CORAL SEA MARINE PARK CORAL REEF HEALTH SURVEY 2023-24

Report on reef surveys
February - March 2023
February - March 2024

PRODUCED FOR PARKS AUSTRALIA, MAY 2024
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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 variety of coral growth forms compete for space on the reef slope of Mellish Reef, Central Coral Sea Marine Park, 24th February 2024. Photograph taken by Victor Huertas

Suggested citation: Hoey AS, Burn D, Chandler JF, Huertas V, Cresswell B, Galbraith G, Martin C, Barnett A, Faul S, Marzonie M, McClure EC (2024) Coral Sea Marine Park Coral Reef Health Survey 2023-24. 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.

Eight members of the Meriam people joined our team during surveys of Ashmore and Boot Reefs during Feb-Mar 2023. Taiku Wailu can be seen here observing Josie Chandler (JCU) surveying coral assemblages on Ashmore Reef.
Image credit: Victor Huertas

Acknowledgements

This *Coral Sea Marine Park Coral Reef Health Survey 2023-24* 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, Eva McClure, Deborah Burn, Josie Chandler, Victor Huertas, Cecilia Martin, Ben Cresswell and Gemma Galbraith, with assistance from Adam Barnett, Sasha Faul and Magena Marzonie. The report was prepared by Andrew Hoey, Eva McClure, Gemma Galbraith, Cecilia Martin and Victor Huertas with contributions by Deborah Burn, Josie Chandler, Ben Cresswell, Adam Barnett, Sasha Faul and Magena Marzonie. 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 Natalie Bool (Marine Parks Officer, South-East Network), Martin Russell (Manager, Coral Sea Marine Park), Mitchell Baskys (Senior Marine Parks Officer, Coral Sea Marine Park), and Russell Gueho (Director, East Region). We also thank Natalie Bool her assistance during the 2023 voyage, and Martin Russel for his assistance during the 2023 and 2024 voyages.

Additional funding was provided through an Our Marine Parks Round Three Grant from the Department of Climate Change, Energy, the Environment and Water to support the surveys of Ashmore and Boot Reefs, and engagement with the Meriam people (Ref No 4-HAY3RAP, *The Jewel in the Coral Sea: the cultural and ecological significance of Ashmore and Boot Reefs)*

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 Rob Benn (owner/skipper), Anita Benn, and the entire crew and staff of MV Iron Joy for enabling this work, despite sometimes trying weather conditions. We also thank Mike Ball Dive Expeditions, in particular Craig Stephen (Managing Director), for their support and provision of a berth to deploy and collect coral settlement tiles on Osprey, Bougainville and Holmes Reefs, and Rodrigo Goyret for his invaluable assistance in the field.

1 Key Points

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 18 reefs within the Coral Sea Marine Park across 2023 and 2024.

Key findings of the 2023/24 surveys were:

- Total shallow water coral cover decreased from 17.3% in 2022 to 14.0% in 2023/24 across the 13 reefs that were surveyed in both years, a mean decline of 18.7%. The change in coral cover varied among regions ranging from 39.7% and 23.8% declines in the southern and central CSMP, respectively, to an 8.9% increase in the northern CSMP.
- The declines in coral cover in the southern and central CSMP were likely attributable to elevated temperatures experienced in March-April 2022.
- The reduction in coral cover from 2022 to 2023/24 (18.7% decline) while lower or comparable to declines recorded following the two previous bleaching events (2020: 39% decline; 2021: 18% decline), occurred against an increasingly shifted baseline of coral communities, with the cover of bleaching-susceptible coral taxa being severely reduced following the 2016, 2017, 2020, and 2021 bleaching events in the CSMP. Collectively, the three most recent bleaching events (2020, 2021, 2022) have led to a 51% decline in shallow water coral cover CSMP reefs, ranging from a 30% decline in coral cover on northern CSMP reefs, to 50% and 59% declines on southern and central CSMP reefs, respectively.
- While low levels of bleaching (<2% of colonies surveyed) were recorded across CSMP reefs during the 2023 surveys, low to moderate levels of bleaching were recorded on reefs in the southern and central CSMP during the 2024 voyage (18.6% of coral colonies were pale or bleached). Importantly, the 2024 marine heatwave in the CSMP was still building at the time of our surveys and did not reach its peak until late March where large areas of the CSMP were exposed to >12 Degree Heating Weeks (DHW) and up to 17 DHW; heat stress >8DHW is expected to lead to substantial bleaching and mortality of corals.
- Six reefs in had very low (< 10%) coral cover (southern CSMP: Frederick Reef: 4%; central CSMP: Marion Reef: 5.9%; Lihou Reef: 6.0%; Diamond Islet: 7.0%; Heralds Cays: 7.5%; Willis Islets: 8.9). Such low coral cover has been shown to disrupt key processes and have lasting consequences for the diversity and functioning of other reef systems.
- The biomass of reef fishes (a key indicator of reef health) declined by 9% and 21% in the northern and central CSMP, respectively, from 2022 to 2023/24, and was primarily related to declines in grazing fishes. Grazing fishes are widely viewed as key functional group on coral reefs because of their capacity to remove algal biomass and prevent algal overgrowth following disturbance.

- Ashmore, Boot, Bougainville, Mellish and Moore Reefs, previously identified as ‘bright spots’ in terms of coral cover, richness and/or fish biomass, were again standouts and appear to have been less adversely affected by the recent bleaching events than other CSMP reefs.
- A sixth ‘bright spot’ reef was also identified, and the only ‘bright spot’ reef in the southern CSMP; Cato Reef with the second highest coral cover (34%) recorded across all CSMP reefs surveyed in 2023/24, more than double the regional average for the southern CSMP (16%).

Recommendations for future monitoring and research:

- Continued monitoring (annual or biennial) of reefs in the CSMP is critical, and should prioritise reefs and sites that have been repeatedly surveyed since 2020. Continued monitoring of these 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. In the absence of regular monitoring, the causes of any changes in reef communities would be largely unknown, severely limiting the capacity of managers to understand the health status of these reefs and make informed decisions.
- We recommend a subset of 8-10 representative reefs be monitored every 1-2 years, 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 the ‘bright spot’ reefs and/or on-route between reefs to facilitate comparisons and maximise the available vessel time.
- Additional means for accessing CSMP should be considered, including the provision of berths on the CSMP Island Health voyages (and vice-versa) and the use of berths on dive tourism vessels (e.g., Mike Ball Dive Expeditions).
- Increased focus on quantifying demographic rates of benthic (namely corals and crustose coralline algae; CCA) and fish taxa to better understand the replenishment and potential resilience of populations to environmental change. Temperature loggers and devices to quantify the settlement and calcification of CCA’s were deployed across 15 CSMP reefs during the 2023/24 voyages. The temperature loggers will have captured the water temperatures experienced at each site during the 2024 marine heatwave and this data will be invaluable in reconciling any differences in the response of coral communities to heat stress among sites and reefs. Retrieving the temperature loggers and CCA devices should be a priority for future work.
- Dedicated investigation into the diet, fitness, and demographics of grazing fishes on CSMP reefs is required to identify the likely mechanism/s for the observed declines in this group following the recent bleaching events.
- 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.

2 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. Previous surveys (2020-2022) of shallow reef habitats across the Coral Sea Marine Park (CSMP) documented widespread and severe bleaching of corals in 2020 and 2021. These back-to-back bleaching events led to a substantial (52%) decline in coral cover in shallow (<15m depth) reef habitats throughout the CSMP.

James Cook University was commissioned by Parks Australia to assess:

(i) the latest condition of benthic, fish and invertebrate communities within the CSMP;

(ii) any ongoing impacts of the back-to-back (2020 and 2021) bleaching events on benthic, fish and invertebrate communities; and

(iii) gain some understanding of the resilience and biodiversity of the CSMP 'bright spot' reefs.

The project undertook detailed surveys of coral, fish and macro-invertebrate communities and associated reef health at 11 CSMP reefs over a 31-day voyage in February-March 2023, and 7 CSMP reefs during a 19-day voyage in February-March 2024. Surveys were conducted to provide rigorous quantitative information on temporal (i.e., 2020, 2021, 2022 and 2023/24) and spatial (i.e., among reefs and regions) patterns in (i) cover and composition of corals and macroalgae; (ii) regional patterns of biodiversity; (iii) coral health, injury, and recruitment; and (iv) abundance and composition of reef fishes, sea snakes, and ecologically or economically important invertebrates. The project surveyed 78 sites across 18 reefs in the CSMP, spanning 13.3 degrees of latitude (~1,900 km) from Boot Reef in the northern CSMP (10.0ºS) to Cato Reef in the southern CSMP (23.3ºS).

The surveys revealed that average cover of hard (scleractinian) corals in shallow habitats across the 18 reefs in 2023 was 18.7% (±1.4 SE), ranging from 4.0% at Frederick Reef in the southern CSMP up to 35.2% at Ashmore Reef in the northern CSMP. There was, however, a marked difference in the temporal change (2022 to 2023/24) in coral cover among the southern, central and northern CSMP. Shallow water coral cover decreased by 16.6% across central CSMP reefs, and decreased by 35.6% across the three southern CSMP that were surveyed in 2022 and 2023/4 (i.e., Frederick, Kenn and Saumarez Reefs). In contrast, coral cover increased by 8.9% across the northern CSMP reefs over the same period.

Although only low-moderate levels of bleaching (Pale - Recently Dead) were recorded across central CSMP reefs and the three southern CSMP reefs in February 2022 (11.9% of colonies surveyed), a large area of the central and southern CSMP was exposed to significant heat stress in March-April 2022. The geographic footprint of this heat stress event coincides with the recorded declines in coral cover from our surveys (Figure 1.1). In the absence of other major disturbances, the recorded declines in coral cover are most likely attributable to the elevated ocean temperatures experienced in March-April 2022. To our knowledge this is the first record of three consecutive bleaching events on coral reefs globally. Importantly, the decline in coral cover on the southern and central CSMP reefs from 2022 to 2023/4 occurred against a shifted baseline of coral communities, with the abundance of bleaching sensitive coral taxa being reduced due to previous (i.e., 2016, 2017, 2020, and 2021) bleaching events. This reduction in coral cover compounded on previous declines due to the 2020 and 2021 bleaching events, resulting in a 51.2% decline in coral cover from 2020 to 2023/24 across the entire CSMP (Central CSMP: 58.6% decline; southern CSMP: 50.2% decline; northern CSMP: 29.6% decline). The decline in coral cover in the central CSMP is considerably greater if the two ‘bright spot’ reefs (i.e., Moore and Mellish Reefs) are excluded (70.1% decline).

Importantly, coral cover on previously identified ‘bright spot’ reefs remained relatively high. For example, coral cover on Moore and Mellish Reefs (19.0% and 25.8%, respectively) are the highest of the nine central CSMP surveyed, and almost double that of the other seven central CSMP reefs (5.9-13.8%). Similarly coral cover at the two of the three ‘bright spot’ reefs surveyed in the northern CSMP remained higher than the regional average (Ashmore: 35.2%; Bougainville: 31.3%; northern CSMP: 30.9%). A sixth ‘bright spot’ reef was also identified. Cato Reef, the southernmost reef in the CSMP, had the second highest coral cover (33.7%) recorded across all CSMP reefs surveyed in 2023/24, more than double the regional average for the southern CSMP (15.8%), and has experienced limited decline in coral cover since 2020. Cato Reef also had higher taxonomic richness of corals, and higher species richness and density of reef fish than regional average.

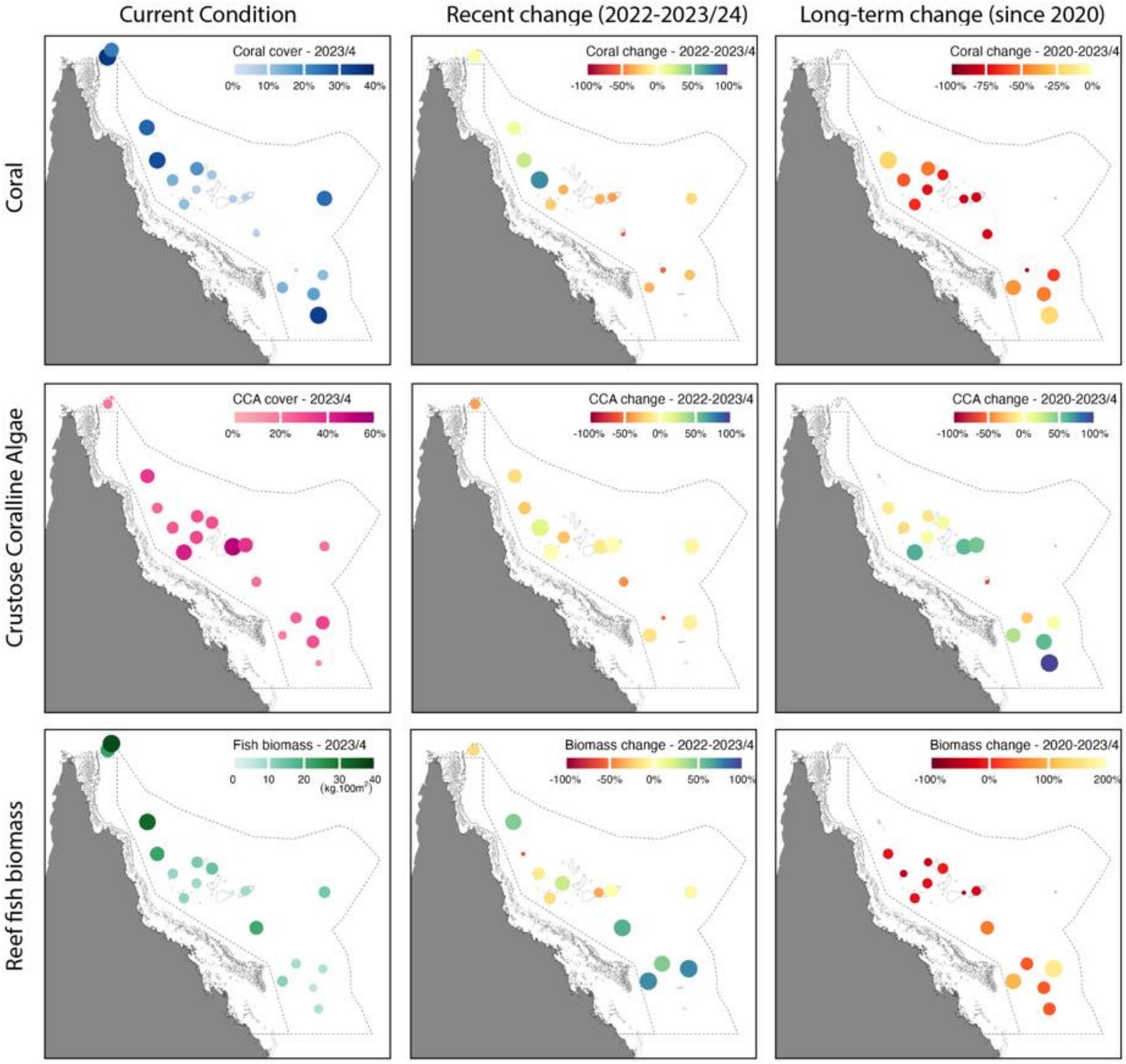

Figure 1.1. Summary of the current (2023/24) condition and recent and longer-term trends in coral cover, crustose coralline algae cover, and reef fish biomass across the Coral Sea Marine Park. Values are averaged across habitats and sites on each reef, and based on surveys of matching sites conducted during 2020, 2022 and 2023/24.

In contrast, five of the nine reefs in the central CSMP (Marion Reef: 5.9%; Lihou Reef: 6.0%; Diamond Islets: 7.0%; Herald Cays: 7.5%; Willis Islets: 8.9%), and Frederick Reef (4.0%) in the southern CSMP have levels of coral cover that are below critical thresholds (<10% cover), and several others that are approaching critical levels (Flinders Reef: 11%; Holmes: 13.8%; Kenn Reef: 11.3%; Saumarez: 13%). While these levels of coral cover are equal to or higher than historical estimates of coral cover on some central CSMP reefs (i.e., 1-6%: Herald Cays, Chilcott Islet and Lihou Reef), such low levels of coral cover have been shown to disrupt key processes and have lasting consequences for the diversity and functioning in other reef systems. It is currently unknown if low coral cover will have the same consequences in reef systems such as the CSMP where coral cover in shallow reef habitats has been historically low. Continued monitoring over the next 5-10 years will be critical to assess whether coral populations and coral cover on these reefs recovers, or collapses, and any associated changes in reef fish and invertebrate communities.

Turf- and/or macro-algae often increase in abundance following widespread coral loss, however we found no evidence of such increases following widespread coral loss in the CSMP from 2020 to 2023/24. Rather, the cover of crustose coralline algae (CCA) increased across all three regions of the CSMP from 2020 to 2022, and largely offset the declines in coral cover over the same period, before declining slightly in 2023/24. It appears therefore that CCA's, rather than turfs or macro-algae, rapidly colonise and grow to cover recently dead coral skeletons on isolated reefs of the CSMP. This is important as CCA's are a critical component of healthy coral reef ecosystems, contributing to reef calcification, the induction of coral larvae to settle, and the provision of 3-dimensional structure for reef associated species.

The density of juvenile corals (an indicator of the recovery potential of coral populations) recorded across the 18 CSMP reefs in 2023/24 was high (36.3 juveniles per 10m^2), and 50% greater than that recorded in 2022 (23.1 juveniles per 10m^2). This increase was largely driven by the higher densities recorded at Ashmore and Boot Reefs (75.5 and 57.1 juveniles per 10m^2, respectively) in the far north of the CSMP, and likely reflects their proximity and hence connectivity with reefs of the Torres Straits and Eastern Fields (PNG). Comparisons of sites that have been repeatedly surveyed since 2020, show the density of juvenile corals have increased by 10-35% from 2022 to 2023/24 (southern CSMP: 18.8 to 21.6 juveniles per 10m^2; central CSMP: 20.2 to 27.4 juveniles per 10m^2; northern CSMP 27.5 to 30.0 juveniles per 10m^2), and are 2- to 6-times greater than the densities recorded prior to and during the 2020 bleaching event. While the increase in the densities of juvenile corals will aid in the recovery of the coral populations across CSMP reefs, the majority of these juvenile corals likely settled onto these reefs prior to the 2020 bleaching event, and as such the full impacts of the 2020, 2021, 2022, and 2024 bleaching events on the supply and settlement of coral larvae are yet to be realised. Coral settlement tiles that were deployed on three CSMP reefs (namely Osprey and Bougainville Reefs) is October 2023, and are currently being collected, will provide greater insight into the supply and settlement of coral larvae to CSMP reefs.

Although there was very little evidence of thermal stress (i.e., bleaching) across the eleven CSMP reefs surveyed in 2023 (1.7% of colonies surveyed were pale to 100% bleached), there was low to moderate bleaching across the seven reefs surveyed in 2024 (11.9% of colonies were pale to 100% bleached). The incidence of heat stress (paling and bleaching) in 2024 varied among reefs, ranging from 2.3% of coral colonies at Cato Reef to 46.6% of coral colonies at Frederick Reef, and was generally greatest on reefs that were surveyed later in the voyage. While the majority of heat stress manifested as the paling of colonies (66.1% of colonies that showed signs of heat stress) with few colonies being completely bleached (5.3% of colonies), the increasing incidence of bleaching toward the end of the voyage is consistent with increasing exposure to heat stress. At the time of our last surveys for 2024 (3rd March) large areas of the southern and central CSMP were exposed to > 8 DHW, and up to 13 DHW in some areas (Figure 1.2), levels of heat stress where severe bleaching and mortality may be expected. Importantly, the marine heatwave continued to build through March with large areas of the central CSMP exposed to >12 DHW and up to 17 DHW in some areas; greater than the heat stress experienced throughout the CSMP during the 2020 bleaching event. Future monitoring (ideally in late 2024 or early 2025) will be critical to assess the impacts of this heat stress on shallow water coral communities.

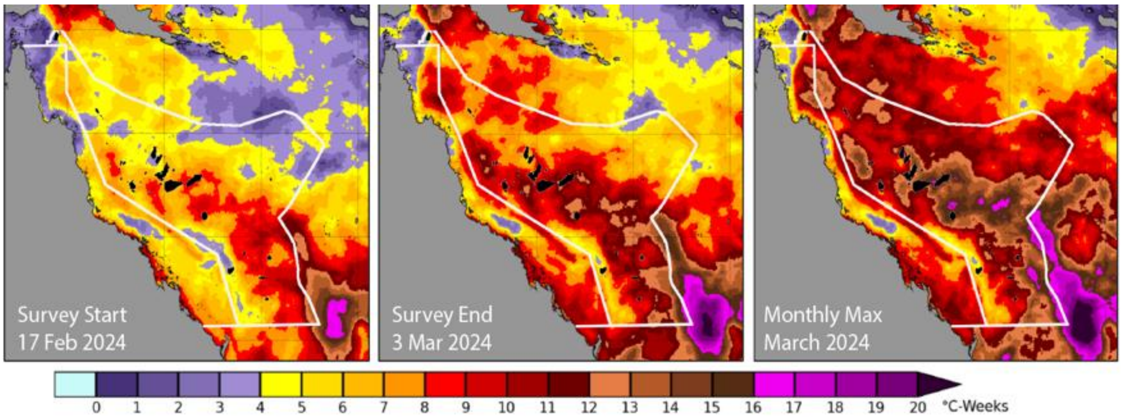

Figure 1.2 Degree heating weeks (DHW) in the Coral Sea Marine Park for February – March 2024 showing the progression of heat stress from the start of the surveys (17th February) to the end of the surveys (3rd March), and the monthly maximum heat stress for March 2024. Images produced using the NOAA CRW 5km product v3.1

Widespread coral mortality commonly leads to declines in reef-associated taxa that rely on corals for food and/or shelter. While there were no substantive changes in the abundances of macro-invertebrates (i.e., sea urchins, sea cucumbers, *Trochus*, *Tridacna* clams) on CSMP reefs in 2023/24, the biomass of reef fishes declined on central and northern CSMP reefs. The initial decrease in reef fish biomass (2020-2022) was largely driven by declines in small-bodied planktivorous fishes (e.g., damselfishes), and corallivorous butterflyfishes that are reliant on live coral for shelter and/or food, as well as grazing herbivorous fishes. While the biomass of corallivorous and planktivorous fishes remained relatively stable between 2022 and 2023/24, the biomass of grazing fishes (primarily surgeonfishes) continued to decline and is now >60% lower than 2020 levels. The continued declines in the biomass of grazing fishes are difficult to reconcile as several studies have reported substantial increases in the abundance and/or biomass of herbivorous fishes following large-scale bleaching-induced coral mortality. Such increases have generally been related to an increase in the availability of their preferred feeding substrata (i.e., algal and cyanobacterial turfs). 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, and/or the rapid colonisation of dead coral skeletons by CCA (as opposed to turfs). 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.

Despite the declines in reef fish biomass on CSMP reefs from 2020 to 2023/24, the biomass of reef fishes (a key indicator of reef health, together with coral cover) recorded across all CSMP reefs in 2023/24 remained high (mean = 1,606 kg per hectare) and likely reflects the isolation and relatively low fishing pressure on CSMP reefs.

While the immediate impacts of the 2020, 2021, and 2022 bleaching events on CSMP reefs are apparent, continued monitoring will be critical to assess the effects of the 2024 bleaching event, as well as any longer-term impacts on the structural complexity of habitats and reef associated fishes and invertebrates, and the potential recovery of shallow water coral assemblages across the CSMP.

The latest (2023/24) surveys revealed:

- Total shallow water coral cover decreased from 17.3% in 2022 to 14.0% in 2023/24 across the 13 reefs that were surveyed in both years, a mean decline of 18.7%. The change in coral cover varied among regions ranging from 39.7% and 23.8% declines in the southern and central CSMP, respectively, to an 8.9% increase in the northern CSMP. There was also considerable variation in the change in coral cover among reefs within each region (e.g., 58.4% decline at Marion Reef vs a 55.7% increase at Holmes Reef).
- Although only low-moderate levels of bleaching were recorded across southern and central CSMP reefs in February 2022 (11.9% of colonies), large areas of the southern and central CSMP were exposed to seawater temperatures above those expected to cause bleaching-induced mortality March-April 2022. In the absence of any other major disturbance, the observed declines in coral cover on southern and central CSMP reefs in 2023/24 are most likely attributable to elevated temperatures experienced in March-April 2022.
- The reduction in coral cover from 2022 to 2023/24 (18.7% decline) while lower or comparable to declines recorded following the two previous bleaching events (2020: 39% decline; 2021: 18% decline), occurred against an increasingly shifted baseline of coral communities, with the cover of bleaching-susceptible coral taxa being severely reduced following the 2016, 2017, 2020, and 2021 bleaching events. Collectively, the three most recent bleaching events (2020, 2021, 2022) have led to a 51% decline in shallow water coral cover CSMP reefs, ranging from a 30% decline in coral cover on northern CSMP reefs, to 50% and 59% declines on southern and central CSMP reefs, respectively.
- While low levels of bleaching (<2% of colonies surveyed) were recorded across CSMP reefs during the 2023 surveys, low to moderate levels of bleaching were recorded on reefs in the southern and central CSMP during the 2024 voyage (18.6% of coral colonies were pale or bleached). However, the 2024 marine heatwave in the CSMP was still building at the time of our surveys and did not reach its peak until late March where large areas of the

CSMP were exposed to >12 DHW and up to 17 DHW; levels of heat stress that are expected to lead to substantial bleaching and mortality of corals.

- Six reefs in had very low (< 10%) coral cover (southern CSMP: Frederick Reef: 4%; central CSMP: Marion Reef: 5.9%; Lihou Reef: 6.0%; Diamond Islet: 7.0%; Heralds Cays: 7.5%; Willis Islets: 8.9). Such low coral cover has been shown to disrupt key processes and have lasting consequences for the diversity and functioning of other reef systems. Continued monitoring over the next 5-10 years will be critical to assess whether coral populations on these reefs recover, or collapse, and any associated changes in reef fish and invertebrate communities.
- Despite the significant loss of live corals over the past three years, there were no substantial increases in macroalgae across the CSMP. Rather the cover of crustose coralline algae, an important component of healthy reef ecosystems, has increased across all three regions of the CSMP.
- Eleven fish species that had not been recorded during surveys or observations on the previous voyages (2018-2022) were recorded during the 2023/24 surveys, taking the total fish species recorded in the CSMP during the past six years of surveys to 650 species. All of these eleven species were recorded at Ashmore Reef in the far north of the CSMP. No new species of coral were observed.
- The biomass of reef fishes declined by 9% and 21% in the northern and central CSMP, respectively, from 2022 to 2023/24, and was primarily related to declines in grazing fishes. Grazing fishes are widely viewed as key functional group on coral reefs because of their capacity to remove algal biomass and prevent algal overgrowth following disturbance. The sustained declines in the abundance and biomass of grazing fishes following the 2020 bleaching event are counter to those reported for coastal and continental shelf reef systems and suggest that these changes may be related to the rapid colonisation of dead coral skeletons by CCA (as opposed to algal and cyanobacterial turfs which are the favoured feeding substrata of these fishes).
- Ashmore, Boot, Bougainville, Mellish and Moore Reefs, previously identified as ‘bright spots’ in terms of coral cover, richness and/or fish biomass, were again standouts. All four reefs appear to have been less adversely affected

by the recent bleaching events than other CSMP reefs, with the highest coral cover being recorded on Ashmore Reef (35%), while coral cover at Mellish and Moore Reefs (26% and 19%, respectively) was almost double that of other reefs in the central CSMP (6-13%).

- A sixth ‘bright spot’ reef was also identified, and the only ‘bright spot’ reef in the southern CSMP. Cato Reef had the second highest coral cover (34%) recorded across all CSMP reefs surveyed in 2023/24, more than double the regional average for the southern CSMP (16%), and has experienced limited decline in coral cover since 2020. Cato Reef also had higher taxonomic richness of corals, and higher species richness and density of reef fish than regional average.
- In addition to the monitoring undertaken, several additional projects were leveraged from this collaboration between James Cook University and Parks Australia and capitalised on available space during the voyages. These leveraged projects represent a significant in-kind contribution and collectively, will increase our understanding of the movement and connectivity of sharks, reef fishes, corals and macro-invertebrates, identify potential genetic adaption of corals, identify fish spawning aggregation sites, and promote the unique nature of the CSMP.

In conclusion, the three consecutive bleaching events (2020, 2021, and 2022) have had a significant impact on coral and reef fish communities across most CSMP reefs surveyed, with another a potential severe and widespread bleaching event unfolding in 2024. The 2022 bleaching event while restricted to the southern and central CSMP caused an 18.7% decline in coral cover and occurred against an increasing shifted baseline of coral communities, with the cover of bleaching-susceptible coral taxa being reduced following the 2016, 2017, 2020, and 2021 bleaching events. Importantly, the 2022 bleaching event was the fifth major bleaching event, and the 2024 bleaching event likely the sixth major bleaching event, in the CSMP in the last 8 years (2016, 2017, 2020, 2021, 2022, and 2024). These recent bleaching events in the CSMP are reflective of the increasing frequency and intensity of marine heatwaves that are affecting coral reefs globally. Continued surveys of CSMP reefs will be critical to assess the potential recovery and resilience of these isolated reef systems in the absence of local anthropogenic stressors, and the longer-term and ongoing impacts of these bleaching events on reef associated species.

Recommendations for future monitoring and research:

- 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), regular (annual or biennial) surveys are critical. In the absence of regular monitoring, the causes of any changes in reef communities would be largely unknown, severely limiting the capacity of managers to understand the health status of these reefs and make informed decisions. For example, future surveys (ideally late 2024 or early 2025) will be critical to detect the impact of the 2024 marine heatwave on reef ecosystems.
- Continued monitoring (annual or biennial) should prioritise reefs and sites that have been repeatedly surveyed since 2020. Continued monitoring of these 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.
- Continued regular (annual or biennial) monitoring of coral, fish, sea snake and invertebrate communities should be conducted on a subset of 8-10 representative reefs, 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 the ‘bright spot’ reefs and/or on-route between reefs to facilitate comparisons and maximise the available vessel time.
- At least 2 days should be spent at each of the representative reefs (weather and conditions permitting) to allow for surveys of additional sites and habitats and targeted research and monitoring. Ideally 5-7 days should be spent at one select reef during each (annual or biennial) voyage year to allow a greater number of sites to be surveyed (i.e., 3-4 sites per day) and thereby provide a

more comprehensive understanding of the composition and health of both shallow and deep reef and non-reef habitats of that reef.

- Additional means for accessing CSMP should be considered, including the provision of berths on the CSMP Island Health voyages (and vice-versa) and the use of berths on dive tourism vessels (e.g., Mike Ball Dive Expeditions).
- Repeat the 3-dimensional habitat mapping of sites mapped during the 2019-2020 voyages in the next 2-3 years. Matching the sites previously mapped will 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 tracked.
- Increased focus on quantifying demographic rates of benthic (namely corals and crustose coralline algae; CCA) and fish taxa to better understand the replenishment and potential resilience of populations to environmental change. Temperature loggers and devices to quantify the settlement and calcification of CCA's were deployed across 15 CSMP reefs during the 2023/24 voyages and coral settlement tiles were deployed across three CSMP reefs in Oct 2023. While the coral settlement tiles are currently being collected via a Mike Ball Dive Expeditions voyage (30 May – 6 June 2024), there is currently no voyage planned to collect the temperature loggers or CCA devices. Importantly, the temperature loggers will have captured the water temperatures experienced at each site during the 2024 marine heatwave and this data will be invaluable in reconciling any differences in the response of coral communities to heat stress among sites and reefs. Retrieving the temperature loggers and CCA devices should be a priority for future work. 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.
- Dedicated investigation into the diet, fitness, and demographics of grazing fishes on CSMP reefs is required to identify the likely mechanism/s for the observed declines in this group following the recent bleaching events.

- The maintenance and replenishment of populations, and the resilience of reef systems within the CSMP is largely dependent on 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 tissue across these regions and subsequent genetic analyses of these samples are required to understand patterns of connectivity, and how they differ among taxa. Some of this work has been initiated, with an initial focus connectivity between the CSMP, GBRMP and New Caeldonia. We recommend expanding on this to include all adjacent regions.
- 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.
- Dedicated monitoring of reef and non-reef habitats using remotely operated underwater vehicles (ROVs) has revealed novel insights into deep-water (20-100m) habitats. However, repeated technical issues with the ROVs, coupled with difficulties and safety concerns in deploying and piloting ROVs from tenders in moderate to strong winds and seas detract from their utility and cost-effectiveness. Monitoring and exploration of deep reef habitats should be considered opportunistically (i.e., when staff are available and conditions allow) rather than a priority for future monitoring.

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3 Background

The Coral Sea is situated off Australia's north-east coast, bounded by Papua New Guinea to the north, the Solomon Islands, Vanuatu and New Caledonia to the east, and the Tasman Sea to the south. The Coral Sea is a critically important and environmentally significant ecosystem owing to i) the extent and diversity of habitats (including many unique habitats), ii) the unique fauna these habitats support, iii) the provision of habitats for species of conservation significance and, iv) connectivity with Australia's Great Barrier Reef (GBR) and other western Pacific provinces (Ceccarelli et al. 2013; Hoey et al. 2020). Australia's marine estate within the Coral Sea is managed through the Coral Sea Marine Park (CSMP) that extends from the eastward margin of the Great Barrier Reef Marine Park (GBRMP) to the outer extent of Australia's Exclusive Economic Zone, some 1,200km offshore (Figure 2.1). The CSMP is among the world's largest and most isolated marine parks, encompassing an area of 989,836km^2, and together with the adjacent Parc Naturel de la Mer de Corail (Natural Park of the Coral Sea – New Caledonia) form the largest protected area in the world (*ca.* 2.3 million km^2; Figure 2.1). Within the CSMP there are approximately 56 islets and cays and 20 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).

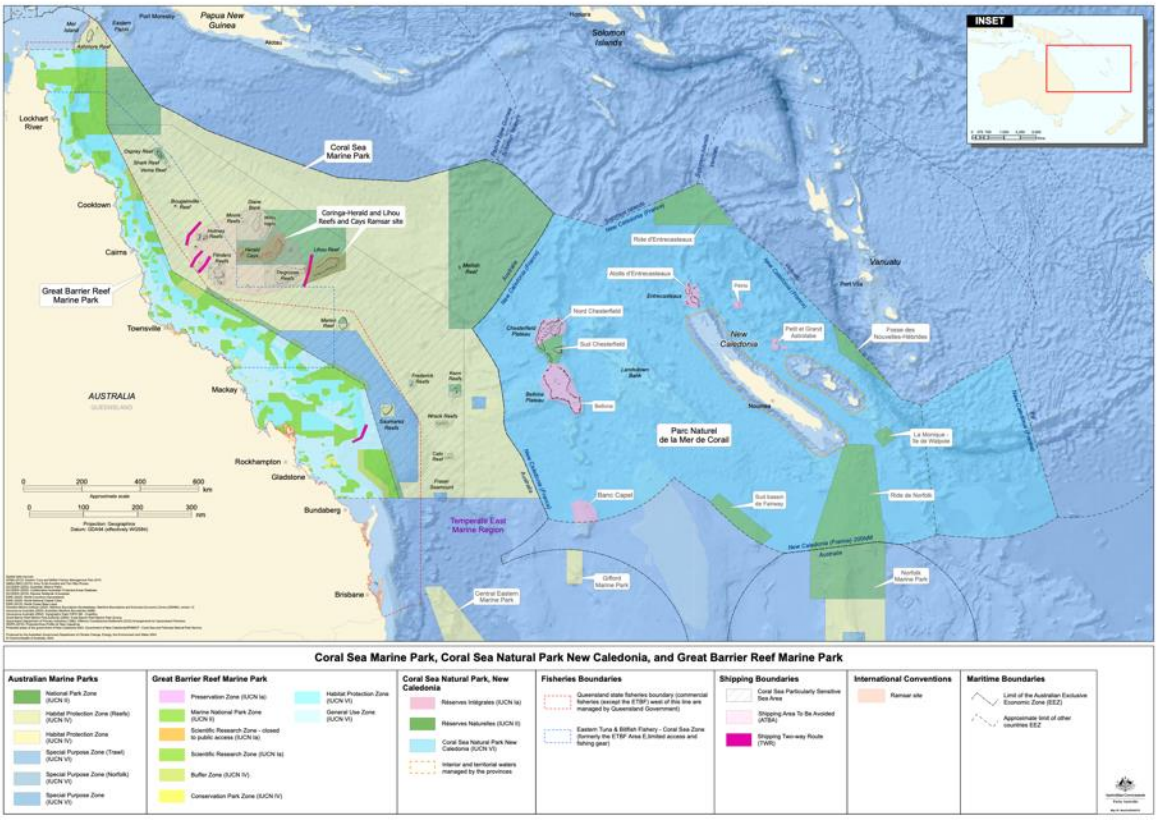


Figure 2.1. Map of the Coral Sea showing the location of the Coral Sea Marine Park and Parc Naturel de la Mer de Corail (Natural Park of the Coral Sea, New Caledonia). Together these two Marine Parks represent the world's largest protected area. The management zones shown were implemented in the Coral 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 reefs of the GBRMP, and are largely shaped by the geomorphic, oceanographic and environmental conditions of the region. 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).

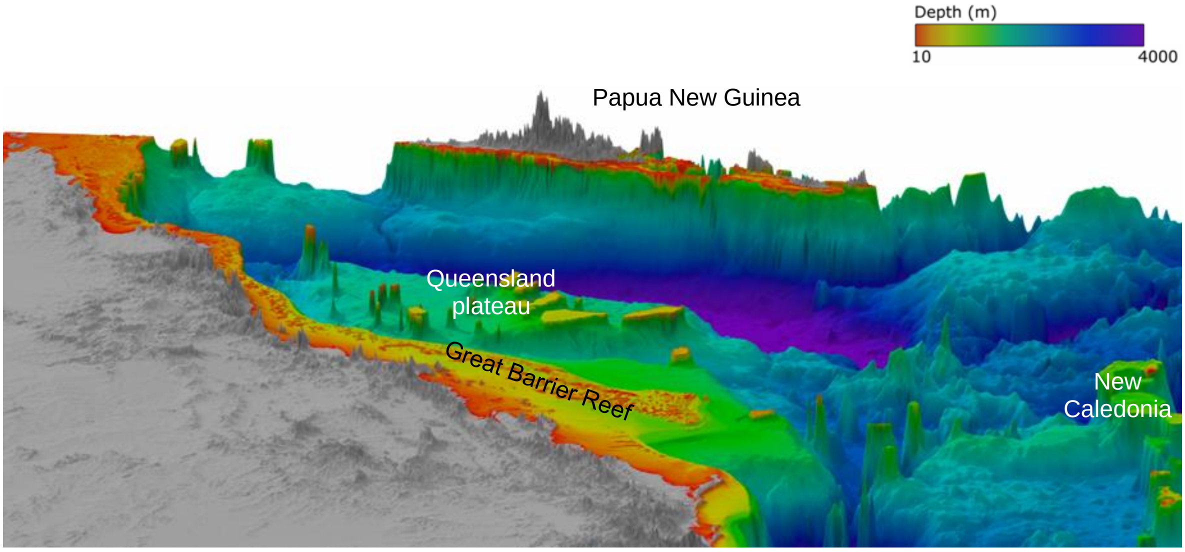


Figure 2.2. Bathymetric map of the Coral Sea showing the location of the Queensland plateau that gives rise to many of the reefs in the central and northern regions of the Coral Sea Marine Park. Three-dimensional visualization generated in R with the package Rayshader (Morgan-Wall, 2024) from a digital elevation model by Beaman 2012.

The CSMP is one of the most isolated coral reef environments in Australian waters, with limited exposure to direct human pressures (e.g., fishing, run-off) relative to more accessible coastal 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 30+ years (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). These frequent disturbances, coupled with the general reliance on self-recruitment for the recovery of coral populations on isolated reefs (Gilmour et al. 2013), most likely contribute to the sustained low coral cover on these reefs (Oxley et al. 2003, 2004; Ceccarelli et al. 2008; Hoey et al. 2020, 2021, 2022).

The reef habitats (down to 100m depth) of the CSMP support unique coral and reef fish communities that are distinct from those of the adjacent GBRMP, and share many species with reefs in the Tasman Sea to the south (i.e., Elizabeth and Middleton Reefs and Lord Howe Island), and nations to the east (New Caledonia, Vanuatu and the Solomon Islands; Hoey et al. 2020). While there is some differentiation of fish and coral communities among the northern, central, and southern regions of the Coral Sea Marine Park, a striking feature of these reefs is the diversity of reef fish (>600 species) and the high abundance and biomass of sharks (mainly the grey reef shark, *Carcharhinus amblyrhynchos,* and the silvertip shark, *C. albimarginatus*) and other large predatory fishes (Ceccarelli et al. 2013; Stuart-Smith et al. 2013; Hoey et al. 2020, 2021, 2022; Galbraith et al. 2022). The high biomass of large predatory fishes is comparable to the other isolated reef systems, such as the Chagos Archipelago in the central Indian Ocean (Graham and McClanahan 2013), and is generally viewed as being characteristic of areas exposed to limited fishing effort.

Despite the isolated nature and hence limited direct human pressures on CSMP reefs, they are increasingly being exposed to the effects of climate change. Indeed, six major thermally-induced coral bleaching events have been recorded in the CSMP in the past two decades (2002, 2004, 2016, 2017, 2020, and 2021), with four of these bleaching events occurring in the past seven years (Oxley et al. 2004, Harrison et al. 2018, 2019, Hoey et al. 2020, 2021, 2022). The two most recent bleaching events (i.e., 2020 and 2021) were the most severe and widespread, and led to a 52% decline in coral cover in shallow (<15m depth) reef habitats throughout the CSMP. 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; Figure 2.3), and 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 larvae (i.e., larvae spawned from adult corals on the same reef rather than those nearby) to replenish coral populations (Gilmour et al. 2013).

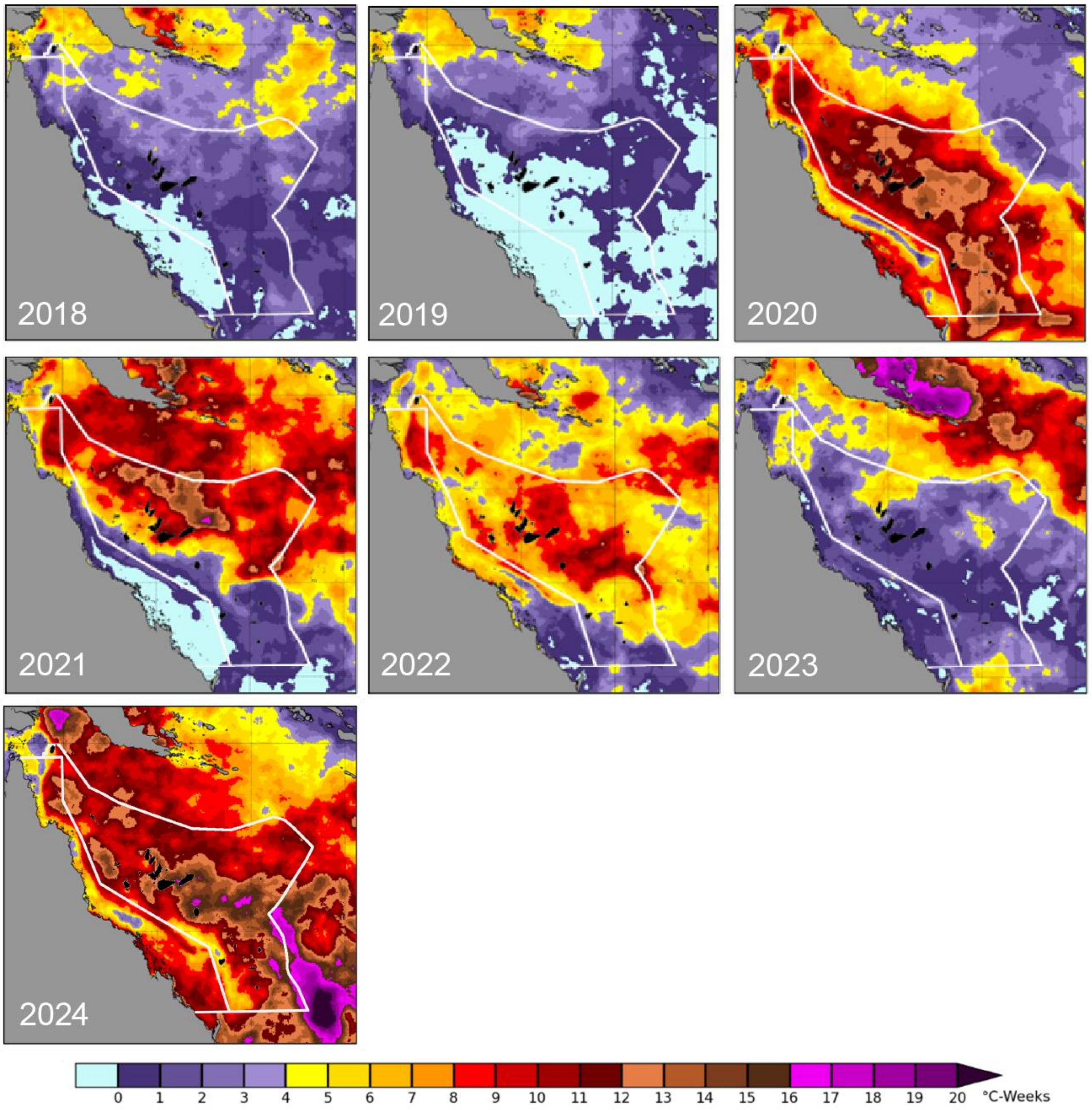


Figure 2.3 Comparison of the maximum Degree Heating Weeks (DHW) experienced throughout the Coral Sea Marine Park during the past seven years (2018-2024). Note the maximum DHW in 2021, 2022 and 2024 occurred in March of each year. Images produced using the NOAA CRW 5km product v3.1

The combined effects of the back-to-back 2020 and 2021 bleaching events in the CSMP resulted in a mean coral cover decreasing from 27% in 2020 to 13% in 2022 across the eleven reefs surveyed in each year, an average decline of 52% (Hoey et al. 2022). There was, however, considerable variation in the decline in coral cover among regions (2022: 28% and 26% declines in the northern and central CSMP, respectively, and a 4% increase in the southern CSMP), among reefs (22% increase to a 59% decline), and sites within reefs (Hoey et al. 2022). Importantly, reefs previously identified ‘bright spots’ due to their higher coral cover, richness and/or fish biomass (Hoey et al. 2020) appeared to be less adversely affected by recent bleaching events than other CSMP reefs. For example, coral cover on Ashmore Reef in the far north of the CSMP increased by 35% from 2018 (26.5% cover) to 2022 (35.9% cover) and remained largely unchanged (*ca*. 30% coral cover) on Mellish Reef in the far east of the CSMP, while coral cover declined substantially on non 'bright spot' reefs over the same period (Hoey et al. 2022). This variation in the response of coral assemblages to heat stress across relatively small spatial scales could reflect differences in the composition of coral communities, local environmental conditions, resilience to heat stress, and/or other unidentified factors (Marzonie et al. 2023). Irrespective of the mechanism, 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 potential recovery of shallow water coral assemblages following the 2020 and 2021 bleaching events, any ongoing effects of coral loss on associated fish and invertebrate communities, and to better understand the dynamics, and factors that contribute to the performance, of the five 'bright spot' reefs.

3.1 Objectives and scope

The purpose of this study was to provide comprehensive assessments of the current condition of benthic and fish communities within the CSMP, assess the impacts of the back-to-back (i.e., 2020 and 2021) bleaching events on benthic, fish and invertebrate communities throughout the CSMP, and gain some understanding of the resilience and biodiversity of the CSMP 'bright spot' reefs.

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

i) benthic cover and composition, including the percentage cover for hard (Scleractinian) and soft (Alcyonarian) corals, macroalgae, and other

sessile organisms;
ii) 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.

