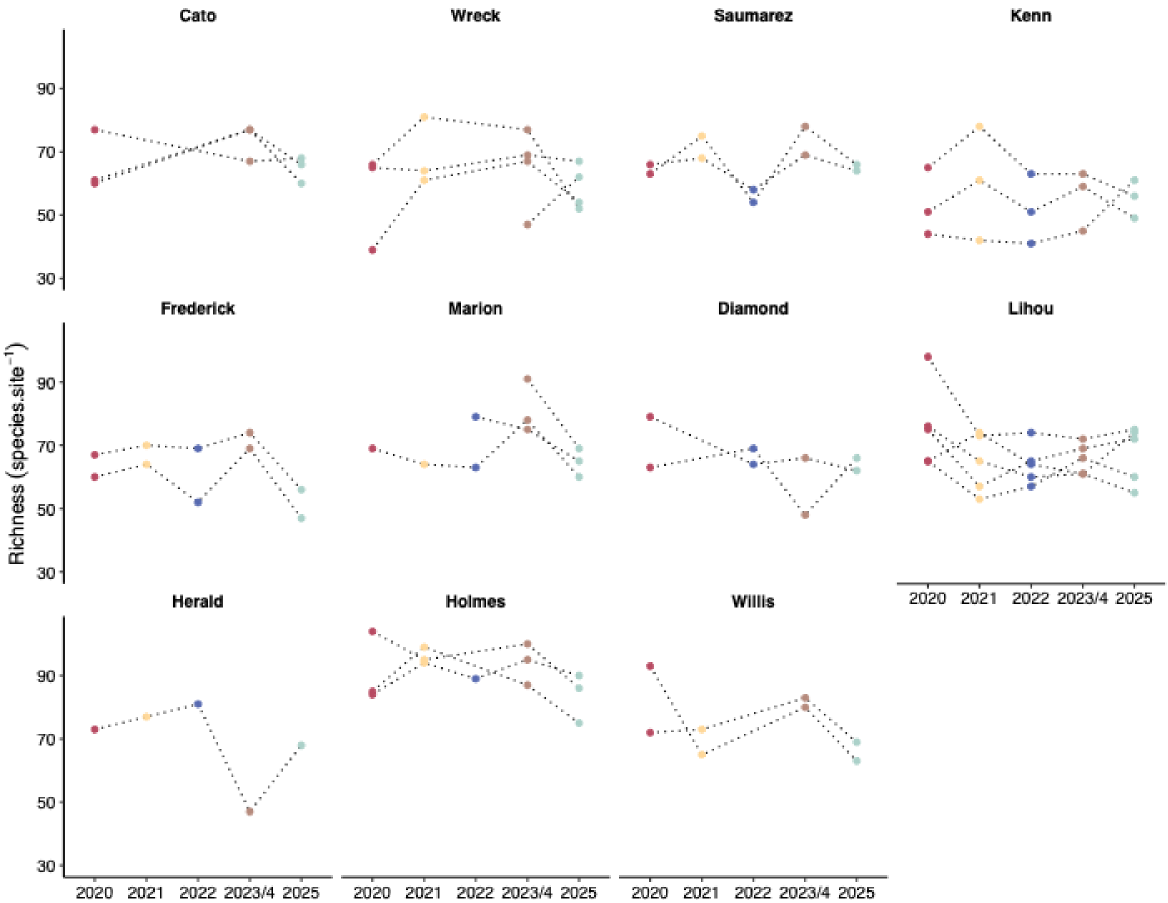

Figure 4.24 Temporal (2020-2025) variation in the species richness of reef fish assemblages among individual sites in the Coral Sea Marine Park. Data are based on surveys of 30 matching sites that were surveyed at least once during 2020-24 and again in 2025.

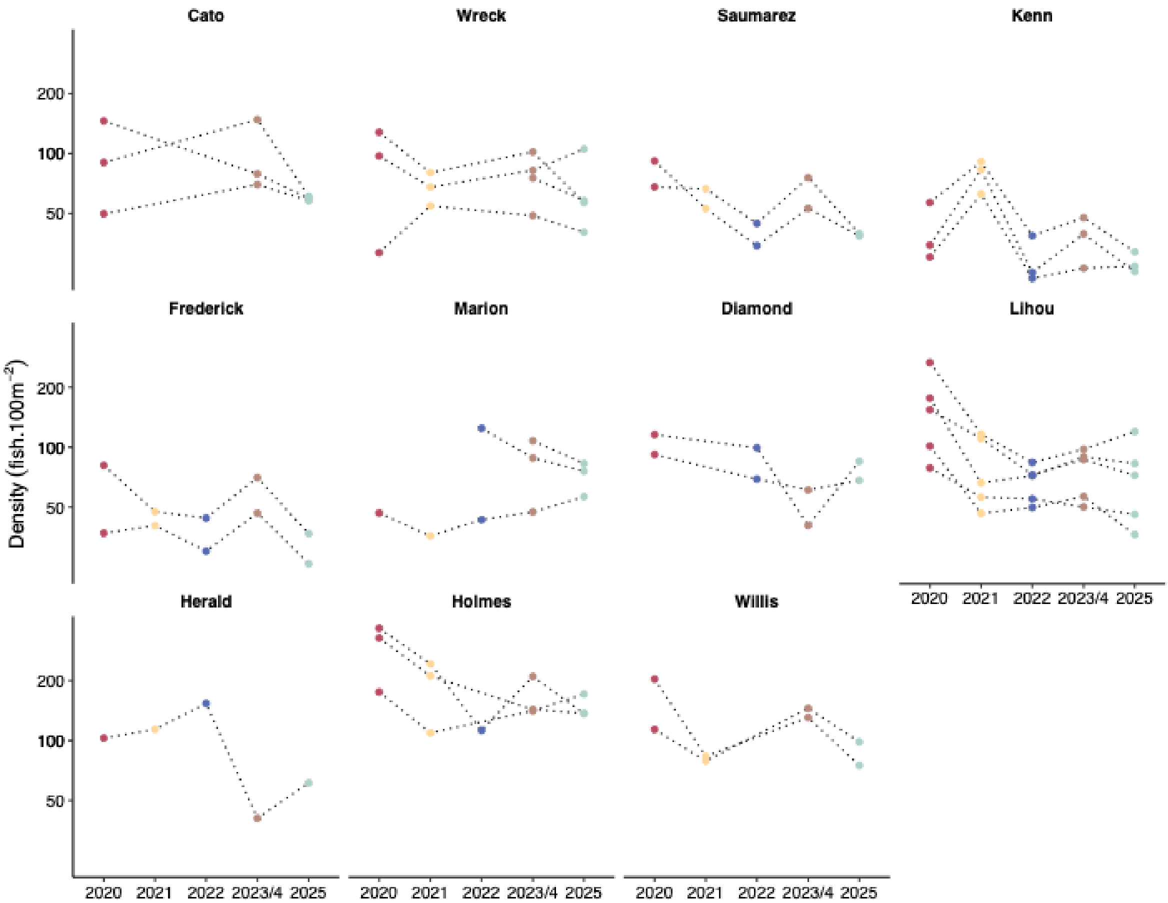

Figure 4.25 Temporal (2020-2025) variation in the density of reef fish assemblages among individual sites in the Coral Sea Marine Park. Data are based on surveys of 30 matching sites that were surveyed at least once during 2020-24 and again in 2025.

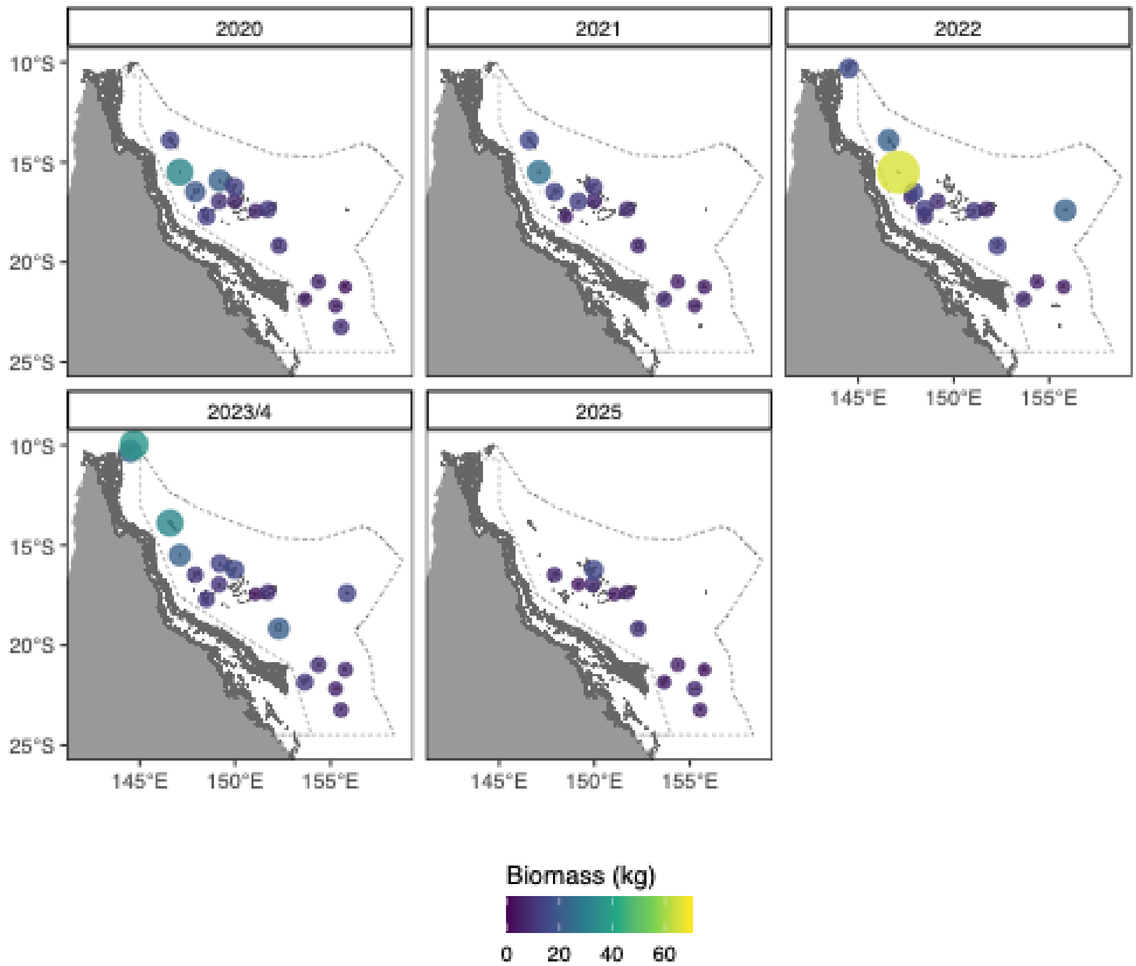

Figure 4.26 Spatial and temporal (2020-2025) variation in the biomass of reef fish on shallow reef habitats (reef crest and reef slope) across 22 reef systems in the Coral Sea Marine Park. The size of individual points is proportional to the average fish biomass at each reef.

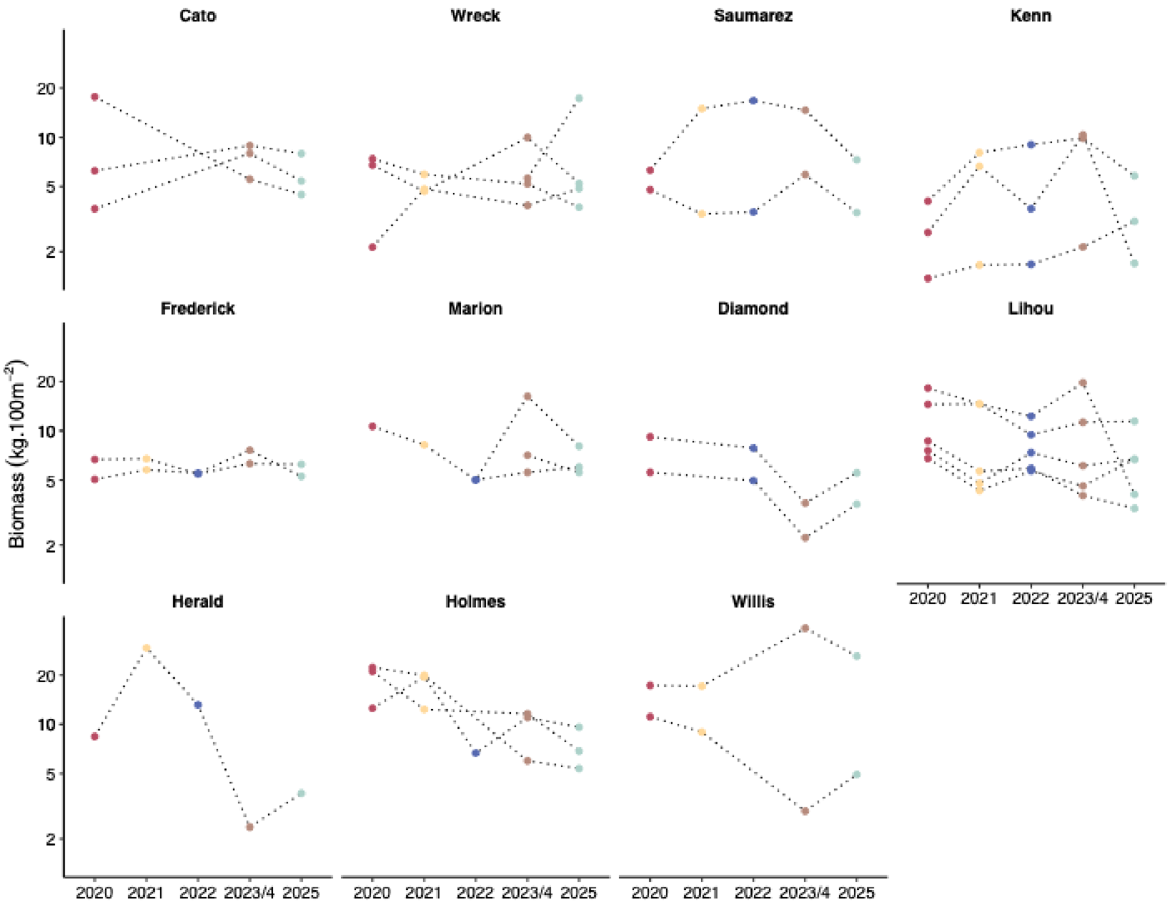

Figure 4.27 Temporal (2020-2025) variation in the biomass of reef fish assemblages among individual sites in the Coral Sea Marine Park. Data are based on surveys of 30 matching sites that were surveyed at least once during 2024 and again in 2025.

4.3.3 Trophic composition of fish assemblages

Fishes were categorised into eleven trophic groups (piscivore, mixed carnivore, benthic invertivore, planktivore, omnivore, corallivore, excavator, scraper, browser, grazer, and farmer) based on their diet, morphology and feeding behaviour. Planktivorous fishes (e.g., fusiliers, anthias and some damselfishes) were the most abundant trophic group on reefs in the CSMP in 2025 accounting for 46.2% of all fish recorded, but only 8.1% of total fish biomass (Figure 4.28) reflecting their generally small body size. Fish biomass was more evenly spread among functional groups with piscivores (27.4%), macroalgal browsers (13.6%), grazing herbivores (11.1%) and benthic invertivores (11.1%) together accounting for 63.2% of total fish biomass recorded across all reefs in 2025 (Figure 4.28b).

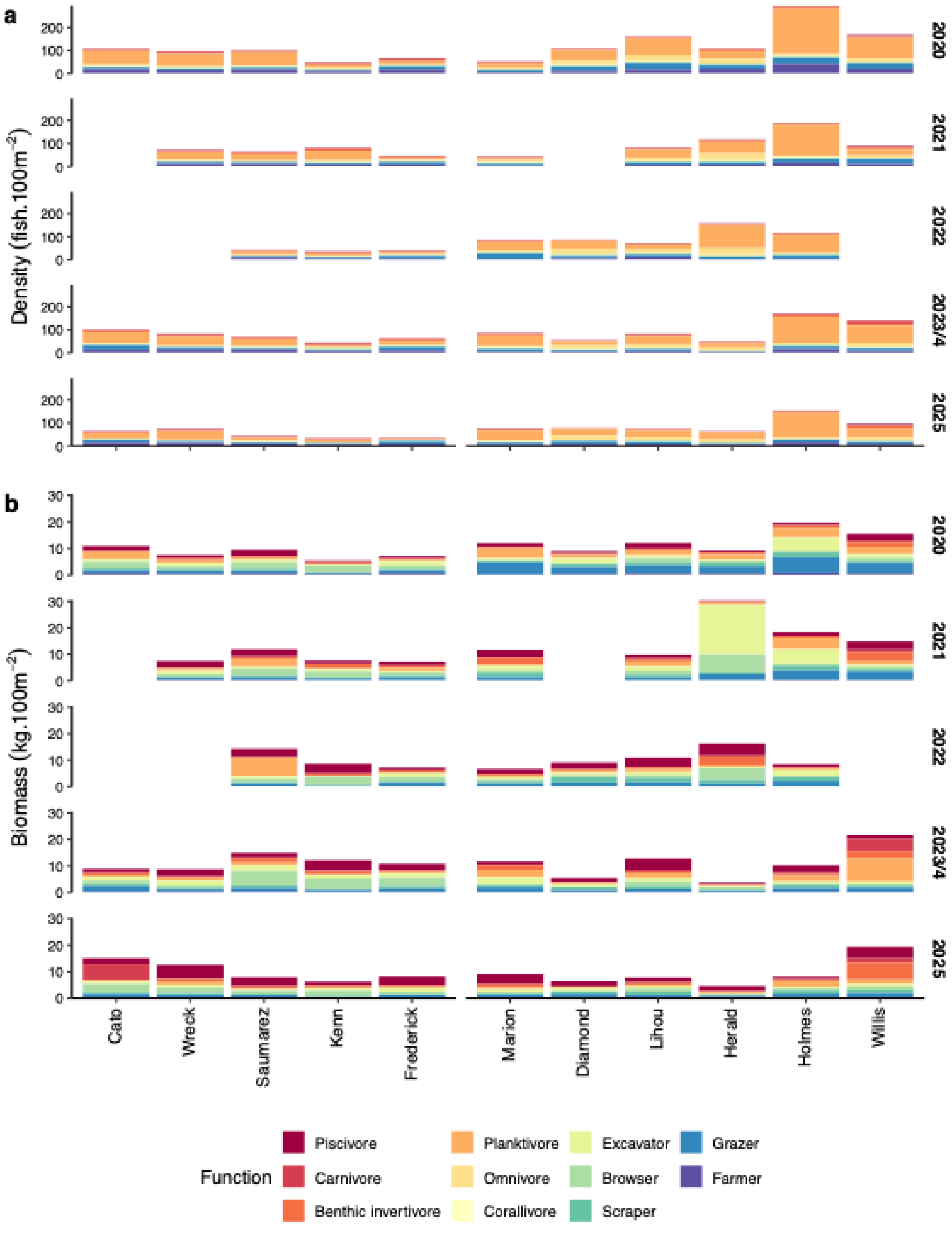

Figure 4.28 Temporal (2020-2025) variation in the functional composition of reef fish assemblages across eleven reefs in the Coral Sea Marine Park based on **(a)** abundance, and **(b)** biomass. Data are based 50m belt transects and values for each reef are averaged across habitats and sites. Diamond, Coringa and Willis Islets, Lihou and Holmes Reefs, and Herald Cays were surveyed in June 2025, and Cato, Wreck, Saumarez, Kenn, Frederick, and Marion Reefs were surveyed in October 2025.

The density and biomass of piscivorous fishes remained relatively stable from 2023/24 to 2025 in both the southern and central CSMP, although current levels are above those recorded in 2020 with the greatest increases recorded in the southern CSMP (Figure 4.29a, 4.30a). In the southern CSMP, the density of piscivorous fishes increased from 0.8 to 1.2 individuals per $100m^2$ from 2020 to 2025 (52.0% increase) and biomass of piscivorous fishes increased from 1.3 to 3.2 kg per $100m^2$ (154.0% increase) over the same period. In contrast, the density and biomass of piscivorous fishes increased by 5.6% and 47.2%, respectively, over the same period in the central CSMP (Figure 4.29a, 4.30a).

In contrast to the increases in the density and biomass of piscivorous fishes, the density and biomass of planktivores, corallivores and grazing herbivores have declined, although the magnitude of the decline differs among trophic groups (Figure 4.29b-d, 4.30b-d). The density and biomass of planktivores and corallivores have declined steadily in the central CSMP since 2020 with values in 2025 being 38 - 82% lower than those recorded across the same reefs in 2020 (planktivore density: 46.5% decline, biomass: 57.2%; corallivore density: 38.2% decline, biomass 81.2% decline; Figure 4.29b-c, 4.30b-c). These declines in the density and biomass of corallivorous and planktivorous fishes likely reflect their reliance of live corals for food and shelter, respectively (Hoey et al. 2016).

The density and biomass of grazing fishes (primarily surgeonfishes) has remained relatively stable across southern CSMP reefs from 2020 to 2025, however there have been substantial declines on central CSMP reefs (Figure 4.29d, 4.30d). The density of grazing fishes has declined by 57.9% and the biomass declined by 68.8% on central CSMP since 2020. These declines were primarily driven by reductions in the density and biomass of grazing surgeonfishes (in particular *Acanthurus lineatus* and *Acanthurus nigrofuscus*). The continued declines in the density and biomass of grazing surgeonfishes are difficult to reconcile as studies from other regions have reported substantial increases in the abundance and/or biomass of herbivorous fishes following large-scale bleaching-induced coral mortality (e.g., Adam et al 2011; Gilmour et al. 2013; Elma et al. 2023). Such increases have generally been related to an increase in the availability of turf-covered substrata and subsequent increases in the growth rates of individual fishes (e.g., parrotfishes: Taylor et al. 2020). The immediate and sustained decline of grazing fishes following the 2020 bleaching event suggest that these changes may be related to the physiological response of these fishes to heat stress (Stuart-Smith et al. 2018), and/or the rapid colonisation of dead coral skeletons by CCA (as opposed to turfs which are the favoured feeding substrata of these fishes). Further dedicated investigation into the diet and fitness of these fishes on CSMP reefs is required to identify the likely mechanism/s for these declines.

