REEF LIFE SURVEY

BIODIVERSITY CHANGE ACROSS THE CORAL SEA MARINE PARK OVER THE PAST DECADE INCLUDING IMPACTS OF SEVERE HEATWAVES

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Images

Graham Edgar Rick Stuart-Smith and Antonia Cooper

Paget Cay, Marion Reef. Image by Graham Edgar

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Orangefin Anemonefish (*Amphiprion chrysopterus*) hides in a bleached anemone, Image by Graham Edgar

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Brown Booby (*Sula leucogaster*) at Kenn Reefs. Image by Graham Edgar

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List of Acronyms

ACRONYM	DESCRIPTION
RLS	Reef Life Survey
B20	Biomass of fish greater than or equal to 20 cm in total length
CTI	Community Temperature Index
CGI	Community Generalisation Index
CCA	Crustose Coralline Algae

Executive Summary

Results described here are based on three sets of surveys of shallow reef biodiversity across all major reef systems in the Coral Sea Marine Park (CSMP). Initial surveys undertaken by Reef Life Survey (RLS) divers in 2012-2015 represent the only Park-wide baseline of reef condition prior to the implementation of the 2018 CSMP management plan and also prior to recent marine heatwaves. Subsequent Park-wide surveys followed two extreme heatwaves with associated bleaching. This report was commissioned by Parks Australia, with a primary focus of using data from these three time periods (a) to assess changes in reef biodiversity in relation to management, including the recently declared Habitat Protection and National Park Zones (2018) as well as IUCN Ia and II zones from the previous Coral Sea Commonwealth Marine Reserve; (b) to understand the ecological impacts of the 2020 heatwave (and associated coral bleaching event) in the context of normal interannual variation and changes resulting from the 2016 heatwave; and (c) to assess overall net change across the marine park over the last decade.

Ecological surveys were conducted by trained RLS divers led by University of Tasmania researchers along 793 50-m transects at 143 sites distributed along the length of the CSMP. Data collected from each site consisted of abundance and size of fishes, abundance of mobile macroinvertebrates and cryptic fishes, and percentage cover of sessile biota.

Total hard coral cover on shallow reefs across the CSMP decreased from 17% of the benthic cover on baseline surveys (2012-2015) to 14% following the 2020 bleaching event (equivalent to a 17% loss of the live hard coral cover observed on baseline surveys). Both 2016 and 2020 heatwave events resulted in similar overall declines (from 17.1% to 15.7% to 14.3% absolute cover), although data for the 2020 heatwave are preliminary as many southern reefs, where greatest impacts are likely, have not been recently assessed by Reef Life Survey. Most coral taxa in the far north region of Ashmore and Boot Reefs recovered from declines associated with the 2016 heatwave by 2021; however, the majority of reefs elsewhere in the CSMP showed overall decline through the last decade, with greatest coral loss occurring in the area extending between Osprey Reef, Bougainville Reef, and reefs in the Willis Islets.

The total biomass of reef fishes also showed widespread and significant decline across the CSMP over the past decade (from mean of 125.42 kg to 118.07 kg per 500 m^2). This biomass decrease, which reflects declining populations of large-bodied fish species, did not appear to be influenced by protection status within the CSMP. Further investigation is needed to determine the ultimate magnitude of fish biomass loss and its cause. Possible factors that should be considered are recreational fishing effort expanding in the CSMP, negative heatwave impacts that manifest after a lag, and natural stochastic variability.

A consistent shift in the reef fish community across the CSMP was evident through time, particularly for reefs in the central region after the 2020 heatwave. This heatwave was accompanied by a reduction in regional differences, with increased similarity of north and south fish faunas to the central fauna (i.e. increased homogenisation).

The mobile macro-invertebrate fauna also showed changing patterns of abundance through time. Species richness generally increased in the early survey years then declined more recently, although patterns were highly patchy between reefs. This patchiness was partly driven by differing taxonomic composition on reefs, with sea urchins predominant in the south and relatively rare further north. Sea urchin densities more than doubled between the first and second survey periods when averaged across all reefs.

Only four species listed as threatened under the EPBC Act were sighted, all turtles; however, a total of 61 species listed as threatened on the IUCN Red List were recorded, primarily sea cucumbers, corals, giant clams, turtles, and large-bodied or small range endemic fishes. None showed consistent population declines over the past decade. Amongst other species of conservation concern, sea snake densities declined in synchrony with the 2016 heatwave, with little apparent subsequent recovery. The most substantial declines in observed sea snake abundances occurred at the two reefs with highest initial densities – Marion and Saumarez.

Bird Island Reef, by Rick Stuart-Smith

Recommendations

- Undertake a targeted investigation of possible causes of broad-scale declines in large fishes, including the potential impact of any fishing, both illegal within the CSMP and legal when animals move outside the CSMP boundary. Such investigation may include obtaining a better understanding of the amount and patterns of recreational fishing pressure across the CSMP, and more targeted species-level analyses of reef monitoring data.

- Further investigate and monitor the key drivers of change in reef biodiversity across the region. Cost-effective management needs better understanding about local, regional and global stressors, and appropriate benchmarks of management success.

- Undertake additional surveys of southern reefs within the next two years to better understand impacts of the 2016 and 2020 heatwaves on reefs in the south. Recent data from southern reefs (additional to Saumarez) would allow future investigations to more accurately assess CSMP-wide changes spanning both heatwaves. Ongoing monitoring should be continued across the full span of the CSMP at an interval of 3-5 years.

- In collaboration with Traditional Owners when the Management Plan is reviewed, consider increased protection from fishing for Boot Reef as a sanctuary for higher predators in the far north, a location for high-end dive tourism, and a scientific reference area with a near intact coral reef food web.

Introduction

The Coral Sea Marine Park (CSMP) is one of the largest and most isolated marine parks in the world, encompassing almost 990,000 km^2 of the Coral Sea, 15,000 km^2 of which include shallow reef systems (Heap and Harris, 2008). The CSMP extends east of the Great Barrier Reef Marine Park (GBRMP) from the latitudes of Bundaberg in southern Queensland to the border with Papua New Guinea, encompassing all waters of the Coral Sea that fall within Australia's exclusive economic zone. It is one of 58 Australian Marine Parks (AMPs) that together cover 2,762,724 km^2 of ocean surrounding Australia (https://parksaustralia.gov.au/marine/), following a fivefold expansion on 1 July 2018, when management plans covering a complex arrangement of park zones were enacted.

The Coral Sea was initially declared a conservation zone in 2009 and proclaimed a Commonwealth Marine Reserve in 2012, prior to the implementation of the 2018 management plan under the Australian Marine Park networks. It is divided into multiple management zones, each assigned an IUCN category. Two former Nature Reserves were incorporated into the CSMP: the Coringa-Herald and Lihou Reef National Nature Reserves. These were proclaimed as IUCN category Ia reserves in 1982 and prohibited recreational and commercial fishing.

The Coral Sea is considered amongst the 4% of the ocean that remains least affected by human impacts, one of the last remaining 'pristine' seas (Ceccarelli et al., 2013, McKinnon et al., 2014). Approximately 30 reefs, shoals and seamounts lie within the Australian Coral Sea, hosting a high percentage of its biodiversity. The distribution of these reefs across the Coral Sea from the Great Barrier Reef to the fringing reefs of New Caledonia and elsewhere are far reaching, creating critical stepping-stones linking the Western Pacific and the Great Barrier Reef (Ceccarelli et al., 2013).

Torres Strait Islanders and coastal Aboriginal people of Cape York continue to assert inherited rights and responsibilities over Sea Country within and adjacent to the CSMP. Some reefs have been managed by Traditional Owners for thousands of years. The use of natural resource forms part of traditional culture and spirituality. The Meriam People's Sea Country extends over the Ashmore Reef region. An Indigenous turtle fishery operates in this area using hand collection and traditional spear methods. More recent human heritage also exists in the Coral Sea Marine Park, with at least 45 historic shipwrecks, dating back to at least the early 1800s.

The first park-wide surveys of reef biodiversity were undertaken by Reef Life Survey (RLS) teams between 2012 and 2015 (Edgar et al., 2015, Edgar et al., 2017a). These surveys not only provided a baseline of the overall spatial patterns in natural values found on shallow reefs against which change through time can be assessed over broad scales, but also provided new biogeographical insights of national management importance. For example, CSMP reefs represent the only locations in Australian waters with fish and large mobile invertebrate species assemblages typical of oceanic Pacific islands. Although located within a few hundred kilometres from the Great Barrier Reef (GBR), reef communities on CSMP reefs are much more closely affiliated to those on the oceanic islands and atolls of Tonga, Samoa, and Niue which lie more than 2,500 km distant (Edgar et al., 2015, Edgar et al., 2020). CSMP reef communities are thus distinct from the GBR, highlighting the existence of a characteristic Coral Sea ecoregion within the Australian EEZ. Coral reefs in the CSMP also support species listed as threatened, migratory or cetacean under the EPBC Act, and remain a stronghold for sea snakes, which are declining in many other regions of the world.

Coral reefs managed in the CSMP are far offshore and not threatened by land-based pressures such as run-off, pollution and urban development. Instead, major threats to the biodiversity and natural values of CSMP reefs include cyclones and marine heatwaves, along with associated coral mortality. Another pressure is recreational, commercial, and illegal, unreported and unregulated (IUU) fishing. Cyclones are believed to have played a role in shaping the regional patterns in coral cover reported in RLS baseline surveys, leading to reduced coral cover on reefs in the central region (Edgar et al., 2015). Yet, despite low coral cover, the same surveys found central CSMP reefs to support a relatively high biomass of reef fishes, especially within the areas protected in the former IUCN Ia zones (Edgar et al., 2015, Edgar et al., 2020).

Three of the largest marine heatwaves recorded in the region have occurred since the RLS surveys. The spatial distribution of prolonged elevated water temperatures differed between 2016, 2017 and 2020 heatwaves (Hoey et al., 2021). The 2017 heatwave generated little detectable impact, whereas the 2016 and 2020 heatwaves caused considerable coral bleaching and mortality (Stuart-Smith et al., 2018, Hoey et al., 2021). The 2016 heatwave resulted in unexpected effects on some reef fish communities in the CSMP and Great Barrier Reef, including increasing numbers of particular fish species, but overall impacts at the scale of the CSMP have not been assessed. Likewise, no quantitative comparisons have previously been possible between impacts of the 2016 and 2020 heatwaves (i.e. involving data pre-2016, post-2020, and also the intervening period), let alone any assessment of the net overall impacts for reef biodiversity in the CSMP over the last decade.

The 2016 and 2020 heatwaves may have impacted fishes directly through elevated temperatures on metabolic, demographic and ecological processes (Day et al., 2018, Stuart-Smith et al., 2017, Mellin et al., 2016), or indirectly through changes in their coral habitats (Wilson et al., 2006). The abundance of large reef fishes and sharks are important contributors to the global uniqueness of the CSMP reefs and are believed to be the result of isolation from human populations and limited historical fishing pressure (Ceccarelli et al., 2013, Edgar et al., 2015). Unknown impacts of recent heatwaves on these distinct natural values may be compounded by a threat of IUU fishing, and relatively poorly understood patterns and changes in recreational fishing pressure. Teasing apart the influence of multiple factors responsible for supporting and maintaining the large fish and shark biomass on CSMP reefs will be difficult. A necessary step is understanding how biomass has been changing in relation to recent heatwaves (and associated coral cover changes), and the effectiveness of the management zones designed to protect biodiversity values into the future.

Aims

Following the initial baseline surveys by Reef Life Survey teams in 2012-2015, this report outlines results of the analysis of data from two CSMP-wide follow-up survey efforts that spanned the two major heatwaves in 2016 and 2020. The analyses and report were funded by Parks Australia, with a primary focus of using data from these three time periods (a) to assess changes in reef biodiversity in relation to management, including the recently declared Habitat Protection and National Park zones (2018) as well as IUCN Ia zones from the previous Coral Sea Commonwealth Marine Reserve; (b) to understand the ecological impacts of the 2020 heatwave (and associated coral bleaching event) in the context of normal interannual variation and changes resulting from the 2016 heatwave; and (c) to assess overall change across the CSMP over the last decade.

Methods

Reef Life Survey (RLS) divers surveyed a total of 793 transects across 143 sites in the Coral Sea Marine Park between 2012 and 2021 (Figure 1). All surveys were conducted following the standardised underwater visual census methods applied globally by the Reef Life Survey (RLS). RLS involves recreational divers trained to a scientific level of data-gathering to make it possible to conduct ecological surveys across broad geographic areas in a cost-effective manner. RLS divers partner with management agencies and university researchers to undertake detailed assessment of biodiversity on coral and rocky reefs, but all divers and boat crew do so in a voluntary capacity. A summary of these methods is provided here. Full details can be downloaded at: www.reeflifesurvey.com/methods.

Each RLS survey involves three distinct searches undertaken along a 50 m transect line. Divers estimated the: (i) abundance and body size of fishes (Method 1), (ii) abundance of large mobile macroinvertebrates, giant clams and cryptic fishes (Method 2), and (iii) percent cover of sessile biota (Method 3). Two transects were generally surveyed per site (Appendix Table 1), generally parallel at different depths. Depths surveyed were restricted by the slope of individual reefs, but, where possible, were selected to encompass a wide depth range (e.g. 6 and 14 m). The same depth strata were repeated on subsequent site visits. Constraints associated with diving bottom time and air consumption generally limited depths to above 16 m. Underwater visibility and depth were recorded at the time of each survey, with visibility measured as the furthest distance at which large objects could be seen along the transect line, and depth as the depth contour followed by the diver when setting the transect line.

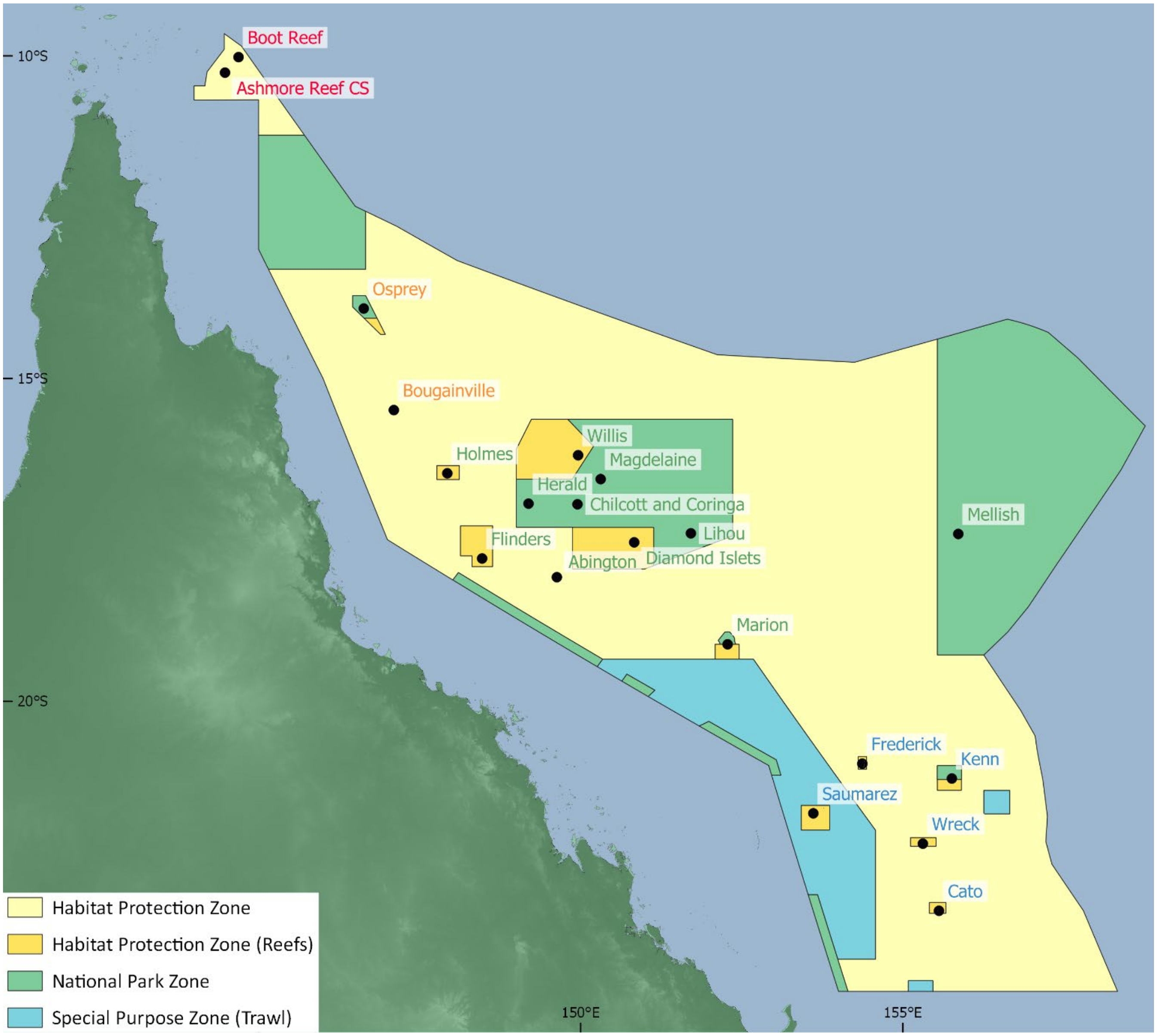

Figure 1. Map of reef locations surveyed by RLS divers within the Coral Sea from 2012 to 2021. Reef names are coloured by their region within the CSMP; far north (red), north (orange), central (green), and south (blue).

Fish Surveys (Method 1)

All fish species sighted within 5 m x 50 m blocks either side of the transect line were recorded on waterproof paper as divers swam slowly along the line (Figure 2). The number and estimated size category of each species were also recorded. Animals were sized into bins by total fish length (from snout to tip of tail) closest to 25, 50, 75, 100, 125, 150, 200, 250, 300, 350, 400, 500, 625 mm, and 125 mm categories above. All species sighted within the blocks were recorded, including a small proportion (<2%) with unknown identity. Photographs were used to later confirm identities with appropriate taxonomic experts, as necessary. In occasional circumstances when no photograph was available, taxa were recorded to the highest taxonomic resolution for which there was confidence (e.g. genus or family, if not species). Other large pelagic animals such as mammals, sea snakes, turtles and cephalopods are also recorded during the Method 1 fish survey, but not considered in analyses focusing on fishes (sea snakes are considered separately). Species observed outside the boundaries of the survey blocks or after the fish survey had been completed were recorded as 'Method 0'. Such records are a presence record for the time and location but were not used in quantitative analyses at the site level. 'Method 0' sightings were also made of invertebrates and any other notable species.

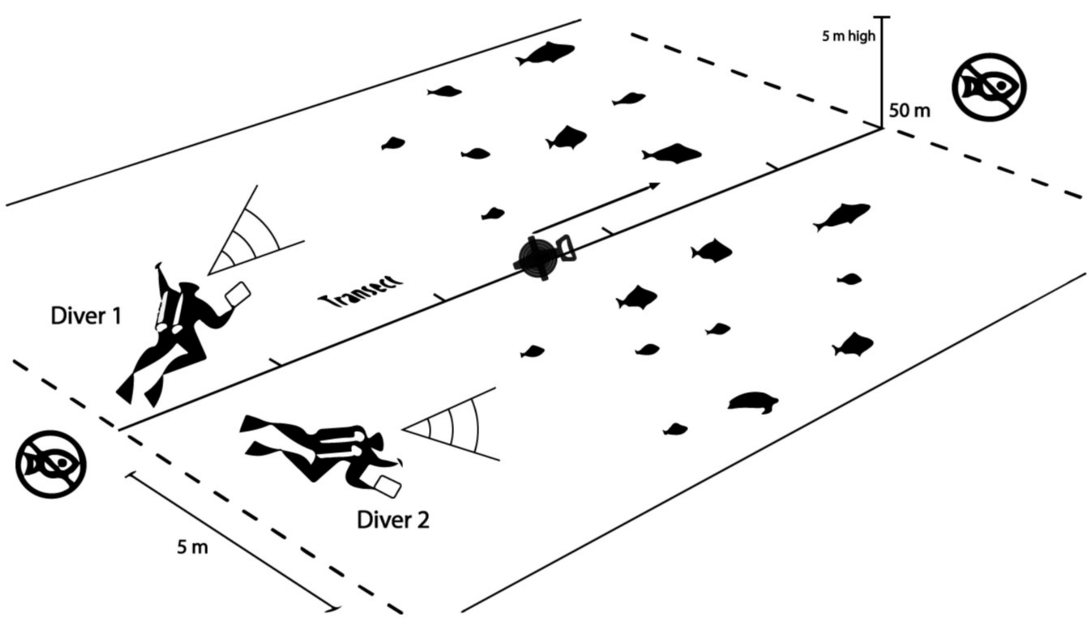

Figure 2. Summary of the Reef Life Survey fish survey (Method 1) approach.

Macroinvertebrate and Cryptic fishes Survey (Method 2)

Large macroinvertebrates (echinoderms, molluscs and crustaceans > 2.5 cm) and cryptic fishes were surveyed along the same transect lines set for fish surveys. Divers swam near the seabed, up each side of the transect line, recording all mobile macroinvertebrates and cryptic fishes on the reef surface within 1 m of the line (Figure 3). This required searching along crevices and undercuts, but without moving rocks or disturbing corals. Cryptic fishes include those from pre-defined families that are inconspicuous and closely associated with the seabed (and are thus disproportionately overlooked during general Method 1 fish surveys). The global list of families defined as cryptic for the purpose of RLS surveys can be found in the online methods manual (www.reeflifesurvey.com/methods). As data from Method 2 were collected in blocks of a different width to protocols applied for Method 1, and were analysed separately from those data, individuals of cryptic fishes known to already be recorded on Method 1 were also recorded as part of Method 2. Sizes were estimated for cryptic fishes within the same size bins as for Method 1.

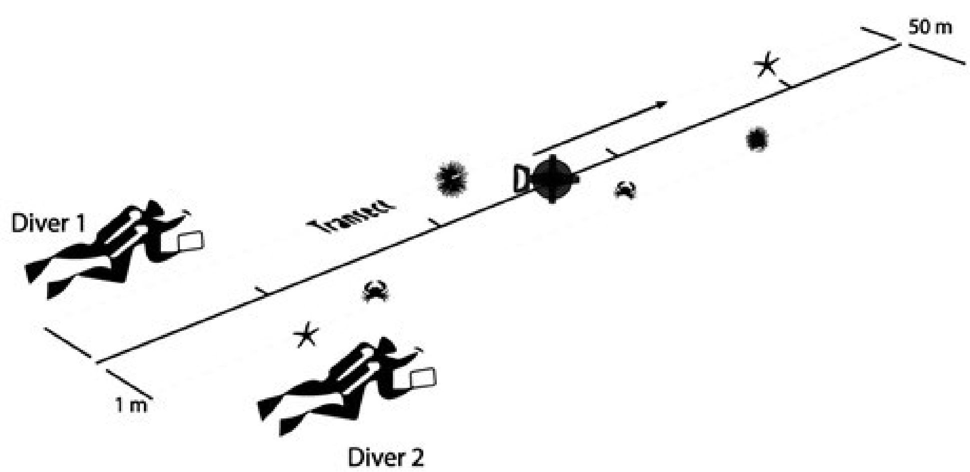

Figure 3. Summary of the Reef Life Survey macroinvertebrate and cryptic fish survey (Method 2) approach.

Photo-quadrats of benthic cover (Method 3)

Information on the percentage cover of sessile animals and macroalgae along the transect lines set for fish and invertebrate surveys was obtained using 20 photo-quadrats taken every 2.5 m along the 50 m transect. Digital photo-quadrats were taken vertically downward from a height sufficient to encompass an area of approximately 0.3 m x 0.3 m.

The percentage cover of different macroalgal, coral, sponge and other attached invertebrate species was obtained from photo-quadrats by recording the coral species or functional group observed under each of five points overlaid on each image, such that 100 points were usually counted for each transect (thus percentage cover was calculated as the number of points each group was scored under).

Functional groups for photo-quadrat processing comprised the standard 50 categories applied in broadscale analysis of RLS data, which are aligned with the CATAMI benthic imagery classification system (Althaus et al. 2015). A coral specialist, Dr Emre Turak, digitised corals in all photoquadrats to provide the highest possible taxonomic resolution and consistency in identifications. Most corals could be identified to the species level. Images have been archived and are available for processing at any resolution through the future.

Statistical analyses

For most sites, two transects were surveyed, each at a different depth. Because community types encountered along individual transects within a site were generally more similar to transects at similar depths at other sites, rather than transects at other depths within the same site, each transect was regarded as an independent sample in analyses. Thus, the unit of replication was total value(s) per pair of adjoining transect blocks (i.e. per 500 m^2 for fishes and per 100 m^2 for mobile macroinvertebrates). Sessile biota percent cover was expressed as percent cover per transect.

Collection of body length data of fishes, along with species identity and abundance, allows for the calculation of species-specific biomass estimates. Fish body mass was calculated from body length estimates using species-level length-weight relationships obtained from Fishbase (Froese and Pauly, 2010; www.fishbase.org). In cases where species-level length-weight coefficients are not available they are taken from similar-shaped species. When length–weight relationships were described in Fishbase in terms of standard length or fork length rather than total length, additional length-length relationships provided in Fishbase allowed conversion to total length, as estimated by divers. For improved accuracy in biomass estimates, the bias in divers' perception of fish size underwater was additionally corrected using the mean relationship provided in Edgar et al. (2004), where a consistent bias was found amongst divers that led to underestimation of small fish sizes and overestimation of large fish sizes. Note that estimates of fish abundance made by divers can be greatly affected by fish behaviour for many species (Edgar et al., 2004); consequently, biomass determinations, like abundance estimates, can reliably be compared only in a relative sense (i.e. for comparisons with data collected using the same methods) rather than providing an accurate absolute estimate of fish biomass for a patch of reef.

Four distinct regions have been identified in the CSMP on the basis of biogeographic patterns in the reef fauna, as outlined in the previous RLS report (Edgar et al., 2015, Edgar et al., 2017a); the far north, north, central and south. Reefs surveyed in each of these regions are shown in Figure 1, and are considered separately in many analyses.

Surveys were grouped into three time periods for consideration of the major 2016 and 2020 heatwave impacts – 1. prior to May 2016; 2. Jun 2016 - May 2020; 3. post Jun 2020.

Univariate statistics

A range of univariate metrics were calculated from the survey data. For fishes these included total biomass estimates, species richness, biomass within trophic groups, and three indicators of reef condition: the biomass of large fishes (B20), community temperature index (CTI) and community generalisation index (CGI). B20 is a global indicator of fishing impacts, with previous analyses revealing lower values in regions of higher fishing impact around Australia (Stuart-Smith et al., 2017). It is calculated as the sum of biomass for all individuals on any survey that are in the 20 cm size class or larger, regardless of species identity. CTI is an indicator of the thermal affinities of the species and responds to sea temperature changes (Stuart-Smith et al., 2015). CTI is calculated as the mean of the thermal affinity of the species present within a survey, weighted by the log of the abundance of the species on the survey. The thermal affinity of the species is the midpoint of each species' thermal distribution (i.e., the temperature range experienced across its full geographic distribution). CGI is similar to CTI in being a community weighted mean, but instead of the thermal affinity used as a trait indicating species temperature preferences, a trait indicating habitat niche breadth is used to indicate whether species generally occupy a wide or narrow range of reef habitat types (Stuart-Smith et al., 2021). CGI has been shown to increase following bleaching and cyclone associated mortality of corals, as a result of a shift in fish species composition towards those that are more generalist (are typically found in a wider range of reef habitats).

For both mobile macroinvertebrates and cryptic fishes, metrics calculated included total abundance and species richness. For sessile biota, metrics included percent cover of various functional/taxonomic groups (crustose coralline algae (CCA), live coral, macroalgae, and turf). All metrics represent mean values per transect area, that is per 500 m^2 for fishes (Method 1), and 100 m^2 for mobile macroinvertebrates and cryptic fishes (Method 2).

Statistical significance of univariate analyses was assessed using fixed-effects analysis of variance (ANOVA) models, with the reef in which a site is located (see Figure 1) and the survey period (pre-2016, 2016-20, post-2020) as fixed effects. Densities were averaged across transects within each site then across sites within each reef for input into models. ANOVAs were fitted using the 'Anova' function of the 'car' package (Fox and Weisberg, 2019) in R (R Core Team, 2021). Heatmaps of change were created using inverse-distance weighted (IDW) interpolation of site-level means (e.g. mean biomass change) and creating a raster using the 'raster' package (Hijmans, 2021) in R.

Multivariate statistics

Fish, cryptic fish, macroinvertebrate and sessile biota communities were investigated using nonmetric multi-dimensional scaling (nMDS). nMDS is a dimension reduction approach, minimising many dimensions (e.g., the abundance of species A, abundance of species B… etc.) into two dimensions (here termed nMDS1 and nMDS2) whilst maintaining as much of the dissimilarity as possible. The loss of information when reducing dimensions is termed 'stress,' which ranges from 0 to 1, with values less than 0.15 representing a 'good fit' (Dugard et al., 2010). nMDS was performed using the 'metaMDS' function within the 'vegan' package (Oksanen et al., 2020) in R using Bray-Curtis distances. Raw abundance data were log(x+1) transformed to minimise the relative importance of dominant species at a site.