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

As well as the objectives listed above, several projects were leveraged from this collaboration between James Cook University and Parks Australia and capitalised on available vessel space during the voyage. These leveraged projects include:
i) Movement and population structure of sharks and large fishes within the CSMP;
ii) Surveys for fish spawning aggregation sites within the CSMP;
iii) Cultural and ecological significance of Ashmore and Boot Reefs;
iv) Filming of a documentary on Sea Country featuring the Meriam people;
v) Vessel grounding assessment at Moore Reefs;
vi) Connectivity and adaptive seascape of corals within the CSMP;
vii) Connectivity of reef fishes and macro-invertebrates within the CSMP.
Further details of these projects are provided in Appendix 1.

Figure 2.4 Top: The *MV Iron Joy* anchored off Mer Island, in the eastern Torres Strait, with the JCU research team, CSMP Manager, vessel crew, representatives of the Meriam people and cinematographers from Millstream Productions on the foredeck as part of the leveraged project: *Jewel in the Coral Sea: the cultural and ecological significance of Ashmore and Boot Reefs*. Additional funding for this project was provided through an Our Marine Parks Round Three Grant. Bottom: The research team and crew of the MV Iron Joy at Frederick Reef. Image credits: Stuart Ireland, Millstream Productions (top), and Victor Huertas (bottom).

4 Methods

Surveys were undertaken at 48 sites across 11 reef systems within the central and northern CSMP during a 31-day voyage, 10th February – 12th March 2023, and 30 sites across 7 reef systems in the southern and central CSMP during a 19-day voyage,14th February – 4th March 2024 (Figure 3.1). The 11 reefs surveyed in 2023 were Flinders (north and south), Holmes (east and west), Lihou, and Moore Reefs, Herald Cays, and Willis, and Diamond Islets in the central CSMP, and Ashmore, Boot, Bougainville and Osprey Reefs in the northern CSMP. The 7 reefs surveyed in 2024 were Cato, Frederick, Kenn, Saumarez and Wreck Reefs in the southern CSMP, and Marion and Mellish Reefs in the central CSMP (Appendix 2). To facilitate direct comparisons in coral health and reef condition among years we re-visited the sites that were surveyed during 2020-2022 (i.e., including the two most recent bleaching events; Hoey et al. 2020, 2021, 2022), or if the reef wasn't surveyed in 2020 or 2021 (i.e., Boot Reef) we attempted to revisit sites that had been surveyed prior to 2020. Sites were relocated using GPS waypoints and a bearing of the direction of the transects from that waypoint.

4.1 Sampling design – diver-based surveys

50 days
18 reefs - 78 sites
24 km of UVC surveys
>550 diver hours

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). The only exceptions to this were two sites where the reef crest could not be safely accessed due to excessive surge and wave action (Willis site 4 and Wreck site 5), and one site inside the lagoon at Boot Reef (Boot site 8) where there wasn't sufficient depth to differentiate the reef slope and crest habitats. In 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).

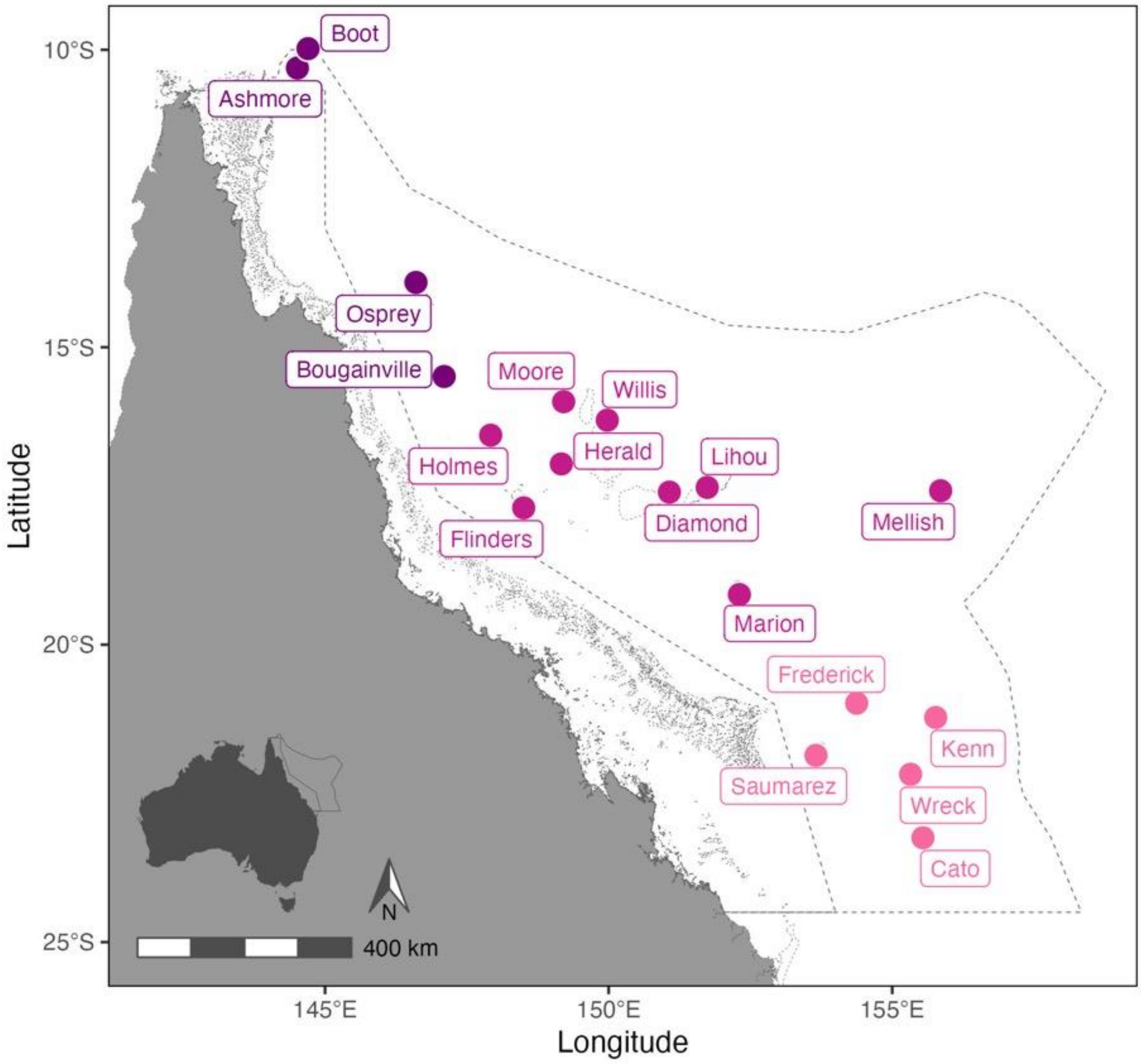


Figure 3.1 Map of the surveyed reefs in the Coral Sea Marine Park during the 2023 and 2024 voyages. Colours relate to the regional allocation of reefs in the southern (pink). central (magenta), and northern (purple) Coral Sea Marine Park which are used throughout the report. Regional allocation is based 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). 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). 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 3). 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, using a 1m bar to accurately determine the boundaries of the survey area. 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.

4.1.1 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). 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, we recorded the taxonomic identity, colony size and health. 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 8 categories (Figure 3.2), to document the extent and severity of bleaching, as well as any other recent injuries, such as 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.

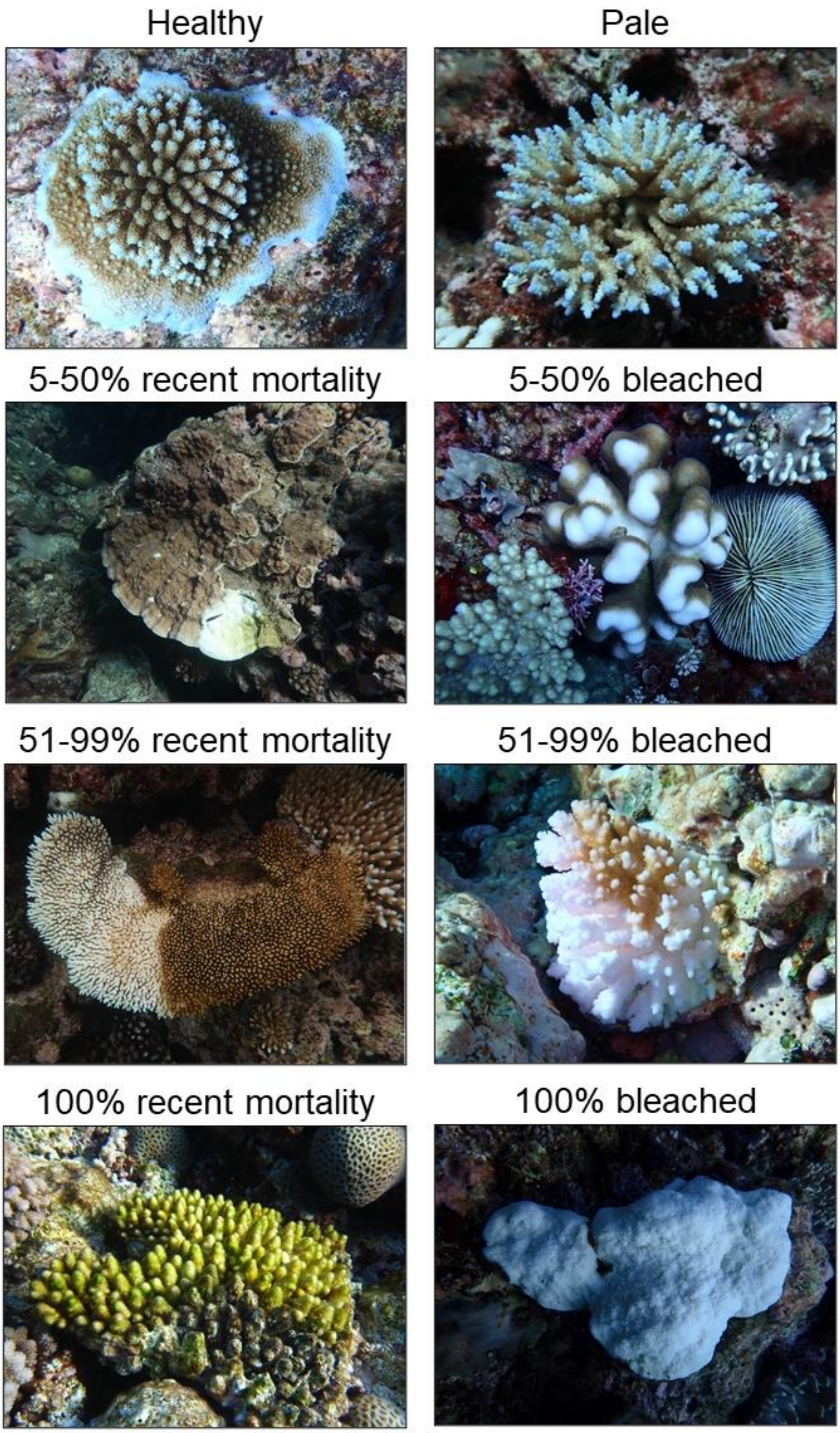


Figure 3.2 Coral health categories used for the in-water coral health assessments. Images on the left provide examples of the four injury categories, whilst images on the right are examples of the coral bleaching categories. Image credits: Deborah Burn, Morgan Pratchett

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

Coral settlement – To directly quantify the supply and settlement of coral larvae among reefs and habitats in the CSMP, coral settlement tiles (terracotta tiles: 11 x 11 x 1cm) were deployed in each of two habitats (reef crest and reef slope) at two sites on each of three reefs (Holmes, Bougainville and Osprey Reefs) in late October 2023. The timing of deployment was selected to be approximately 6-weeks prior to the predicted coral spawning, and access to the reefs to deploy the tiles was facilitated by Mike Ball Dive Expeditions. These tiles are due to be collected on an upcoming voyage with Mike Ball Dive Expeditions (30 May – 6 June).

Crustose Coralline Algae (CCA) settlement and growth - To directly quantify the settlement and growth (calcification) of crustose coralline algae (CCA) among reefs and habitats in the CSMP, a series of CCA devices were deployed across eight reefs in Feb-Mar 2023, and six reefs in Feb-Mar 2024. The CCA devices 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 reinforcing bar was driven vertically into the reef framework using a hammer, avoiding areas of live coral (Figure 3.4). Three replicate CCA devices were deployed in each of two habitats (reef crest and reef slope) at 32 sites across fourteen reefs (2 sites at each of Flinders, Lihou, Moore, Holmes, Cato, Wreck, Kenn, Marion and Saumarez Reefs, and East Diamond Islet; 3 sites at each of Bougainville, Osprey, Ashmore, and Mellish Reefs; Appendix 3). Additional devices were deployed at ~20m on the reef slope at each of the 3 sites on Mellish Reef. Each CCA device was individually numbered. These deployments were more widespread and comprehensive than the 2-3 sites originally planned at Bougainville and Osprey Reefs. These additional devices are not scheduled for collection in 2024, rather will be collected on future voyages (e.g., 2025) together with the temperature loggers.

4.1.2 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 4 for a comprehensive list of species surveyed.

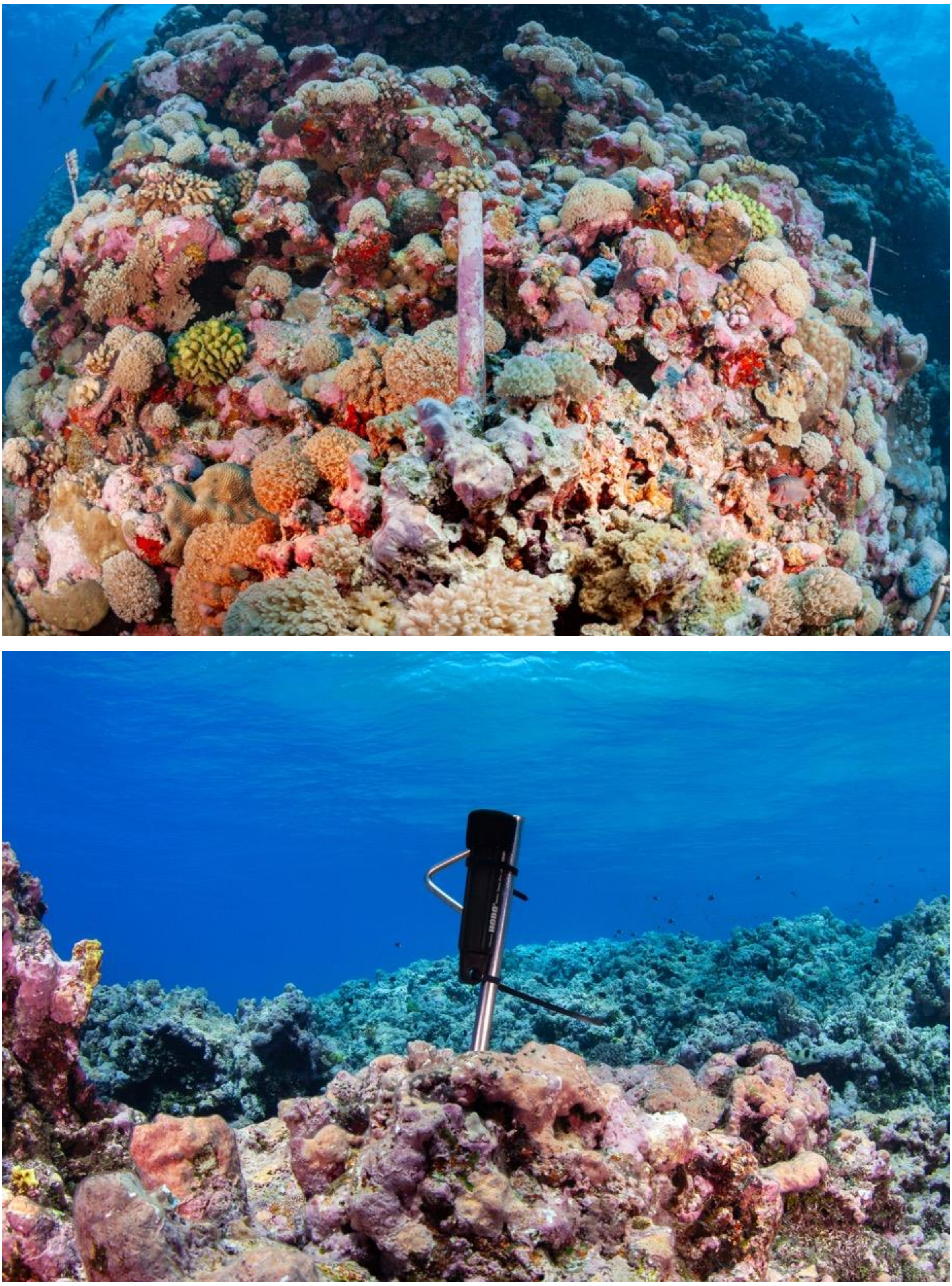


Figure 3.4 Photographs of crustose coralline algae (CCA) devices and temperature loggers deployed in Feb-Mar 2023 and Feb-Mar 2024. Top: CCA devices deployed on the reef slope of Osprey Reef. Bottom: Hobo temperature logger deployed on the reef crest at Willis Islets. Image credits: Victor Huertas.

4.1.3 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.

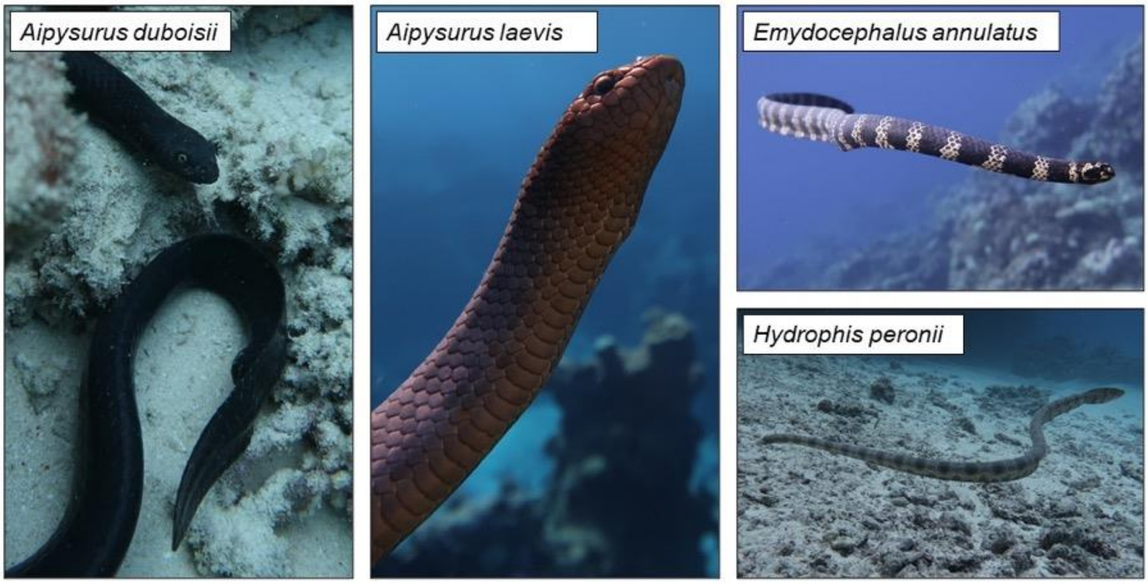


Figure 3.5 Photographs of the four species of sea snake that are commonly observed within the Coral Sea Marine Park; Dubois' sea snake, *Aipysurus duboisii*; Olive sea snake, *Aipysurus laevis*; Turtle-headed sea snake, *Emydocephalus annulatus;* Spiny headed or Horned sea snake, *Hydrophis peronii*.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

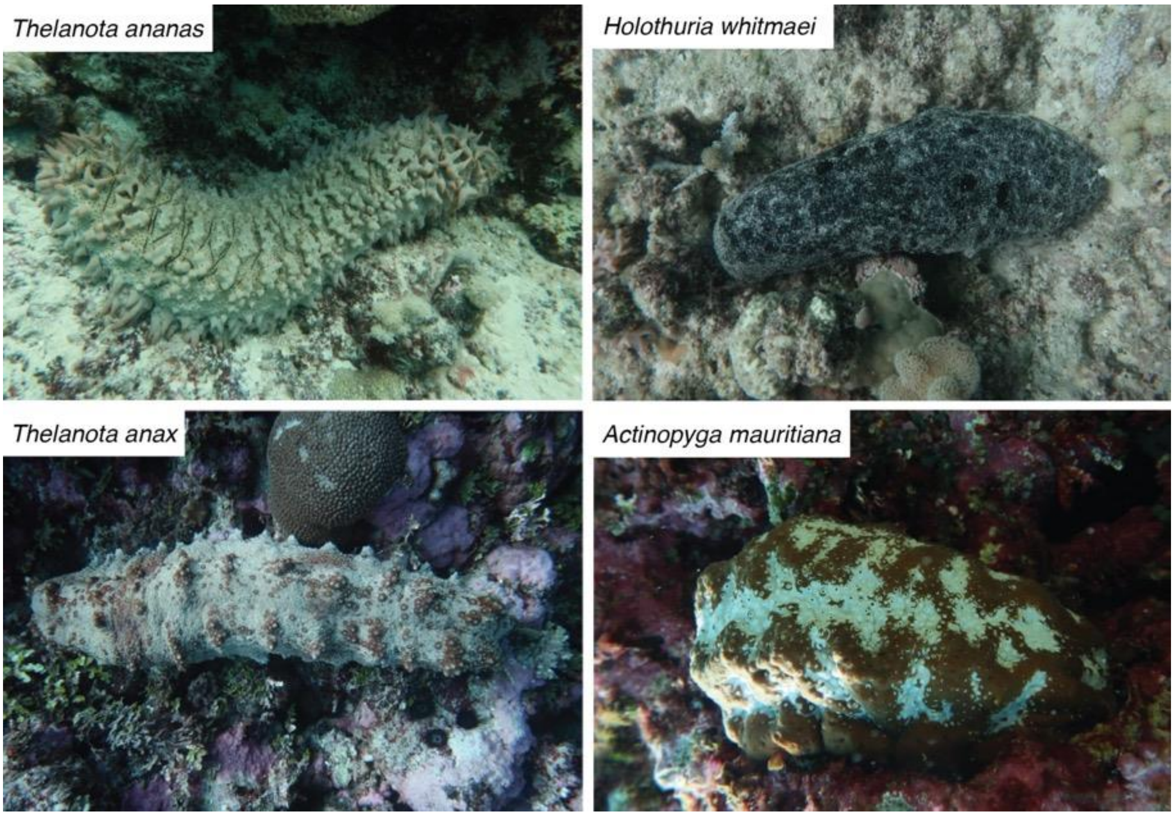


Figure 3.6 Photographs of four species of sea cucumber that are commonly observed within the Coral Sea Marine Park; Prickly redfish, *Thelanota ananas*; Black teatfish, *Holothuria whitmaei*; Amber fish, *Thelanota anax*; and Surf redfish, *Actinopyga mauritiana*. Image credits: Deborah Burn

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).

4.2 Sampling design – ROV surveys

Remotely Operated Vehicles (ROVs) were used to survey deeper (15 - 100m depth) reef and non-reef habitats throughout the CSMP. In addition to the onboard navigation camera, ROVs (BlueRobotics BlueRov2) were fitted with a forward-facing high-definition video system to record fish assemblages (GoPro Hero 8 systems). The ROVs were also fitted with downward and sideward facing time lapse cameras (GoPro Hero 8 cameras inside aluminium T-housings) to record benthic assemblages. The time lapse cameras were set to take a photo every 10 seconds, capturing an image of the benthos every ~2m. Combining the forward-facing system to record fish and the time lapse cameras to record the benthos, the ROVs were essentially able to replicate diver-based surveys (see Section 3.1 above) at depths of up to 100m.

The ROVs were deployed, piloted and retrieved from a tender to the main vessel (Figure 3.7). At each site, the ROV was deployed and descended to the maximum depth possible depending on the habitat type, sea conditions, and maximum depth rating of the ROV (i.e., 100m). Once at the target depth, the ROV was positioned ~0.5m above the substratum (or alongside for vertical reef walls), and two timed transects were conducted at a constant depth, with 5-10m between replicate transects. Each transect was 2.5 minutes long and by travelling at a known speed of 0.2 m/s, equated to a distance of approximately 30m. After the second transect, the ROV ascended by ~10m and two transects were conducted at this shallower depth in the opposite direction to the previous two transects (i.e., at the depth band immediately below). This survey pattern was repeated at ~10m depth bands until the two final transects were conducted in the upper 10m (Figure 3.8).

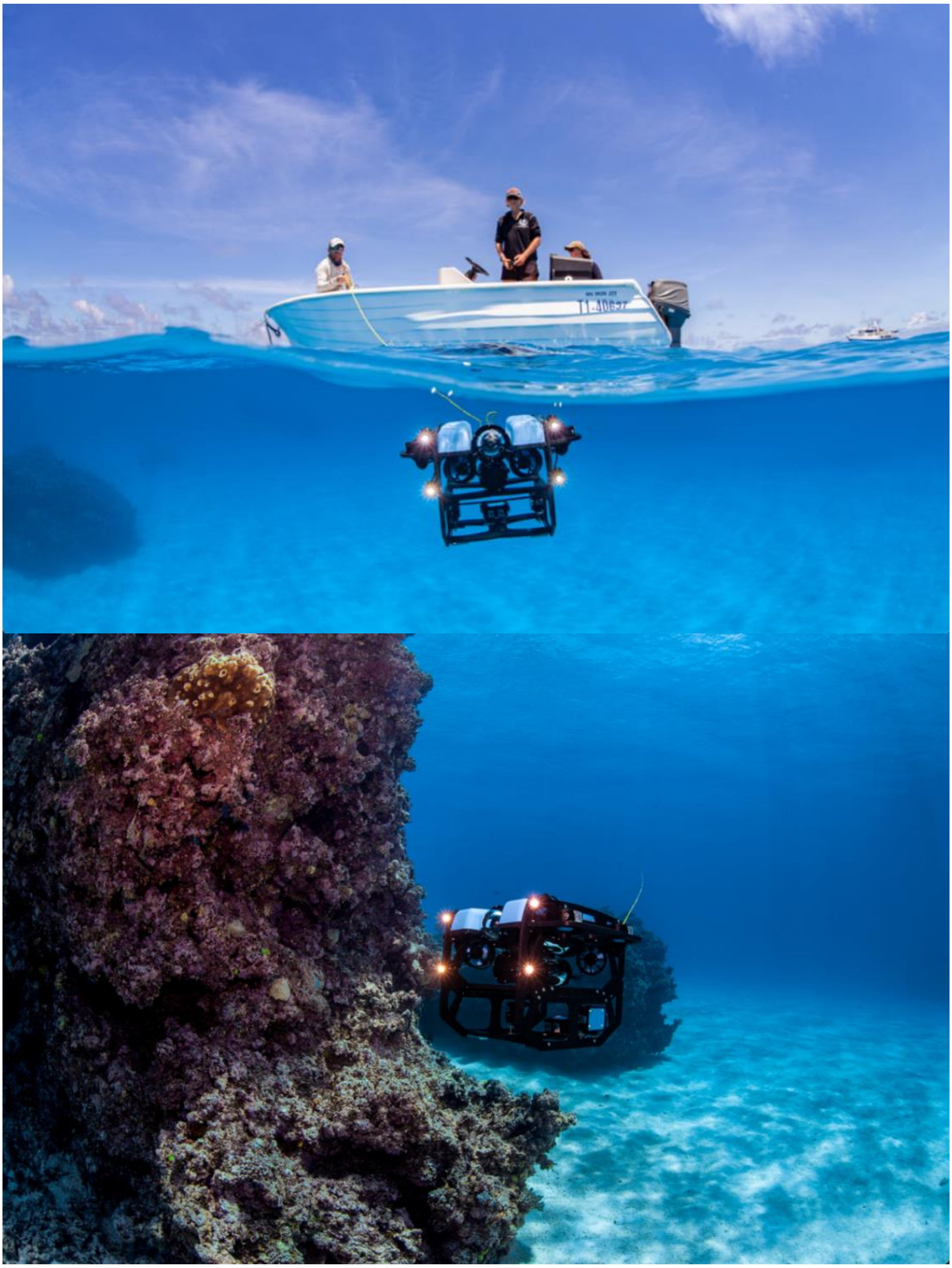


Figure 3.7 Photographs showing the operation of the Remotely Operated Vehicle (ROV) from a tender to the *MV Iron Joy* in the Coral Sea Marine Park. Top: The ROV (Blue Robotics BlueROV2) being deployed from the tender with the operator (Gemma Galbraith, standing) piloting the ROV, while an assistant manages the tether (Ben Cresswell). Bottom: The ROV navigating around a shallow bommie. Image credits: Victor Huertas

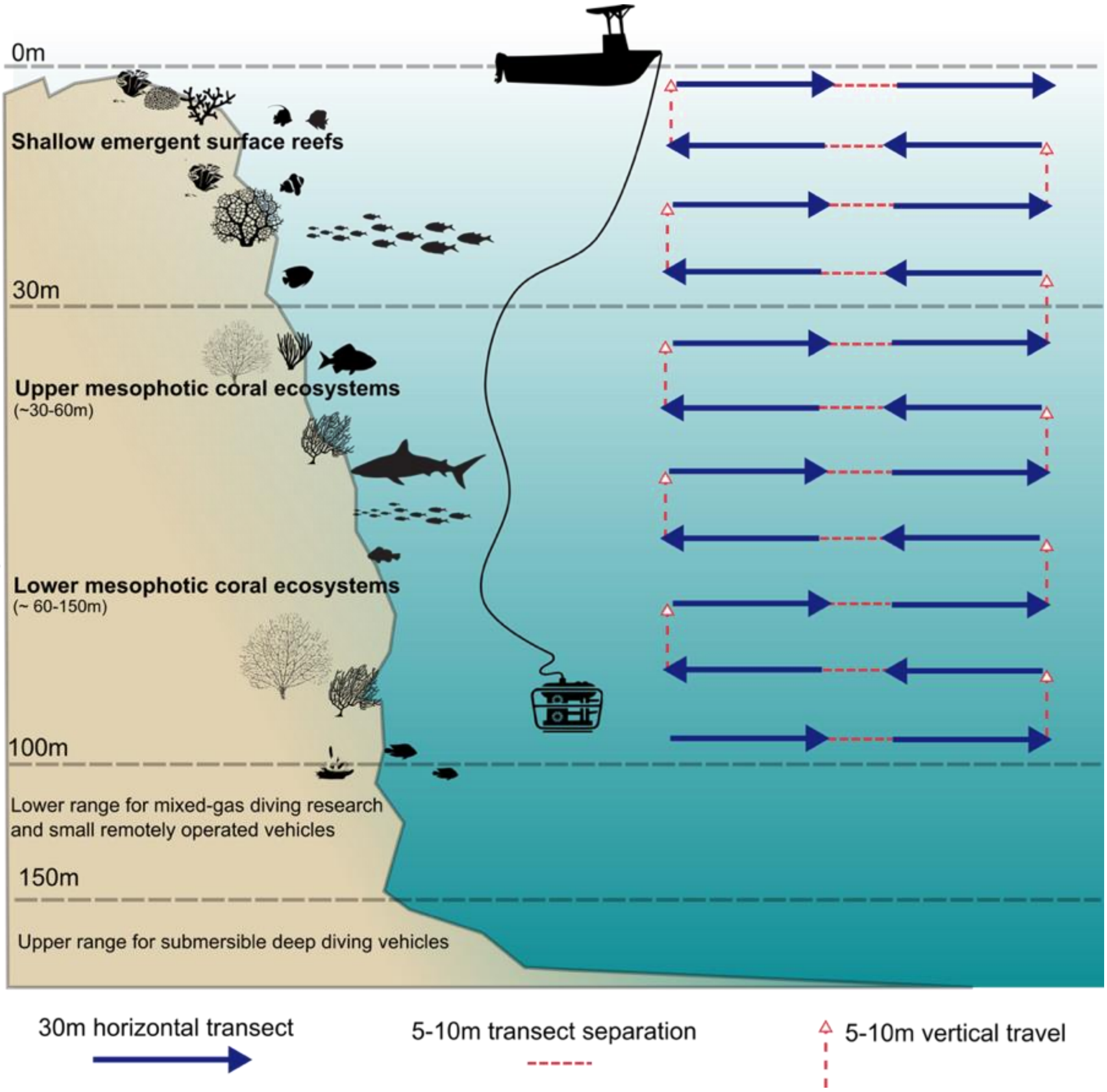


Figure 3.8 Remotely Operated Vehicle (ROV) transect survey methodology used to survey fish and benthic assemblages in the Coral Sea Marine Park. All ROV surveys were conducted at depths between 5 – 100m using the BlueRobotics BlueRov2.

157 ROV transects were undertaken at 18 sites across nine reef systems within the central and northern CSMP during Feb-Mar 2023, and 118 ROV transects were undertaken at 17 sites across five reef systems within the central and northern CSMP during Feb-Mar 2024. The nine reefs surveyed in 2023 were Flinders (north and south), Holmes (east and west) and Lihou Reefs, Herald Cays, and East Diamond Islet in the central CSMP, and Ashmore, Boot, Bougainville and Osprey Reefs in the northern CSMP. The five reefs surveyed in 2024 were Saumarez, Kenn and Frederick in the southern CSMP, and Mellish and Marion in the central CSMP. Both ROV units experienced significant technical issues with overheating batteries during the course of the 2023 voyage. This led to unpredictable off

gassing of electrical components in the electronics enclosure, and caused two significant flooding events. Replacement components were sourced in order to make repairs at sea, however, these equipment issues did reduce the capacity to survey sites at Moore Reefs, Herald Cays and Willis Islets as originally planned. Unfavourable weather during the Feb-Mar 2024 voyage limited the deployment of the ROV, and hence the survey of sites at Wreck and Cato reefs.

4.2.1 Image processing – ROV surveys

Video analyses - Fish species and abundance data were extracted from the ROV videos using the specialised software EventMeasure (SeaGis Pty Ltd, Australia). Footage from each ROV transect was played back in EventMeasure, with each fish along the transect identified to species level and counted. Any individual fish that could not be identified to species level were recorded to genus or family. Species richness and density were calculated for each transect and standardised to 150m^2.

Benthic image analyses – The benthic environment from each ROV transect was categorised from still images taken parallel to the reef topography, using the free cloud-based machine learning platform ReefCloud (AIMS 2024). Photographs were uploaded to ReefCloud, grouped at the level of Transect within each Site on each Reef. On each photo, a grid of 12 uniformly spaced points was overlayed for observer annotation, using a custom classification label set developed specifically for CSMP Reefs. The label set was designed to reflect the classification system used in shallow water diver surveys, with modifications to account for the low light environments and lower resolution of still images taken on deep reefs (i.e., higher emphasis on morphological characteristics than taxonomic characteristics). Through annotation of 12 points per image, the user trained a computer model on each benthic category via machine learning. Once sufficiently trained, the model classified another 38 points per image. The ReefCloud platform includes model validation tools to check the performance of the model in classifying points. Point classifications (50 points per image) were exported as a .csv file to calculate percent cover of 12 benthic categories of interest, including, crustose coralline algae (CCA), hard coral, reef pavement, turf algae, *Halimeda*, other macroalgae, gorgonians, softcoral, sponge, unconsolidated substrate, recently dead coral, and unidentified.

4.3 Temperature loggers

To directly quantify water temperatures at ‘bright spot’ and adjacent reefs a series of long-term temperature loggers were deployed during both the Feb-Mar 2023 and Feb-Mar 2024 voyages. The temperature loggers (Hobo Water Temp Pro v2 Data Logger - U22-001) were programmed to record water temperature every 30 minutes, and attached to a stainless steel stake driven vertically into the reef substrata, avoiding areas of live coral (Figure 3.4). A temperature logger was deployed in each of two habitats (reef crest and reef slope) at 22 sites across nine reefs in 2023 (2 sites at each of Flinders, Lihou, and Moore Reefs, and East Diamond and Willis Islets; 3 sites at each of Bougainville, Holmes, Osprey, and Ashmore Reefs) and at 13 sites across six reef in 2024 (2 sites at each of Cato, Wreck, Kenn, Saumarez and Marion Reefs; 3 sites at Mellish Reef; Appendix 3). An additional logger was deployed at ~20m on the reef slope at each of the three sites on Mellish Reef in Feb 2024.

4.4 Data handling and analysis

Data from the 2023 and 2024 surveys were combined with those of the previous voyages (2018-2022) 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 2023).

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 comparisons among years, 58 sites were identified that were surveyed in the years 2023 and 2024 that had been surveyed at least once between 2020-2022 (Appendix 2). This included 15 sites in the Southern CSMP, 36 sites in the Central CSMP, and 7 sites in the Northern CSMP. 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.

5 *Findings*

5.1 Shallow water benthic communities

The back-to-back (2020 and 2021) bleaching events in the CSMP were severe and widespread, and resulted in a decrease in shallow water coral cover from 27% in 2020 to 13% in 2022, a mean decline of 52% (Hoey et al. 2021, 2022). There was, however, considerable variation in the change in coral cover among regions (e.g., change from 2021 to 2022: 28% and 26% declines in the northern and central CSMP, respectively, and a 4% increase in the southern CSMP), among reefs (59% decline at Holmes Reefs to a 22% increase at Saumarez Reef), and sites within reefs (e.g., 18% vs 45% declines at Herald 1 and Herald 4, respectively; Hoey et al. 2022). Understanding the ongoing impacts of, and the potential recovery from, these bleaching events on the cover and composition of coral assemblages, and the associated fish and invertebrate communities, is critical in assessing the current health of reefs in the CSMP.

5.1.1 Coral cover and richness

The average cover of hard (Scleractinian) corals recorded across the 78 CSMP sites surveyed in 2023 and 2024 was 18.65% (±1.42SE), ranging from 4.00% (±1.35 SE) at Frederick Reef in the southern CSMP up to 35.19% (±2.84 SE) at Ashmore Reef in the northern CSMP (Figure 4.1a). Average coral cover was approximately two- to three-fold greater on reefs in the northern CSMP (averaging 30.95 ± 1.89 %; although that dropped to 26.32 ± 1.62 % if Ashmore Reef was excluded), compared to the central (12.57 ± 1.56 %) and southern CSMP reefs (15.79 ± 2.67 %)

The average taxonomic richness of corals across the CSMP, based on the number of hard (Scleractinian) coral taxa (mostly genera) recorded using the 50m point-intercept transects at each survey site, was 15.0 taxa per site and ranged from 8.7 taxa per site (± 0.9 SE) at Frederick Reef in the southern CSMP to 18.2, 18.7 and 19.0 taxa per site (± 0.3 SE) at Boot, Osprey and Moore Reefs, respectively (Figure 4.1b). Coral richness displayed a similar pattern to coral cover among CSMP regions, with coral richness being generally greater in the northern CSMP

(17.5 taxa per site), compared to the central and southern CSMP (14.0 and 13.7 taxa per site, respectively; Figure 4.1b).

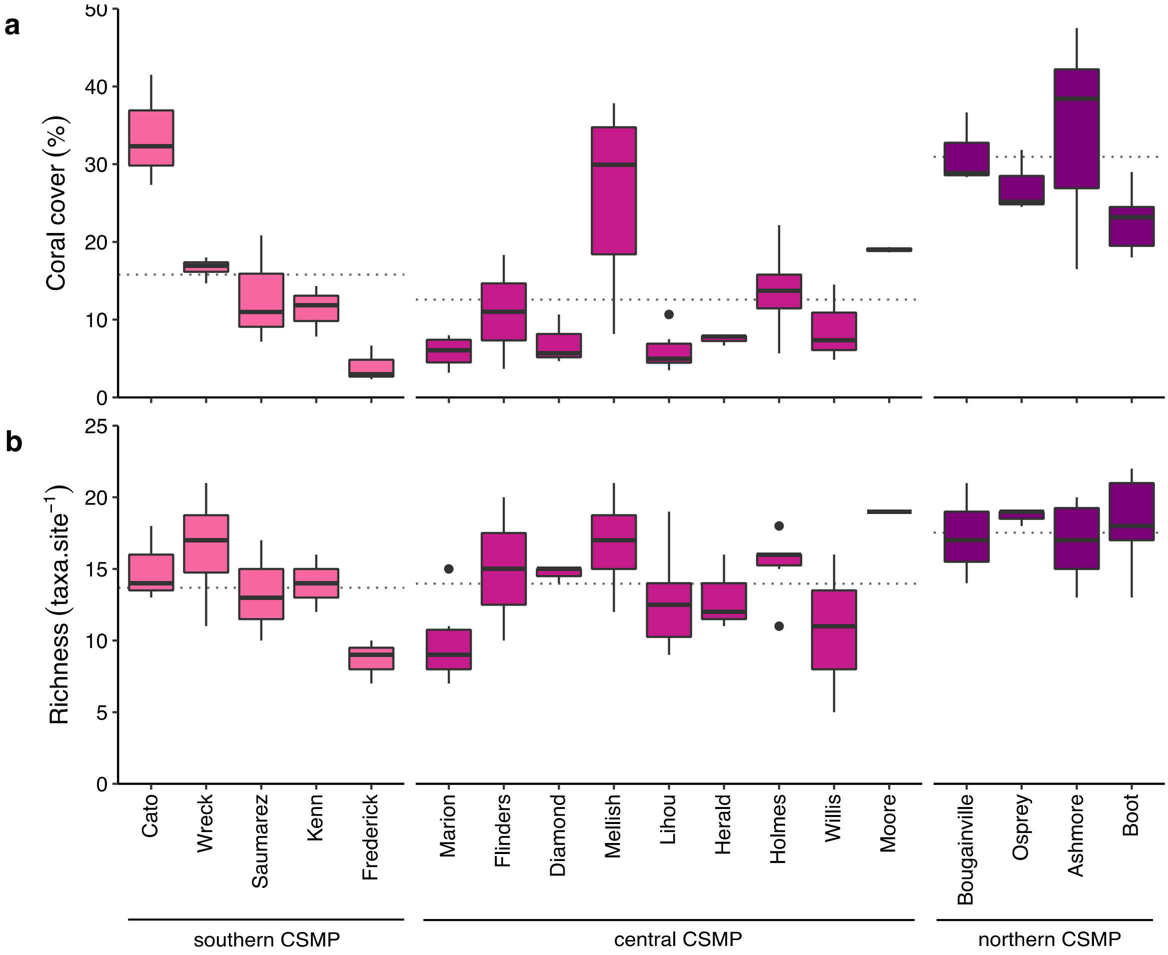


Figure 4.1 Variation in coral cover and coral richness among 18 reefs in the Coral Sea Marine Park (CSMP) in 2023-24. Data are based on the 50m point-intercept transects, with data for richness based on the number of coral taxa recorded at each of the 78 sites (i.e., pooled across transects and slope 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. Flinders, Lihou, Holmes, Moore, Bougainville, Osprey, Ashmore and Boot Reefs, Herald Cays, and Diamond and Willis Islets were surveyed in 2023, and Cato, Wreck, Saumarez, Kenn, Frederick, Marion and Mellish Reefs were surveyed in 2024.

There was, however, considerable variation in both coral cover and richness among reefs within each of the CSMP regions. In the southern CSMP, coral cover was >2-fold higher at Cato Reef (33.72 %) than the other four reefs (4.00 – 16.63 %), while Frederick Reef had the lowest coral cover (4.00 %) and lowest coral richness (8.7 taxa per site) of the five reefs (Figure 4.1). In the central CSMP, Mellish and Moore Reefs had the highest coral cover (25.81 and 19.00 %, respectively) and highest richness (16.8 and 19.0 taxa per site, respectively) of the nine central CSMP reefs. In contrast, both coral cover and coral richness at Willis Islets (cover: 8.89%; richness: 10.7 taxa per site), Lihou Reef (cover: 6.00%; richness: 12.8 taxa per site), Marion Reef (cover: 5.86 %; richness: 9.8 taxa per site) and Herald Cays (cover: 7.50%; richness: 13.0 taxa per site) were lower than the regional average (Figure 4.1). In the northern CSMP, average coral cover ranged from 22.83% at Boot Reef to 35.19% at Ashmore Reef, while coral richness was relatively consistent across reefs (17.0 – 18.7 taxa per site; Figure 4.1).

5.1.2 Temporal changes in coral cover and richness

Coral cover - Comparisons of coral cover in shallow reef habitats across the 17 reefs that were surveyed in 2020, 2021, 2022, and/or 2023/24 (i.e., excluding Boot Reef) revealed a marked difference in the temporal patterns in coral cover among the three CSMP regions, most notably from 2022 to 2023/24 (Figure 4.2). While coral cover declined in all three CSMP regions 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: 14.74%; 2023: 12.23%; a decline of 16.6 %), remained remarkably stable in the southern CSMP (2022: 15.65 %; 2023/24: 15.64 %), and increased by 8.9% in the northern CSMP over the same period (2022: 26.17%; 2023: 28.50%; Figure 4.2). These changes in coral cover from 2022 to 2023/24 were relatively consistent between habitats (i.e., the reef crest: 1-3m depth; reef slope: 7-10m) in the southern and central CSMP, while changes in coral cover on northern CSMP reefs differed between habitats (Figure 4.3). Coral cover was consistently lower on the reef crest (range: 13.8 – 17.0 %) than the reef slope (35.5 – 67.1%) across all years (i.e., 2020-2023/24), with the increase in coral cover from 2022 to 2023/24 being largely driven by an 17.2% increase in coral cover on the reef slope (2022: 35.5%; 2023: 41.6%).

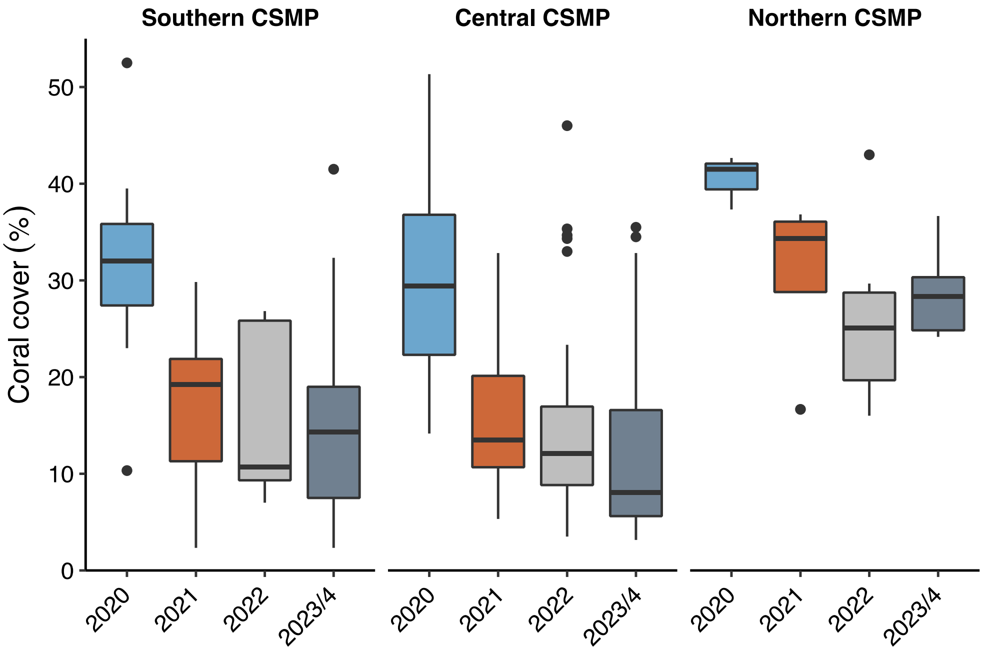


Figure 4.2 Temporal change in coral cover within the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

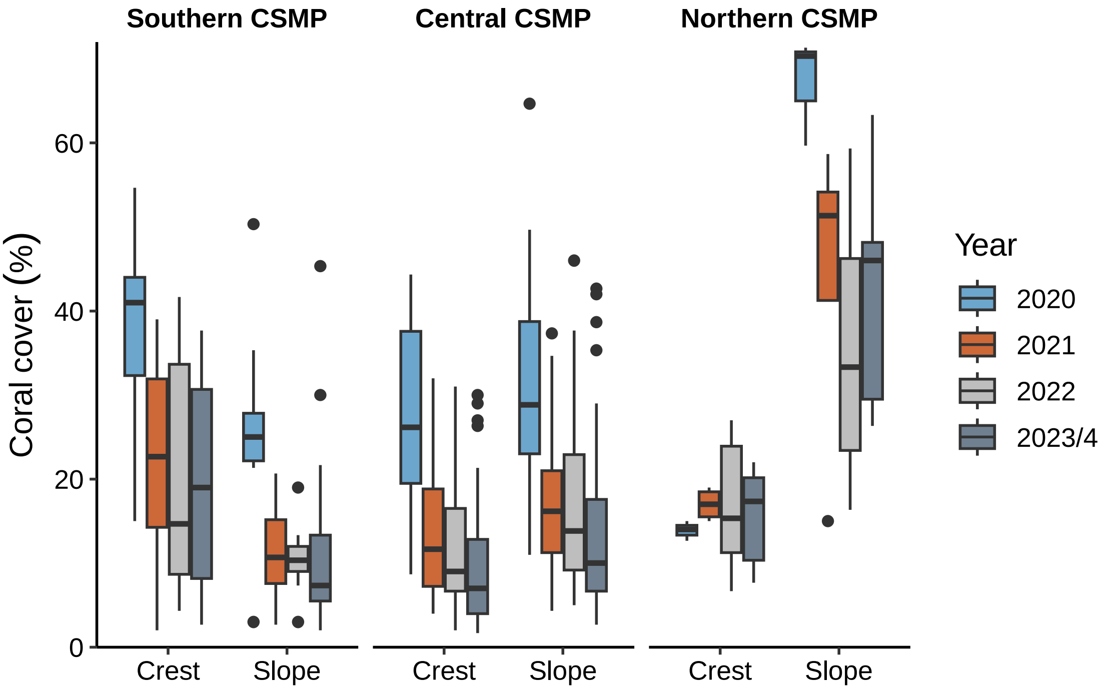


Figure 4.3 Temporal variation in coral cover between shallow reef habitats (reef crest and reef slope) within the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites in 2020, 2021, 2022, and/or 2023/24 across 17 reefs and pooled between habitats (reef slope and reef crest) within each site.