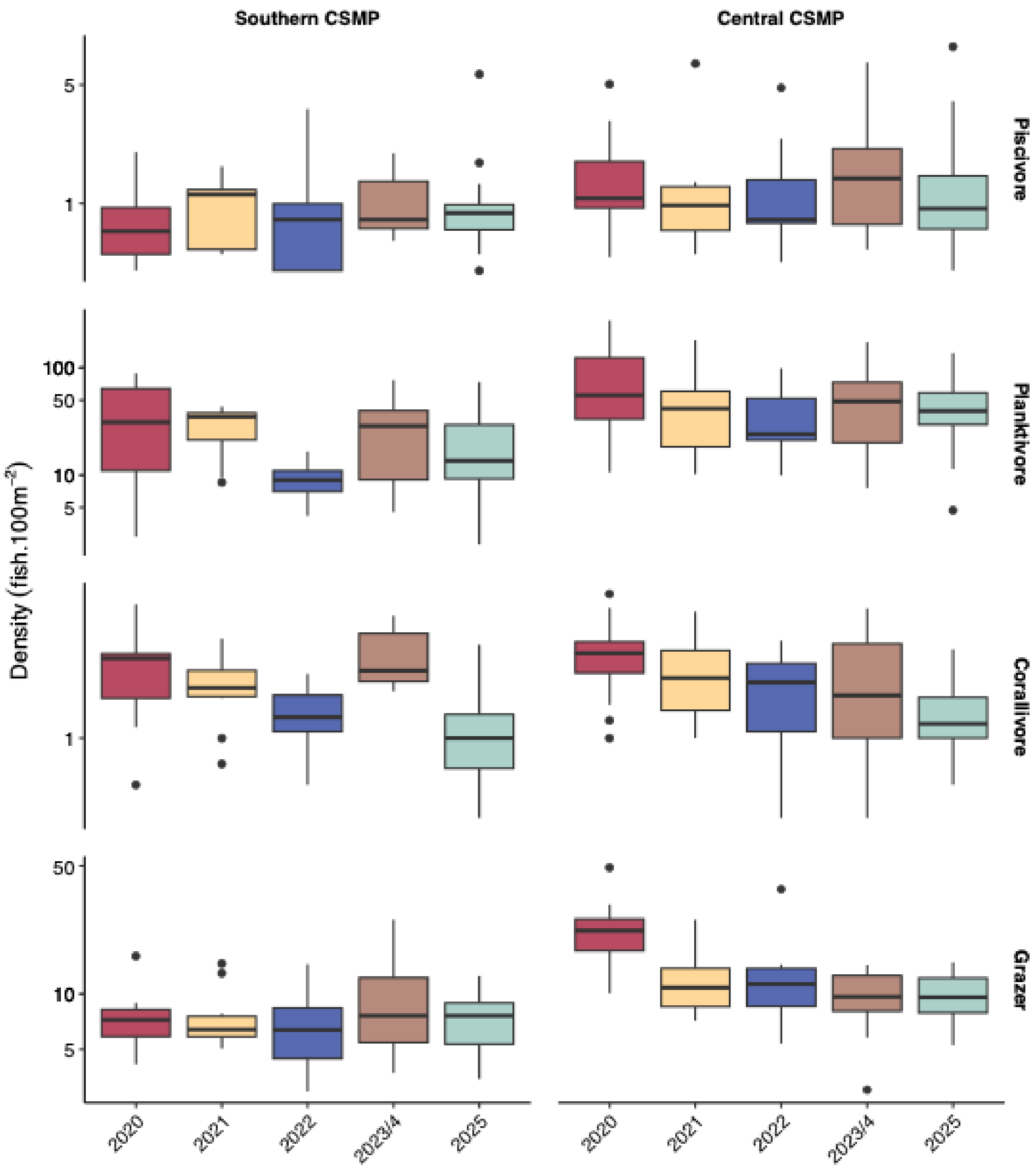

Figure 4.29 Spatial and temporal (2020-2025) variation in the density of **(a)** piscivorous, **(b)** planktivorous, **(c)** corallivorous, and **(d)** grazing fishes among the two regions of the Coral Sea Marine Park. Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at once during 2020-2024, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays). Note: data are presented on a log_{10}-scale.

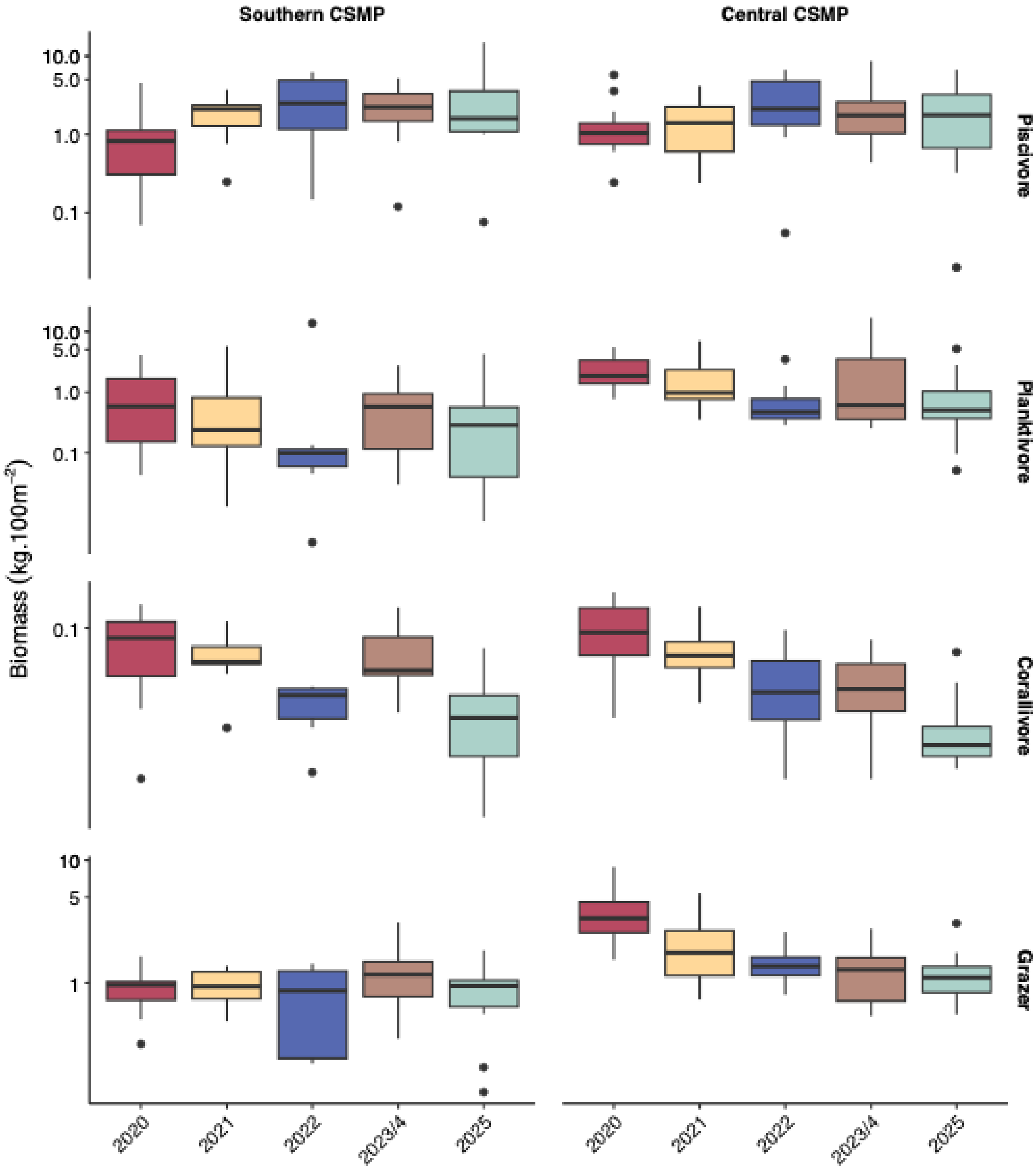

Figure 4.30 Spatial and temporal (2020-2025) variation in the biomass of **(a)** piscivorous, **(b)** planktivorous, **(c)** corallivorous, and **(d)** grazing fishes between two regions of the Coral Sea Marine Park Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at once during 2020-2024, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays). Note: data are presented on a log_{10}-scale.

Figure 4.31 Photograph showing a school of grazing surgeonfish (*Acanthurus triostegus*) on a shallow reef flat on Kenn Reefs, southern Coral Marine Park, October 2025. Image credit: Fiona Hagger.

4.3.4 Fish community composition

Taxonomic composition – The greatest variation in the taxonomic composition of reef fish assemblages, like coral assemblages (see Section 4.1.3 above), was between the two CSMP regions (Figure 4.32). The central CSMP reefs were tightly clustered in the right-hand side of the nMDS space, while the southern CSMP reefs were clustered in the left-hand side of the nMDS space (Figure 4.32). There was no evidence of a shift in the taxonomic composition of reef fish assemblages within the southern or central CSMP from 2020 to 2025(Figure 4.33).

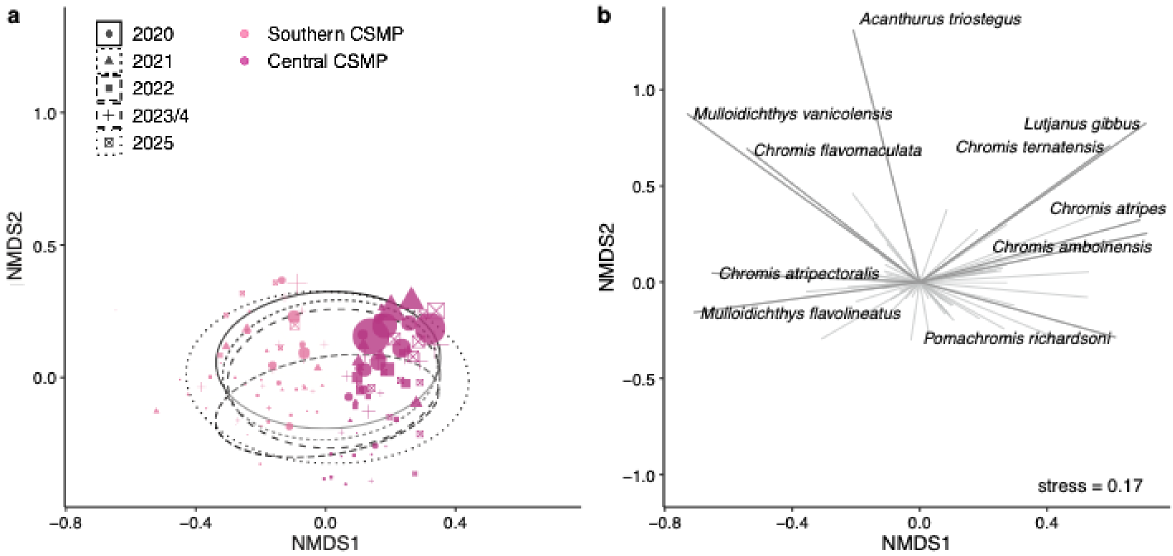

Figure 4.32 Regional and temporal (2020-2025) variation in the taxonomic composition of reef fish assemblages within the Coral Sea Marine Park. Non-metric multidimensional scaling (nMDS) plot showing the variation in reef fish composition among years for the two regions of the Coral Sea Marine Park. Analyses are based on abundance data from 30 sites that were surveyed in 2025 and at least once during 2020-2024. The size of individual points is proportional to the total fish abundance on each reef. Vectors in the right-hand side plot indicate key taxa that account for the variation in fish composition displayed in the corresponding left-hand side plot.

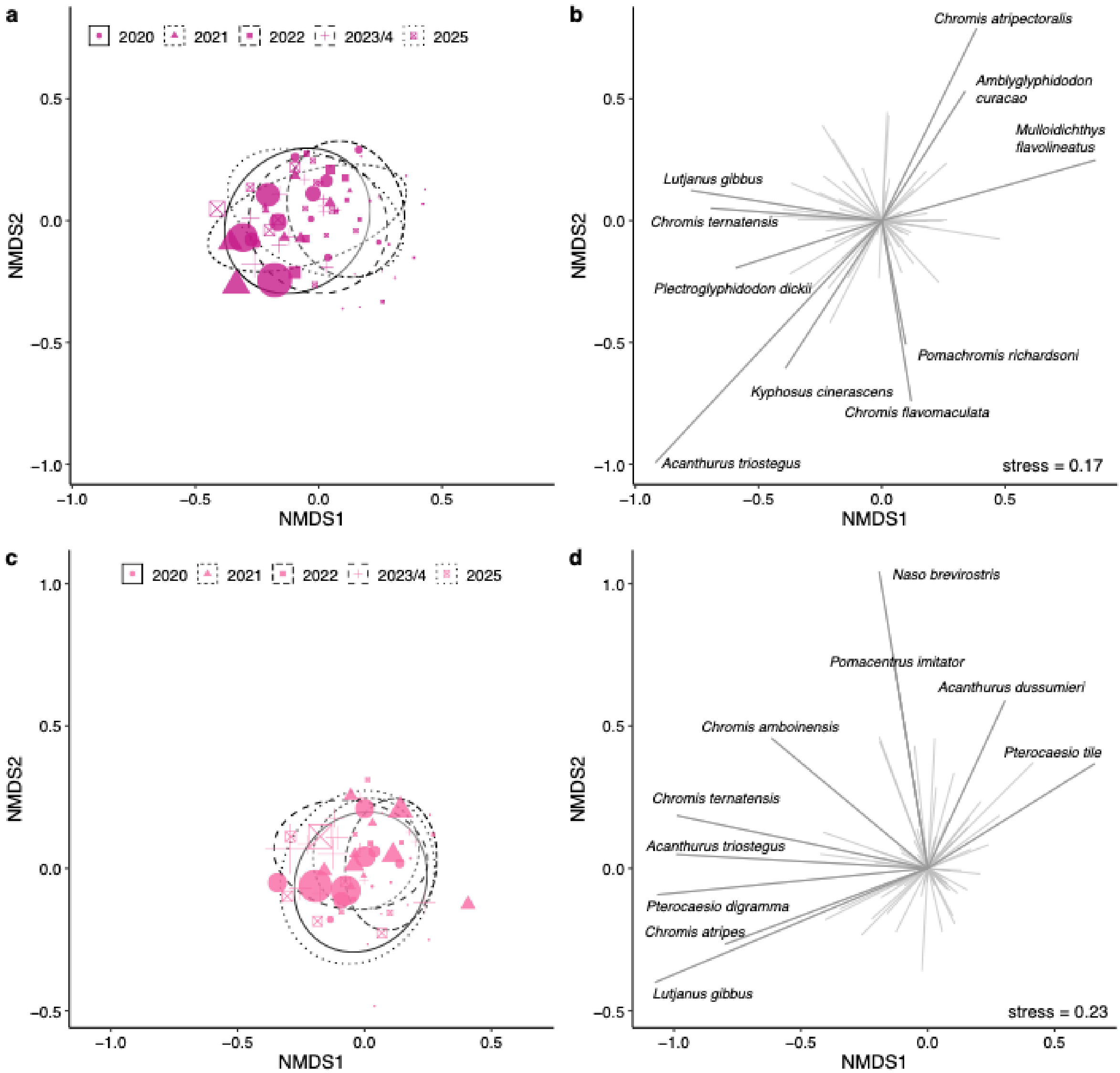

Figure 4.33 Non-metric multidimensional scaling (nMDS) plots showing the temporal (2020-2025) variation in the taxonomic composition of reef fish assemblages among reefs in the **(a,b)** central and **(c,d)** southern Coral Sea Marine Park. Analyses are based on abundance data from 30 sites that were surveyed at least once during 2020-2024 and again in 2025; 16 sites in the central CSMP and 14 sites in the southern CSMP. The size of individual points is proportional to the total fish abundance at each site. Vectors in the right-hand side plot indicate key taxa that account for variation in fish composition displayed in the corresponding left-hand side plot.

Trophic composition – Similar to taxonomic composition, the greatest variation in the trophic composition of reef fish assemblages, was evident between the two CSMP regions, with considerable overlap among years (Figure 4.34). Despite changes in the density of individual trophic groups among years (Figure 4.29), there was little evidence of temporal change in the trophic composition of reef fish assemblages in either the southern or central CSMP (Figure 4.35 a-d). This likely reflects the variation in trophic composition among sites within each region.

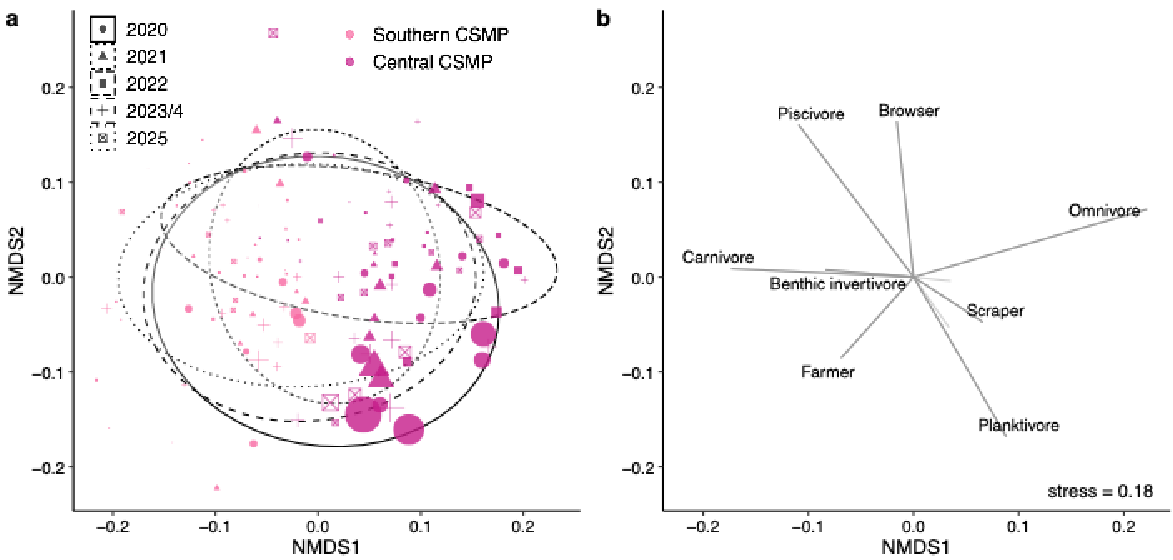

Figure 4.34 Regional and temporal (2020-25) variation in the functional composition of reef fish assemblages within the Coral Sea Marine Park. Non-metric multidimensional scaling (nMDS) plot showing the variation in reef fish functional composition among years for the two regions of the Coral Sea Marine Park. Analyses are based on abundance data from 30 sites that were surveyed at least once during 2020-24 and again in 2025. The size of individual points is proportional to the total fish abundance on each reef. Vectors in the right-hand side plot indicate key groups that account for the variation in fish composition displayed in the corresponding left-hand side plot.

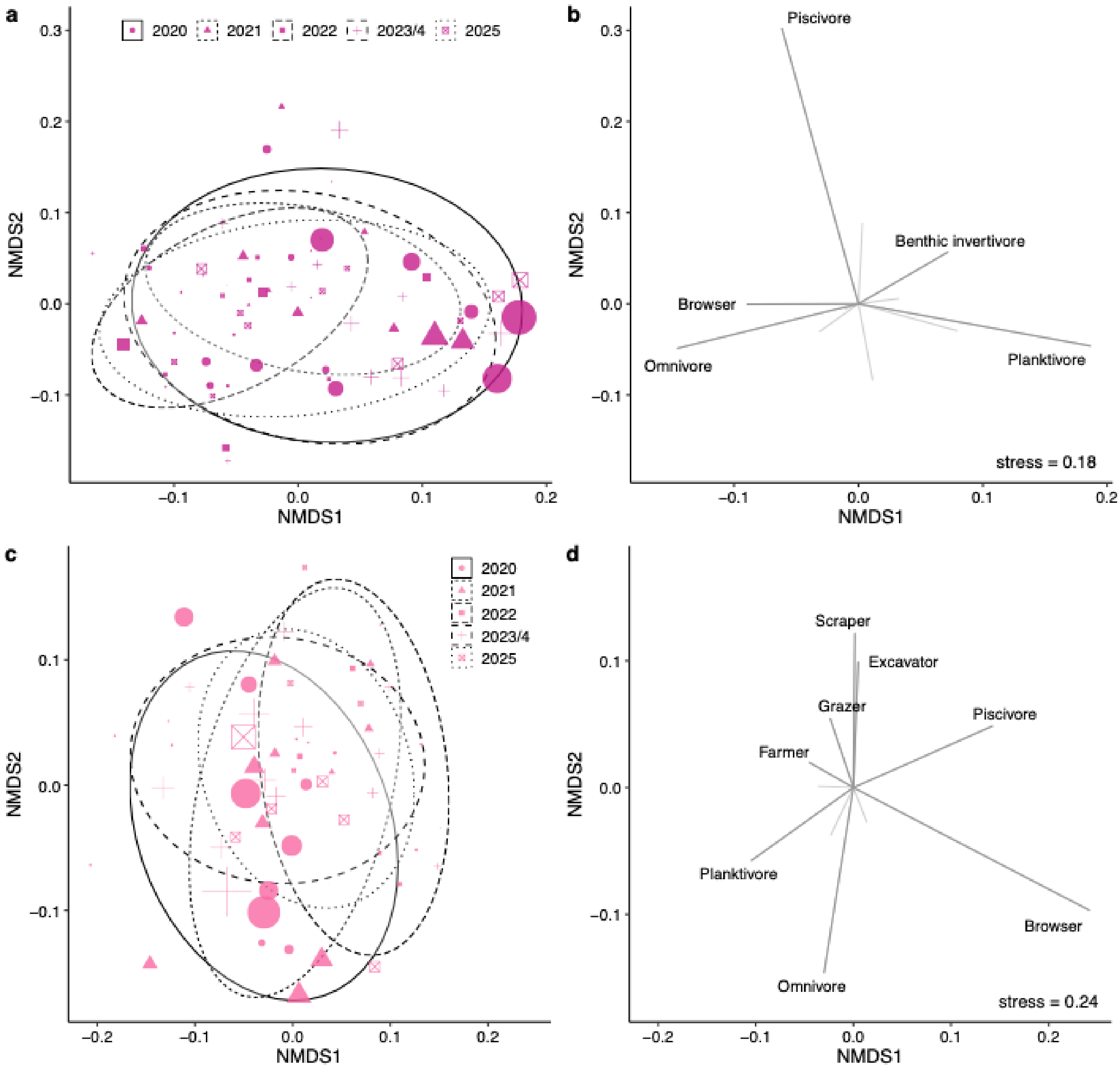

Figure 4.35 Non-metric multidimensional scaling (nMDS) plots showing the temporal (2020-2025) variation in the functional composition of reef fish assemblages among reefs in the **(a,b)** central, and **(c,d)** southern Coral Sea Marine Park. Analyses are based on abundance data from 30 sites that were surveyed at least once during 2020-24 and again in 2025; 16 sites in the central CSMP and 14 in the southern CSMP. The size of individual points is proportional to the total fish abundance at each site. Vectors in the right-hand side plot indicate key groups that account for variation in fish composition displayed in the corresponding left-hand side plot.