Statistical significance of differences between multivariate groups was assessed using fixed-effects permutational multivariate analysis of variance (PERMANOVA) models, with the reef (see Figure 1) and the survey year as fixed effects. PERMANOVA models were fitted using the 'adonis' function of the 'vegan' package in R (Oksanen et al., 2020).

Results

Benthic community

A total of 281 stony coral taxa and 5 hydrocorals were identified from photo-quadrats across the span of the CSMP. The magnitude of change in total cover of hard corals differed greatly between CSMP reefs. The change was likely as a result of the 2016 and 2020 marine heatwaves and associated coral bleaching events (Figure 4). The most severe coral cover declines subsequent to the 2016 event occurred in the northern and far northern reefs, while southern reefs showed minor increases in coral cover or no change. In contrast, the 2020 heatwave resulted in declines across reefs in the southern half of the CSMP whereas cover on far northern reefs increased. The net outcome of both heatwaves was that declines in coral cover have prevailed, and the overall cover of living hard corals is now less than when the first RLS surveys were undertaken.

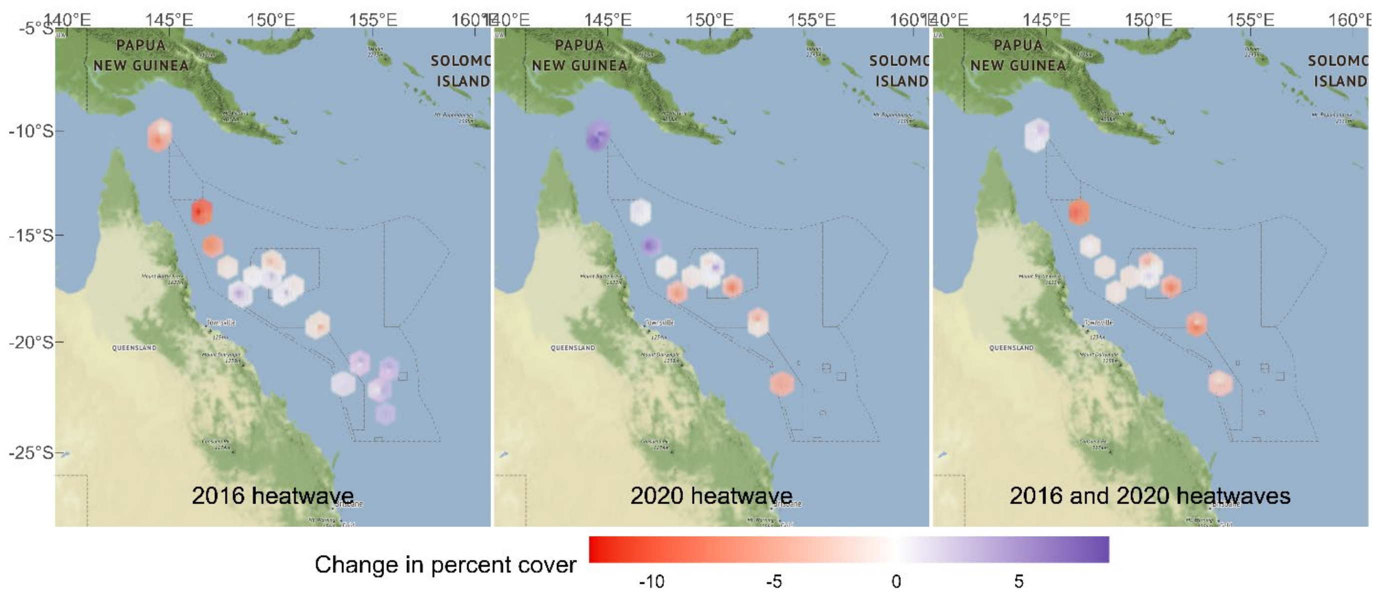

Figure 4. Change in percent cover of Live Hard Corals on CS reefs across two major bleaching events. Data in the left map show change in coral cover from pre 2016 surveys to those between 2016 and 2020 (i.e. mean of live hard coral cover at each site in 2017-2020 minus mean live hard coral cover pre 2016). Middle map shows change in coral cover values from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in coral cover per site from pre 2016 surveys to post 2020 surveys. All values are absolute change in percent cover, i.e. a loss of 10% represents an estimated reduction in overall live hard coral cover at the site equivalent to 10% of the seabed, rather than 10% of starting coral cover values. Reds represent a reduction in coral cover through time and blues an increase.

When assessed at the reef level, changes in hard coral cover showed consistent trends within the separate regions, although overall change through time across the whole CSMP was not statistically significant (Figure 5). Northern reefs (Osprey and Bougainville Reefs) and some central reefs (Willis and Magdelaine) show the impact of the 2016 heatwave to be associated with the largest coral cover reductions across all reefs and time periods monitored. No post 2020 coral cover data are available for southern reefs other than Saumarez Reef, but all the southern reefs showed increases from pre 2016 to the 2016-2020 period. The net change in live hard coral cover from the pre 2016 surveys to the post 2020 surveys was a minor (and non-significant) decline of ~2.8% (17.1% to 14.3%). Patterns of change were not directly associated with management status (Figure 6), with no significant differences between Habitat Protection and National Park zones (including 'no-fishing' zones that existed prior to the 2018 CSMP management plan).

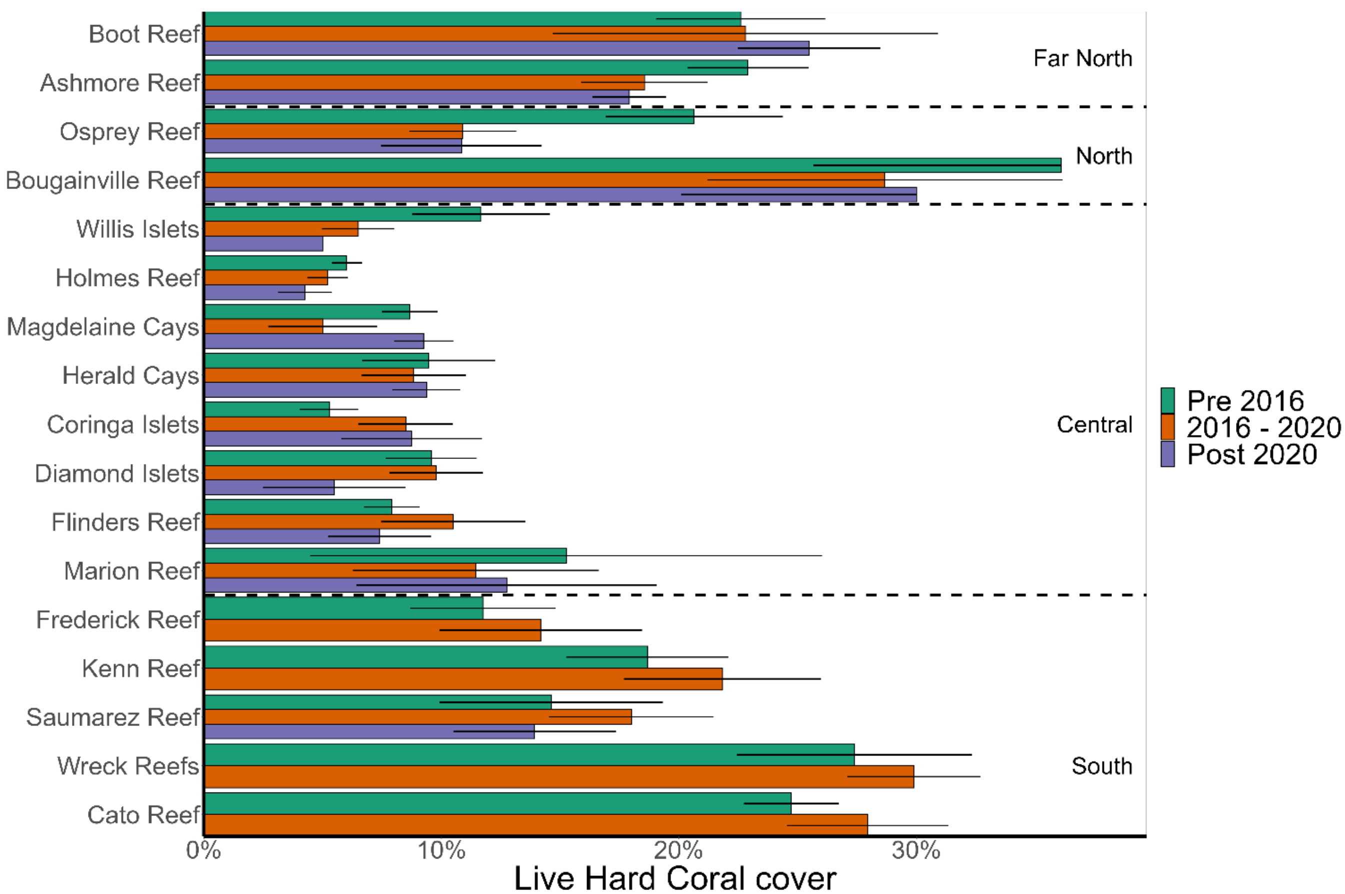

Figure 5. Changes in total Live Hard Coral cover by reef and region. Error bars represent ± 1 SE. Coral cover varies significantly between reefs ($p < 0.001$), but not between time periods. See Table 2 for full statistics. All values are absolute change in percent cover. Patterns shown here differ slightly from those described in Figure 1 heatmaps because means reflect data from all sites in each reef, rather than only the subset of sites that were surveyed in both time intervals, as in heatmap comparisons.

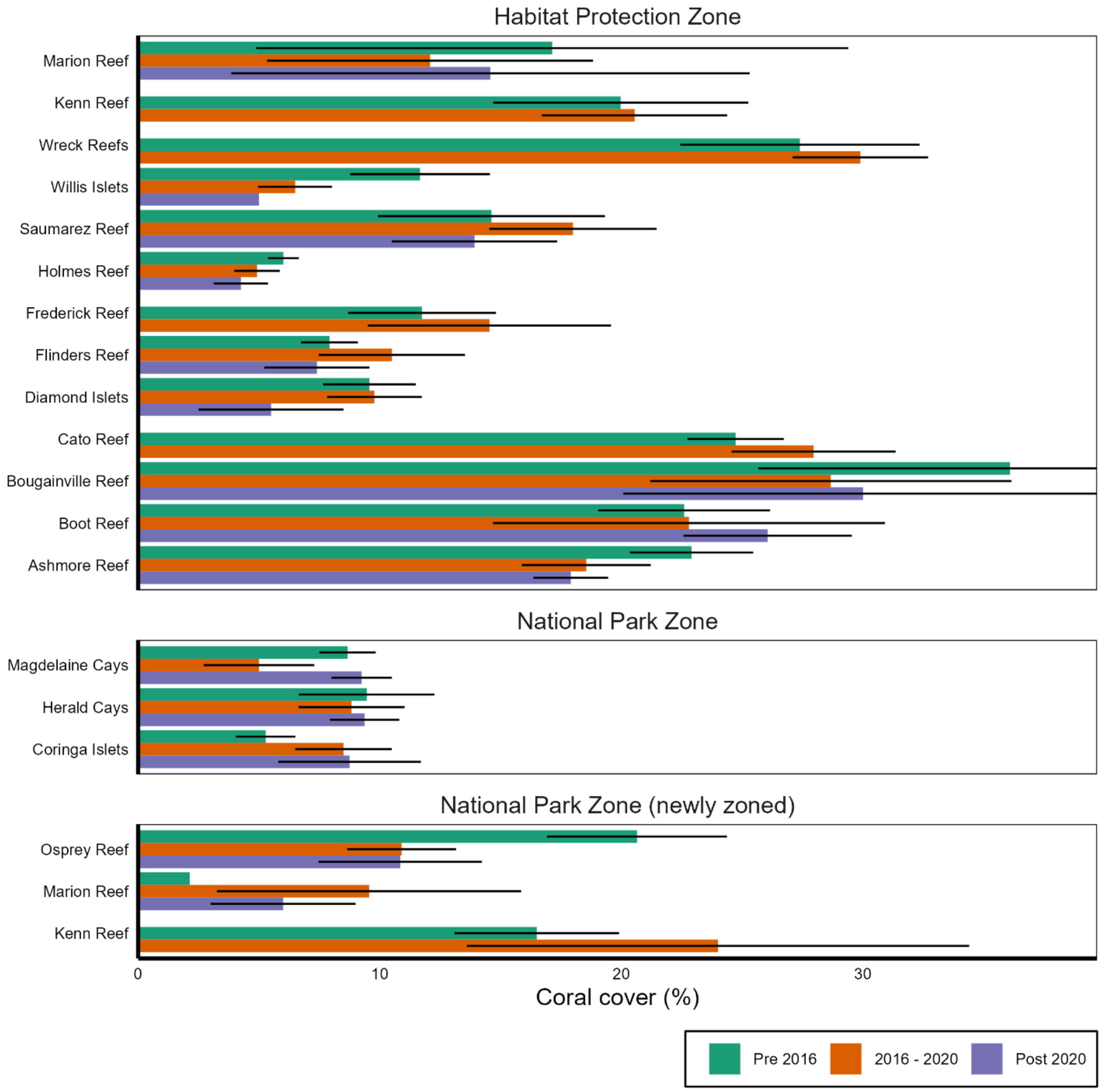

Figure 6. Live hard coral cover by protection status. Error bars represent ± 1 SE. Newly zoned national park refers to zones declared National Park Zones (in 2018) that were not previously within an IUCN Ia or II zone.

Plots depicting taxon-specific trends in corals (Figure 7) indicated substantial declines in *Isopora palifera* and *Acropora muricata* in the far north in the most recent surveys, while massive species of *Porites* and encrusting *Montipora* species declined in the north. *Isopora palifera* declined from the dominant coral species (by % cover) at Saumarez Reef in the first two periods to not being recorded in any photo-quadrats from the same sites in the post 2020 period. *Porites lichen* also declined in the south following the 2020 heatwave, although, as for *I. palifera*, this can only be confirmed for Saumarez Reef.

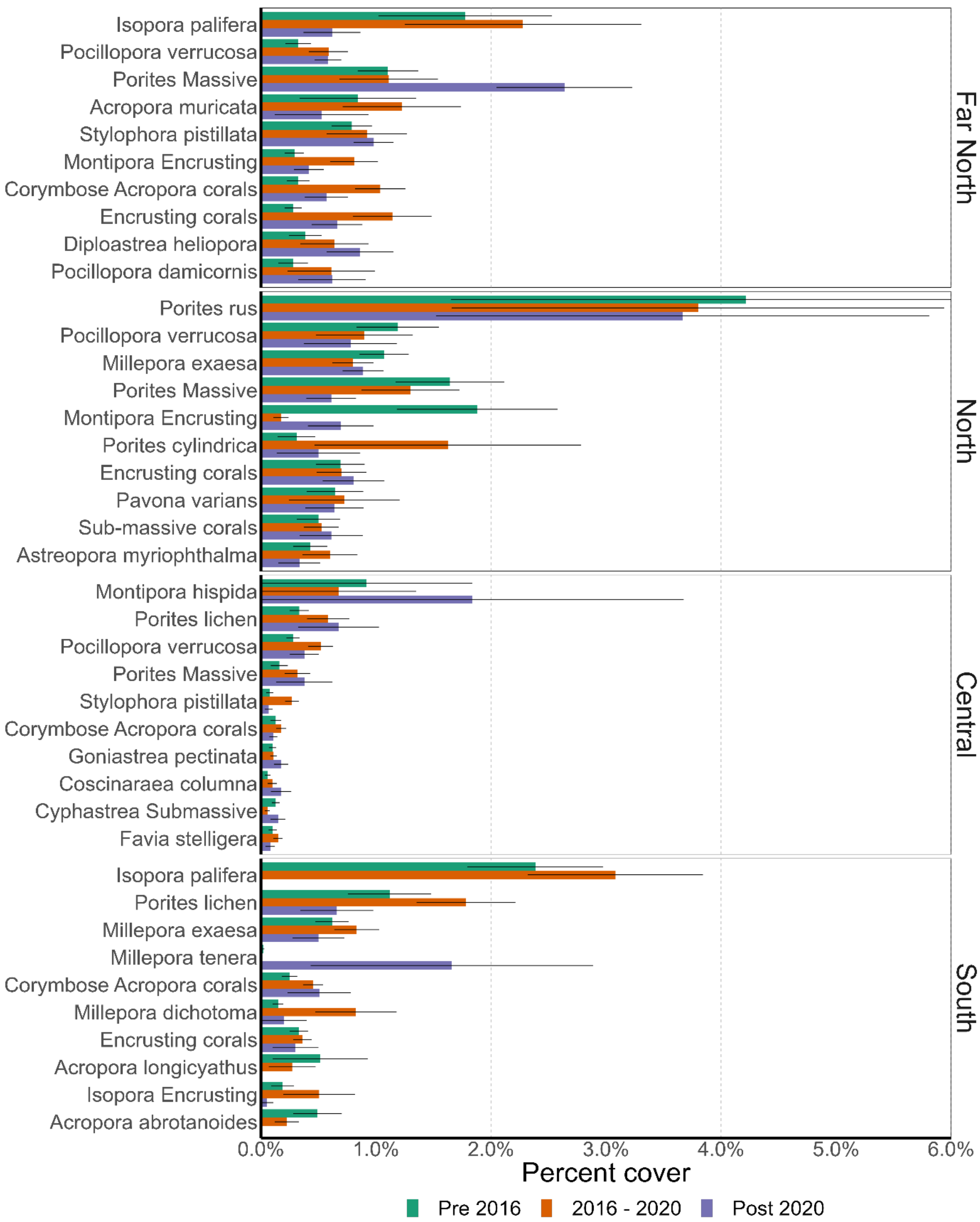

Figure 7. Changes in the cover of the dominant coral taxa (by percent cover) for each of the four regions in the Coral Sea Marine Park, and each time period (Pre 2016 heatwave, 2016-2020, Post 2020 heatwave). Error bars represent ± 1 SE. Patterns shown here differ slightly from those described in Figure 1 heatmaps because means reflect data from all sites in each reef, rather than only the subset of sites that were surveyed in both time intervals, as in heatmap comparisons.

Fish community

A total of 676 species of bony fishes (Actinopterygii), 11 sharks and rays (Elasmobranchii), and 9 reptiles were recorded during surveys across the span of the Coral Sea Marine Park. Trends in fish communities also reflected larger regional scale patterns associated with heatwaves and coral bleaching (Figure 8, Figure 9), much more so than responses to management and zoning (Figure 10). Regional gains in biomass at the north and north-west reefs associated with the 2016 heatwave were largely reversed during the 2020 heatwave, with significant biomass decline across reefs from 2016-2020 to post 2020 surveys (Appendix Table 3), greatest at central reefs (Figure 9). A net overall reduction in fish biomass of 7.34 kg (125.42 kg to 118.07 kg) per 500 m^2 was observed at the scale of the CSMP from pre 2016 to post 2020 surveys. No significant difference in biomass change was observed between sites in Habitat Protection and National Park zones (including those which existed prior to the new management plan for the CSMP in 2018; Figure 10). In general, sites with highest fish biomass exhibited the greatest declines, reducing the variation between reefs to a more consistent level across the Park. Sites in the National Park Zone at Magdelaine Cays showed the most pronounced reductions in fish biomass from pre 2016 to post 2020, on average.

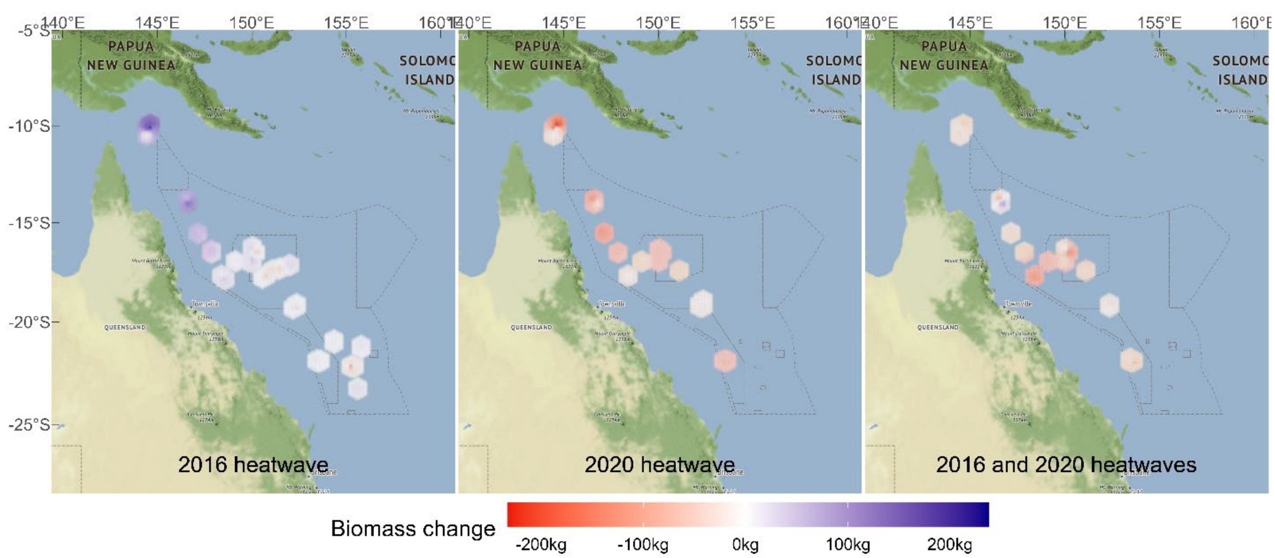

Figure 8. Change in total fish biomass over two heatwave events. Data in the left map show change in total fish biomass (kg) from pre 2016 surveys to those between 2016 and 2020 (i.e. mean fish biomass at each site in 2017-2020 minus mean biomass pre 2016). Middle map shows change in biomass values from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in biomass per site from pre 2016 surveys to post 2020 surveys. Reds represent a reduction in fish biomass through time and blues an increase.

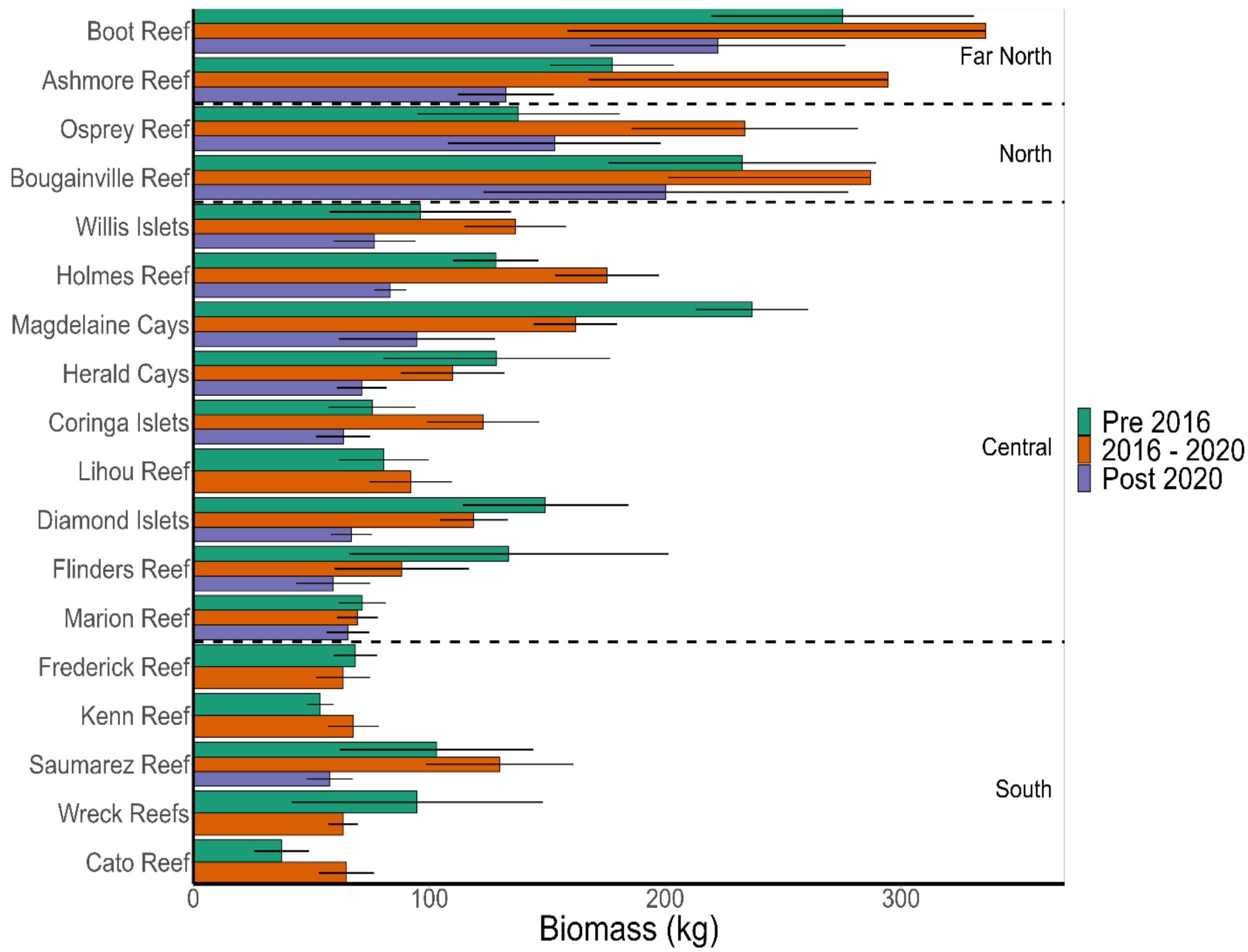

Figure 9. Total fish biomass of Coral Sea reefs over three time periods. Error bars represent ± 1 SE. Fish biomass varied by reef ($p < 0.001$) and between time periods ($p < 0.001$). See Table 3 for full statistics.

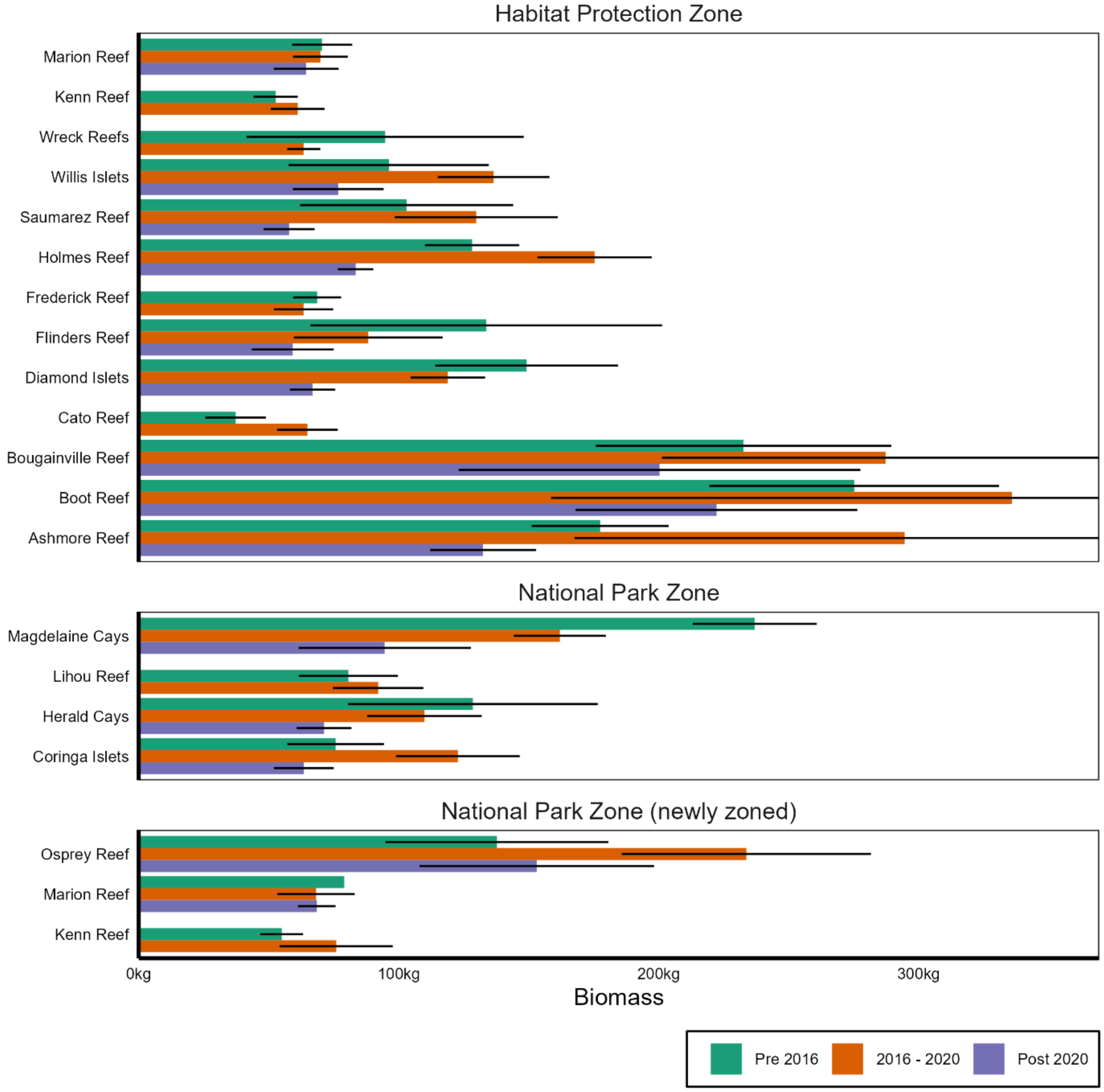

Figure 10. Fish biomass per 500 m^2 by protection status. Error bars represent ± 1 SE. Newly zoned national park refers to zones declared National Park Zones (in 2018) that were not previously within an IUCN Ia or II zone.