Changes in coral cover varied among reefs within each region, yet were relatively consistent among sites within each reef between 2022 and 2023/24 (Figure 4.5). In the central CSMP changes in coral cover between 2022 and 2023/24 ranged from a 58.4% decline on Marion Reef (2022: 13.83%; 2023/24: 5.75%) to a 49.5% increase at Holmes Reef (2022: 9.20%; 2023/24: 13.75%). It should be noted that the increase in coral cover at Holmes Reef is small in absolute terms (4.5% increase) and is partly an artefact of the limited number of surveys that were completed at Holmes Reef in 2022 due to unfavourable weather at the time of the surveys. Notably, coral cover at Moore Reefs, a previously identified 'bright spot' reef that hadn't been resurveyed since 2020, decreased from 39.50% in 2020 to 19.00% in 2023/24, a decline of 51.9%. Despite this decline in coral cover, the present coral cover at Moore Reefs (19.00%) is the second highest of the nine central CSMP surveyed, and over 50% greater than the regional average for the central CSMP reefs (12.3%). There was also a small decline in coral cover at Mellish Reef from 2022 to 2023/34 (2022: 27.36%; 2023/4: 24.10%), yet coral cover at Mellish was the highest of all central CSMP reefs in 2023/24 (Figure 4.4, 4.5).

Despite overall coral cover appearing stable between 2022 and 2023/24 in the southern CSMP, this was partly attributable to the inclusion of Cato and Wreck Reefs that were last surveyed in 2020 and 2021, respectively. Excluding these two reefs revealed a 39.7% decline in coral cover on southern CSMP reefs between 2022 and 2023/24, ranging from a 35.6% decline on Kenn Reef (2022: 17.61%; 2023/24: 11.33%) to a 54.7% decline on Frederick Reef (2022: 8.83%; 2023/24: 4.00%; Figure 4.5).

The cause/s of the declines in coral cover on the southern and central CSMP reefs from 2022 to 2023/24 are difficult to determine, however the relatively widespread nature of the declines suggest that they are unlikely to be related to localised disturbances. Moderate levels of bleaching (Pale - Recently Dead) were recorded across some southern and central CSMP reefs in February 2022, ranging from

10.8% of colonies surveyed at Holmes Reefs to 37.8% at Marion Reef, with mean of 11.9% across the southern central CSMP (Hoey et al. 2022). This bleaching of corals in the southern and central CSMP coincided with a period of elevated water temperatures, with the greatest heat stress occurring in March 2022 and continuing into April 2022 in some areas (i.e., after the 2022 surveys had been completed; Figure 4.6). Importantly, the central and eastern region of the Queensland Plateau (including Herald Cays, Diamond and Willis Islets, and Lihou and Moore Reefs) and Marion Reef were exposed to 8-11 Degree Heating Weeks (DHW) in March 2022 (Figure 4.6), coinciding with the greatest declines in coral cover from our 2023/24 surveys. DHW combines the intensity and duration of heat stress experienced during the previous 3 months, and is a strong predictor of bleaching with DHW >4 likely to lead to significant bleaching, and DHW>8 likely to lead to significant mortality (Hughes et al. 2018), especially in more thermally sensitive species. While we cannot rule out other potential causes for the recorded declines in coral cover, the widespread declines across much of the southern and central CSMP, coupled with a lack of recently broken and/or dislodged corals that would be consistent with physical damage from severe storms (e.g., Fabricius et al. 2008), suggest that these declines are most likely related to bleaching-induced mortality. It is important to note that some paling and bleaching of corals was observed on southern and central CSMP reefs during the 2024 surveys (see Section 4.5.2), however there was negligible evidence of recent mortality from this event.

Overall, coral cover has declined by 51.2% across the CSMP from 2020 to 2023/24 with the greatest decline recorded in the central CSMP (58.6% decline), followed by a 50.2% decline in the southern and a 29.6% decline in northern CSMP.

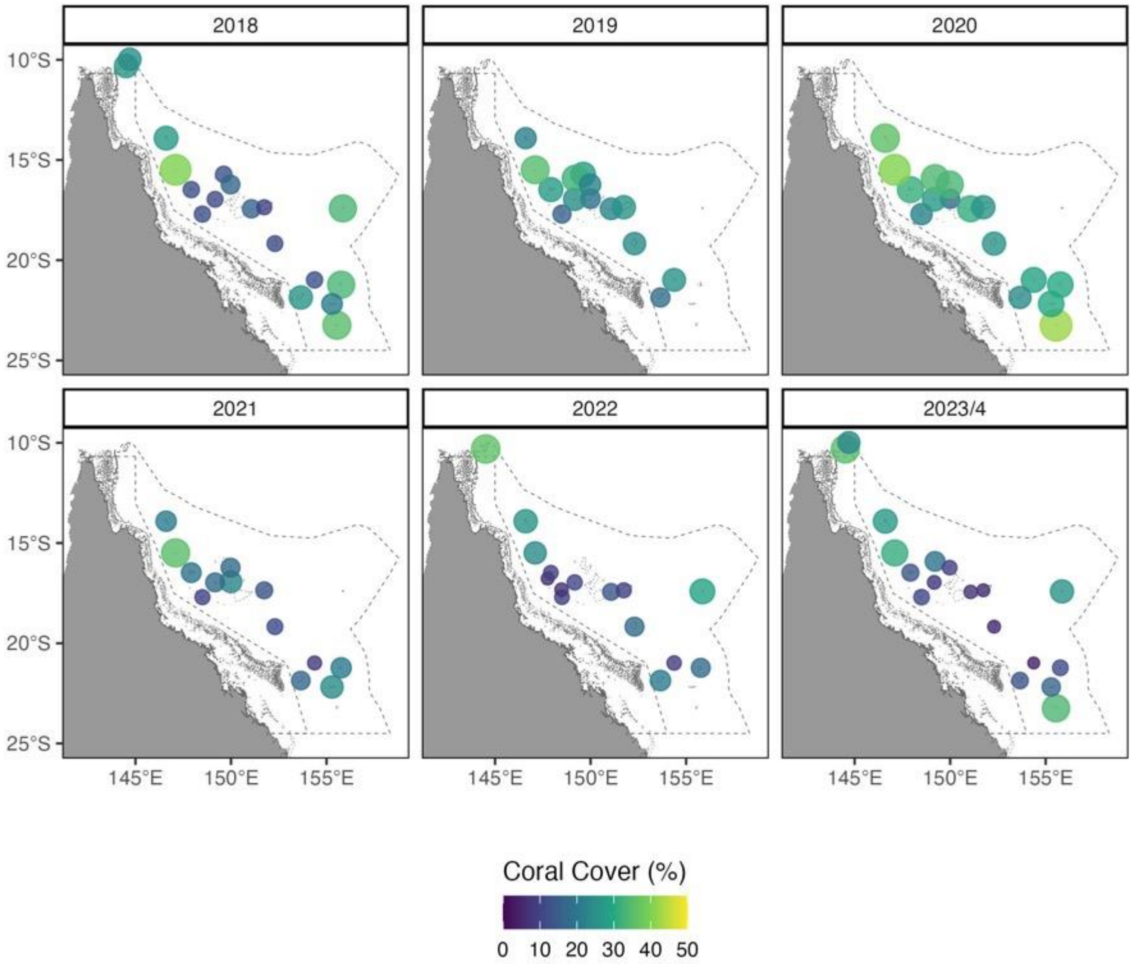


Figure 4.4 Spatial and temporal (2018-2023/24) variation in the cover of live hard (scleractinian) corals on shallow reef habitats (reef crest and reef slope) across 22 reef systems in the Coral Sea Marine Park. The size of individual points is proportional to the cover of live coral at each reef.

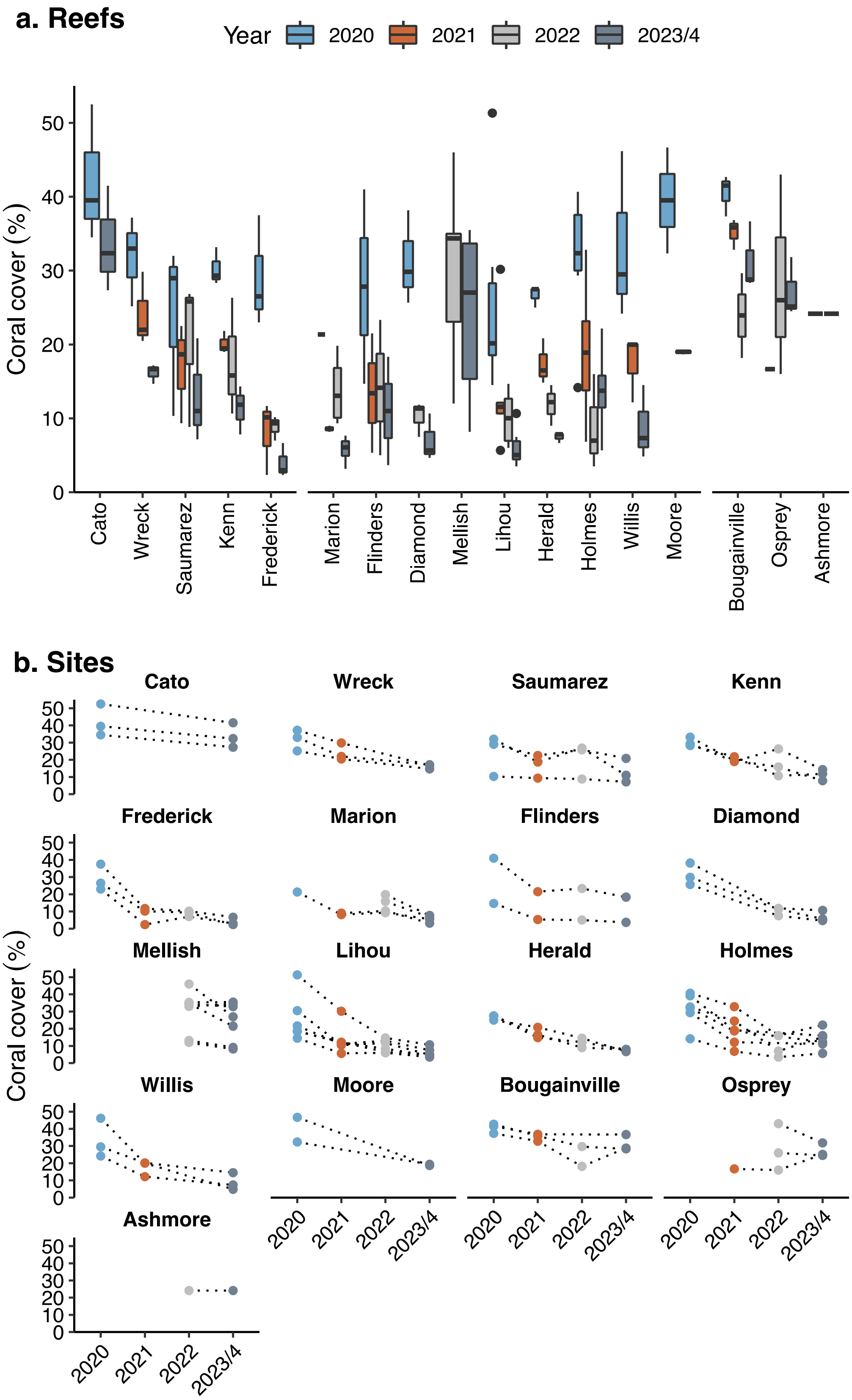


Figure 4.5 Temporal variation in coral cover among **(a)** seventeen reefs, and **(b)** 58 sites in the Coral Sea Marine Park that were surveyed at least once in 2020-22 and again in 2023/24. Data are based on surveys of matching sites in each year and pooled between habitats (reef slope and reef crest)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

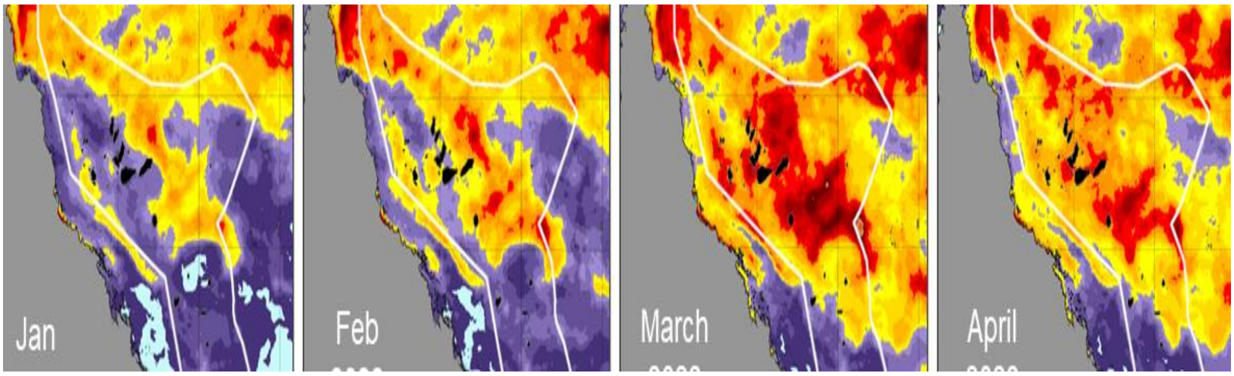


Figure 4.6 Progression of heat stress experienced throughout the Coral Sea Marine Park from January to April 2022. Colours represent the maximum Degree Heating Weeks (DHW). DHW combines the intensity and duration of heat stress experienced during the previous 3 months into one single number. It is a strong predictor of bleaching with DHW >4 likely to lead to significant bleaching, and DHW>8 likely to lead to significant mortality (Hughes et al. 2018), especially in more thermally sensitive species.

Coral richness – In contrast to coral cover, coral richness declined across all three CSMP regions from 2022 to 2023/24 (Figures 4.7, 4.8). Average coral richness declined from 16.3 to 13.2 taxa per site on southern CSMP reefs, from 16.9 to 14.2 taxa per site on central CSMP reefs, from 20.3 to 17.6 taxa per site on northern CSMP reefs from 2022 to 2023/24 (Figure 4.7). These declines were generally consistent among reefs in each region, the only exception being Holmes Reefs where average coral richness increased from 12.3 to 15.3 taxa per site from 2022 to 2023/24 (Figure 4.8). This apparent increase in richness on Holmes Reefs is likely related to some sites and zones on Holmes Reef not being surveyed in 2022 (as discussed previously).

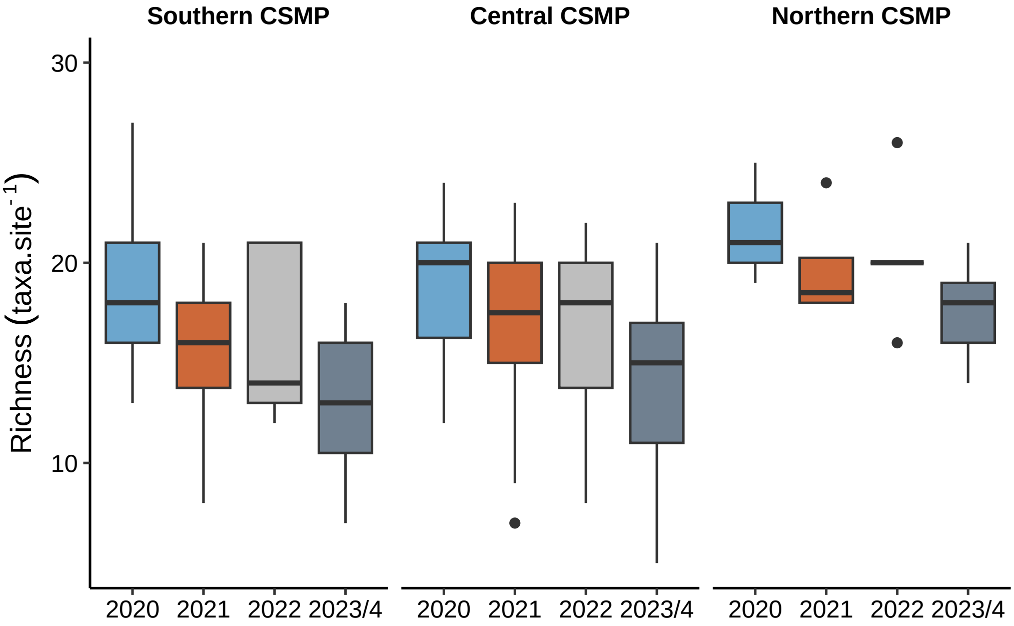


Figure 4.7 Temporal change in coral richness among the three regions in the Coral Sea Marine Park from 2020 to 2023/24. Data are based on surveys of 58 sites across 17 reefs that were surveyed at least once in 2020-22 and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs). Data are based on the number of coral taxa recorded at each of 58 sites (i.e., pooled across slope and crest habitats).

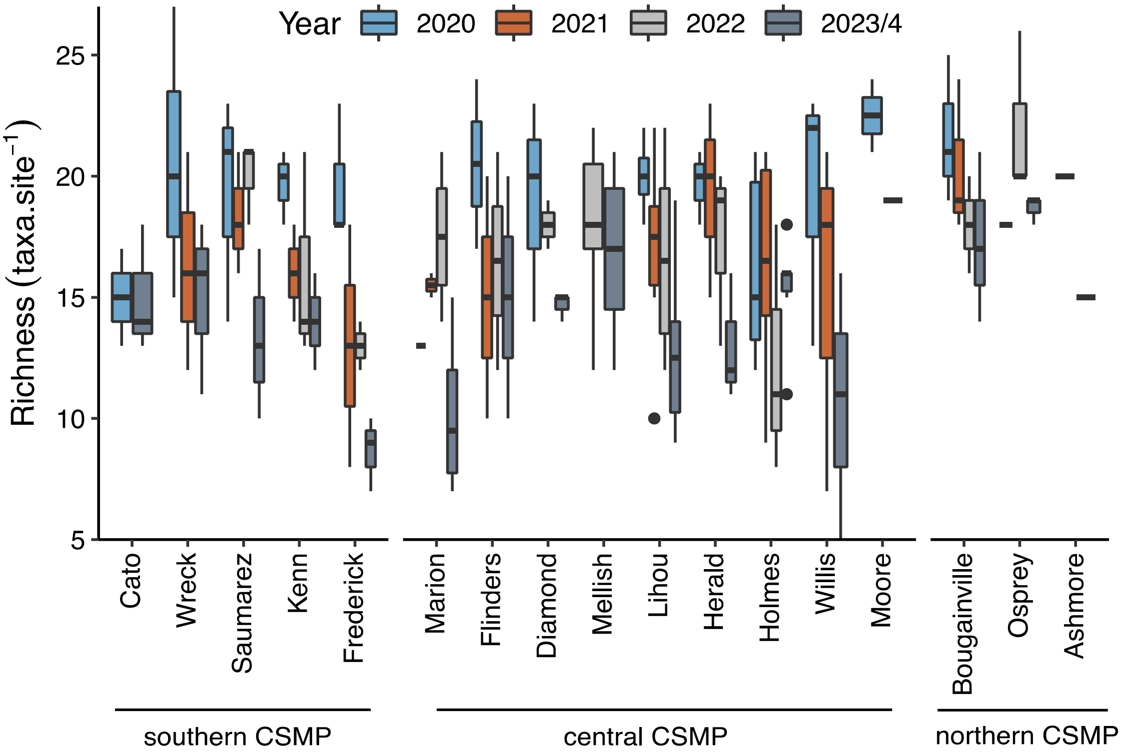


Figure 4.8 Temporal change in coral richness among 17 reefs in the Coral Sea Marine Park from 2020 to 2023/24. Data are based on the number of coral taxa recorded at each of 58 sites (i.e., pooled across slope and crest habitats). One to seven sites were surveyed at each reef.

5.1.3 Coral composition

The composition of shallow water coral assemblages in the CSMP varied both spatially (among regions) and temporally (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 from northern CSMP reefs were positioned on the right-hand side of the nMDS space and were characterised by a higher cover of branching *Porites, Montipora*, and *Pocillopora* (Figure 4.9 a,b).

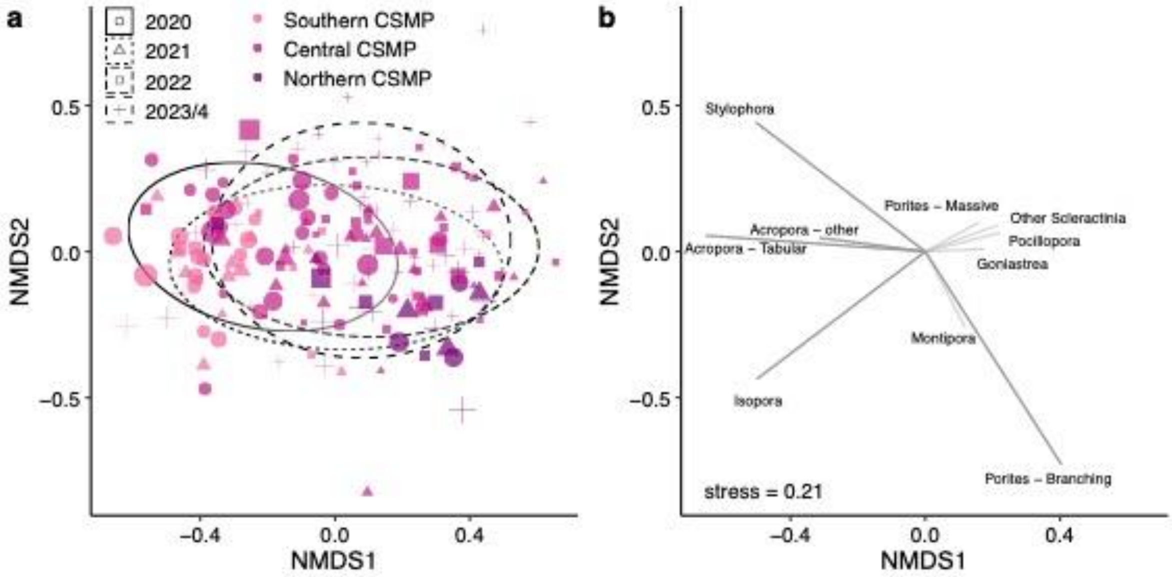


Figure 4.9 Regional and temporal (2020-2023/24) variation in the composition of shallow water coral assemblages within the Coral Sea Marine Park. Non-metric multidimensional scaling (nMDS) plot showing the variation in coral composition among years for the three regions of the Coral Sea Marine Park. Analyses are based on data from 58 sites that were surveyed at least once in 2020-2022, and again in 2023/24. 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 this spatial variation, there is a temporal change in coral assemblages through time (from left to right in the nMDS space) with the relative cover of tabular and 'other' *Acropora* and *Isopora* decreasing, and the relative cover of *Porites, Goniastrea, Pocillopora* and other Scleractinia increasing (Figure 4.9, 4.10). These directional shifts in coral composition were most evident in the southern and central CSMP (Figure 4.10a,b), with coral assemblages tending to become more variable among sites in the northern CSMP from 2020 to 2023/24 (Figure 4.10c).

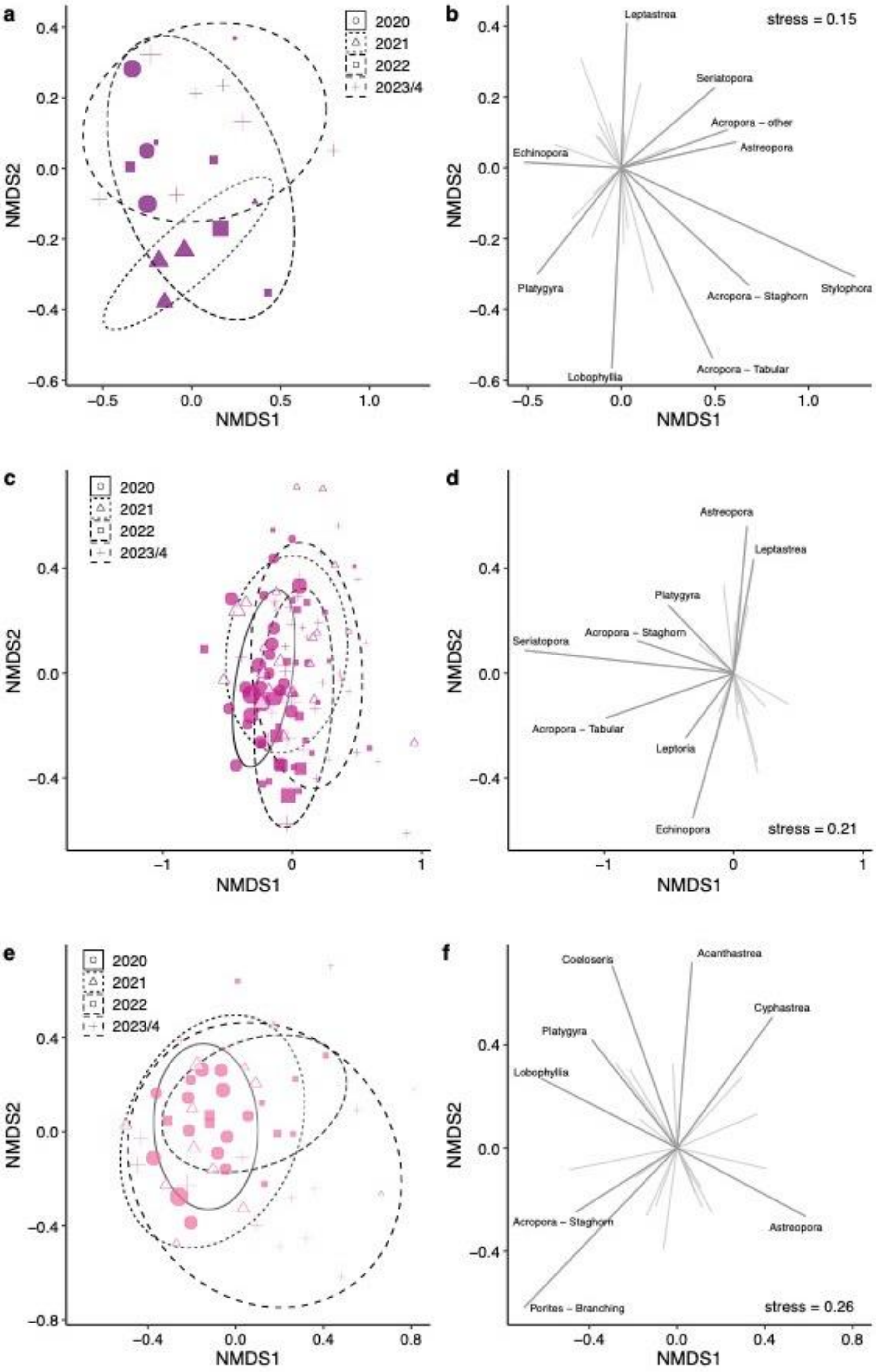


Figure 4.10 Non-metric multidimensional scaling (nMDS) plots showing the temporal variation (2020-2023/24) in shallow water coral composition among reefs in the **(a,b)** northern, **(c,d)** central, and **(e,f)** southern Coral Sea Marine Park. Analyses are based on data from 58 sites that were surveyed at least once in 2020-22 and again in 2023/24 (northern: 7 sites; central: 36 sites; southern: 15 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 Diverse coral assemblages and abundant planktivorous fish communities on the slopes at Osprey (left; November 2023), and Bougainville Reefs (right; November 2023) within the Coral Sea Marine Park. Image credits: Victor Huertas

Photographs of low coral cover habitats at Wreck Reef (top; February 2024), Moore Reef (middle; February 2023) and Herald Cays Reef (bottom; February 2023) within the Coral Sea Marine Park. Image credits: Victor Huertas

5.2 Algal assemblages

Macroalgae - Following the mortality of corals, opportunistic benthic taxa (in particular algae) often increase in abundance as they rapidly colonise the dead coral skeletons (Diaz-Pulido and McCook 2002). If these changes in benthic composition persist, they can inhibit the recovery of coral populations, and the associated assemblages and ecosystem goods and services they provide (Moberg and Folke 1999; Pratchett et al. 2014; Woodhead et al. 2019). Notably, shifts from coral- to macroalgal-dominance have been documented following large-scale coral mortality (e.g., Jamaica: Hughes 1994; Great Barrier Reef: Cheal et al. 2010; Seychelles: Graham et al. 2015). Once established, these macroalgal-dominated areas tend to persist due to a series of positive, or reinforcing, feedbacks that promote macroalgal assemblages and limit the recovery of coral populations (e.g., Hoey and Bellwood 2011; Van de Leemput et al. 2016; Johns et al. 2018). Predicted increases in the frequency and intensity of temperature-induced bleaching events and severe tropical storms under ongoing and future climate change has led to concerns that an increasing number of reefs may be overgrown by macroalgae (Hughes et al. 2017, 2018; Souter et al. 2021; Bellwood et al. 2019).

The cover of macroalgae across the 18 CSMP reefs surveyed in 2023/24 was generally low, with total macroalgal cover averaging 7.81%. Macroalgal cover was 4.6-fold greater on reefs in the central CSMP (10.93%) than the northern CSMP (2.37%; Figure 4.12). Macroalgal cover also varied among reefs within each region, ranging from 0.0% to 3.03% on Bougainville and Ashmore Reefs, respectively, in the northern CSMP, and from 4.97% to 22.28% on Marion Reef and Herald Cays, respectively, in the central CSMP, and from 1.767% to 18.00% on Kato and Saumarez Reefs, respectively in the southern CSMP (Figure 4.12).

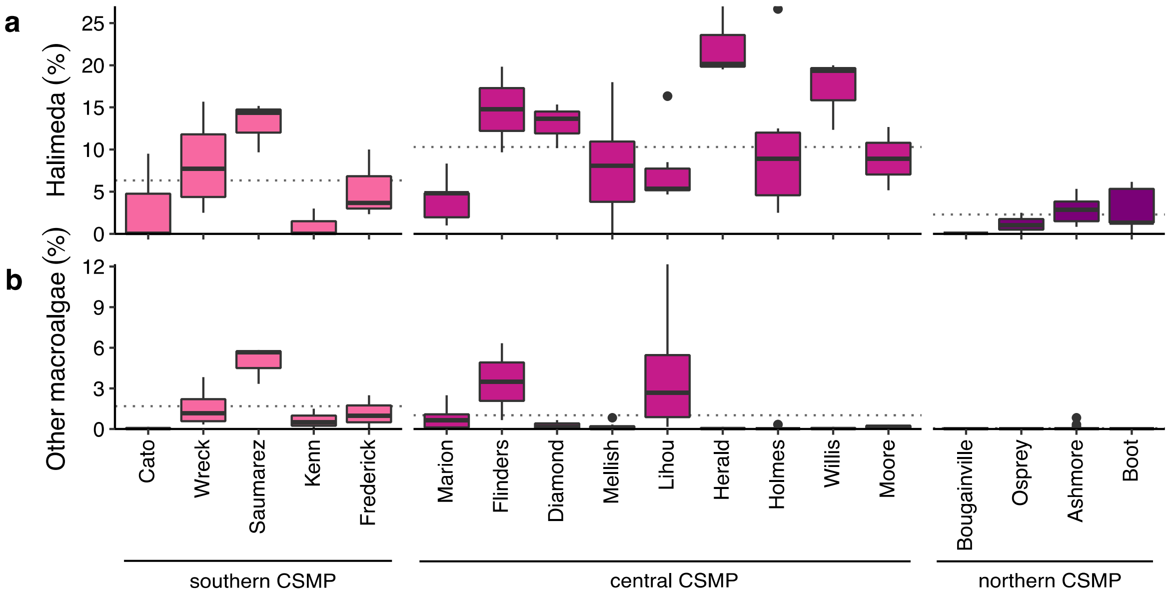


Figure 4.12 Variation in the cover of **(a)** *Halimeda* spp and **(b)** 'other' macroalgae among 18 reefs in the Coral Sea Marine Park (CSMP) in 2023-24. Data are based on the 50m point-intercept transects at each of the 78 sites (i.e., pooled across transects and slope and crest habitats). Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Dotted lines represent regional averages. Flinders, Lihou, Holmes, Moore, Bougainville, Osprey, Ashmore and Boot Reefs, Herald Cays, and Diamond and Willis Islets were surveyed in 2023, and Cato, Wreck, Saumarez, Kenn, Frederick, Marion and Mellish Reefs were surveyed in 2024.

Comparisons of macroalgal cover in shallow reef habitats across the 17 reefs that were surveyed at least once during 2020-2022 and again in 2023/2024 revealed a marked difference in the temporal patterns in macroalgal cover among the three CSMP regions (Figure 4.13). While macroalgal cover has remained low and relatively stable on reefs in the northern CSMP from 2020-2023 (0.16 – 2.59%), total macroalgal cover declined in the central CSMP from 7.66% (2020) to 4.24% (2022), before increasing 2.5-fold to 10.93% in 2023/24 (Figure 4.13).

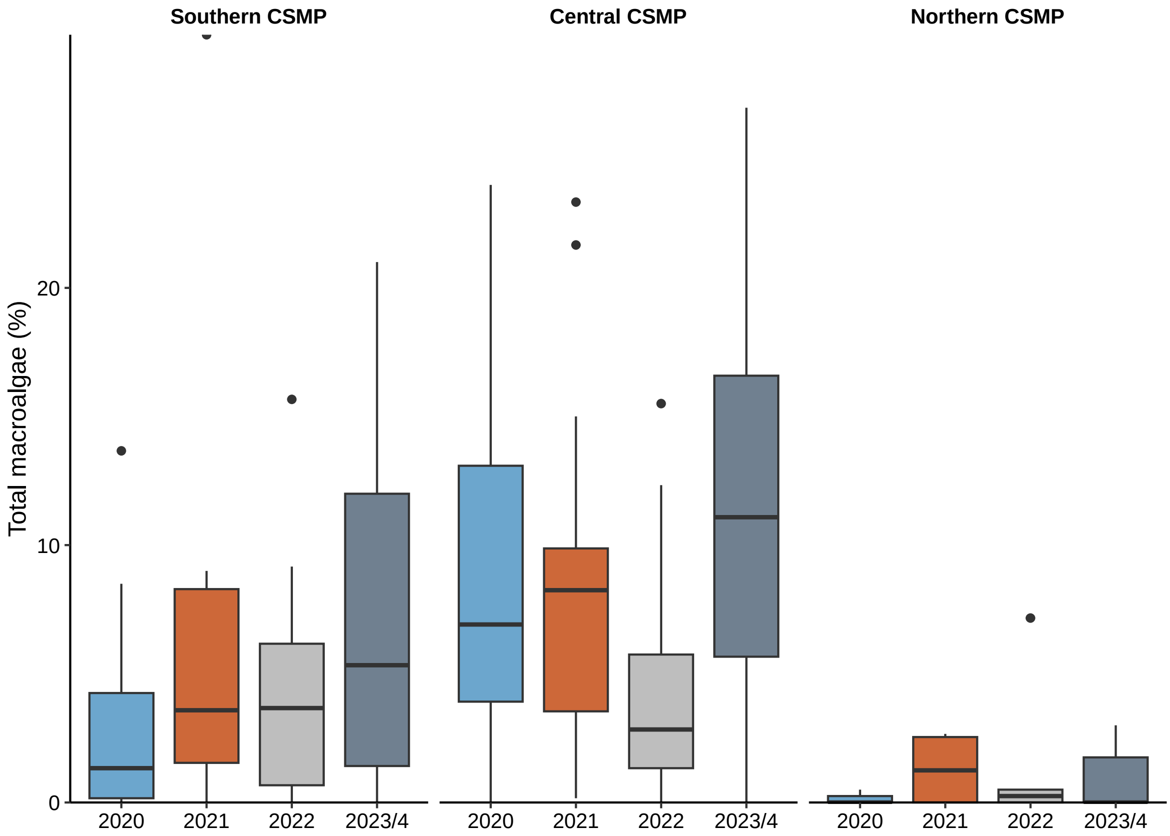


Figure 4.13 Temporal change in total macroalgae cover within the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at least once during 2020 - 2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

The green calcified macroalga *Halimeda* spp. accounted for >90% of all macroalgae recorded across all sites in 2023/24. The cover of *Halimeda* spp. increased 2.5-fold on reefs in the central CSMP from 2022 (4.23%) to 2023/24 (10.63%), and 5-fold on reefs in the southern CSMP over the same period (2022: 1.05%; 2023/24: 5.71%; 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). Unlike many large canopy-forming algae, such as *Sargassum,* that predominate on coastal 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. The cover of 'other' macroalgae was extremely low across all regions of the CSMP in 2023/24 (southern: 1.8%; central: 1.1%; northern: 0.0%; Figure 4.15). There was, however, some variation in the cover of ‘other’ macroalgae among reefs in the southern and central CSMP. In the central CSMP, the cover of ‘other’ macroalgae ranged from 0.06% at Herald Cays, Willis Islets and Holmes Reefs to 3.50% (primarily *Caulerpa*) at Flinders Reef and 4.06% (primarily *Rhipiliopsis*) at Lihou Reef (Figure 4.15). Similarly in the southern CSMP the cover of ‘other’ macroalgae ranged from 0.06% at Cato Reef to 4.94% (primarily *Caulerpa*) at Saumarez Reef.

Caulerpa and *Rhipiliopsis* are both fleshy green algae (Chlorophyta). *Caulerpa* has a creeping habit and can quickly grow to occupy areas free of other benthic taxa (i.e., hard corals, soft corals, sponges), while *Rhipiliopsis* has flattened fan-like blades that can form clumps but rarely exceed 1cm in height (Littler and Littler 2003). While the cover of *Caulerpa* has decreased at Saumarez Reef, the cause/s of the increases in *Caulerpa* at Flinders Reef and *Rhipiliopsis* at Lihou Reef (Figure 4.15) are unknown. While these increases are not currently a concern, they should be monitored to detect any further increases. Despite the declines in coral cover on shallow reef habitats throughout the southern and central CSMP from 2020 to 2023/24 (Figure 4.2), the cover of fleshy macroalgae (excluding *Halimeda*) has remained low throughout the CSMP (0.93%), and considerably lower than other oceanic reefs, such as Elizabeth and Middleton Reefs, and Lord Howe Island to the south (Hoey et al. 2011, 2018, 2024).

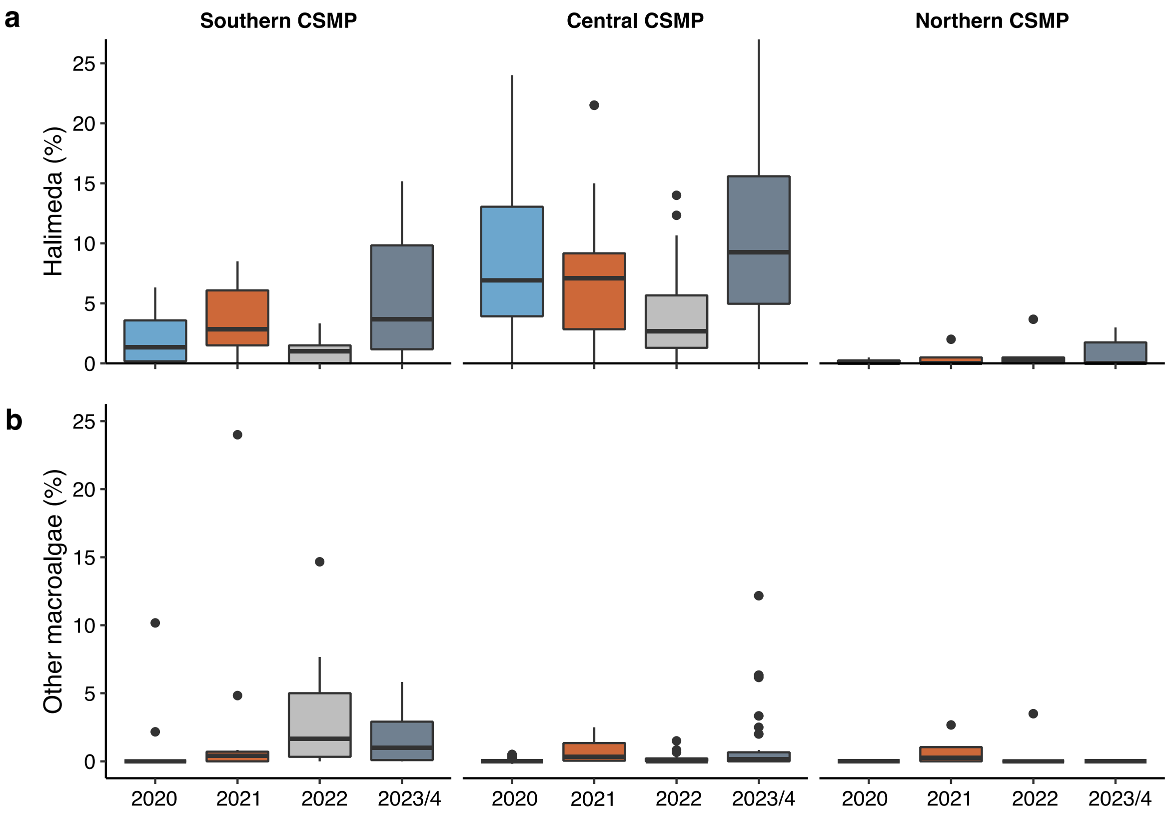


Figure 4.14 Temporal variation in the cover of **(a)** *Halimeda* spp. and **(b)** 'other' macroalgae within the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at least once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

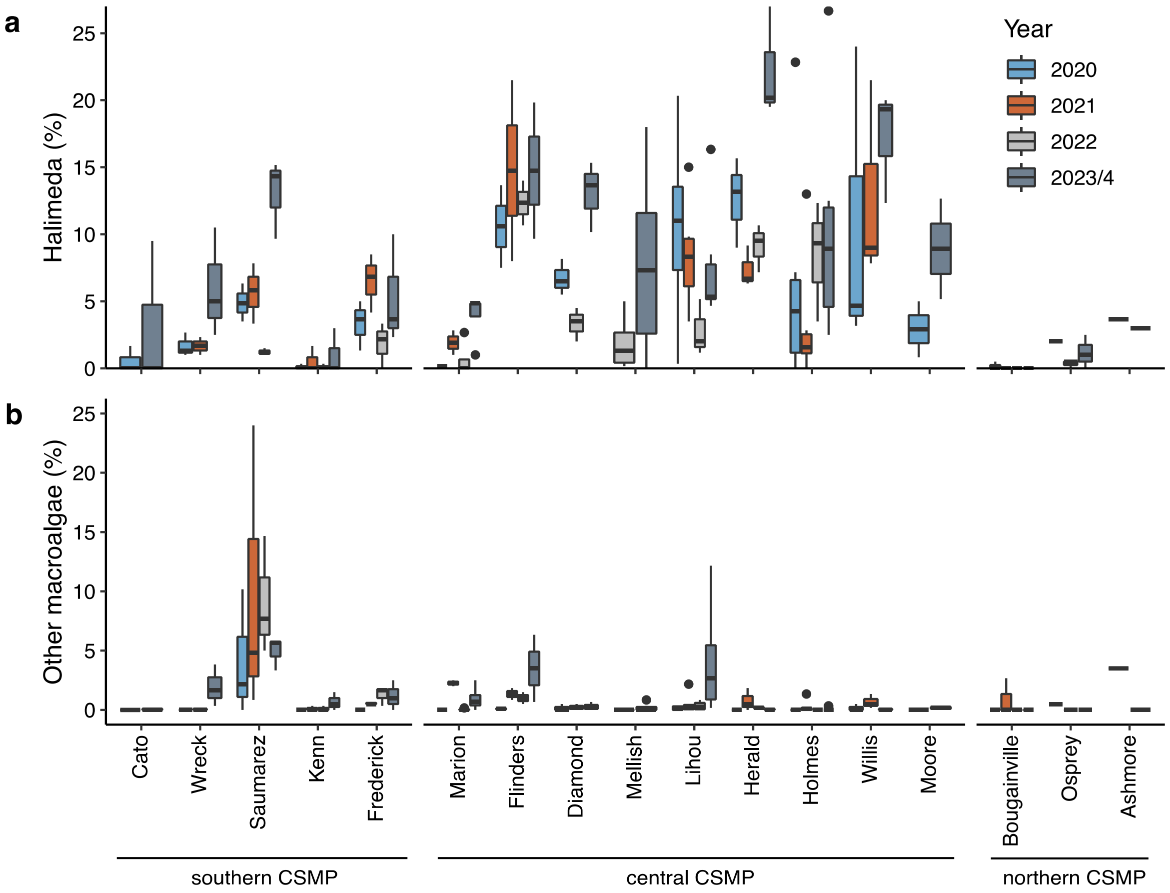


Figure 4.15 Temporal variation in the cover of **(a)** *Halimeda* spp and **(b)** 'other' macroalgae among 17 reefs in the Coral Sea Marine Park. Data are based on surveys of 58 matching sites that were surveyed at least once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

Crustose coralline algae (CCA) – The average cover of crustose coralline algae recorded across the 78 CSMP sites surveyed in 2023/24 was 25.77% (±1.45 SE), making it one of the most abundant benthic groups on reefs in the CSMP (Figure 4.16). Average CCA cover was generally greater on reefs in the central CSMP reefs (29.35 ± 2.18%) compared to the northern (20.71 ± 2.22%) and southern CSMP (24.30 ± 2.84%), although there was considerable variation among reefs within each region. Average CCA cover varied from 14.7% (Cato Reef) to 32.9% (Kenn Reef) in the southern CSMP, 20.8% (Mellish Reef) to 51.7% (Diamond Islets) in the central CSMP, from 12.7% (Boot Reef) to 35.6% (Osprey Reef) in the northern CSMP (Figure 4.16).