Figure 4.36 A school of grazing surgeonfishes (primarily juvenile *Acanthurus nigrofuscus*) on the reef crest at Marion Reef in February 2022. There was a large reduction in the density and biomass of these fishes across reefs in the central Coral Sea Marine Park in 2025. Image credit: Victor Huertas

4.3.5 Sharks

The average density and biomass of sharks (mainly the grey reef shark *Carcharhinus amblyrhynchus*, silvertip shark *Carcharhinus albimarginatus*, and whitetip reef shark *Triaenodon obesus*) were relatively similar between the southern CSMP (density: 0.07 sharks per $100m^2$; biomass 2.5 kg per $100m^2$) and central CSMP (density: 0.08 sharks per $100m^2$; biomass 3.2 kg per $100m^2$), but was highly variable among reefs in each region (Figure 4.37). The density of sharks recorded ranged from 0 sharks per $100m^2$ at Saumarez Reef in the southern CSMP to 0.13 at Coriga Islets and Holmes Reef in the central CSMP, and 0.16 sharks per $100m^2$ at Cato Reef in the southern CSMP (Figure 4.37a). Similarly the average biomass of sharks ranged from 0 kg per $100m^2$ at Saumarez Reef to 9.11 kg per $100m^2$ at Cato Reef in the southern CSMP (Figure 4.37b).

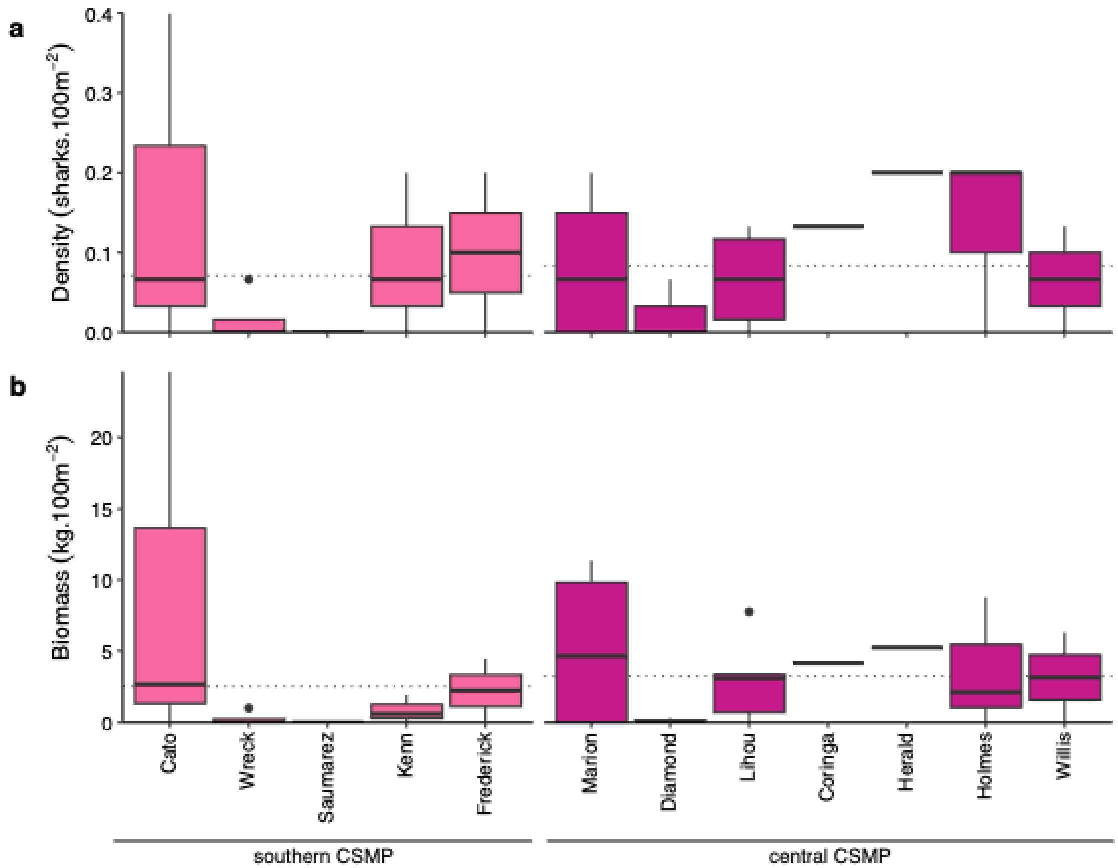

Figure 4.37 Spatial variation in the **(a)** density, and **(b)** biomass of sharks among the twelve reefs surveyed in the Coral Sea Marine Park during 2025. Data are based on the 50m belt transects and averaged across sites and habitats. Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Dotted lines represent regional averages. Diamond, Coringa and Willis Islets, Lihou and Holmes Reefs, and Herald Cays were surveyed in June 2025, and Cato, Wreck, Saumarez, Kenn, Frederick, and Marion Reefs were surveyed in October 2025.

There has been a slight increase in the density of sharks in the southern CSMP from 2020 to 2025 (0.03 and 0.07 sharks per $100m^2$, respectively) and has remained relatively stable in the central CSMP from 2021 to 2025 (0.09 and 0.08 sharks per $100m^2$, respectively) after an initial decline from 2020 (0.13 sharks per $100m^2$; Figure 4.38a). The temporal patterns in the biomass of sharks were broadly similar to those of density (Figure 4.38b). These regional trends in the density and biomass of sharks should be treated with caution given the high variability among and within individual reefs (Figure 4.39). For example, the high shark biomass recorded at Cato Reef in 2025 was largely due to a tiger shark *Galeocerdo cuvier* (2.8m in length) being recorded at one site (Cato 1). Importantly, there was no evidence of a systematic decline in the density or biomass of sharks across the CSMP that may otherwise indicate an increase in fishing pressure.

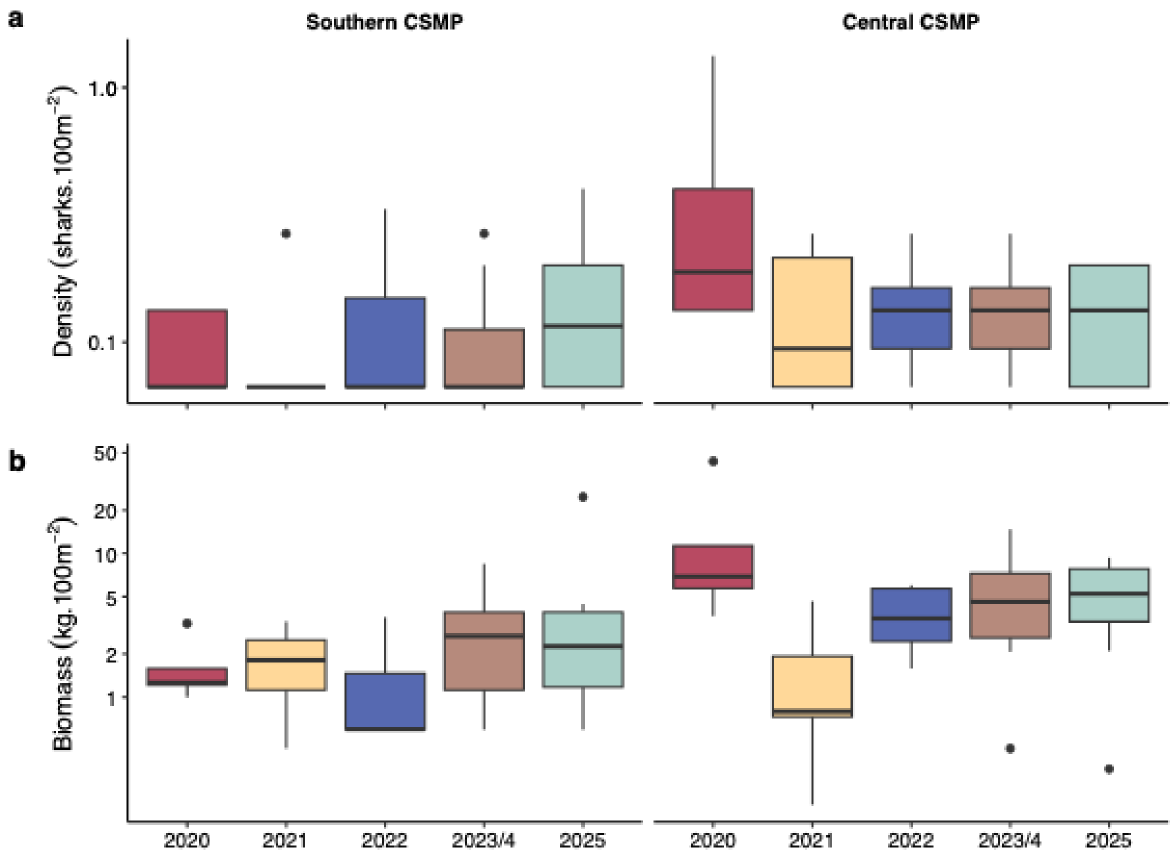

Figure 4.38 Temporal (2020-2025) variation in the **(a)** density and **(b)** biomass of sharks among the two regions of the Coral Sea Marine Park. Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at once during 2020-24, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays). Note: data are presented on a $\log_{10}$-scale.

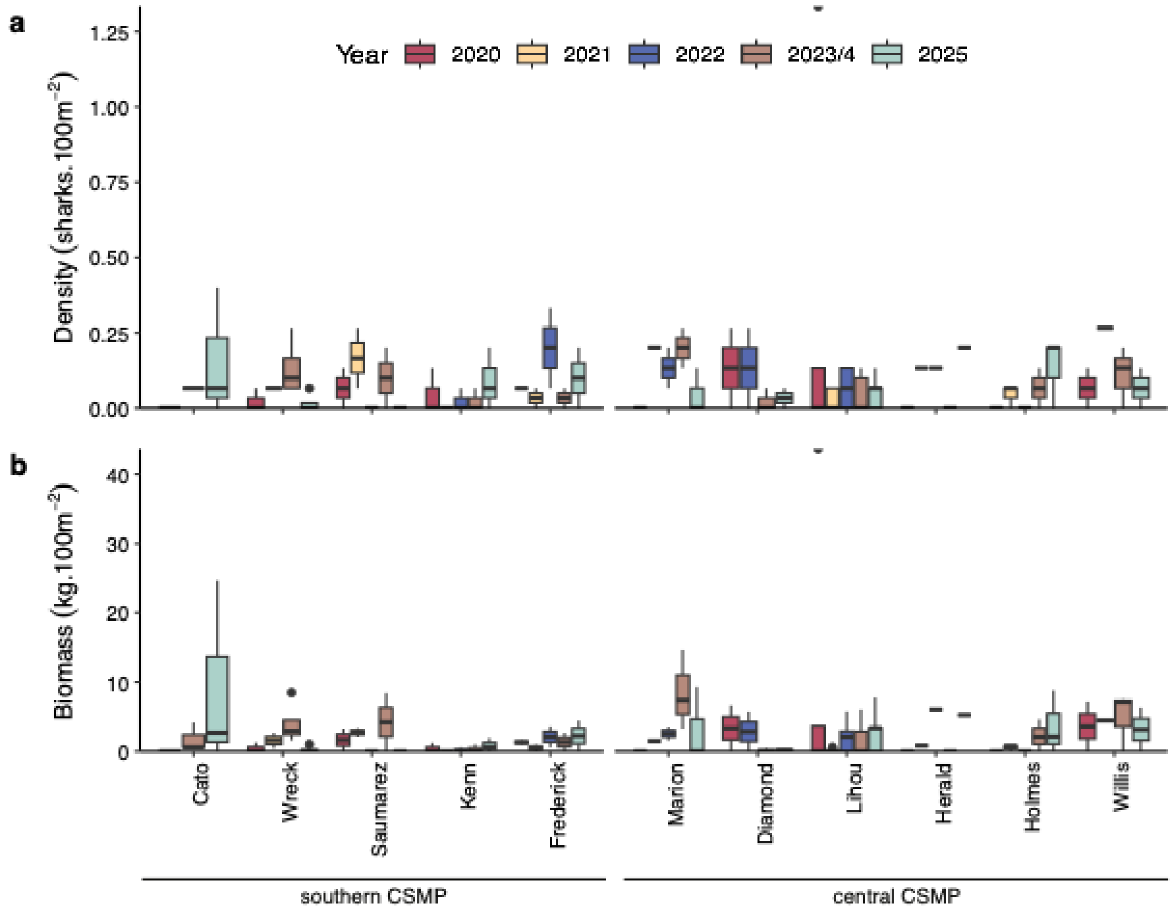

Figure 4.39 Temporal (2020-2025) variation in the **(a)** density and **(b)** biomass of sharks among eleven reefs in the Coral Sea Marine Park. Data are based on surveys of 30 matching sites that were surveyed at least once during 2020-24, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays).

4.4 Other reef taxa

4.4.1 Sea snakes

52 sea snakes (45 olive sea snakes, 6 Dubois sea snake, and 1 horned sea snake) were recorded across the twelve CSMP reefs in 2025 compared to 65, 50, 28 and 20 individuals in 2023/24, 2022, 2021 2020, respectively. Consistent with previous surveys (i.e., 2020-2024) sea snakes were regularly observed on all reefs in the southern CSMP and at Marion Reef, the southernmost reef of the central CSMP, but were not observed at the other six central CSMP reefs surveyed (Figure 4.40). The mean density of sea snakes recorded in 2025 varied from 0 to 0.9 snakes per 250m^2 (Saumarez and Kenn Reefs, respectively) in the southern CSMP, and 0.02 snakes per 250m^2 at Marion Reef (Figure 4.40).

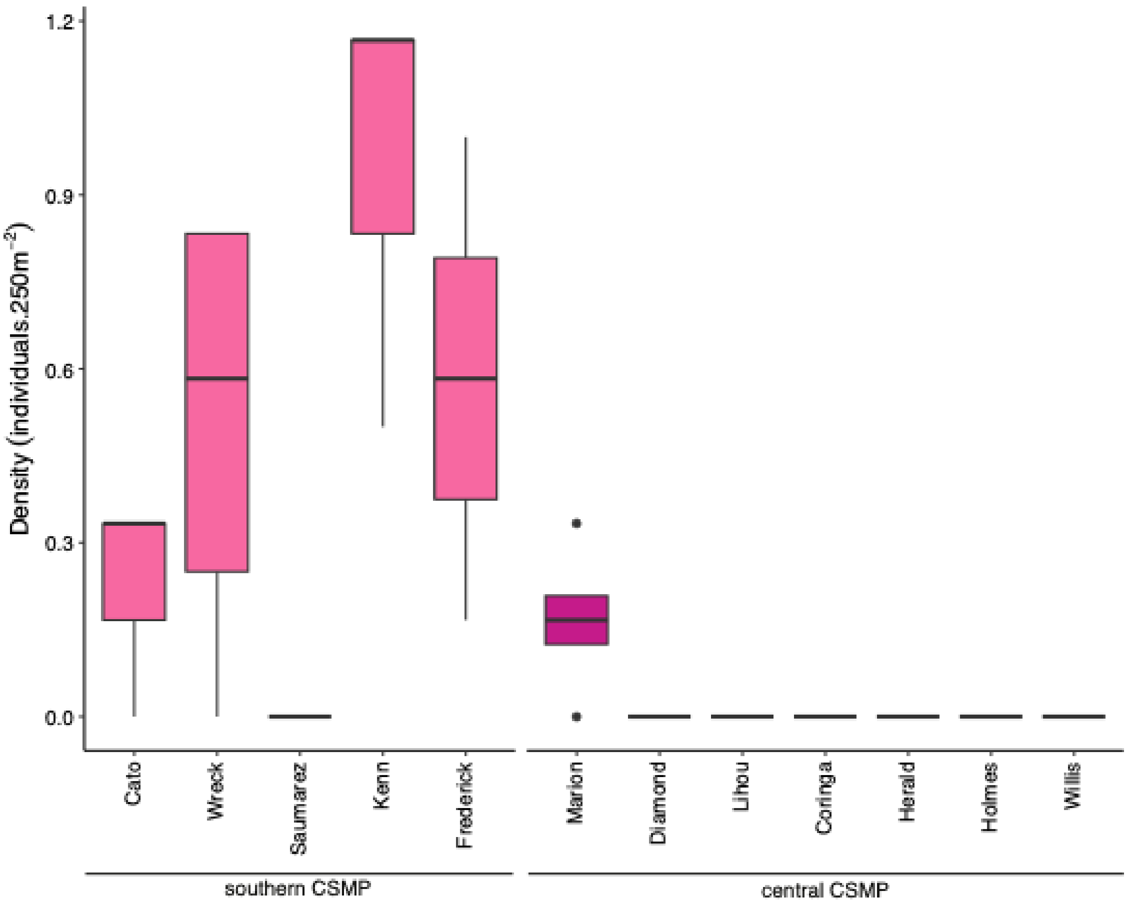

Figure 4.40 Spatial variation in the density of sea snakes among the twelve reefs surveyed in the Coral Sea Marine Park during 2025. Data are based on the 50m belt transects and averaged across sites and habitats. Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Diamond, Coringa and Willis Islets, Lihou and Holmes Reefs, and Herald Cays were surveyed in June 2025, and Cato, Wreck, Saumarez, Kenn, Frederick, and Marion Reefs were surveyed in October 2025.

The density of sea snakes has remained remarkably stable from 2023/24 to 2025 in both the the southern CSMP and central CSMP (i.e., Marion Reef only), following earlier increases in the southern CSMP from 2020 (0.13 snakes per 250m^2) to 2023/24 (0.55 snakes per 250m^2; Figure 4.41). These changes have been largely consistent among reefs, the only exception being Saumarez Reef in the southern CSMP where the density of sea snakes declined from 0.75 snakes per 250m^2 in 2024 to 0 snakes per 250m^2 in 2025 (Figure 4.42). Although no sea snakes were recorded within the transects at Saumarez Reef in 2025, several sea snakes were observed outside the transect areas.

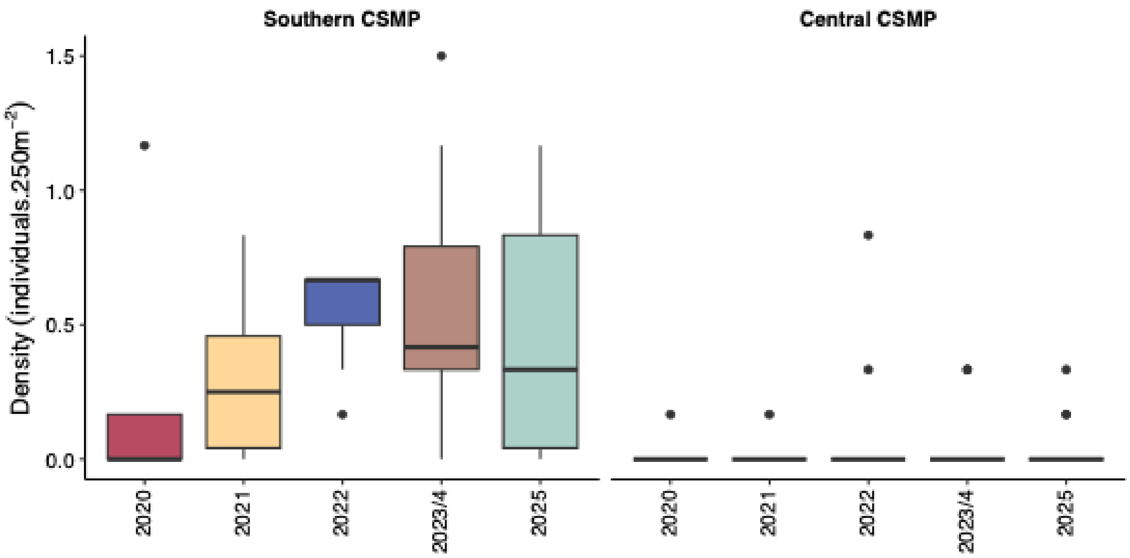

Figure 4.41 Temporal (2020-2025) variation in the density of sea snakes among the two regions of the Coral Sea Marine Park. Data are based on surveys of 30 matching sites across eleven reefs that were surveyed at least once during 2020-24, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays).