Changes in fish community structure also occurred over the regional scale of the CSMP, with broadly shifting composition and abundance of species over the course of the two major heatwaves leading to fish community structures in 2020 that were more similar between far north and south than observed in previous surveys (Figure 11). In other words, the net outcome of both heatwaves was for the reefs in the south and far north to become more similar to those at central reefs, generating a regional 'homogenisation' effect. This is evident in Figure 11 where the red (far north) and purple (south) ellipses nearly touch each other post-2020 (solid ellipses, bottom plot), whereas more widely separated pre-2016 (dashed ellipses). Note that the stress level for the MDS plot was high (0.22), indicating that the plots are not a good representation of multivariate patterns, and require caution in interpretation.

The PERMANOVA confirmed a significant interaction between time period and region, however, indicating that community change through time did differ between regions. Investigation of trends in each of the most abundant species recorded along transects in each region revealed complex and variable patterns (Figure 12), suggesting that overall community level change was also complex and driven by a large combination of shifting abundances and occurrences of coral reef fishes across the broader seascape.

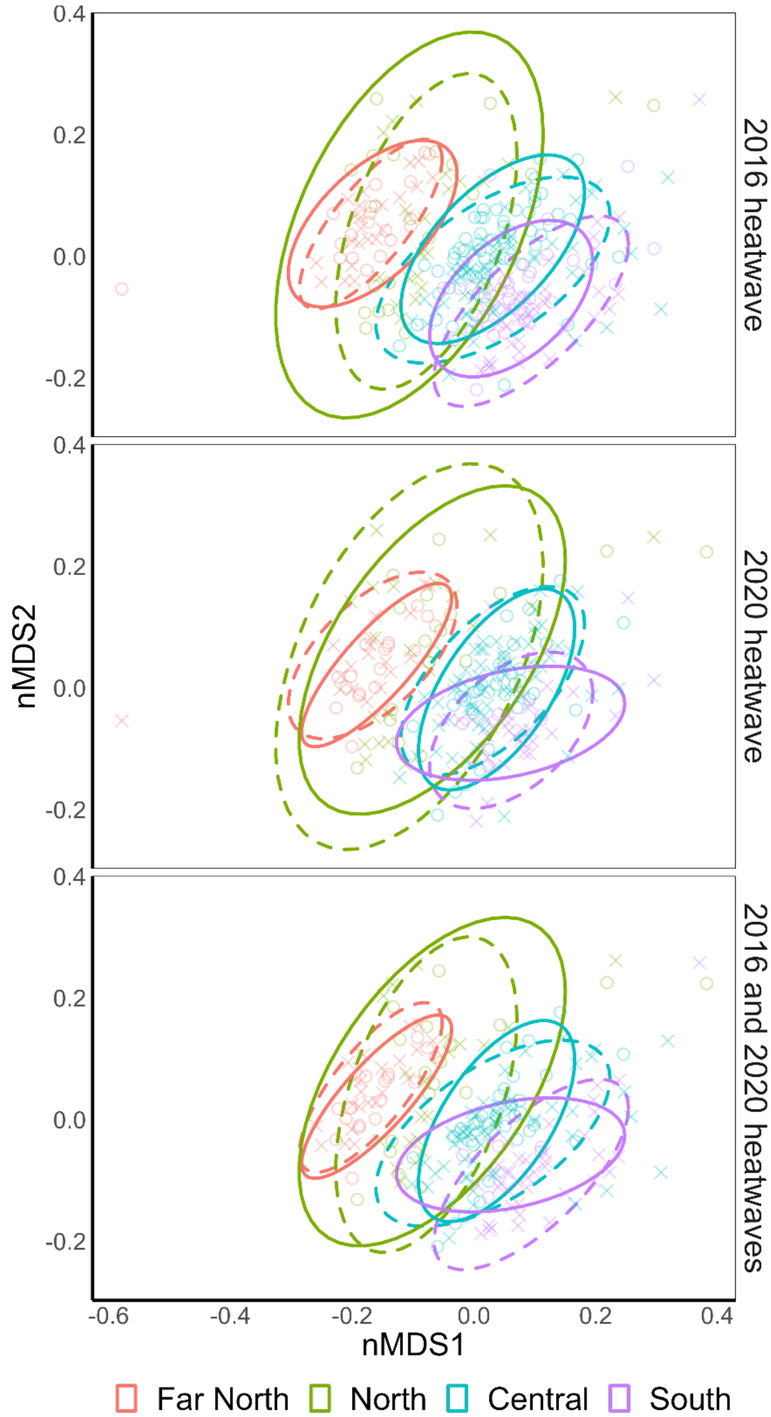

Figure 11. Change in fish community structure over two heatwave events. Community compositions at a site are represented by a single point in the two-dimensional space using non-metric multidimensional scaling (nMDS). Crosses and dotted ellipses infer the position before the heatwave(s), circles and solid ellipses infer the position after the heatwave(s). Orange = far north, Green = north, Blue = central, Purple = south. Stress = 0.22. Fish community structure significantly differed between regions ($p < 0.001$), between time periods ($p < 0.001$), and change in community structure through time differed among regions ($p < 0.001$). See Table 4 for full statistics.

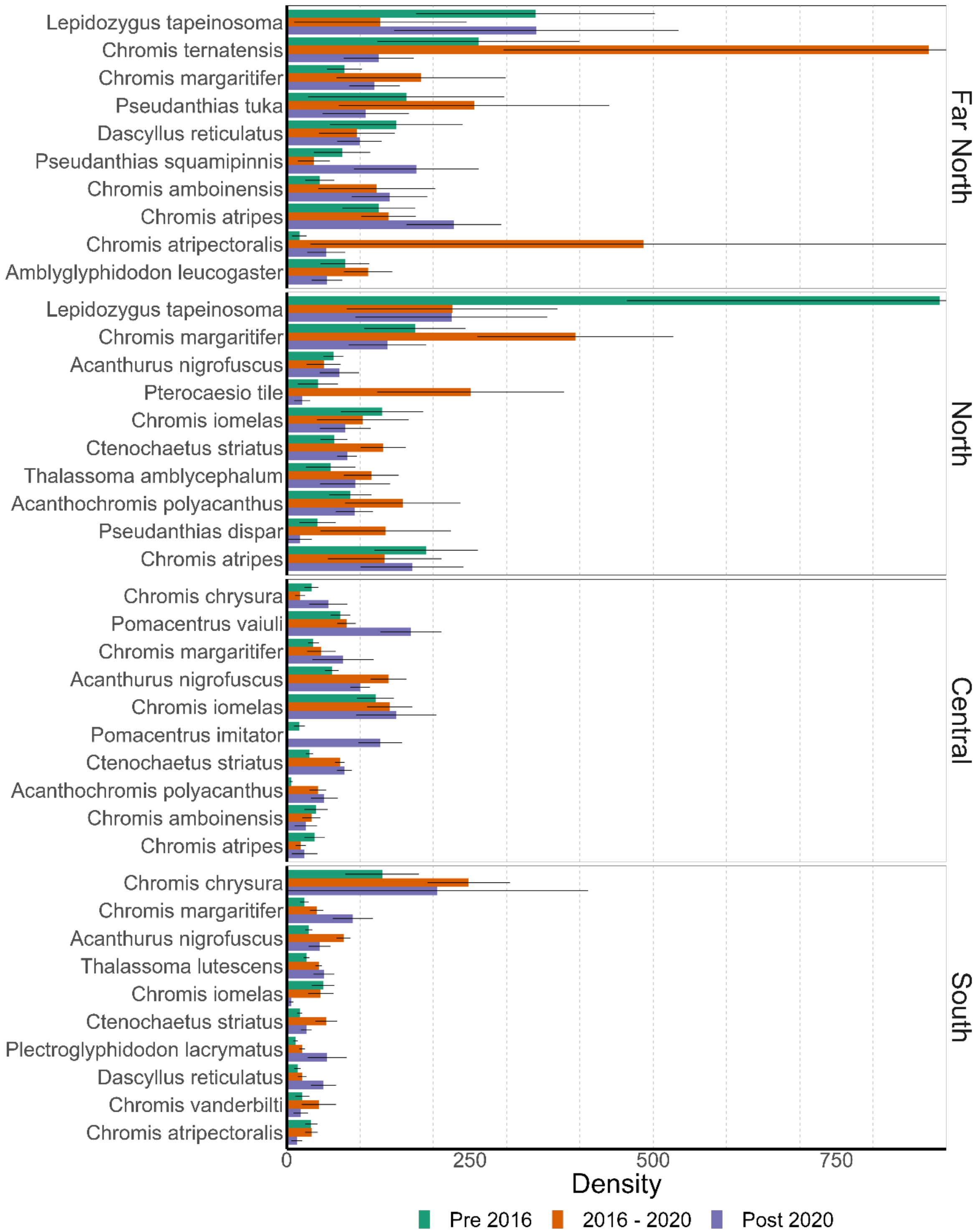

Figure 12. Dominant fish species (by mean density per transect) for each of the four regions in the Coral Sea Marine Park, and for each time period (Pre 2016 heatwave, 2016-2020, Post 2020 heatwave). Error bars represent ± 1 SE.

Sharks, surgeonfishes, fusiliers and parrotfishes dominated fish biomass across transects (Figure 13), and varied considerably in responses over time, albeit with more reductions than increases. Declines in shark and coral trout biomass appeared to be relatively consistent between regions and years, especially in terms of declines from the 2016-2020 to post 2020 periods.

When large fish biomass was considered in aggregate using the B20 indicator (Figure 14, Figure 15), trends largely reflected those in total fish biomass. Declines in B20 observed in the south from pre 2016 to 2016-2020 were more obvious than changes in total fish biomass, however, and may have potentially been exacerbated up to the post 2020 period, although survey data are lacking for most southern reefs in this period. No effect of zoning on B20 change was observed (Figure 16).

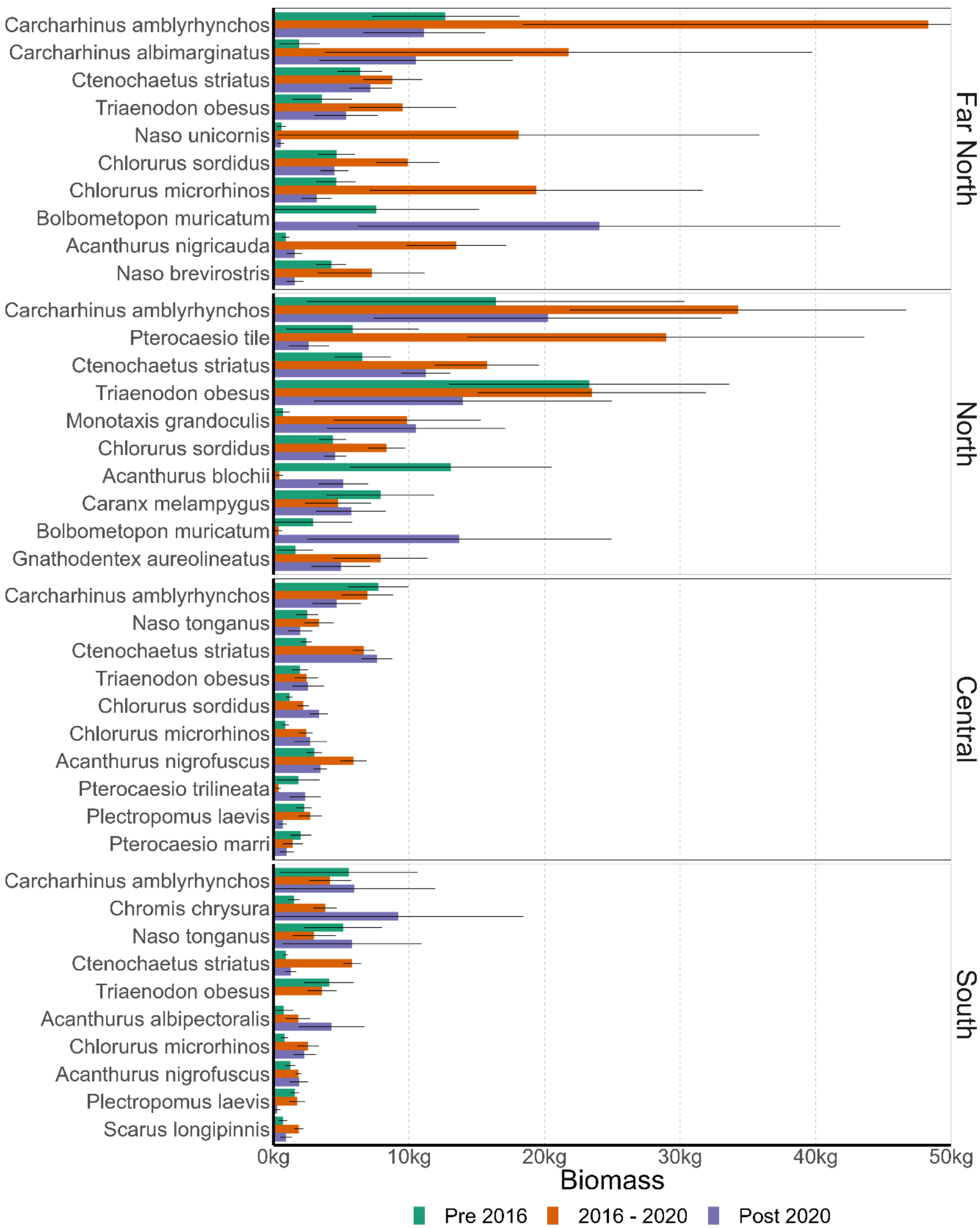

Figure 13. Dominant fish species (by mean biomass per transect) for each of the four regions in the Coral Sea, and each time period (Pre 2016 heatwave, 2016-2020, Post 2020 heatwave). Error bars represent ± 1 SE.

Large Fish biomass (B20)

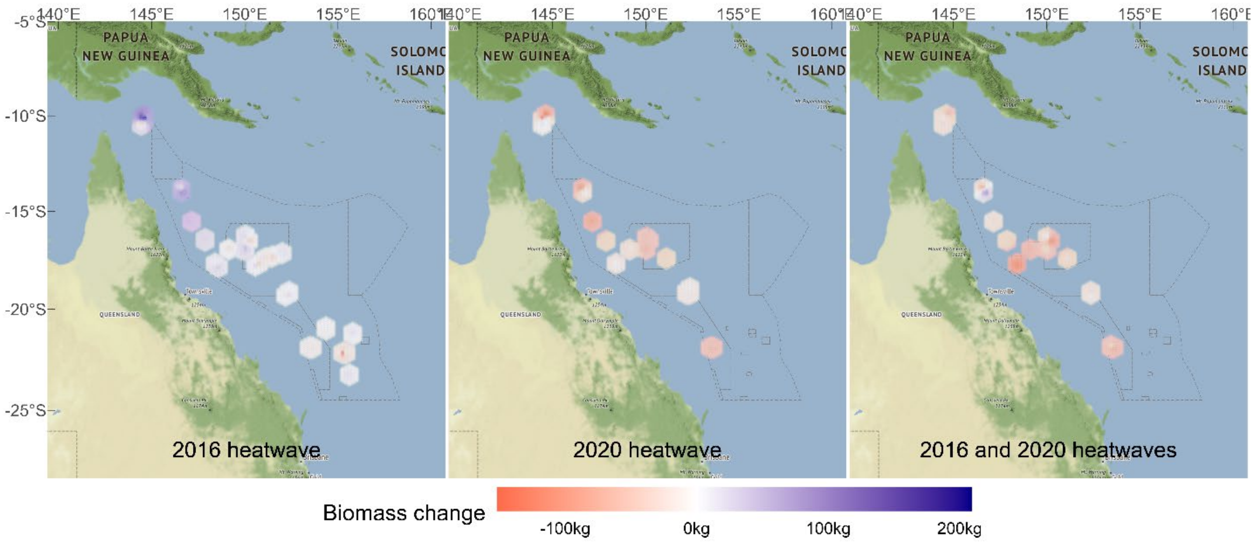

Figure 14. Change in Large fish biomass (B20) over two heatwave events. Data in the left map show change in B20 (kg) from pre 2016 surveys to those between 2016 and 2020 (i.e. mean B20 at each site in 2017-2020 minus mean B20 pre 2016). Middle map shows change in B20 values from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in B20 per site from pre 2016 surveys to post 2020 surveys. Reds represent a reduction in large fish biomass through time and blues an increase.

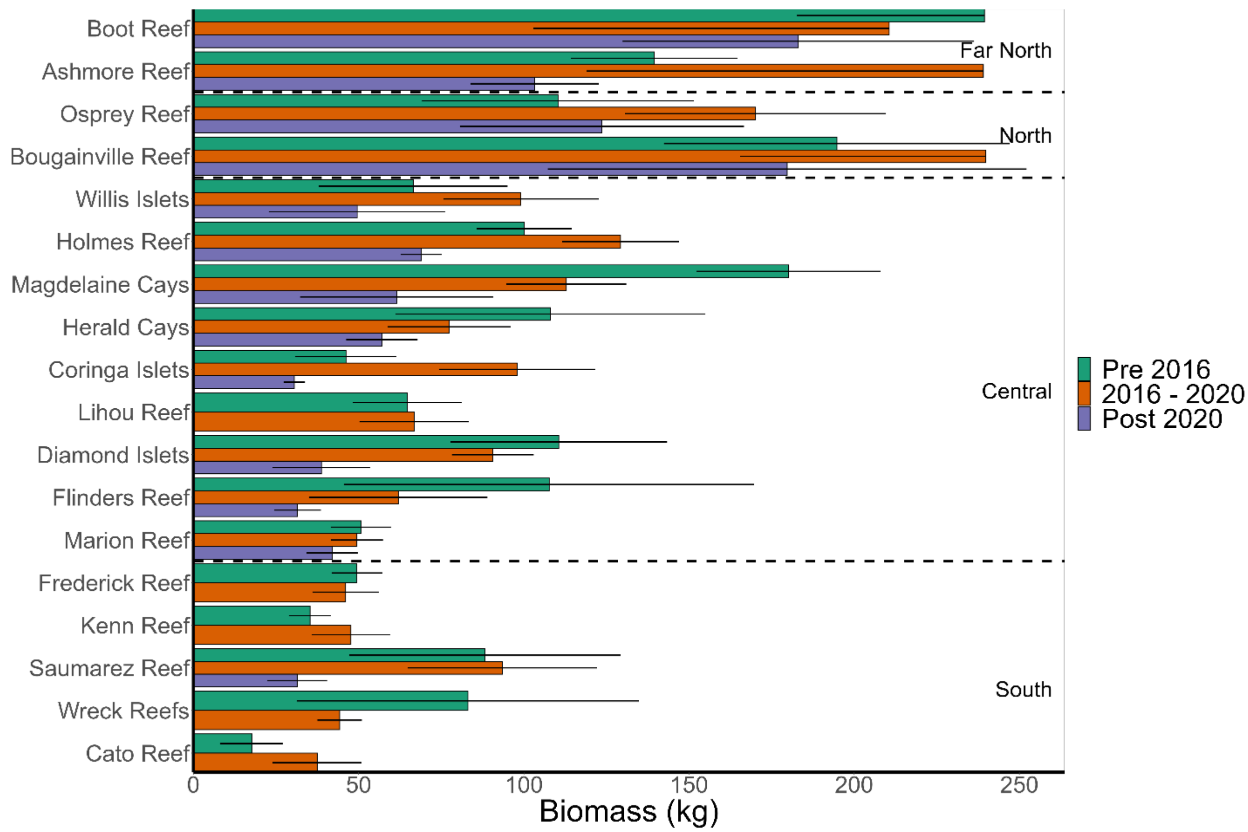

Figure 15. Large fish biomass (B20) of Coral Sea reefs over three time periods, separated by two major heatwave events. Error bars represent ± 1 SE. Large fish biomass varied by reef ($p < 0.001$) and between time periods ($p = 0.011$). See Table 5 for full statistics.

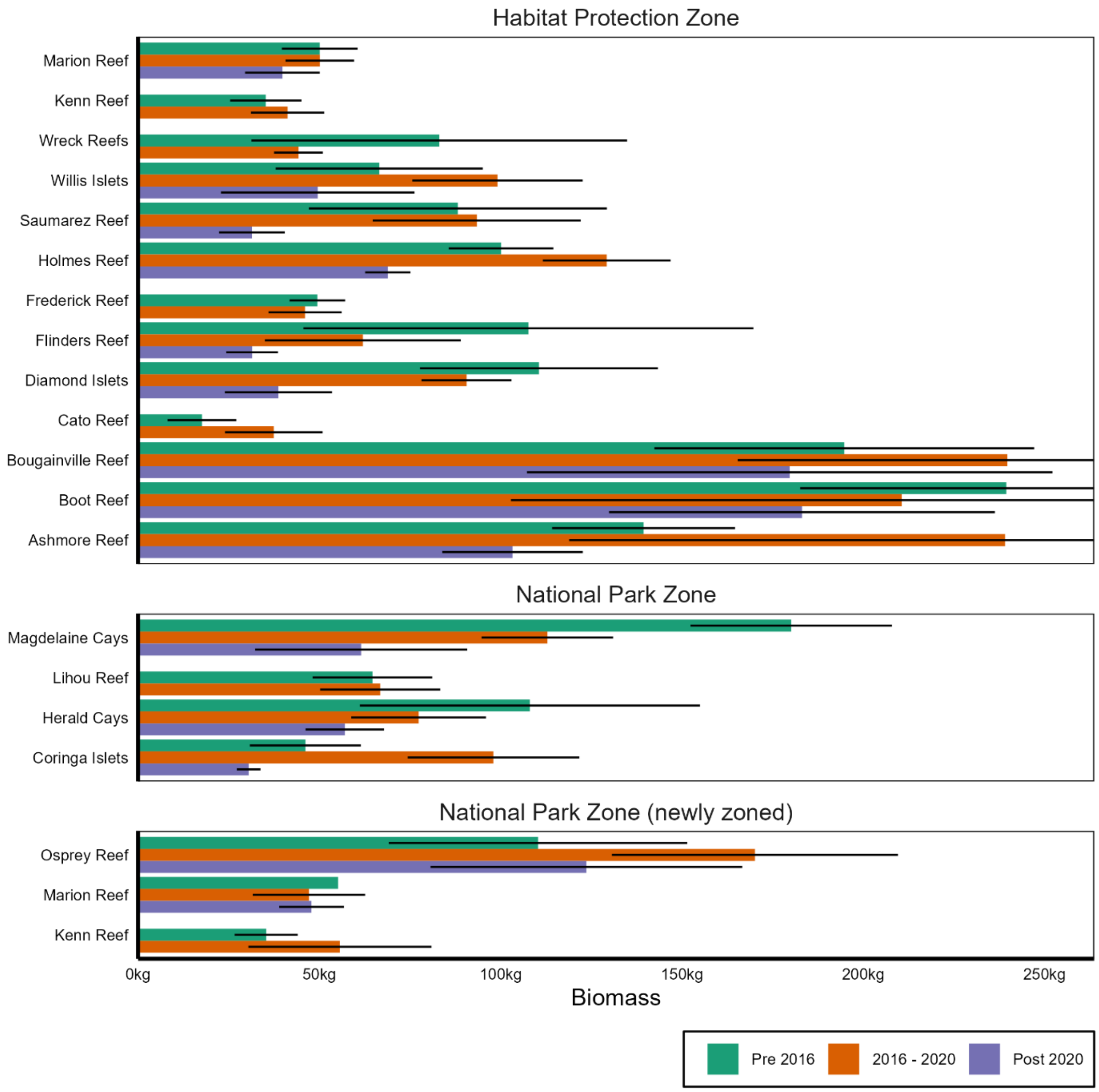

Figure 16. Large fish biomass (B20) per 500 m^2 by protection status. Error bars represent ± 1 SE. Newly zoned national park refers to zones declared National Park Zones (in 2018) that were not previously within an IUCN Ia or II zone.

Fish Community Temperature Index (CTI) and Community Generalisation Index (CGI)

Spatial patterns in CTI showed a latitudinal gradation of fishes preferring warmer seas in the northern CSMP to those with cooler affinities in the south (Figure 17), although limited evidence existed for systematic change in values through time. Some declines in CTI previously identified in the central reefs associated with the 2016 heatwave have either continued or subsided, meaning that these reefs now have relatively 'cooler' fish communities than in baseline RLS surveys prior to 2016.

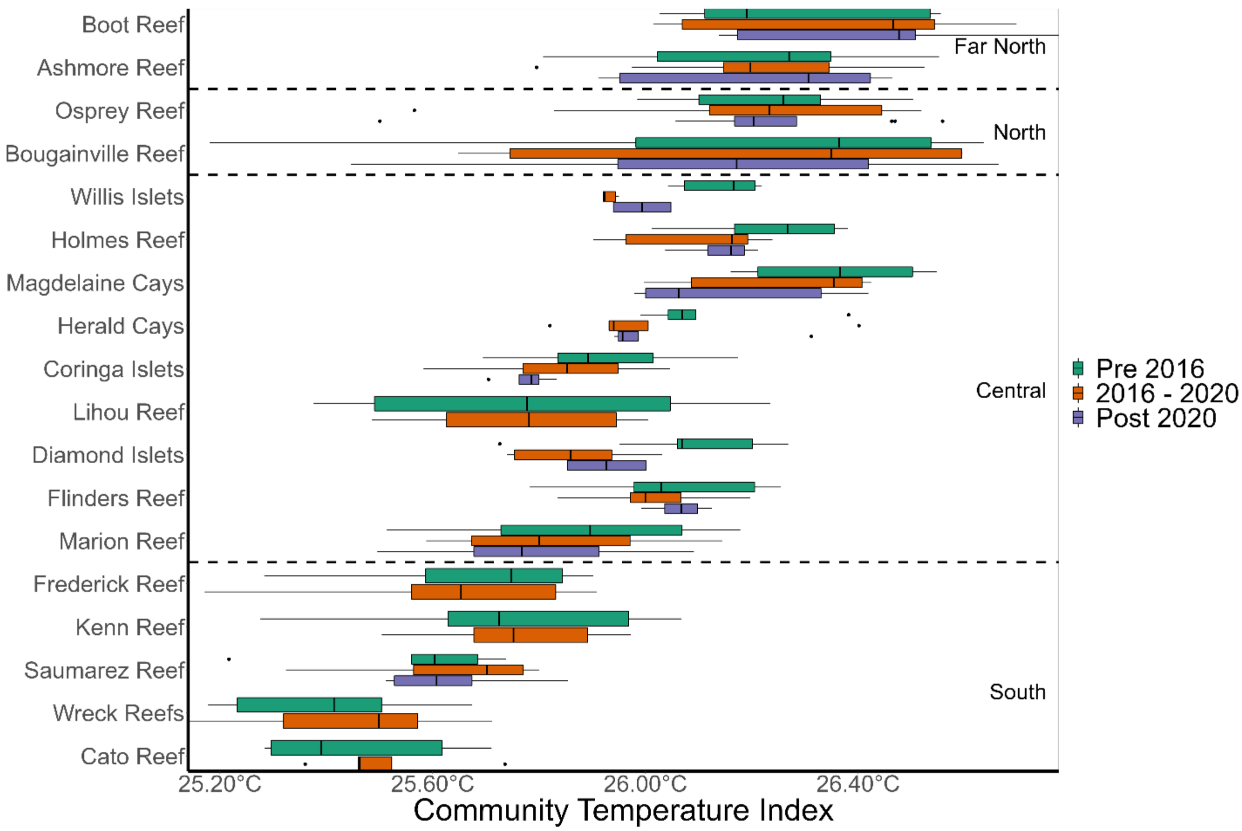

Figure 17. Community Temperature Index (CTI) values for fish communities surveyed at 19 reefs, within 4 regions, in the Coral Sea. Error bars represent ± 1 SE of the mean site-level CTI value.

The distribution of CGI values across reefs also shows a spatial trend towards more habitat specialist fishes in the north and generalists in the south, although this was not as strong as the trend in CTI. Change in CGI through time was not significant at the scale of the CSMP and whole period.