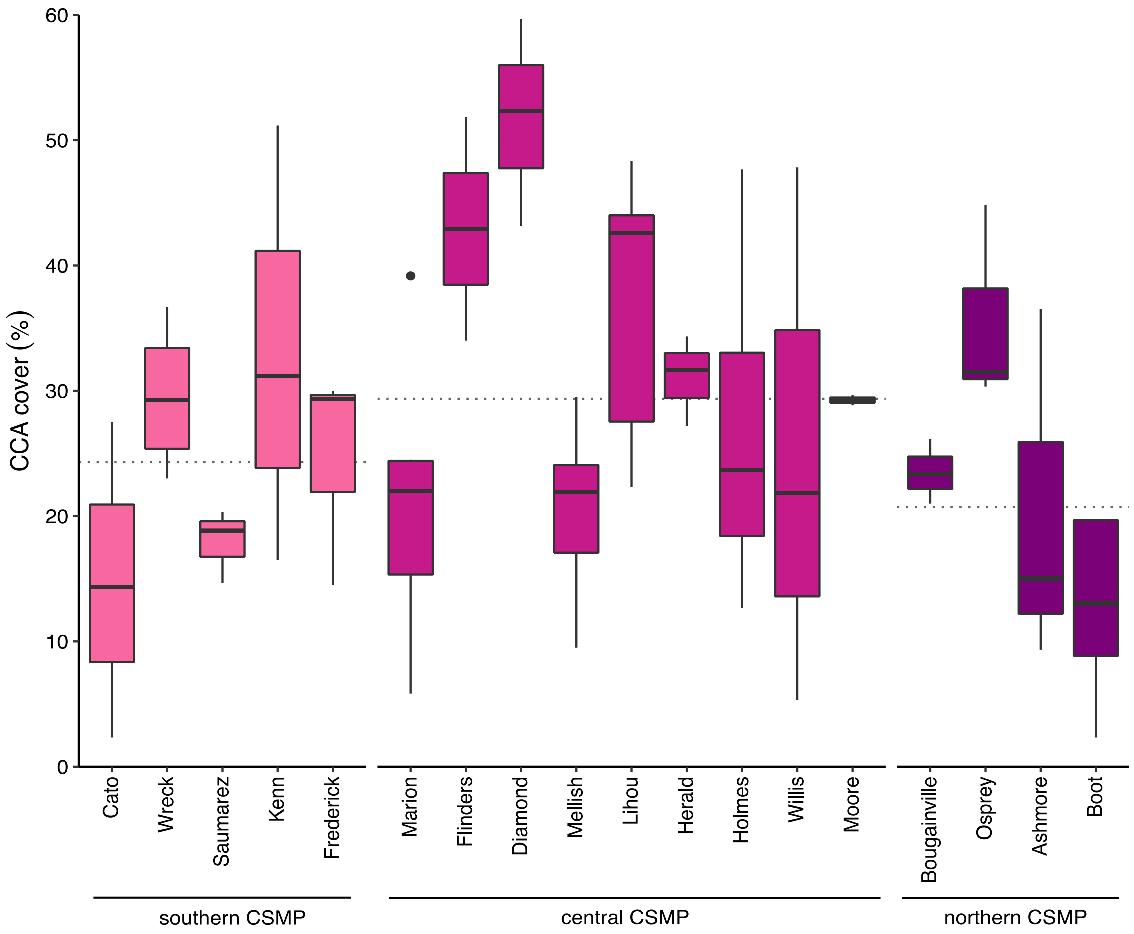


Figure 4.16 Variation in the cover of crustose coralline algae (CCA) among 18 reefs in the Coral Sea Marine Park (CSMP) in 2023-24. Data are based on the 50m point-intercept transects at each of the 78 sites (i.e., pooled across transects and slope and crest habitats). Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Dotted lines represent regional averages. Flinders, Lihou, Holmes, Moore, Bougainville, Osprey, Ashmore and Boot Reefs, Herald Cays, and Diamond and Willis Islets were surveyed in 2023, and Cato, Wreck, Saumarez, Kenn, Frederick, Marion and Mellish Reefs were surveyed in 2024.

Comparisons of CCA cover in shallow reef habitats across the 17 reefs that were surveyed at least once in 2020-2022 and again in 2023/24 revealed similar temporal patterns in the CCA cover across all three regions. CCA cover increased from 2020 to 2022, before declining across all three regions in 2023/2024 (Figure 4.17). The increases in CCA cover from 2020 to 2022 coincided with declines in coral cover over the same period across all regions (Figure 4.2). For example, CCA cover in the central CSMP increased from 28.15% to 41.77% from 2020 to 2022 (an absolute increase of 13.62%), which largely offset the decline in coral cover in the central CSMP over the same period (2020: 28.89%, 2022: 10.05%; an absolute decline of 18.84%). It appears therefore that CCA's, rather than turfs (including turf algae and cyanobacteria) or macroalgae, are able to rapidly colonise and/or grow to cover recently dead coral skeletons. This is important as CCA's are generally viewed as a critical component of healthy coral reef ecosystems, contributing to reef calcification, cementing and infilling (e.g., Teichert et al. 2020; Cornwall et al. 2023), inducing the settlement of coral larvae (e.g., Harrington et al. 2004; Abdul Wahab et al. 2023), and potentially the provision of 3-dimensional structure for reef associated species (Hoey et al. 2022).

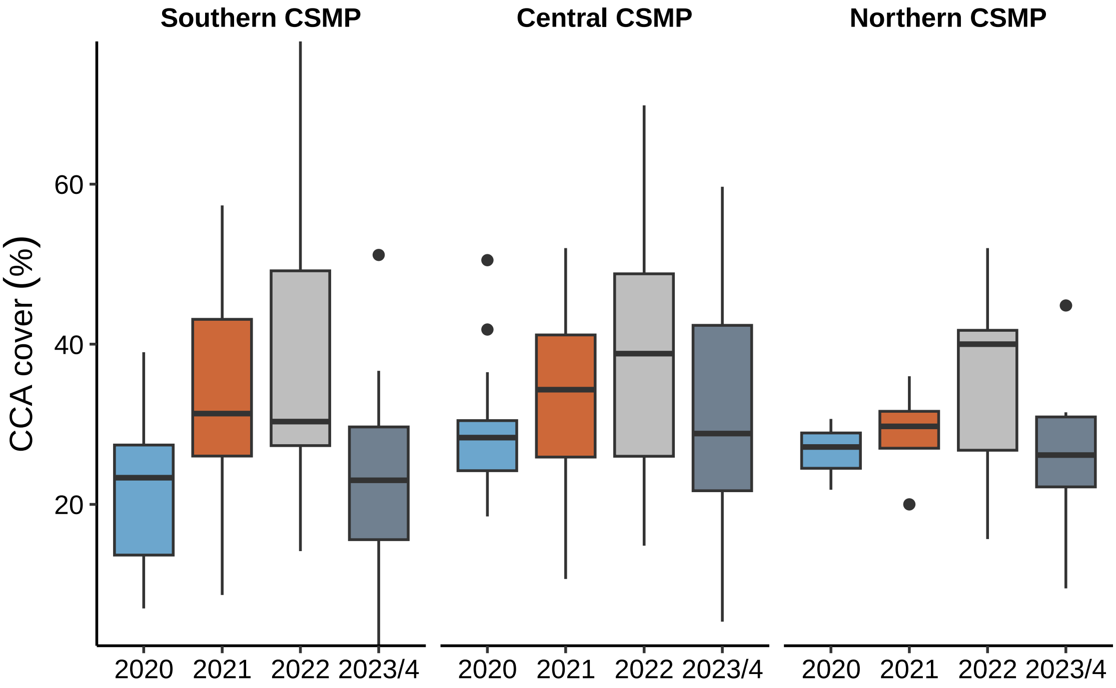
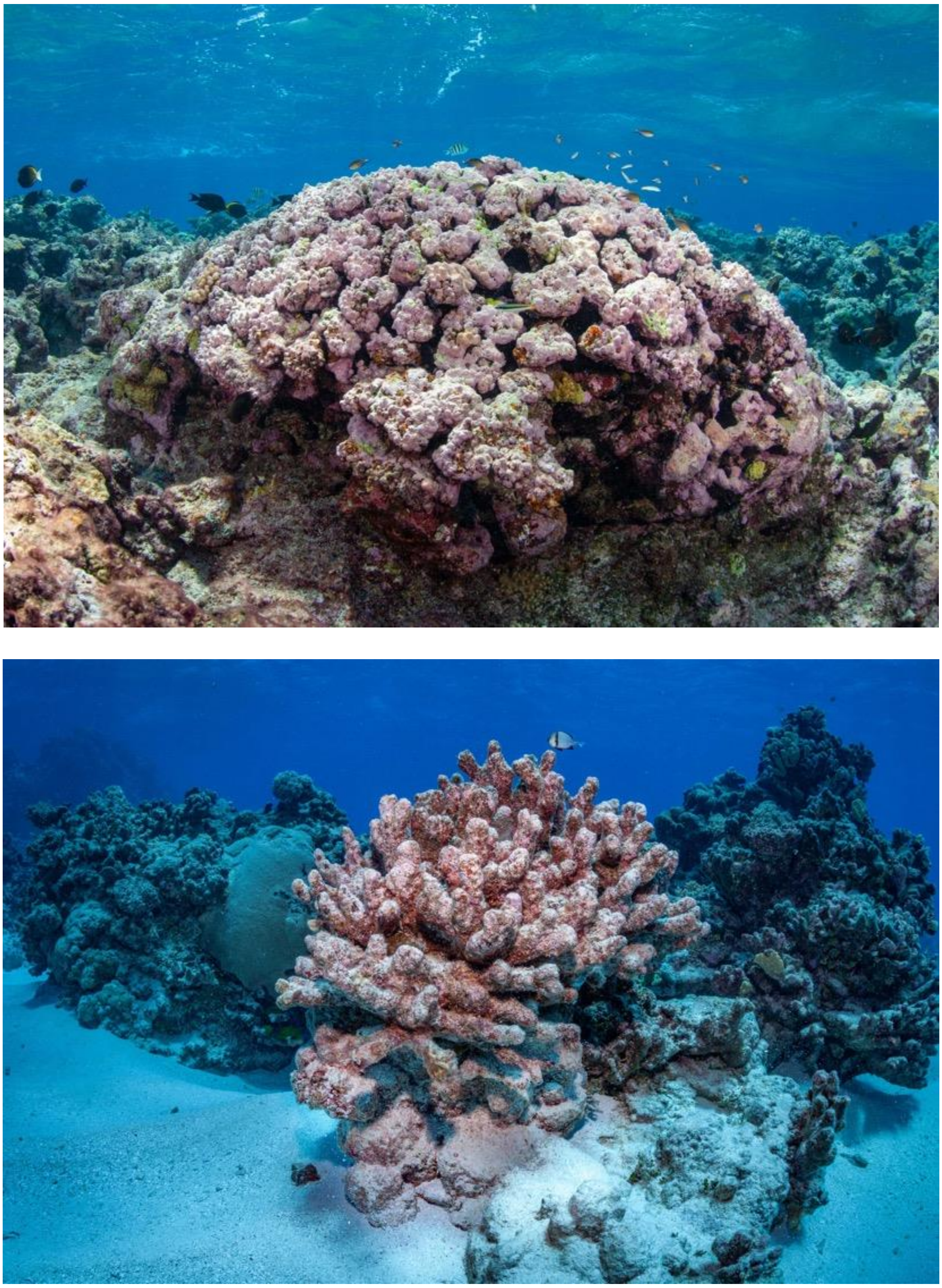


Figure 4.17 Temporal change in the cover of Crustose Coralline Algae (CCA) within the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at least once during 2020-22 and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

A decline in CCA cover from 2022 to 2023/24 was evident across all three regions; from 38.2% to 23.8% in the southern CSMP, 36.9% to 30.1% in the central CSMP, and 35.4% to 26.7% in the northern CSMP (Figure 4.17). While the declines in CCA cover were relatively similar across reefs in the northern CSMP, there was considerable variation among reefs in both the southern and central CSMP (Figure 4.18). The decline in CCA cover within the central CSMP was largely driven by declines at three reefs (Marion Reef, Diamond Islets and Herald Cays), and within the southern CSMP was largely driven by a decline at a single reef, Frederick Reef (Figure 4.18).



Images showing dead corymbose and branching coral skeletons colonised by crustose coralline algae at Willis (top) and Frederick (bottom) Reefs. Image credits: Victor Huertas

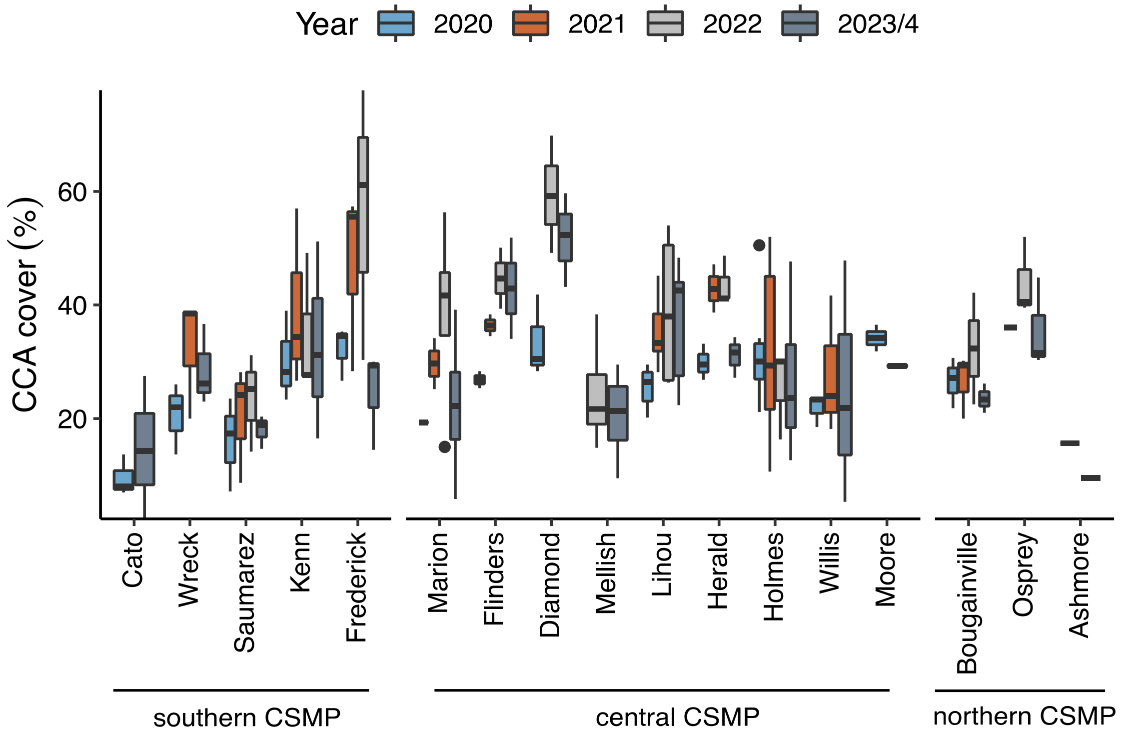


Figure 4.18 Temporal variation in the cover of Crustose Coralline Algae (CCA) among 17 reefs in the Coral Sea Marine Park. Data are based on surveys of 58 matching sites that were surveyed at least once during 2020-2022 and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

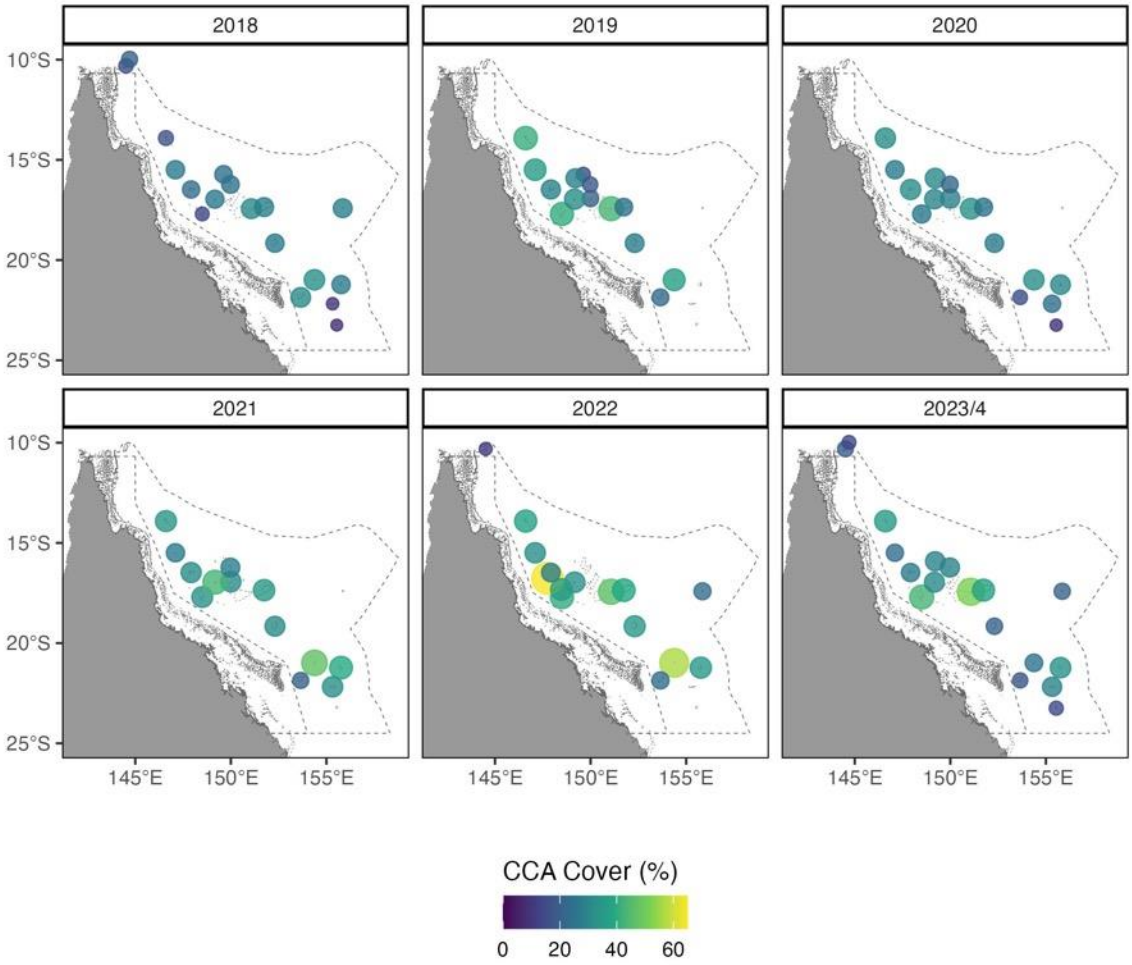


Figure 4.19 Spatial and temporal (2018-2023) variation in crustose coralline algae (CCA) cover on shallow reef habitats (reef crest and reef slope) across 22 reef systems in the Coral Sea Marine Park. The size of individual points is proportional to CCA cover at each reef.

5.3 Shallow Water Coral Reef Fish Assemblages

Reductions in coral cover and shifts in the composition of coral assemblages, as has been experienced across the CSMP following the 2020, 2021, and 2022 bleaching events (Figures 4.2, 4.9), often lead to reductions in the structural complexity of reef habitats and the associated reef fish and invertebrate assemblages (e.g., Wilson et al. 2006; Stella et al. 2011; Hoey et al. 2016; Robinson et al. 2019). The greatest and most immediate effects on bleaching-induced coral mortality are on fishes that rely on these corals for food (i.e., corallivores) or shelter (e.g., Pratchett et al. 2008; Hoey et al. 2016), and have been shown to lead to shifts in the composition of fish assemblages from coral specialists to habitat and/or diet generalists (e.g., Bellwood et al. 2006a, 2012; Richardson et al. 2018). In particular, the loss of fast-growing, and thermally sensitive tabular and staghorn *Acropora* (Burn et al. 2023) have been shown to reduce the three-dimensional structure and functionality of reef habitats (Hughes et al. 2018; McWilliam et al. 2020). While reductions in live coral cover may have immediate effects on species that rely on live corals as adults, it has been estimated that approximately 75% of reef fish species use live coral at some stage during their life cycle (e.g., as a settlement or juvenile habitat; Coker et al. 2014). Any effects of coral loss on these species may take several years to be realised (e.g., Graham, et al. 2007).

5.3.1 Richness, density and biomass of reef fishes

A total of 102,224 fishes were recorded across the 78 sites and 18 reefs surveyed in 2023/24. Eleven fish species that had not been recorded during surveys or observations of shallow reef habitats of the CSMP on the previous voyages (2018-2022) were recorded during the 2023/24 surveys. All of these eleven species (*Chromis richardsoni, Cirrhilabrus* sp., *Epinephelus spilotoceps, Lutjanus biguttatus, Naso lopezi, N. minor, N. thynnoides, Pentapodus aureofasciatus, Pycnochromis lineatus, Scarus festivus,* and *Sphyraena qenie*) were recorded from Ashmore and Boot Reefs in the far north of the CSMP. Three of these species (*N. lopezi, N. minor,* and *P. aureofasciatus*) have been previously recorded in deeper (>40m) reef habitats in the CSMP using baited remote underwater video systems (BRUVs; Galbraith et al. 2022), and the remaining eight species were new records for the CSMP, taking the total fish species recorded in the CSMP during the past six years of surveys to 650 species (Appendix 5).

The richness, density, and biomass of reef fishes were generally lower on reefs in the southern CSMP, intermediate on reefs in the central CSMP, and highest on reefs in the northern 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 69 species per site in the southern CSMP, 72 species per site in the central CSMP to 90 species per site in the northern CSMP, and from 56 species (Kenn Reef) to 100 species per site (Osprey Reef) among individual reefs. Variation in average species richness of reef fishes was greatest in the central CSMP ranging from 59 species per site at Diamond Islets to 87-89 species per site at Holmes and Moore Reefs (Figure 4.20a). There was also considerable variation in species richness of reef fish among southern CSMP reefs, ranging from 56 species (Kenn Reef) to 76 species per site (Frederick and Saumarez Reefs). Reef fish species richness was less variable among reefs in the northern CSMP, ranging from 87 to 100 species per site at Ashmore and Osprey Reefs, respectively (Figure 4.20a). As noted previously (Hoey et al. 2020, 2021), the higher species richness of corals and reef fishes in the northern CSMP (Figures 4.1b, 4.20a) is consistent with well-known latitudinal gradients in the diversity of marine species (Hillebrand 2004; Bellwood and Hughes 2001).

In 2023/24 regional averages in fish densities were approximately 2-fold higher in the northern CSMP (219.0 individuals per 100 m^2) compared to the southern and central CSMP (82.5 and 121.8 individuals per 100 m^2, respectively; Figure 4.20b). Like fish species richness there was considerable variation in the density of reef fish recorded among reefs within each region. This variation was most pronounced among reefs in the southern and central CSMP, where the mean density of reef fishes varied 4-fold among reefs (southern CSMP: 37.9 to 140.4 0 individuals per 100 m^2 at Kenn and Frederick Reefs, respectively; central CSMP: 56.3 to 223.0 individuals per 100 m^2 at Diamond Islets and Moore Reefs, respectively; Figure 4.20b). Mean density of reef fish was less variable among reefs in the northern CSMP, ranging from 192.3 (Boot Reef) to 275.3 individuals per 100 m^2 (Osprey Reef, Figure 4.20b).

Regional patterns in reef fish biomass were similar in direction but greater in magnitude to those of fish species richness and density. The mean reef fish biomass recorded on reefs in the northern CSMP (27.1 kg per 100m^2) was 2-fold to 3.3-fold greater than that recorded on reefs on southern CSMP (8.1 kg per 100m^2) and central CSMP reefs (12.9 kg per 100m^2, respectively; Figure 4.20c). Reef fish biomass varied widely (~12-fold) among reefs, ranging from 3.1 kg per 100 m^2 at Diamond Islets in the central CSMP to 36.5 kg per 100 m^2 at Boot Reef in the northern CSMP (Figure 4.20c). In the central CSMP reef fish biomass was greatest at Willis Islets and Marian, Mellish and Moore Reefs (13.2-23.6 kg per 100 m^2) and lowest at Diamond Islets (3.1 kg per 100 m^2). Reef fish biomass was less variable among reefs in the southern (ranging from 6.2 to 11.4 kg per 100 m^2 at Wreck and Saumarez Reefs, respectively) and northern CSMP (ranging from 23.2 to 36.5 kg per 100 m^2 at Ashmore and Boot Reefs, respectively; Figure 4.20c). It is important to note that the ‘bright spot’ reefs (i.e., Mellish, Moore, Bougainville, Ashmore and Boot Reefs) were again among the highest in richness, density and biomass of reef fish.

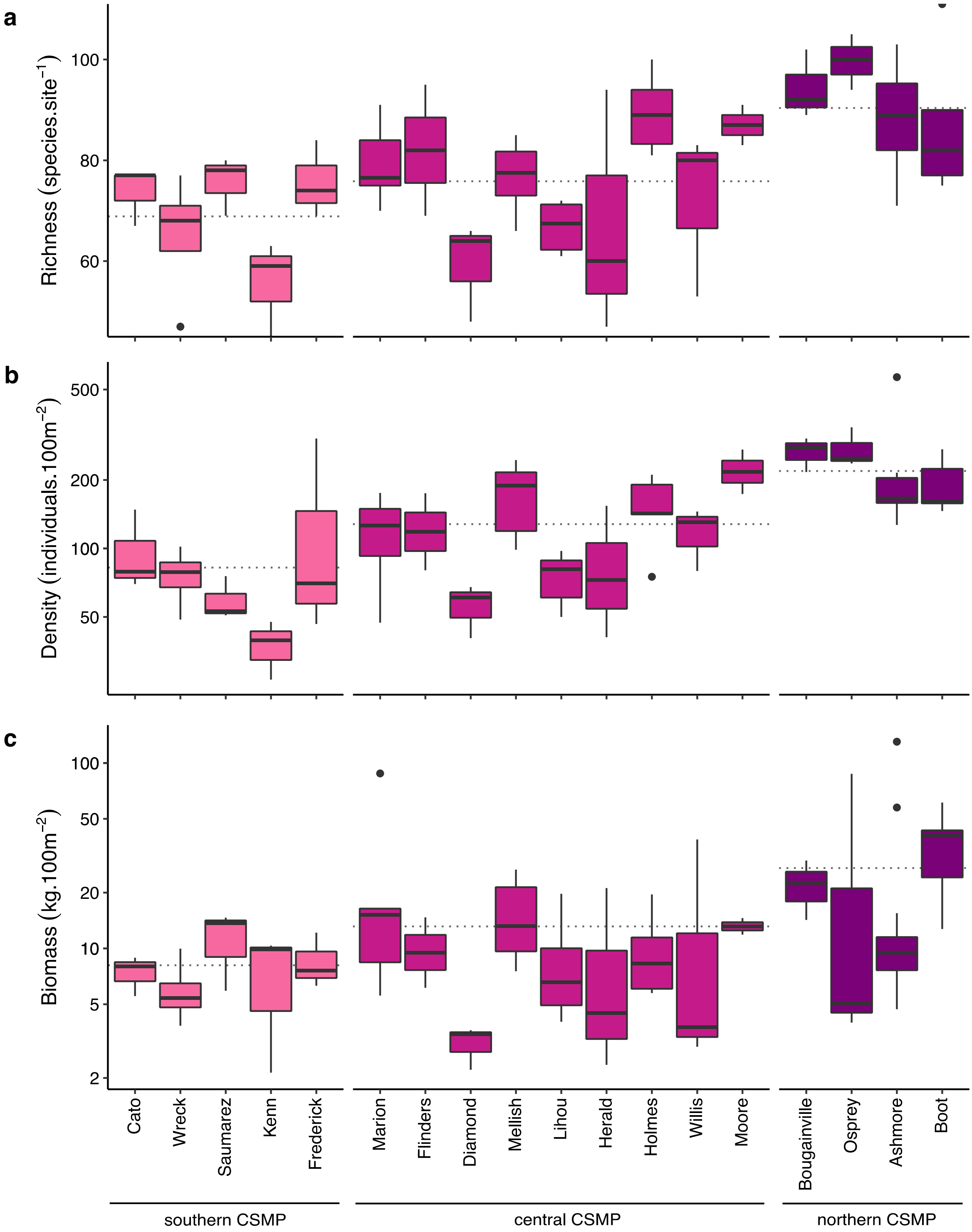


Figure 4.20 Spatial variation in the **(a)** species richness, **(b)** abundance, and **(c)** biomass of coral reef fishes among the 18 reefs surveyed in the Coral Sea Marine Park during

2023/24. Data are based on the 50m belt transects, with data for richness based on the number of fish species recorded at each of the 78 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.

5.3.2 Temporal changes in reef fish richness, density and biomass

Richness – On the reefs that were surveyed in at least once during 2020-2022 and again in 2023/24, the number of fish species recorded per site was variable among years in the southern CSMP, relatively stable in the northern CSMP, and declined gradually from 2020 to 2022 in the central CSMP (2020: 82 species; 2021: 76 species; 2022: 71 species), before increasing in 2023/24 (75 species per site; Figure 4.21a). This reduction in species richness in the central CSMP likely reflects the loss of fish species that are dependent of corals for food and/or shelter following the 58.6% reduction in coral cover on central CSMP reefs over this period (Figure 4.2). Despite some interannual differences, the declines in species richness were relatively consistent among reefs and sites in each region (Figures 4.23, 4.25) The only exception being Moore Reefs, where species richness increased from 82 to 87 species per site from 2020 to 2023 (Figures 4.22a, 4.23).

Density – The density of reef fishes showed a similar pattern of decline across all regions from 2020 to 2022, with average density of reef fish declining by 34%, 38%, and 48% in the northern, southern, and central CSMP, respectively, before recovering slightly in the southern and central CSMP but declining further in the northern CSMP in 2023/24 (Figure 4.21b). These changes in density were primarily driven by changes in abundance of corallivores, planktivores and grazing herbivores (see Section 4.3.3 below). Changes in mean density of reef fish from 2022 to 2023/24 were reasonably consistent among reefs in the southern CSMP with all reefs experiencing increases in density, however there was considerable variation among reefs in both the central and northern CSMP (Figure 4.22b). In the central CSMP, changes in reef fish density from 2022 to 2023/24 ranged from a 33.9% decline at Diamond Islets to a 69% increase at Mellish Reef, with the regional increase being largely driven by increases at three reefs (i.e., Flinders, Holmes and Mellish Reefs; Figures 4.22b, 4.25). Similarly, in the northern CSMP changes in reef fish density from 2022 to 2023/24 ranged from a 43% decline at Bougainville Reef to a 13% increase at Ashmore Reef.

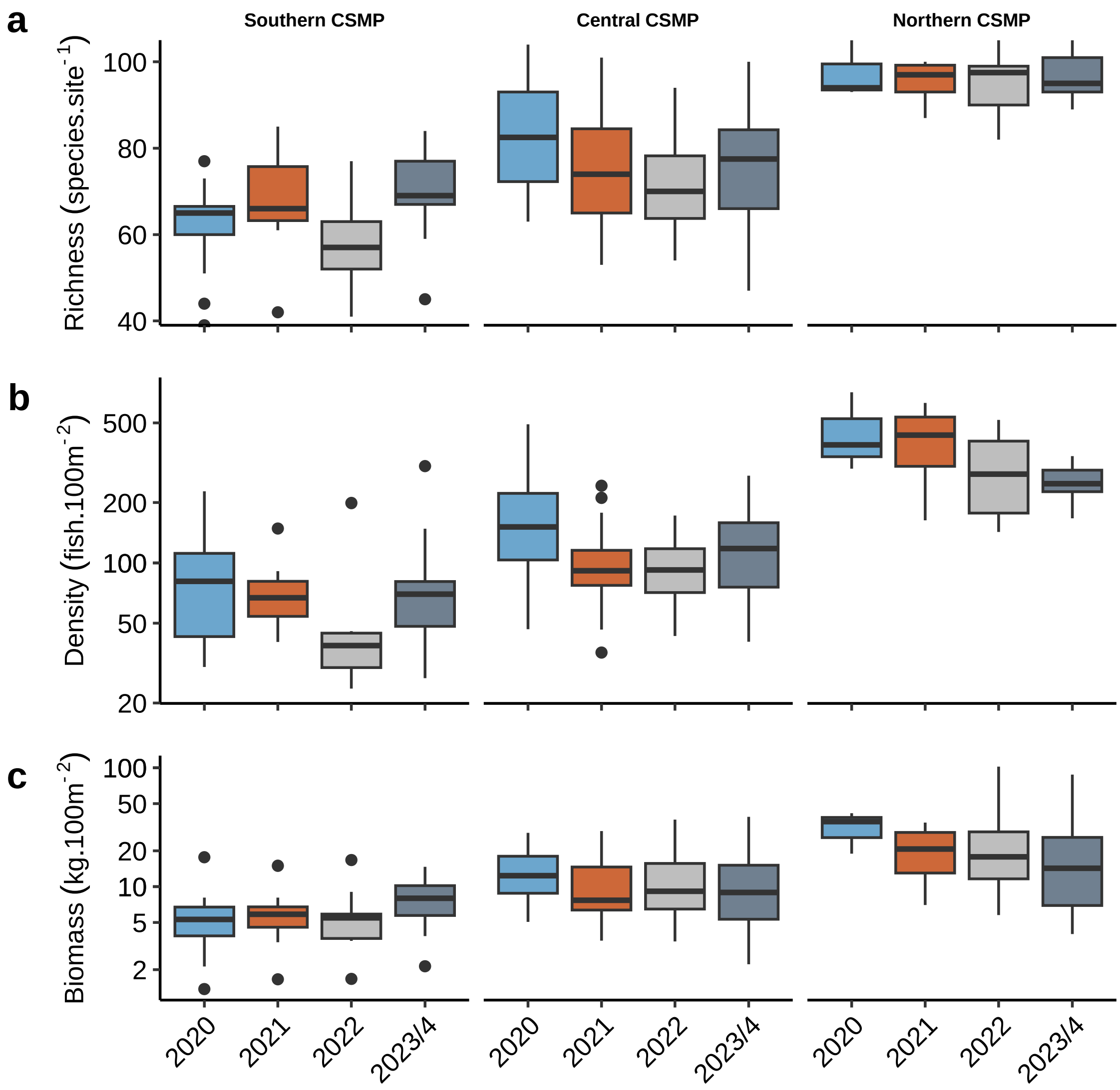


Figure 4.21 Temporal variation in the **(a)** species richness, **(b)** density, and **(c)** biomass of reef fish assemblages among the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs). 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 2022 broadly mirrored those of reef fish density in each of the three regions, although biomass declined further from 2022 to 2023/24 in the central (9% decline) and northern CSMP (21% decline) while biomass increased in southern CSMP (31% increase; Figure 4.21c). Note, the large increase in biomass in 2022 on northern CSMP reefs was driven by two schools (100 individuals in total) of the bumphead parrotfish, *Bolbometopon muricatum* (each 80-100cm in total length) being recorded along the reef crest at Bougainville 5 (Figures 4.22c, 4.27). These schools were not observed during the 2023/24 surveys and was almost solely attributable to recorded decline in biomass on Northern CSMP reefs. With the exception of the increase in reef fish biomass at Bougainville Reef in 2022, the declines in reef fish biomass have been largely consistent across reefs in the central and northern CSMP (Figures 4.22c, 4.26), and sites within each of those reefs (Figure 4.27).

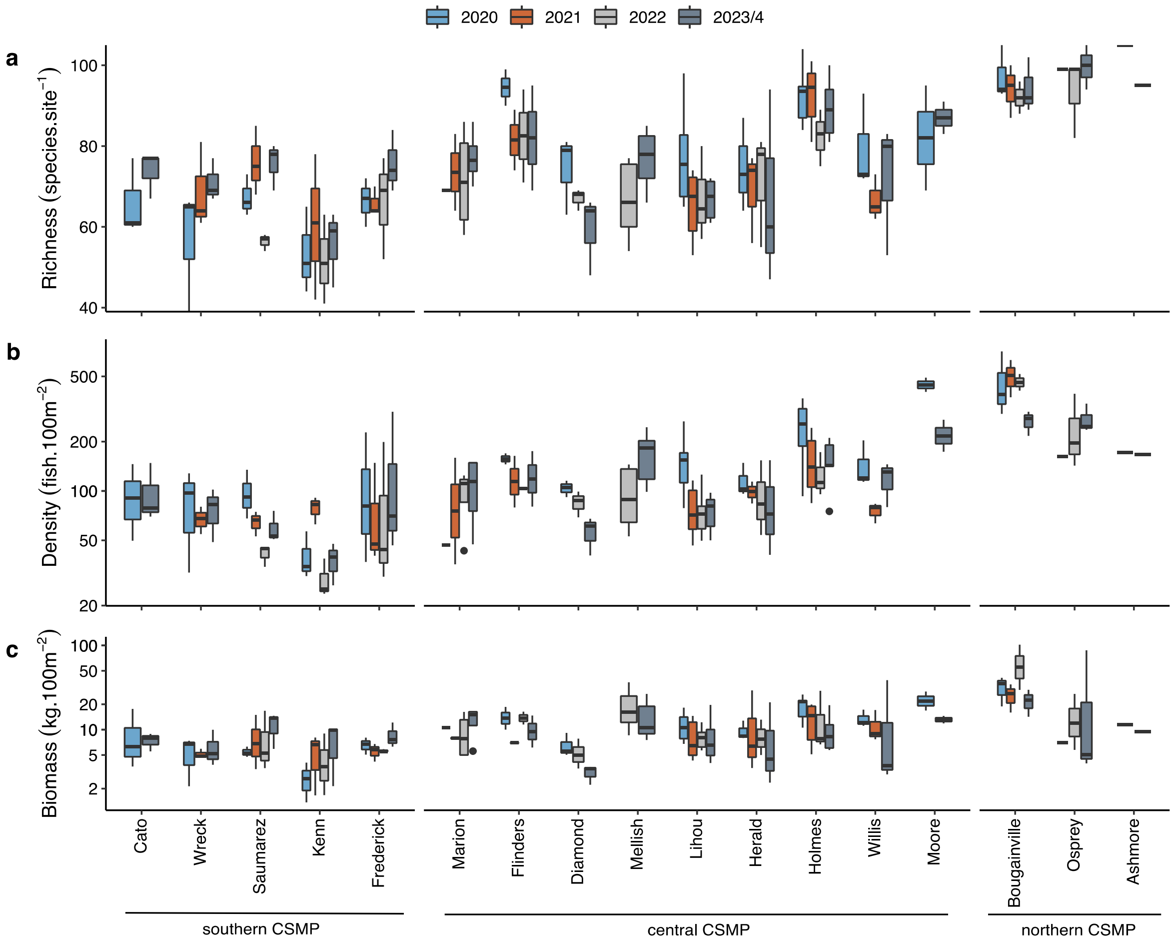


Figure 4.22 Temporal variation in the **(a)** species richness, **(b)** density, and **(c)** biomass of reef fish assemblages among 17 reefs in the Coral Sea Marine Park. Data are based on surveys of 58 matching sites that were surveyed at once during 2020-2022, and again in 2023/24. Note: the data for **(b)** density, and **(c)** biomass are presented on a $\log_{10}$-scale.

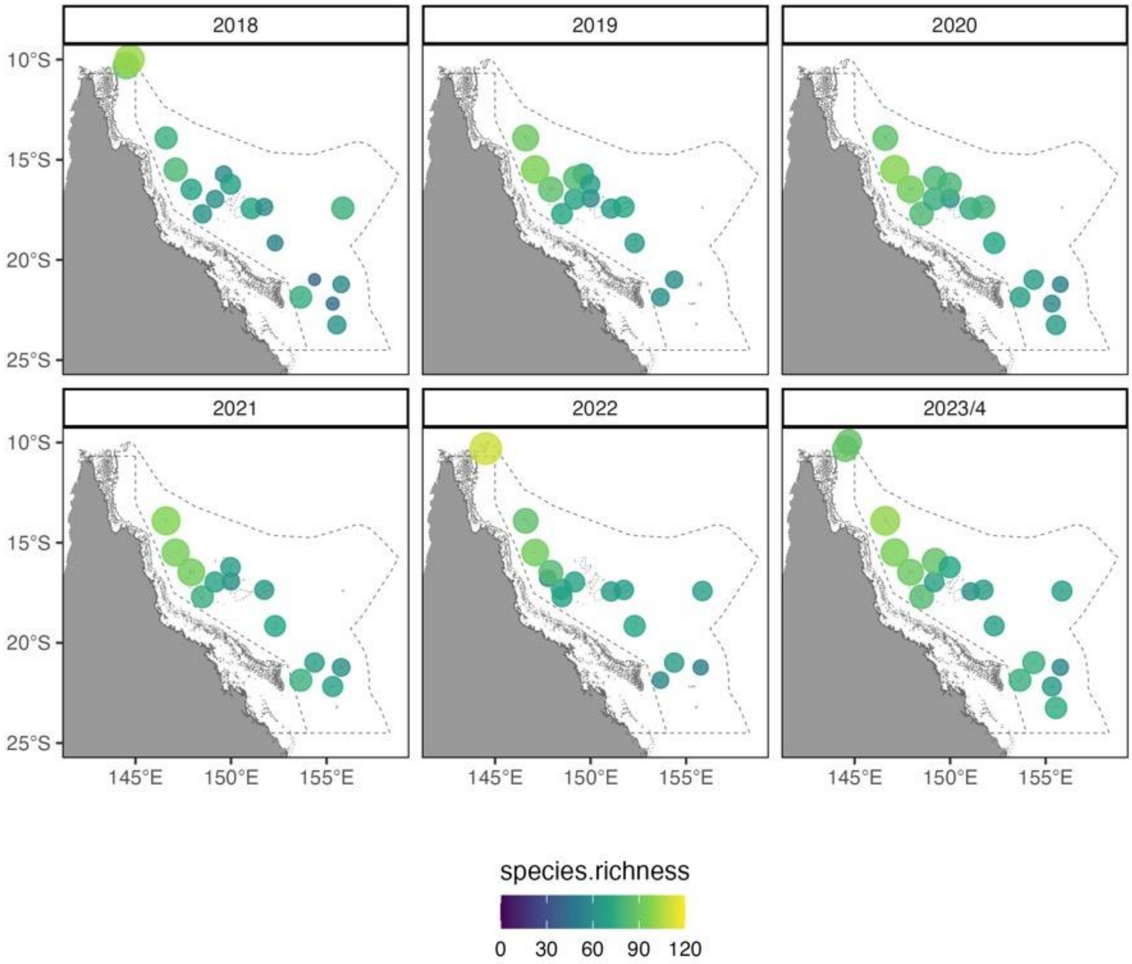


Figure 4.23 Spatial and temporal variation in the species richness of reef fish and sharks on shallow reef habitats (reef crest and reef slope) across 22 reef systems in the Coral Sea Marine Park (2018-2023/24). The size of individual points is proportional to the number of fish species recorded at each reef.

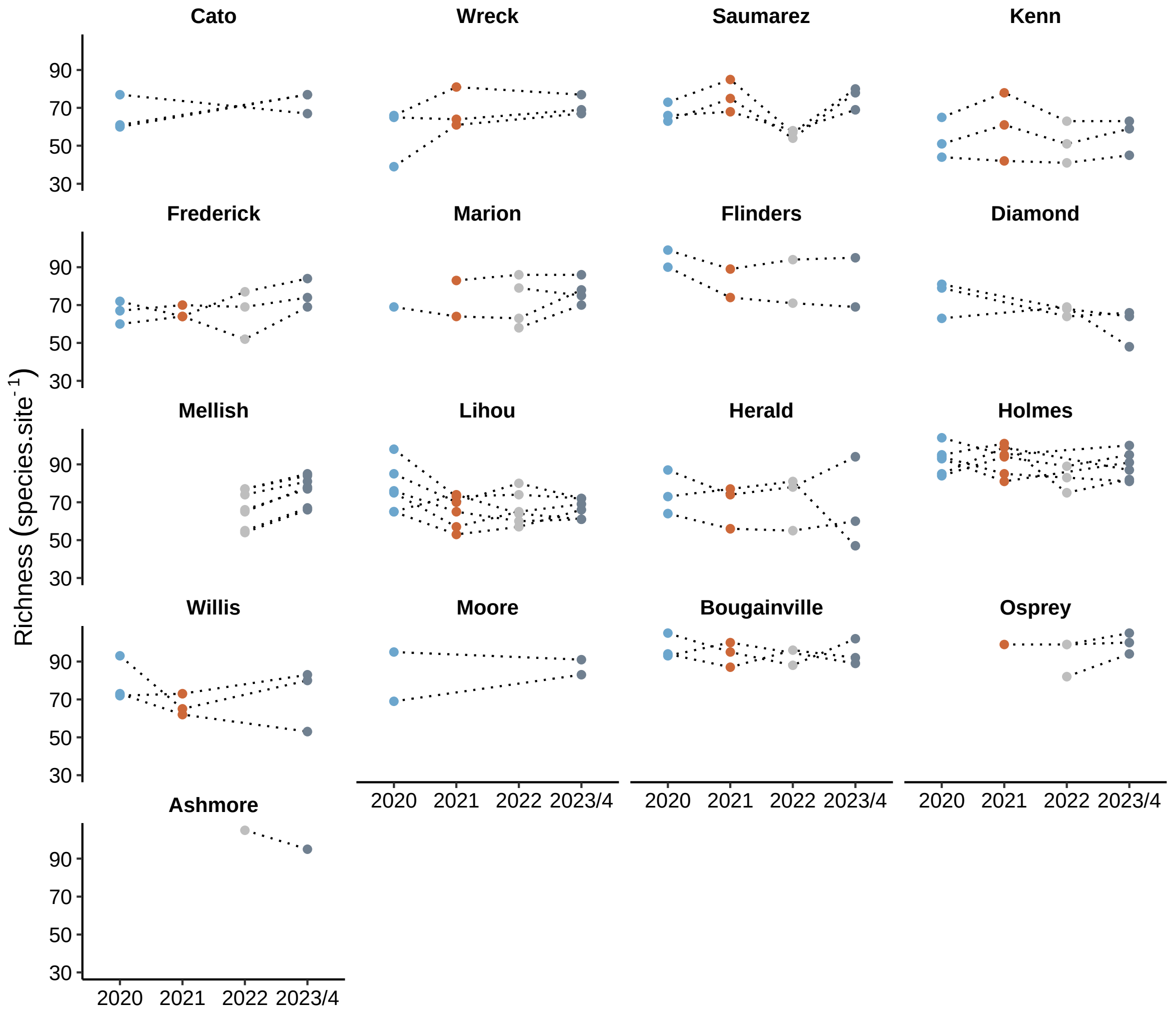


Figure 4.24 Temporal variation in the species richness of reef fish assemblages among individual sites in the Coral Sea Marine Park. Data are based on surveys of 58 matching sites that were surveyed at least once during 2020-2022 and again in 2023/24.