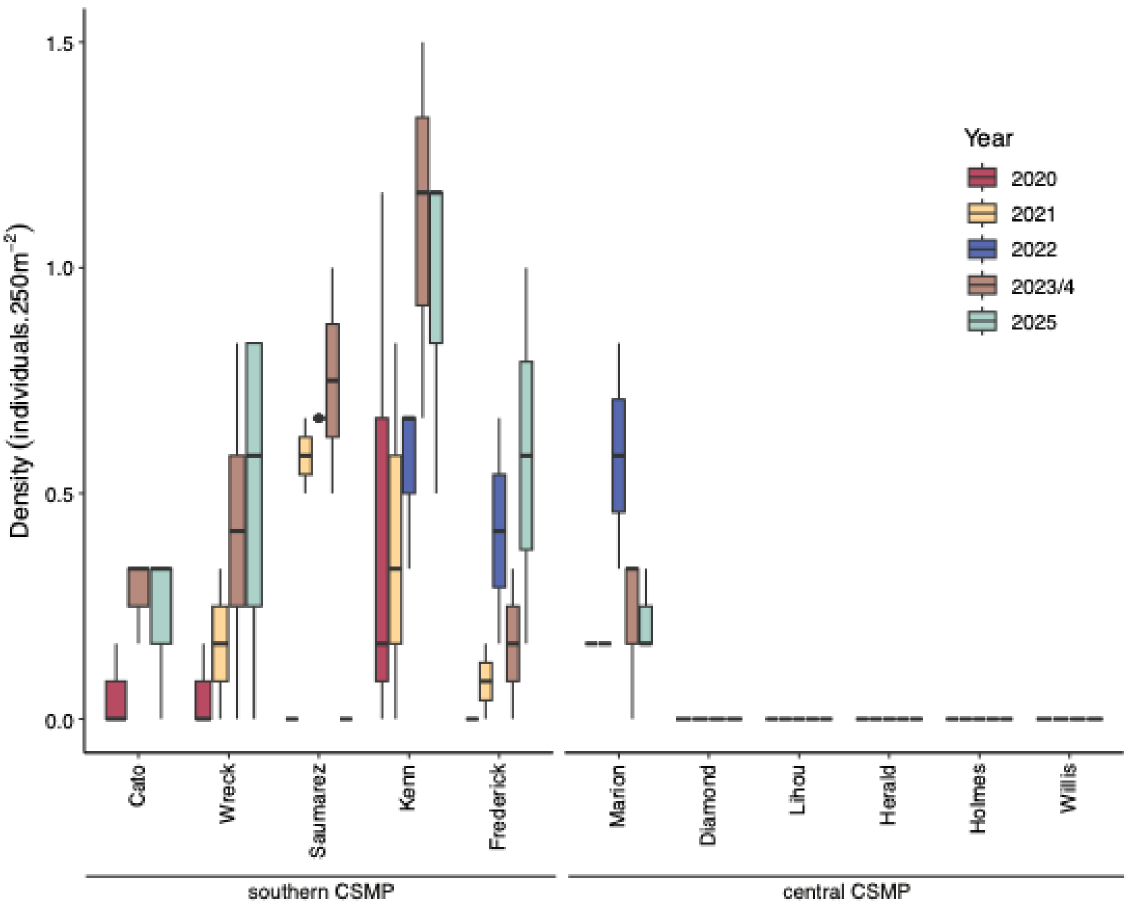

Figure 4.42 Temporal (2020-2025) variation in the density of sea snakes among eleven reefs in the Coral Sea Marine Park. Data are based on surveys of 30 matching sites that were surveyed at least once during 2020-24, and again in 2025 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays).

4.4.2 Macro-invertebrates

Giant Clams – 528 giant clams were recorded across the twelve CSMP reefs in 2025, with the vast majority (506 individuals, 95.8%) being *Tridacna maxima* and *Tridacna squamosa.* The only other species recorded was *Tridacna derasa* (20 individuals, 4.2%). The density of giant clams across all twelve reefs surveyed in 2025 was 2.6 clams per 100m^2, and was 7-fold greater in the southern CSMP (5.2 clams per 100m^2) than the central CSMP (0.8 clams per 100m^2; Figure 4.43a). Consistent with surveys from previous years there was considerable variation among reefs, ranging from (0.5 clams per 100m^2 at Willis Islets to 13.7 clams per 100m^2 at Kenn Reef (Figure 4.43a).

The density of giant clams has remained relatively consistent from 2020 to 2025 on individual reefs within the CSMP, with Kenn Reef having consistently higher densities of clams than any other reef surveyed (Figure 4.44a).

Trochus –*Tectus* spp. (formerly *Trochus*) were again relatively rare across the CSMP, with 49 individuals recorded across the twelve CSMP reefs in 2025 (mean density: 0.24 individuals per $100m^2$). The density of Trochus was similar between the southern (0.28 individuals per $100m^2$) and central CSMP (0.21 individuals per $100m^2$), however varied considerable among individual reefs, ranging from 0 at Coringa and Willis Islets and Herald Cays to 0.8 individuals per $100m^2$ at Frederick Reef (Figure 4.43b). There have been no notable changes in the density of Trochus on any of the reefs surveyed from 2020-2025 (Figure 4.44b), and likely reflects the very low densities recorded within the transects.

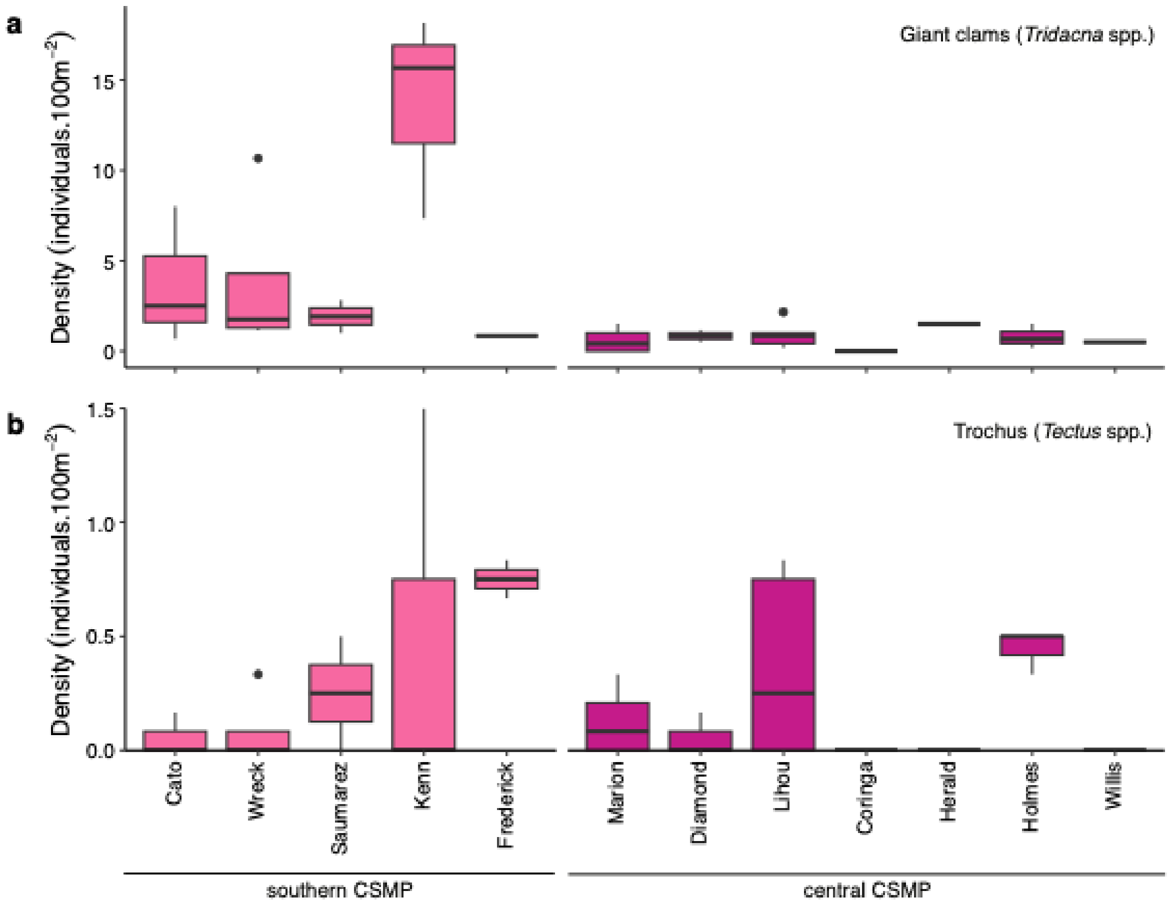

Figure 4.43 Spatial variation in the abundance of **(a)** giant clams, and **(b)** Trochus among the twelve reefs surveyed in the Coral Sea Marine Park during 2025. Data are based on the 50m belt transects and averaged across sites and habitats. Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1).

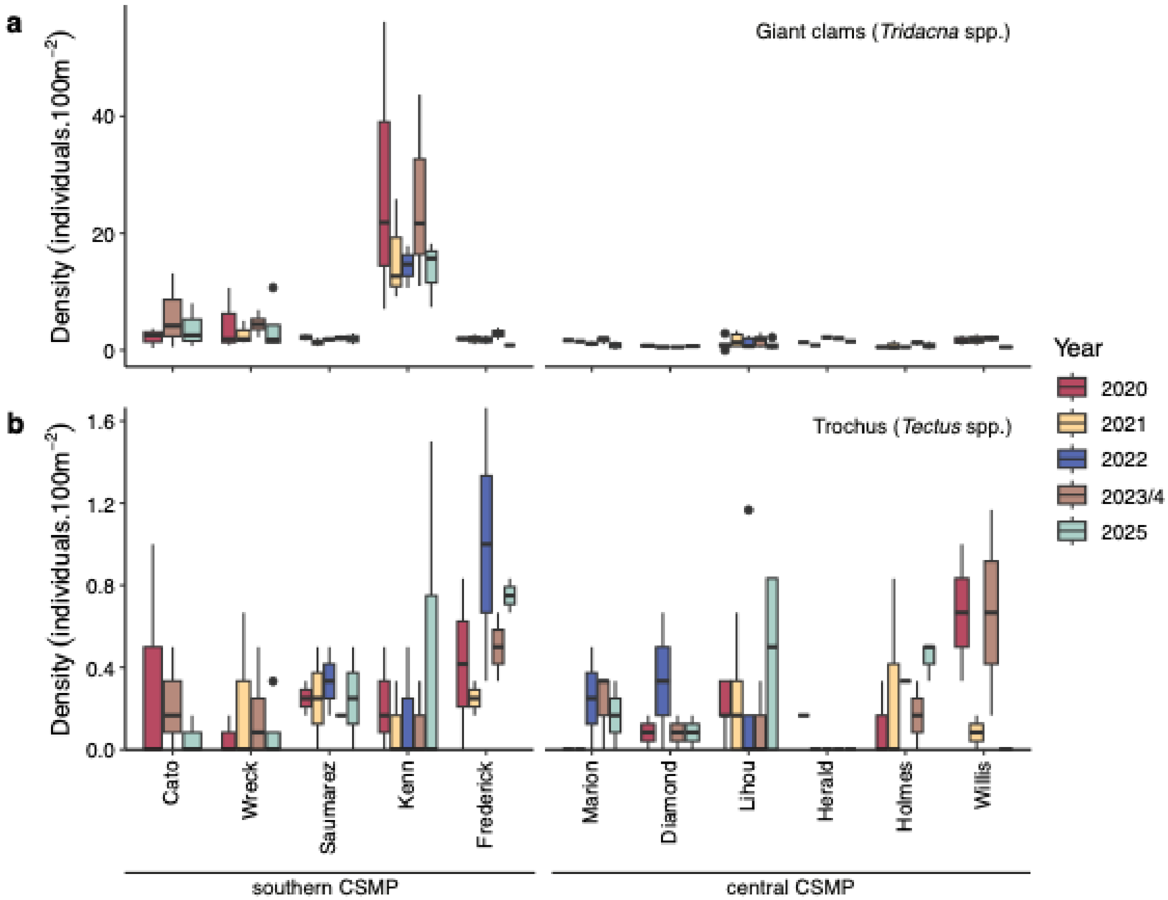

Figure 4.44 Spatial and temporal (2020-2025) variation in the abundance of **(a)** giant clams, and **(b)** Trochus among eleven reefs in the Coral Sea Marine Park. Data are based on replicate 50m transects at each of 30 matching sites surveyed at least once during 2020-24 and again in 2025.

Sea urchins – 4,274 long-spined sea urchins (*Diadema* spp.) were recorded across the twelve reefs in 2025, with all but 2 individuals being recorded on the five southern CSMP reefs (mean density: 42.6 urchins per 100m^2; Figure 4.45a). There was considerable variation in sea urchin densities among reefs in the southern CSMP, ranging from 0.8 urchins per 100m^2 at Saumarez to 142 urchins per 100m^2 at Kenn Reef (Frederick: 3.2; Cato: 33.1; Wreck 44.8 urchins per 100m^2; Figure 4.45a). Despite increases in the density of sea urchin at Cato and Wreck Reefs from 2023/24 to 2025, sea urchin densities in the southern CSMP have remained remarkably consistent of this period (2023/24: 48.1 urchins per 100m^2; 2025: 50.9 urchins per 100m^2; Figure 4.46a). The high densities of *Diadema* in the southern CSMP likely reflects a natural latitudinal gradient, rather than a population increase due to the removal of their predators as has been documented on tropical reefs elsewhere (e.g., Hughes 1994; McClanahan 1998), and is not cause for concern.

Sea cucumbers – 74 sea cucumbers (Holothuroidea) from seven species were recorded across the twelve CSMP reefs in 2025, equating to a mean density of 0.36 individuals per 100m^2. The most abundant species were *Thelenota ananas* (23.0%), *Thelenota anax* (23.0%), *Actinopyga mauritiana* (18.9%), and *Stichopus chloronotus* (14.9%). The other species recorded were *Bohadschia argus, Holothuria whitmaei*, and *Holothuria atra.* The density of sea cucumbers was comparable between the southern and central CSMP (0.33 and 0.38 indivdiuals per 100m^2, respectively), however was variable among individual reefs, ranging from 0 individuals per 100m^2 at Coringa and Willis Islets and Frederick Reef, to 1.45 individuals per 100m^2 at Marion Reef (Figure 4.45b).

The densities of sea cucumbers recorded across the eleven reefs in 2025 were greater than those recorded in 2023/24 (2023/24: 0.29 individuals per 100m^2; 2025: 0.36 individuals per 100m^2), but lower than the densities recorded in 2020 or 2021 (0.43 individuals per 100m^2) (Figure 4.46b).

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 (Hoey et al. 2020, 2021), 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. Robust assessments of giant clam, trochus, and sea cucumber populations would require dedicated surveys over the preferred habitat of each species. Specifically, these would include deeper lagoonal habitats dominated by sand for sea cucumbers (*sensu* Kinch et al. 2008), shallow exposed reef flat habitats for trochus (Ahmed and Hill 1994), and lagoonal shallow reef flat habitats for giant clams (Braley 1987).

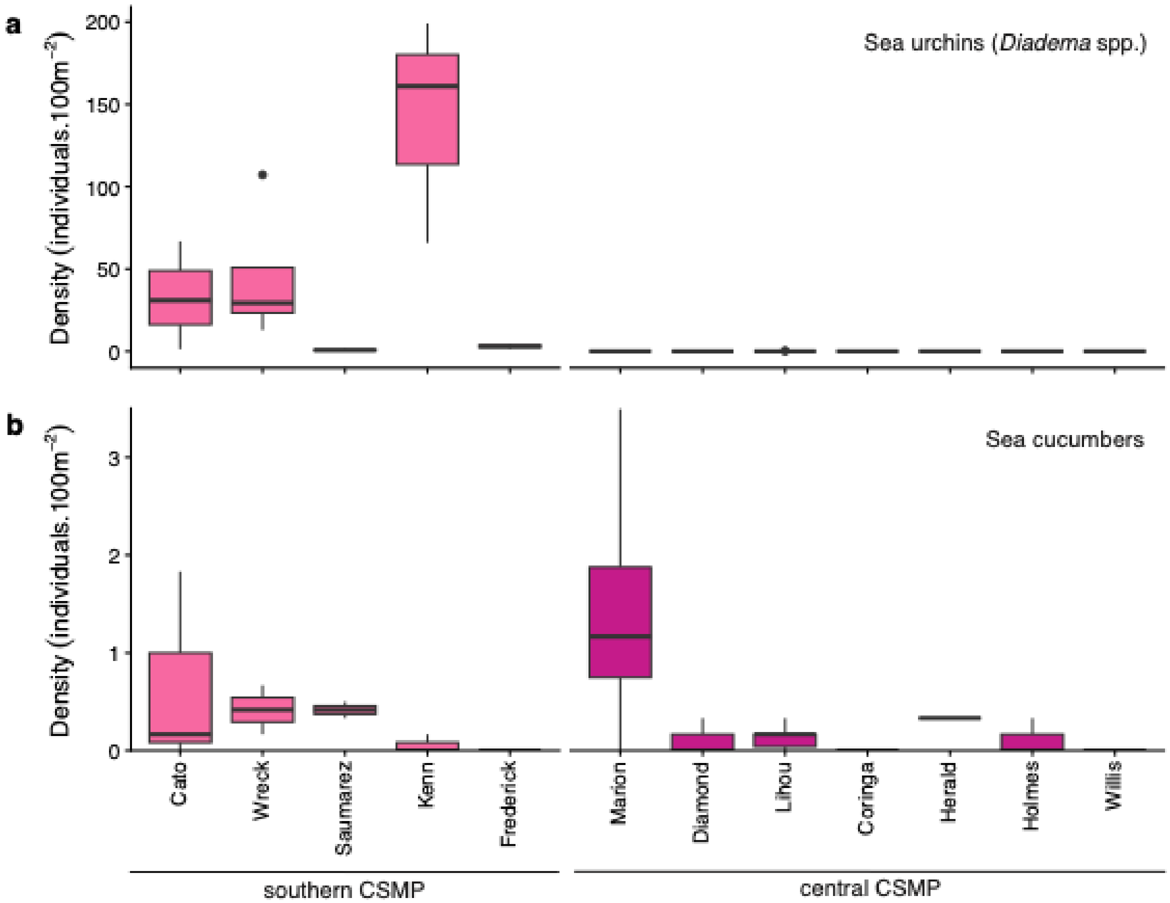

Figure 4.45 Spatial variation in the abundance of **(a)** long-spined sea urchins (*Diadema* spp.) and **(b)** sea cucumbers (Holothuroidea) among the twelve reefs surveyed in the Coral Sea Marine Park during 2025. Data are based on 50 x 2 m belt transects. Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Diamond, Coringa and Willis Islets, Lihou and Holmes Reefs, and Herald Cays were surveyed in June 2025, and Cato, Wreck, Saumarez, Kenn, Frederick, and Marion Reefs were surveyed in October 2025.

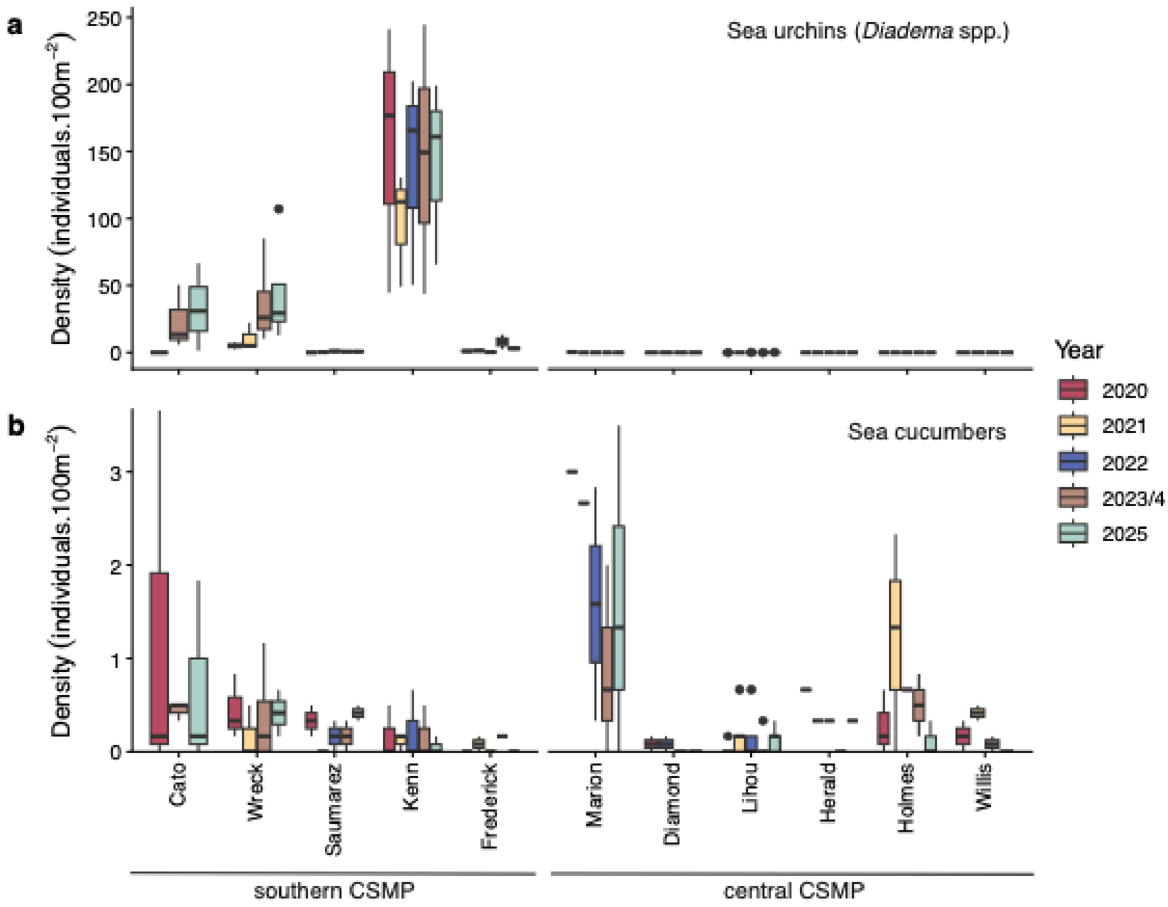

Figure 4.46 Spatial and temporal (2020-2025) variation in the abundance of **(a)** sea urchins (*Diadema* spp.) and **(b)** sea cucumbers (Holothuroidea) among twelve reefs in the Coral Sea Marine Park. Data are based on replicate 50 x 2m transects at each of 30 matching sites that were surveyed at least once during 2020-24 and again in 2025.

4.5 Coral health and injury

4.5.1 Coral colony size distribution

Shallow coral assemblages of the twelve CSMP reefs surveyed in 2025 were dominated by relatively small coral colonies (<20cm diameter), with few colonies larger than 40cm diameter recorded (Figures 4.47). This predominance of small colonies appears to be characteristic of CSMP reefs and has been evident since this series of surveys was initiated in 2018 (Figure 4.47; Hoey et al. 2024). This predominance of small coral colonies has been linked to areas of frequent disturbance (e.g., severe storms and heat stress) and/or low rates of recovery due to isolation and low rates of recruitment (Dietzel et al. 2020). Although the density of coral colonies was generally higher in the southern than the central CSMP, the distribution among size classes was similar (Figure 4.47).