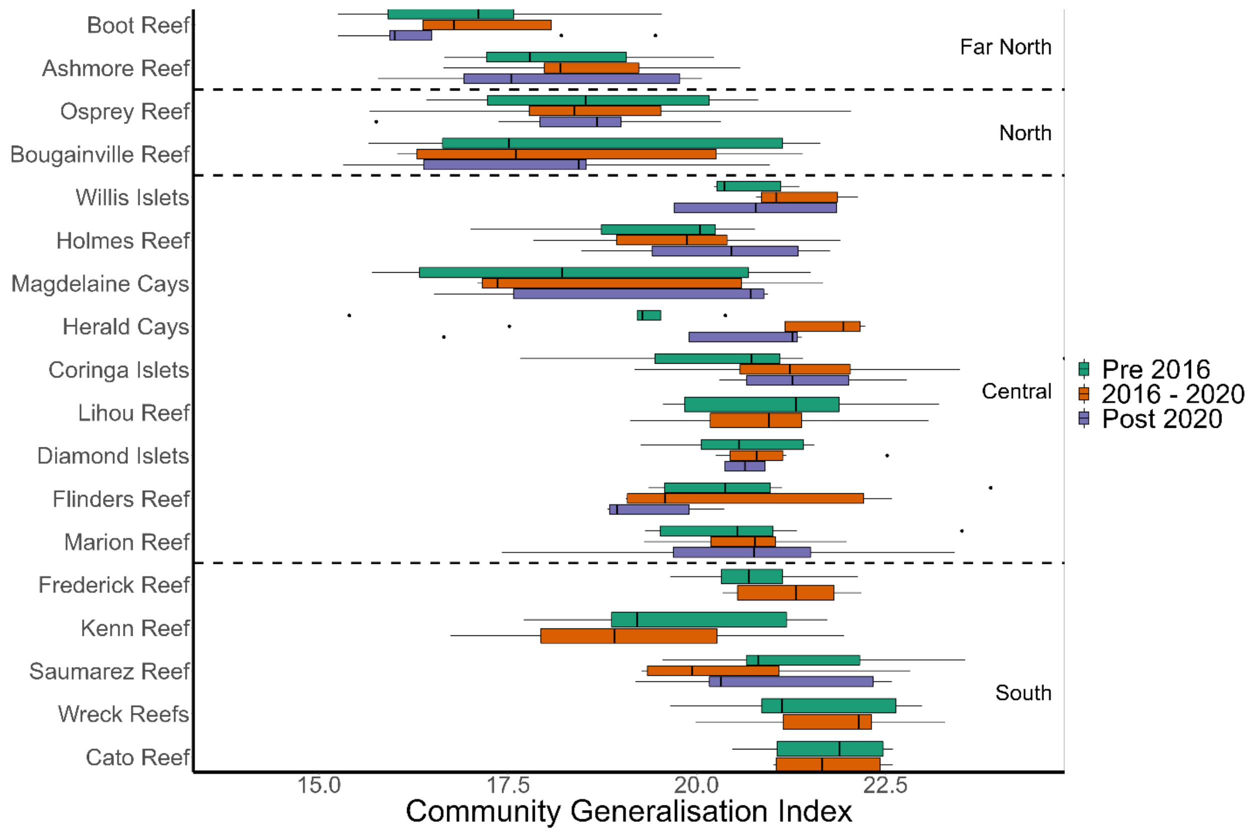

Figure 18. Community Generalisation Index (CGI) values for fish communities surveyed at 19 reefs, within 4 Coral Sea regions. Error bars represent ± 1 SE of the mean site-level CGI value.

Herbivorous fish biomass

Trends in herbivorous fish biomass on transects also followed similar broad regional trends to those in total biomass, with increases in the far north from the 2016 heatwave reversed during the 2020 heatwave, and a general pattern of net decline across the CSMP through all time periods (Figure 19, Figure 20). Changes in herbivorous fish biomass did not differ significantly between management zones (Figure 21).

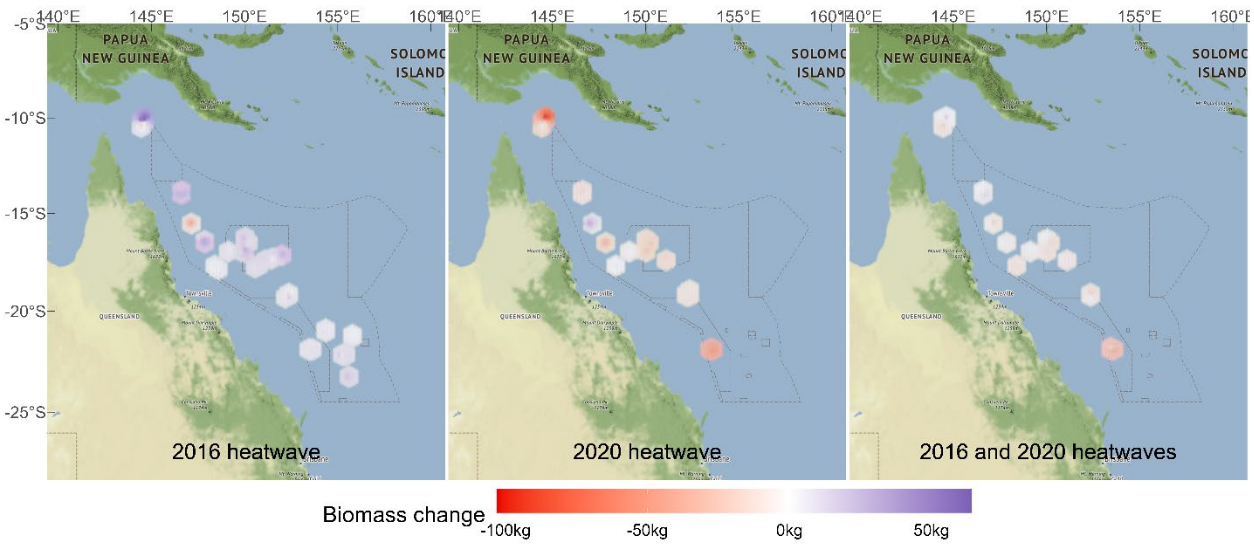

Figure 19. Change in herbivorous fish biomass over two heatwave events. Data in the left map show change in herbivorous fish biomass (kg) from pre 2016 surveys to those between 2016 and 2020 (i.e. mean herbivorous fish biomass at each site in 2017-2020 minus mean biomass pre 2016). Middle map shows change in herbivorous fish biomass values from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in herbivorous fish biomass per site from pre 2016 surveys to post 2020 surveys. Reds represent a reduction in herbivorous fish biomass through time and blues an increase.

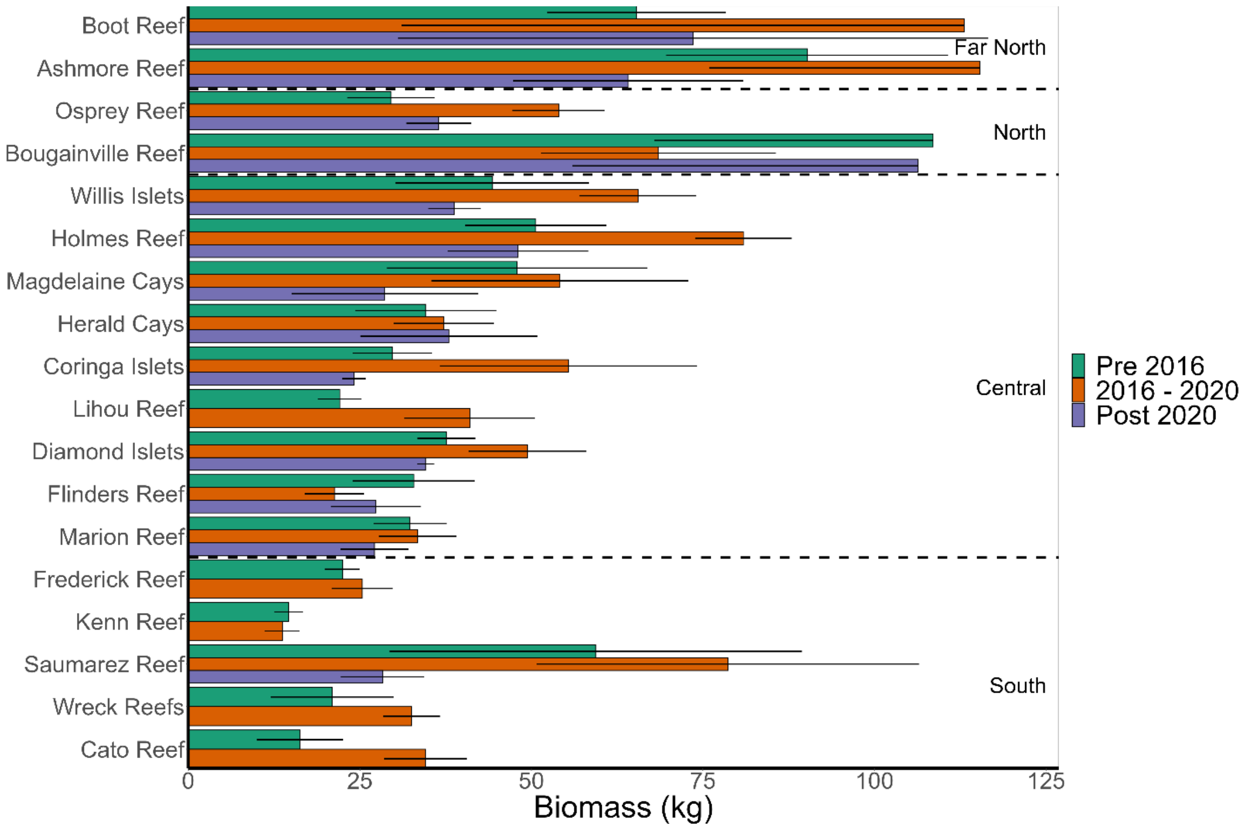

Figure 20. Mean biomass (kg per 500 m^2) of herbivorous fishes on surveys at 18 Coral Sea reefs over three time periods, separated by two major heatwave events. Error bars represent ± 1 SE of the mean site-level biomass. Herbivorous fish biomass varied by reef ($p < 0.001$) and between time periods ($p = 0.001$). See Table 6 for full statistics.

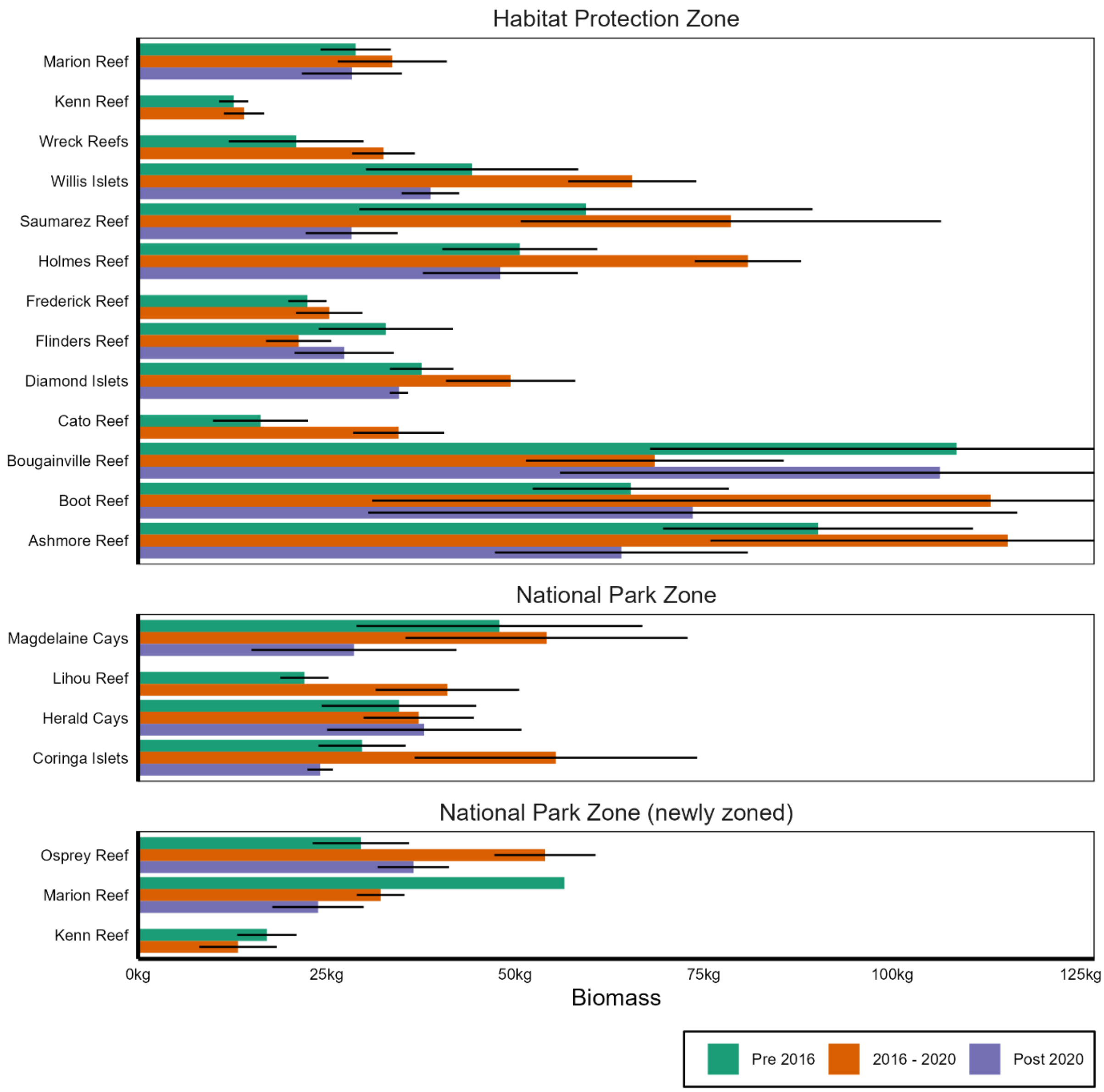

Figure 21. Herbivorous fish biomass per 500 m^2 by protection status. Error bars represent ± 1 SE. Newly zoned national park refers to zones declared National Park Zones (in 2018) that were not previously within an IUCN Ia or II zone.

Mobile macroinvertebrate community

Macroinvertebrates

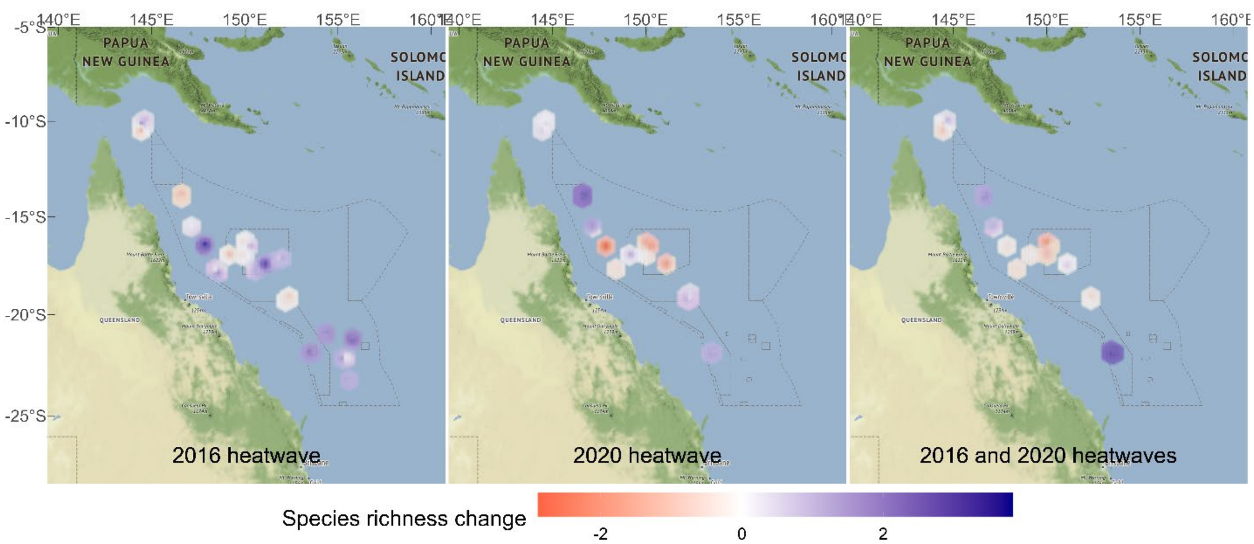

Figure 22. Change in macroinvertebrate species richness (number of species per 100 m^2) over two heatwave events. Data in the left map show change in macroinvertebrate richness from pre 2016 surveys to those between 2016 and 2020 (i.e. mean macroinvertebrate richness at each site in 2017-2020 minus mean richness pre 2016). Middle map shows change in macroinvertebrate richness from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in macroinvertebrate richness per site from pre 2016 surveys to post 2020 surveys. Reds represent a reduction in macroinvertebrate species richness through time and blues an increase.

For mobile macro-invertebrates, a total of 120 gastropod, 2 cephalopod, 29 crustacean, 20 sea star, 22 holothurian, 23 crinoid, and 12 sea urchin species were observed by divers during surveys in the Coral Sea Marine Park. Seven giant clam species were also recorded.

Mobile macroinvertebrate richness changed in a highly patchy manner over the 2016 heatwave period, while changes observed over the 2020 heatwave appear to have been stronger and contributed most to patterns of net change over the entire period (Figure 22, Figure 23). A slight increase in the number of mobile macroinvertebrate species recorded per transect was observed at Osprey and Saumarez Reefs, while some declines occurred on central reefs.

Sea urchins were the dominant members of the mobile macroinvertebrate community at southern Coral Sea reefs but were comparatively scarce on central and northern reefs. An increase in sea urchin densities was observed in the south as a result of the 2016 heatwave (Figure 24, Figure 25) (mostly for species *Diadema setosum* and *Diadema savignyi,* and for locations Wreck Reefs, Cato Reef and Kenn Reef), but data were too limited to investigate the effects of the 2020 heatwave; Saumarez Reef was the only reef surveyed in the south in the most recent period, but has low sea urchin densities, as do most other regions for which the effects of the 2020 heatwave could be investigated. Sea cucumber density varied among reefs but did not change significantly through time (Figure 32, Figure 33).

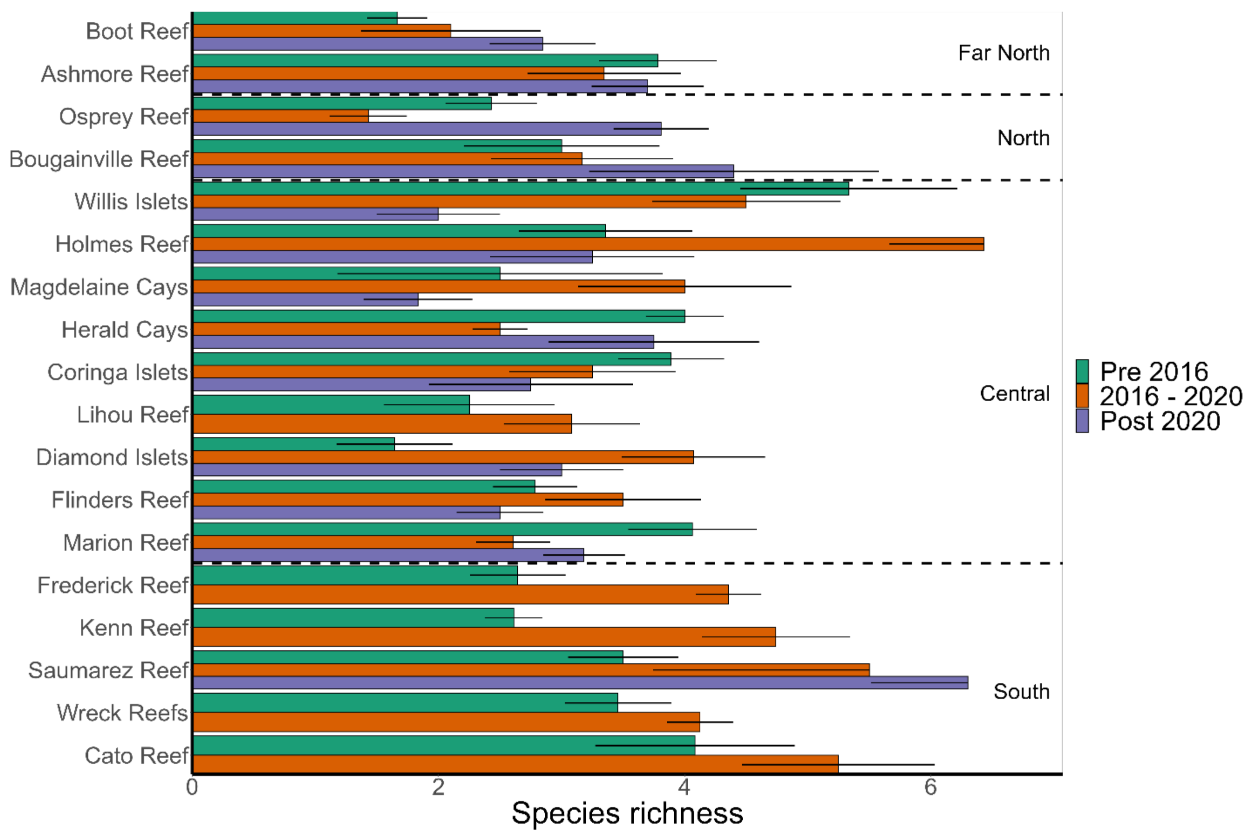

Figure 23. Number of macroinvertebrate species recorded on a survey (100 m^2) across 18 reefs, in four regions of the Coral Sea. Error bars represent ± 1 SE of the mean site-level richness. Macroinvertebrate richness varied by reef ($p < 0.001$), between time periods ($p = 0.015$), and varied differently with time period at different reefs (significant interaction between reef and time period, $p < 0.001$). See Table 8 for full statistics.

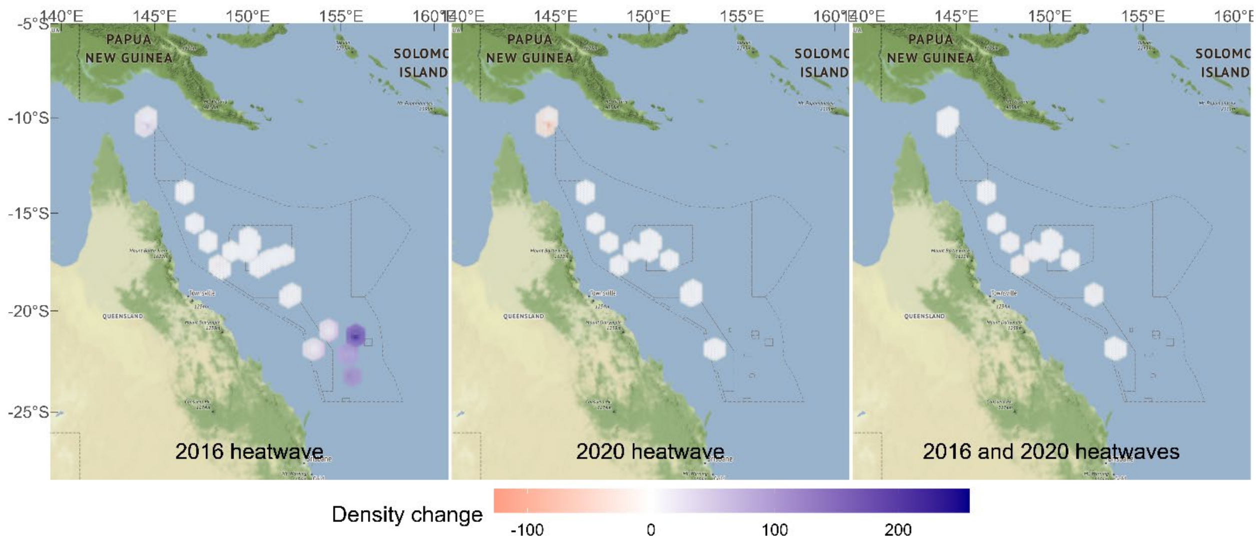

Figure 24. Change in sea urchin density (number of individuals per 100 m^2) over two heatwave events. Data in the left map show change in sea urchin density from pre 2016 surveys to those between 2016 and 2020 (i.e. mean sea urchin density at each site in 2017-2020 minus mean density pre 2016). Middle map shows change in sea urchin density from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in sea urchin density per site from pre 2016 surveys to post 2020 surveys. Reds represent a reduction in sea urchin density through time and blues an increase.

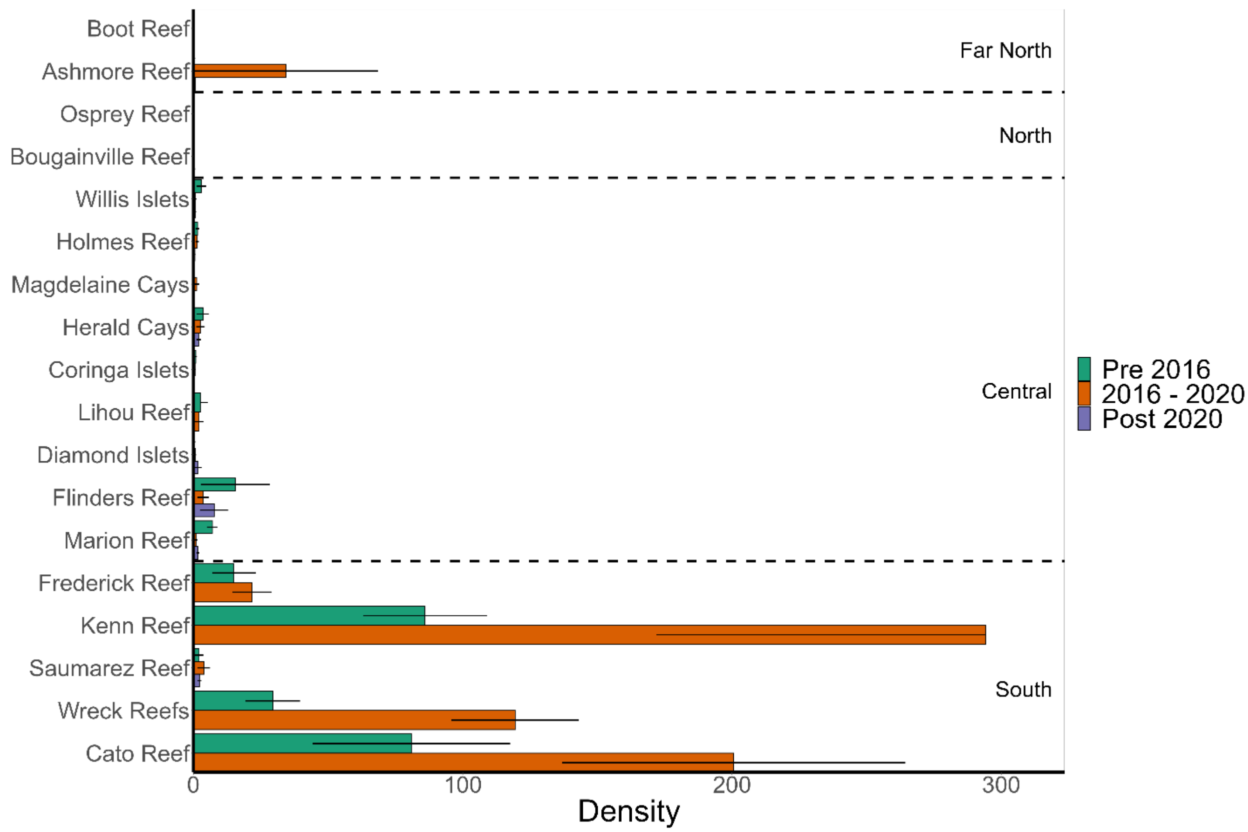

Figure 25. Sea urchin density (individuals per 100 m^2) at 18 reefs in four regions of the Coral Sea, at three time points before during and after two major heatwave events in 2016 and 2020. Error bars represent ± 1 SE of the mean site-level density. Total urchin density varied by reef ($p < 0.001$) and by the reefs varies differently with time period reefs (significant interaction between reef and time period, $p = 0.015$). Urchin density significantly increased in the Wreck Reefs from Pre-2016 to 2016-2020 ($p = 0.002$). See Table 9 for full statistics.

Taxa of conservation concern

Threatened species

Four turtle species that are listed as threatened under the EPBC Act were observed during surveys in the CSMP (Table 12). Many more species (n = 61) were recorded that are listed as threatened on the IUCN Red List, including holothurians, giant clams and fishes (Table 13). Most of these were infrequently scored on surveys, although the giant clam *Tridacna derasa* and the Humphead Maori wrasse *Cheilinus undulatus* were observed frequently. Although the latter was observed on fewer transects in the central and southern regions after the 2016-2020 period, none of the threatened species showed a consistently strong decrease or increase in the number of sites where present between any period. In addition to listed threatened species, a number of other taxa of conservation concern—sharks and sea snakes—were also observed in moderately high numbers, highlighting the importance of the CSMP for conservation.

Eretmochelys imbricata

Caretta caretta

Natator depressus

Chelonia mydas

Plate 1 Four turtle species were observed during surveys in the Coral Sea Marine Park. All are listed as threatened under the EPBC Act.