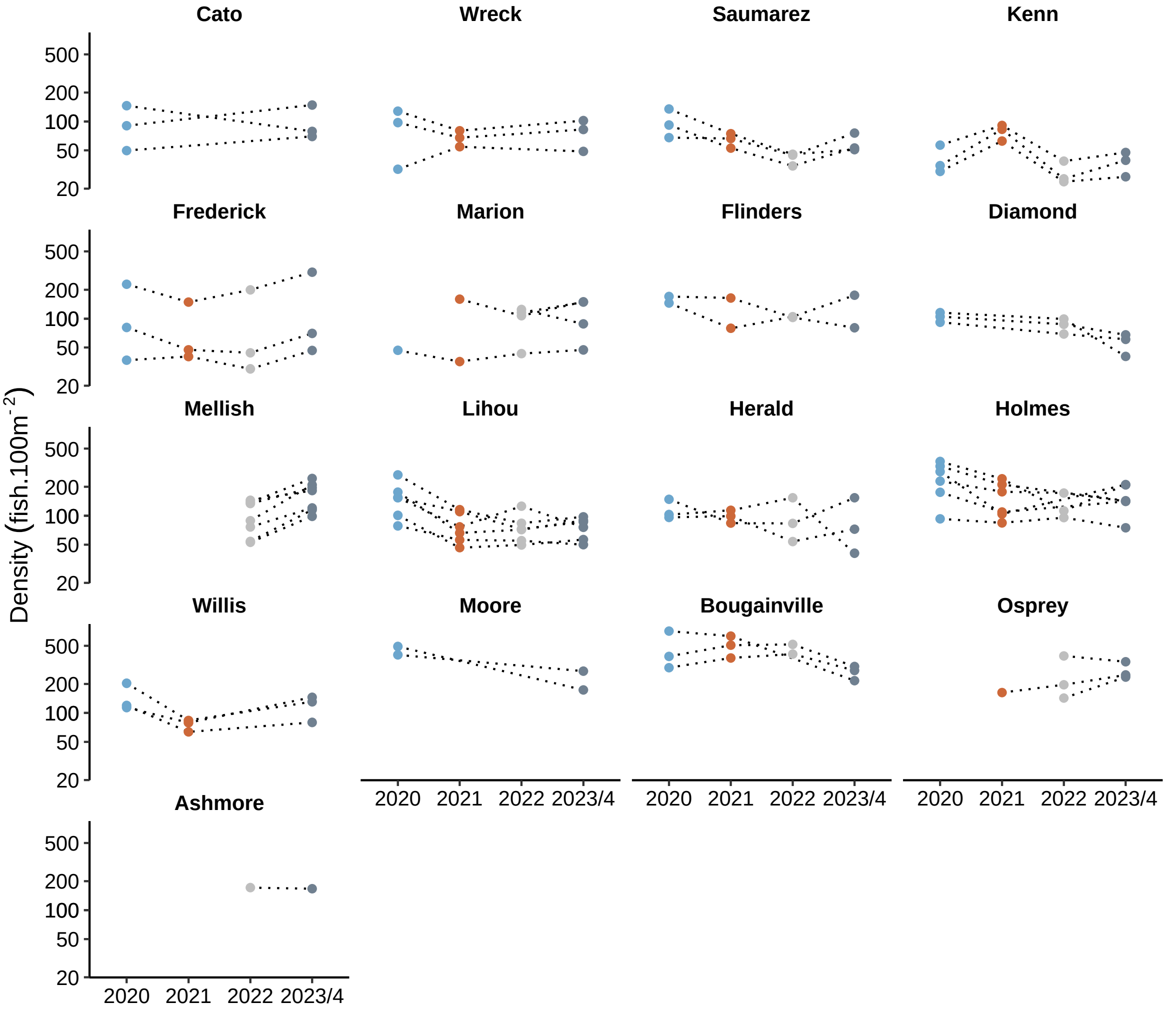


Figure 4.25 Temporal variation in the density of reef fish assemblages among individual sites in the Coral Sea Marine Park. Data are based on surveys of 58 matching sites that were surveyed at least once during 2020-2022 and again in 2023/24, and pooled across reef slope and reef crest transects.

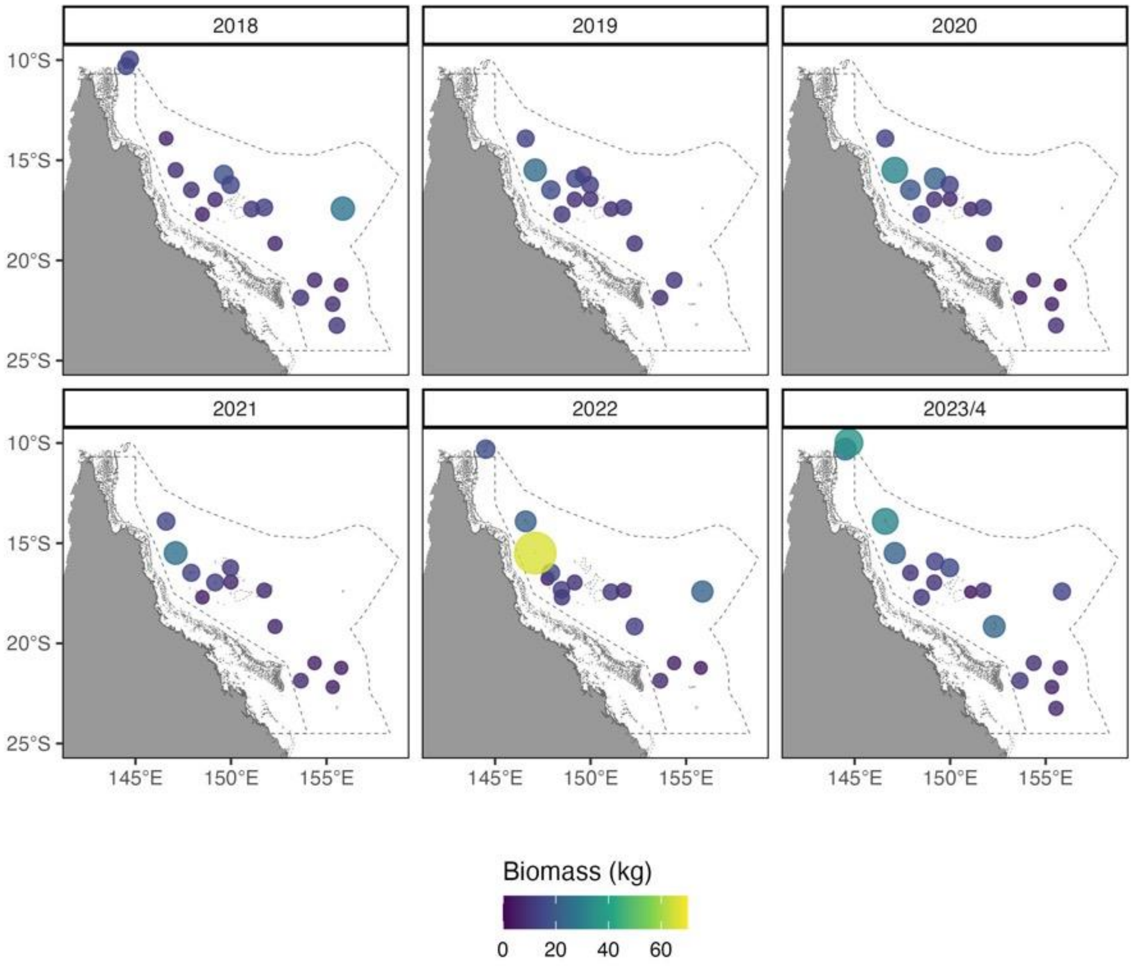


Figure 4.26 Spatial and temporal variation in the biomass of reef fish on shallow reef habitats (reef crest and reef slope) across 22 reef systems in the Coral Sea Marine Park. The size of individual points is proportional to the average fish biomass at each reef.

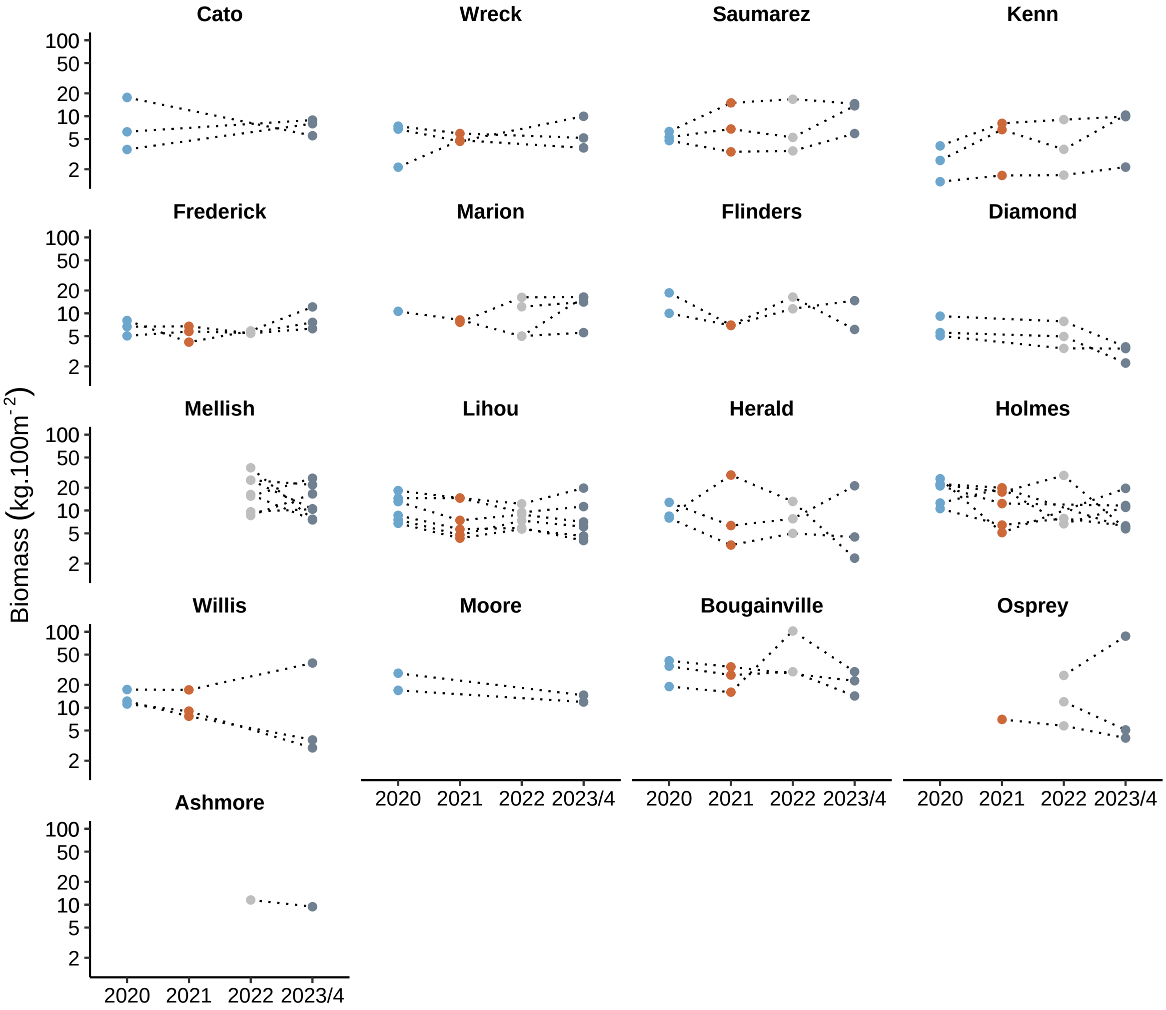


Figure 4.27 Temporal variation in the biomass of reef fish assemblages among individual sites in the Coral Sea Marine Park. Data are based on surveys of 58 matching sites that were surveyed at least once during 2020-2022 and again in 2023/24, and pooled across reef slope and reef crest transects.

5.3.3 Functional composition of fish assemblages

Fishes were categorised into eleven functional 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 functional group on reefs in the CSMP accounting fo 61.3% of all fish recorded, but only 16.0% of total fish biomass, from 2020-2023/24 (Figure 4.28). Fish biomass was more evenly spread among functional groups with grazing herbivores (14.1%), piscivores (17.2%), planktivores (16.0%), and excavating parrotfishes (18.4%) together accounting for 65.7% of total fish biomass from 2020-2023 (Figure 4.28).

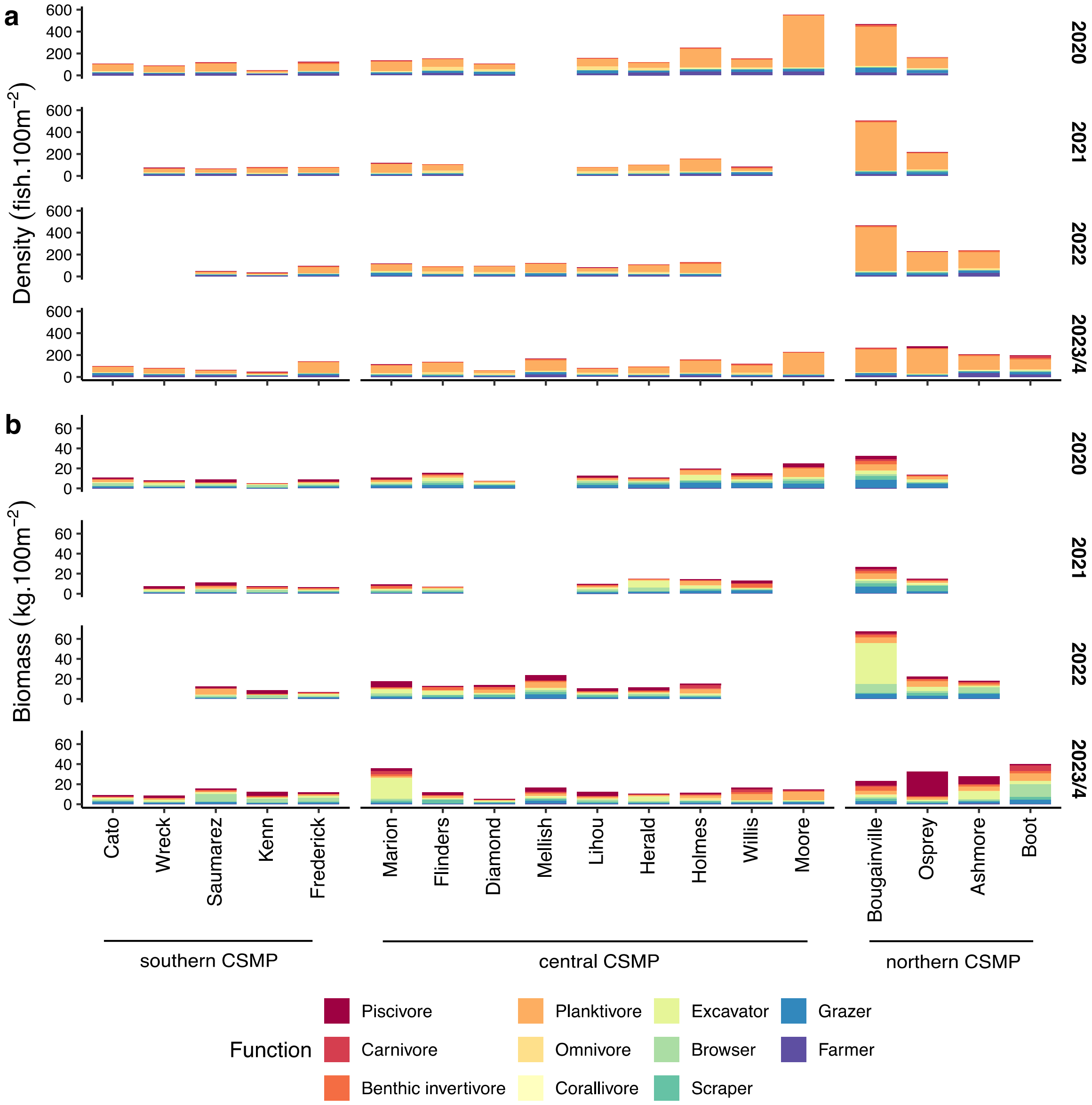


Figure 4.28 Temporal variation in the functional composition of reef fish assemblages across 18 reefs in the Coral Sea Marine Park based on **(a)** abundance, and **(b)** biomass. Data are based 50m belt transects and values for each reef are averaged across habitats and sites.

Following the 2020 and 2021 coral bleaching events, the density of corallivorous fishes across the southern and central CSMP, and planktivorous fishes across all three CSMP regions had declined, likely reflecting their reliance of live corals for food and shelter, respectively (Hoey et al. 2022). There was, however, a 5-39% increase in the density of corallivores from 2022 to 2023/4 in both the southern and central CSMP, while the density of corallivores remained relatively stable in the northern CSMP over the same period (Figure 4.29c). Similarly, the density of planktivorous fish (primarily fusiliers, anthias and damselfish) increased by 49-53% on southern and central CSMP reefs from 2022 to 2023/24 but continued to decline (24% decline) on northern CSMP reefs (Figure 4.29b). While the density of corallivores in the southern CSMP are now comparable to those recorded in 2020, the density of corallivores in the central CSMP, and the density of planktivorous fish across all three regions are considerably lower than those recorded in 2020 (Figure 4.29b,c). The majority of planktivorous and corallivorous fishes are small-bodied and hence are not major contributors to reef fish biomass. The density and biomass of piscivorous fishes have remained relatively stable across the three regions of the CSMP from 2022 to 2023/24 (Figures 4.29a, 4.30a), the only exception being a large increase in density and biomass of piscivores in the northern CSMP in 2023/24 due to a school of several hundred big eye trevally, *Caranx sexfaciatus*, at one site (North Horn) at Osprey Reef (Figures 4.29a, 4.30a, 4.31).

Previous declines in the density and biomass of grazing herbivorous fishes on central and northern CSMP reefs between 2020 and 2022 (Hoey et al. 2022) were maintained in 2022 with further declines in density and biomass of this group evident in both regions in 2023/24 (Figures 4.29d, 4.30d). In contrast, the density and biomass of grazing fishes in the southern CSMP was relatively stable from 2020 to 2022 and increased by 41% and 57% from 2022 to 2023/24, respectively. The density (and biomass) of grazing fishes has now declined by 56.6% (biomass: 48.1%) and 65.4% (biomass: 71.4%) in the central and northern CSMP, respectively, since 2020 (Figures 4.29d, 4.30d). 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 several studies 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). Such increases have generally been related to an increase in the availability of EAM-covered substrata (i.e., turfs) 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.

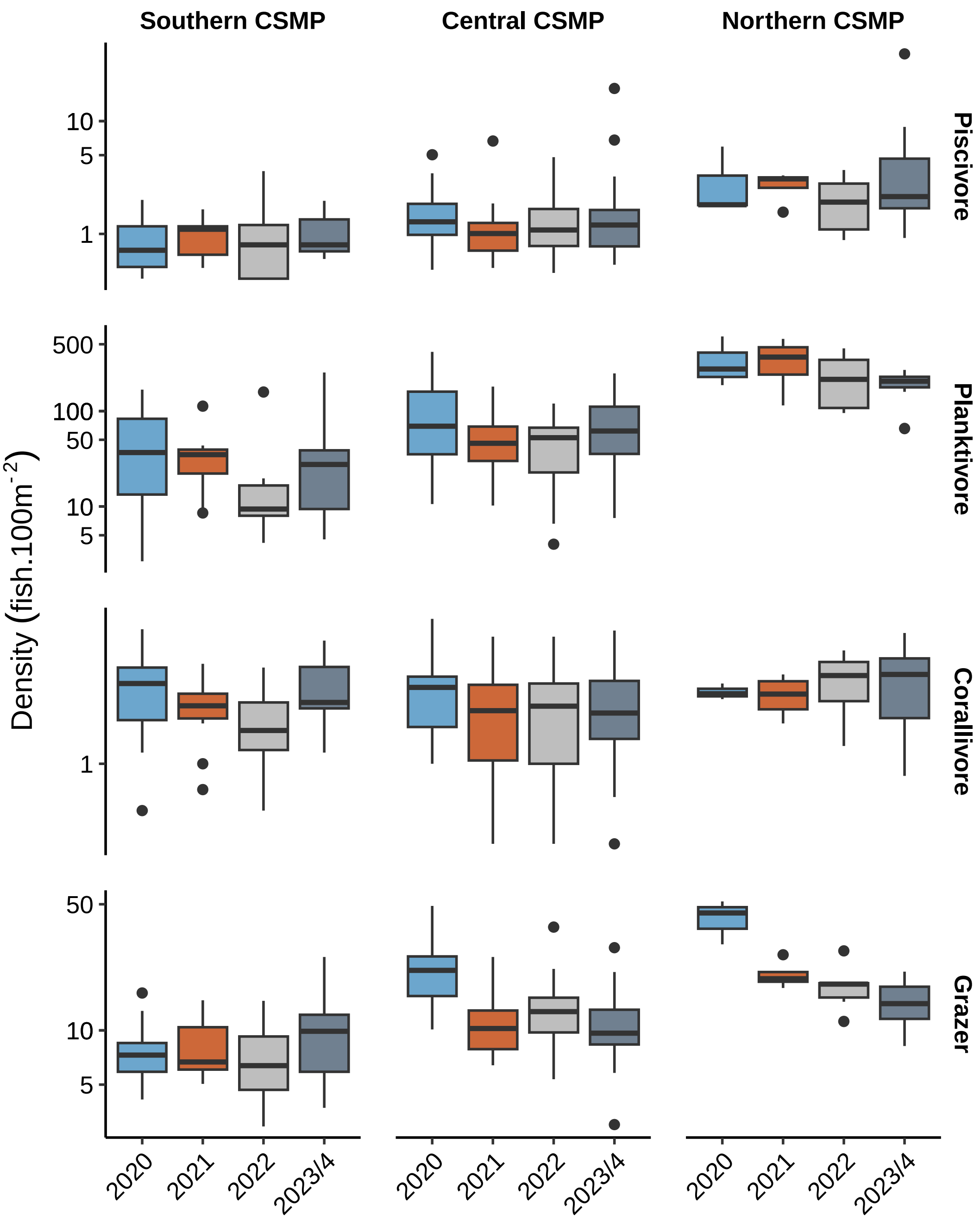


Figure 4.29 Spatial and temporal variation in the density of **(a)** piscivorous, **(b)** planktivorous, **(c)** corallivorous, and **(d)** grazing fishes among the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs). Note: data are presented on a $\log_{10}$-scale.

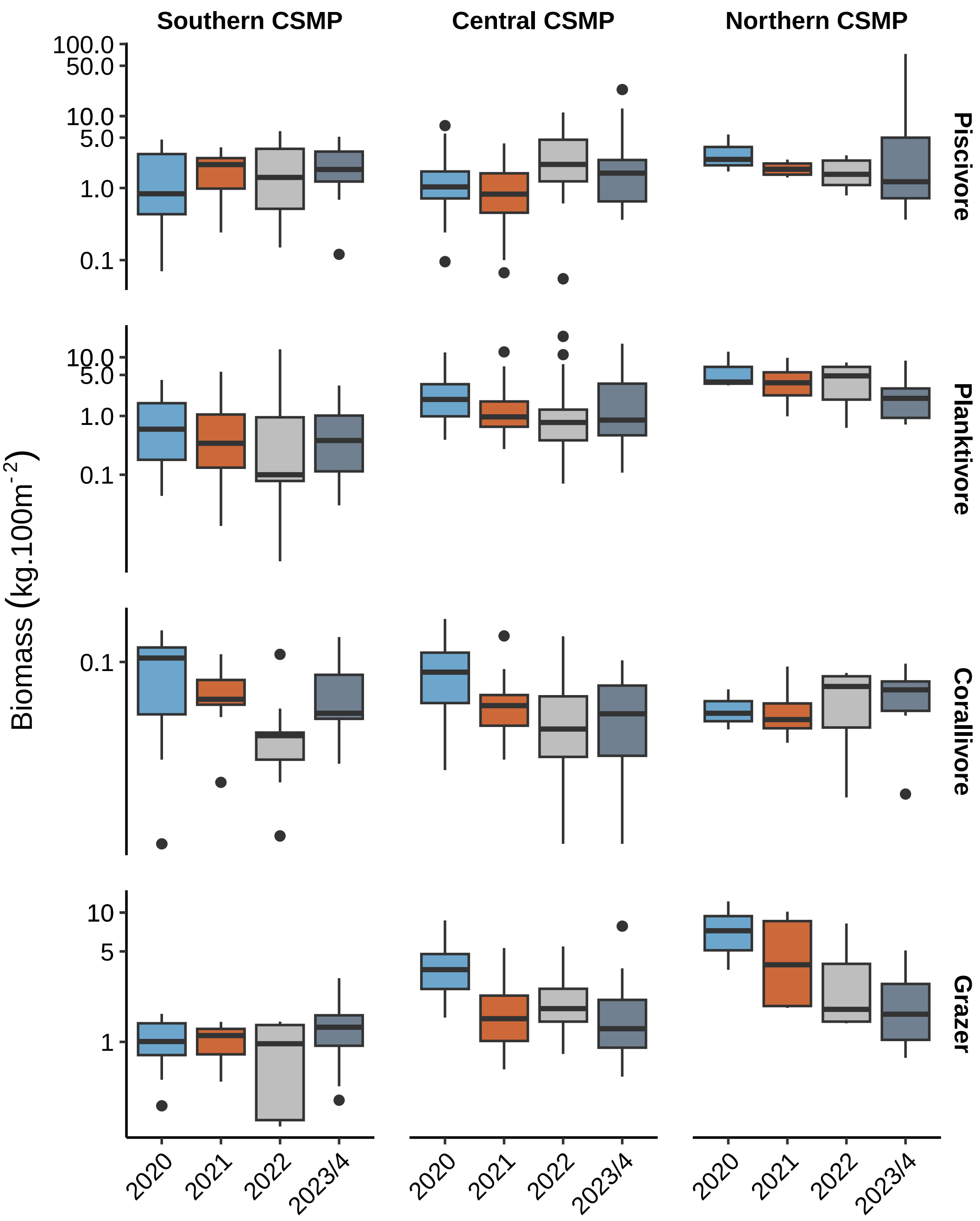


Figure 4.30 Spatial and temporal variation in the biomass of **(a)** piscivorous, **(b)** planktivorous, **(c)** corallivorous, and **(d)** grazing fishes among the three regions of the Coral Sea Marine Park Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs). Note: data are presented on a $\log_{10}$-scale.

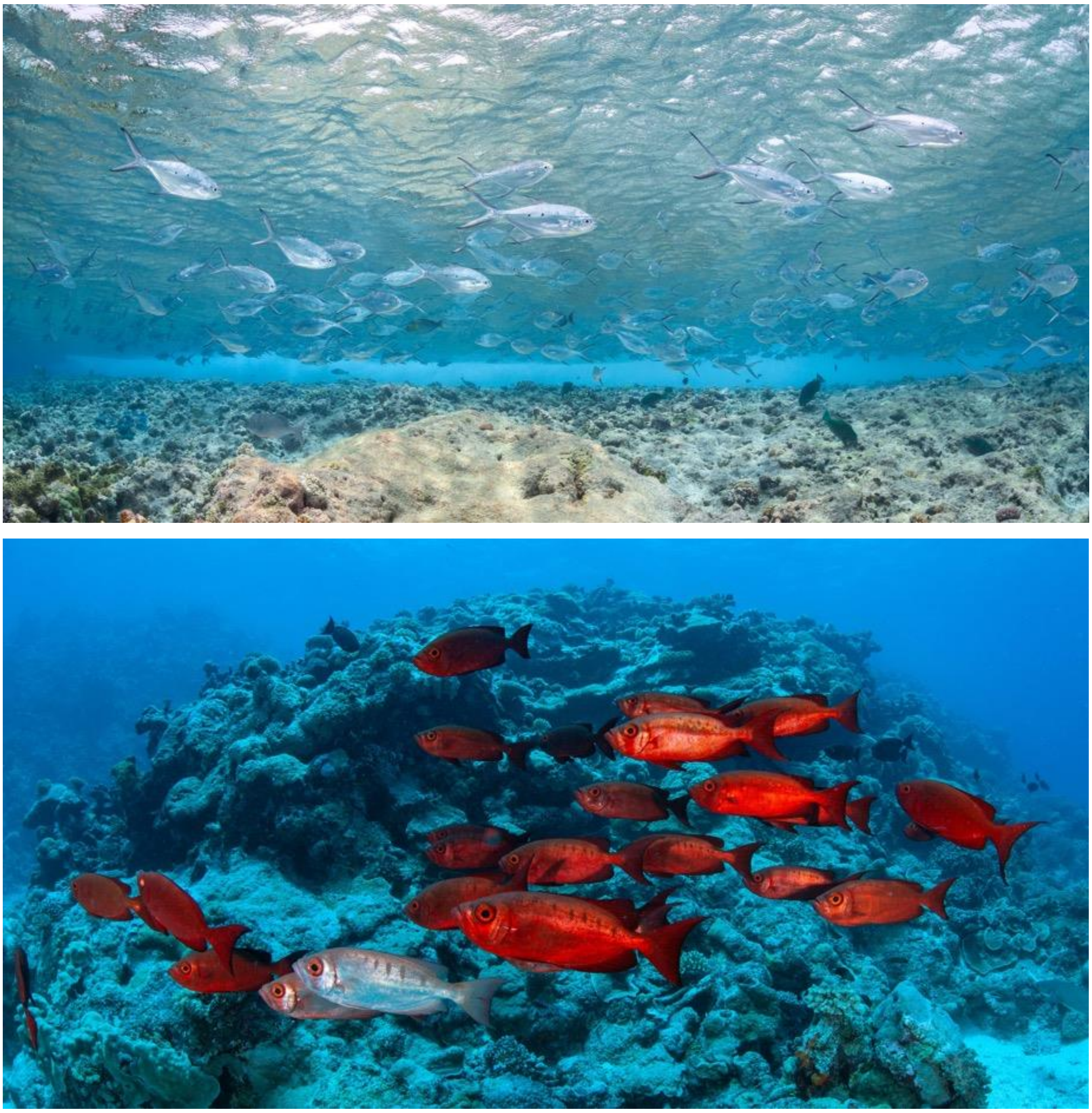


Figure 4.31 Photographs of fish schools at Osprey Reef, northern Coral Sea Marine Park, November 2023. Top: School of small-spotted dart (*Trachinotus baillonii*) on the crest at North Horn. Bottom: School of bigeyes (*Priacanthus hamrur*) at False Entrance. Image credits: Victor Huertas.

5.3.4 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 among the three CSMP regions (Figure 4.32). The northern CSMP reefs were tightly clustered in the right-hand side of the nMDS space, the southern CSMP reefs were generally in the left-hand side, and the central CSMP reefs more evenly spread throughout the nMDS space (Figure 4.32). There was no evidence of a shift in the taxonomic composition of reef fish assemblages within each of the three CSMP regions from 2020 to 2023/4 (Figure 4.33), although the taxonomic composition of reef fish assemblages in the central CSMP has become variable from 2020 to 2023/24 (i.e., the sites are less clustered in the MDS space; Figure 4.33). The nMDS of the taxonomic composition of reef fish assemblages among years and the three regions of the CSMP failed to converge.

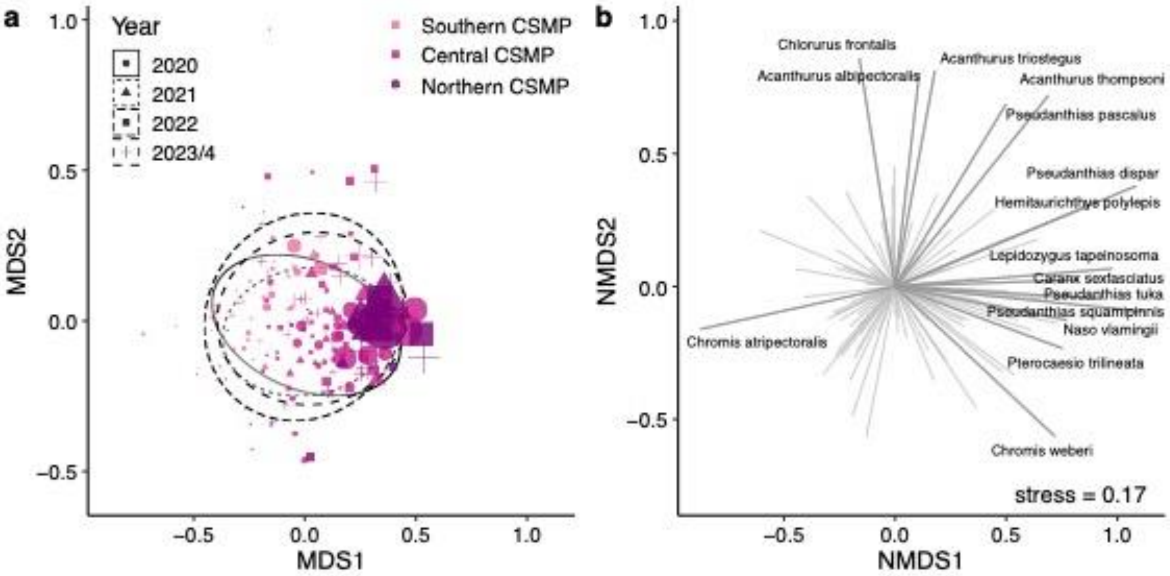


Figure 4.32 Regional and temporal variation in the taxonomic composition of reef fish assemblages within the Coral Sea Marine Park. Non-metric multidimensional scaling (nMDS) plot showing the variation in reef fish composition among years for the three regions of the Coral Sea Marine Park. Analyses are based on abundance data from 58 sites that were surveyed in 2023/24 and at least once during 2020-2022. 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.

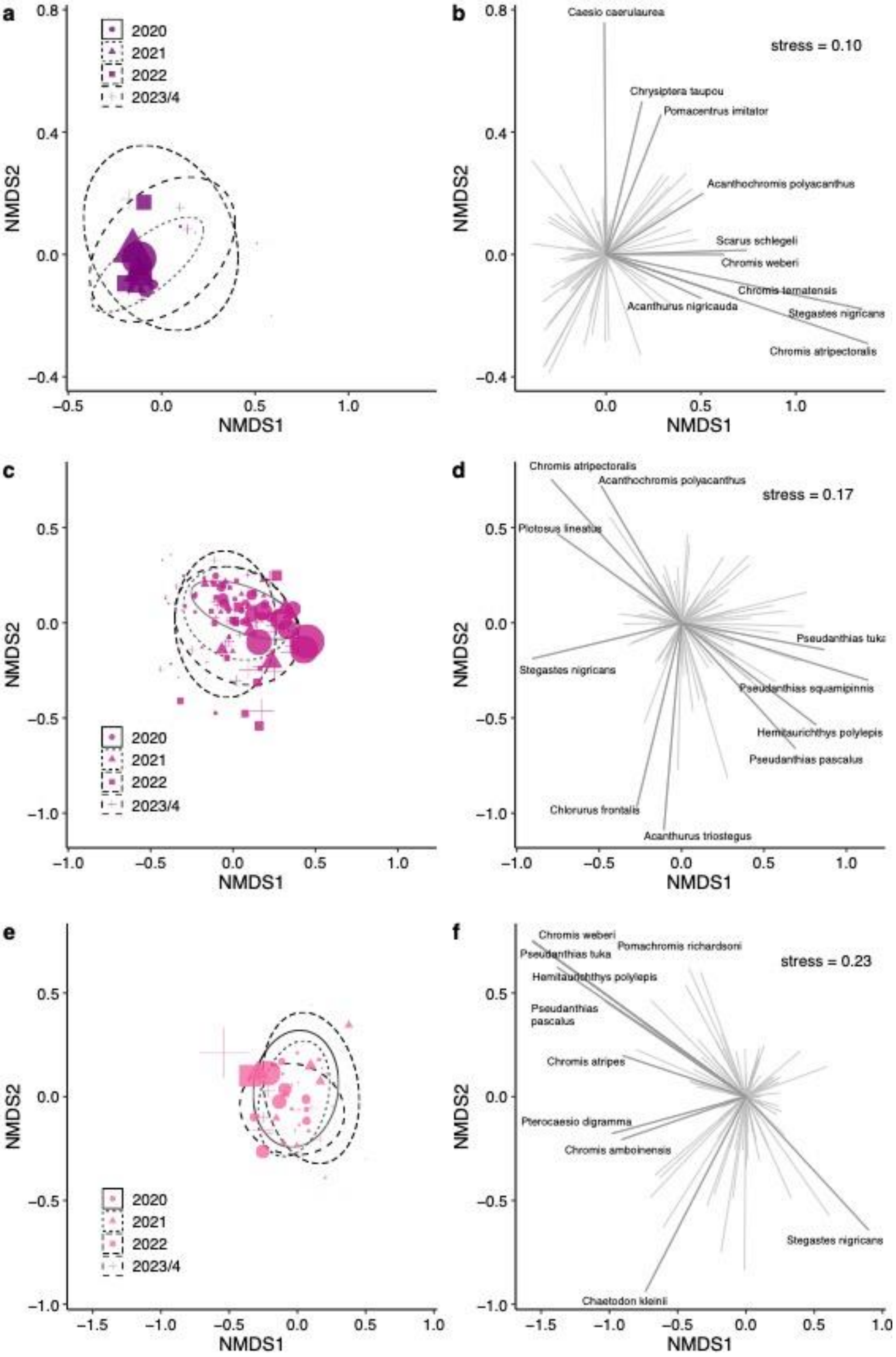


Figure 4.33 Non-metric multidimensional scaling (nMDS) plots showing the temporal variation in the taxonomic composition of reef fish assemblages among reefs in the **(a,b)** northern, **(c,d)** central and **(e,f)** southern Coral Sea Marine Park. Analyses are based on abundance data from 58 sites that were surveyed at least once during 2020-2022 and again in 2023/24; 7 in the northern CSMP, 36 in the central CSMP and 15 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.

Functional composition – Similar to taxonomic composition, the greatest variation in the functional composition of reef fish assemblages, was evident among the three CSMP regions, with considerable overlap among years (Figure 4.34). Comparing the functional composition for each of the three regions separately show negligible change in the functional composition of reef fish assemblages among years for the northern and central CSMP (Figure 4.35 a-d). There was some evidence of a shift in the functional composition of reef fish assemblages on southern CSMP reefs, with assemblages in 2020 being characterised by a higher abundance of omnivores and mixed carnivores, and assemblages in 2022 and 2023/24 being characterised by a higher abundance of browsers and scraping and excavating parrotfishes (Figure 4.35 e,f).

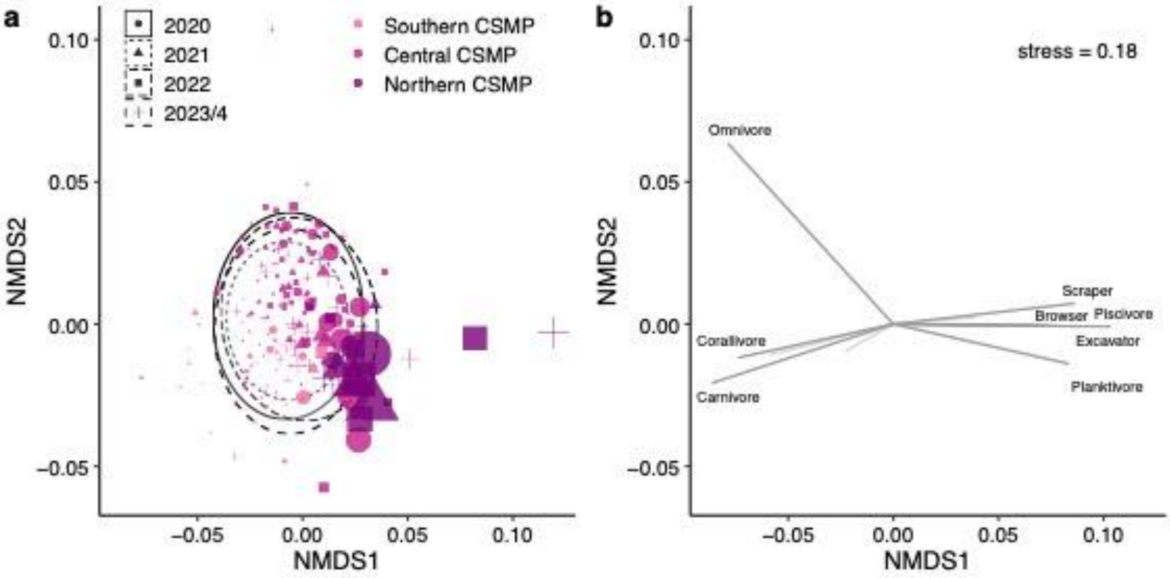


Figure 4.34 Regional and temporal (2020-23) variation in the functional composition of reef fish assemblages within the Coral Sea Marine Park. Non-metric multidimensional scaling (nMDS) plot showing the variation in reef fish functional composition among years for the three regions of the Coral Sea Marine Park. Analyses are based on abundance data from 58 sites that were surveyed at least once during 2020-2022 and again in 2023/24. 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.

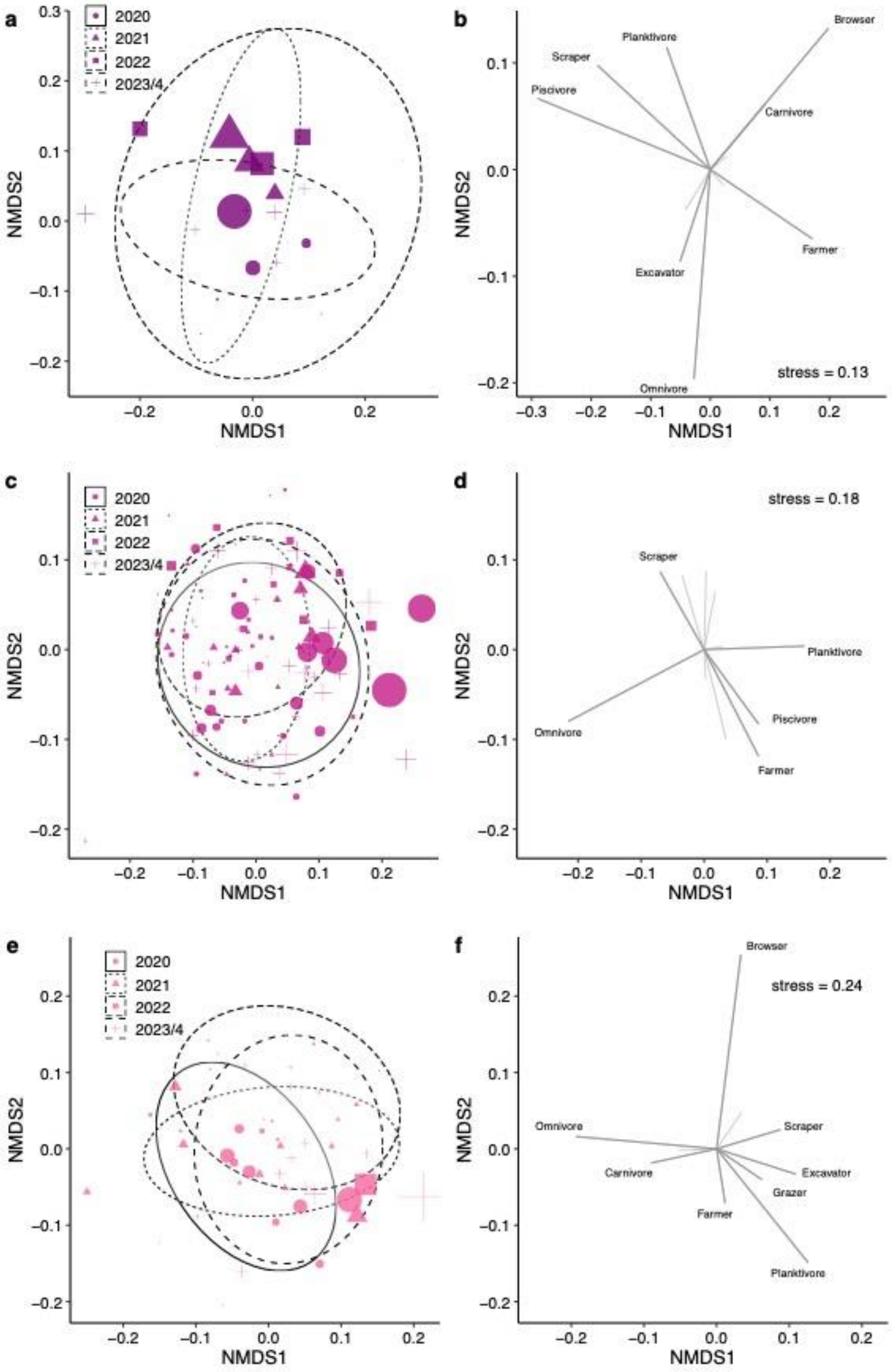


Figure 4.35 Non-metric multidimensional scaling (nMDS) plots showing the temporal variation in the functional composition of reef fish assemblages among reefs in the **(a,b)** northern, **(c,d)** central, and **(e,f)** southern Coral Sea Marine Park. Analyses are based on abundance data from 58 sites that were surveyed at least once during 2020-2022 and again in 2023/24; 7 in the northern CSMP, 36 in the central CSMP and 15 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 Photographs of abundant and high biomass fish communities on the exposed aspect of Boot Reef, northern Coral Sea Marine Park. Top: Large school of bumphead parrotfish (*Bolbometopon muricatum*) on the shallow reef crest. Each individual is 80-100cm long. Bottom: School of paddletail snapper (*Lutjanus gibbus*) closely associated with the benthos at 12m on the reef slope. Note the difference in the benthic communities between habitats. Image credits: Andrew Hoey

5.3.5 Sharks

The density and biomass of sharks (mainly the grey reef shark *Carcharhinus amblyrhynchus*, silvertip shark *Carcharhinus albimarginatus*, and whitetip reef shark *Triaenodon obesus*) were generally lower on reefs in the southern CSMP (density: 0.08 sharks per 100m^2; biomass 2.4 kg per 100m^2), intermediate on reefs in the central CSMP (density: 0.15 sharks per 100m^2; biomass 5.7 kg per 100m^2), and highest on reefs in the northern CSMP (density: 0.18 sharks per 100m^2; biomass 6.6 kg per 100m^2). There was, however considerable variation among reefs in each region, ranging from 0.02 sharks per 100m^2 at Kenn Reef to 0.32 sharks per 100m^2 at Boot Reef (Figure 4.37).

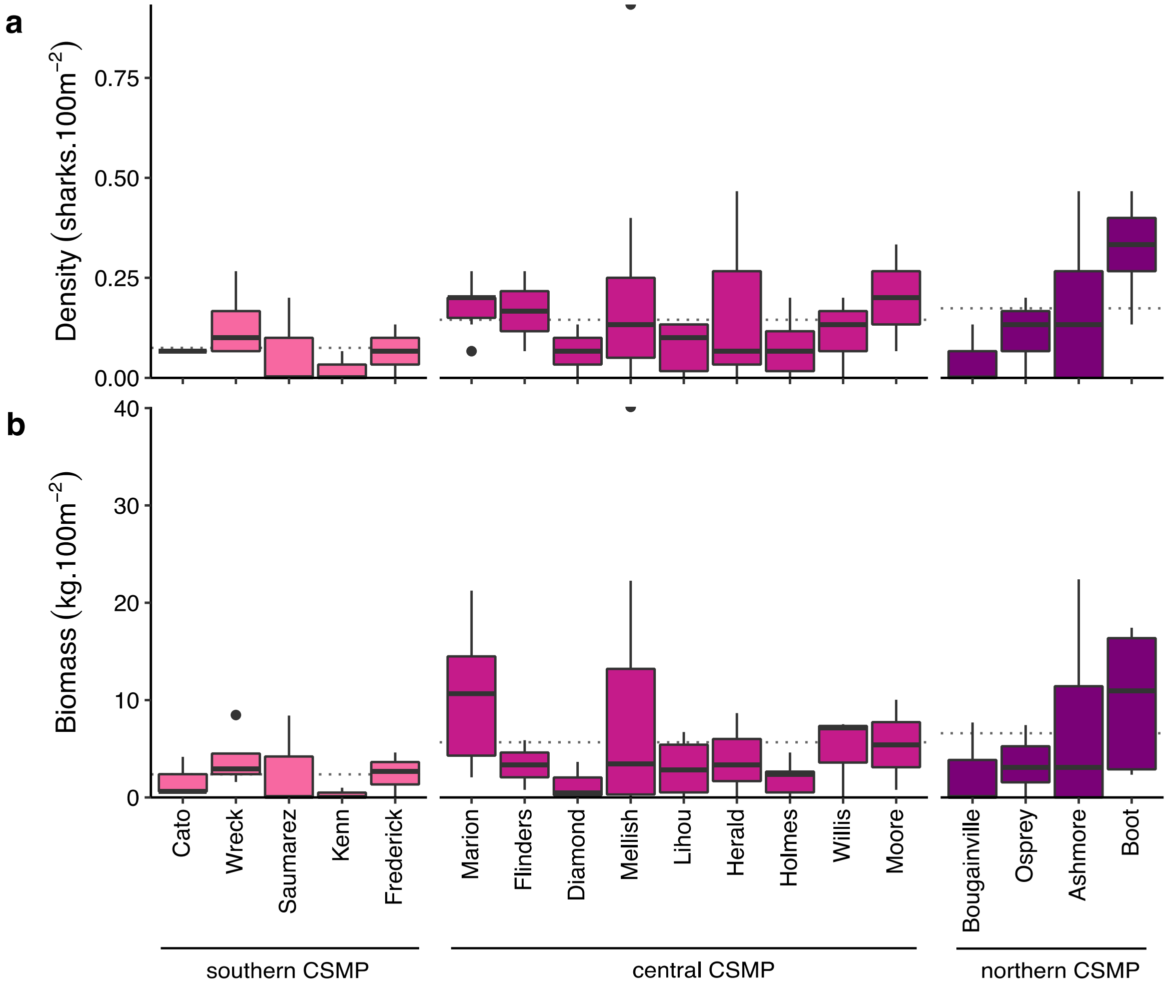


Figure 4.37 Spatial variation in the **(a)** density, and **(b)** biomass of sharks among the 18 reefs surveyed in the Coral Sea Marine Park during 2023/24. Data are based on the 50m belt transects and pooled across slope and crest habitats). Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Dotted lines represent regional averages.