While the abundance of larger colony size classes (41-60cm and >60cm) have remained relatively stable from 2023/24 to 2025, there have been considerable declines in the smaller size classes (<5cm and 6-20cm) over that period (Figure 4.47). This decline was particularly pronounced in the smallest size class (<5cm diameter, i.e., juvenile corals) in the central CSMP where densities declined from 34.0 colonies per $10m^2$ in 2023/24 to 6.0 colonies per $10m^2$ in 2025; an 82% decline (Figure 4.47).

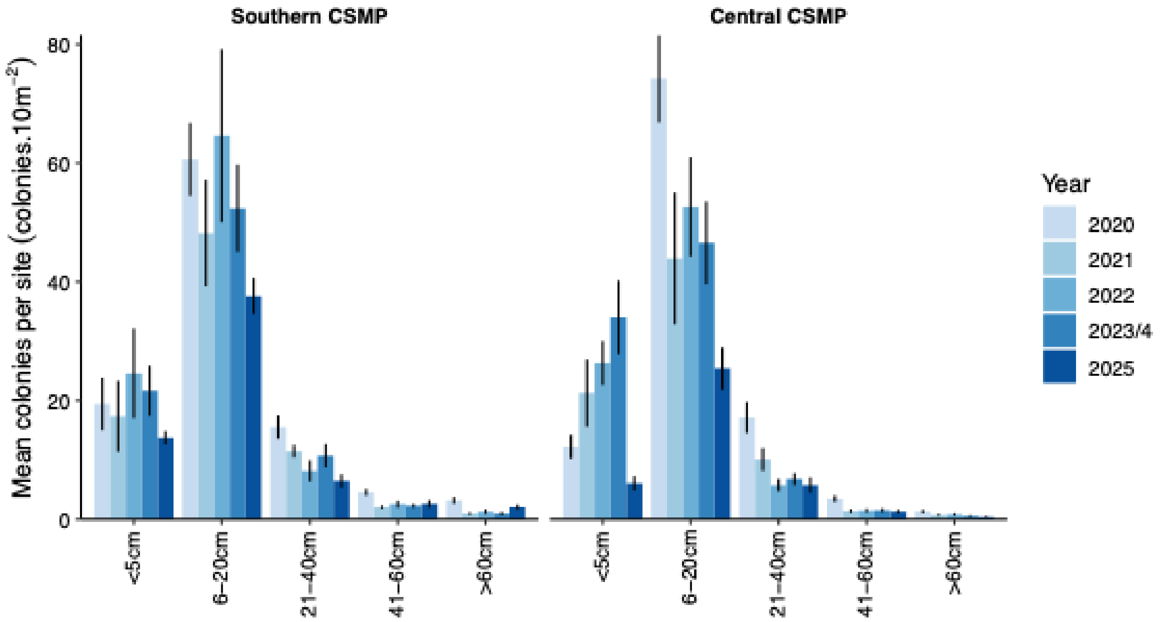

Figure 4.47 Temporal (2020-2025) variation in the size frequency distribution of coral colonies surveyed across two regions of the Coral Sea Marine Park. Data are based on 30 sites across eleven reefs that were surveyed at least once during 2020-24 and again in 2025. southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Holmes, Lihou and Marion Reefs, Willis and Diamond Islets, and Herald Cays.

4.5.2 Juvenile corals

2,291 juvenile corals (≤5cm diameter; Rylaarsdam 1983) were recorded across the 34 sites and twelve reefs surveyed in the CSMP in 2025, equating to a mean density of 11.4 juvenile corals per $10m^2$. This is lower than recorded across all previous years (2020: 15 juvenile corals per $10m^2$; 2021: 16.4 juvenile corals per $10m^2$; 2022: 23.1 juvenile corals per $10m^2$; 2023/24: 36.3 juveniles per $10m^2$), and a 69% decline from the densities reported in 2023/24 (Figure 4.48). Some caution needs to be applied when comparing across all reefs surveyed, rather than those that have been resurveyed in multiple years. The mean densities of juvenile corals recorded in 2025 were 2.3-fold higher in the southern CSMP (13.7 juvenile corals per 10m^2) than the central CSMP (6.0 juvenile corals per 10m^2). There was however considerable variation among individual reefs in each region, ranging from 3.6 to 15.9 juvenile corals per 10m^2 at Willis Islets and Marion Reef, respectively, in the central CSMP, and from 11.7 to 19.1 at Cato and Saumarez Reefs, respectively, in the southern CSMP (Figure 4.48).

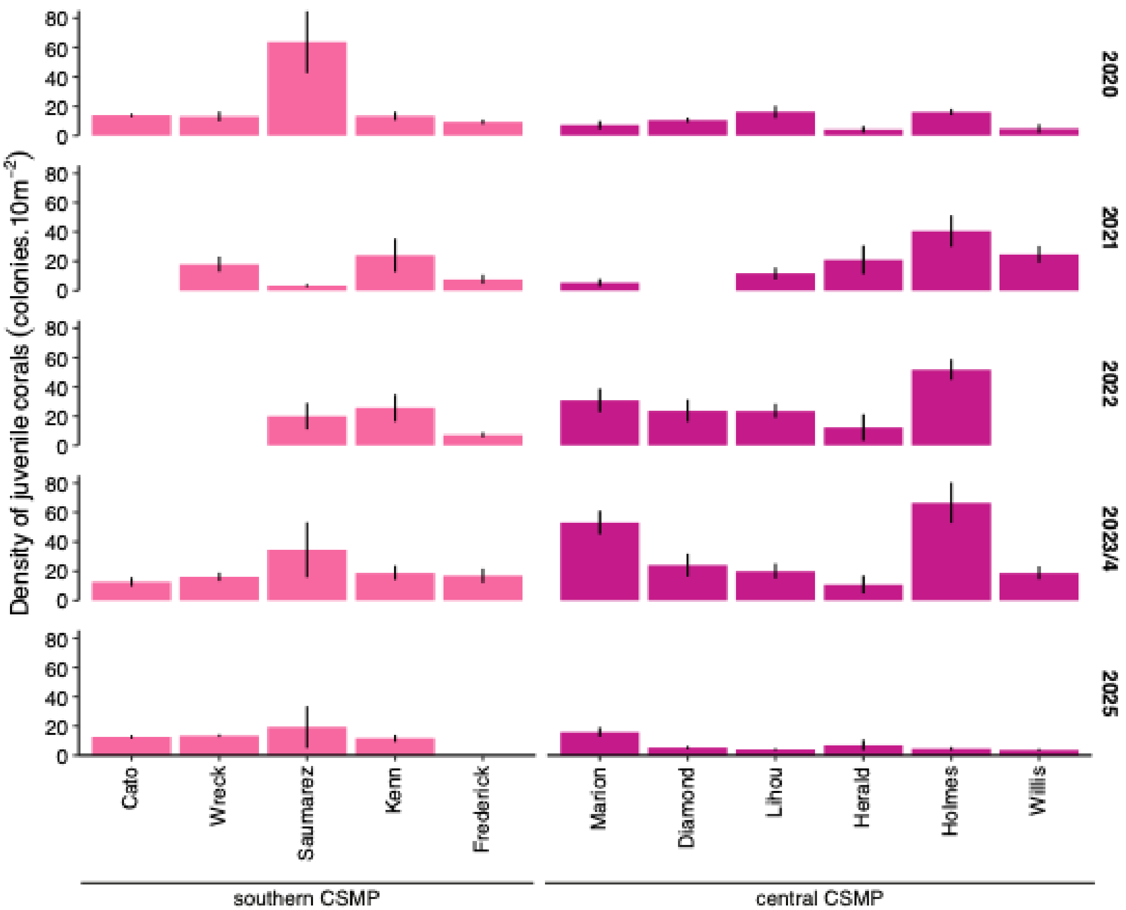

Figure 4.48 Temporal (2020-2025) variation in the mean (±SE) density of juvenile corals at eleven reefs surveyed in the Coral Sea Marine Park. Data are based on the number of juvenile corals (<5cm diameter) surveyed within 10 x 1 m belt transects at each site. Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Densities of juvenile corals surveyed were always >1 colony.10m^{-2}, reefs with zero juveniles indicate they were not surveyed in that year.

Comparisons of the eleven reefs that were surveyed at least once in 2020-2024 and again in 2025 show the density of juvenile corals has declined markedly in both the southern (21.6 to 13.7 juvenile corals per $10m^2$) and central CSMP (34.0 to 6.0 juvenile corals per $10m^2$) from 2023/24 to 2025 (Figure 4.49). Juvenile coral densities recorded in 2025 are considerably lower than all previous estimates for both the southern (2020-2023/4: 19.5 - 24.6 juvenile corals per $10m^2$) and central CSMP (2020-2023/24: 12.2 – 34.0 juvenile corals per $10m^2$; Figure 4.49).

The density of juvenile corals declined across most reefs from 2023/24 to 2025, the only exception being Cato Reef in the southern CSMP where juvenile coral densities remained relatively stable (2023/24: 12.7 juvenile coral per $10m^2$; 2025: 12.6 juvenile corals per $10m^2$; Figure 4.50). The decline in juvenile coral densities across the other ten reefs was highly variable, ranging from a 22% decline at Wreck Reefs (2023/24: 17.2 juvenile coral per $10m^2$; 2025: 13.4 juvenile corals per $10m^2$) to a 93.2% decline at Holmes Reefs (Figure 4.50). While thermal stress experienced throughout the southern and central CSMP in 2024 and 2025 may have contributed to the declines in juvenile corals, the magnitude of the decline is concerning. It is important to recognise that even prior to these declines the densities of juvenile corals in the CSMP were at the lower end of density estimates for other regions (e.g., mid-shelf GBR: 6.1-8.2 juvenile corals per m^2, Trapon et al. 2013; Palmyra Atoll: 17.1 juvenile corals per m^2, Roth and Knowlton 2009; New Caledonia: 2 - 11.6 juvenile corals per m^2, Adjeroud et al. 2010).

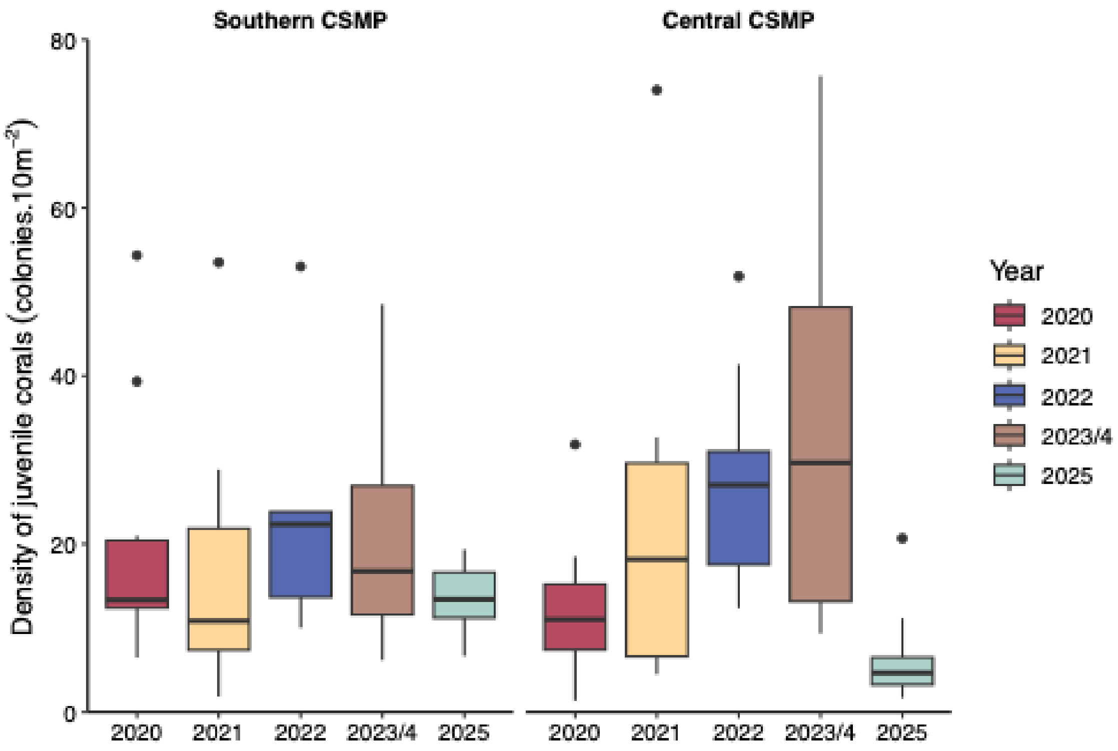

Figure 4.49 Spatial and temporal (2020-2025) variation in the density of juvenile corals (<5cm diameter) between two regions of the Coral Sea Marine Park. Data are based on replicate 10 x 1m transects at each of 30 matching sites across eleven reefs that were surveyed at least once during 2020-24 and again in 2025 (central: Diamond and Willis Islets, Holmes, Lihou and Marion Reefs, and Herald Cays; southern: Cato, Wreck, Saumarez, Kenn, and Frederick Reefs).

The abundance of juvenile corals on a reef is a product of the supply and successful settlement of larvae, together with the survival and growth of newly settled corals. In the CSMP, larval supply from external sources (i.e., other reefs) is likely to be limited by the isolation and limited connectivity among reefs, with reefs relying largely on locally produced larvae for the replenishment of coral populations (i.e., self-recruitment; Gilmour et al. 2013). Following major disturbance events (e.g., mass bleaching) that cause extensive mortality of corals, local production of coral larvae is impeded due to the mortality of brood stock, and reduced fecundity of surviving broodstock as energy is partitioned away from reproduction and toward growth and colony repair (Hughes et al. 2019; Frisch et al. 2019). Given the growth rates of juvenile corals (Babcock and Mundy 1996; Edmunds 2007; Doropoulos et al. 2016) the majority of juvenile corals recorded between 2021-2024 likely settled onto these reefs during or prior to 2020 (e.g., Doropoulos et al. 2021). Consequently, we may only now be starting to see the effects of the four recent bleaching events (i.e., 2020, 2021, 2022 and 2024) on the abundance of juvenile corals and the replenishment of coral populations in the CSMP. Continued monitoring of the juvenile assemblages in the CSMP is critical to understand the full effects of recent bleaching events (i.e. 2020, 2021, 2023 and 2024) on the replenishment of coral populations and the future recovery of these isolated and unique reefs.

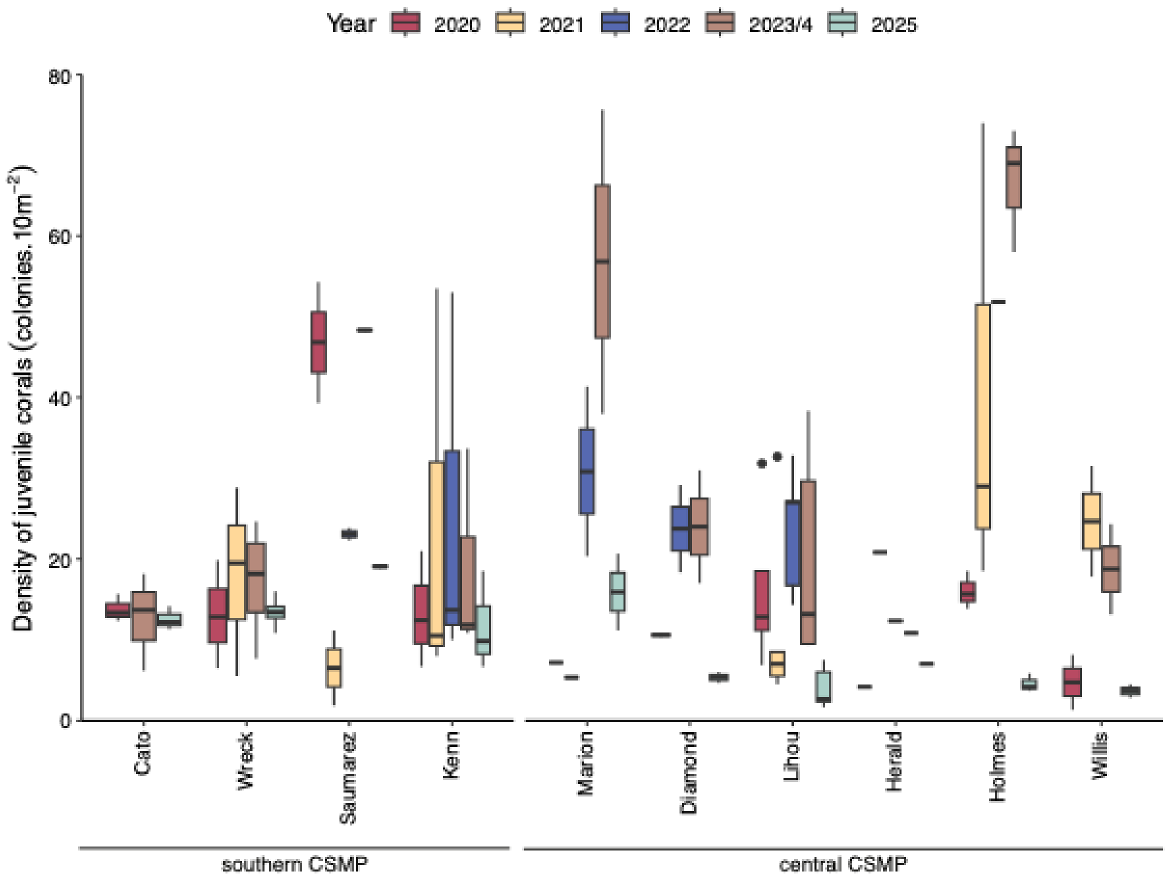

Figure 4.50 Spatial and temporal (2020-2025) variation in the density of juvenile corals (<5cm diameter) among eleven reefs within the Coral Sea Marine Park. Data are based on replicate 10 x 1m transects at each of 30 matching sites that were surveyed at least once during 2020-24 and again in 2025.

4.5.3 Coral condition

The vast majority (92.4%) of corals surveyed in 2025 were healthy with relatively little evidence of heat stress or recent mortality (Figures 4.51, 4.52). The percent of colonies exhibiting signs of injury (5-100% recent mortality) because of various stressors was again low in 2025 (2.2%), consistent with previous surveys of the CSMP (Hoey et al. 2024; Burn et al. 2022). The low percent of colonies exhibiting signs of heat stress (pale to 100% bleached) in 2025 (4.7%; Figure 4.51) is perhaps not surprising given the timing of the surveys in June and October 2025, several months after the peak heat stress in March 2025 (Figure 4.53). Interestingly, the incidence of heat stress among reefs across the central CSMP (i.e., greatest on Diamond Islets and Lihou Reef) broadly aligned with the heat stress experienced across the central CSMP in March 2025, with >8 DHW in the eastern region of the Queensland Plateau (Figure 4.53). The bleaching recorded on these reefs may, therefore, represent corals that had bleached during March/April and had survived but not fully recovered at the time of the surveys.

As expected, the incidence of heat stress (paling and bleaching) varied among coral taxa with heat sensitive taxa such as *Acropora* (7.8%), *Pocillopora* (12.0%) and *Stylophora* (10.2%) being more affected than other taxa (Loya et al. 2001; Figure 4.52).

Given the ongoing and predicted future effects of climate change (e.g., Hughes et al. 2018), further heat stress events within the CSMP are inevitable, and as such continued monitoring will be critical to not only quantify the impacts and potential recovery of coral and fish populations, but also to understand the capacity of coral and fish populations to adapt to changing environmental conditions.

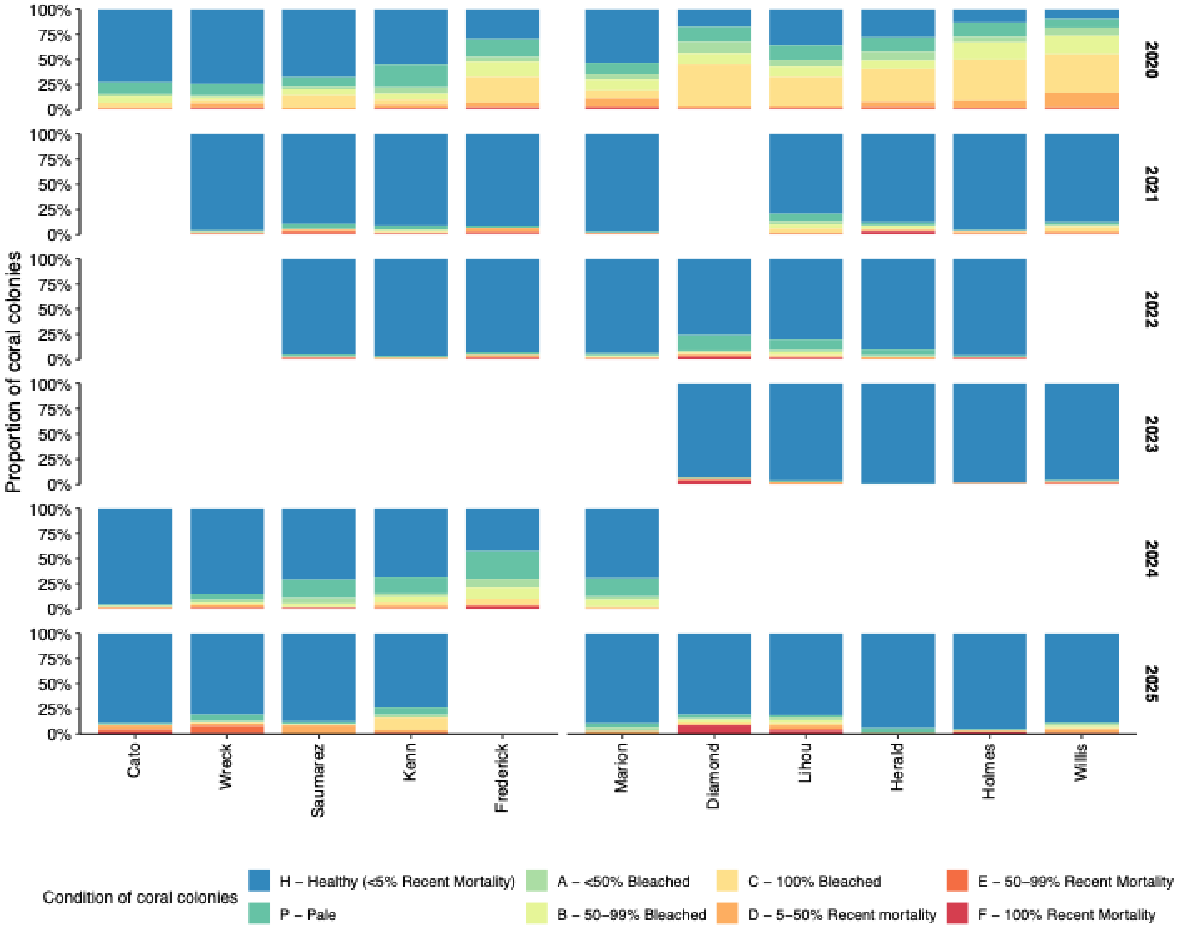

Figure 4.51 The proportion of coral colonies in each of eight health categories from 'healthy' to 'recently dead' recorded at eleven reefs within the Coral Sea Marine Park from 2020 to 2025. Diamond, Coringa and Willis Islets, Lihou and Holmes Reefs, and Herald Cays were surveyed in June 2025, and Cato, Wreck, Saumarez, Kenn, Frederick, and Marion Reefs were surveyed in October 2025.