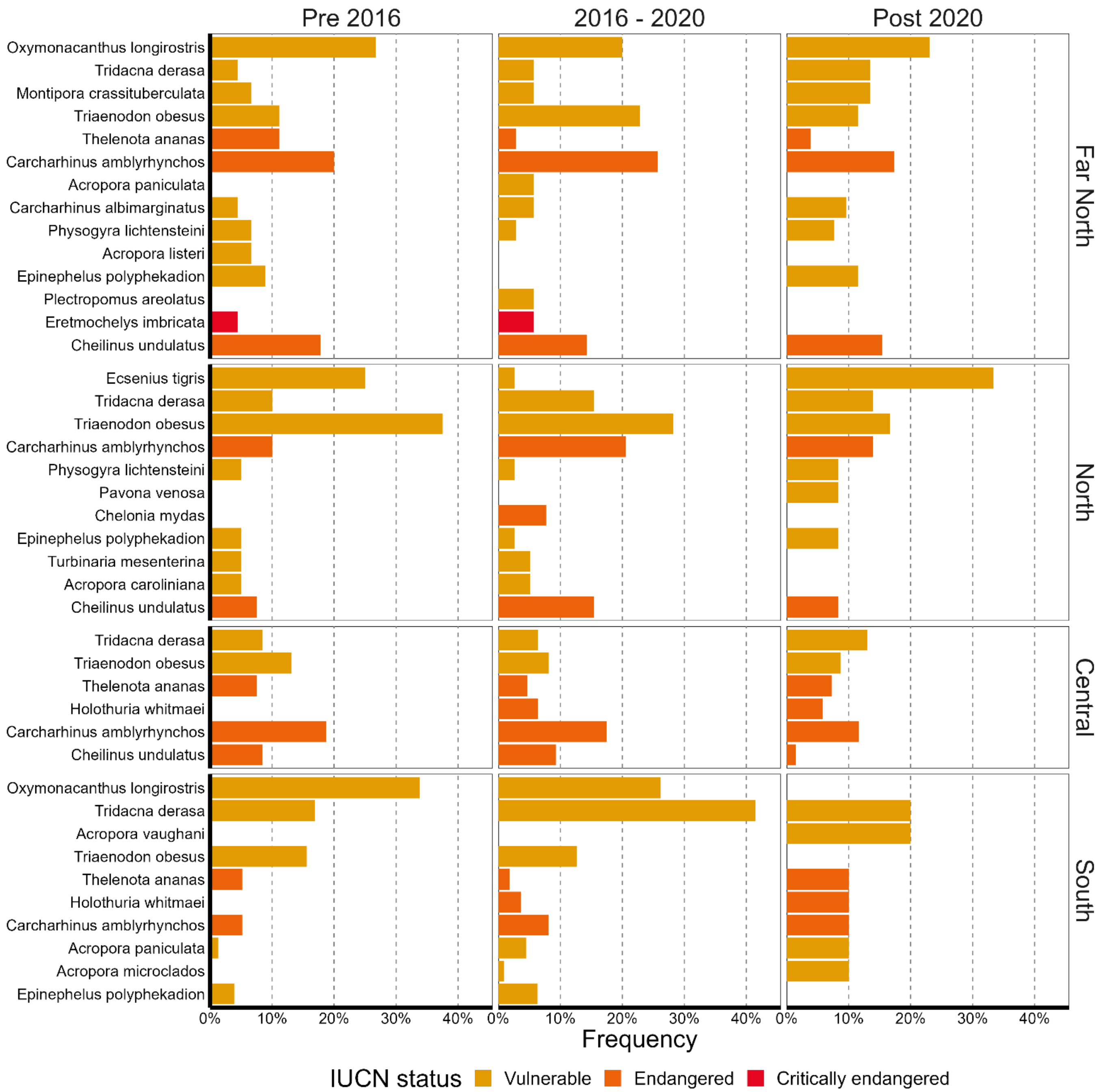

Figure 26. Frequency of occurrence (percent of surveys with an observation) of a subset of IUCN threatened species observed across all sites surveyed in the Coral Sea. For a list of all threated species observed see Table 13.

Sharks

The biomass of sharks on reef surveys was highly variable among sites, reefs, regions and times (Figure 27, Figure 28). Although not statistically significant across the full span of the CSMP (Appendix Table 7), large declines in mean shark biomass values occurred in some central and north reefs over the 2016 heatwave period and have not shown subsequent signs of recovery. Changes in shark biomass over the entire study duration were not significantly associated with management zone (Figure 29, Appendix Table 7).

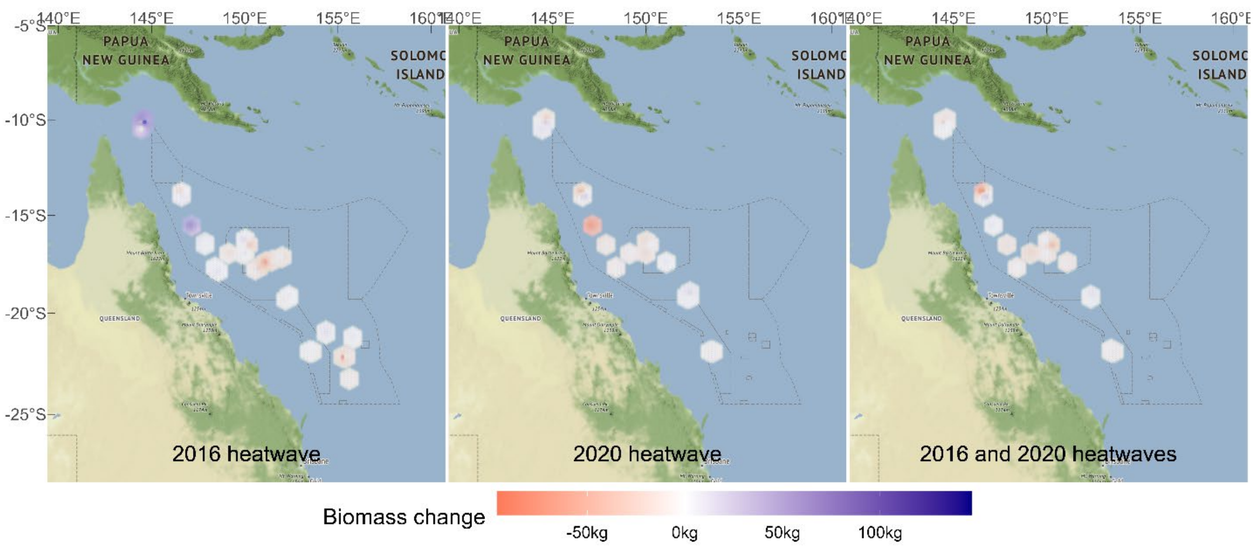

Figure 27. Change in shark biomass over two heatwave events. Data in the left map show change in shark biomass (kg) from pre 2016 surveys to those between 2016 and 2020 (i.e. mean shark biomass at each site in 2017-2020 minus mean biomass pre 2016). Middle map shows change in shark biomass values from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in shark biomass per site from pre 2016 surveys to post 2020 surveys. Reds represent a reduction in shark biomass through time and blues an increase.

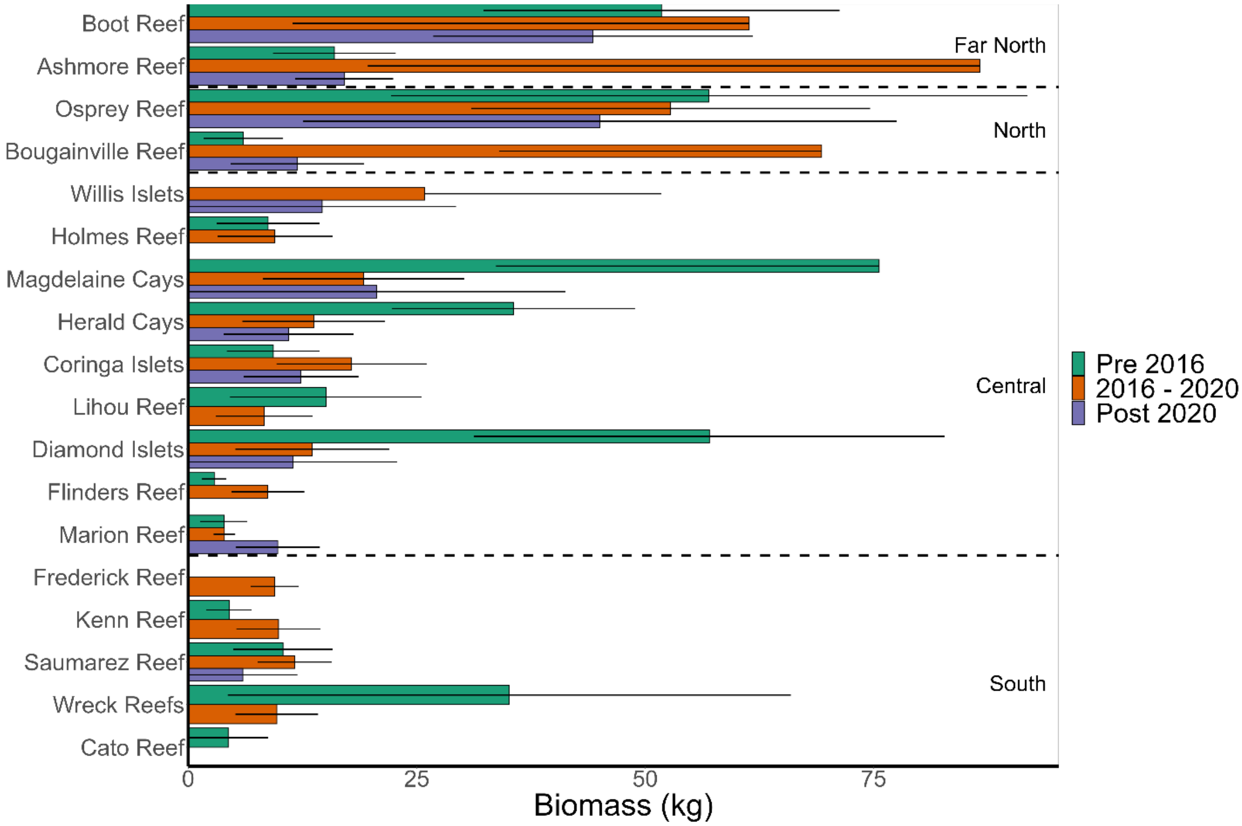

Figure 28. Mean biomass (kg) of sharks on surveys at 18 Coral Sea reefs over three time periods, separated by two major heatwave events. Error bars represent ± 1 SE of the mean site-level biomass. Shark biomass varied by reef (p = 0.003) but not between time periods across the span of the CSMP. See Table 7 for full statistics.

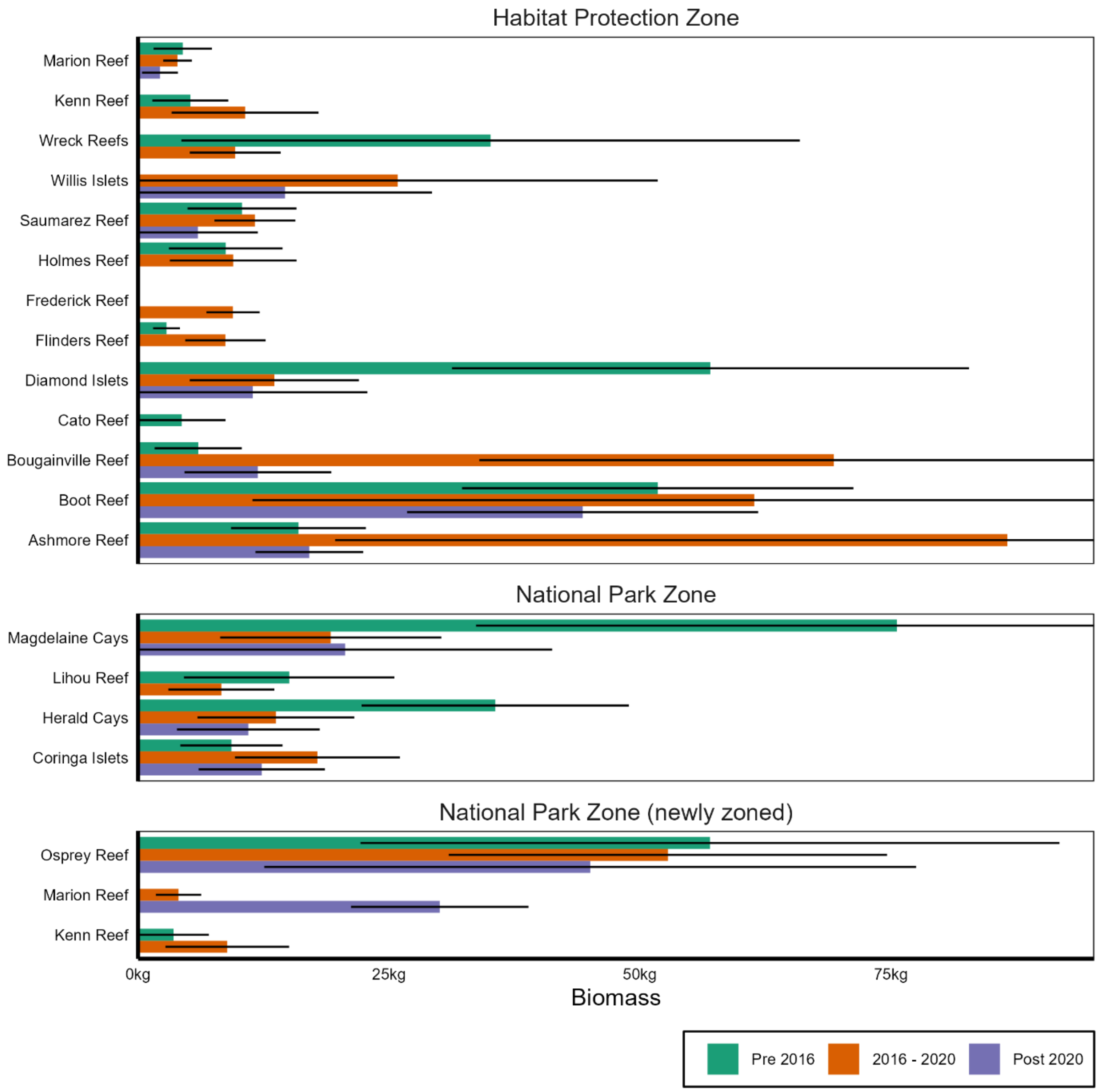

Figure 29. Shark biomass per 500 m^2 by protection status. Error bars represent ± 1 SE. Newly zoned national park refers to zones declared National Park Zones (in 2018) that were not previously within an IUCN Ia or II zone.

Sea snakes

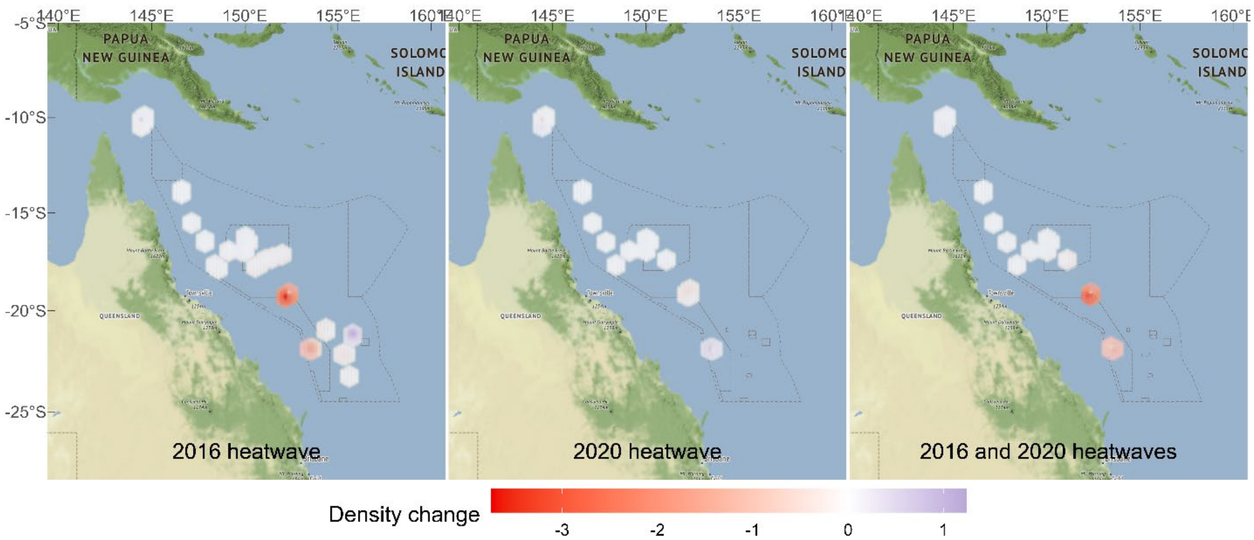

Figure 30. Change in sea snake density (number of individuals per 500 m^2) over two heatwave events. Data in the left map show change in sea snake density from pre 2016 surveys to those between 2016 and 2020 (i.e. mean sea snake density at each site in 2017-2020 minus mean density pre 2016). Middle map shows change in sea snake density from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in sea snake density per site from pre 2016 surveys to post 2020 surveys. Reds represent a reduction in sea snake density through time and blues an increase.

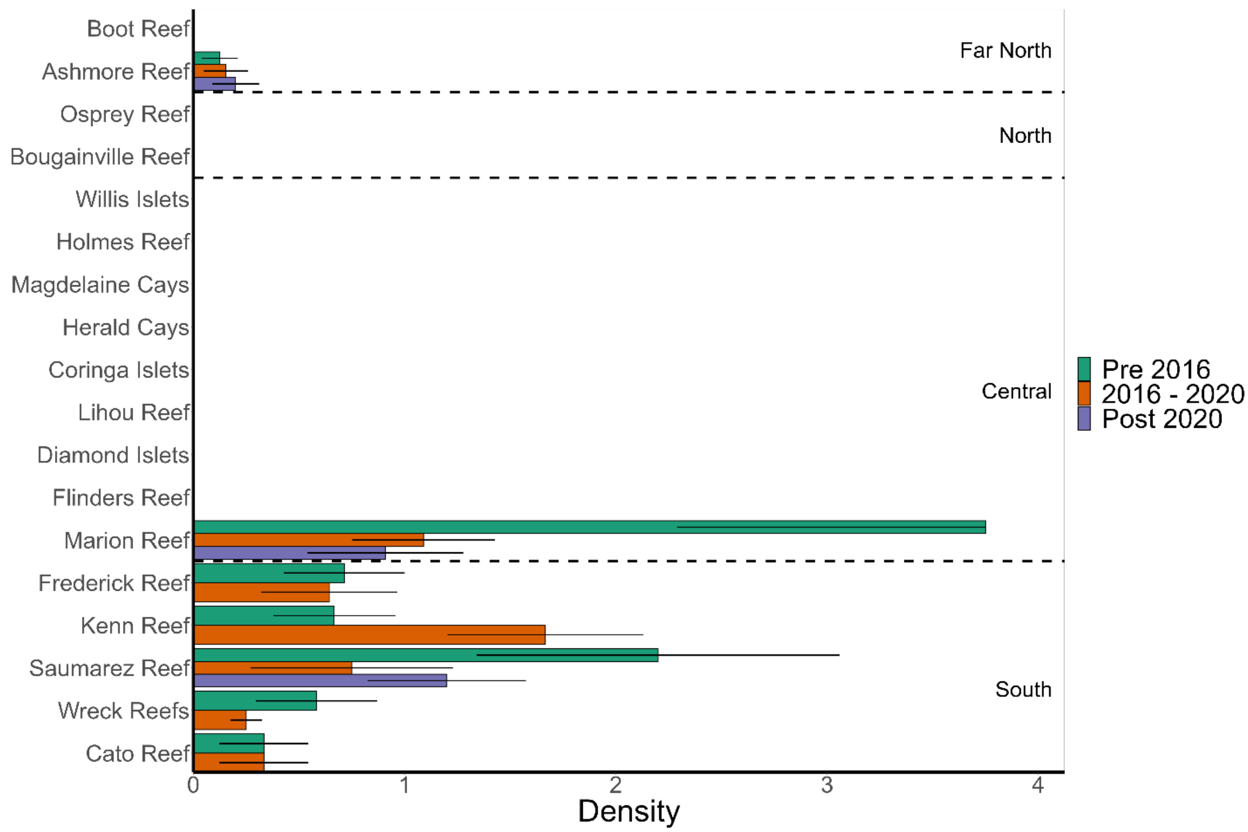

Figure 31. Sea snake density (individuals per 500 m^2) at 18 reefs in the Coral Sea. Error bars represent ± 1 SE of the mean site-level density. Sea snake density varied by reef ($p < 0.001$), but not with time period. See Table 11 for full statistics. Marion Reef showed a significant decline in sea snake density from Pre-2016 to 2016-2020 ($p = 0.04$), and remained statistically different from the Pre-2016 density in Post-2020 ($p = 0.002$).

Sea snakes were abundant on southern Coral Sea reefs, rare on reefs in the far north and absent from the reefs in between. The 2016 heatwave had a substantial effect on sea snake densities in the south and at Marion Reef, where populations did not recover or change much in the following period up to the post 2020 surveys (Figure 30, Figure 31). High variability between sites resulted in non-significant overall net change from pre 2016 to post 2020 at the scale of the CSMP, but the declines at Marion Reef were significant, and sea snake densities observed in post 2020 surveys were only around one quarter of those observed in the pre-2016 surveys of this reef. A decline observed at Saumarez Reef at the time of the 2016 heatwave has also persisted, with sea snake numbers remaining relatively low through to the post 2020 period.

Sea cucumbers

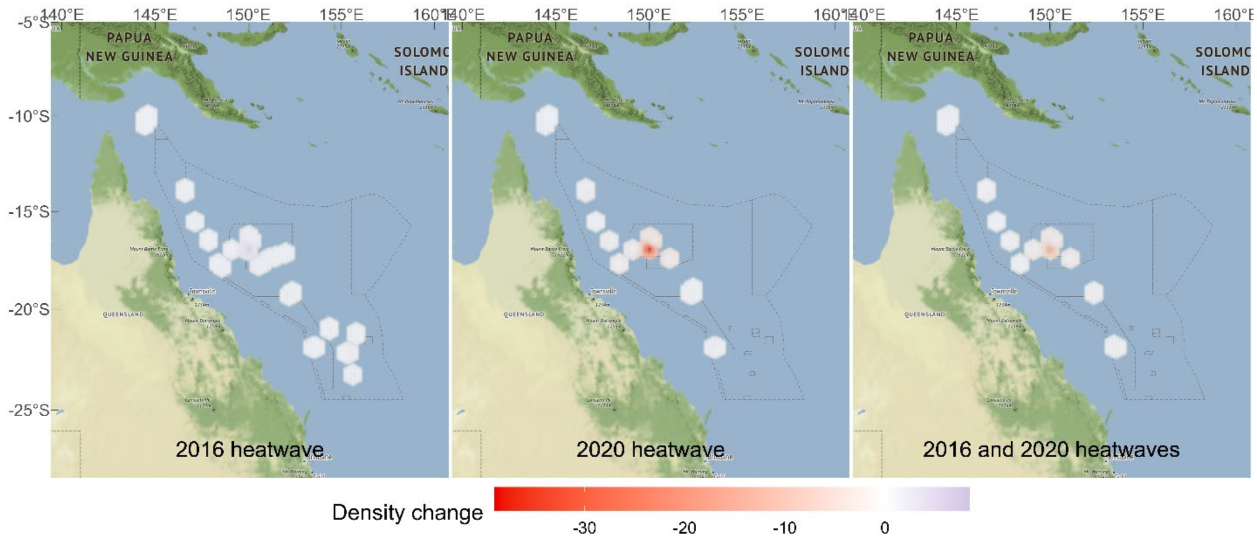

Figure 32. Change in sea cucumber density (number of individuals per 100 m^2) over two heatwave events. Data in the left map show change in sea cucumber density from pre 2016 surveys to those between 2016 and 2020 (i.e. mean sea cucumber density at each site in 2017-2020 minus mean density pre 2016). Middle map shows change in sea cucumber density from post 2020 surveys minus 2017-2020 values, while right map shows overall net change in sea cucumber density per site from pre 2016 surveys to post 2020 surveys. Reds represent a reduction in sea cucumber density through time and blues an increase.

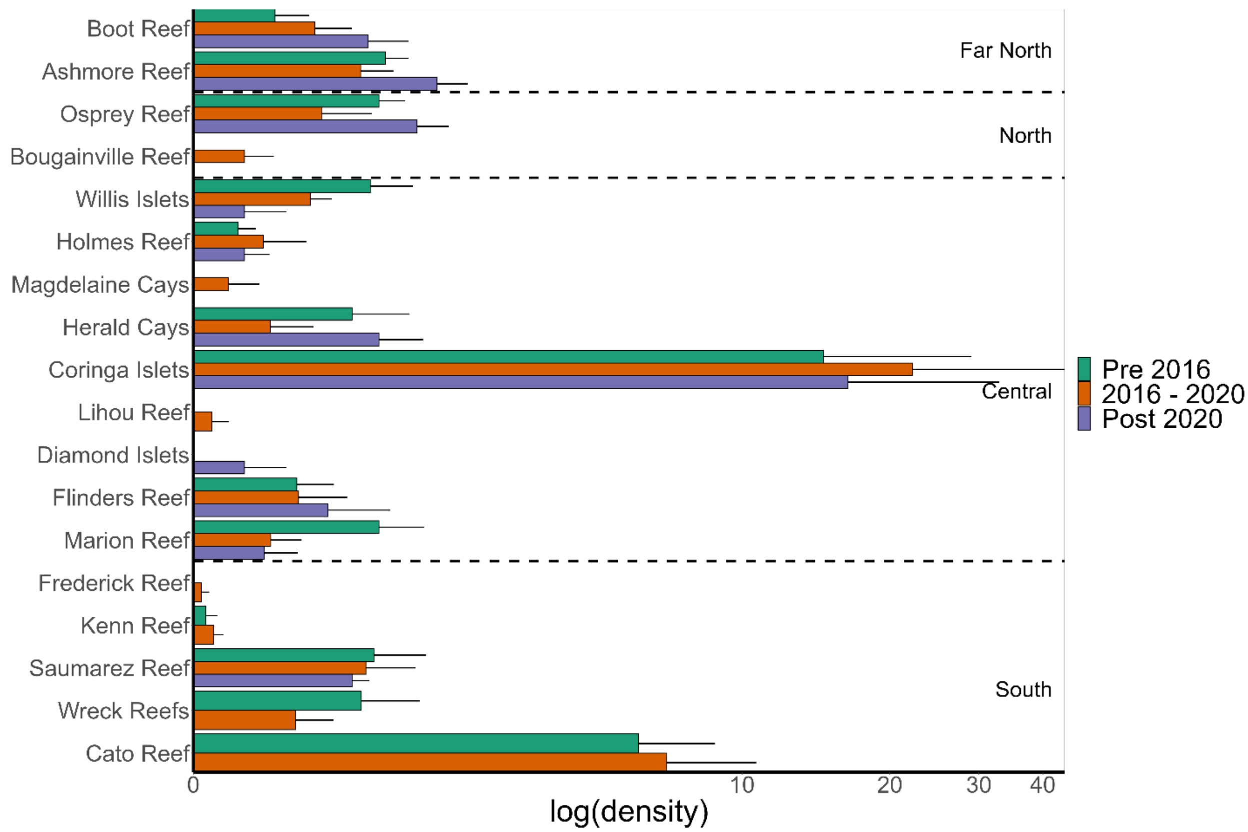

Figure 33. Log density (individuals per 100 m^2) of sea cucumbers in 18 reefs in four regions of the Coral Sea. Error bars represent ± 1 SE of the mean site-level density. Sea cucumber density varied by reef ($p < 0.001$), but not with time period. See Table 10 for full statistics.

Sea cucumber densities remained exceptionally stable through both periods of investigation (Figure 32 and Figure 33). The only major exception was a decline at Willis Islets, where the population decreased in both periods. This decline may be fishing related as Willis Islets remains open to sea cucumber extraction, whereas other nearby islands (Magdelaine, Coringa and Herald) remain closed.

Discussion

The goals of this report were to assess change in reef ecological condition and natural values across the Coral Sea Marine Park, as observed through three Park-wide surveys by Reef Life Survey teams. Analysis of survey data allowed (a) changes in reef biodiversity through time to be partitioned among reefs surveyed in recently declared Habitat Protection and National Park zones (2018) as well as IUCN Ia and II zones from the previous Coral Sea Commonwealth Marine Reserve; and (b) the ecological impacts of the 2020 heatwave (and associated coral bleaching event) to be compared with changes resulting from the 2016 heatwave, and overall net change in reef fish and invertebrate communities from 2012 to 2021. The results indicate that:

1. Regional-scale biodiversity change most likely associated with environmental conditions (heatwaves and associated bleaching) dominated responses of reef communities and overwhelmed any potential signals of management zone-related change; and
2. Reef communities exhibited substantially different responses to the 2016 and 2020 heatwaves. These responses differed not only in terms of the spatial footprint of changing coral cover, but also in the direction and magnitude of changes in reef fish and invertebrate communities.