The density and biomass of sharks was relatively stable through time in each of the three regions of the CSMP (Figure 4.38) and on reefs within each region (Figure 4.39). Importantly, there was no evidence of a decline in the density and biomass of sharks across the CSMP that may otherwise indicate an increase in fishing pressure.

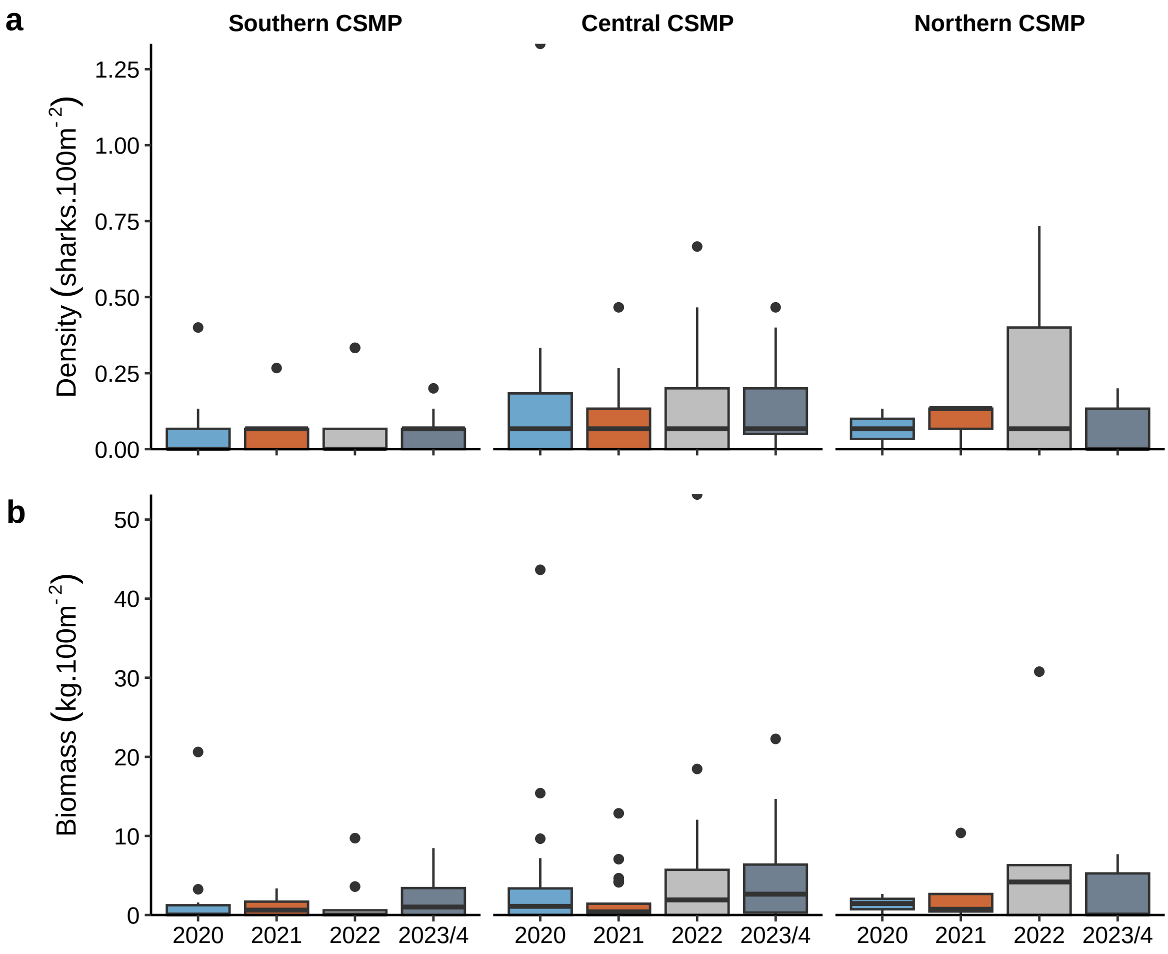


Figure 4.38 Temporal variation in the **(a)** density and **(b)** biomass of sharks among the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

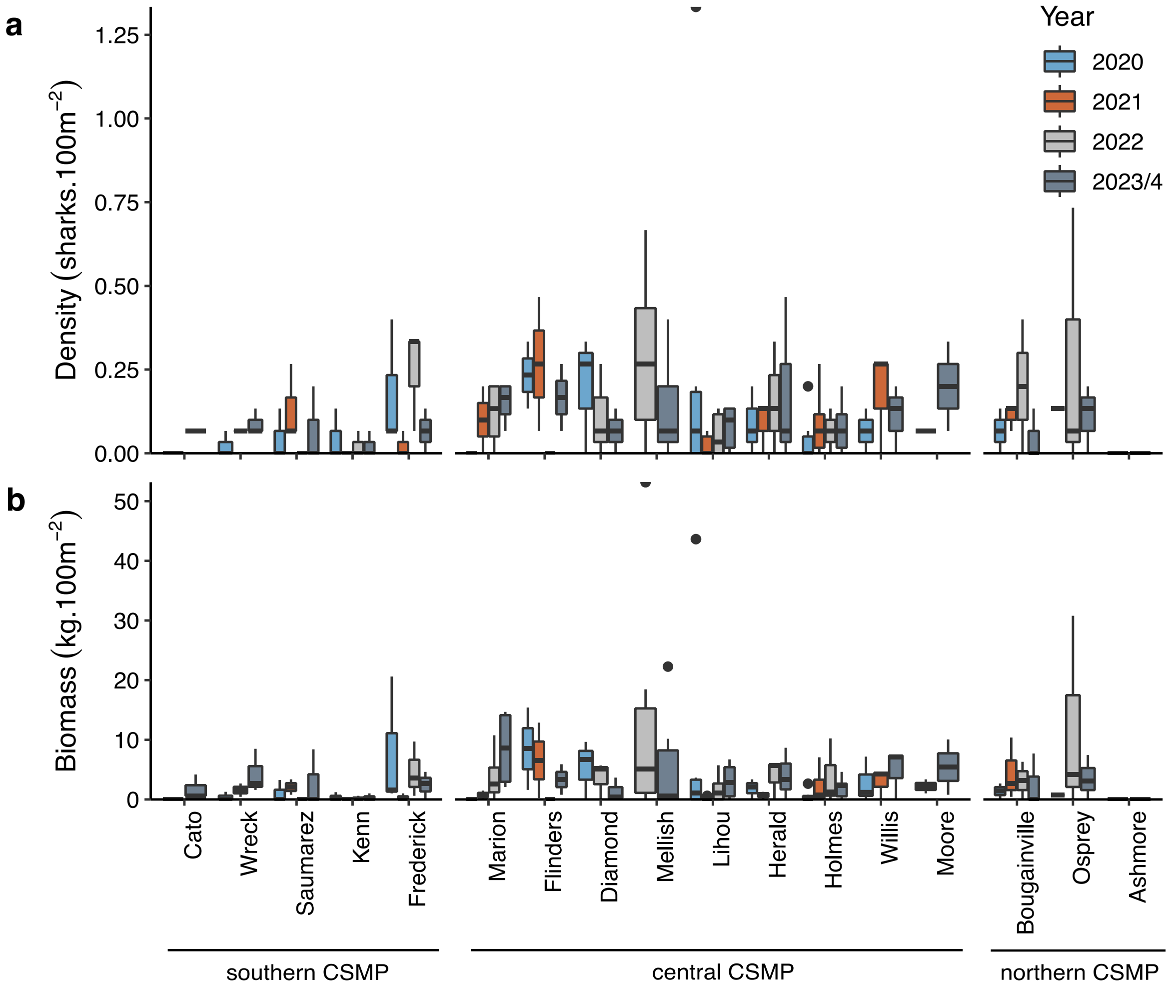


Figure 4.39 Temporal variation in the **(a)** density and **(b)** biomass of sharks among 17 reefs in the Coral Sea Marine Park. Data are based on surveys of 58 matching sites that were surveyed at once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

5.4 Other reef taxa

5.4.1 Sea snakes

A total of 65 sea snakes were recorded across the 18 CSMP reefs in 2023/24 compared to 50, 28 and 20 individuals in 2022, 2021 2020, respectively. The vast majority of sea snakes recorded across all years were the olive sea snake *Aipysurus laevis* (89 - 95% of sea snakes observed). Consistent with previous surveys in 2020-2022 (Hoey et al. 2022) 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 (and presumably absent) at all other reefs in the central CSMP, and Bougainville and Osprey Reefs in the northern CSMP

(Figure 4.40). In 2023/24 the mean density of sea snakes varied from 0.3 to 1.1 snakes per 250m^2 (Cato and Kenn Reefs, respectively) in the southern CSMP, and only a single individual was observed across 12 sites at Ashmore Reef (mean density: 0.01 snakes per 250m^2; Figure 4.40). This is markedly lower than the mean density of sea snakes recorded at Ashmore Reef in 2022 (0.2 individuals per 250m^2), and likely reflects differences in the sites surveyed, rather than a reduction in the sea snake population at Ashmore Reef. The vast majority of sites surveyed in 2022 were inside the lagoon, however these sites were largely inaccessible in 2023/24 due to strong westerly and north-westerly winds. In contrast, the majority of sites surveyed in 2023/24 were on the exposed eastern and south-eastern aspect of Ashmore Reefs, and the only sea snake observed was recorded at the only sheltered lagoon site surveyed.

The marked latitudinal gradient in the abundance of sea snakes within the CSMP is similar to that reported on the GBRMP using baited remote underwater video station (BRUVS) sampling (Udyawer et al. 2014), with the highest prevalence and diversity of sea snakes occurring in central and southern GBRMP. Such latitudinal gradients in the distribution and diversity of sea snakes of the genera *Aipysurus* and *Emydocephalus* (e.g., Lukoschek et al. 2007) are generally attributed to the limited thermal tolerance of these species (Heatwole et al. 2012). However, the olive sea snake *Aipysurus laevis,* which is by far the most abundant species observed in shallow reef habitats in the CSMP (accounting for >90% of individuals observed) was also recorded at the northernmost CSMP reef (i.e., Ashmore Reef) and is also found in the warmer, lower latitude waters of the north Western Australian coast, Timor Sea, Gulf of Carpentaria, and southern New Guinea (O’Shea 1996; Lukoschek et al. 2007). The disjunct distribution of sea snakes, and in particular *A. laevis*, with the CSMP suggest these are separate populations (or even sub-species), that may have different tolerances to environmental temperatures. While dedicated research would be required to identify the drivers of the distribution of sea snakes within the CSMP and the potential connectivity between southern and northern populations, the potential susceptibility of sea snakes to increasing water temperatures and other human stressors (Lukoscheck et al. 2013; Somaweera et al. 2021) highlights the need to continue to monitor populations throughout the CSMP.

The density of sea snakes has steadily increased on reefs in the southern CSMP from 0.2 individuals per 250m^2 in 2020 to 0.6 individuals per 250m^2 in 2023/24, a 3-fold increase (Figure 4.41). These increases have been largely consistent among reefs, although the density of sea snakes did experience a ~50% decline in Frederick and Marion Reefs from 2022 to 2023/24 (Figure 4.42).

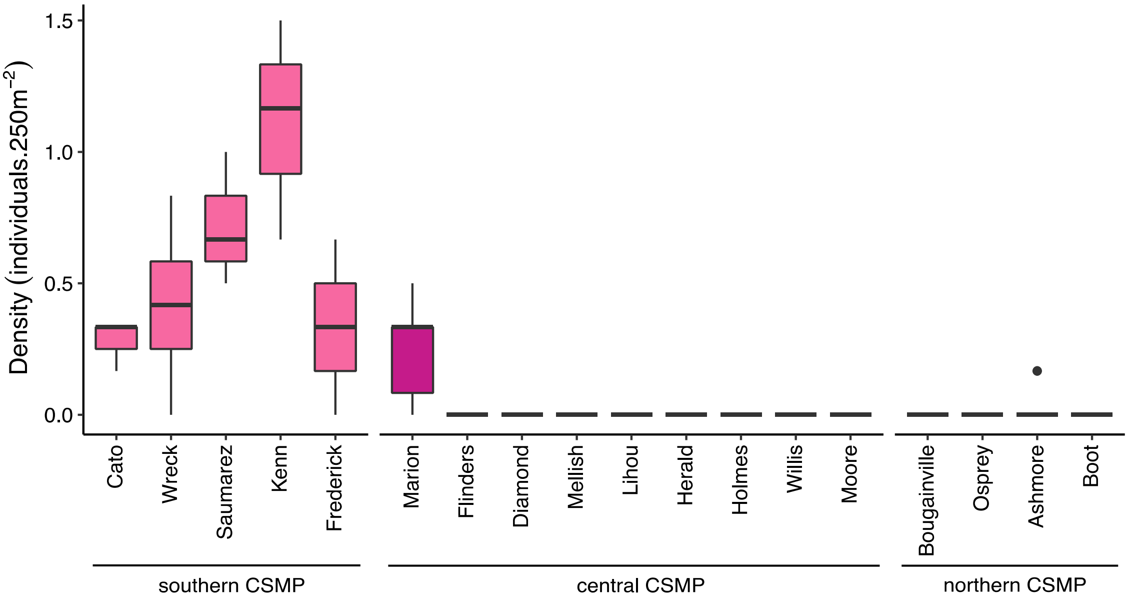


Figure 4.40 Spatial variation in the density of sea snakes among the 18 reefs surveyed in the Coral Sea Marine Park during 2023/24. Data are based on the 50m belt transects and pooled across slope and crest habitats). Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1).

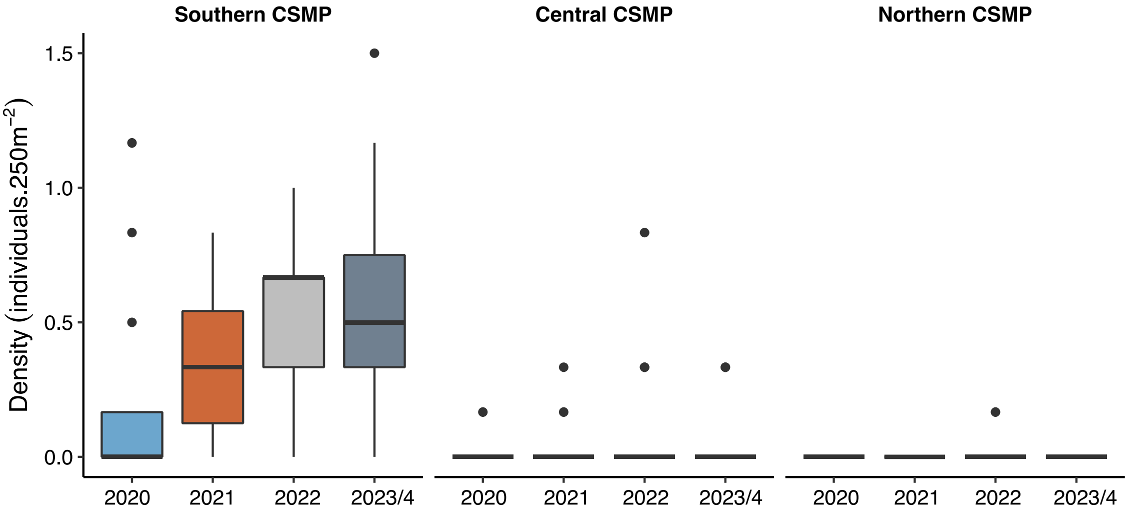


Figure 4.41 Temporal variation in the density of sea snakes among the three regions of the Coral Sea Marine Park. Data are based on surveys of 58 matching sites across 17 reefs that were surveyed at once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

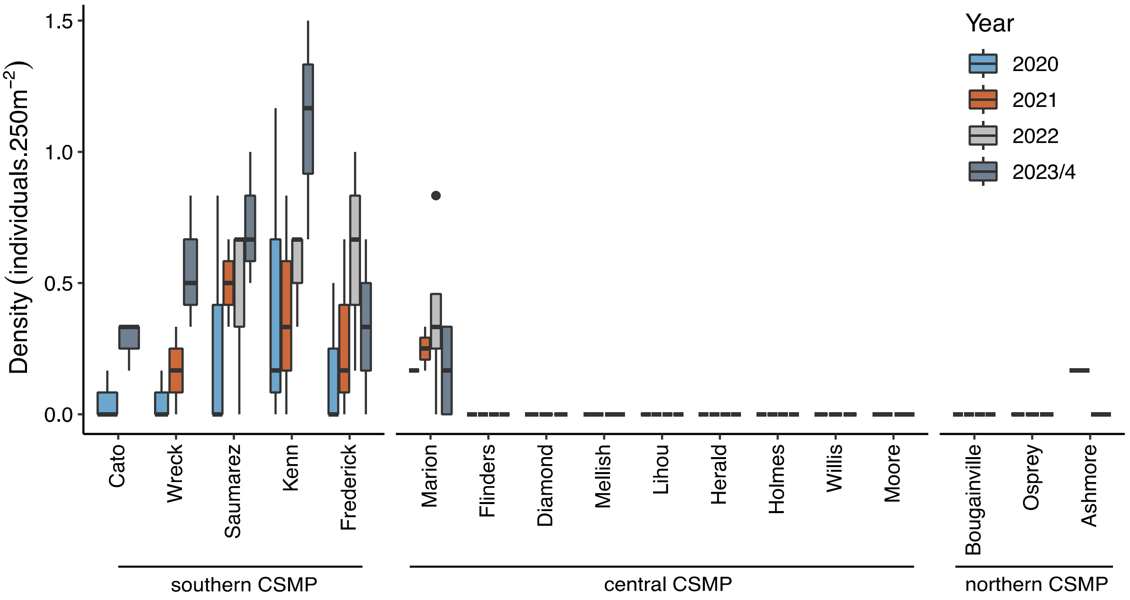


Figure 4.42 Temporal variation in the density of sea snakes among 17 reefs in the Coral Sea Marine Park. Data are based on surveys of 58 matching sites that were surveyed at once during 2020-2022, and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs)

5.4.2 Macro-invertebrates

Giant Clams – Overall, 1,225 giant clams (*Tridacna* spp. and *Hippopus hippopus*) were recorded across the 18 CSMP reefs in 2023/24, with the vast majority (1,193 individuals, 97.4%) being *Tridacna maxima* and *Tridacna squamosa.* The other species recorded were *Tridacna derasa* (19 individuals, 1.5%), *Tridacna gigas* (4 individuals, all of which were recorded on Ashmore Reef, 0.3%), *Tridacna crocea* (8 individuals, 0.6%), and H*ippopus hippopus* (1 individual at Kenn Reef; 0.1%). The density of giant clams across all reefs in 2023/24 was 2.7 clams per 100m^2, and ranged from 0.9, 1.6 to 7.8 clams per 100m^2 in the northern, central and southern CSMP, respectively (Figure 4.33a). There was, however, considerable variation among reefs in each region, ranging from (0.3 clams per 100m^2 at Flinders Reef to 25.4 clams per 100m^2 at Kenn Reef (Figure 4.33a).

The density of giant clams has remained relatively consistent from 2020 to 2023/24 on individual reefs within the CSMP (Figure 4.34a). There is some temporal variability in the density estimates for giant clams at Kenn Reef (declining from 2020 to to 2021 before returning to 2020 levels in 2023/24). This temporal variation may relate to slight differences in the placement of the transects among years, rather than changes in the populations of clams at these sites.

Trochus –*Tectus* spp. (formerly *Trochus*) were relatively rare across the CSMP, with 116 individuals recorded across the 18 CSMP reefs in 2023/24 (mean density: 0.25 individuals per 100m^2). The density of Trochus was similar among the three CSMP regions (0.22, 0.25, and 0.26 individuals per 100m^2 in the southern, central and northern CSMP, respectively), however varied considerable among individual reefs (0 to 0.77 individuals per 100m^2 at Flinders and Marion Reef, respectively; Figure 4.43b). Comparisons of the 17 CSMP reefs that were surveyed at least once during 2020-22 and again in 2023/24 show the densities of Trochus have remained relatively stable on each reef (Figure 4.44b). The only exception to this Ashmore Reef where the density of Trochus increased from 0.16 to 1.33 individuals per 100m^2 from 2022 to 2023/24 (Figure 4.44b), however it is important to note that these estimates are based on a single site and may not represent broader changes in populations at this reef.

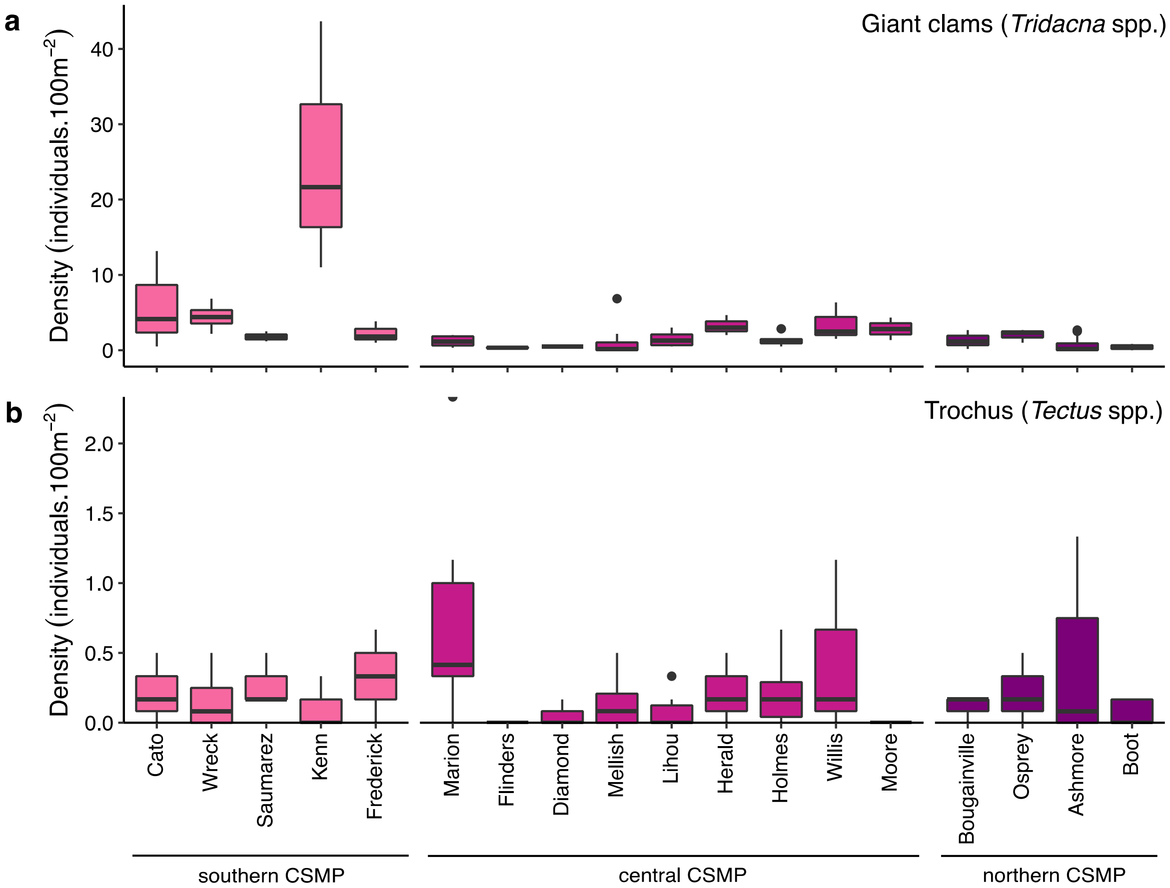


Figure 4.43 Spatial and temporal variation in the abundance of **(a)** giant clams, and **(b)** Trochus among the 18 reefs surveyed in the Coral Sea Marine Park during 2023/24. Data are based on the 50m belt transects and pooled across slope and crest habitats). Reefs

are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1). Bottom: giant clam (*Tridacna*) on the reef slope at Mellish Reef, central CSMP. Note the turf algae growing on the shell of the clam. Image credit: Victor Huertas

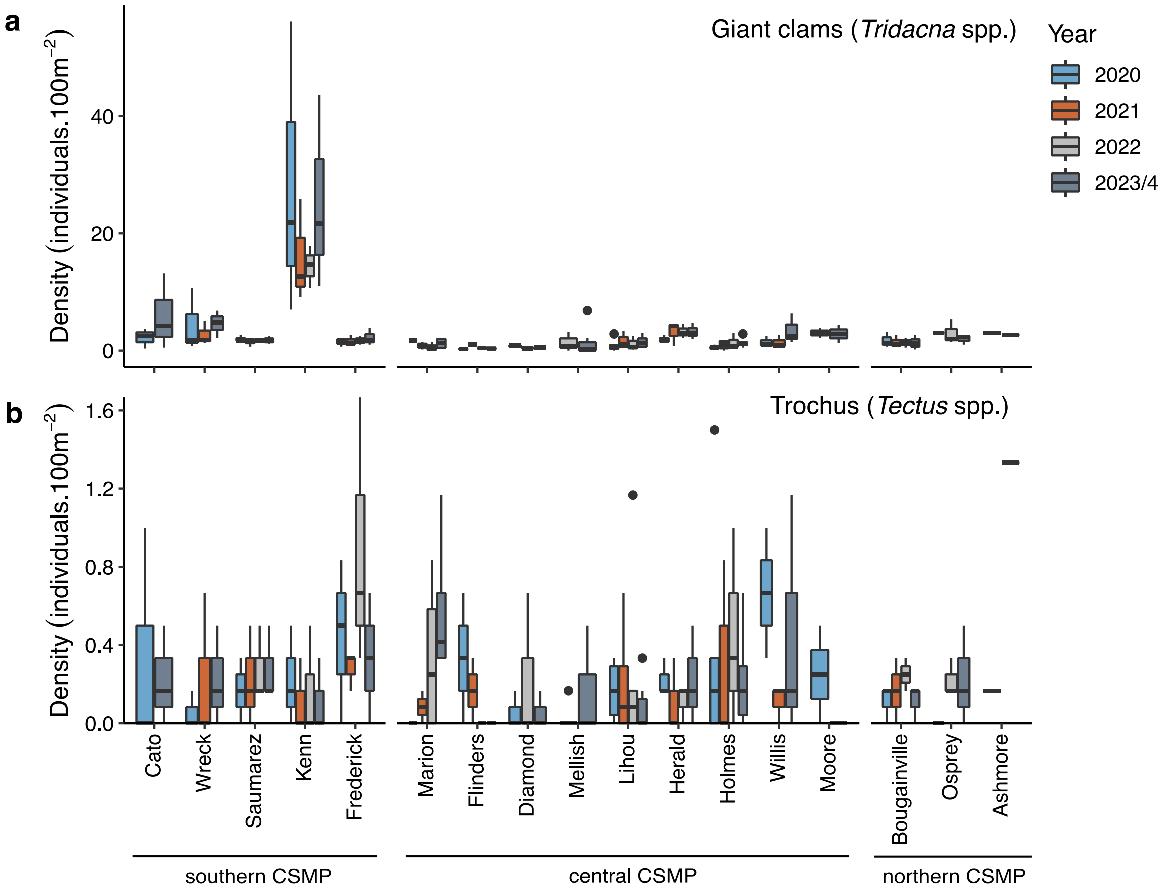


Figure 4.44 Spatial and temporal variation in the abundance of **(a)** giant clams, and **(b)** Trochus among 17 reefs in the Coral Sea Marine Park. Data are based on replicate 50m transects at each of 58 matching sites surveyed at least once during 2020-2022 and again in 2023/24.

Sea urchins – Overall, 4,121 long-spined sea urchins (*Diadema* spp.) were recorded across the 18 reefs in 2023/24 with the vast majority (4,090 individuals, 99.2%) being recorded on reefs in the southern CSMP (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 148 urchins per 100m^2 at Kenn Reef. Sea urchins were rare across the central and northern CSMP reefs in 2023/24, with only 27 and 4 individuals being recorded in each region, respectively (Figure 4.45a). Despite increases in sea urchin densities on some of the reefs in the southern CSMP (namely Cato, Wreck, and Frederick Reefs), the differences in sea urchin densities among regions and reefs are largely consistent with previous surveys (2018-2022; Figure 4.46a). *Diadema* are generally more abundant on subtropical reefs, such as Lord Howe Island, and Elizabeth and Middleton Reefs (Hoey et al. 2011, 2018, 2024), and as such their greater abundance on reefs 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).

Many sea urchin species (including *Diadema* spp.) are herbivorous, and as such are often viewed as having a positive effect on coral reefs through their ability to reduce the biomass of macroalgae and prevent shifts to macroalgae dominance (e.g., Humphries et al. 2020; Williams 2022). However, on Indo-Pacific reefs high densities of sea urchins, and *Diadema* in particular, are seen as a sign of overfishing and/or reef degradation (McClannahan et al. 1994; Glynn and Manzello 2015) and can result in net erosion of reef carbonates and destabilisation of the reef framework through their feeding (Glynn et al. 1979; Eakin 1996).

Sea cucumbers – 133 sea cucumbers (Holothuroidea) from 11 species were recorded across the 18 CSMP reefs in 2023/24, equating to an average of 0.29 individuals per 100m^2. The densities of sea cucumbers were generally greater (average: 0.36 individuals per 100m^2) and less variable among reefs in the northern CSMP (0.33-0.40 individuals per 100m^2) than in the central CSMP (average: 0.25 individuals per 100m^2; range 0.0-0.58 individuals per 100m^2) and southern CSMP (average: 0.32 individuals per 100m^2; range 0.11-0.50 individuals per 100m^2; Figure 4.45b). The most abundant species were *Actinopyga mauritiana* (39.9%), *Thelenota ananas* (13.5%), *Holothuria atra* (11.3%), *Stichopus chloronotus* (10.5%), *Pearsonothuria graeffei* (7.5%), and *Bohadschia argus* (6.8%). The other species recorded were *Holothuria whitmaei*, *Holothuria fuscopunctata, Actinopyga palauensis, Holothuria edulis,* and *Thelenota anax.* The density of sea cucumbers within the shallow reef habitats surveyed within the CSMP showed limited change between years (Figure 4.46b). The only exception to this is at Marion Reef in the central CSMP where densities of sea cucumbers has declined consistently among years from 3.00 individuals per 100m^2 in 2020 to 0.58 individuals per 100m^2 in 2023/24 (an 80% decline). The cause of this decline is unclear, and may reflect natural variation in population size, movements among habitats, and/or reductions due to fishing.

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).

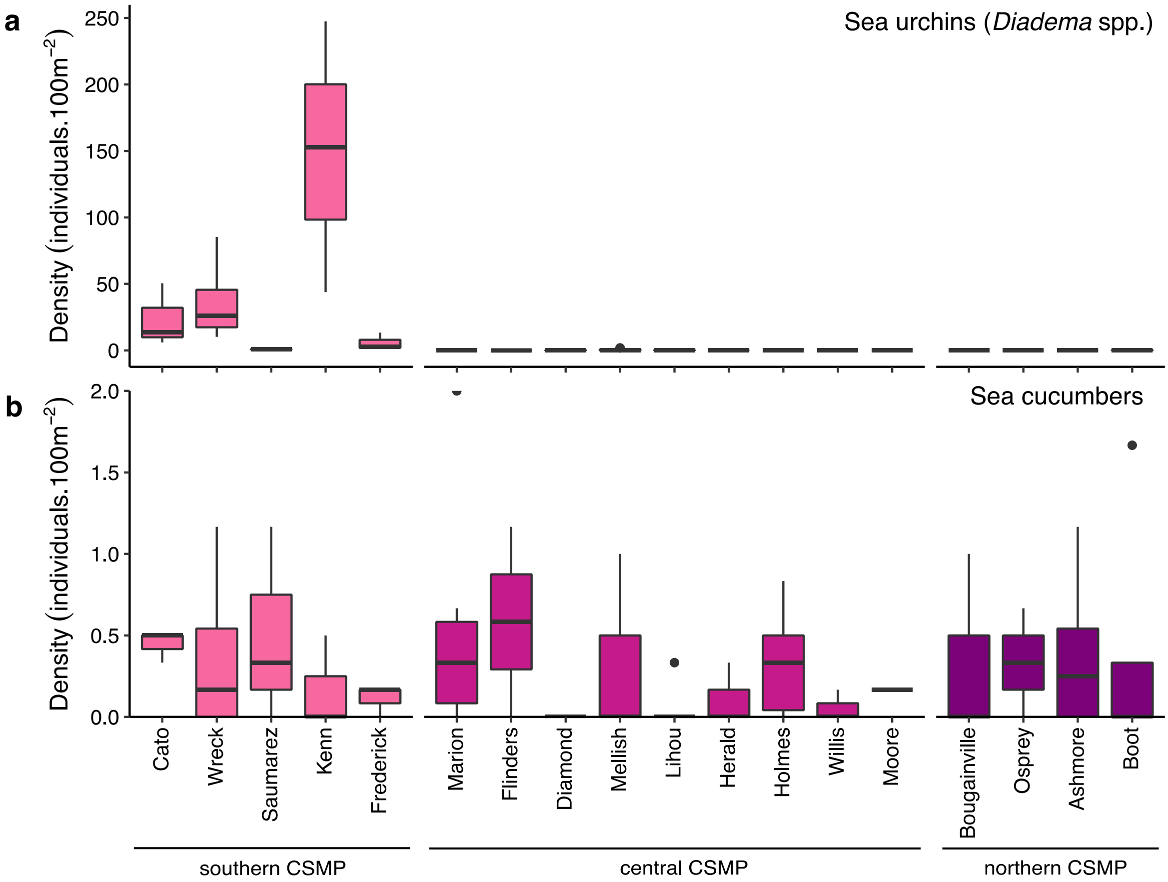


Figure 4.45 Spatial and temporal variation in the abundance of **(a)** long-spined sea urchins (*Diadema* spp.) and **(b)** sea cucumbers (Holothuroidea) among the 18 reefs surveyed in the Coral Sea Marine Park during 2023/24. Data are based on 50 x 2 m belt transects. Reefs are arranged from south to north (left to right) and coloured by *a priori* regional assignments (following Figure 3.1).

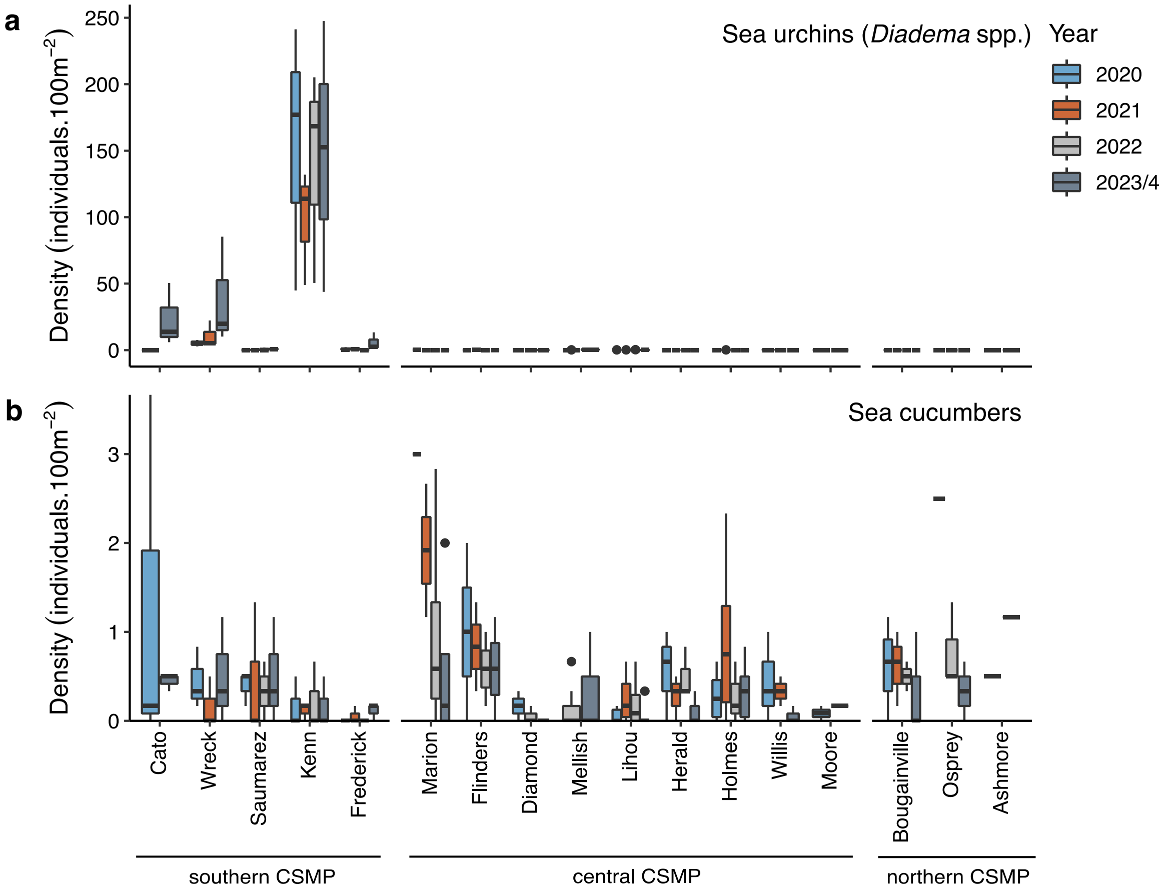


Figure 4.46 Spatial and temporal variation in the abundance of **(a)** sea urchins (*Diadema* spp.) and **(b)** sea cucumbers (Holothuroidea) among 17 reefs in the Coral Sea Marine Park. Data are based on replicate 50 x 2m transects at each of 58 matching sites that were surveyed at least once during 2020-202 and again in 2023/24.

5.5 Coral health and injury

5.5.1 Coral colony size distribution

Shallow coral assemblages of the 18 CSMP reefs surveyed in 2023/24 were dominated by relatively small coral colonies (<20cm diameter), with few colonies larger than 40cm diameter recorded (Figures 4.47, 4.48). This predominance of small colonies has been evident in the CSMP since this series of surveys was initiated in 2018 (Figure 4.48; Hoey et al. 2020, 2021, 2022), and is indicative of a system that is exposed to frequent disturbance and/or low rates of recovery (Dietzel et al. 2020). Comparisons among regions reveal that the southern and central CSMP have a similar abundance of juvenile coral colonies (<5cm diameter) but a lower abundance of small (6-20cm) and large coral colonies (21-40cm, 41-

60cm and >60cm) than the northern CSMP (Figure 4.47). There is also considerable variation in the distribution of coral size classes among reefs, with Cato, Mellish and Bougainville having a greater proportion of large coral colonies (21-40cm, 41-60cm and >60cm) than other reefs within the southern, central, and northern CSMP, respectively (Figure 4.48).

There has been a marked reduction (34.5% decline) in the abundance of larger coral colonies (>20cm diameter) from 2020-2023/24, with the greatest declines in the >60cm (68.9% decline) and 40-60cm (38.4% decline) size classes (Figure 4.47). These declines in larger coral colonies (>20cm diameter) have been most pronounced in the southern and central CSMP (44.0 - 44.4% decline), compared to the northern CSMP (22.1% decline). These declines provide further evidence for the likely bleaching related mortality in the central and southern CSMP due to heat stress after our surveys in February 2022 (see also Section 4.1.2). Over the same time period, the density of juvenile corals (<5cm diameter) has doubled across the CSMP, driven largely by increases in the central and northern CSMP (Figure 4.47). The density of small corals (6-20cm diameter) has remained relatively stable in the southern CSMP, decreased in the central CSMP (33.7% decline), and increased in the northern CSMP (66.5% increase) from 2020 to 2023/24.

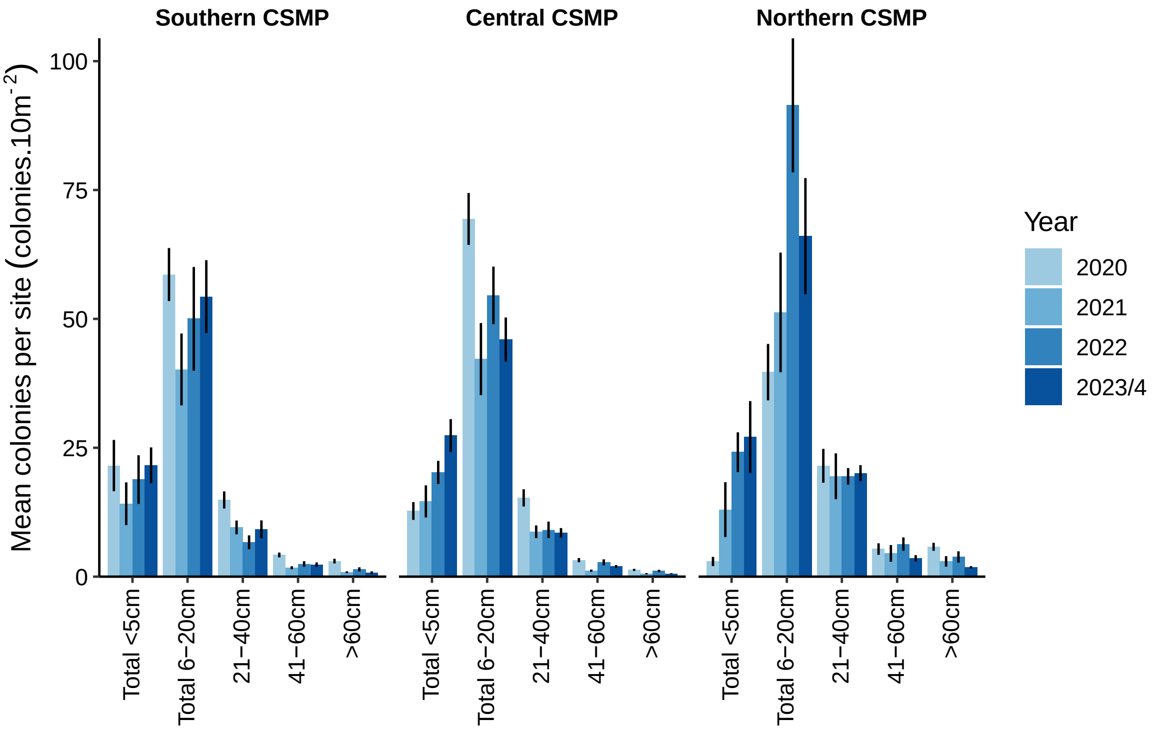


Figure 4.47 Temporal variation in the size frequency distribution of coral colonies surveyed across three regions of the Coral Sea Marine Park. Data are based on 54 sites across 17 reefs that were surveyed at least once during 2020-2022 and again in 2023/24.

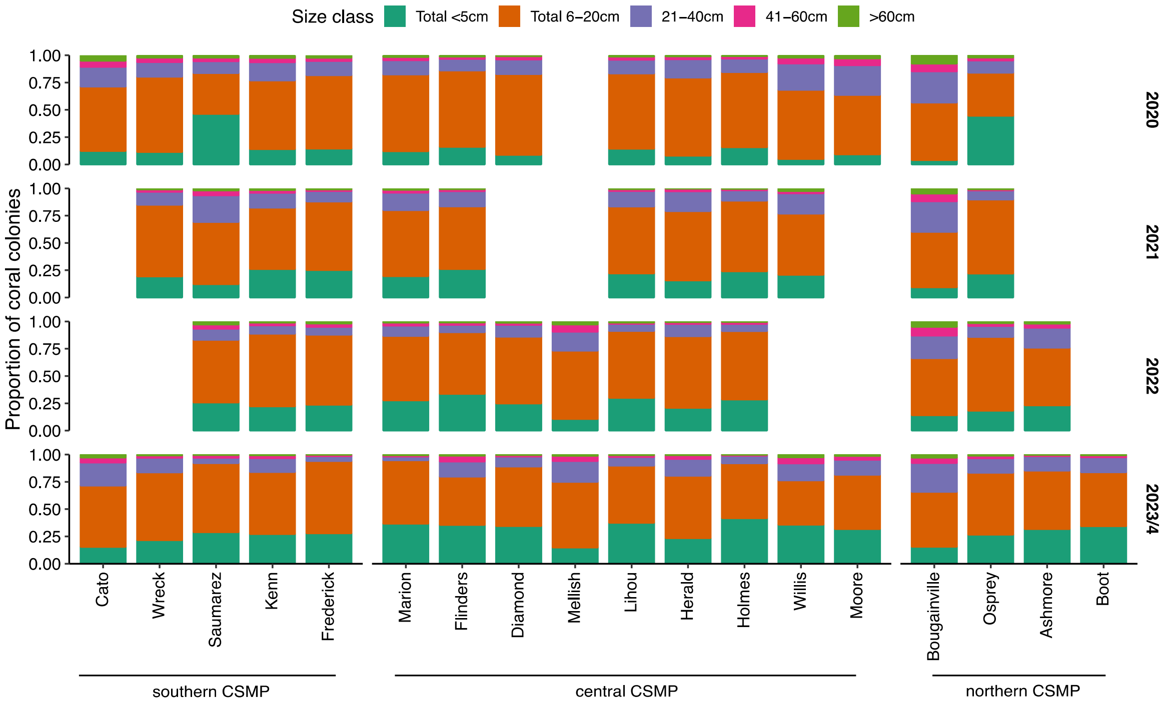


Figure 4.48 Proportion of coral colonies within each size class at 18 reefs within the Coral Sea Marine Park from 2020 to 2023/24.

5.5.2 Coral condition

In 2023, the vast majority (97.8%) of corals surveyed at each reef were healthy and was consistent with the low levels of heat stress experienced throughout the CSMP in 2023 (Figures 4.49, 4.50, 4.51). However, the percentage of healthy corals was considerably lower (80.1%) across all reefs surveyed in 2024 (Figure 4.49). The percent of colonies exhibiting signs of injury (5-100% recent mortality) as a result of various stressors was low in both 2023 (1.3%) and 2024 (1.4%) and consistent with previous surveys of the CSMP (Hoey et al. 2020, 2021; Burn et al. 2022). The percent of colonies exhibiting signs of heat stress (pale to 100% bleached), however, was 11-fold greater in 2024 (18.6%) than in 2023 (1.7%; Figure 4.49). The incidence of heat stress (paling and bleaching) in 2024 varied among reefs, ranging from 2.3% at Cato Reef to 46.6% at Frederick Reef (Figure 4.49). As expected, the incidence of paling and bleaching varied among coral taxa with heat sensitive taxa such as *Stylophora* (66%), *Seriatopora* (42%), and *Montipora* (38%) being more affected than other taxa (Loya et al. 2001; Figure 4.50). Interestingly, the incidence of paling and bleaching among *Acropora* colonies was lower than expected (16.1%) and may reflect some adaptation to heat stress following exposure to previous heat stress and bleaching events.

At the time of our surveys the majority of heat stress manifested primarily as the paling of colonies (66.1% of colonies that showed signs of heat stress), with only 5.3% of colonies being completely bleached (Figures 4.49, 4.50). While this level of bleaching was significantly less than that observed during the 2020 bleaching event (61.9% of colonies bleached), the heat stress experienced in the CSMP in 2024 was still building at the time of the surveys and did not reach its peak until late March (Figure 4.51). Importantly, the lowest incidence of bleaching in 2024 was recorded on the first few reefs surveyed (Cato Reef: 2.3%; Wreck Reef: 11.5%; Mellish Reef: 5.7% of colonies), and conversely the highest incidence of bleaching was recorded on the last few reefs surveyed (Frederick Reef: 46.6%; Saumarez Reef: 31.2%; Marion: 26.6% of colonies). This variation is consistent with increasing heat stress over the duration of our surveys. At the time of our last surveys for 2024 (3rd March) large areas of the southern and central CSMP were exposed to > 8 DHW, and up to 13 DHW in some areas (Figure 4.51), levels of heat stress where severe bleaching and mortality may be expected (Hughes et al.