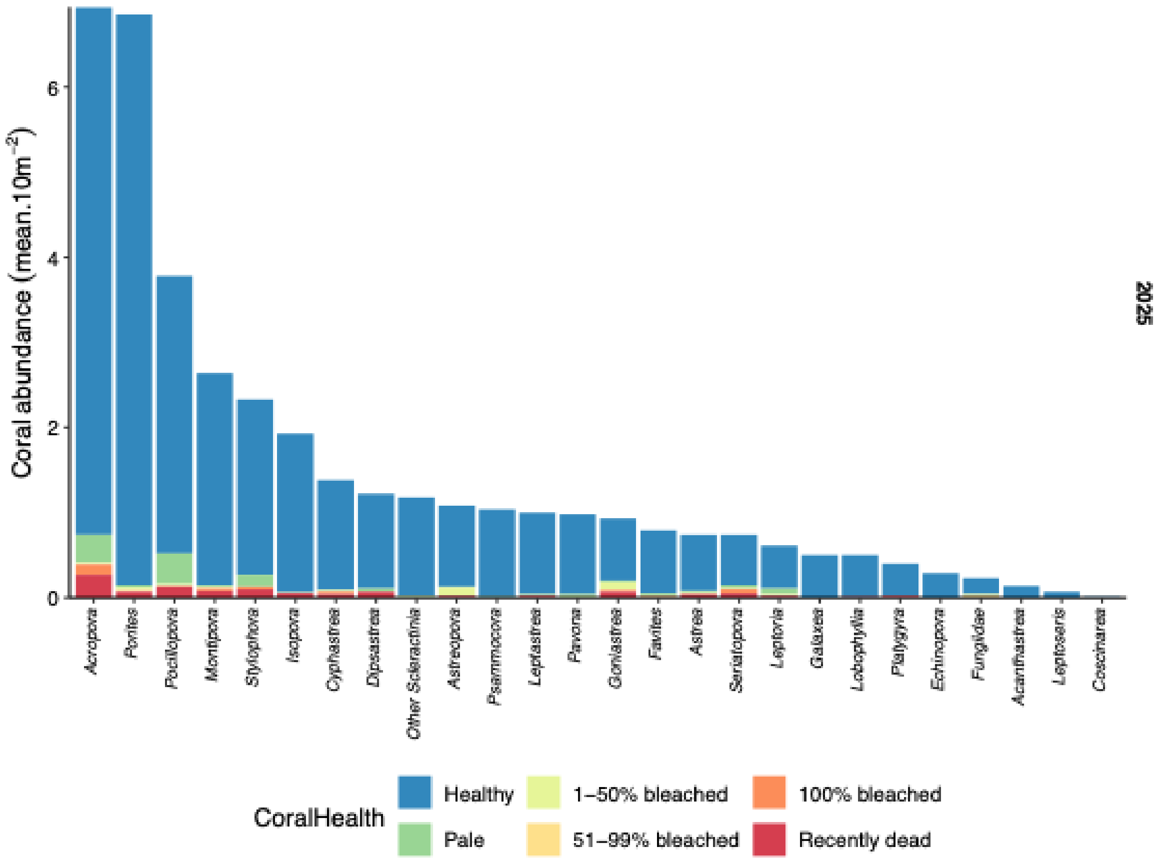

Figure 4.52 Mean density of coral colonies (per 10m^2) in the 26 most common scleractinian genera (including a pooled 'other Scleractinia' category) in each of six bleaching health categories from 'healthy' (blue) to 'recent bleaching mortality' (red) observed at sites across twelve reefs in the CSMP during June and October 2025.

Photographs of bleached corals on the reef slope of reefs in the central Coral Sea Marine Park in June 2025. This bleaching was evident several months after the peak heat stress experienced on these reefs. Note the algae starting to overgrow the bleached coral in the lower right image, indicating the coral tissue has died. Image credits: Morgan Pratchett.

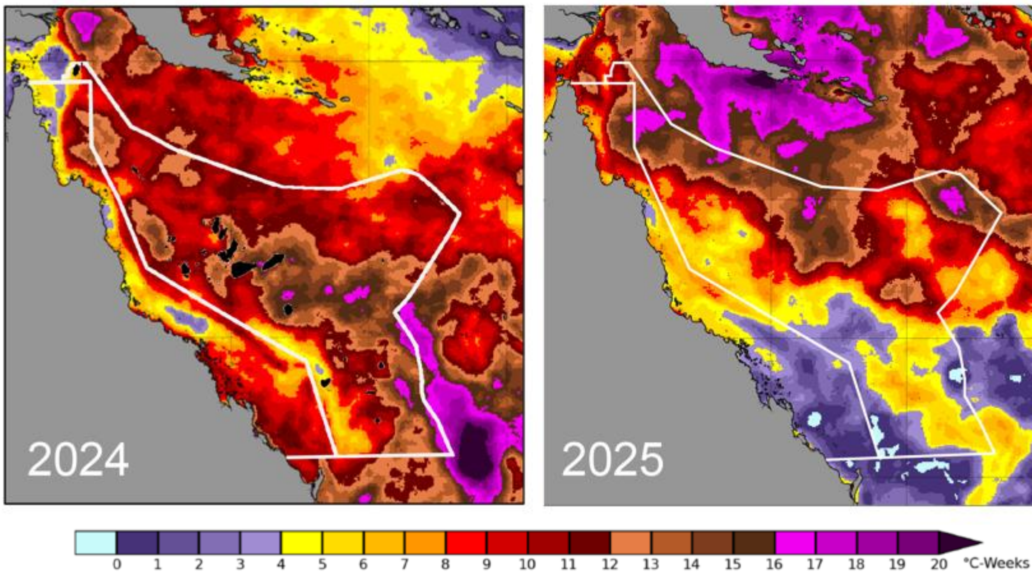

Figure 4.53 Maximum heat stress (Degree heating weeks; DHW) in the Coral Sea Marine Park for March 2024 and March 2025 (i.e., after the 2024 CSMP Reef Health surveys but prior to the 2025 surveys). Images produced using the NOAA CRW 5km product v3.1

4.6 Comparison among management zones

Of the twelve reefs surveyed in 2025, two reefs (Kenn and Marion Reefs) have multiple management zones whereby approximately half of the reef area is with a Habitat Protection Zone (HPZ) and the other half is within a National Park Zone (NPZ). Surveys were conducted within each of these zones on each reef, thereby allowing comparisons between zones. It should be noted that due to the time available at each reef only 1-2 sites were surveyed within each zone at each reef, and as such any observed trends may be sensitive to the particular sites surveyed.

Coral cover did not differ consistently between zones. Coral cover was higher within the NPZ (23.2%) than the HPZ (16.9 ± 4.4%) at Kenn Reefs, but lower within the NPZ (8.4 ± 0.3%) than the HPZ (13.6 ± 4.9%) at Marion Reef (Figure 4.54a). The mean biomass of reef fishes was similar between zones on Kenn Reef (HPZ: 3.8 ± 2.1 kg per $100m^2$; NPZ: 3.1 kg per $100m^2$), and 1.7-fold greater within the NPZ than the HPZ on Marion Reef (NPZ: 11.9 ± 6.3 kg per $100m^2$; HPZ: 7.0 ± 1.0 kg per $100m^2$; Figure 4.54b).

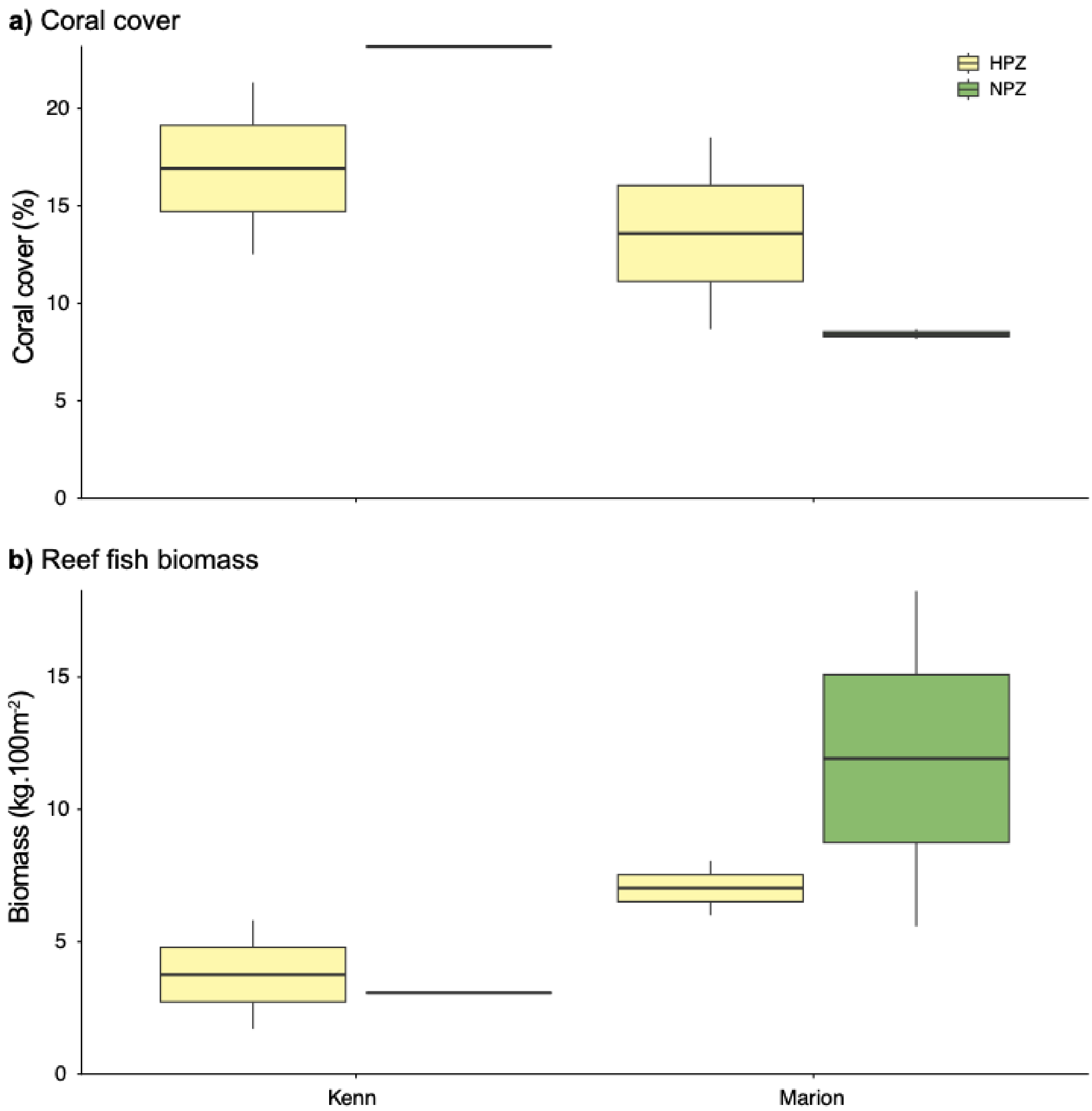

Figure 4.54 Comparison of **(a)** coral cover and **(b)** reef fish biomass between Habitat Protection Zones (HPZ, *yellow*) and National Park Zones (NPZ, *green*) at Kenn and Marion Reefs. Two sites were surveyed in each zone at each reef, except the NPZ at Kenn Reefs where only one site was surveyed.

5 Conclusions

Human activities have altered most of the world's ecosystems, and are now considered one of, if not the, dominant drivers of the structure and functioning of ecosystems (Diaz et al. 2019; Keck et al. 2025). Foremost among these activities, is human-induced climate change, with increasing temperatures affecting all levels of biological organisation, including individuals, populations, communities and ecosystems. Coral reefs are one of the world's most biodiverse ecosystems, yet climate-induced coral bleaching threatening the persistence of reef globally (Hughes et al. 2017). While the first global bleaching event was recorded in 1998, ongoing changing climate has seen an increase in the severity and frequency of marine heatwaves, with the third and fourth global bleaching event occurring across the 2015/16 and 2023/24 summers (Reimer et al. 2024; Eakin et al. 2026). The fourth global bleaching event has been the most severe to date with NOAA's bleaching alert scale having to be extended to reflect the extreme heat (>20 DHW) experienced in many regions (Alert Level 5 – near complete mortality; NOAA 2024). The ongoing and predicted future effects of climate change on reefs have led to concerns that reefs are approaching critical thresholds at which key processes are disrupted (Wilson et al. 2006; Graham et al. 2015), and the persistence of reefs is threatened (Bellwood et al. 2019). While isolated reef systems, such as those in the CSMP, are often described as being 'near pristine' due to their limited exposure to local anthropogenic pressures (e.g., fishing, terrestrial run-off), the effects of climate change are pervasive. Indeed, the CSMP has experienced water temperature that are expected to lead to widespread bleaching and mortality of corals in seven of the past 10 years (2016, 2017, 2020, 2021, 2022, 2024 and 2025; Harrison et al. 2018, 2019, Hoey et al. 2020, 2021, 2022, 2024). Assessing the effects of, and the potential recovery from, recent bleaching events on shallow coral reef communities are critical to better understand the dynamics and the longer-term health of this unique reef system.

5.1 Benthic assemblages

The surveys conducted in June and October 2025 under this project revealed shallow water coral cover increased from 12.6% in 2023/24 to 15.1% in 2025 across the eleven reefs that were surveyed in both years, a mean increase of

20.1%. This increase in coral cover was surprising given reefs in the southern and central CSMP experienced substantial heat stress in March 2024 (>12 degree heating weeks; DHW) and reefs in the eastern region of the central CSMP experienced significant heat stress again in March 2025 (>8 DHW; Figure 4.53). DHW combines the intensity and duration of heat stress experienced during the previous 3 months from satellite imagery into a single index. It is a strong predictor of bleaching with DHW >4 likely to lead to significant bleaching, and DHW>8 likely to lead to significant mortality, especially in more sensitive species (Hughes et al. 2017).

The increase in coral cover, albeit relatively small in absolute terms, likely reflects a shifted baseline toward more bleaching resistant coral communities due to the loss of thermally-sensitive species and/or thermally-sensitive genotypes (within a species) following the five previous bleaching events (i.e., 2016, 2017, 2020, 2021, and 2022). The only exception to this was Cato Reef, the southernmost reef in the CSMP that experienced a decline in coral cover from 2023/24 (33.7%) to 2025 (20.3%). Cato Reef had largely escaped the effects of recent bleaching events in the CSMP, and as such the observed decline likely reflects a high cover of thermally sensitive coral taxa (e.g., *Acropora*) and the mortality of these corals due to elevated temperatures in March and April 2024. Similar changes in the incidence of bleaching in response to heat stress were observed following the 2016 bleaching event on the GBR, with reefs exposed to 8-9 DHW having >90% probability of severe bleaching in 2016, compared to only a 50% probability for reefs exposed to the same heat stress in 2017 (Hughes et al. 2019). Variation in heat tolerance among corals has also been linked to annual temperature ranges, the rate of warming, the frequency of, and prior exposure to, heat stress events (e.g., Ainsworth et al. 2016; Jurriaans and Hoogenboom 2020; Marzonie et al. 2023). Examination of *in situ* temperature profiles from retrieved temperature loggers will provide important insights into the temperatures experienced by corals, whether the satellite derived temperatures accurately reflect the local conditions, and the potential role of local upwelling or mixing in cooling surface waters.

Together with the small increase in coral cover, there was a moderate increase in the cover of macroalgae from 2023/24 to 2025 (2023: 10.7%; 2025: 17.5%) with this increase being driven by changes in the cover of *Halimeda, a* green calcified alga that is a common feature of oceanic reefs and an important contributor to calcification and production of reef sediments (Drew 1983). Unlike many large canopy-forming algae, such as *Sargassum,* that predominate on nearshore reefs of the GBRMP and elsewhere (e.g., Wismer et al. 2009; Hoey and Bellwood 2010; Rasher et al. 2013), high abundances of *Halimeda* is not considered to be symptomatic of reef degradation. Moreover, differences in the timing of the surveys in 2023/24 (February-March) and 2025 (June and October) likely contributed to the increase in *Halimeda*. Macroalgal assemblages are temporally dynamic, with individual taxa showing seasonal variation in growth, senescence, and hence cover and biomass (Martin-Smith 1993; Fulton et al. 2014; Loffler and Hoey 2018). On inshore reefs of the GBR, for example, the brown canopy-forming macroalga *Sargassum* often dominates algal communities during the austral summer but is largely absent with only their holdfasts remaining during winter (Loffler and Hoey 2018). Future surveys during the warmer and cooler months are needed to determine if the increase in *Halimeda* is due to seasonal variation or is reflective of a longer-term change.

The density of juvenile corals (an indicator of the recovery potential of coral populations) declined by 67% across the eleven CSMP reefs from 2023/24 to 2025 (28.5 and 9.5 juveniles per $10m^2$, respectively), and was most pronounced on the central CSMP reefs. The cause of this decline is difficult to ascertain, although is likely related to the bleaching and mortality of juvenile corals due to heat stress (Álvarez-Noriega et al. 2018; Burn et al. 2023) experienced in early 2024 and 2025, and/or the lag effects of previous bleaching events on coral broodstock and larval supply. The majority of juvenile corals recorded prior to the 2025 surveys (i.e., 2021-4) likely settled onto these reefs during or prior to 2020 (e.g., Doropoulos et al. 2021). Consequently, the effects of the four recent bleaching events (i.e., 2020, 2021, 2022 and 2024) on adult coral brood stock, the production and settlement of coral larvae, and hence the replenishment of coral populations in the CSMP may only be starting to be fully realised. Irrespective, the large decline in the density of juvenile corals, coupled with the low coral cover on many of the reefs surveyed will significantly reduce or inhibit the recovery of coral populations. The next few years may be critical in determining whether coral populations and coral cover on these reefs recover, or collapse, as well as the implications for reef fish and invertebrate communities.

5.2 Reef fish assemblages

The richness, density and biomass of reef fish assemblages on the eleven reefs surveyed declined from 2023/24 to 2025. Given the small increase in coral cover over this period, these declines likely reflect a lagged response of reef fish communities to previously bleaching-induced declines in coral cover and the erosion of the physical structure they provide (e.g., Graham et al. 2007). Numerous studies and reviews have quantified the effects of coral mortality and/or reductions in the physical structure of the reef (as the dead coral skeletons erode). Collectively these studies have shown that fishes that depend on live coral for food or shelter are the first and most adversely affected by coral loss, however many other species that don't have a direct reliance on corals as adults often show a lagged response (Graham et al. 2007; Pratchett et al. 2011, 2014; Richardson et al. 2018). Indeed small-bodied corallivorous and planktivorous fishes were the first to decline following the 2020 bleaching event in the CSMP, however there have also been substantial declines in the density and biomass of grazing fishes in the central CSMP from 2020 to 2023/24, with further declines evident in 2025. The biomass of grazing fishes on the central CSMP reefs surveyed is now only ~30% of that recorded in 2020.

Grazing fishes are widely viewed as a key group on coral reefs, providing a conduit of energy transfer from primary producers to higher trophic levels, influencing the standing biomass of algal communities (e.g., Bellwood et al. 2006b; Hoey and Bellwood 2009, 2011; Rasher et al. 2013), and herbivorous fishes of the Queensland Plateau are recognised as a Key Ecological Feature in the CSMP. This top-down view of herbivorous fishes shaping algal and benthic communities is increasingly debated, with many researchers advocating that herbivorous fish populations are determined largely by the bottom-up processes (e.g., food availability and habitat features; Russ et al. 2015; Clements et al. 2017; reviewed in Hoey and Johansen 2026). The continued and sustained declines in the biomass of grazing fishes are difficult to reconcile as previous studies have reported increases in the abundance and/or biomass of herbivorous fishes following large-scale bleaching-induced coral mortality (e.g., Adam et al 2011; Gilmour et al. 2013; Taylor et al. 2020). Such increases have generally been related to an increase in the availability of their preferred feeding substrata (i.e., turf assemblages that rapidly colonise dead coral skeletons; Diaz-Pulido and McCook 2002), and subsequent increases in the growth rates of fishes (parrotfishes: Taylor et al. 2020). The recorded declines in the density biomass of grazing fishes across the central CSMP may be related to the physiological response of these fishes to heat stress (Stuart-Smith et al. 2018), although this seems unlikely as other groups (e.g., piscivores) were largely unaffected. It seems more likely that the rapid colonisation of dead coral skeletons by CCA, as opposed to turf assemblages, and/or temperature-induced changes in the nutritional quality of their food (Graba-Landry et al. 2020) may be limiting the ability of these fishes to acquire sufficient energy. Further dedicated investigation into the diet and fitness of these fishes on CSMP reefs is required to identify the mechanism/s for these declines.