Effects of marine protected areas on reef biodiversity are typically first observed in fish communities, for example through changes in the biomass of large fishes and top predators (such as sharks and jacks) (Edgar et al., 2014, Coleman et al., 2015). In this study, the majority of fish metrics appeared to capture a consistent signal of decline through time and across the CSMP, including total fish biomass, the biomass of large fishes (B20), sharks and herbivorous fishes. No statistically significant difference in these changes was attributable to the three zone types considered. In combination with the consistency in change among metrics, this suggests broad regional drivers of change, rather than local ecological responses, including to particular management strategies.

Spatial patterns among zones in the Coral Sea have previously been reported (Edgar et al., 2015), in which reef sites in the former IUCN Ia zones at Coringa-Herald and Lihou supported 71% more large fish biomass and 94% more sharks compared to similar reefs outside these zones where fishing was allowed. In this assessment of change through this timeframe across the whole of CSMP, fish biomass declined within these zones, at rates equivalent to (and sometimes greater than) reefs in Habitat Protection Zones and recently declared National Park Zones (2018 management plan). A lack of management response in terms of change through time should not be unexpected, however, as fishing pressure is considered low throughout the CSMP, and new zones have not been in place for sufficient time to accrue substantial benefits of protection.

Regardless of the causes, the observed declines in key metrics of reef fish ecological condition are concerning, as they indicate erosion of the natural values that make the CSMP globally unique. Declines in sharks on reefs where formerly abundant is a particular concern, with the CSMP one of the global hotspots for shark diversity and biomass (Edgar et al., 2017b). Although causes for the fish declines are unknown and could relate to factors other than fishing (see below), declines in sharks potentially relate to illegal, unreported and unregulated (IUU) fishing. **A management recommendation is thus to further investigate potential for illegal fishing for sharks, and other causes of decline in fishes more broadly. Such investigation should include obtaining a better understanding of the amount and patterns of recreational fishing pressure across the CSMP, and more targeted species-level analyses of the RLS and JCU reef monitoring datasets.**

The second key outcome of these analyses was that the two major heatwaves spanned by surveys had very different impacts on reef communities. Differences in the spatial footprint of thermal anomalies and residual impacts of previous bleaching events may explain trends in coral cover change (see below) and potentially the 'homogenisation' of reef fish community structure (convergence on northern and southern fish communities towards structures more similar to the central region) (Hoey et al., 2021). Reverse trajectories of total reef fish biomass between the 2016 and 2020 bleaching events, patterns in herbivorous fish biomass change, and a 'cooling' of fish communities in the central reefs (i.e. reduced CTI values), however, collectively suggest that drivers of change may be more complicated than the 'simple' explanations associated with habitat loss (coral cover declines from bleaching mortality) and extreme temperatures (affecting distributions and abundance of resident species). Trends at Magdelaine Cays particularly illustrate this. These reefs are protected in a National Park Zone, experienced coral cover declines from the 2016 bleaching, but subsequent recovery, while declines in fish biomass, sharks, mobile invertebrate richness and CTI persisted.

Factors contributing to recent fish biomass decline in the CSMP thus remain speculative, although lags following bleaching events are possible, given delays of months to years between coral death and disintegration of coral structure (e.g. Glynn, 1994). Many fish species respond to the structural character of coral reefs for refuge rather than living coral as a food source (Wilson et al., 2008), while others capitalise on the surprisingly high productivity of small invertebrates on dead corals coated with turfs (Fraser et al., 2021). Heatwaves can also increase mobility of fishes, including large predatory species such as coral trout (Brown et al., 2021). Such uncertainty on the causes of biodiversity change makes it difficult to understand the extent to which management responses (through CSMP zoning or regulations associated with sources of human disturbance) may provide benefits and halt or reverse declines in condition. **A key recommendation is further investigation of the possible drivers of change in reef biodiversity across the region. Effective management likely needs better understanding about what is and is not presently manageable, but importantly, ongoing monitoring results need to be put into appropriate context in terms of agreed benchmarks of management success.**

Trends in hard coral cover across the CSMP appear more easily explainable by the spatial footprint of the 2016 and 2020 heatwaves and bleaching events as reefs showing largest coral declines were also most impacted by high temperatures (Stuart-Smith et al., 2018, Hoey et al., 2021). Total coral cover declines were most severe at reefs in the north following the 2016 event, with mean coral cover almost halving to ca. 10% at Osprey Reef and declining by a fifth to 18% at Ashmore Reef in the far north. Declines in central reefs and signs of declines in the south (which were confirmed and reported in Hoey et al., 2021) were observed following the 2020 heatwave, which led to an overall decline of 2.8% in live hard corals from pre 2016 heatwave to post 2020 heatwave.

Decreasing populations of coral taxa often relate to species' sensitivity to heat stress. Declines observed through the 2020 heatwave for coral taxa such as massive *Porites* may therefore stand out because cover of more heat-sensitive coral taxa (such as branching and tabular *Acropora*) was already low; i.e. losses of more sensitive taxa probably occurred prior to both the 2016 and 2020 heatwaves. Nevertheless, *Isopora palifera* appears sensitive to bleaching but was the dominant taxon in the far north and south regions in the pre-2016 surveys, declining to a rare taxon on the same reefs post-2020.

Moderate declines in coral cover around 2020 on southern Coral Sea reefs reported by Hoey et al. (2021) could not be confirmed for most reefs in our study, given that only Saumarez Reef was surveyed in the south in the post-2020 period. However, declines observed in this study at Saumarez from the 2020 heatwave were substantial, in line with results of Hoey et al (2021). Nevertheless, data from early surveys by RLS teams at Saumarez in 2013 indicated that coral cover had been increasing up until the 2020 heatwave and provide a different perspective on bleaching impact at this reef by suggesting the 2020 declines only marginally exceeded gains in the years preceding 2020. In other words, the presence of baseline data from 2013, in this case, indicates only minor net reductions associated with the 2020 heatwave, in the context of the cover observed only seven years prior. Even though post-2020 data were not available for other reefs in the south, increases in coral cover equivalent to those observed at Saumarez occurred across all the southern reefs surveyed by RLS from original surveys in 2013 to the 2016-2020 period.

It is therefore possible that the losses reported from the 2020 bleaching event for the four other surveyed reefs in the south are less severe when considered in the context of this longer time frame. Differences in interpretation of impacts illustrated by these different baseline years (the 'shifting baselines' phenomenon) of course apply more broadly, in that the magnitude of impacts observed through CSMP surveys are all limited to the context of the last decade, and may appear more or less severe in the context of the last 20-40 years, for example. This is unavoidable given the relatively short time the Coral Sea reefs have been studied in comparison to the nearby Great Barrier Reef. **Given prior RLS surveys of reefs in the south provide context also spanning the 2016 bleaching event, a further recommendation in this report is to survey the other southern**

reefs within two years. This would allow future studies to better assess CSMP-wide changes spanning the 2020 heatwave. Ongoing monitoring should be continued across the full span of the CSMP at an interval of 3-5 years.

Also related to shifting baselines, Ashmore and Boot Reef have previously been identified as 'bright spots' (Hoey et al., 2021), in large part due to the high biomass of fishes including sharks observed in 2018 surveys. Although total fish and shark biomass tended to decline through the decadal period of investigation at Ashmore and Boot Reefs, these reefs still remain relatively pristine by global standards, with Boot Reef maintaining the highest fish biomass across the CSMP. However, fish biomass observed in 2018 surveys, from which the original 'bright spots' categorisation was made, followed a substantial increase in total and large fish biomass that accompanied the 2016 heatwave. Surveys by RLS teams recorded ~48% increase in fish biomass at Ashmore and Boot Reefs from 2015 to 2016 (post-heatwave), and declines in sharks, B20 and total fish biomass since then. In post-2020 surveys, such values were below pre-2016 values at both reefs, which could potentially tarnish the status of these reefs as bright spots. More positively, coral cover did not decrease at these remote northern reefs over time, but rather showed minor (non-significant) increase.

Because of its extremely large area and great distance from any populated settlement (other than the small meteorological station at Willis Island), the Coral Sea Marine Park provides refuge to globally significant populations of many threatened taxa that have been overexploited to the point of local extirpation elsewhere. Included amongst these taxa are species of sea cucumber, giant clam, turtle, shark and bony fish. Threatened reef species surveyed on CSMP reefs showed inconsistent changes through time, largely a consequence of small population density and stochastic sightings, nevertheless no threatened species showed a consistent and substantial decline.

The CSMP also hosts large populations of several sea snake species. These persisted through the period of study, albeit with a major decline coincident with the 2016 heatwave at the reef with highest initial densities (Marion Reef), then subsequent stability (Edgar et al., 2020). A critical outstanding scientific question relates to the identity of drivers of sea snake loss, including the absence of these reptiles from reefs across the central region.

With respect to possible management actions to safeguard biodiversity values across the full span of the CSMP, priority should be given to safeguarding a reef ecosystem within the far north region as an IUCN II reserve. This is currently the only region within the CSMP lacking a highly protected reef. The fauna recorded on Ashmore and Boot reefs reflects a unique combination of regional species and geomorphic types, and includes species present in the more sheltered lagoonal habitats of the networked continental shelf reefs and species more typical of highly exposed and isolated oceanic reefs. Due to proximity to the Coral Triangle, just to the north, a rich Indo-Pacific reef assemblage is present that is more diverse than elsewhere in the CSMP. Importantly, large predators remain highly abundant despite the reefs being open to fishing, their remoteness likely protecting them from overexploitation. Prevailing currents are expected to provide good connectivity with the reefs nearby, both on the shelf and in the Coral Sea. Their seemingly intact community structure also suggests the potential for high resilience from heating stress.

Thus, through the longer term as the Management Plan is reviewed, we recommend consideration be given to fully protecting the ecosystem at Boot Reef. This is the obvious location for a sanctuary zone in the far north as smaller and more remote than Ashmore Reef, isolated from other reefs by deep water, and with highest shark biomass in the CSMP. Shark densities at Boot Reef were only exceeded by densities at the Kermadecs Islands amongst Pacific nations investigated by Reef Life Survey divers (Edgar et al., 2017a), indicating that this reef comprises one of the few remaining locations across the Pacific with a near intact food web, including a full complement of higher predators.

This recommended change to zoning should only occur with the support of Mer Traditional Owners, who need to be engaged well before Management Plan review. Although some loss of fishing grounds would occur with a zoning change, multiple benefits would accrue, including potential for high-end dive tourism with divers worldwide attracted to accessible reefs with near-pristine shark numbers and a full range of coral habitats, and greater recognition of sea country ownership leading to co-management opportunities.

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Appendices

Survey sites

Table 1. Survey site details and the number of surveys perform at each site each time period. Pre = 2012-2016, Mid = 2016-2020, and Post = 2021-2021

Site code	Reef name	Region	Latitude	Longitude	Pre	Mid	Post
CS189	Ashmore Reef	far north	-10.447	144.4335	2	2	4
CS185	Ashmore Reef	far north	-10.4453	144.4492	2	2	4
CS187	Ashmore Reef	far north	-10.4414	144.4529	2	2	4
CS188	Ashmore Reef	far north	-10.4412	144.4302	2	2	4
CS186	Ashmore Reef	far north	-10.4342	144.4524	2	2	4
CS192	Ashmore Reef	far north	-10.3766	144.5328	2	-	4
CS191	Ashmore Reef	far north	-10.3745	144.5339	2	2	4
CS190	Ashmore Reef	far north	-10.2992	144.5215	2	2	-
CS198	Ashmore Reef	far north	-10.2326	144.5868	2	2	-
CS197	Ashmore Reef	far north	-10.2273	144.5896	2	2	-
CS195	Ashmore Reef	far north	-10.2177	144.5954	2	2	-
CS212	Ashmore Reef	far north	-10.1459	144.5701	2	2	-
CS211	Ashmore Reef	far north	-10.1441	144.5763	2	2	-
CS199	Ashmore Reef	far north	-10.1433	144.4407	2	-	2
CS200	Ashmore Reef	far north	-10.1156	144.4578	2	2	2
CS204	Boot Reef	far north	-10.1051	144.6851	2	1	2
CS201	Ashmore Reef	far north	-10.0761	144.4715	2	-	2
CS193	Boot Reef	far north	-10.0388	144.692	2	2	4
CS194	Boot Reef	far north	-10.0348	144.6989	2	-	2
CS208	Boot Reef	far north	-9.98877	144.6913	2	2	2
CS205	Boot Reef	far north	-9.98595	144.6792	1	-	1
CS209	Boot Reef	far north	-9.97456	144.694	3	2	4
CS207	Boot Reef	far north	-9.96837	144.6946	1	2	3
CS175	Bougainville Reef	north	-15.4908	147.0872	2	2	2
CS173	Bougainville Reef	north	-15.4889	147.1072	2	2	2
CS171	Bougainville Reef	north	-15.4886	147.0903	2	2	-
CS174	Bougainville Reef	north	-15.4843	147.1076	2	2	2
CS172	Bougainville Reef	north	-15.4825	147.0993	2	2	2
CS176	Bougainville Reef	north	-15.4814	147.1045	2	2	2
CS178	Osprey Reef	north	-13.9938	146.6907	2	2	2
CS177	Osprey Reef	north	-13.9856	146.6914	2	2	2
CS179	Osprey Reef	north	-13.9756	146.6755	2	2	2
CS180	Osprey Reef	north	-13.9669	146.6672	2	2	2
CS181	Osprey Reef	north	-13.9662	146.6806	2	2	2

Site code	Reef name	Region	Latitude	Longitude	Pre	Mid	Post
CS157	Osprey Reef	north	-13.8954	146.5576	2	2	-
CS155	Osprey Reef	north	-13.8914	146.5531	2	2	2
CS182	Osprey Reef	north	-13.8903	146.5725	2	2	2
CS183	Osprey Reef	north	-13.8872	146.5673	2	2	2
CS156	Osprey Reef	north	-13.883	146.5624	2	2	2
CS158	Osprey Reef	north	-13.87	146.5777	2	2	2
CS153	Osprey Reef	north	-13.8554	146.6246	2	2	2
CS154	Osprey Reef	north	-13.854	146.6254	2	2	2
CS184	Osprey Reef	north	-13.8012	146.5461	2	1	2
CS1	Marion Reef	central	-19.297	152.2352	2	8	-
CS3	Marion Reef	central	-19.2848	152.2208	2	8	-
CS2	Marion Reef	central	-19.2844	152.212	2	8	-
CS232	Marion Reef	central	-19.2586	152.3479	-	4	2
CS6	Marion Reef	central	-19.258	152.3418	2	8	2
CS5	Marion Reef	central	-19.2532	152.3482	2	8	2
CS219	Marion Reef	central	-19.2429	152.3554	-	4	2
CS4	Marion Reef	central	-19.2303	152.3259	2	8	2
CS233	Marion Reef	central	-19.1766	152.2663	-	2	2
CS234	Marion Reef	central	-19.1662	152.2712	-	2	2
CS7	Marion Reef	central	-19.1254	152.3881	2	8	2
CS8	Marion Reef	central	-19.0953	152.3871	2	8	2
CS220	Marion Reef	central	-18.9867	152.3451	-	2	2
CS221	Marion Reef	central	-18.9855	152.3412	-	4	2
CS122	Flinders Reef	central	-17.8772	148.5117	2	2	-
CS123	Flinders Reef	central	-17.829	148.5051	2	2	-
CS113	Diamond Islets	central	-17.7747	150.6328	2	2	-
CS126	Flinders Reef	central	-17.7167	148.4387	2	2	2
CS127	Flinders Reef	central	-17.7151	148.4373	2	2	2
CS125	Flinders Reef	central	-17.7142	148.4445	2	-	2
CS111	Diamond Islets	central	-17.713	150.7345	2	2	-
CS110	Diamond Islets	central	-17.7118	150.7369	2	2	-
CS128	Flinders Reef	central	-17.7058	148.4606	2	2	2
CS129	Flinders Reef	central	-17.703	148.4618	2	2	2
CS103	Diamond Islets	central	-17.4353	151.0703	2	2	2
CS104	Diamond Islets	central	-17.4347	151.0713	1	2	-
CS102	Diamond Islets	central	-17.417	151.0713	2	2	2
CS101	Diamond Islets	central	-17.4143	151.0726	2	2	-
CS100	Lihou Reef	central	-17.3584	151.5299	2	2	-
CS92	Lihou Reef	central	-17.1253	152.0759	2	2	-
CS170	Lihou Reef	central	-17.119	152.0003	1	2	-
CS95	Lihou Reef	central	-17.1168	152.0008	2	2	-
CS94	Lihou Reef	central	-17.116	151.9976	1	2	-

Site code	Reef name	Region	Latitude	Longitude	Pre	Mid	Post
CS96	Lihou Reef	central	-17.1137	151.9606	2	2	-
CS17	Coringa Islets	central	-16.9716	149.9048	2	2	-
CS18	Coringa Islets	central	-16.9613	149.9055	2	2	-
CS10	Herald Cays	central	-16.9478	149.1826	2	2	-
CS134	Coringa Islets	central	-16.9366	150.0009	2	2	2
CS11	Herald Cays	central	-16.9365	149.197	2	2	2
CS14	Coringa Islets	central	-16.9357	149.9941	2	-	2
CS132	Coringa Islets	central	-16.9316	149.9904	2	2	-
CS130	Coringa Islets	central	-16.9313	149.999	2	2	2
CS131	Coringa Islets	central	-16.9301	150.002	2	2	2
CS12	Herald Cays	central	-16.9301	149.1933	2	2	1
CS13	Herald Cays	central	-16.9282	149.2023	2	2	2
CS16	Coringa Islets	central	-16.9225	150.0114	2	2	-
CS15	Coringa Islets	central	-16.9225	150.0065	2	2	-
CS9	Herald Cays	central	-16.9219	149.2	2	2	2
CS139	Magdelaine Cays	central	-16.5338	150.2685	2	2	2
CS140	Magdelaine Cays	central	-16.5309	150.2697	2	2	2
CS141	Magdelaine Cays	central	-16.521	150.2771	2	2	2
CS147	Holmes Reef	central	-16.5127	147.8403	2	2	-
CS148	Holmes Reef	central	-16.5081	147.8402	2	2	2
CS149	Holmes Reef	central	-16.5049	147.8414	2	2	2
CS146	Holmes Reef	central	-16.4997	147.8435	2	2	2
CS150	Holmes Reef	central	-16.4949	147.8493	2	2	2
CS151	Holmes Reef	central	-16.4759	147.8661	2	2	-
CS152	Holmes Reef	central	-16.4682	147.8647	2	2	-
CS143	Willis Islets	central	-16.2991	149.9629	2	2	2
CS145	Willis Islets	central	-16.2927	149.9614	2	2	2
CS144	Willis Islets	central	-16.286	149.9596	2	2	-
CS22	Cato Reef	south	-23.2549	155.5546	2	2	-
CS21	Cato Reef	south	-23.2529	155.5516	2	2	-
CS20	Cato Reef	south	-23.2473	155.5348	2	2	-
CS24	Cato Reef	south	-23.2447	155.5423	2	2	-
CS25	Cato Reef	south	-23.244	155.5489	2	2	-
CS23	Cato Reef	south	-23.2404	155.557	2	2	-
CS41	Wreck Reefs	south	-22.1977	155.2944	2	2	-
CS39	Wreck Reefs	south	-22.1899	155.3555	2	4	-
CS42	Wreck Reefs	south	-22.186	155.176	2	2	-
CS38	Wreck Reefs	south	-22.1859	155.3558	2	4	-
CS36	Wreck Reefs	south	-22.1854	155.3617	2	4	-
CS31	Wreck Reefs	south	-22.1768	155.474	2	4	-
CS44	Wreck Reefs	south	-22.1763	155.1646	2	2	-
CS45	Wreck Reefs	south	-22.1758	155.178	2	2	-

Site code	Reef name	Region	Latitude	Longitude	Pre	Mid	Post
CS32	Wreck Reefs	south	-22.1731	155.477	2	4	-
CS34	Wreck Reefs	south	-22.1708	155.4546	1	2	-
CS35	Wreck Reefs	south	-22.1687	155.4508	2	4	-
CS33	Wreck Reefs	south	-22.1636	155.4538	2	4	-
CS50	Saumarez Reef	south	-21.9174	153.5797	2	2	2
CS51	Saumarez Reef	south	-21.9163	153.5867	2	2	2
CS48	Saumarez Reef	south	-21.8973	153.5376	2	2	2
CS47	Saumarez Reef	south	-21.8966	153.5435	2	2	2
CS46	Saumarez Reef	south	-21.8517	153.5212	2	-	2
CS52	Kenn Reef	south	-21.2571	155.7542	2	2	-
CS55	Kenn Reef	south	-21.2535	155.7609	2	4	-
CS54	Kenn Reef	south	-21.2507	155.7583	2	4	-
CS56	Kenn Reef	south	-21.248	155.7636	2	4	-
CS57	Kenn Reef	south	-21.2454	155.765	2	4	-
CS61	Kenn Reef	south	-21.2087	155.7698	2	3	-
CS59	Kenn Reef	south	-21.2037	155.7659	2	2	-
CS60	Kenn Reef	south	-21.2028	155.7728	2	4	-
CS58	Kenn Reef	south	-21.1999	155.7658	2	4	-
CS72	Frederick Reef	south	-21.0204	154.3727	2	4	-
CS71	Frederick Reef	south	-21.0203	154.3699	2	4	-
CS65	Frederick Reef	south	-21.0065	154.392	2	2	-
CS63	Frederick Reef	south	-21.0003	154.3944	2	2	-
CS64	Frederick Reef	south	-20.9979	154.3937	2	2	-
CS73	Frederick Reef	south	-20.937	154.3957	2	4	-
CS74	Frederick Reef	south	-20.9362	154.3972	2	4	-

Table 2. ANOVA output results of the Live Hard coral cover (%) by reef and time period (Pre 2016, 2016 to 2020, and Post 2020). For plot see Figure 5.

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Live Hard Coral cover	Reef	16	18055.81	1128.488	7.394	<.001***
	Time period	2	243.573	121.787	0.798	0.451
	Reef*Time period	24	1499.954	62.498	0.409	0.994
	Residuals	265	40447.01	152.63		

Table 3. ANOVA output results of the log fish biomass by reef and time period (Pre 2016, 2016 to 2020, and Post 2020). For plot see Figure 9.

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Biomass (log, kg)	Reef	17	62.735	3.69	7.592	<.001***
	Time period	2	7.708	3.854	7.928	<.001***
	Reef*Time period	29	7.995	0.276	0.567	0.966
	Residuals	298	144.852	0.486		

Table 4. PERMANOVA output of fish community structure by region and time period (Pre 2016, 2016 to 2020, and Post 2020). For nMDS plot see Figure 11.

Factor	Df	Sum Sq	Mean Sq	F value	p value
Region	3	13.394	4.465	24.902	<.001***
Time period	2	1.779	0.889	4.961	<.001***
Region*Time period	6	2.291	0.382	2.13	<.001***
Residuals	335	60.059	0.179		
Total	346	77.523			

Table 5. ANOVA output results of log large fish biomass (B20) by Reef and time period (Pre 2016, 2016 to 2020, and Post 2020). For plot see Figure 15.

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Biomass (log, kg)	Reef	17	88.394	5.2	5.831	<.001***
	Time period	2	8.094	4.047	4.538	0.011*
	Reef*Time period	29	17.842	0.615	0.69	0.886
	Residuals	298	265.753	0.892		

Table 6. ANOVA output results of log herbivorous fish biomass by Reef and time period (Pre 2016, 2016 to 2020, and Post 2020). for plot, see Figure 20.

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Biomass (log, kg)	Reef	17	59.554	3.503	6.957	<.001***
	Time period	2	6.857	3.428	6.809	0.001**
	Reef*Time period	29	12.114	0.418	0.83	0.721
	Residuals	298	150.055	0.504		

Table 7. ANOVA output results of log shark biomass by Reef and time period (Pre 2016, 2016 to 2020, and Post 2020).

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Biomass (log, kg)	Reef	17	117.544	6.914	2.259	0.003**
	Time period	2	9.255	4.628	1.512	0.222
	Reef*Time period	29	75.008	2.586	0.845	0.699
	Residuals	298	912.272	3.061		

Table 8. ANOVA output results of log macroinvertebrate richness by Reef and time period (Pre 2016, 2016 to 2020, and Post 2020). For plot, see Figure 23.

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Species richness	Reef	17	171.44	10.085	4.31	<.001***
	Time period	2	19.868	9.934	4.246	0.015*
	Reef*Time period	29	198.686	6.851	2.928	<.001***
	Residuals	298	697.258	2.34		

Table 9. ANOVA output results of log urchin density (number of individuals per 100 m^2) by Reef and time period (Pre 2016, 2016 to 2020, and Post 2020).

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Density (log)	Reef	17	652.853	38.403	53.046	<.001***
	Time period	2	3.197	1.599	2.208	0.112
	Reef*Time period	29	35.855	1.236	1.708	0.015*
	Residuals	298	215.738	0.724		

Table 10. ANOVA output results of log sea cucumber density (number of individuals per 100 m^2) by Reef and time period (Pre 2016, 2016 to 2020, and Post 2020). For plot, see Figure 33.

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Density (log)	Reef	17	35.162	2.068	5.105	<.001***
	Time period	2	1.359	0.68	1.677	0.189
	Reef*Time period	29	4.527	0.156	0.385	0.999
	Residuals	298	120.73	0.405		

Table 11. ANOVA output results of log sea snake density (number of individuals per 100 m^2) by Reef and time period (Pre 2016, 2016 to 2020, and Post 2020).

Variable	Factor	Df	Sum Sq	Mean Sq	F value	p value
Density (log)	Reef	17	24.829	1.461	14.59	<.001***
	Time period	2	0.193	0.097	0.966	0.382
	Reef*Time period	29	4.223	0.146	1.455	0.066
	Residuals	298	29.832	0.1		

Table 12. List of species listed as threatened under the EPBC Act

Species	Class	# sites observed
Chelonia mydas	Reptilia	11
Eretmochelys imbricata	Reptilia	9
Caretta caretta	Reptilia	1
Natator depressus	Reptilia	1

Table 13. List of IUCN threatened species and the number of sites at which they were observed.

Species	Class	IUCN status	# sites observed
Oxymonacanthus longirostris	Actinopterygii	Vulnerable	54
Cheilinus undulatus	Actinopterygii	Endangered	44
Ecsenius tigris	Actinopterygii	Vulnerable	24
Epinephelus polyphekadion	Actinopterygii	Vulnerable	19
Bolbometopon muricatum	Actinopterygii	Vulnerable	16
Plectropomus areolatus	Actinopterygii	Vulnerable	4
Coris bulbifrons	Actinopterygii	Vulnerable	1
Acropora paniculata	Anthozoa	Vulnerable	14
Montipora crassituberculata	Anthozoa	Vulnerable	13
Physogyra lichtensteini	Anthozoa	Vulnerable	13
Acropora polystoma	Anthozoa	Vulnerable	9
Acropora listeri	Anthozoa	Vulnerable	8
Turbinaria reniformis	Anthozoa	Vulnerable	8
Montipora caliculata	Anthozoa	Vulnerable	7
Acropora verweyi	Anthozoa	Vulnerable	6
Turbinaria mesenterina	Anthozoa	Vulnerable	5
Acropora microclados	Anthozoa	Vulnerable	4
Acropora vaughani	Anthozoa	Vulnerable	4
Turbinaria stellulata	Anthozoa	Vulnerable	4
Acanthastrea brevis	Anthozoa	Vulnerable	3
Acanthastrea hemprichii	Anthozoa	Vulnerable	3
Isopora cuneata	Anthozoa	Vulnerable	3
Pavona bipartita	Anthozoa	Vulnerable	3

Species	Class	IUCN status	# sites observed
Pocillopora danae	Anthozoa	Vulnerable	3
Acropora aculeus	Anthozoa	Vulnerable	2
Acropora caroliniana	Anthozoa	Vulnerable	2
Acropora globiceps	Anthozoa	Vulnerable	2
Astreopora cucullata	Anthozoa	Vulnerable	2
Galaxea astreata	Anthozoa	Vulnerable	2
Heliofungia actiniformis	Anthozoa	Vulnerable	2
Isopora brueggemanni	Anthozoa	Vulnerable	2
Pavona decussata	Anthozoa	Vulnerable	2
Pavona venosa	Anthozoa	Vulnerable	2
Platygyra yaeyamaensis	Anthozoa	Vulnerable	2
Turbinaria peltata	Anthozoa	Vulnerable	2
Acropora abrolhosensis	Anthozoa	Vulnerable	1
Acropora anthocercis	Anthozoa	Vulnerable	1
Acropora echinata	Anthozoa	Vulnerable	1
Acropora lovelli	Anthozoa	Vulnerable	1
Leptoseris yabei	Anthozoa	Vulnerable	1
Lobophyllia dentatus	Anthozoa	Vulnerable	1
Montipora australiensis	Anthozoa	Vulnerable	1
Montipora capricornis	Anthozoa	Vulnerable	1
Montipora corbettensis	Anthozoa	Vulnerable	1
Seriatopora dendritica	Anthozoa	Vulnerable	1
Triaenodon obesus	Elasmobranchii	Vulnerable	73
Carcharhinus amblyrhynchos	Elasmobranchii	Endangered	68
Carcharhinus albimarginatus	Elasmobranchii	Vulnerable	10
Pateobatis fai	Elasmobranchii	Vulnerable	3
Aetobatus ocellatus	Elasmobranchii	Vulnerable	2
Carcharhinus melanopterus	Elasmobranchii	Vulnerable	1
Nebrius ferrugineus	Elasmobranchii	Vulnerable	1
Urogymnus asperrimus	Elasmobranchii	Vulnerable	1
Thelenota ananas	Holothuroidea	Endangered	27
Holothuria whitmaei	Holothuroidea	Endangered	16
Actinopyga miliaris	Holothuroidea	Vulnerable	6
Holothuria nobilis	Holothuroidea	Endangered	5
Actinopyga mauritiana	Holothuroidea	Vulnerable	4
Chelonia mydas	Reptilia	Endangered	8
Eretmochelys imbricata	Reptilia	Critically endangered	7
Caretta caretta	Reptilia	Vulnerable	1

Table 14. Species list and frequency of observation at a site.