2018). Importantly, the marine heat wave continued to build through March with large areas of the central CSMP exposed to >12 DHW and up to 17 DHW in some areas. Future monitoring (ideally in late 2024 or early 2025) will be critical to assess the impacts of this heat stress on shallow water coral communities.

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.

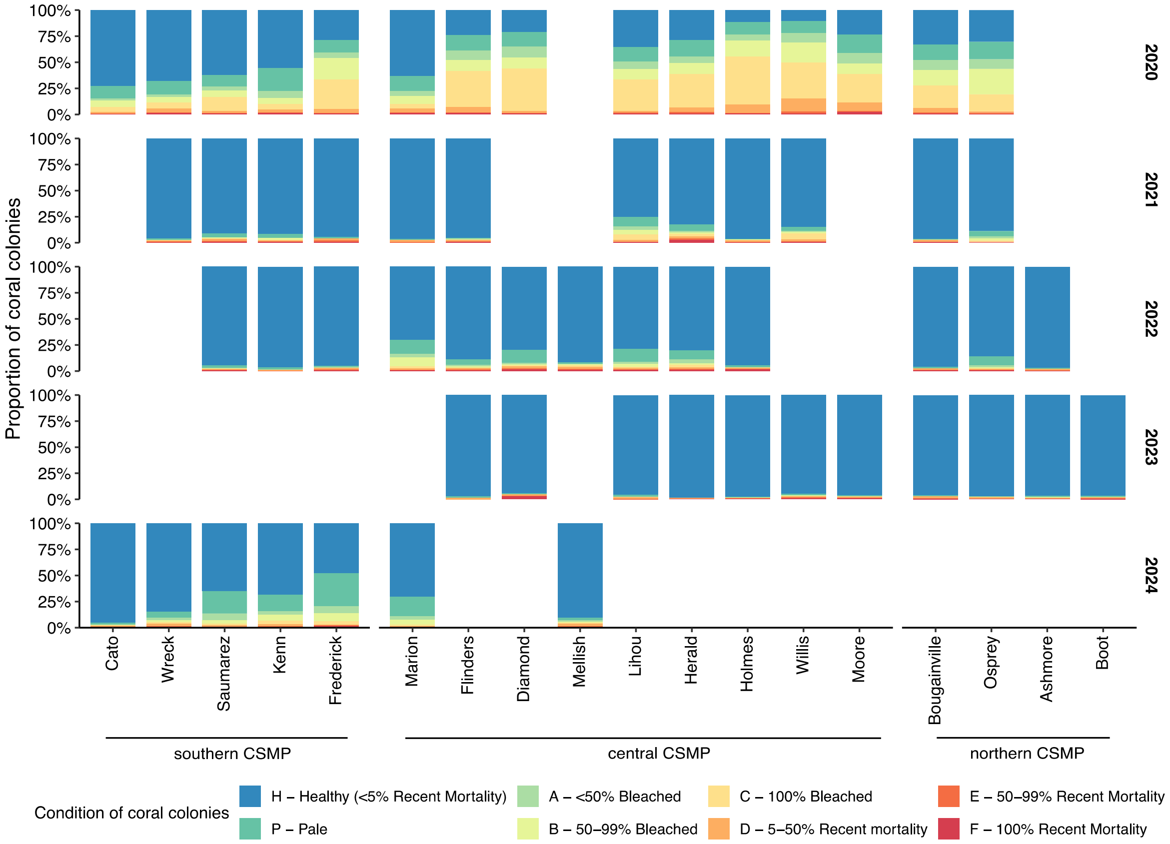


Figure 4.49 The proportion of coral colonies in each of eight health categories from ‘healthy’ to ‘recently dead’ recorded at 18 reefs within the Coral Sea Marine Park from 2020 to 2024. Note: not all reefs were surveyed in each year, with 11 reefs surveyed in 2023, and 7 reefs surveyed in 2024.

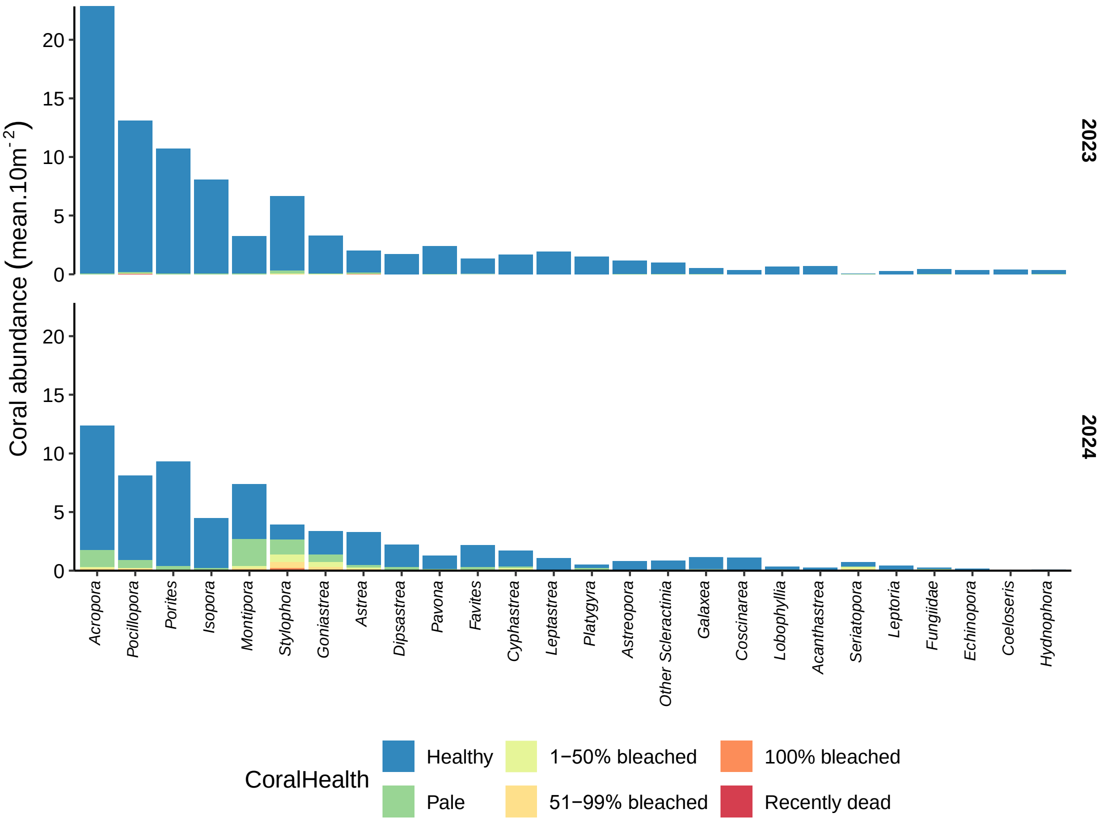


Figure 4.50 Mean density of coral colonies (per 10m^2) in the 26 most common scleractinian genera (including a pooled ‘other Scleractinia’ category) in each of six bleaching health categories from ‘healthy’ (blue) to ‘recent bleaching mortality’ (red) observed at sites across 18 reefs in the CSMP during February – March 2023 and February – March 2024.

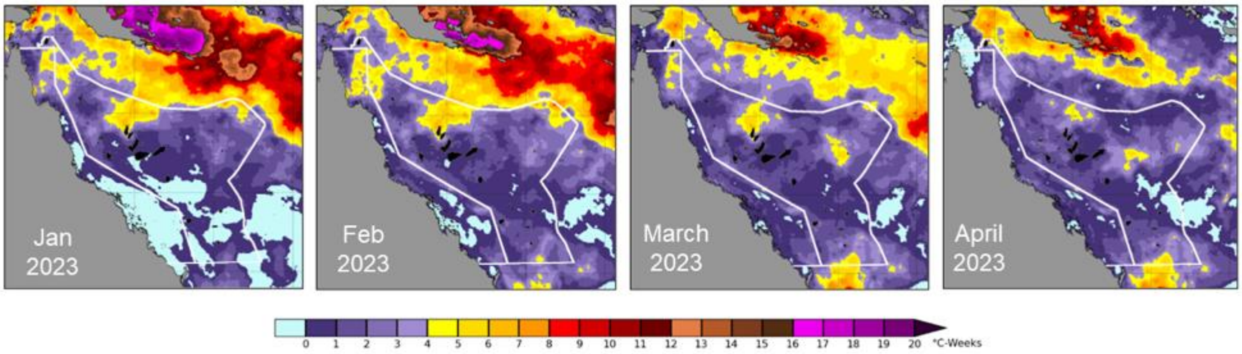


Figure 4.51 Mean monthly maximum degree heating weeks (DHW) in the Coral Sea Marine Park for January - April 2023. Images produced using the NOAA CRW 5km product v3.1

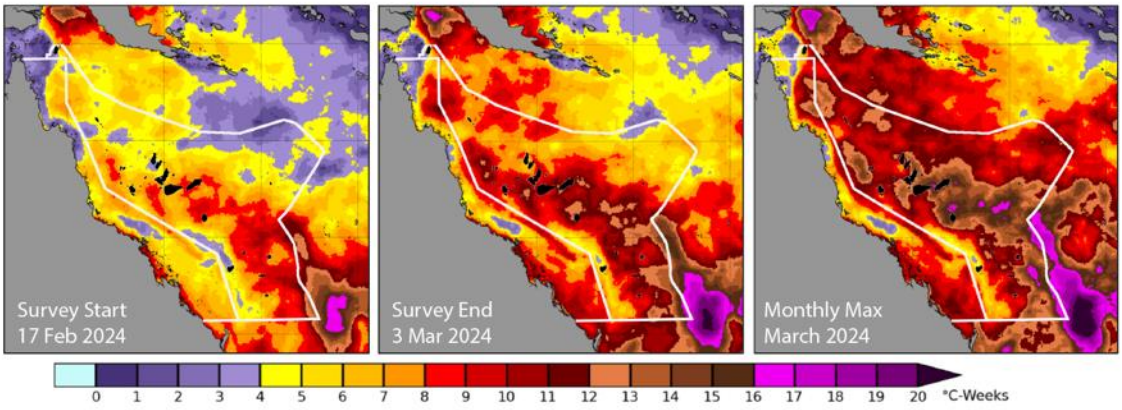


Figure 4.52 Degree heating weeks (DHW) in the Coral Sea Marine Park for February – March 2024 showing the progression of heat stress from the start of the surveys (17th February) to the end of the surveys (3rd March), and the monthly maximum heat stress for March 2024. Images produced using the NOAA CRW 5km product v3.1

5.5.3 Juvenile corals

A total of 17,002 juvenile corals (≤5cm diameter; Rylaarsdam 1983) were recorded across the 78 sites and 18 reefs surveyed in the CSMP in 2023 and 2024, equating to a mean density of 36.3 juvenile corals per $10m^2$, and representing an increase in the densities of juvenile corals reported in previous years (2020: 15 juvenile corals per $10m^2$; 2021: 16.4 juvenile corals per $10m^2$; 2022: 23.1 juvenile corals per $10m^2$). Some caution needs to be applied when comparing across all reefs surveyed, rather than those that have been resurveyed in multiple years. The higher overall density of juvenile corals in 2023/24 was largely driven by the higher densities recorded at Ashmore and Boot Reefs in the far north of the CSMP (75.5 and 57.1 juvenile corals per $10m^2$, respectively; Figure 4.53), and likely reflects their proximity and hence connectivity with reefs of the Torres Straits and Eastern Fields (PNG). Overall, the mean densities of juvenile corals recorded in 2023/24 were 2-fold higher in the northern CSMP (59.6 juvenile corals per $10m^2$) than the central CSMP (28.2 juvenile corals per $10m^2$), and 2.6-fold higher than in the southern CSMP (22.7 juvenile corals per $10m^2$). There was however considerable variation among individual reefs in each region, ranging from 13.5 to 75.6 juvenile corals per $10m^2$ at Bougainville Reef and Ashmore Reef, respectively, in the northern CSMP, from 12.6 to 52.1 juvenile corals per $10m^2$ at Mellish and Holmes Reefs, respectively, in the central CSMP, and from 13.0 to 40.8 at Cato and Saumarez Reefs, respectively, in the southern CSMP (Figure 4.53). Notably, the lowest density of juvenile corals recorded in each region (Cato, Mellish and Bougainville Reefs) coincided with some of the highest coral cover recorded in each region (Figure 4.1), and may reflect a lack of benthic space for the settlement of corals rather than a limited supply of coral larvae.

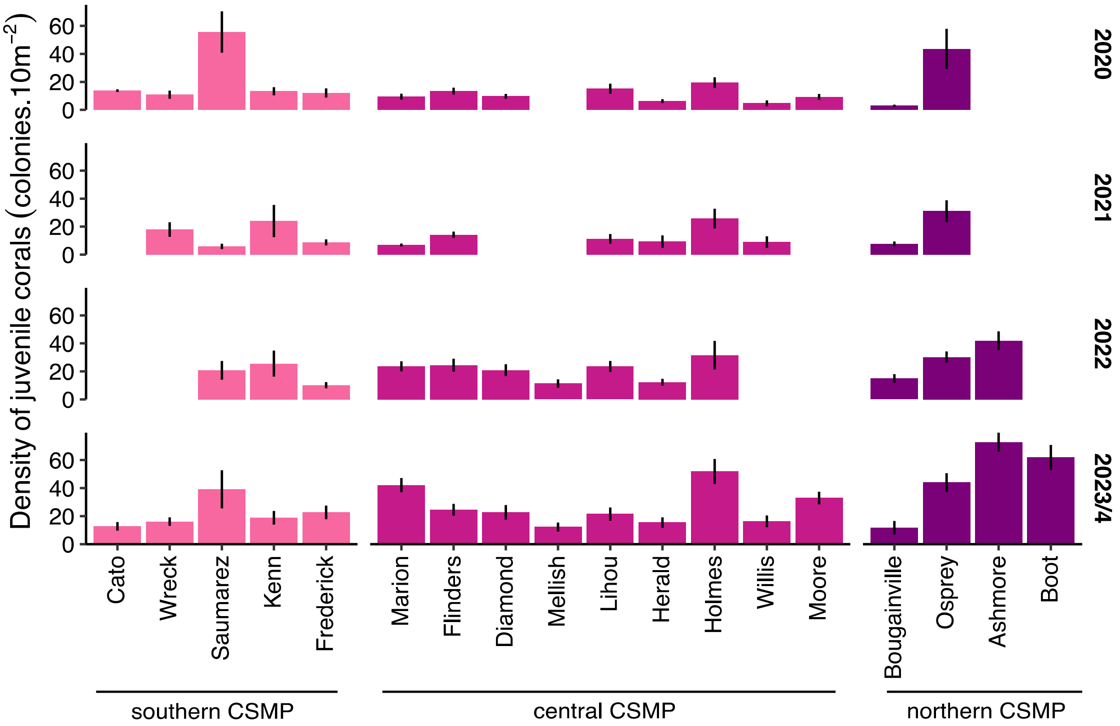


Figure 4.53 Variation in the mean (±SE) density of juvenile corals at 18 reefs surveyed in the Coral Sea Marine Park from 2020 to 2023/4. Data are based on the number of juvenile corals (<5cm diameter) surveyed within 10 x 1 m belt transects at each site. Reefs are arranged from south to north (left 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 17 reefs that were surveyed at least once in 2020-2022 and again in 2023/24 show the density of juvenile corals has increased across all three regions between 2022 and 2023/24 (southern CSMP from 18.8 to 21.6 juveniles per 10m^2; central CSMP from 20.2 to 27.4 juvenile corals per 10m^2; northern CSMP from 27.5 to 30.0 juvenile corals per 10m^2) and are now considerably greater than the densities recorded prior to and during the 2020 bleaching event (Hoey et al. 2020; Figure 4.54). These increases in the densities of juvenile corals have been largely consistent among reefs (Figure 4.55) and will aid in the recovery of the coral populations following the 2020, 2021, and 2022 bleaching events.

Despite these recent increases in the densities of juvenile corals across all regions of the CSMP in 2023/24 (average 3.6 juvenile corals per m^2) are still 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). They are, however, greater than the densities of juvenile corals recorded following major bleaching events on oceanic reefs (Scott Reef: <1 juvenile corals per m^2, Gilmour et al. 2013; Maldives: 2.9 juvenile corals per m^2, Pisapia et al. 2019).

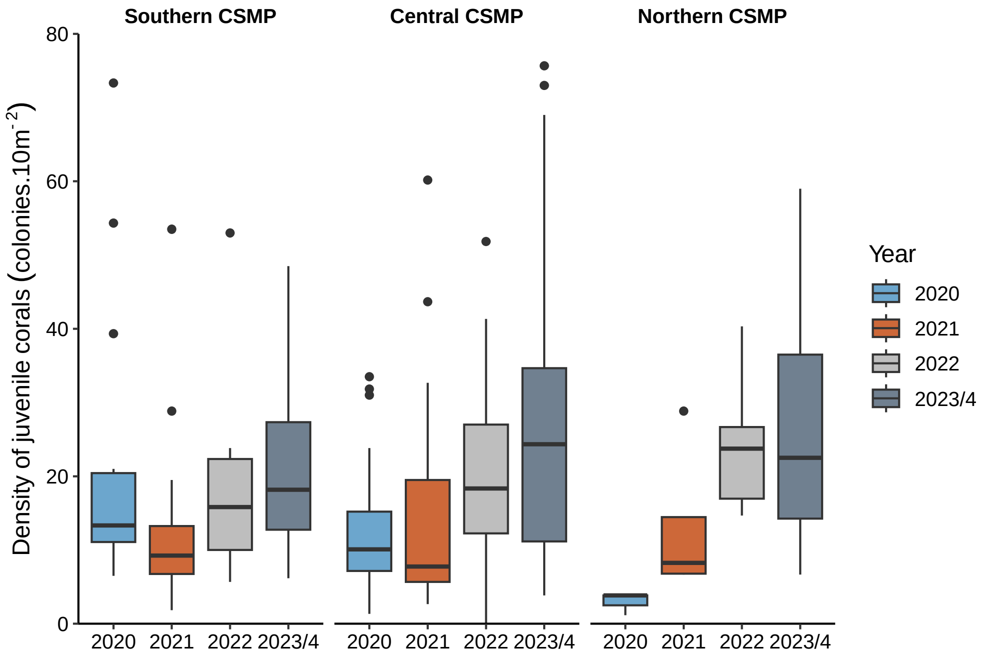


Figure 4.54 Spatial and temporal variation in the density of juvenile corals (<5cm diameter) among three regions of the Coral Sea Marine Park. Data are based on replicate 10 x 1m transects at each of 58 matching sites across 17 reefs that were surveyed at least once during 2020-202 and again in 2023/24 (southern CSMP: Cato, Frederick, Kenn, Saumarez and Wreck Reefs; central CSMP: Flinders, Holmes, Lihou, Moore, Marion and Mellish Reefs, Willis and Diamond Islets, and Herald Cays; northern CSMP: Ashmore, Bougainville and Osprey Reefs).

Images showing colonies of *Acropora* corals that have settled and established on areas of crustose coralline algae (CCA). Top: A juvenile branching *Acropora* coral (left) and a juvenile submassive *Goniastrea* coral (right) that have settled on coral skeletons covered by CCA on Marion and Mellish Reefs, respectively. Bottom: shallow reef crest habitat on Osprey Reef showing high cover of CCA's and a high density of juvenile and small *Acropora* and *Pocillopora* colonies. Image credits: Victor Huertas

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 as energy is partitioned away from reproduction and toward growth and colony repair (Hughes et al. 2019; Frisch et al. 2019). The majority of juvenile corals recorded during the 2023/24 surveys 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 yet to be fully realised. Continued monitoring of the juvenile assemblages in the CSMP will be critical to understand the full effects of the 2020, 2021, 2022, and 2024 bleaching events on the replenishment of coral populations and the future recovery of these isolated and unique reefs.

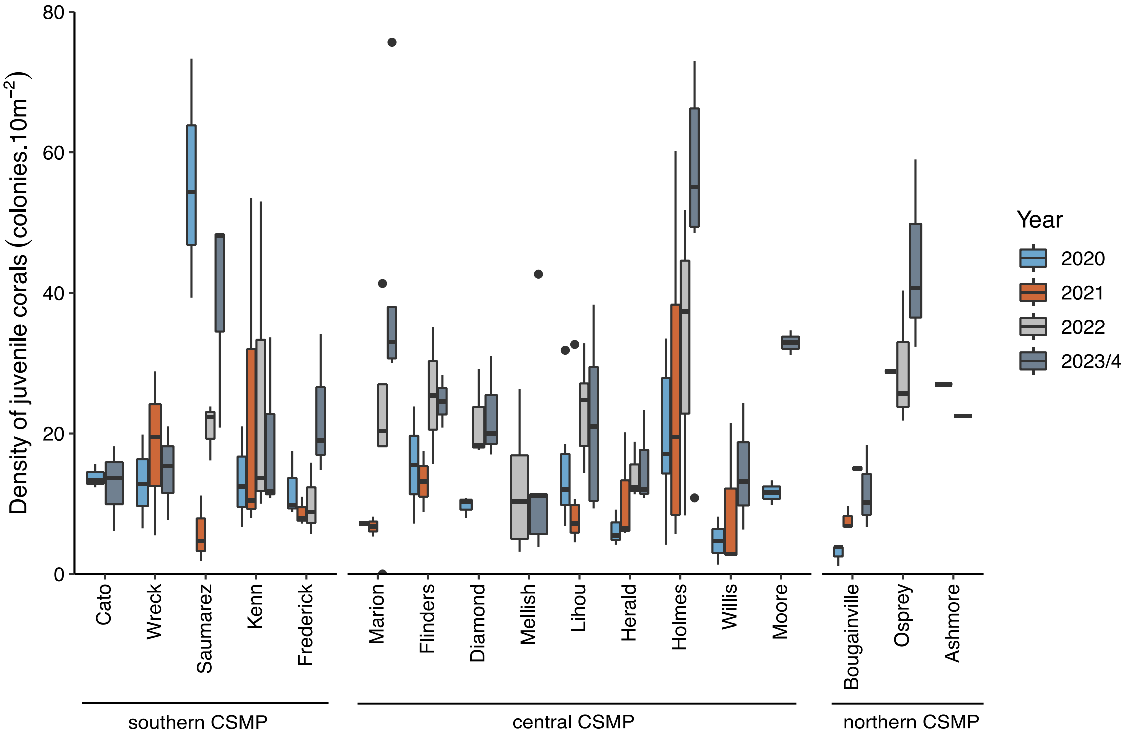


Figure 4.44 Spatial and temporal variation in the density of juvenile corals (<5cm diameter) among 17 reefs within the Coral Sea Marine Park. Data are based on replicate 10 x 1m transects at each of 58 matching sites that were surveyed at least once during 2020-202 and again in 2023/24

5.6 ROV Surveys of Deep Habitats

Despite technical issues with the two ROV units in 2023 and unfavourable weather conditions limiting ROV deployments in 2024, a total of 275 transects were successfully conducted across depths of 0-110m on 14 reefs in 2023/2024 (2023: 118 transects across 9 reefs; 2024: 157 transects across 5 reefs).

5.6.1 Deep-water benthic assemblages

Coral cover – Coral cover in deeper habitats was generally higher in the northern CSMP compared to the central CSMP (Figure 4.56), consistent with differences in shallow water habitats (Figure 4.1). Average coral cover was generally low across all depth bands in the central CSMP, and declined with increasing depth, from 9.0% at 20m to 0.9% at 100m. Coral cover was generally higher on reefs in the northern CSMP and displayed a more pronounced change with depth, decreasing from 40.9% at 10m to 7.7% at 60m after which it remained relatively stable from 60-100m (7.8-6.2%; Figure 4.56). These declines in coral cover with depth were largely consistent among reefs within each region (Figure 4.57), although it should be noted that there were some areas of high coral cover between 70-90m in the central CSMP (in particular Edna Cay, Lihou Reef; Figure 4.58) and between 40-60m in the northern CSMP (Bougainville Reef).

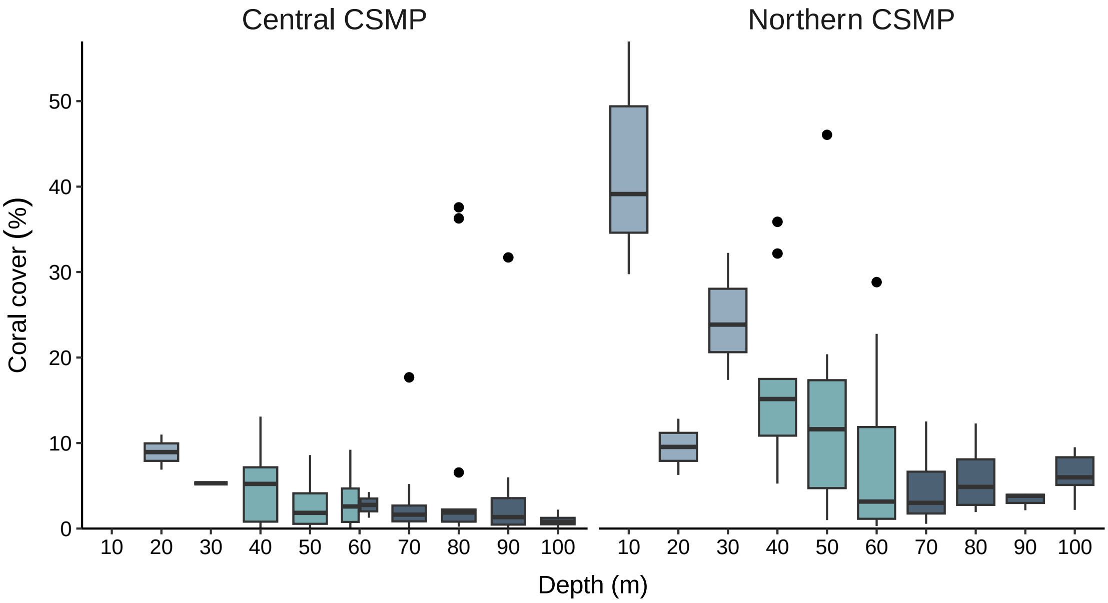


Figure 4.56 Variation in coral cover among depth bands on reefs in the central and northern Coral Sea Marine Park (CSMP). Coral cover is based on two ROV transects in each depth band at each of 11 sites and five reefs in the central CSMP, and at each of 10 sites and four reefs in the northern CSMP.

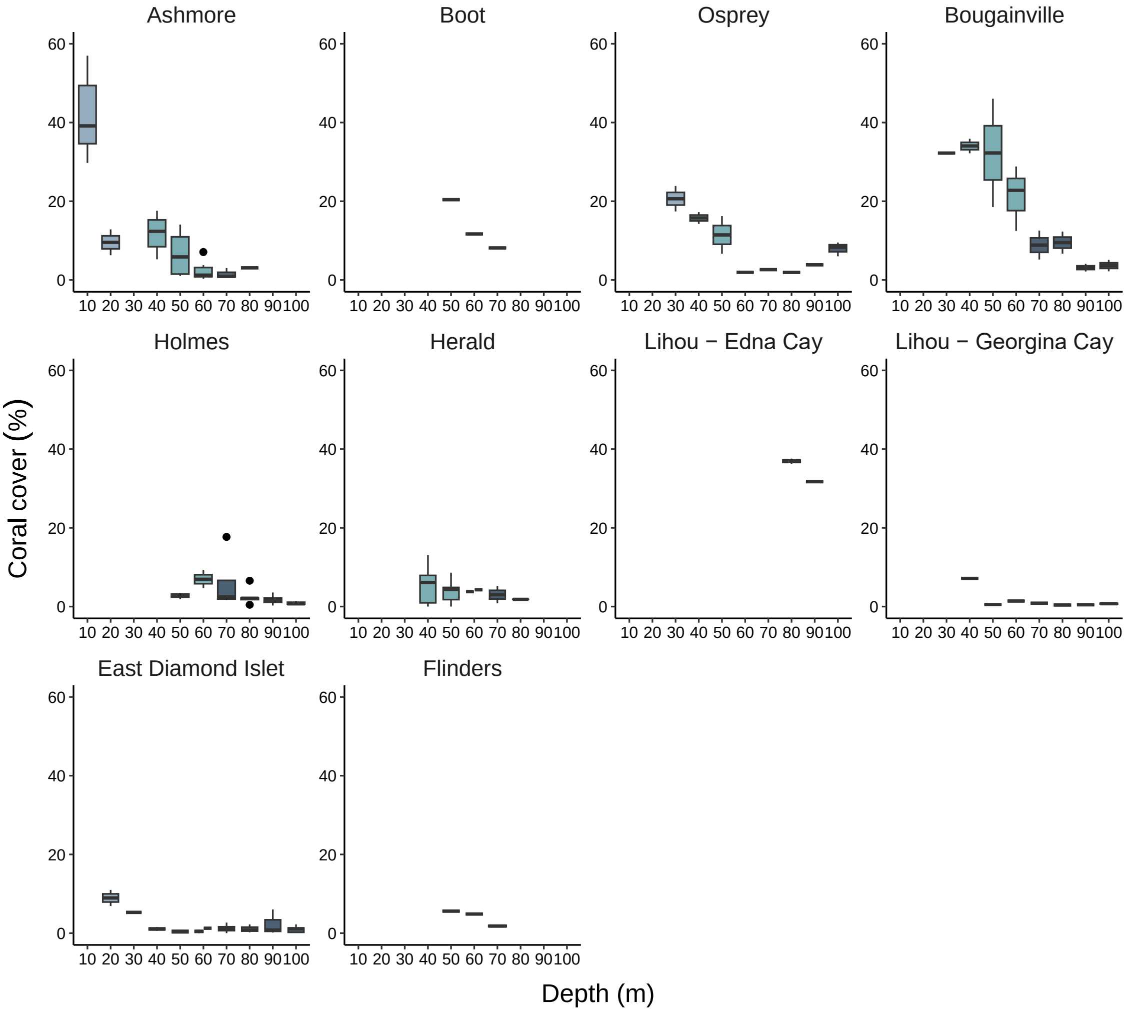


Figure 4.57 Variation in coral cover among depth bands on nine reefs in the central and northern Coral Sea Marine Park (CSMP). Coral cover is based on two ROV transects in each depth band at each of 21 sites. Northern CSMP reefs are presented in the top row and central CSMP reefs in the middle and bottom rows. Note: two sites on Lihou Reef (Edna Cay and Georgina Cay) are presented separately.

Figure 4.58 High coral cover mesophotic coral ecosystem surveyed at 77m adjacent to Edna Cay, Lihou Reef. The high coral cover at this site was first discovered by ROV surveys in July 2021 and was resurveyed during the 2023 voyage.

The other major components of deep-water benthic habitats across the central and northern CSMP were unconsolidated substrata (i.e. sand and rubble) that accounted for 42.0% and 25.5%, the green calcified alga *Halimeda* that accounted for 29.5% and 28.4%, and ‘other’ macroalgae that accounted for 13.8% and 3.1% of substrata across the central and northern CSMP, respectively (Figure 4.59). The cover of unconsolidated substrata varied considerably among reefs and depths, accounting for up to 80% cover in some depth bands on Ashmore Reef and Diamond Islets, compared to <10% across all depths sampled on Bougainville and Flinders Reefs.

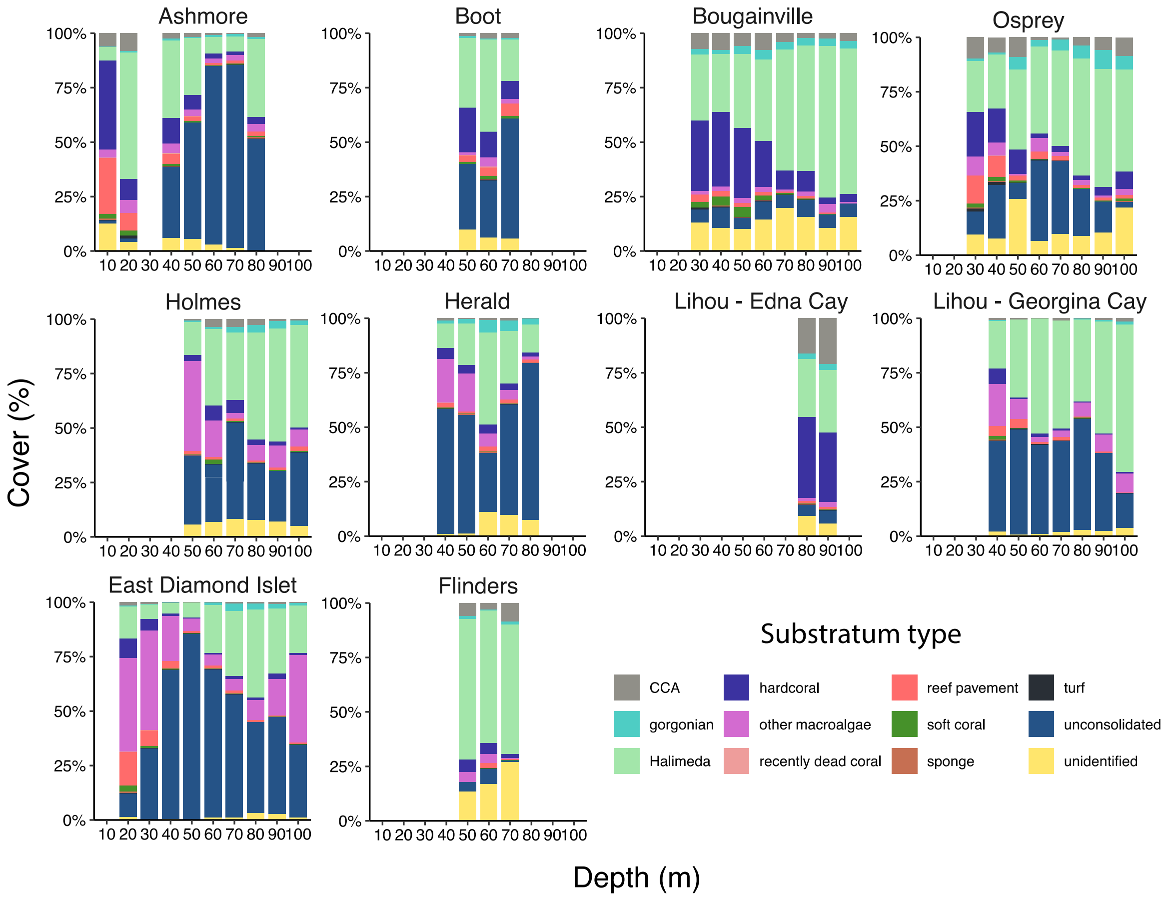


Figure 4.59 Variation in benthic assemblages among depth bands on nine reefs in the central and northern Coral Sea Marine Park (CSMP). Substratum cover is based on two ROV transects in each depth band at each of 21 sites. Northern CSMP reefs are presented in the top row and central CSMP reefs in the middle and bottom rows. Note: two locations on Lihou Reef (Edna Cay and Georgina Cay) are presented separately to highlight the differences in benthic assemblages.

Macroalgae (*Halimeda* and 'other' macroalgae) were major component of deep habitats across all nine reefs sampled (Figure 4.59). The cover of *Halimeda* (pooled across the nine reefs sampled) generally increased with depth, from 6.1% at 0-10m to 47.7% at 81-90m, with a secondary peak of 36.4% at 11-20m (Figure 4.60a). This pattern of increasing *Halimeda* cover with depth was largely consistent across reefs, although the peak in cover varied among reefs, ranging from 42.4% and 42.3% on Herald Cays and Boot Reef, respectively, to 70.0% on Bougainville Reef (Figure 4.60b). The only exception to this increasing cover of *Halimeda* with depth was Ashmore Reef, where the highest cover (58.1%) was recorded in the 11-20m depth band, after which cover decreased to 7.0% at 71-80m, before increasing to 35.8% at 81-90m (Figure 4.60b).

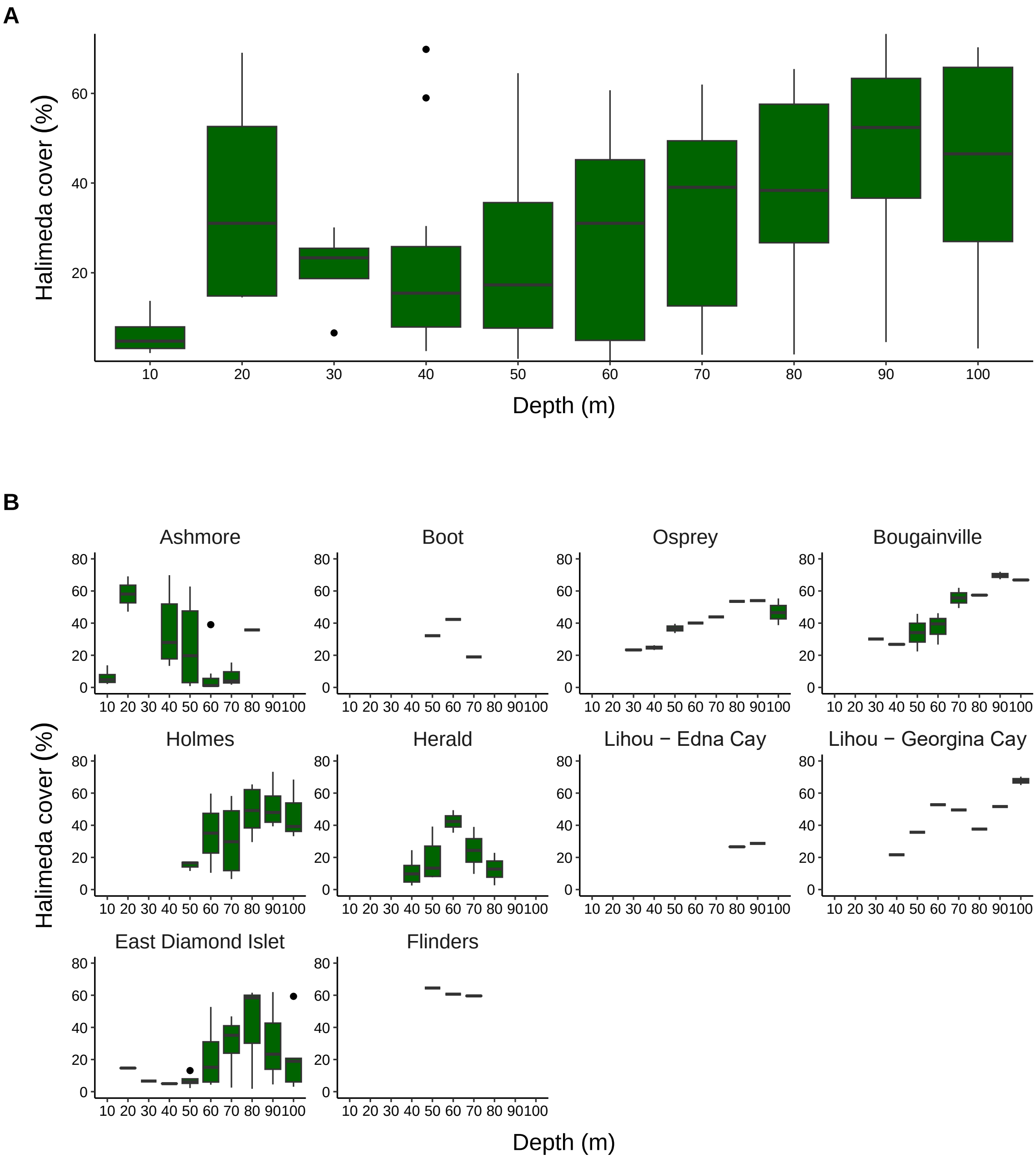


Figure 4.60 Variation in the cover of *Halimeda* spp. **(a)** among depth bands in the central and northern Coral Sea Marine Park (CSMP), and **(b)** among depth bands and among nine reefs in the central and northern CSMP. *Halimeda* cover is based on two ROV transects in each depth band at each of 11 sites and five reefs in the central CSMP, and at each of 10 sites and four reefs in the northern CSMP

The cover of ‘other’ macroalgae (pooled across the nine reefs sampled) displayed a bimodal distribution among depths, with peaks of 24.4% and 16.6% at 11-20m and 91-100m, and a low of 2.9% at 61-70m (Figure 4.61a). This pattern was largely driven by the cover of ‘other’ macroalgae at Diamond Islets, with the cover at the other eight reefs being generally low (Figure 4.61b).

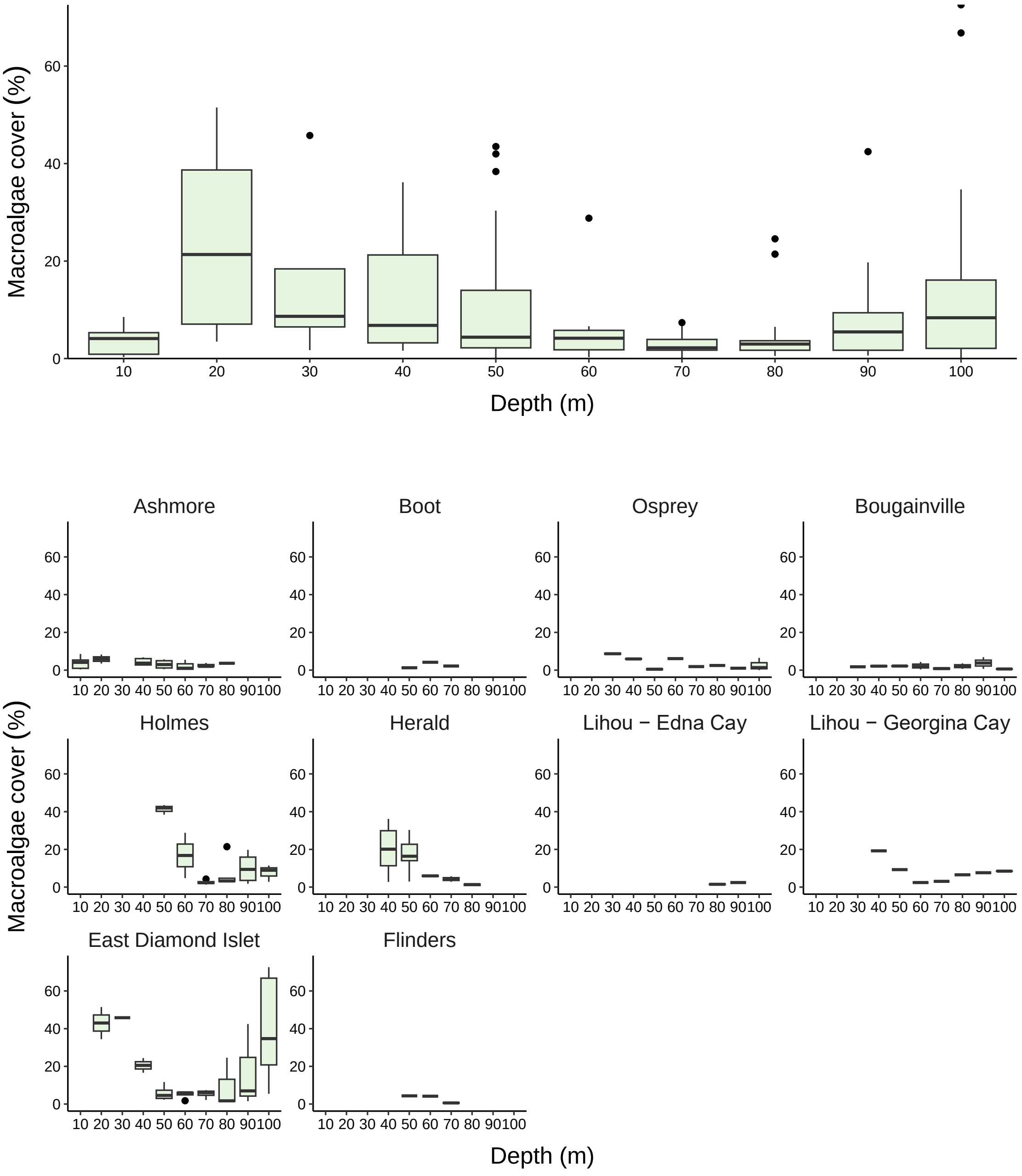


Figure 4.60 Variation in the cover of ‘other’ macroalgae (i.e., excluding *Halimeda*) **(a)** among depth bands in the central and northern Coral Sea Marine Park (CSMP), and **(b)** among depth bands and among nine reefs in the central and northern CSMP. Cover is based on two ROV transects in each depth band at each of 11 sites and five reefs in the central CSMP, and at each of 10 sites and four reefs in the northern CSMP

5.6.2 Deep-water fish assemblages

In total, 12,016 fish from 258 species were recorded across the 157 transects, at all depths, equating to a mean density of 75.5 individuals per 150m^2. Both the density and taxonomic (species) richness of fish assemblages tended to decrease and become less variable with increasing depth (Figure 4.61). Average density of reef fish declined from 181.67 individuals per 150m^2 at 21-30m to 41.9 individuals per 150m^2 at 91-100m (Figure 4.61a). Similarly, average species richness declined from 26.0 species per 150m^2 at 31-40m to 8.8 species per 150m^2 at 91-100m (Figure 4.61b).

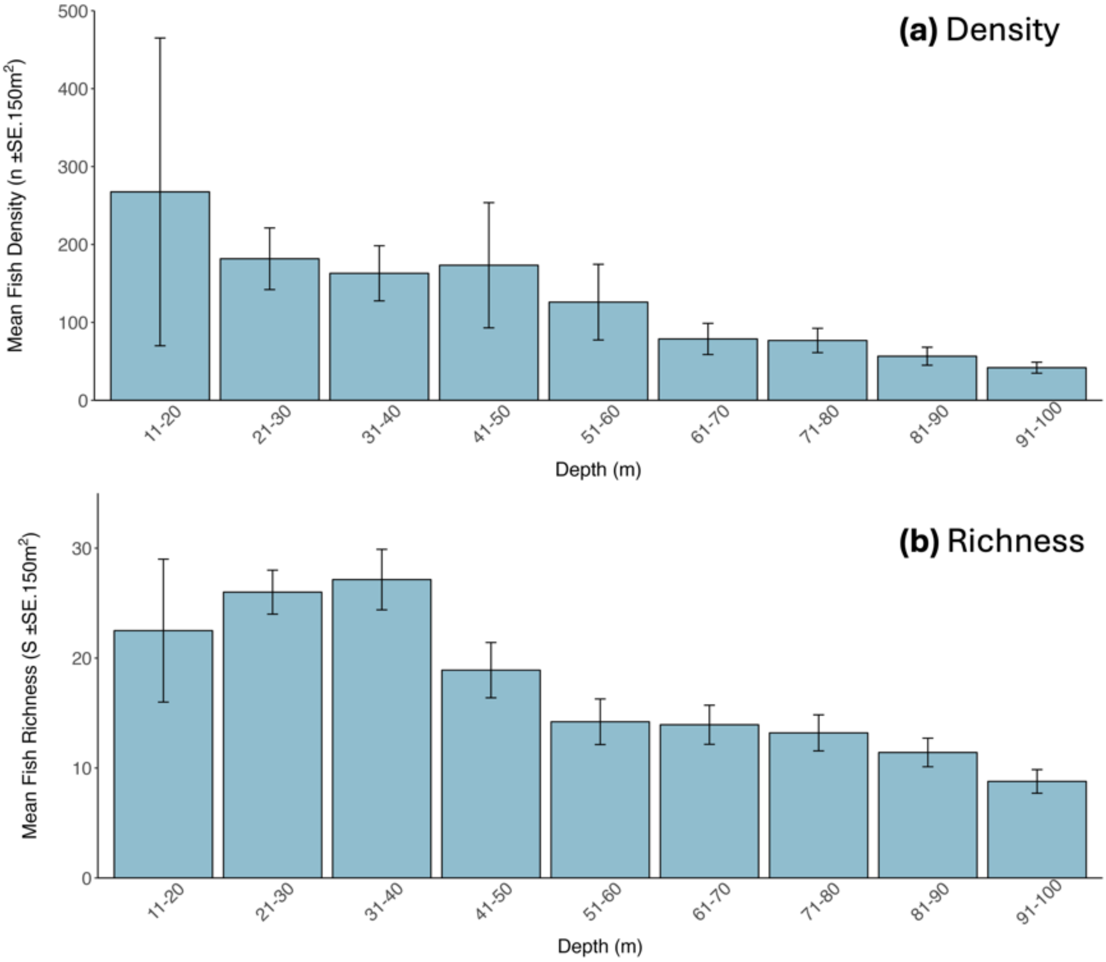


Figure 4.61 Variation in the **(a)** density and **(b)** species richness of reef fish among depth bands in the central and northern Coral Sea Marine Park (CSMP). Data is based on two ROV transects in each depth band at each of 10 sites and five reefs in the central CSMP, and at each of 8 sites and four reefs in the northern CSMP.