The density of sharks, sea snakes and macro-invertebrates (giant clams, Trochus, sea urchins, and sea cucumbers) was relatively stable between 2023/24 and 2025, however, the current density of sea cucumbers are ~20% lower than those recorded in 2020 and 2021. The cause/s of this decline are unclear and could be related to natural population variability, changes in habitat and environmental conditions, and/or harvesting (Purcell et al. 2013). Future surveys in reef and non-reef habitats (e.g., sandy lagoons) are critical to understand the current status and future viability of sea cucumber populations throughout the CSMP.

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.

5.3 Recommendations

Regular comprehensive monitoring of coral reef environments in the CSMP is essential to understand its structure, function, ecological significance, and changing health and condition, especially in light of the increasing incidence of marine heat waves. Annual monitoring of CSMP reefs since 2018 has greatly improved our understanding of the unique nature of these reefs, providing a contemporary baseline for future research and monitoring, and importantly has identified drivers of change (i.e., major bleaching events), as well as unexpected changes (e.g., declines in grazing fishes and sea cucumbers). 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) among reefs and regions within the CSMP will greatly improve our understanding of the vulnerability, recovery potential, and resilience of shallow coral reef environments in the CSMP to ongoing and future disturbances, as well as potential interactions among increasingly frequent and more intense heat stress events. Given the low coral cover and recorded declines in juvenile corals in 2025, continued monitoring of the density of juvenile corals together with assessments of coral settlement (i.e., using settlement tiles) will be critical to understand the potential replenishment and recovery of coral populations, as well as local stock-recruitment relationships for shallow water corals within the CSMP.

To effectively monitor the potential recovery of coral populations and communities, as well as any changes in the associated fish and invertebrate communities following major disturbances, we recommend annual (or biennial) monitoring of benthic (coral, macroalgae, CCA), fish, sea snakes and macro-invertebrate communities using the same methods and sites as previous (2018-25) surveys. More regular surveys (e.g., biannual) will be necessary to determine if the recor4ded increases in macroalgae in the central CSMP reflect an actual increase or seasonal variation. The consistency of survey method is critical to ensure any changes are due to changes in the ecological communities, rather than an artefact of any difference/s in the survey methods. In the absence of any major environmental disturbances the time between recurrent surveys of individual reefs could be extended to 2-5 years, however this appears unlikely given predicted increases intensity of disturbances affecting reefs globally (Hughes et al. 2018; Mellin et al. 2024), and the heat stress experienced in the CSMP over recent years. Given this increased incidence of disturbance, coupled with the logistical constraints of working in the CSMP (i.e., isolation and exposure), regular (i.e., annual or biennial) surveys of at least a subset of representative reefs are critical. We recommend a subset of 8-12 representative reefs should be surveyed each year, with all 22 CSMP reefs to be re-surveyed every 3-5 years. These representative reefs should prioritise the six 'bright spot' reefs (i.e., Ashmore, Boot, Bougainville, Cato, Moore and Mellish Reefs), as well as reefs that are adjacent to these 'bright spot' reefs and/or on-route between reefs to facilitate comparisons and maximise the available vessel time, as well as any reefs identified as important source reefs from ongoing projects of biological and physical connectivity (i.e., Saumarez and Marion Reefs). Consideration should also be given to parallel research and monitoring on islands within the CSMP, to optimise the use of available vessel time and berths. With these considerations in mind, we recommend the following 12 reefs be surveyed annually Cato, Kenn and Saumarez Reefs in the southern CSMP; Flinders, Holmes, Lihou, Marion and Mellish Reefs, and Herald Cays in the central CSMP, and Bougainville and Osprey Reefs in the northern CSMP. We do not include Ashmore and Boot Reefs here given their location in the far north of the CSMP, and hence the addition travel time and cost of accessing these reefs, however given their connection to peoples of the Meriam nation (the only reefs in the CSMP with direct links to first nations people) special consideration should be given to these reefs. Monitoring and research on Ashmore and Boot Reefs would provide an important opportunity to continue engagement and capacity building with first nations people of the Meriam nation.

Comparisons of National Park and Habitat Protection Zones (NPZ and HPZ) on Kenn and Marion Reefs provided preliminary evidence on the potential benefits of NPZ on reef fish biomass on Marion Reef (reef fish biomass was similar between NPZ and HPZ on Kenn Reef). However, these comparisons were based on 1-2 sites per management zone per reef, and as such they should be interpreted with caution. Additional surveys (and hence time) in each zone on Kenn and Marion Reefs and other reefs with multiple zones (i.e., Bougainville Reef), are essential to provide robust estimates and greater certainty of any effect of management zoning on coral reef communities. Given the reported declines in sea cucumbers and the large area of lagoonal and non-reef habitat within both Kenn and Marion Reefs, we recommend dedicated surveys of sea cucumber populations within these areas. A minimum of 3 days should be allocated to each of these reefs (weather and conditions permitting) to allow for surveys of additional reef sites and additional berths to allow for towed diver and/or towed video surveys of lagoonal habitats.

Several projects aimed at understanding potential variation in water temperatures, and the settlement and calcification rates of crustose coralline algae (CCA) between 'bright spot' and other reefs were initiated during the 2023/24 voyages and collected and redeployed during the 2025 voyages, and coral settlement tiles that were deployed on three CSMP reefs in October 2023 (Holmes, Bougainville and Osprey Reefs). These projects are aimed at better understanding key processes on CSMP and should be continued and expanded upon to include projects to quantify key demographic rates of corals and reef fish. Tourism operators (mainly Mike Ball Dive Expeditions) offer a cost-effective alternative for deploying and retrieving equipment from some of the western reefs in the CSMP (Osprey, Bougainville, Holmes and Flinders Reefs), and maintaining the current array of temperature loggers deployed in June and October 2025 across the broader southern and central CSMP voyages should be a priority.

Establishing fixed plots at a select number of sites and using high resolution photogrammetry to create 3-dimensional maps would allow the fate of individual coral colonies, and the topographic complexity of the habitat to be tracked through time. Repeating the 3-dimensional habitat mapping of sites mapped during the 2019-2020 voyages (i.e., prior to the 4 most recent bleaching events) in the next 1-2 years would provide some insight into relative contribution of live corals versus the underlying reef matrix and coralline algae in providing habitat structure. These existing 3-dimensional maps were not created for fixed plots and were not of sufficient resolution to quantify the growth of individual corals. We also recommend dedicated research and collections to quantifying demographic rates (growth, mortality) for fish and identifying key settlement and nursery habitats. Ideally this would include grazing fish species so that the likely mechanism/s for the observed declines in this group following the recent bleaching events could be identified.

The maintenance and replenishment of populations, and the resilience of reef systems within the CSMP is largely dependent on the supply of larvae, and hence the connectivity among and within reefs in the CSMP and adjacent regions (i.e., GBRMP, Temperate East Marine Parks Network, New Caledonia, Vanuatu, Solomon Islands and Papua New Guinea). Dedicated collections of animal tissues across these regions, and subsequent genetic analyses of these samples are required to understand patterns of connectivity, and how they differ among taxa. 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 macro-invertebrates of potential commercial value (i.e., sea cucumber, *Tridacna* clams). Several projects are currently investigating the potential connectivity of coral, reef fish, shark, macro-invertebrate, and bird populations across the Coral Sea region, and is the focus of an *Our Marine Parks Round 4 Grant*.

Finally, surveys conducted over the past 7 years have highlighted the importance and unique nature of shallow water reef communities of the CSMP. Comparable monitoring and research in all regions within and bordering the CSMP, including the GBRMP, Australia's Temperate East Marine Parks Network, New Caledonia, Solomon Islands and Papua New Guinea, is required to establish the biogeographical significance of the CSMP. Cross-jurisdictional meetings, workshops, and ultimately scientific expeditions would be invaluable to better understand biological and ecological connections among these regions.

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6 APPENDIX 1 – Sites surveyed

List of sites surveyed across twelve reefs in the Coral Sea Marine Park (CSMP) during June and October 2025. * indicates sites that were surveyed at least once during 2020-2024, and form the basis of the temporal comparisons. # indicates new sites that were surveyed for the first time in 2025.

Sector	Reef	Site	Exposure	Aspect	Lat	Long
Southern	Cato	Cato 1*	Sheltered	NW	-23.24763	155.53525
Southern	Cato	Cato 2*	Sheltered	NW	-23.24515	155.54097
Southern	Cato	Cato 3*	Sheltered	NW	-23.24406	155.54829
Southern	Frederick	Frederick 1*	Sheltered	NE	-21.01111	154.351
Southern	Frederick	Frederick 4*	Sheltered	W	-20.93838	154.39737
Southern	Kenn	Kenn 1*	Sheltered	NE	-21.2476	155.76616
Southern	Kenn	Kenn 2*	Sheltered	NE	-21.25323	155.76216
Southern	Kenn	Kenn 4*	Sheltered	W	-21.20459	155.77238
Southern	Saumarez	Saumarez 3*	Sheltered	NW	-21.9178	153.58452
Southern	Saumarez	Saumarez 5*	Sheltered	W	-21.75002	153.76973
Southern	Wreck	Wreck 1*	Sheltered	NW	-22.19267	155.33405
Southern	Wreck	Wreck 2*	Sheltered	W	-22.17814	155.17674
Southern	Wreck	Wreck 3*	Sheltered	NW	-22.18667	155.17049
Southern	Wreck	Wreck 5*	Exposed	N	-22.16641	155.4639
Central	Coringa	Coringa 1#	Sheltered	NW	-16.96981	149.90363
Central	Diamond	Diamond 1*	Semi-sheltered	NE	-17.44199	151.06255
Central	Diamond	Diamond 2*	Sheltered	N	-17.43684	151.06972
Central	Diamond	Diamond 9#	Semi sheltered	North	-17.6571	150.82336
Central	Herald	Herald 1*	Semi-exposed	N	-16.94348	149.18565
Central	Holmes	Holmes 1*	Sheltered	NW	-16.52613	147.80701
Central	Holmes	Holmes 2*	Semi-sheltered	W	-16.51181	147.84
Central	Holmes	Holmes 10*	Semi-exposed	NW	-16.52143	147.83772
Central	Lihou	Lihou 1*	Sheltered	NW	-17.59707	151.48956
Central	Lihou	Lihou 2*	Sheltered	N	-17.59065	151.50027
Central	Lihou	Lihou 4*	Semi-sheltered	N	-17.12527	151.82535
Central	Lihou	Lihou 5*	Semi-sheltered	N	-17.12113	151.82939
Central	Lihou	Lihou 7*	Exposed	SE	-17.41725	151.86607
Central	Lihou	Lihou 8#	Sheltered	N	-17.41009	151.88113
Central	Marion	Marion 5#	Exposed	SW	-18.98541	152.34488
Central	Marion	Marion 7*	Sheltered	N	-19.29511	152.23782
Central	Marion	Marion 9*	Lagoon	NE	-19.23144	152.17848
Central	Marion	Marion 10*	Semi-sheltered	NW	-19.00823	152.37038
Central	Willis	Willis 2*	Sheltered	W	-16.28728	149.9593
Central	Willis	Willis 7*	Semi-sheltered	NW	-16.11697	149.97095

7 APPENDIX 2 – CCA devices and temperature loggers

List of Coral Sea Marine Park (CSMP) reefs and sites in which temperature loggers and crustose coralline algae (CCA) devices were collected and/or redeployed during the June and October 2025 voyages

Reef	Site	Temperature loggers		CCA devices		Date
		Collected	Replaced	Collected	Replaced	
Cato	Cato 1	Y	Y	Y	Y	13/10/2025
Kenn	Kenn 1	Y	Y	Y	Y	17/10/2025
Kenn	Kenn 4	Y	Y	Y	Y	17/10/2025
Saumarez	Saumarez 3	Y	Y	Y		21/10/2025
Saumarez	Saumarez 5	Y	Y	Y		21/10/2025
Wreck	Wreck 1	Y	Y	Y	Y	14/10/2025
Wreck	Wreck 3	Y	Y	Y	Y	16/10/2025
Diamond	Diamond 1	Y (17/02/2025)	Y	Y (17/02/2025)	Y	11/06/2025
Diamond	Diamond 2	Y (17/02/2025)	Y	Y (17/02/2025)	Y	11/06/2025
Flinders	Flinders 5	Y		Y	Y	14/02/2025
Flinders	Flinders 7	Y		Y	Y	15/02/2025
Holmes	Holmes 2	Y	Y			13/06/2025
Holmes	Holmes 5	Y (23/02/2025)		Y		23/02/2025
Holmes	Holmes 6	Y (23/02/2025)		Y		23/02/2025
Lihou	Lihou 1	Y	Y	Y	Y	08/06/2025
Lihou	Lihou 4	Y	Y	Y	Y	10/06/2025
Marion	Marion 7	Y	Y			20/10/2025
Marion	Marion 9	Y	Y			20/10/2025
Willis	Willis 2	Y	Y	Y	Y	07/06/2025

8 APPENDIX 3 – Fish species surveyed

List of fish species recorded from reefs in the southern, central and northern CSMP and the transect area in which they are surveyed.

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		

9 APPENDIX 4 – Fish species records

List of conspicuous (i.e., non-cryptic) fish species recorded and/or observed within each region of the CSMP during 2018-2025. A separate column is provided for cryptobenthic fish species that were identified during targeted collections using clove oil.

Count	Species	Southern	Central	Northern	Cryptobenthic
1	*Abudefduf sexfasciatus*	1		1	
2	*Abudefduf vaigiensis*	1	1	1	
3	*Acanthochromis polyacanthus*		1	1	1
4	*Acanthurus albipectoralis*	1	1	1	
5	*Acanthurus blochii*	1	1	1	
6	*Acanthurus dussumieri*	1	1	1	
7	*Acanthurus grammoptilus*		1		
8	*Acanthurus guttatus*	1	1	1	
9	*Acanthurus lineatus*	1	1	1	
10	*Acanthurus maculiceps*		1		
11	*Acanthurus mata*		1	1	
12	*Acanthurus nigricans*	1	1	1	
13	*Acanthurus nigricauda*	1	1	1	
14	*Acanthurus nigrofuscus*	1	1	1	1
15	*Acanthurus nigroris*	1	1	1	
16	*Acanthurus nubilis*		1		
17	*Acanthurus olivaceus*	1	1	1	
18	*Acanthurus pyroferus*	1	1	1	
19	*Acanthurus thompsoni*	1	1	1	
20	*Acanthurus triostegus*	1	1	1	
21	*Acanthurus xanthopterus*	1	1	1	
22	*Aethaloperca rogaa*			1	
23	*Aetobatus narinari*		1		
24	*Aetobatus ocellatus*	1			
25	*Aluteres scriptus*	1	1	1	
26	*Amanses scopas*	1		1	
27	*Amblycirrhitus bimacula*				1
28	*Amblyeleotris steinitzi*		1	1	
29	*Amblyglyphidodon aureus*	1	1	1	
30	*Amblyglyphidodon curacao*	1	1		
31	*Amblyglyphidodon leucogaster*	1	1	1	
32	*Amphiprion akindynos*	1	1		
33	*Amphiprion chrysopterus*		1	1	
34	*Amphiprion clarkii*	1		1	
35	*Amphiprion melanopus*	1	1	1	
36	*Amphiprion perideraion*		1	1	
37	*Anampses caeruleopunctatus*	1	1	1	
38	*Anampses femininus*	1	1		
39	*Anampses geographicus*		1	1	
40	*Anampses meleagrides*	1			
41	*Anampses neoguinaicus*	1	1	1	
42	*Anampses twistii*	1	1	1	
43	*Antennarius nummifer*				1
44	*Antennarius pictus*				1
45	*Anyperodon leucogrammicus*			1	
46	*Aphareus furca*	1	1	1	
47	*Apogon crassiceps*				1
48	*Apogon doederleini*			1	
49	*Apogon doryssa*				1
50	*Apogon seminigricaudus*				1
51	*apogonid sp.*				1
52	*Apolemichthys trimaculatus*			1	

53	*Aprion virescens*	1	1	1	
54	*Arothron hispidus*	1			
55	*Arothron nigropunctatus*	1	1	1	
56	*Arothron stellatus*	1	1		
57	*Aseraggodes sp.*				1
58	*Assessor flavissimus*			1	
59	*Asterropteryx semipunctata*				1
60	*Aulostomus chinensis*	1	1	1	
61	*Balenoperca chabanaudi*		1	1	
62	*Balistapus undulatus*	1	1	1	
63	*Balistoides conspicillum*	1	1	1	
64	*Balistoides viridescens*	1	1	1	
65	*Belonoperca chabanaudi*			1	
66	*Bodianus anthioides*		1	1	
67	*Bodianus axillaris*	1	1	1	
68	*Bodianus dictynna*		1	1	
69	*Bodianus loxozonus*		1	1	
70	*Bodianus mesothorax*	1	1	1	
71	*Bodianus perditio*	1			
72	*Bolbometopon muricatum*		1	1	
73	*Brachaluteres prionurus*		1		
74	*Brosmophyciops pautzkei*				1
75	*Bryaninops sp.*				1
76	*bythitid sp.*				1
77	*Cabillus tongarevae*				1
78	*Caesio caerulaurea*			1	
79	*Caesio cuning*		1		
80	*Caesio lunaris*		1	1	
81	*Caesio teres*		1	1	
82	*Callogobius sclateri*				1
83	*Calotomus carolinus*	1	1	1	
84	*Cantherhines dumerilii*	1	1		
85	*Cantherhines pardalis**		1		
86	*Canthigaster amboinensis*	1	1		
87	*Canthigaster axiologus*	1			
88	*Canthigaster bennetti*	1	1		
89	*Canthigaster janthinoptera*		1		
90	*Canthigaster papua*		1		1
91	*Canthigaster valentini*	1	1	1	1
92	*Caracanthus maculatus*	1	1	1	1
93	*Caracanthus unipinna*				1
94	*Carangoides ferdau*		1	1	
95	*Carangoides fulvoguttatus*			1	
96	*Carangoides orthogrammus*	1	1	1	
97	*Carangoides plagiotaenia*			1	
98	*Caranx ignobilis*	1	1	1	
99	*Caranx lugubris*		1	1	
100	*Caranx melampygus*	1	1	1	
101	*Caranx papuensis*		1		
102	*Caranx sexfasciatus*	1	1	1	
103	*Caranx sp.*			1	
104	*Carcharhinus albimarginatus*	1	1	1	
105	*Carcharhinus amblyrhynchos*	1	1	1	
106	*Celotomus carolinus*	1			
107	*Centropyge bicolor*	1	1	1	
108	*Centropyge bispinosa*	1	1	1	1
109	*Centropyge fisheri*		1		
110	*Centropyge flavissima*	1	1	1	
111	*Centropyge heraldi*	1	1	1	1
112	*Centropyge hybrid 'smokey'*	1	1		1
113	*Centropyge loricula*	1	1	1	

114	*Centropyge tibicen*	1			1
115	*Centropyge vrolikii*	1	1	1	
116	*Centropyge woodheadi*	1			
117	*Cephalopholis argus*	1	1	1	
118	*Cephalopholis leopardus*		1	1	1
119	*Cephalopholis miniata*		1	1	
120	*Cephalopholis spiloparaea*		3		
121	*Cephalopholis urodeta*	1	1	1	1
122	*Cercamia eremia*				1
123	*Cetoscarus ocellatus*	1	1	1	1
124	*Chaetodon auriga*	1	1	1	
125	*Chaetodon baronessa*			1	
126	*Chaetodon bennetti*	1		1	
127	*Chaetodon citrinellus*	1	1	1	
128	*Chaetodon ephippium*	1	1	1	
129	*Chaetodon flavirostris*	1	1	1	
130	*Chaetodon kleinii*	1	1	1	
131	*Chaetodon lineolatus*	1	1	1	
132	*Chaetodon lunula*	1	1	1	
133	*Chaetodon lunulatus*	1	1	1	
134	*Chaetodon melannotus*	1	1	1	
135	*Chaetodon mertensii*	1	1	1	
136	*Chaetodon meyeri*		3	1	
137	*Chaetodon ocellicaudus*	1			
138	*Chaetodon ornatissimus*	1	1	1	
139	*Chaetodon oxycephalus*			1	
140	*Chaetodon pelewensis*	1	1	1	
141	*Chaetodon plebeius*	1	1	1	
142	*Chaetodon punctatofasciatus*			1	
143	*Chaetodon rafflesi*		1		
144	*Chaetodon reticulatus*	1	1	1	
145	*Chaetodon semeion*		1	1	
146	*Chaetodon speculum*	1	1	1	
147	*Chaetodon trifascialis*	1	1	1	
148	*Chaetodon ulietensis*	1	1	1	
149	*Chaetodon unimaculatus*	1	1	1	
150	*Chaetodon vagabundus*	1	1	1	
151	*Chanos chanos*			1	
152	*Cheilinus chlorourus*	1	1	1	
153	*Cheilinus fasciatus*		1	1	
154	*Cheilinus oxycephalus*	1	1	1	
155	*Cheilinus trilobatus*	1	1	1	
156	*Cheilinus undulatus*	1	1	1	
157	*Cheilodipterus macrodon*		1		
158	*Chlorurus bleekeri*			1	
159	*Chlorurus frontalis*	1	1		
160	*Chlorurus japanensis*	1		1	
161	*Chlorurus microrhinos*	1	1	1	
162	*Chlorurus spilurus*	1	1	1	
163	*Choerodon fasciatus*		1		
164	*Chromis agilis*	1	1	1	
165	*Chromis alpha*		1		
166	*Chromis amboinensis*	1	1	1	
167	*Chromis atripectoralis*	1	1	1	
168	*Chromis atripes*	1	1	1	
169	*Chromis chrysura*	1	1	1	
170	*Chromis flavomaculata*	1			
171	*Chromis fumea*		1		
172	*Chromis iomelas*	1	1	1	1
173	*Chromis lepidolepis*	1	1	1	
174	*Chromis margaritifer*	1	1	1	1