Species	Class	# sites	Species	Class	# sites
Ctenochaetus striatus	Actinopterygii	222	***Neopomacentrus bankieri***	Actinopterygii	1
Gomphosus varius	Actinopterygii	222	***Neopomacentrus cyanomos***	Actinopterygii	1
Labroides dimidiatus	Actinopterygii	222	***Ogilbyina queenslandiae***	Actinopterygii	1
Acanthurus nigrofuscus	Actinopterygii	212	***Ostorhinchus apogonoides***	Actinopterygii	1
Zanclus cornutus	Actinopterygii	209	***Ostorhinchus cavitensis***	Actinopterygii	1
Parupeneus multifasciatus	Actinopterygii	207	***Ostorhinchus compressus***	Actinopterygii	1
Halichoeres hortulanus	Actinopterygii	204	***Ostorhinchus taeniophorus***	Actinopterygii	1
Thalassoma lutescens	Actinopterygii	202	***Oxycheilinus bimaculatus***	Actinopterygii	1
Chromis margaritifer	Actinopterygii	200	***Oxycheilinus celebicus***	Actinopterygii	1
Chlorurus sordidus	Actinopterygii	197	***Paracaesio sordida***	Actinopterygii	1
Forcipiger flavissimus	Actinopterygii	195	***Parapercis schauinslandii***	Actinopterygii	1
Anampses neoguinaicus	Actinopterygii	194	***Parapercis xanthozona***	Actinopterygii	1
Plectroglyphidodon lacrymatus	Actinopterygii	193	***Parupeneus indicus***	Actinopterygii	1
Halichoeres biocellatus	Actinopterygii	191	***Pentapodus paradiseus***	Actinopterygii	1
Thalassoma hardwicke	Actinopterygii	191	***Pervagor melanocephalus***	Actinopterygii	1
Chaetodon pelewensis	Actinopterygii	190	***Phyllogobius platycephalops***	Actinopterygii	1
Pomacentrus vaiuli	Actinopterygii	183	***Platax boersii***	Actinopterygii	1
Naso lituratus	Actinopterygii	178	***Plectropomus oligacanthus***	Actinopterygii	1
Oxycheilinus unifasciatus	Actinopterygii	178	***Pomacanthus semicirculatus***	Actinopterygii	1
Paracirrhites arcatus	Actinopterygii	175	***Pomacentrus nagasakiensis***	Actinopterygii	1
Chlorurus microrhinos	Actinopterygii	169	***Pomacentrus tripunctatus***	Actinopterygii	1
Dascyllus reticulatus	Actinopterygii	168	***Premnas biaculeatus***	Actinopterygii	1
Lutjanus bohar	Actinopterygii	168	***Pristicon trimaculatus***	Actinopterygii	1
Pseudocheilinus hexataenia	Actinopterygii	168	***Pseudanthias pictilis***	Actinopterygii	1
Chromis iomelas	Actinopterygii	167	***Pseudanthias pleurotaenia***	Actinopterygii	1
Plectropomus laevis	Actinopterygii	165	***Pseudanthias rubrizonatus***	Actinopterygii	1
Hemigymnus fasciatus	Actinopterygii	162	***Pseudochromis cyanotaenia***	Actinopterygii	1
Zebrasoma velifer	Actinopterygii	162	***Ptereleotris heteroptera***	Actinopterygii	1
Labroides bicolor	Actinopterygii	156	***Pterocaesio pisang***	Actinopterygii	1
Monotaxis grandoculis	Actinopterygii	156	***Rhinecanthus lunula***	Actinopterygii	1
Centropyge vrolikii	Actinopterygii	155	***Rhinecanthus verrucosus***	Actinopterygii	1
Chaetodon citrinellus	Actinopterygii	153	***Salarias fasciatus***	Actinopterygii	1
Plectroglyphidodon johnstonianus	Actinopterygii	152	***Sargocentron tiereoides***	Actinopterygii	1
Zebrasoma scopas	Actinopterygii	152	***Scolopsis margaritifer***	Actinopterygii	1
Caranx melampygus	Actinopterygii	151	***Scolopsis monogramma***	Actinopterygii	1
Canthigaster valentini	Actinopterygii	144	***Scomberoides tol***	Actinopterygii	1
Chaetodon plebeius	Actinopterygii	144	***Scomberomorus commerson***	Actinopterygii	1
Stegastes fasciolatus	Actinopterygii	144	***Scomberomorus queenslandicus***	Actinopterygii	1
Thalassoma amblycephalum	Actinopterygii	144	***Scorpaenodes parvipinnis***	Actinopterygii	1
Paracirrhites forsteri	Actinopterygii	142	***Scorpaenopsis oxycephala***	Actinopterygii	1
Chaetodon mertensii	Actinopterygii	139	***Selar crumenophthalmus***	Actinopterygii	1

Species	Class	# sites	Species	Class	# sites
Eviota guttata	Actinopterygii	138	***Selaroides leptolepis***	Actinopterygii	1
Myripristis kuntee	Actinopterygii	136	***Sphyraena helleri***	Actinopterygii	1
Scarus niger	Actinopterygii	136	***Sphyraena qenie***	Actinopterygii	1
Ctenochaetus binotatus	Actinopterygii	135	***Stegastes apicalis***	Actinopterygii	1
Chaetodon lunulatus	Actinopterygii	134	***Stegastes lividus***	Actinopterygii	1
Macropharyngodon meleagris	Actinopterygii	134	***Synchiropus bartelsi***	Actinopterygii	1
Naso tonganus	Actinopterygii	132	***Synchiropus moyeri***	Actinopterygii	1
Scarus chameleon	Actinopterygii	131	***Synodus jaculum***	Actinopterygii	1
Chromis agilis	Actinopterygii	129	***Taeniamia zosterophora***	Actinopterygii	1
Scarus altipinnis	Actinopterygii	128	***Thalassoma purpureum***	Actinopterygii	1
Chaetodon auriga	Actinopterygii	126	***Trimma capostriatum***	Actinopterygii	1
Chromis atripes	Actinopterygii	125	***Trimma nasa***	Actinopterygii	1
Naso unicornis	Actinopterygii	125	***Valenciennea longipinnis***	Actinopterygii	1
Pomacentrus philippinus	Actinopterygii	125	***Stylophora pistillata***	Anthozoa	88
Scarus longipinnis	Actinopterygii	124	***Pocillopora verrucosa***	Anthozoa	85
Thalassoma nigrofasciatum	Actinopterygii	124	***Corymbose Acropora corals***	Anthozoa	81
Acanthurus pyroferus	Actinopterygii	123	***Encrusting corals***	Anthozoa	80
Cephalopholis urodeta	Actinopterygii	122	***Porites lichen***	Anthozoa	74
Stethojulis bandanensis	Actinopterygii	121	***Sub-massive corals***	Anthozoa	73
Neoniphon sammara	Actinopterygii	117	***Porites Massive***	Anthozoa	72
Acanthurus lineatus	Actinopterygii	115	***Montipora Encrusting***	Anthozoa	69
Pygoplites diacanthus	Actinopterygii	115	***Isopora palifera***	Anthozoa	57
Macolor niger	Actinopterygii	114	***Goniastrea pectinata***	Anthozoa	52
Acanthurus nigricans	Actinopterygii	113	***Cyphastrea Submassive***	Anthozoa	49
Heniochus chrysostomus	Actinopterygii	113	***Favia stelligera***	Anthozoa	49
Arothron nigropunctatus	Actinopterygii	112	***Pavona varians***	Anthozoa	46
Chaetodon flavirostris	Actinopterygii	109	***Astreopora myriophthalma***	Anthozoa	45
Plectroglyphidodon dickii	Actinopterygii	109	***Acropora cerealis***	Anthozoa	41
Chromis vanderbilti	Actinopterygii	108	***Goniastrea edwardsi***	Anthozoa	35
Bodianus axillaris	Actinopterygii	106	***Pocillopora damicornis***	Anthozoa	35
Acanthochromis polyacanthus	Actinopterygii	105	***Porites vaughani***	Anthozoa	35
Acanthurus blochii	Actinopterygii	104	***Leptoria phrygia***	Anthozoa	34
Hipposcarus longiceps	Actinopterygii	104	***Leptastrea Submassive***	Anthozoa	33
Aphareus furca	Actinopterygii	103	***Massive corals***	Anthozoa	32
Chrysiptera taupou	Actinopterygii	103	***Coscinaraea columna***	Anthozoa	31
Ptereleotris evides	Actinopterygii	103	***Tabular Acropora corals***	Anthozoa	29
Chromis chrysura	Actinopterygii	102	***Favia pallida***	Anthozoa	27
Parupeneus cyclostomus	Actinopterygii	102	***Acropora loripes***	Anthozoa	26
Acanthurus nigricauda	Actinopterygii	101	***Montipora Submassive***	Anthozoa	25
Chaetodon kleinii	Actinopterygii	100	***Favites abdita***	Anthozoa	24
Chaetodon trifascialis	Actinopterygii	99	***Merulina ampliata***	Anthozoa	24
Ctenochaetus cyanocheilus	Actinopterygii	97	***Acropora humilis***	Anthozoa	23
Halichoeres trimaculatus	Actinopterygii	97	***Symphyllia recta***	Anthozoa	23

Species	Class	# sites	Species	Class	# sites
Chromis xanthura	Actinopterygii	96	***Acropora***	Anthozoa	22
Gnathodentex aureolineatus	Actinopterygii	96	***Favites Encrusting***	Anthozoa	22
Monotaxis heterodon	Actinopterygii	96	***Leptastrea Encrusting***	Anthozoa	22
Anampses twistii	Actinopterygii	94	***Echinopora lamellosa***	Anthozoa	21
Parupeneus pleurostigma	Actinopterygii	93	***Pocillopora meandrina***	Anthozoa	21
Sufflamen chrysopterum	Actinopterygii	92	***Acropora gemmifera***	Anthozoa	20
Scarus frenatus	Actinopterygii	89	***Acropora muricata***	Anthozoa	20
Thalassoma quinquevittatum	Actinopterygii	89	***Pocillopora eydouxi***	Anthozoa	20
Thalassoma lunare	Actinopterygii	88	***Acropora nasuta***	Anthozoa	19
Chromis lepidolepis	Actinopterygii	86	***Echinopora gemmacea***	Anthozoa	19
Chromis ternatensis	Actinopterygii	85	***Acropora longicyathus***	Anthozoa	18
Naso brevirostris	Actinopterygii	84	***Astrea curta***	Anthozoa	18
Scarus schlegeli	Actinopterygii	84	***Cyphastrea Encrusting***	Anthozoa	18
Chromis amboinensis	Actinopterygii	81	***Lobophyllia hemprichii***	Anthozoa	18
Myripristis berndti	Actinopterygii	81	***Porites cylindrica***	Anthozoa	18
Ostracion meleagris	Actinopterygii	81	***Porites Submassive***	Anthozoa	18
Centropyge flavissima	Actinopterygii	80	***Acropora austera***	Anthozoa	17
Cirrhilabrus punctatus	Actinopterygii	80	***Acropora valida***	Anthozoa	17
Pomacentrus bankanensis	Actinopterygii	80	***Pocillopora***	Anthozoa	17
Acanthurus dussumieri	Actinopterygii	79	***Porites rus***	Anthozoa	17
Chaetodon ephippium	Actinopterygii	79	***Seriatopora hystrix***	Anthozoa	17
Acanthurus olivaceus	Actinopterygii	78	***Acropora hyacinthus***	Anthozoa	16
Aprion virescens	Actinopterygii	78	***Fungia***	Anthozoa	16
Cephalopholis argus	Actinopterygii	77	***Acropora abrotanoides***	Anthozoa	15
Synodus variegatus	Actinopterygii	76	***Diploastrea heliopora***	Anthozoa	15
Chromis atripectoralis	Actinopterygii	75	***Favia matthaii***	Anthozoa	15
Pterocaesio tile	Actinopterygii	75	***Favia Submassive***	Anthozoa	15
Epinephelus merra	Actinopterygii	74	***Favites halicora***	Anthozoa	15
Oxycheilinus digramma	Actinopterygii	73	***Acropora cytherea***	Anthozoa	14
Oxycheilinus digramma	Actinopterygii	73	***Acropora lutkeni***	Anthozoa	14
Chaetodon ulietensis	Actinopterygii	71	***Acropora paniculata***	Anthozoa	14
Amblyglyphidodon curacao	Actinopterygii	70	***Acropora secale***	Anthozoa	14
Chaetodon melannotus	Actinopterygii	70	***Acropora tenuis***	Anthozoa	14
Coris gaimard	Actinopterygii	70	***Digitate corals (live)***	Anthozoa	14
Nemateleotris magnifica	Actinopterygii	70	***Favites Submassive***	Anthozoa	14
Abudefduf vaigiensis	Actinopterygii	69	***Montipora grisea***	Anthozoa	14
Gnatholepis cauerensis	Actinopterygii	69	***Solid plate corals***	Anthozoa	14
Naso vlamingii	Actinopterygii	68	***Acropora Bushy arborescent***	Anthozoa	13
Oxymonacanthus longirostris	Actinopterygii	68	***Acropora grandis***	Anthozoa	13
Parupeneus crassilabris	Actinopterygii	68	***Goniastrea retiformis***	Anthozoa	13
Acanthurus thompsoni	Actinopterygii	67	***Hydnophora exesa***	Anthozoa	13
Cheilodipterus macrodon	Actinopterygii	67	***Montipora crassituberculata***	Anthozoa	13
Coris aygula	Actinopterygii	67	***Physogyra lichtensteini***	Anthozoa	13

Species	Class	# sites		Species	Class	# sites
Bodianus mesothorax	Actinopterygii	66		***Acropora Staghorn***	Anthozoa	12
Chaetodon unimaculatus	Actinopterygii	65		***Isopora Encrusting***	Anthozoa	12
Mulloidichthys vanicolensis	Actinopterygii	65		***Pavona maldivensis***	Anthozoa	12
Pempheris oualensis	Actinopterygii	65		***Seriatopora caliendrum***	Anthozoa	12
Parapercis queenslandica	Actinopterygii	64		***Favites complanata***	Anthozoa	11
Pomacentrus coelestis	Actinopterygii	64		***Isopora Submassive***	Anthozoa	11
Chaetodon ornatissimus	Actinopterygii	63		***Pavona duerdeni***	Anthozoa	11
Dascyllus trimaculatus	Actinopterygii	63		***Acanthastrea echinata***	Anthozoa	10
Pomacentrus imitator	Actinopterygii	62		***Branching corals***	Anthozoa	10
Mulloidichthys flavolineatus	Actinopterygii	61		***Coscinaraea exesa***	Anthozoa	10
Cetoscarus ocellatus	Actinopterygii	60		***Foliose/Plate corals***	Anthozoa	10
Cheilinus undulatus	Actinopterygii	60		***Leptoseris mycetoseroides***	Anthozoa	10
Aulostomus chinensis	Actinopterygii	59		***Phymastrea magnistellata***	Anthozoa	10
Chromis weberi	Actinopterygii	58		***Platygyra sinensis***	Anthozoa	10
Macolor macularis	Actinopterygii	58		***Acropora polystoma***	Anthozoa	9
Cantherhines pardalis	Actinopterygii	57		***Echinopora horrida***	Anthozoa	9
Centropyge heraldi	Actinopterygii	57		***Galaxea fascicularis***	Anthozoa	9
Sargocentron caudimaculatum	Actinopterygii	57		***Goniastrea Submassive***	Anthozoa	9
Centropyge bicolor	Actinopterygii	56		***Montipora Solid plates***	Anthozoa	9
Cheilinus trilobatus	Actinopterygii	56		***Oxypora lacera***	Anthozoa	9
Epibulus insidiator	Actinopterygii	56		***Platygyra contorta***	Anthozoa	9
Paraluteres prionurus	Actinopterygii	56		***Acropora listeri***	Anthozoa	8
Eviota prasites	Actinopterygii	54		***Coeloseris mayeri***	Anthozoa	8
Myripristis violacea	Actinopterygii	54		***Favia rotumana***	Anthozoa	8
Balistapus undulatus	Actinopterygii	53		***Leptastrea pruinosa***	Anthozoa	8
Siganus argenteus	Actinopterygii	53		***Platygyra pini***	Anthozoa	8
Parupeneus barberinus	Actinopterygii	52		***Turbinaria reniformis***	Anthozoa	8
Pterocaesio marri	Actinopterygii	52		***Acropora florida***	Anthozoa	7
Chaetodon lineolatus	Actinopterygii	51		***Favia favus***	Anthozoa	7
Cheilinus chlorourus	Actinopterygii	51		***Gardineroseris planulata***	Anthozoa	7
Cheilodipterus quinquelineatus	Actinopterygii	51		***Leptastrea purpurea***	Anthozoa	7
Lutjanus kasmira	Actinopterygii	51		***Montipora caliculata***	Anthozoa	7
Amblyglyphidodon leucogaster	Actinopterygii	50		***Stony corals***	Anthozoa	7
Cirripectes stigmaticus	Actinopterygii	50		***Stylocoeniella guentheri***	Anthozoa	7
Stegastes nigricans	Actinopterygii	50		***Acropora granulosa***	Anthozoa	6
Cirrhitichthys falco	Actinopterygii	48		***Acropora selago***	Anthozoa	6
Acanthurus auranticavus	Actinopterygii	47		***Acropora verweyi***	Anthozoa	6
Caesio caerulaurea	Actinopterygii	47		***Astreopora gracilis***	Anthozoa	6
Helcogramma chica	Actinopterygii	47		***Astreopora Submassive***	Anthozoa	6
Hemitaurichthys polylepis	Actinopterygii	47		***Cyphastrea microphthalma***	Anthozoa	6
Labropsis australis	Actinopterygii	47		***Favia lizardensis***	Anthozoa	6
Pseudanthias squamipinnis	Actinopterygii	47		***Galaxea horrescens***	Anthozoa	6
Centropyge tibicen	Actinopterygii	46		***Goniopora Submassive***	Anthozoa	6

Species	Class	# sites		Species	Class	# sites
Chromis retrofasciata	Actinopterygii	46		***Montipora Foliose***	Anthozoa	6
Meiacanthus atrodorsalis	Actinopterygii	46		***Montipora nodosa***	Anthozoa	6
Scarus rubroviolaceus	Actinopterygii	46		***Montipora undata***	Anthozoa	6
Acanthurus nigroris	Actinopterygii	45		***Pavona clavus***	Anthozoa	6
Bodianus loxozonus	Actinopterygii	45		***Platygyra daedalea***	Anthozoa	6
Labrichthys unilineatus	Actinopterygii	45		***Platygyra Submassive***	Anthozoa	6
Pomacanthus imperator	Actinopterygii	45		***Platygyra verweyi***	Anthozoa	6
Pomacentrus lepidogenys	Actinopterygii	45		***Stylophora subseriata***	Anthozoa	6
Pomacentrus magniseptus	Actinopterygii	45		***Acropora clathrata***	Anthozoa	5
Acanthurus albipectoralis	Actinopterygii	44		***Acropora Digitate***	Anthozoa	5
Cheilinus oxycephalus	Actinopterygii	44		***Acropora divaricata***	Anthozoa	5
Cypho purpurascens	Actinopterygii	44		***Acropora monticulosa***	Anthozoa	5
Lutjanus gibbus	Actinopterygii	44		***Cyphastrea serailia***	Anthozoa	5
Naso caesius	Actinopterygii	44		***Favites russelli***	Anthozoa	5
Pervagor alternans	Actinopterygii	44		***Goniastrea australensis***	Anthozoa	5
Plectropomus leopardus	Actinopterygii	43		***Hydnophora microconos***	Anthozoa	5
Pomacentrus amboinensis	Actinopterygii	43		***Isopora Columnar or digitate***	Anthozoa	5
Pseudocheilinus evanidus	Actinopterygii	43		***Leptastrea inaequalis***	Anthozoa	5
Scarus psittacus	Actinopterygii	43		***Montipora danae***	Anthozoa	5
Ostracion cubicus	Actinopterygii	41		***Montipora verrucosa***	Anthozoa	5
Oxycheilinus orientalis	Actinopterygii	41		***Organ-pipe coral (Tubipora)***	Anthozoa	5
Amphiprion chrysopterus	Actinopterygii	40		***Phymastrea valenciennesi***	Anthozoa	5
Chaetodon reticulatus	Actinopterygii	40		***Turbinaria mesenterina***	Anthozoa	5
Plotosus lineatus	Actinopterygii	40		***Acanthastrea Submassive***	Anthozoa	4
Halichoeres prosopeion	Actinopterygii	39		***Acropora digitifera***	Anthozoa	4
Serranocirrhitus latus	Actinopterygii	39		***Acropora microclados***	Anthozoa	4
Amblyglyphidodon aureus	Actinopterygii	38		***Acropora vaughani***	Anthozoa	4
Balistoides viridescens	Actinopterygii	38		***Coral Species***	Anthozoa	4
Heniochus monoceros	Actinopterygii	38		***Goniopora tenuidens***	Anthozoa	4
Plectorhinchus picus	Actinopterygii	38		***Isopora Branching***	Anthozoa	4
Pomacentrus brachialis	Actinopterygii	38		***Montipora aequituberculata***	Anthozoa	4
Pseudanthias pascalus	Actinopterygii	38		***Montipora floweri***	Anthozoa	4
Pterocaesio trilineata	Actinopterygii	38		***Pavona explanulata***	Anthozoa	4
Acanthurus xanthopterus	Actinopterygii	37		***Porites Encrusting***	Anthozoa	4
Halichoeres marginatus	Actinopterygii	37		***Stylophora***	Anthozoa	4
Pseudanthias tuka	Actinopterygii	37		***Stylophora Branching***	Anthozoa	4
Anampses caeruleopunctatus	Actinopterygii	36		***Symphyllia Submassive***	Anthozoa	4
Cheilinus fasciatus	Actinopterygii	36		***Tubipora***	Anthozoa	4
Anampses geographicus	Actinopterygii	35		***Turbinaria frondens***	Anthozoa	4
Chromis viridis	Actinopterygii	35		***Turbinaria stellulata***	Anthozoa	4
Scarus oviceps	Actinopterygii	35		***Acanthastrea brevis***	Anthozoa	3
Echeneis naucrates	Actinopterygii	34		***Acanthastrea hemprichii***	Anthozoa	3
Naso hexacanthus	Actinopterygii	34		***Acropora carduus***	Anthozoa	3

Species	Class	# sites		Species	Class	# sites
Scolopsis bilineata	Actinopterygii	34		***Acropora elseyi***	Anthozoa	3
Amphiprion akindynos	Actinopterygii	32		***Acropora intermedia***	Anthozoa	3
Chrysiptera talboti	Actinopterygii	31		***Acropora latistella***	Anthozoa	3
Forcipiger longirostris	Actinopterygii	31		***Acropora pulchra***	Anthozoa	3
Heniochus varius	Actinopterygii	31		***Acropora sarmentosa***	Anthozoa	3
Lethrinus olivaceus	Actinopterygii	31		***Astreopora listeri***	Anthozoa	3
Pomachromis richardsoni	Actinopterygii	31		***Bottlebrush Acropora corals***	Anthozoa	3
Sargocentron diadema	Actinopterygii	31		***Echinopora Encrusting***	Anthozoa	3
Stegastes gascoynei	Actinopterygii	31		***Echinopora mammiformis***	Anthozoa	3
Variola louti	Actinopterygii	31		***Heliopora coerulea (blue coral)***	Anthozoa	3
Chaetodon lunula	Actinopterygii	30		***Isopora cuneata***	Anthozoa	3
Chromis kennensis	Actinopterygii	30		***Lobophyllia corymbosa***	Anthozoa	3
Hologymnosus annulatus	Actinopterygii	30		***Lobophyllia hataii***	Anthozoa	3
Melichthys vidua	Actinopterygii	30		***Montipora hoffmeisteri***	Anthozoa	3
Myripristis vittata	Actinopterygii	30		***Montipora monasteriata***	Anthozoa	3
Kyphosus cinerascens	Actinopterygii	29		***Montipora tuberculosa***	Anthozoa	3
Cirrhilabrus laboutei	Actinopterygii	28		***Mycedium elephantotus***	Anthozoa	3
Dascyllus aruanus	Actinopterygii	28		***Pavona bipartita***	Anthozoa	3
Myripristis murdjan	Actinopterygii	28		***Pavona Submassive***	Anthozoa	3
Scarus forsteni	Actinopterygii	28		***Pocillopora danae***	Anthozoa	3
Anampses femininus	Actinopterygii	27		***Seriatopora***	Anthozoa	3
Chaetodon vagabundus	Actinopterygii	27		***Tubastrea***	Anthozoa	3
Caranx ignobilis	Actinopterygii	26		***Acropora aculeus***	Anthozoa	2
Cetoscarus bicolor	Actinopterygii	26		***Acropora caroliniana***	Anthozoa	2
Coris dorsomacula	Actinopterygii	26		***Acropora globiceps***	Anthozoa	2
Ecsenius fourmanoiri	Actinopterygii	26		***Acropora millepora***	Anthozoa	2
Pterocaesio digramma	Actinopterygii	26		***Acropora robusta***	Anthozoa	2
Belonoperca chabanaudi	Actinopterygii	25		***Acropora samoensis***	Anthozoa	2
Canthigaster bennetti	Actinopterygii	25		***Acropora yongei***	Anthozoa	2
Carangoides orthogrammus	Actinopterygii	25		***Astrea annuligera***	Anthozoa	2
Ecsenius tigris	Actinopterygii	25		***Astreopora cucullata***	Anthozoa	2
Epinephelus polyphekadion	Actinopterygii	25		***Branching Acropora***	Anthozoa	2
Neocirrhites armatus	Actinopterygii	25		***Cyphastrea***	Anthozoa	2
Pomacentrus moluccensis	Actinopterygii	25		***Digitate corals***	Anthozoa	2
Halichoeres chrysus	Actinopterygii	24		***Echinophyllia Encrusting***	Anthozoa	2
Halichoeres margaritaceus	Actinopterygii	24		***Favia***	Anthozoa	2
Plagiotremus laudandus	Actinopterygii	24		***Favites flexuosa***	Anthozoa	2
Plagiotremus tapeinosoma	Actinopterygii	24		***Galaxea astreata***	Anthozoa	2
Chromis alpha	Actinopterygii	23		***Goniopora lobata***	Anthozoa	2
Chromis xanthochira	Actinopterygii	23		***Heliofungia actiniformis***	Anthozoa	2
Gymnocranius euanus	Actinopterygii	23		***Hydnophora rigida***	Anthozoa	2
Valenciennea strigata	Actinopterygii	23		***Isopora brueggemanni***	Anthozoa	2
Gymnothorax javanicus	Actinopterygii	22		***Isopora elizabethensis***	Anthozoa	2