The majority of fish observed in deep habitats were planktivores (84.1% of individuals), followed by micro-invertivores (3.8%) and croppers/grazers (3.5%; Figure 4.62). The representation of most functional groups were relatively consistent among depth zones, except for the herbivorous scrapers and cropper grazers, and macro-invertivores that decreased with depth, and generalist carnivores (i.e., pisci-invertivores that increased in relative abundance with depth (Figure 4.62).

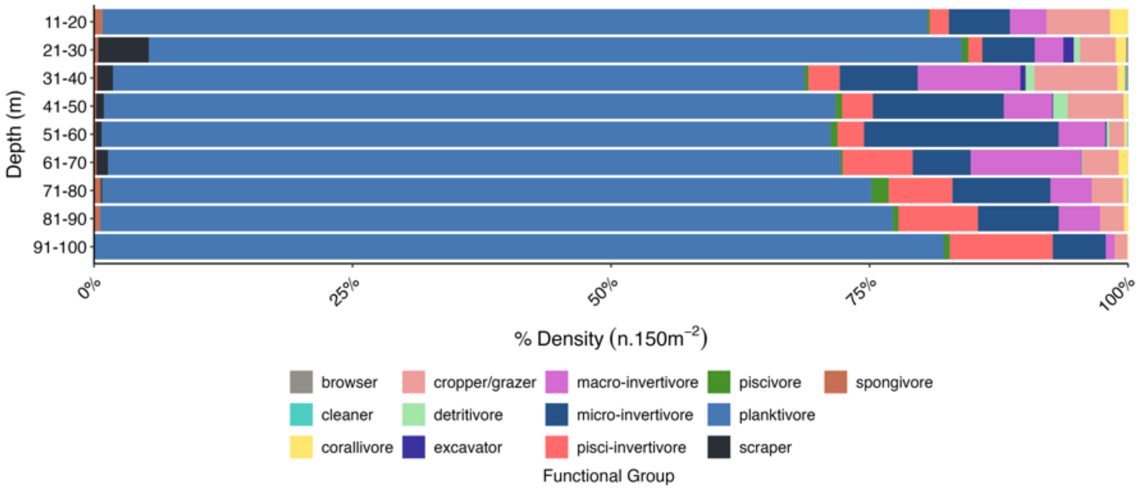


Figure 4.62 Variation in the functional composition of reef fish assemblages among depths in the Coral Sea Marine Park. Data is based on two ROV transects in each depth band at each of 10 sites and five reefs in the central CSMP, and at each of 8 sites and four reefs in the northern CSMP.

5.6.3 Range extensions and novel habitats

The ROV video surveys conducted during the 2023 and 2024 voyages revealed the presence of three fish species that hadn't been previously recorded within the CSMP, and represent significant range extensions for these species. ROV surveys confirmed the presence of Randall's Tilefish (*Hoplolatius randalli*) at East Diamond Islet, and Lihou, Ashmore and Boot Reefs*.* Individuals thought to be *H. randalli* were initially recorded by ROV at Lihou reef during ROV surveys in 2021, however, exact identification could not be made from the footage at this time. A total of eight individuals have now been recorded at reefs spanning the northern and central CSMP (Ashmore, Boot and Lihou Reefs and East Diamond Islet), all at depths below 50m. These observations by ROV in the CSMP represent the southernmost occurrence records for the species and expand the known extent of occurrence for *H. randalli* by almost 10 degrees of latitude (Figure 4.63a).

The ROV surveys on the 2023 and 2024 voyages also recorded four new species that have not previously been recorded in shallow or deep habitats of the CSMP: the speckled maori wrasse (*Oxycheilinus arenatus*), the shortsnout chromis (*Azurina brevirostris*), the Harlequin hind (*Cephalopholis polleni*) and the spotted soapfish (*Pogonoperca punctata*; Figure 4.64). *Cephalopholis polleni,* previously only known in Australian waters from the Cocos (Keeling) and Christmas Islands in the Indian ocean, was observed at Osprey reef at 97m (Figure 4.63b). *Pogonoperca punctata,* previously recorded from the Northern Territory and also the Cocos (keeling) and Christmas Islands in Australian waters, was recorded at East Diamond Islet, 53m (Figure 4.63c). Both *C. polleni* and *P. punctata* are known from the wider Indo-Pacific region but these observations in the CSMP represent the southernmost records of these species.

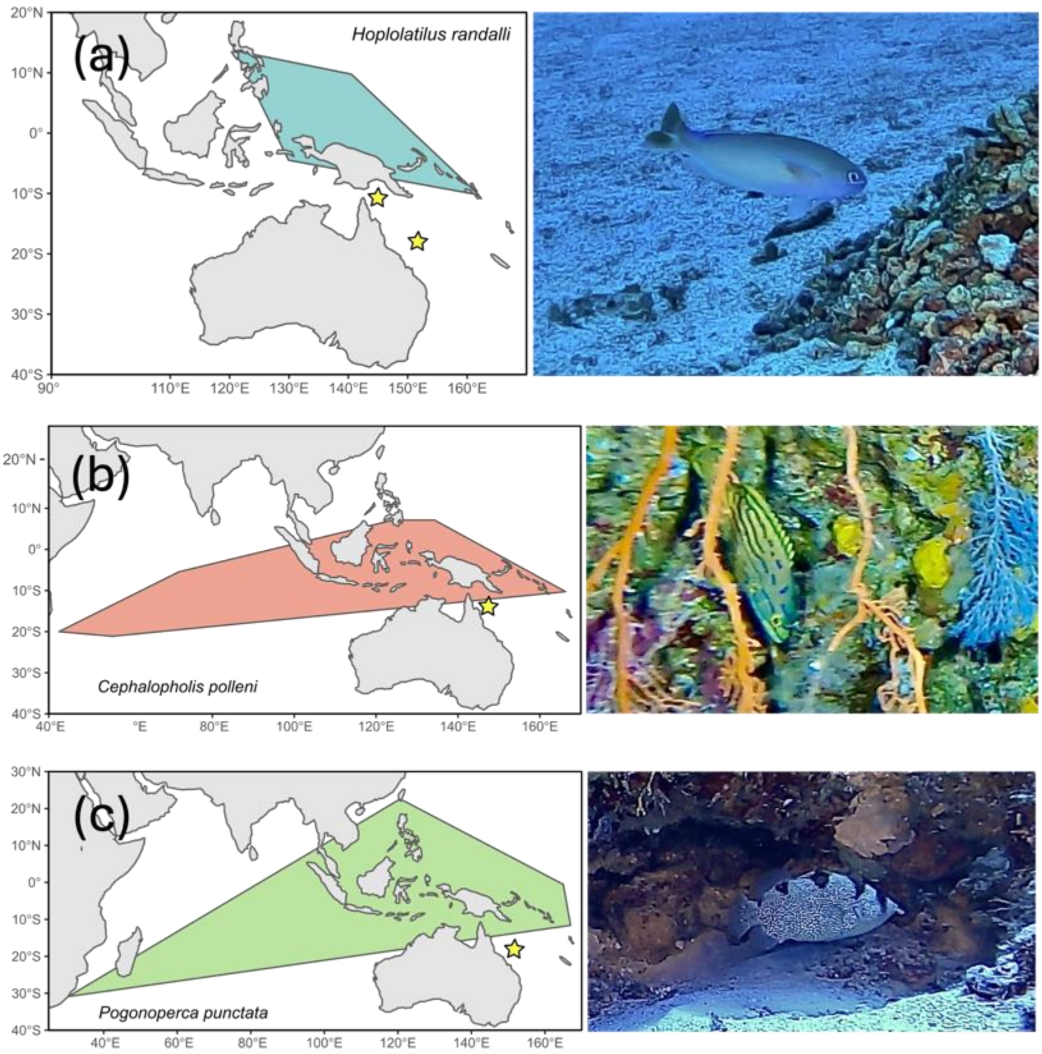


Figure 4.63 Current extent of occurrence plotted as colored hulls for a) *Hoplolatilus randalli,* b) *Cephalopholis polleni,* and c) *Pogonoperca punctata.* Occurrence data were obtained from Ocean Biodiversity Information System (www.obis.org) and the Global Biodiversity Information Facility (www.gbif.org). New observations of each species from the CSMP during 2023 ROV surveys are represented by yellow stars.

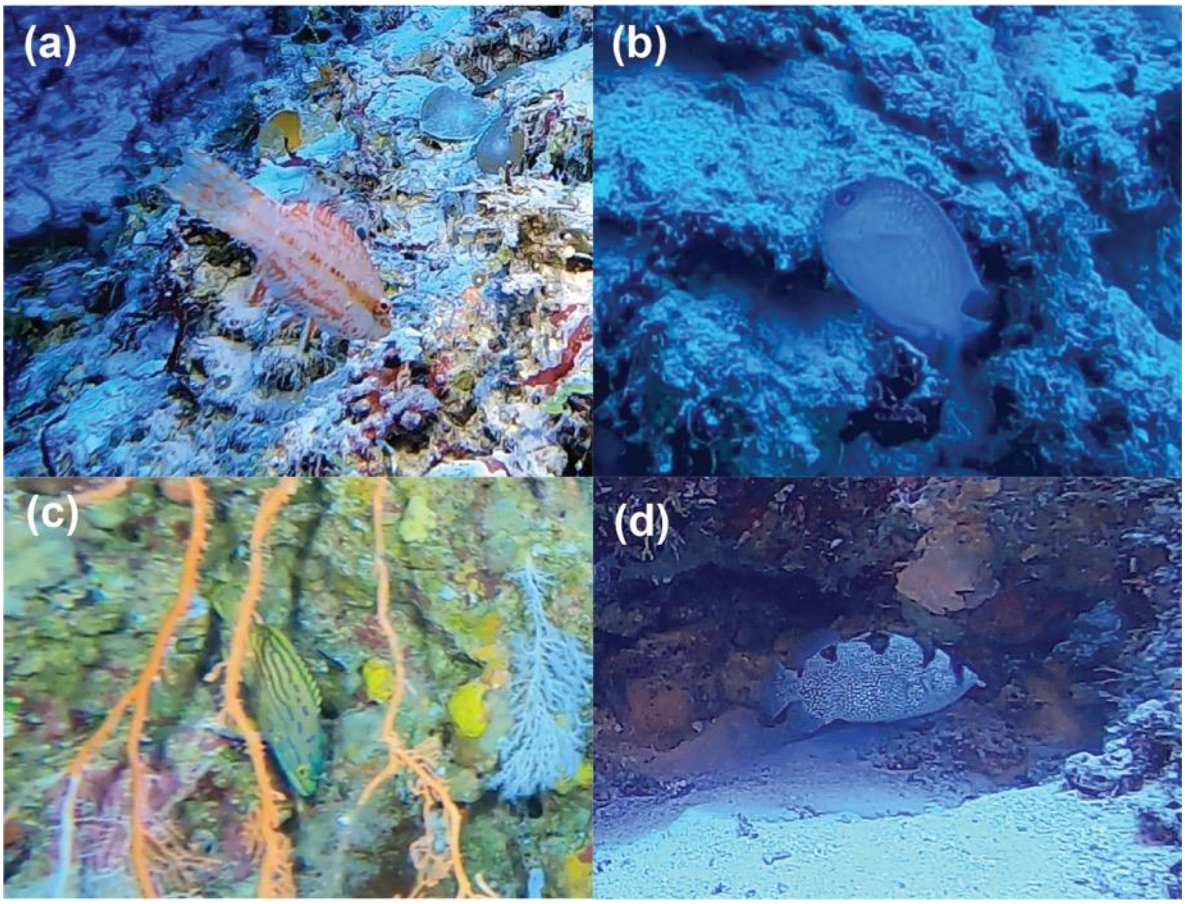


Figure 4.64 Photographs of new fish species records for the Coral Sea Marine Park recorded using a Remotely Operated Vehicle (ROV) during 2023 and 2024. **(a)** the speckeld maori wrasse *Oxycheilinus arenatus* recorded at 84m on East Dimond Islet, **(b)** the shortsnout chromis *Azurina brevirostris* recorded at 72m on Bougainville Reef, **(c)** the harlequin hind *Cephalopholis polleni* recorded at 91m on Osprey Reef, and **(d)** the spotted soapfish *Pogonoperca punctata* recorded at 53m on East Dimond Islet.

Seagrass is rare throughout the CSMP with previous surveys detecting small areas with sparse cover. A large and dense bed of seagrass (the sickle-leaved cymodocea, *Thalassodendron ciliatum*) was recorded at a depth of 25-30m around the base of a large bommie in the lagoon at Saumarez Reef, southern CSMP in March 2024 (Figure 4.65). The seagrass meadow encircled the bommie and extended for 6-8m from its base, and represents the largest meadow we are aware of in the Coral Sea Marine Park.

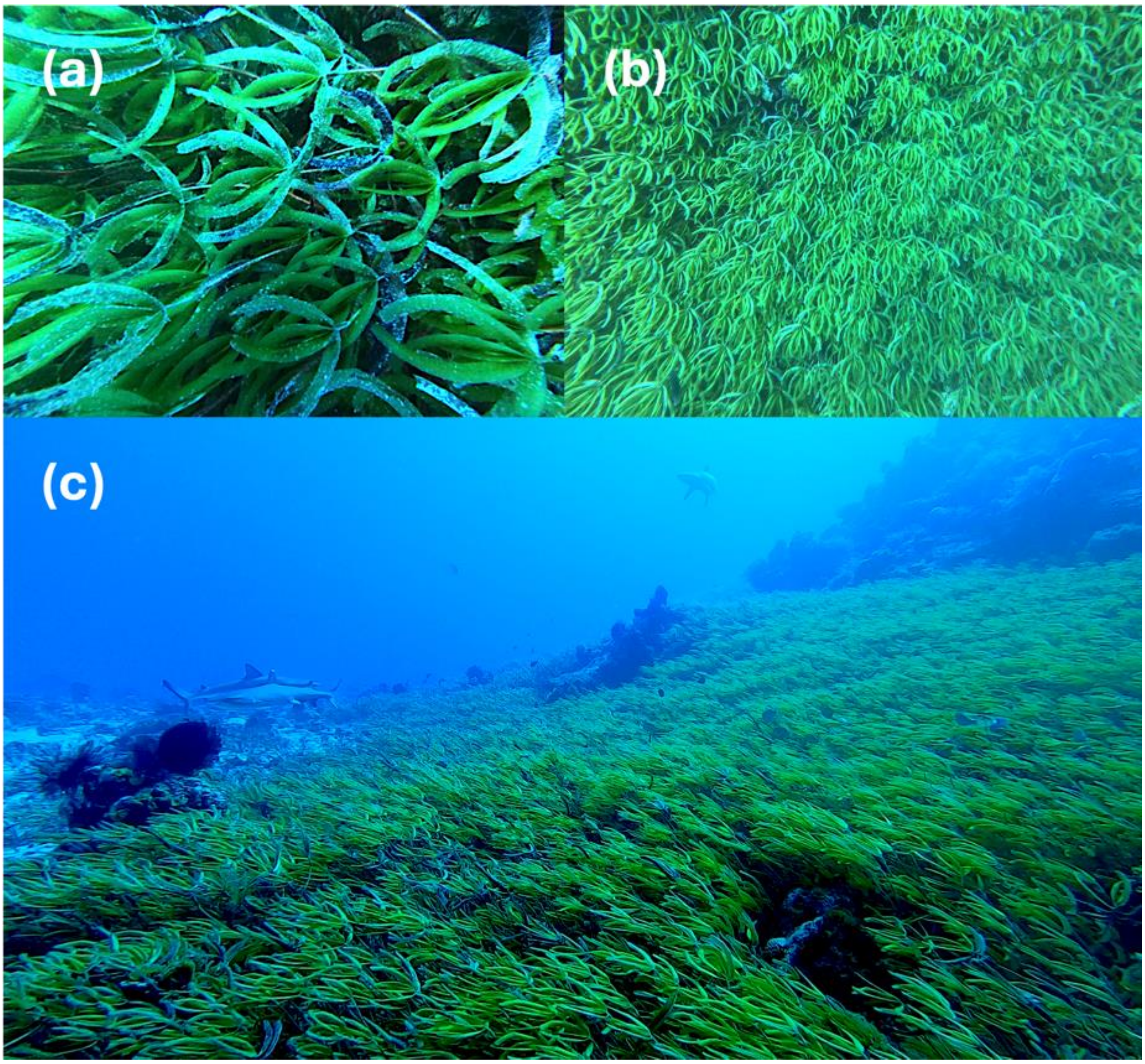


Figure 4.65 An extensive seagrass meadow recorded by remotely operated vehicle (ROV) at a depth of 25-30m in the lagoon at Saumarez Reef. **(a)** Distinct thalli of *Thalassodendron ciliatum* (the sickle-leaved cymodocea), **(b)** overview of dense coverage of T. *ciliatum*, and **(c)** dense band of *Thalassodendron ciliatum* at 28m around the base of a bommie in the Saumarez lagoon

5.7 Additional observations

5.7.1 Fish spawning aggregations

An aggregation of >20 large humphead maori wrasse (*Cheilinus undulatus*) was recorded at Bougainville site 1 on the morning of 21st February 2023. The majority of individuals were large (>90cm total length) and were positioned in open water 10-40m from the reef edge (Figure 4.66). This is a significant observation as this species usually occurs individually or in small groups (i.e., 2-3 individuals). It is also one of the largest species of teleosts (bony fish) that associates with coral reefs and is listed as *Vulnerable* on the International Union for Conservation of Nature

(IUCN) Red List. No spawning aggregations were observed during the 2024 voyage.

Figure 4.66 Several large Humphead Maori Wrasse (*Cheilinus undulatus*) aggregating in open water 10-40m off the reef edge at Bougainville Site 1 on the 21st February 2023. Image credit: Andrew Hoey

5.7.2 Vessel Moorings

Visual inspections were made of any existing vessel moorings sighted on Holmes and Bougainville Reefs. Where possible photographs were taken of the mooring lines, and the GPS coordinates of the moorings recorded. Two moorings were recorded and inspected at Holmes Reef and one mooring at Bougainville Reef. The moorings generally consisted of a length of chain or rope that passed through holes in the reef and was secured back onto itself. The mooring lines themselves were of variable condition (Figure 4.67).

5.7.3 Debris

Several large square 'quadrats' were observed on the reef slope at Holmes site 1 on the 20th February 2023. The quadrats were constructed of 2-3m lengths of PVC tube (orange electrical conduit) and secured with cable ties, with one of the quadrats having a temperature logger attached (Figure 4.68). These quadrats have been observed at this site previously, and given the level of fouling appear to have been in place for several years. The quadrats are in generally poor condition and should be considered for removal on future voyages.

Figure 4.67 Images of mooring lines attached to large bommies at Holmes Reef. Image credits: Andrew Hoey

Figure 4.68 Large abandoned quadrats observed on the reef slope at site 1 on Holmes Reef, 20th February 2023. Image credits: Andrew Hoey

6 Conclusions

Globally, coral reefs are being increasingly exposed to the effects of climate change, with climate-induced coral bleaching now recognised as the foremost threat to coral reefs globally (Hughes et al. 2017). The severity and frequency of marine heatwaves, and associated bleaching of corals, have increased over recent decades, with the likelihood of mass-coral bleaching events occurring in any given year now being three-fold higher than prior to 2000 (Hughes et al. 2018). The ongoing and predicted future effects of climate change on reefs have led to concerns that some reefs will become overgrown by macroalgae and/or approach critical thresholds at which key processes are disrupted (Wilson et al. 2006; Graham et al. 2015). While isolated reef systems, such as those in the CSMP, are often described as being ‘pristine’ or ‘near pristine’ due to their limited exposure to local anthropogenic pressures (e.g., fishing, terrestrial run-off) relative to more accessible coastal or inshore reefs (e.g., McCauley et al. 2010; Graham and McClanahan 2013), the effects of climate change are pervasive. Indeed, the CSMP has experienced four major bleaching events in the seven years preceding the 2023/24 surveys (2016, 2017, 2020, and 2021; Harrison et al. 2018, 2019, Hoey et al. 2020, 2021, 2022). Of these four events the 2020 and 2021 bleaching events were the most severe and widespread, and led to a 52% decline in coral cover in shallow (<15m depth) reef habitats throughout the CSMP. There was, however, considerable variation in the decline in coral cover among regions, reefs, and sites within reefs (Hoey et al. 2022). Importantly, the five ‘bright spot’ reefs (Hoey et al. 2020) appeared to be less adversely affected by recent bleaching events than other CSMP reefs. Assessing the potential recovery of shallow water coral assemblages following recent bleaching events, any ongoing effects of coral loss on associated fish and invertebrate communities, are critical to better understand the dynamics, and factors that contribute to the performance, of the five ‘bright spot’ reefs, and the longer-term health of this unique reef system as a whole.

6.1 The 2022 coral bleaching event

The surveys conducted in February-March 2023 and February March 2024 under this project revealed further declines in coral cover in the central CSMP (16.6%

decline between 2022 and 2023) and some reef in the southern CSMP (35.6% decline on Frederick, Kenn and Saumarez between 2022 and 2024), but not northern CSMP (8.9% increase). These declines in coral cover are likely related to the heat stress experienced through much of the central and southern CSMP during March-April 2022. Although only low-moderate levels of bleaching were recorded across central CSMP reefs, and three southern CSMP reefs in February and March 2022 (11.9% of colonies; Hoey et al. 2022), the central and eastern region of the Queensland Plateau in the central CSMP (including Herald Cays, Diamond and Willis Islets, and Lihou and Moore Reefs) was exposed to seawater temperatures above those expected to cause bleaching-induced mortality (>6 DHW; Hughes et al. 2017) in March-April 2022, with some areas exposed to 8-11 DHW (Figure 4.6). In the absence of any other major disturbance, and the limited heat stress experienced across the entire CSMP in 2023 (Figure 4.51), the observed declines in coral cover on central CSMP reefs in 2023 and southern CSMP reefs in 2024 are most likely attributable to elevated temperatures experienced in March-April 2022. This 2022 bleaching event represents the fifth major bleaching event in the CSMP in the past seven years, and is, to our knowledge, the first record of three consecutive bleaching events on coral reefs globally.

The observed declines in coral cover on the central CSMP reefs in 2023 (16.6% decline) were not as great as may have been expected based on recorded levels of DHW (i.e., 8-11 DHW) in March-April 2022. DHW combines the intensity and duration of heat stress experienced during the previous 3 months into one 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 relatively low incidence of mortality likely reflects a shifted baseline toward more bleaching resistant coral communities due to the loss of thermally sensitive species following the four previous bleaching events (i.e., 2016, 2017, 2020, and 2021) and or the loss of thermally sensitive genotypes within a species, and as such the severity of this bleaching event should not be underestimated. 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 a range of factors, including 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).

The most recent declines in coral cover on central and southern CSMP reefs compounded on previous declines due to the 2020 and 2021 bleaching events. The net effect of these three consecutive bleaching events is a 58.6% and a 50.2% decline in shallow water (<15m) coral cover across the central and southern CSMP, respectively. Importantly, several reefs in the central CSMP (Marion, Lihou and Holmes Reefs, and Diamond Islets) and Frederick Reef in the southern CSMP have levels of coral cover that are approaching or below critical thresholds (<10% cover) that have been shown to disrupt key processes and the maintenance of biodiversity and ecosystem functions in other reef systems (Wilson et al. 2006; Graham et al. 2015; Pratchett et al. 2021). Despite the extensive coral loss there have been no concomitant increases in macroalgae, rather the dead coral skeletons appear to have been rapidly colonised by crustose coralline algae (CCA). This differentiation is critical, as increases in macroalgal biomass can break key ecological feedbacks, further suppressing the recovery of coral populations (e.g., Hoey and Bellwood 2011; Van de Leemput et al. 2016; Johns et al. 2018). In contrast, CCA's are a critical component of healthy reef ecosystems, contributing to reef calcification and stabilisation of the reef framework (e.g., Teichert et al. 2020; Cornwall et al. 2023), promoting the settlement and survival of coral larvae (e.g., Harrington et al. 2004; Abdul Wahab et al. 2023), and inhibiting the settlement and colonisation of fleshy fouling organisms (Littler and Littler 2013).

Current levels of coral cover on central CSMP reefs (mean: 12.2%; range: 5.8-24.1%) are generally greater than that of historical surveys of isolated bommies within the lagoons at Herald Cays, Chilcott Islet and Lihou Reef (1-5% in 2003 to ~6% in 2007; Oxley et al. 2003; Ceccarelli et al. 2008), indicating that such low coral cover may not be uncommon on these reefs. While it is currently unknown if coral cover <10% will disrupt key processes and limit the recovery of these central CSMP reefs, any further coral loss is likely to have lasting consequences on the health and resilience of these unique ecosystems. The next few years may be critical in determining whether coral populations and coral cover on these reefs recovers, or collapses, as well as the implications for reef fish and invertebrate communities.

6.2 The 2024 coral bleaching event

Climate change and associated disturbances are increasingly shaping the composition and state of coral reefs globally (e.g., Hughes et al. 2017, 2018; Pratchett et al. 2020), and it is becoming critical to understand the patterns of disturbance, as well as the responses, recovery and resilience of individual reefs and reef systems. Reefs in the CSMP have experienced five major coral bleaching events over the past 7 years (i.e., 2016, 2017, 2020, 2021, 2022), including three consecutive bleaching events from 2020-22. While low levels of heat stress and negligible bleaching were evident across the CSMP in 2023, low to moderate levels of bleaching were recorded on reefs in the southern and central CSMP during the 2024 voyage (18.6% of coral colonies were pale or bleached). However, the 2024 marine heatwave in the CSMP was still building at the time of the surveys and did not reach its peak until late March (Figure 4.51). Consistent with the building intensity of the marine heatwave the highest incidence of bleaching recorded during the 2024 voyage was on the last three reefs surveyed (Frederick Reef: 46.6%; Saumarez Reef: 31.2%; Marion: 26.6% of colonies). At the time of our last surveys for 2024 (Saumarez Reef, 3rd March) large areas of the southern and central CSMP were exposed to > 8 DHW (Figure 4.51), levels of heat stress where severe bleaching and mortality may be expected (Hughes et al. 2018). Importantly, the marine heat wave continued to build through March with large areas of the central CSMP exposed to >12 DHW and up to 17 DHW in some areas. These levels of heat stress are greater than those experienced during the 2020 bleaching event that led to *ca.* 40% decline in shallow water coral cover across the CSMP (Hoey et al. 2021). Future monitoring (ideally in late 2024 or early 2025, and prior to any potential future heat stress) will be critical to assess the impacts of this marine heat wave on shallow water coral communities.

6.3 Reef fish

The biomass of reef fishes has steadily declined on southern, central and northern CSMP reefs from 2020 to 2022, with further declines being evident on central and northern CSMP reefs between 2022 and 2023/24 (9% and 21 % declines, respectively), while there was an increase on southern CSMP reefs over the same period. These declines in reef fish biomass since 2020 are likely related (at least to some degree) to the reductions in coral cover during this period (2020-2023/24). The initial decrease in reef fish biomass (2020-2022) was largely driven by declines in small-bodied planktivorous fishes (e.g., damselfishes), and corallivorous butterflyfishes that are reliant on live coral for shelter and food, respectively. These fishes are often the first and most adversely affected groups following coral loss (e.g., Pratchett et al. 2011, 2014), and have shown signs of recovery on some reefs in the past 2 years. There have, however, been steady declines in the density and biomass of grazing fishes (primarily surgeonfishes, and in particular *Acanthurus lineatus* and *Acanthurus nigrofuscus*) from 2020-2022 in the central and northern CSMP, with further declines recorded in 2023/24. The biomass of grazing fishes on central and northern CSMP reefs is now >60% lower than 2020 levels. Interestingly the density and biomass of grazing fishes has remained relatively stable on southern CSMP reefs over this time period (2020-2023/4).

Grazing fishes are widely viewed as a critical functional group on coral reefs preventing algal overgrowth and maintaining a healthy balance between corals and algae (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). The continued and sustained declines in the biomass of grazing fishes are difficult to reconcile as several previous studies 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; 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 individual fishes (Taylor et al. 2020). The recorded declines in the density biomass of grazing fishes across the central and northern 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, may be limiting the food available for these fishes. Further dedicated investigation into the diet and fitness of these fishes on CSMP reefs is required to identify the mechanism/s for these declines.

Despite these declines, the biomass of reef fishes (a key indicator of reef health) recorded across all reefs in the CSMP in 2023/24 remained high (range: 309 – 3,684 kg per hectare; mean = 1,606 kg per hectare) relative to coral reef environments globally (Cinner et al. 2016) and higher than estimates of unfished biomass for coral reefs globally (1,000-1,250 kg per hectare; MacNeil et al. 2015; McClanahan 2018). This high biomass, especially of sharks and large-bodied piscivores, likely reflects the isolation and limited fishing pressure on CSMP reefs.

6.4 Bright spot reefs

Importantly, coral cover and fish biomass on previously identified ‘bright spot’ reefs (Hoey et al. 2020) remained relatively high. For example, coral cover on Moore and Mellish Reefs (19.0% and 25.8%, respectively) are the highest of the nine central CSMP surveyed, and almost double that of the other seven central CSMP reefs (5.9-13.8%). Similarly coral cover at the two of the three ‘bright spot’ reefs surveyed in the northern CSMP remained higher than the regional average (Ashmore: 35.2%; Bougainville: 31.3%; northern CSMP: 30.9%). Although coral cover recorded at Boot Reef, the third ‘bright spot’ reef in the northern CSMP, was considerably lower than the regional average, it was similar to previously surveys (2018: 24.7%; 2023/24: 22.8%), this reef supported higher than average species richness and density of reef fish, the second highest taxonomic richness of corals, and the highest biomass of fish across all reefs surveyed in 2023/24. lower than the regional average and is likely related to differences in the habitats surveyed in each year, rather than a decline in coral cover. Unfortunately, differences in the survey frequency at these ‘bright spot’ reefs make temporal comparisons difficult. For example, Moore Reefs was surveyed in 2020 and 2023, Mellish Reef in 2018, 2022 and 2023, Boot Reef in 2018 and 2023, Ashmore Reef in 2018, 2022, and 2023, and Bougainville Reef annually since 2018. As such understanding their response to, and recovery from, recurrent disturbances (namely bleaching), and how this compares to other reefs is difficult to isolate.

Together with the five previously identified ‘bright spot’ reefs, Cato Reef (the southernmost reef in the CSMP) was a standout in terms of coral cover. Coral cover on Cato Reef in 2023/24 (33.7%) was the second highest across all CSMP reefs surveyed, and more than double the regional average for the southern CSMP (15.8%), and has experienced limited decline in coral cover since 2020. Cato Reef also had higher taxonomic richness of corals, and higher species richness and density of reef fish than regional average, and is a ‘bright spot’ among reefs in the southern 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.

6.5 Recommendations

Regular comprehensive monitoring of coral reef environments in the CSMP is essential to understand its structure and function, ecological significance, and changing health and condition, especially in light of the increasing incidence of heat stress events. Annual monitoring of CSMP reefs since 2018 has greatly improved our understanding of the unique nature of these reefs, provides a contemporary baseline for future research and monitoring, and importantly has identified drivers of change (i.e., major bleaching events). In the absence of regular monitoring, the causes of such changes would be largely unknown, severely limiting the capacity of managers to make informed decisions. Monitoring of shallow-water coral communities on CSMP reefs in late 2024 or early 2025 (i.e., before any future heat stress) is critical to quantify the effects of the 2024 marine heat wave on these unique ecosystems. 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. Continued monitoring of both coral settlement and the density of juvenile corals will be critical to understand the potential replenishment of coral populations following repeated bleaching events, 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 monitoring of benthic (coral, macroalgae, CCA), fish, sea snakes and macro-invertebrate communities using the same methods and sites as previous (2018-24) 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. 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), and as highlighted by the three successive bleaching events experienced in the CSMP in the 3 years from 2020-2022, and the potentially major bleaching event unfolding in 2024. 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 8-10 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. Some consideration should also be given to parallel research and monitoring on islands within the CSMP. With these considerations in mind, we recommend as a minimum the following 10 reefs be surveyed annually Cato and Kenn Reefs in the southern CSMP; Flinders, Holmes, Lihou, 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, or Moore Reefs given the lack of a safe anchorage and difficulties in accessing these reefs under most weather conditions.

On reefs where suitable overnight anchorages are available, a minimum of 2 days should be allocated to each of the representative reefs (weather and conditions permitting) to allow for surveys of additional sites and habitats (e.g., weather exposed aspects) and targeted research and collections. In addition to the regular surveys of representative reefs, we recommend intensive sampling (5-7 days) of a single reef during each voyage, with a different reef to be surveyed in consecutive voyages. Spending 5-7 days at a reef would allow *ca.* 15-28 sites to be surveyed compared to the current 3-5 sites per reef, thereby providing a much more comprehensive understanding of the status and health of each reef, as well as allowing questions such as the following to be addressed: do reef areas that are adjacent to channels have higher coral cover and/or densities of juvenile corals than those in sheltered back reef or lagoonal environments? During the 2023 voyage, ~2 weeks were spent at Ashmore and Boot Reefs which allowed surveys to be conducted over a much greater range of habitats and sites, including the exposed south-east aspect of these reefs, and within the enclosed lagoon at Boot Reef. The sites on the exposed south-east aspect of Ashmore and Boot Reefs have not been observed or surveyed by western scientists previously, and were found to support rich coral communities and possibly the greatest reef fish biomass recorded across all of our surveys since 2018. Greater detail of the surveys on these reefs are provided in the report for the *Our Marine Parks Round 3 Grant – The Jewel in the Coral Sea: The cultural and ecological significance of Ashmore and Boot Reefs* that funded this aspect of the voyage (see Hoey et al. 2024).

Dedicated monitoring of deep reef and non-reef (i.e., soft-bottom, macroalgae beds, seagrass) habitats using remotely operated underwater vehicles (ROVs) has provided new insights and understanding into these habitats and CSMP reefs more broadly. However, repeated technical issues and safety concerns in deploying and piloting the ROVs from tenders under moderate to high wind (and sea) conditions compromise the efficiency and cost-effectiveness of these surveys. While deep habitats occupy a greater area than shallow reef habitats throughout the CSMP, are largely unexplored and likely less impacted by disturbance, any monitoring of these habitats using ROVs, as well as other technologies (e.g., towed videos), should be considered an optional and opportunistic component of any future monitoring rather than a priority.

Several projects aimed at understanding potential variation in water temperatures, and the settlement and calcification rates of crustose coralline algae (CAA) between ‘bright spot’ and other reefs were initiated during the 2023 and 2024 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. While the coral settlement tiles are currently being collected via a Mike Ball Dive Expeditions voyage (30 May – 6 June 2024) with results to be provided in the near future, there is currently no voyage planned to collect the 73 temperature loggers and 198 CCA devices deployed across 35 sites and 15 reefs across the CSMP. Importantly, the temperature loggers will have captured the water temperatures experienced at each site during the 2024 marine heatwave and this data will be invaluable in reconciling any differences in the response of coral communities to heat stress among sites and reefs. Given the temperature loggers will record temperatures for 2 years, we recommend the temperature loggers (and CCA devices) deployed on central and northern CSMP reefs in 2023 should be collected in early 2025, and those deployed in 2024 in the southern CSMP and Marion and Mellish Reefs be collected in early 2026. Ideally, some or all of these loggers and CCA devices should be replaced, thereby providing a longer term record.

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 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 project are underway to investigate the potential connectivity of coral, reef fish, shark, macro-invertebrate, and bird populations across the Coral Sea region.

The current scheduling of surveys for late summer-early autumn (i.e., February-March) is designed to capture the incidence and extent of bleaching. Indeed the 2020 surveys coincided with the peak in the heat stress, although surveys were conducted prior to the peak in heat stress in 2021, 2022 and 2024. Targeting this period for the surveys limits the capacity to explore other important biological and ecological processes, especially those related to the spawning and settlement of corals, fishes and invertebrates. While biannual surveys would allow for much more detailed understanding of reproduction and other seasonal processes, as well as allowing for the more effective deployment and maintenance of in-water sampling devices (e.g., tilt current meters only record for ~3 months), the cost of running multiple dedicated voyages per year is likely prohibitive. We recommend that additional research and monitoring could be achieved by either making use of existing dive tourism expeditions to the CSMP (e.g., Mike Ball Dive Expeditions), or combining with other planned voyages (e.g., CSMP Island Health).

Finally, surveys conducted over the past 6 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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7 APPENDIX 1 – Leveraged projects

Five additional projects were leveraged from this collaboration between James Cook University and Parks Australia and capitalised on available space during the voyage. * indicates projects funded under an *Our Marine Parks – Round 3 Grant*, however the scope of these projects was increased substantively through activities completed during the 2023 voyage

Project description	Key Personnel	Institution
Movement and population structure of sharks and large fishes within the CSMP	Dr Adam Barnett Prof Andrew Hoey Mr Ben Cresswell	James Cook University James Cook University James Cook University
Opportunistic surveys for fish spawning aggregations	Prof Andrew Hoey Mr Martin Russell	James Cook University Science and Conservation of Fish Aggregations
The cultural and ecological significance of Ashmore and Boot Reefs*	Prof Andrew Hoey Dr Eva McClure Dr Gemma Galbriath Mr Ben Cresswell Dr Victor Huertas Ms Deborah Burn Ms Josie Chandler Mr Martin Russell 8 representatives of the Meriam People	James Cook University James Cook University James Cook University James Cook University James Cook University James Cook University James Cook University Parks Australia Mer Island PBC
Sea Country Documentary*	Mr Alaneo Gloor Mr Stuart Ireland Prof Andrew Hoey Mr Martin Russell Meriam People	Millstream Productions Millstream Productions James Cook University Parks Australia Mer Island PBC
Vessel Grounding at Moore Reefs	Prof Andrew Hoey Dr Eva McClure Dr Gemma Galbriath Mr Ben Cresswell Dr Victor Huertas Ms Deborah Burn Ms Josie Chandler Dr Natalie Bool	James Cook University James Cook University James Cook University James Cook University James Cook University James Cook University James Cook University Parks Australia
Connectivity and adaptive seascape of corals within the CSMP	Ms Magena Marzonie Prof Andrew Hoey Dr Victor Huertas Mr Martin Russell	James Cook University James Cook University James Cook University Parks Australia
Connectivity of reef fishes, sharks and macro-invertebrates within the CSMP	Prof Andrew Hoey Dr Adam Barnett Ms Sasha Faul Ms Cecilia Martin Dr Eva McClure Dr Gemma Galbriath Mr Ben Cresswell Dr Victor Huertas	James Cook University James Cook University James Cook University James Cook University James Cook University James Cook University James Cook University James Cook University

8 APPENDIX 2 – Sites surveyed

List of sites surveyed across 18 reefs in the Coral Sea Marine Park (CSMP) during February – March 2023 and February – March 2024. * indicates sites that were surveyed in 2020, 2021, 2022, and/or 2023/24, and form the basis of the temporal comparisons. # indicates new sites that were surveyed for the first time in 2023/2024

Sector	Reef	Site	Exposure	Aspect	Lat	Long
2023						
Central	Diamond	Diamond 1*	Semi-sheltered	NE	-17.442	151.0626
Central	Diamond	Diamond 2*	Sheltered	N	-17.4368	151.0697
Central	Diamond	Diamond 6*	Sheltered	W	-17.4187	151.0712
Central	Flinders	Flinders 5*	Sheltered	W	-17.8616	148.4665
Central	Flinders	Flinders 7*	Exposed	NE	-17.5368	148.5511
Central	Herald	Herald 1*	Semi-exposed	N	-16.9435	149.1857
Central	Herald	Herald 4*	Sheltered	SW	-16.9725	149.1287
Central	Herald	Herald 6*	Sheltered	W	-16.9919	149.1308
Central	Holmes	Holmes 1*	Sheltered	NW	-16.5261	147.807
Central	Holmes	Holmes 10*	Semi-exposed	NW	-16.5214	147.8377
Central	Holmes	Holmes 2*	Semi-sheltered	W	-16.5118	147.84
Central	Holmes	Holmes 5*	Semi-sheltered	NW	-16.5053	147.9675
Central	Holmes	Holmes 6*	Semi-sheltered	NW	-16.419	147.9898
Central	Holmes	Holmes 7*	Semi-sheltered	NW	-16.4269	147.9844
Central	Lihou	Lihou 1*	Sheltered	NW	-17.5971	151.4896
Central	Lihou	Lihou 2*	Sheltered	N	-17.5907	151.5003
Central	Lihou	Lihou 4*	Semi-sheltered	N	-17.1253	151.8254
Central	Lihou	Lihou 5*	Semi-sheltered	N	-17.1211	151.8294
Central	Lihou	Lihou 7*	Exposed	SE	-17.4173	151.8661
Central	Lihou	Lihou 9*	Lagoon	SE	-17.1302	151.8393
Central	Moore	Moore 3*	Semi-exposed	N	-15.8774	149.1596
Central	Moore	Moore 4*	Sheltered	W	-15.9648	149.1943
Central	Willis	Willis 2*	Sheltered	W	-16.2873	149.9593
Central	Willis	Willis 4*	Semi-exposed	NE	-16.2826	149.9657
Central	Willis	Willis 7*	Semi-sheltered	NW	-16.117	149.971
Northern	Ashmore	Ashmore 7*	Sheltered	North	-10.4391	144.429
Northern	Ashmore	Ashmore 8#	Exposed	E	-10.2535	144.5743
Northern	Ashmore	Ashmore 9#	Exposed	E	-10.2607	144.5568
Northern	Ashmore	Ashmore 10#	Sheltered	E	-10.3831	144.3813
Northern	Ashmore	Ashmore 11#	Sheltered	E	-10.3895	144.3839
Northern	Ashmore	Ashmore 12#	Exposed	SE	-10.3983	144.4905
Northern	Ashmore	Ashmore 13#	Exposed	SE	-10.4031	144.4869
Northern	Ashmore	Ashmore 14#	Exposed	SE	-10.4149	144.4773
Northern	Ashmore	Ashmore 15#	Exposed	SE	-10.4085	144.4811
Northern	Ashmore	Ashmore 16#	Exposed	SE	-10.3983	144.5394

Northern	Ashmore	Ashmore 17#	Lagoon	S	-10.1588	144.5812
Northern	Ashmore	Ashmore 18#	Lagoon	S	-10.0691	144.5298
Northern	Boot	Boot 4#	Exposed	E	-9.98998	144.6943
Northern	Boot	Boot 5#	Exposed	E	-10.0021	144.6958
Northern	Boot	Boot 6#	Exposed	E	-9.97152	144.7215
Northern	Boot	Boot 7#	Exposed	E	-9.97534	144.7131
Northern	Boot	Boot 8#	Lagoon	W	-9.98221	144.6956
Northern	Bougainville	Bougainville 1*	Sheltered	N	-15.4927	147.0864
Northern	Bougainville	Bougainville 4*	Semi-exposed	SW	-15.5067	147.1123
Northern	Bougainville	Bougainville 5*	Semi-exposed	SW	-15.5008	147.0989
Northern	Osprey	Osprey 1*	Exposed	N	-13.8013	146.5461
Northern	Osprey	Osprey 2*	Sheltered	W	-13.901	146.5619
Northern	Osprey	Osprey 6*	Sheltered	S	-13.8808	146.5588
2024						
Central	Marion	Marion 7*	Sheltered	N	-19.29511	152.23782
Central	Marion	Marion 8b*	Exposed	W	-19.2983	152.23422
Central	Marion	Marion 9*	Lagoon	NE	-19.23144	152.17848
Central	Marion	Marion 12*	Exposed	E	-19.11646	152.4016
Central	Marion	Marion 14#	Exposed	E	-19.00893	152.37706
Central	Mellish	Mellish 1*	Sheltered	NE	-17.41608	155.8531
Central	Mellish	Mellish 2*	Sheltered	N	-17.41767	155.85738
Central	Mellish	Mellish 6*	Sheltered	SW	-17.39041	155.8616
Central	Mellish	Mellish 7*	Sheltered	SW	-17.37424	155.84311
Central	Mellish	Mellish 8*	Exposed	S	-17.43929	155.86292
Central	Mellish	Mellish 9*	Sheltered	W	-17.42651	155.85326
Central	Mellish	Mellish 10*	Sheltered	W	-17.36842	155.83971
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 2*	Semi-sheltered	W	-21.01043	154.34743
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	Saumarez	Saumarez 7*	Sheltered	NW	-21.91194	153.59119
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

9 APPENDIX 3 – CCA devices and temperature loggers

List of Coral Sea Marine Park (CSMP) reefs and sites in which Crustose Coralline Algae (CCA) devices and/or temperature loggers were deployed during February - March 2023

Reef	Site	Temperature loggers	CCA devices	Date
Flinders	Flinders 5	Y	Y	11/2/2023
	Flinders 7	Y	Y	11/2/2023
Diamond	Diamond 1	Y	Y	13/2/2023
	Diamond 2	Y	Y	13/2/2023
Lihou	Lihou 1	Y	Y	14/2/2023
	Lihou 4	Y	Y	15/2/2023
Willis	Willis 2	Y		16/2/2023
	Willis 7	Y		17/2/2023
Moore	Moore 4	Y	Y	18/2/2023
	Moore 3	Y	Y	18/2/2023
Holmes	Holmes 6	Y	Y	19/2/2023
	Holmes 5	Y	Y	19/2/2023
	Holmes 2	Y		20/2/2023
Bougainville	Bougainville 5	Y	Y	21/2/2023
	Bougainville 4	Y	Y	21/2/2023
	Bougainville 1	Y	Y	21/2/2023
Osprey	Osprey 6	Y	Y	22/2/2023
	Osprey 2	Y	Y	22/2/2023
	Osprey 1	Y	Y	22/2/2023
Ashmore	Ashmore 7	Y	Y	28/2/2023
	Ashmore 17	Y	Y	7/3/2023
	Ashmore 18	Y	Y	7/3/2023
Cato	Cato 3	Y	Y	17/2/2024
	Cato 1	Y	Y	17/2/2024
Wreck	Wreck 3	Y	Y	18/2/2024
	Wreck 1	Y	Y	18/2/2024
Kenn	Kenn 1	Y	Y	20/2/2024
	Kenn 4	Y	Y	20/2/2024
Mellish	Mellish 5a	Y	Y	22/2/2024
	Mellish 9	Y	Y	22/2/2024
	Mellish 7	Y	Y	23/2/2024
Marion	Marion 9	Y	Y	28/2/2024
	Marion 7	Y	Y	28/2/2024
Saumarez	Saumarez 5	Y	Y	2/3/2024
	Saumarez 7	Y	Y	2/3/2024

10 APPENDIX 4 – Fish species surveyed

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

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

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

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

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

11 APPENDIX 5 – Fish species records

List of conspicuous (i.e., non-cryptic) fish species recorded and/or observed within each region of the CSMP during 2018-2023. A separate column is provided for cryptobenthic fish species that were identified during targeted collections using clove oil. * indicates species that were recorded for the first time in 2023

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**