175	*Chromis retrofasciata*	1	1	1	
176	*Chromis richardsoni**	1			
177	*Chromis ternatensis*	1	1	1	
178	*Chromis vanderbilti*	1	1	1	1
179	*Chromis viridis*	1	1		
180	*Chromis weberi*		1	1	
181	*Chromis xanthochira*	1	1		
182	*Chromis xanthura*	1	1	1	
183	*Chrysiptera biocellata*	1	1	1	
184	*Chrysiptera brownriggii*		1	1	
185	*Chrysiptera flavipinnis*		1		
186	*Chrysiptera glauca*	1			
187	*Chrysiptera rollandi*		1		1
188	*Chrysiptera talboti*			1	
189	*Chrysiptera taupou*	1	1	1	1
190	*Cirrhilabrus exquisitus*	1	1	1	
191	*Cirrhilabrus laboutei*	1	1		1
192	*Cirrhilabrus lineatus*		1		
193	*Cirrhilabrus punctatus*	1	1	1	1
194	*Cirrhilabrus scottorum*	1	1	1	
195	*Cirrhilabrus sp.**	1			
196	*Cirrhitichthys falco*	1	1		1
197	*Cirrhitichthys oxycephalus*			1	
198	*Cirrhitus pinnulatus*	1			
199	*Cirripectes castaneus*		1	1	1
200	*Cirripectes filamentosus*				1
201	*Cirripectes stigmaticus*	1	1		1
202	*Coris aygula*	1	1	1	
203	*Coris batuensis*			1	1
204	*Coris dorsomacula*	1	1		
205	*Coris gaimard*	1	1	1	
206	*Cosmocampus banneri*				1
207	*Crossosalarias macrospilus*				1
208	*Ctenochaetus binotatus*	1	1	1	
209	*Ctenochaetus cyanocheilus*	1	1	1	
210	*Ctenochaetus striatus*	1	1	1	
211	*Ctenogobiops pomastictus*				1
212	*Cypho purpurascens*	1	1	1	1
213	*Dascyllus aruanus*	1			
214	*Dascyllus reticulatus*	1	1	1	1
215	*Dascyllus trimaculatus*	1	1	1	
216	*Dasyatis kuhlii*		1		
217	*Decapterus macarellus*		1		
218	*Dinematichthys ilucoetiodes*				1
219	*Dinematichthys sp.?*				1
220	*Diodon hystrix*		1		
221	*Diplogrammus goramensis*				1
222	*Dischistodus melanotus*	1			
223	*Dischistodus prosopotaenia*			1	
224	*Dischistodus pseudochrysopoecilus*	1			
225	*Doryrhamphus melanopleura*				1
226	*Doryrhamphus sp.*				1
227	*Echeneis naucrates*	1	1	1	
228	*Echidna polyzona*				1
229	*Ecsenius bicolor*			1	
230	*Ecsenius fourmanoiri*	1			
231	*Ecsenius stictus*				1
232	*Ecsenius tigris*				1
233	*Elegatis bipinnulata*		1	1	
234	*Encheliophis homei?*				1

235	*Enneapterygius atrogulare?*				1
236	*Enneapterygius flavoccipitis*				1
237	*Enneapterygius sp.*				1
238	*Enneapterygius sp. 1*				1
239	*Enneapterygius sp. 1*				1
240	*Enneapterygius tutuilae*				1
241	*Epibulus insidiator*	1	1	1	
242	*Epinephelus coioides*		1		
243	*Epinephelus cyanopodus*	1			
244	*Epinephelus fasciatus*	1		1	
245	*Epinephelus fuscoguttatus*			1	
246	*Epinephelus hexagonatus*	1	1	1	
247	*Epinephelus howlandensis*	1			
248	*Epinephelus lanceolatus*		1		
249	*Epinephelus merra*	1	1	1	
250	*Epinephelus polyphekadion*	1	1	1	
251	*Epinephelus quoyanus*		1		
252	*Epinephelus spilotoceps**				
253	*Epinephelus tauvina*		1		
254	*Epinephelus tukula*			1	
255	*Euthynnus affinis*	1			
256	*Eviota afelei*				1
257	*Eviota ancora*				1
258	*Eviota atriventris*				1
259	*Eviota cf. teresae*				1
260	*Eviota cometa*				1
261	*Eviota distigma*				1
262	*Eviota fallax*				1
263	*Eviota fasciola*				1
264	*Eviota flebilis*				1
265	*Eviota guttata*		1		
266	*Eviota herrei*				1
267	*Eviota infulata*				1
268	*Eviota latifasciata*				1
269	*Eviota melanosphena*				1
270	*Eviota melasma*				1
271	*Eviota monostigma*				1
272	*Eviota nebulosa*				1
273	*Eviota occasa*				1
274	*Eviota prasites*	1			1
275	*Eviota punctulata*				1
276	*Eviota queenslandica*				1
277	*Eviota readeri*				1
278	*Eviota sigillata*				1
279	*Eviota singula*				1
280	*Eviota sp.*				1
281	*Eviota sp. 1*				1
282	*Eviota sp. 1a*				1
283	*Eviota sp. 1b*				1
284	*Eviota sp. 3*				1
285	*Eviota sp. 4*				1
286	*Eviota sp. 5*				1
287	*Eviota sparsa*				1
288	*Eviota specca*				1
289	*Eviota variola*				1
290	*Eviota zebrina*				1
291	*Exallias brevis*	1	1		
292	*Fistularia commersonii*	1	1	1	
293	*Forcipiger flavissimus*	1	1	1	
294	*Forcipiger longirostris*	1	1	1	
295	*Fowleria aurita*				1

296	*Fowleria vaiulae*				1
297	*Fusigobius gracilis*				1
298	*Fusigobius humeralis*				1
299	*Fusigobius neophytus*				1
300	*Fusigobius sp.*				1
301	*Galeocerdo cuvier*	1	1		
302	*Genicanthus melanospilos*		1	1	
303	*Genicanthus watanabei*		1		
304	*Glyptoparus delicatulus*				1
305	*Gnathanodon speciosus*	1			
306	*Gnathodentex aureolineatus*	1	1	1	
307	*Gnatholepis cauerensis*		1		1
308	*Gnatholepis sp.*				1
309	*gobiid sp.*				1
310	*Gobiodon prolixus*				1
311	*Gobiodon quinquestrigatus*				1
312	*Gobiodon rivulatus*				1
313	*Gomphosus varius*	1	1	1	
314	*Gracila albomarginata*			1	
315	*Grammistes sexlineatus*		1	1	
316	*Gymnapogon philippinus*				1
317	*Gymnapogon sp.*				1
318	*Gymnocranius euanus*	1	1		
319	*Gymnocranius grandoculis*			1	
320	*Gymnocranius microdon*	1	1		
321	*Gymnosarda unicolor*	1	1	1	
322	*Gymnothorax favagineus*		1		
323	*Gymnothorax flavimarginatus*				1
324	*Gymnothorax fuscomaculatus*				1
325	*Gymnothorax gracilicauda*				1
326	*Gymnothorax javanicus*	1	1	1	
327	*Gymnothorax meleagris*	1			
328	*Gymnothorax sp.*				1
329	*Gymnothorax zonipectis*				1
330	*Halicampus dunckeri*				1
331	*Halichoeres biocellatus*	1	1	1	1
332	*Halichoeres chrysus*			1	
333	*Halichoeres hortulanus*	1	1	1	
334	*Halichoeres margaritaceus*	1	1	1	
335	*Halichoeres marginatus*	1	1	1	
336	*Halichoeres melanurus*			1	1
337	*Halichoeres nebulosus*	1			
338	*Halichoeres ornatissimus*	1	1	1	
339	*Halichoeres prosopeion*		1	1	
340	*Halichoeres trimaculatus*	1	1	1	1
341	*Helcogramma sp.*				1
342	*Helcogramma striatum*				1
343	*Hemiglyphidodon plagiometopon*			1	
344	*Hemigymnus fasciatus*	1	1	1	
345	*Hemitaurichthys polylepis*	1	1	1	
346	*Heniochus acuminatus*		1	1	
347	*Heniochus chrysostomus*	1	1	1	
348	*Heniochus monoceros*	1	1	1	
349	*Heniochus singularis*		1	1	
350	*Heniochus varius*	1	1	1	
351	*Heteropriacanthus carolinus*				1
352	*Heteropriacanthus cruentatus*			1	
353	*Himantura fai*		1		
354	*Hipposcarus longiceps*	1	1	1	
355	*Hologymnosus annulatus*	1	1	1	
356	*Hologymnosus doliatus*	1	1		

357	*Hoplolatilus starcki*			1	
358	*Iniistius pavo*	1			
359	*Kaupichthys brachychirus*				1
360	*Kyphosus bigibbus*	1			
361	*Kyphosus cinerascens*	1	1	1	
362	*Kyphosus vaigiensis*	1	1	1	
363	*Labrichthys unilineatus*			1	1
364	*labrid sp.*				1
365	*Labroides bicolor*	1	1	1	
366	*Labroides dimidiatus*	1	1	1	1
367	*Labroides pectoralis*	1		1	
368	*Labropsis australis*	1	1	1	
369	*Labropsis xanthonota*		1	1	
370	*Lepadichthys frenatus*				1
371	*Lepadichthys sp.*				1
372	*Lepidozygus tapeinosoma*		1	1	
373	*Lethrinus atkinsoni*		1		
374	*Lethrinus erythracanthus*		1	1	
375	*Lethrinus nebulosus*	1	1	1	
376	*Lethrinus olivaceus*	1	1	1	
377	*Lethrinus sp. 1*		1		
378	*Lethrinus xanthocheilus*	1	1	1	
379	*Limnichthys fasciatus*				1
380	*Liopropoma susumi*	1			1
381	*Luposicya lupus*				1
382	*Lutjanus argentimaculatus*			1	
383	*Lutjanus biguttatus**				
384	*Lutjanus bohar*	1	1	1	
385	*Lutjanus fulvus*		1	1	
386	*Lutjanus gibbus*	1	1	1	
387	*Lutjanus kasmira*	1	1	1	
388	*Lutjanus monostigma*		1	1	
389	*Lutjanus rivulatus*	1	1	1	
390	*Lutjanus semicinctus*			1	
391	*Luzonichthys sp*			1	
392	*Luzonichthys waitei*			1	
393	*Macolor macularis*	1	1	1	
394	*Macolor niger*	1	1	1	
395	*Macropharyngodon choati*		1		
396	*Macropharyngodon kuiteri*		1		
397	*Macropharyngodon meleagris*	1	1	1	
398	*Macropharyngodon negrosensis*	1	1		
399	*Malacanthus latovittatus*	1	1	1	
400	*Meiacanthus atrodorsalis*		1	1	1
401	*Melichthys vidua*	1	1	1	
402	*Monotaxis grandoculis*	1	1	1	
403	*Monotaxis heterodon*	1	1	1	
404	*Mulloidichthys flavolineatus*	1	1		
405	*Mulloidichthys vanicolensis*	1	1	1	
406	*Myripristis adusta*			1	
407	*Myripristis kuntee*	1	1	1	
408	*Myripristis murdjan*		1		
409	*Myripristis vittata*		1		
410	*Naso annulatus*	1	1	1	
411	*Naso brachycentron*		1	1	
412	*Naso brevirostris*	1	1	1	
413	*Naso caesius*	1	1	1	
414	*Naso hexacanthus*	1	1	1	
415	*Naso lituratus*	1	1	1	
416	*Naso lopezi*	1			
417	*Naso minor*	1			

418	*Naso tonganus*	1	1	1	
419	*Naso thynnoides**	1			
420	*Naso unicornis*	1	1	1	
421	*Naso vlamingii*	1	1	1	
422	*Neamia octospina*				1
423	*Nebrius ferrugineus*	1	1	1	
424	*Nemateleotris magnifica*	1		1	1
425	*Neocirrhites armatus*	1	1	1	1
426	*Neoglyphidodon nigroris*			1	
427	*Neoniphon sammara*	1	1	1	
428	*Neopomacentrus azysron*			1	
429	*Neopomacentrus cf cyanomos*		1		
430	*Neosynchiropus morrisoni*				1
431	*Neotrygon kuhlii*	1	1		
432	*Norfolkia thomasi*				1
433	*Novaculichthys taeniourus*	1	1		1
434	*Odonus niger*		1		
435	*Ogilbyina queenslandiae*				1
436	*Opistognathus seminudus*				1
437	*Opistognathus stigmosus*				1
438	*Ostorhinchus cyanosoma*				1
439	*Ostracion cubicus*	1	1		
440	*Ostracion meleagris*		1	1	
441	*Oxycheilinus digramma*	1	1	1	
442	*Oxycheilinus orientalis*	1	1	1	1
443	*Oxycheilinus unifasciatus*	1	1	1	
444	*Oxymonacanthus longirostris*	1	1	1	
445	*Paracaesio sordida*			1	
446	*Paracanthurus hepatus*	1	1	1	
447	*Paracentropyge multifasciatus*		1	1	
448	*Paracirrhites arcatus*	1	1	1	1
449	*Paracirrhites forsteri*	1	1	1	
450	*Paracirrhites hemistictus*	1	1		
451	*Paragobiodon echinocephalus*				1
452	*Paragobiodon lacunicolus*				1
453	*Paragobiodon xanthosoma*				1
454	*Parapercis clathrata*				1
455	*Parupeneus barberinoides*		1		
456	*Parupeneus barberinus*	1	1	1	
457	*Parupeneus ciliatus*	1	1	1	
458	*Parupeneus crassilabris*	1	1	1	
459	*Parupeneus cyclostomus*	1	1	1	
460	*Parupeneus multifasciatus*	1	1	1	
461	*Parupeneus pleurostigma*	1	1	1	
462	*Parupeneus spilurus*		1		
463	*Pempheris oualensis*	1			
464	*Pentapodus aureofasciatus*				
465	*Pervagor alternans*	1	1		
466	*Pervagor janthinosoma*	1	1		1
467	*Plagiotremus rhinorhynchos*		1	1	
468	*Plagiotremus tapeinosoma*		1	1	
469	*Platax batavianus*		1		
470	*Platax pinnatus*		1		
471	*Platax teira*		1		
472	*platycephalid sp.*				1
473	*Plectorhinchus albovittatus*		1	1	
474	*Plectorhinchus chaetodonoides*	1	1	1	
475	*Plectorhinchus lessonii*		1	1	
476	*Plectorhinchus lineatus*		1	1	
477	*Plectorhinchus picus*	1	1		
478	*Plectranthias nanus*				1

479	*Plectroglyphidodon dickii*	1	1	1	
480	*Plectroglyphidodon imparipennis*	1	1	1	
481	*Plectroglyphidodon johnstonianus*	1	1	1	
482	*Plectroglyphidodon lacrymatus*	1	1	1	1
483	*Plectroglyphidodon leucozonus*			1	
484	*Plectroglyphidodon phoenixensis*	1	1		
485	*Plectropomus areolatus*		1	1	
486	*Plectropomus laevis*	1	1	1	
487	*Plectropomus leopardus*	1	1	1	
488	*Plectropomus oligacanthus*			1	
489	*Plectrypops lima*				1
490	*Plesiops caeruleolineatus*				1
491	*Pleurosicya mossambica*				1
492	*Plotosus lineatus*	1	1	1	1
493	*Pomacanthus imperator*	1	1	1	
494	*Pomacanthus sexstriatus*			1	
495	*Pomacentrus amboinensis*			1	1
496	*Pomacentrus auriventris*			1	
497	*Pomacentrus bankanensis*	1	1	1	
498	*Pomacentrus brachialis*	1		1	1
499	*Pomacentrus chrysurus*		1	1	
500	*Pomacentrus coelestis*	1	1	1	
501	*Pomacentrus imitator*	1	1	1	
502	*Pomacentrus lepidogenys*	1	1	1	
503	*Pomacentrus moluccensis*	1	1	1	
504	*Pomacentrus nagasakiensis*		1	1	1
505	*Pomacentrus pavo*			1	
506	*Pomacentrus philippinus*	1		1	1
507	*Pomacentrus vaiuli*	1	1	1	1
508	*Pomacentrus wardi*	1			
509	*Pomachromis richardsoni*	1	1	1	
510	*Priacanthus blochii*		1		
511	*Priacanthus hamrur*		1		
512	*Priolepis cincta*				1
513	*Priolepis compita*				1
514	*Priolepis inhaca*				1
515	*Priolepis kappa*				1
516	*Priolepis pallidicincta*				1
517	*Priolepis psygmophila*				1
518	*Priolepis sp.*				1
519	*Prionurus maculatus*	1			
520	*Pristiapogon exostigma*				1
521	*Prteragogus sp.*	1			
522	*Pseudanthias cooperi*		1		
523	*Pseudanthias pascalus*	1	1	1	
524	*Pseudanthias pleurotaenia*		1	1	
525	*Pseudanthias squamipinnis*	1	1	1	
526	*Pseudanthias tuka*	1	1	1	
527	*Pseudobalistes flavimarginatus*		1	1	
528	*Pseudobalistes fuscus*	1	1	1	
529	*Pseudocheilinus evanidus*	1	1	1	1
530	*Pseudocheilinus hexataenia*	1	1	1	1
531	*Pseudocheilinus octotaenia*		1		
532	*Pseudochromis sp.*				1
533	*Pseudochromis tapeinosoma*				1
534	*Pseudocoris yamashiroi*			1	
535	*Pseudodax moluccanus*	1	1	1	
536	*Pseudogramma polyacanthus*				1
537	*Pseudojuloides cerasinus*		1		
538	*Pseudoplesiops annae*				1
539	*Pseudoplesiops sp.*				1

540	*Pseudoplesiops wassi*				1
541	*Pteragogus cryptus*	1	1		1
542	*Pteragogus sp.*	1	1		
543	*Ptereleotris evides*	1	1	1	
544	*Ptereleotris zebra*		1	1	
545	*Pterocaesio digramma*	1	1		
546	*Pterocaesio marri*		1	1	
547	*Pterocaesio tile*	1	1	1	
548	*Pterocaesio trilineata*	1	1	1	
549	*Pterois volitans*	1		1	1
550	*Pygoplites diacanthus*	1	1	1	1
551	*Pycnochromis lineatus**	1			
552	*Rhinecanthus aculeatus*			1	
553	*Rhinecanthus rectangulus*	1	1	1	
554	*Sargocentron caudimaculatum*		1		
555	*Sargocentron ittodai*				1
556	*Sargocentron spiniferum*	1	1	1	
557	*Saurida gracilis*	1			
558	*Scarini sp.*				1
559	*Scarus altipinnis*	1	1	1	
560	*Scarus chameleon*	1	1	1	
561	*Scarus dimidiatus*		1	1	
562	*Scarus festivus**	1			
563	*Scarus forsteni*	1	1	1	
564	*Scarus frenatus*	1	1	1	
565	*Scarus ghobban*			1	
566	*Scarus globiceps*	1	1	1	
567	*Scarus longipinnis*	1	1	1	
568	*Scarus niger*	1	1	1	
569	*Scarus oviceps*	1	1	1	
570	*Scarus psittacus*	1	1	1	
571	*Scarus rubroviolaceus*	1	1	1	
572	*Scarus schlegeli*	1	1	1	
573	*Scarus spinus*	1	1	1	
574	*Scarus viridifucatus*			1	
575	*Scarus xanthopleura*	1	1	1	
576	*Scolopsis bilineata*	1		1	
577	*Scomberoides commersonianus*		1		
578	*Scomberoides lysan*		1	1	
579	*Scomberoides sp*			1	
580	*Scomberomorus commerson*			1	
581	*scorpaenid sp.*				1
582	*Scorpaenodes corallinus*				1
583	*Scorpaenodes guamensis*				1
584	*Scorpaenopsis macrochir*				1
585	*Scorpaenopsis sp.*				1
586	*Sebastapistes corallinus*				1
587	*Sebastapistes cyanostigma*				1
588	*Sebastapistes cyanostigma*			1	
589	*Serranocirrhites latus*	1	1	1	
590	*Siganus argenteus*	1	1	1	
591	*Siganus corallinus*	1	1		
592	*Siganus doliatus*				
593	*Siganus puellus*	1			
594	*Siganus punctatissimus*		1		
595	*Siganus punctatus*	1	1	1	
596	*Siganus vulpinus*	1	1	1	
597	*Siganus woodlandi*	1	1		
598	*Siphamia tubifer*				1
599	*Sphyraena barracuda*	1	1	1	
600	*Sphyraena forsteri*		1		

601	*Sphyraena qenie**				
602	*Stegastes fasciolatus*	1	1	1	
603	*Stegastes gascoynei*	1			
604	*Stegastes nigricans*	1	1	1	1
605	*Stegostoma fasciatum*	1	1		
606	*Stethojulis bandanensis*	1	1	1	1
607	*Stethojulis interrupta*	1			
608	*Stethojulis strigiventer*	1	1	1	
609	*Sufflamen bursa*	1	1	1	
610	*Sufflamen chrysopterum*	1	1	1	
611	*Suttonia lineata*				1
612	*Synodus binotatus*				1
613	*Synodus dermatogenys*				1
614	*Synodus variegatus*	1	1	1	
615	*Synodus varigatus*				1
616	*Taeniura lymma*		1		
617	*Taeniura meyeni*	1	1		
618	*Thalassoma amblycephalum*	1	1	1	1
619	*Thalassoma hardwicke*	1	1	1	
620	*Thalassoma lunare*	1	1	1	
621	*Thalassoma lutescens*	1	1	1	1
622	*Thalassoma nigrofasciatum*	1	1	1	
623	*Thalassoma purpureum*	1	1	1	
624	*Thalassoma quinquevittatum*	1	1	1	
625	*Thalassoma trilobatum*		1	1	
626	*Thysanophrys celebicus*				1
627	*Trachinotus baillonii*			1	
628	*Trachinotus blochii*			1	
629	*Triaenodon obesus*	1	1	1	
630	*Trimma caesiura*				1
631	*Trimma emeryi*				1
632	*Trimma lantana*				1
633	*Trimma macrophthalma*				1
634	*Trimma maiandros*				1
635	*Trimma milta*				1
636	*Trimma necopinna*				1
637	*Trimma okinawae*				1
638	*Trimma sp.*				1
639	*Trimmatom eviotops*				1
640	*Trimmatom macropodus*				1
641	*Trimmatom nanus*				1
642	*Trimmatom sp.*				1
643	*Ucla xenogrammus*				1
644	*Valenciennea strigata*		1	1	
645	*Variola albimarginata*		1	1	
646	*Variola louti*	1	1	1	
647	*Xenisthmus eirospilus*				1
648	*Zanclus cornutus*	1	1	1	
649	*Zebrasoma scopas*	1	1	1	
650	*Zebrasoma velifer*	1	1	1	
Total		**325**	**385**	**355**	**213**