Species	Class	# sites		Species	Class	# sites
Novaculichthys taeniourus	Actinopterygii	22		***Leptoseris Foliose***	Anthozoa	2
Parapercis clathrata	Actinopterygii	22		***Leptoseris Submassive***	Anthozoa	2
Parapercis millepunctata	Actinopterygii	22		***Lobophyllia***	Anthozoa	2
Plectorhinchus chaetodonoides	Actinopterygii	21		***Lobophyllia pachysepta***	Anthozoa	2
Bolbometopon muricatum	Actinopterygii	20		***Montipora incrassata***	Anthozoa	2
Cantherhines dumerilii	Actinopterygii	20		***Pavona decussata***	Anthozoa	2
Ctenogobiops pomastictus	Actinopterygii	20		***Pavona minuta***	Anthozoa	2
Helcogramma striata	Actinopterygii	20		***Pavona venosa***	Anthozoa	2
Macropharyngodon kuiteri	Actinopterygii	20		***Platygyra Encrusting***	Anthozoa	2
Acanthurus grammoptilus	Actinopterygii	19		***Platygyra ryukyuensis***	Anthozoa	2
Bodianus dictynna	Actinopterygii	19		***Platygyra yaeyamaensis***	Anthozoa	2
Neoniphon opercularis	Actinopterygii	19		***Psammocora nierstraszi***	Anthozoa	2
Parupeneus ciliatus	Actinopterygii	19		***Psammocora profundacella***	Anthozoa	2
Amphiprion perideraion	Actinopterygii	18		***Symphyllia agaricia***	Anthozoa	2
Carangoides plagiotaenia	Actinopterygii	18		***Symphyllia radians***	Anthozoa	2
Epinephelus fasciatus	Actinopterygii	18		***Tubastrea coccinea***	Anthozoa	2
Hemigymnus melapterus	Actinopterygii	18		***Turbinaria Encrusting***	Anthozoa	2
Pteragogus enneacanthus	Actinopterygii	18		***Turbinaria Foliose***	Anthozoa	2
Scomberoides lysan	Actinopterygii	18		***Turbinaria peltata***	Anthozoa	2
Thalassoma jansenii	Actinopterygii	18		***Acanthastrea Encrusting***	Anthozoa	1
Acanthurus triostegus	Actinopterygii	17		***Acropora abrolhosensis***	Anthozoa	1
Amphiprion melanopus	Actinopterygii	17		***Acropora anthocercis***	Anthozoa	1
Chaetodon baronessa	Actinopterygii	17		***Acropora Arborescent table***	Anthozoa	1
Cirrhilabrus scottorum	Actinopterygii	17		***Acropora chesterfieldensis***	Anthozoa	1
Dischistodus melanotus	Actinopterygii	17		***Acropora echinata***	Anthozoa	1
Eviota melasma	Actinopterygii	17		***Acropora Encrusting***	Anthozoa	1
Halichoeres nebulosus	Actinopterygii	17		***Acropora lovelli***	Anthozoa	1
Pristiapogon kallopterus	Actinopterygii	17		***Acropora microphthalma***	Anthozoa	1
Rhinecanthus rectangulus	Actinopterygii	17		***Acropora subulata***	Anthozoa	1
Scarus globiceps	Actinopterygii	17		***Acropora torihalimeda***	Anthozoa	1
Ucla xenogrammus	Actinopterygii	17		***Anacropora Branching***	Anthozoa	1
Abudefduf sexfasciatus	Actinopterygii	16		***Astreopora Encrusting***	Anthozoa	1
Calotomus carolinus	Actinopterygii	16		***Columnar corals***	Anthozoa	1
Chlorurus bleekeri	Actinopterygii	16		***Coscinaraea Encrusting***	Anthozoa	1
Istigobius rigilius	Actinopterygii	16		***Coscinaraea Submassive***	Anthozoa	1
Pervagor janthinosoma	Actinopterygii	16		***Ctenactis crassa***	Anthozoa	1
Pteragogus cryptus	Actinopterygii	16		***Cyphastrea Branching***	Anthozoa	1
Sufflamen bursa	Actinopterygii	16		***Cyphastrea decadia***	Anthozoa	1
Canthigaster amboinensis	Actinopterygii	15		***Echinopora pacificus***	Anthozoa	1
Canthigaster janthinoptera	Actinopterygii	15		***Favia amicorum***	Anthozoa	1
Cephalopholis leopardus	Actinopterygii	15		***Favia rotundata***	Anthozoa	1
Chaetodon bennetti	Actinopterygii	15		***Favites pentagona***	Anthozoa	1
Cirrhilabrus exquisitus	Actinopterygii	15		***Fungia concinna***	Anthozoa	1

Species	Class	# sites		Species	Class	# sites
Fusigobius neophytus	Actinopterygii	15		***Fungia horrida***	Anthozoa	1
Istigobius decoratus	Actinopterygii	15		***Goniopora columna***	Anthozoa	1
Koumansetta rainfordi	Actinopterygii	15		***Goniopora Columnar or digitate***	Anthozoa	1
Lepidozygus tapeinosoma	Actinopterygii	15		***Goniopora Encrusting***	Anthozoa	1
Naso annulatus	Actinopterygii	15		***Hydnophora Encrusting***	Anthozoa	1
Plectorhinchus lineatus	Actinopterygii	15		***Hydnophora grandis***	Anthozoa	1
Synodus dermatogenys	Actinopterygii	15		***Isopora***	Anthozoa	1
Amphiprion clarkii	Actinopterygii	14		***Leptastrea transversa***	Anthozoa	1
Coris batuensis	Actinopterygii	14		***Leptoseris***	Anthozoa	1
Ecsenius aequalis	Actinopterygii	14		***Leptoseris Encrusting***	Anthozoa	1
Hologymnosus doliatus	Actinopterygii	14		***Leptoseris hawaiiensis***	Anthozoa	1
Lethrinus nebulosus	Actinopterygii	14		***Leptoseris scabra***	Anthozoa	1
Neoglyphidodon nigroris	Actinopterygii	14		***Leptoseris yabei***	Anthozoa	1
Parapercis australis	Actinopterygii	14		***Lobophyllia dentatus***	Anthozoa	1
Siganus punctatus	Actinopterygii	14		***Merulina scabricula***	Anthozoa	1
Siganus vulpinus	Actinopterygii	14		***Montipora australiensis***	Anthozoa	1
Synodus binotatus	Actinopterygii	14		***Montipora capricornis***	Anthozoa	1
Anampses meleagrides	Actinopterygii	13		***Montipora Columnar or digitate***	Anthozoa	1
Caesio teres	Actinopterygii	13		***Montipora corbettensis***	Anthozoa	1
Cephalopholis cyanostigma	Actinopterygii	13		***Montipora efflorescens***	Anthozoa	1
Eviota sebreei	Actinopterygii	13		***Montipora foliosa***	Anthozoa	1
Kyphosus bigibbus	Actinopterygii	13		***Montipora foveolata***	Anthozoa	1
Plagiotremus rhinorhynchos	Actinopterygii	13		***Montipora informis***	Anthozoa	1
Priacanthus hamrur	Actinopterygii	13		***Montipora palawanensis***	Anthozoa	1
Pseudocheilinus octotaenia	Actinopterygii	13		***Montipora peltiformis***	Anthozoa	1
Pseudocoris yamashiroi	Actinopterygii	13		***Podabacia crustacea***	Anthozoa	1
Saurida nebulosa	Actinopterygii	13		***Porites***	Anthozoa	1
Amblygobius phalaena	Actinopterygii	12		***Porites Branching***	Anthozoa	1
Caesio lunaris	Actinopterygii	12		***Porites Columnar or digitate***	Anthozoa	1
Plectorhinchus lessonii	Actinopterygii	12		***Porites Solid plates***	Anthozoa	1
Pomacentrus reidi	Actinopterygii	12		***Psammocora Submassive***	Anthozoa	1
Amblyeleotris steinitzi	Actinopterygii	11		***Psammocora superficialis***	Anthozoa	1
Eviota atriventris	Actinopterygii	11		***Sandalolitha robusta***	Anthozoa	1
Exallias brevis	Actinopterygii	11		***Seriatopora dendritica***	Anthozoa	1
Gobiodon quinquestrigatus	Actinopterygii	11		***Stylocoeniella Encrusting***	Anthozoa	1
Gymnocranius superciliosus	Actinopterygii	11		***Tubastrea micranthus***	Anthozoa	1
Halichoeres melanurus	Actinopterygii	11		***Fromia indica***	Asteroidea	16
Halichoeres ornatissimus	Actinopterygii	11		***Linckia multifora***	Asteroidea	15
Neoniphon argenteus	Actinopterygii	11		***Culcita novaeguineae***	Asteroidea	9
Parupeneus barberinoides	Actinopterygii	11		***Celerina heffernani***	Asteroidea	6
Scarus dimidiatus	Actinopterygii	11		***Echinaster luzonicus***	Asteroidea	5
Scarus flavipectoralis	Actinopterygii	11		***Gomophia watsoni***	Asteroidea	5

Species	Class	# sites		Species	Class	# sites
Canthigaster axiologus	Actinopterygii	10		***Linckia laevigata***	Asteroidea	5
Carangoides ferdau	Actinopterygii	10		***Fromia monilis***	Asteroidea	4
Caranx lugubris	Actinopterygii	10		***Neoferdina cumingi***	Asteroidea	4
Chromis fumea	Actinopterygii	10		***Acanthaster planci***	Asteroidea	3
Gymnosarda unicolor	Actinopterygii	10		***Fromia milleporella***	Asteroidea	3
Heniochus acuminatus	Actinopterygii	10		***Mithrodia clavigera***	Asteroidea	3
Labropsis xanthonota	Actinopterygii	10		***Choriaster granulatus***	Asteroidea	2
Macropharyngodon negrosensis	Actinopterygii	10		***Linckia guildingi***	Asteroidea	2
Paracanthurus hepatus	Actinopterygii	10		***Dactylosaster cylindricus***	Asteroidea	1
Parapercis hexophtalma	Actinopterygii	10		***Echinaster callosus***	Asteroidea	1
Pentapodus aureofasciatus	Actinopterygii	10		***Fromia hemiopla***	Asteroidea	1
Stegastes punctatus	Actinopterygii	10		***Leiaster leachi***	Asteroidea	1
Anyperodon leucogrammicus	Actinopterygii	9		***Nardoa novaecaledoniae***	Asteroidea	1
Caesio cuning	Actinopterygii	9		***Neoferdina insolita***	Asteroidea	1
Cephalopholis miniata	Actinopterygii	9		***Tridacna maxima***	Bivalvia	185
Choerodon fasciatus	Actinopterygii	9		***Tridacna crocea***	Bivalvia	96
Chrysiptera flavipinnis	Actinopterygii	9		***Tridacna derasa***	Bivalvia	79
Ctenogobiops mitodes	Actinopterygii	9		***Tridacna squamosa***	Bivalvia	70
Ecsenius stictus	Actinopterygii	9		***Tridacna gigas***	Bivalvia	24
Gobiodon citrinus	Actinopterygii	9		***Hippopus hippopus***	Bivalvia	4
Naso brachycentron	Actinopterygii	9		***Tridacna noae***	Bivalvia	1
Neoglyphidodon melas	Actinopterygii	9		***Octopus cyanea***	Cephalopoda	3
Ostorhinchus properuptus	Actinopterygii	9		***Sepia latimanus***	Cephalopoda	1
Ptereleotris zebra	Actinopterygii	9		***Oxycomanthus bennetti***	Crinoidea	50
Elagatis bipinnulata	Actinopterygii	8		***Himerometra robustipinna***	Crinoidea	26
Gymnothorax meleagris	Actinopterygii	8		***Cenolia glebosus***	Crinoidea	9
Heniochus singularius	Actinopterygii	8		***Anneissia bennetti***	Crinoidea	8
Lutjanus rivulatus	Actinopterygii	8		***Comanthus mirabilis***	Crinoidea	8
Ostorhinchus cyanosoma	Actinopterygii	8		***Comaster schlegelii***	Crinoidea	7
Ostorhinchus nigrofasciatus	Actinopterygii	8		***Tropiometra afra***	Crinoidea	7
Paracentropyge multifasciata	Actinopterygii	8		***Comanthus suavia***	Crinoidea	5
Parapercis multiplicata	Actinopterygii	8		***Oligometra serripinna***	Crinoidea	5
Pictichromis coralensis	Actinopterygii	8		***Cenometra bella***	Crinoidea	4
Pomacentrus chrysurus	Actinopterygii	8		***Himerometra magnipinna***	Crinoidea	4
Pomacentrus wardi	Actinopterygii	8		***Clarkcomanthus littoralis***	Crinoidea	3
Pseudobalistes fuscus	Actinopterygii	8		***Clarkcomanthus luteofuscum***	Crinoidea	3
Trimma benjamini	Actinopterygii	8		***Comaster nobilis***	Crinoidea	3
Acanthurus mata	Actinopterygii	7		***Amphimetra tessellata***	Crinoidea	1
Amblyeleotris wheeleri	Actinopterygii	7		***Capillaster multiradiatus***	Crinoidea	1
Arothron meleagris	Actinopterygii	7		***Clarkcomanthus comanthipinna***	Crinoidea	1
Arothron stellatus	Actinopterygii	7		***Comanthus alternans***	Crinoidea	1
Cheilodipterus artus	Actinopterygii	7		***Comanthus briareus***	Crinoidea	1

Species	Class	# sites		Species	Class	# sites
Dischistodus pseudochrysopoecilus	Actinopterygii	7		***Comanthus gisleni***	Crinoidea	1
Eviota pellucida	Actinopterygii	7		***Comanthus parvicirrus***	Crinoidea	1
Fistularia commersonii	Actinopterygii	7		***Comaster multifidus***	Crinoidea	1
Fusigobius signipinnis	Actinopterygii	7		***Stephanometra indica***	Crinoidea	1
Kyphosus vaigiensis	Actinopterygii	7		***Echinometra mathaei***	Echinoidea	149
Lutjanus quinquelineatus	Actinopterygii	7		***Diadema savignyi***	Echinoidea	49
Macropharyngodon ornatus	Actinopterygii	7		***Echinothrix calamaris***	Echinoidea	22
Malacanthus brevirostris	Actinopterygii	7		***Diadema setosum***	Echinoidea	11
Ostracion solorensis	Actinopterygii	7		***Echinothrix diadema***	Echinoidea	7
Paracirrhites hemistictus	Actinopterygii	7		***Heterocentrotus mamillatus***	Echinoidea	6
Pseudobalistes flavimarginatus	Actinopterygii	7		***Heterocentrotus mamillatus***	Echinoidea	6
Pseudochromis fuscus	Actinopterygii	7		***Phyllacanthus imperialis***	Echinoidea	6
Siganus corallinus	Actinopterygii	7		***Tripneustes gratilla***	Echinoidea	3
Siganus punctatissimus	Actinopterygii	7		***Eucidaris metularia***	Echinoidea	1
Thalassoma trilobatum	Actinopterygii	7		***Parasalenia poehlii***	Echinoidea	1
Amblyeleotris guttata	Actinopterygii	6		***Prionocidaris callista***	Echinoidea	1
Bodianus perditio	Actinopterygii	6		***Carcharhinus amblyrhynchos***	Elasmobranchii	110
Canthigaster papua	Actinopterygii	6		***Triaenodon obesus***	Elasmobranchii	91
Caranx sexfasciatus	Actinopterygii	6		***Carcharhinus albimarginatus***	Elasmobranchii	13
Chaetodon aureofasciatus	Actinopterygii	6		***Aetobatus ocellatus***	Elasmobranchii	3
Chrysiptera biocellata	Actinopterygii	6		***Pateobatis fai***	Elasmobranchii	3
Cirripectes castaneus	Actinopterygii	6		***Nebrius ferrugineus***	Elasmobranchii	2
Gobiodon histrio	Actinopterygii	6		***Neotrygon kuhlii***	Elasmobranchii	2
Gracila albomarginata	Actinopterygii	6		***Taeniura meyeni***	Elasmobranchii	2
Grammatorcynus bilineatus	Actinopterygii	6		***Carcharhinus melanopterus***	Elasmobranchii	1
Lotilia klausewitzi	Actinopterygii	6		***Hemiscyllium ocellatum***	Elasmobranchii	1
Myripristis adusta	Actinopterygii	6		***Taeniura lymma***	Elasmobranchii	1
Plectroglyphidodon imparipennis	Actinopterygii	6		***Phyllidiella pustulosa***	Gastropoda	59
Plectropomus maculatus	Actinopterygii	6		***Tectus pyramis***	Gastropoda	56
Sargocentron ittodai	Actinopterygii	6		***Thuridilla gracilis***	Gastropoda	44
Saurida gracilis	Actinopterygii	6		***Thuridilla gracilis***	Gastropoda	44
Sphyraena barracuda	Actinopterygii	6		***Drupella cornus***	Gastropoda	40
Taeniamia fucata	Actinopterygii	6		***Conus miles***	Gastropoda	27
Trimma lantana	Actinopterygii	6		***Chromodoris elisabethina***	Gastropoda	22
Aioliops novaeguineae	Actinopterygii	5		***Conus flavidus***	Gastropoda	20
Chaetodon rafflesii	Actinopterygii	5		***Lambis truncata***	Gastropoda	20
Chrysiptera rollandi	Actinopterygii	5		***Cerithium nodulosum***	Gastropoda	17
Cirrhilabrus cyanopleura	Actinopterygii	5		***Vasum turbinellus***	Gastropoda	17
Ctenogobiops tangaroai	Actinopterygii	5		***Chromodoris lochi***	Gastropoda	13
Eviota sigillata	Actinopterygii	5		***Vasum ceramicum***	Gastropoda	13
Lutjanus fulvus	Actinopterygii	5		***Phyllidia coelestis***	Gastropoda	11
Myripristis amaena	Actinopterygii	5		***Pteraeolidia semperi***	Gastropoda	10

Species	Class	# sites		Species	Class	# sites
Pempheris schwenkii	Actinopterygii	5		***Turbo argyrostomus***	Gastropoda	10
Platax pinnatus	Actinopterygii	5		***Cerithium echinatum***	Gastropoda	9
Pomacentrus adelus	Actinopterygii	5		***Conus distans***	Gastropoda	9
Pterois antennata	Actinopterygii	5		***Lambis lambis***	Gastropoda	8
Scarus ghobban	Actinopterygii	5		***Pteraeolidia ianthina***	Gastropoda	8
Siganus fuscescens	Actinopterygii	5		***Chelidonura inornata***	Gastropoda	7
Trimma readerae	Actinopterygii	5		***Latirolagena smaragdulus***	Gastropoda	7
Acanthurus leucocheilus	Actinopterygii	4		***Phyllidia varicosa***	Gastropoda	7
Aethaloperca rogaa	Actinopterygii	4		***Rochia nilotica***	Gastropoda	7
Apolemichthys trimaculatus	Actinopterygii	4		***Conus emaciatus***	Gastropoda	6
Bryaninops natans	Actinopterygii	4		***Cypraea tigris***	Gastropoda	6
Centropyge loricula	Actinopterygii	4		***Drupa morum***	Gastropoda	6
Cheilodipterus isostigmus	Actinopterygii	4		***Drupa ricinus***	Gastropoda	6
Chelmon marginalis	Actinopterygii	4		***Lambis scorpius***	Gastropoda	6
Chromis analis	Actinopterygii	4		***Tectus virgatus***	Gastropoda	6
Epinephelus lanceolatus	Actinopterygii	4		***Thuridilla neona***	Gastropoda	6
Epinephelus tauvina	Actinopterygii	4		***Astralium rhodostomum***	Gastropoda	5
Eviota bifasciata	Actinopterygii	4		***Conus marmoreus***	Gastropoda	5
Gnatholepis anjerensis	Actinopterygii	4		***Drupa rubusidaeus***	Gastropoda	5
Grammistes sexlineatus	Actinopterygii	4		***Lambis chiragra***	Gastropoda	5
Halichoeres chloropterus	Actinopterygii	4		***Latirus gibbulus***	Gastropoda	5
Lethrinus erythracanthus	Actinopterygii	4		***Latirus polygonus***	Gastropoda	5
Meiacanthus ditrema	Actinopterygii	4		***Phyllidia elegans***	Gastropoda	5
Meiacanthus lineatus	Actinopterygii	4		***Phyllidiella lizae***	Gastropoda	5
Meiacanthus phaeus	Actinopterygii	4		***Trochus maculatus***	Gastropoda	5
Meiacanthus reticulatus	Actinopterygii	4		***Cassis cornuta***	Gastropoda	4
Odonus niger	Actinopterygii	4		***Conus capitaneus***	Gastropoda	4
Pictichromis paccagnellae	Actinopterygii	4		***Conus lividus***	Gastropoda	4
Plectropomus areolatus	Actinopterygii	4		***Conus virgo***	Gastropoda	4
Pleurosicya mossambica	Actinopterygii	4		***Chromodoris annae***	Gastropoda	3
Pseudodax moluccanus	Actinopterygii	4		***Chromodoris willani***	Gastropoda	3
Pterois volitans	Actinopterygii	4		***Conus coronatus***	Gastropoda	3
Rhinecanthus aculeatus	Actinopterygii	4		***Conus leopardus***	Gastropoda	3
Scarus rivulatus	Actinopterygii	4		***Conus litteratus***	Gastropoda	3
Siganus puellus	Actinopterygii	4		***Conus miliaris***	Gastropoda	3
Stegastes albifasciatus	Actinopterygii	4		***Conus musicus***	Gastropoda	3
Strongylura incisa	Actinopterygii	4		***Conus rattus***	Gastropoda	3
Trimma taylori	Actinopterygii	4		***Coralliophila neritoidea***	Gastropoda	3
Aluterus scriptus	Actinopterygii	3		***Hypselodoris bullockii***	Gastropoda	3
Amanses scopas	Actinopterygii	3		***Conomurex luhuanus***	Gastropoda	2
Arothron mappa	Actinopterygii	3		***Conus imperialis***	Gastropoda	2
Bodianus anthioides	Actinopterygii	3		***Conus sanguinolentus (cf)***	Gastropoda	2
Bodianus diana	Actinopterygii	3		***Conus vexillum***	Gastropoda	2

Species	Class	# sites		Species	Class	# sites
Cephalopholis sexmaculata	Actinopterygii	3		***Cyerce nigricans***	Gastropoda	2
Chaetodon punctatofasciatus	Actinopterygii	3		***Drupina grossularia***	Gastropoda	2
Chaetodon semeion	Actinopterygii	3		***Gourmya gourmyi***	Gastropoda	2
Chromis caudalis	Actinopterygii	3		***Gymnodoris citrina***	Gastropoda	2
Chrysiptera brownriggii	Actinopterygii	3		***Mitra contracta***	Gastropoda	2
Cirrhilabrus lineatus	Actinopterygii	3		***Nembrotha cristata***	Gastropoda	2
Cirrhitus pinnulatus	Actinopterygii	3		***Peristernia nassatula***	Gastropoda	2
Ctenogobiops feroculus	Actinopterygii	3		***Pleuroploca trapezium***	Gastropoda	2
Diodon hystrix	Actinopterygii	3		***Rhinoclavis fasciata***	Gastropoda	2
Ecsenius australianus	Actinopterygii	3		***Rhinoclavis sinensis***	Gastropoda	2
Epinephelus maculatus	Actinopterygii	3		***Roboastra gracilis***	Gastropoda	2
Gobiodon okinawae	Actinopterygii	3		***Tambja morosa***	Gastropoda	2
Kyphosus sectatrix	Actinopterygii	3		***Carminodoris estrelyado***	Gastropoda	1
Labroides pectoralis	Actinopterygii	3		***Chicoreus brunneus***	Gastropoda	1
Lutjanus monostigma	Actinopterygii	3		***Chicoreus ramosus***	Gastropoda	1
Luzonichthys waitei	Actinopterygii	3		***Chromodoris dianae***	Gastropoda	1
Naso thynnoides	Actinopterygii	3		***Conus boeticus***	Gastropoda	1
Ostorhinchus angustatus	Actinopterygii	3		***Conus muriculatus***	Gastropoda	1
Ostorhinchus aureus	Actinopterygii	3		***Conus mustelinus***	Gastropoda	1
Ostorhinchus neotes	Actinopterygii	3		***Conus planorbis***	Gastropoda	1
Platax teira	Actinopterygii	3		***Conus pulicarius***	Gastropoda	1
Plectorhinchus albovittatus	Actinopterygii	3		***Conus striatus***	Gastropoda	1
Plectroglyphidodon phoenixensis	Actinopterygii	3		***Conus varius***	Gastropoda	1
Pomacentrus grammorhynchus	Actinopterygii	3		***Coryphellina albomarginata***	Gastropoda	1
Pomacentrus nigromarginatus	Actinopterygii	3		***Coryphellina rubrolineata***	Gastropoda	1
Pomacentrus pavo	Actinopterygii	3		***Doriprismatica dendrobranchia***	Gastropoda	1
Priacanthus blochii	Actinopterygii	3		***Epidendrium billeeanum***	Gastropoda	1
Sargocentron microstoma	Actinopterygii	3		***Glossodoris cincta***	Gastropoda	1
Scarus festivus	Actinopterygii	3		***Goniobranchus coi***	Gastropoda	1
Stethojulis strigiventer	Actinopterygii	3		***Goniobranchus decorus***	Gastropoda	1
Trachinotus blochii	Actinopterygii	3		***Goniobranchus geometricus***	Gastropoda	1
Apogon limenus	Actinopterygii	2		***Goniobranchus sinensis***	Gastropoda	1
Arothron caeruleopunctatus	Actinopterygii	2		***Goniobranchus verrieri***	Gastropoda	1
Bryaninops erythrops	Actinopterygii	2		***Halgerda aurantiomaculata***	Gastropoda	1
Bryaninops yongei	Actinopterygii	2		***Halgerda tessellata***	Gastropoda	1
Cantherhines fronticinctus	Actinopterygii	2		***Haliotis ovina***	Gastropoda	1
Canthigaster epilampra	Actinopterygii	2		***Harpago chiragra***	Gastropoda	1
Caracanthus maculatus	Actinopterygii	2		***Hypselodoris maculosa***	Gastropoda	1
Carangoides fulvoguttatus	Actinopterygii	2		***Latirus lanceolatus***	Gastropoda	1
Caranx papuensis	Actinopterygii	2		***Lentigo lentiginosus***	Gastropoda	1
Cephalopholis microprion	Actinopterygii	2		***Lotoria lotoria***	Gastropoda	1
Chaetodon meyeri	Actinopterygii	2		***Mancinella armigera***	Gastropoda	1

Species	Class	# sites		Species	Class	# sites
Chromileptes altivelis	Actinopterygii	2		***Melo amphora***	Gastropoda	1
Chrysiptera starcki	Actinopterygii	2		***Mitra stictica***	Gastropoda	1
Cirripectes chelomatus	Actinopterygii	2		***Monetaria annulus***	Gastropoda	1
Coradion altivelis	Actinopterygii	2		***Morula uva***	Gastropoda	1
Cyprinocirrhites polyactis	Actinopterygii	2		***Nebularia chrysostoma***	Gastropoda	1
Decapterus macarellus	Actinopterygii	2		***Notodoris citrina***	Gastropoda	1
Diagramma pictum	Actinopterygii	2		***Noumea simplex***	Gastropoda	1
Dischistodus prosopotaenia	Actinopterygii	2		***Oliva amethystina***	Gastropoda	1
Epinephelus hexagonatus	Actinopterygii	2		***Peristernia australiensis***	Gastropoda	1
Epinephelus quoyanus	Actinopterygii	2		***Petalifera ramosa***	Gastropoda	1
Epinephelus tukula	Actinopterygii	2		***Philinopsis pilsbryi***	Gastropoda	1
Glyptoparus delicatulus	Actinopterygii	2		***Phyllidia ocellata***	Gastropoda	1
Hemiglyphidodon plagiometopon	Actinopterygii	2		***Phyllodesmium briareum***	Gastropoda	1
Hoplolatilus starcki	Actinopterygii	2		***Pleuroploca filamentosa***	Gastropoda	1
Leptoscarus vaigiensis	Actinopterygii	2		***Purpura dumosa***	Gastropoda	1
Lethrinus semicinctus	Actinopterygii	2		***Ranularia pyrum***	Gastropoda	1
Ogilbyina novaehollandiae	Actinopterygii	2		***Roboastra luteolineata***	Gastropoda	1
Oxycheilinus nigromarginatus	Actinopterygii	2		***Talparia talpa***	Gastropoda	1
Platax orbicularis	Actinopterygii	2		***Thorunna furtiva***	Gastropoda	1
Pleurosicya micheli	Actinopterygii	2		***Thuridilla carlsoni***	Gastropoda	1
Pomacanthus sexstriatus	Actinopterygii	2		***Bohadschia argus***	Holothuroidea	44
Pomacentrus australis	Actinopterygii	2		***Stichopus chloronotus***	Holothuroidea	35
Pomacentrus nigromanus	Actinopterygii	2		***Thelenota ananas***	Holothuroidea	35
Pristiapogon exostigma	Actinopterygii	2		***Holothuria atra***	Holothuroidea	30
Pristiapogon fraenatus	Actinopterygii	2		***Bohadschia graeffei***	Holothuroidea	21
Pseudanthias ?cooperi	Actinopterygii	2		***Bohadschia graeffei***	Holothuroidea	21
Pseudanthias huchtii	Actinopterygii	2		***Holothuria whitmaei***	Holothuroidea	16
Pseudojuloides cerasinus	Actinopterygii	2		***Holothuria fuscorubra***	Holothuroidea	14
Pseudolabrus guentheri	Actinopterygii	2		***Holothuria edulis***	Holothuroidea	8
Sargocentron tiere	Actinopterygii	2		***Actinopyga mauritiana***	Holothuroidea	7
Scarus tricolor	Actinopterygii	2		***Actinopyga miliaris***	Holothuroidea	7
Scarus xanthopleura	Actinopterygii	2		***Holothuria nobilis***	Holothuroidea	7
Signigobius biocellatus	Actinopterygii	2		***Thelenota anax***	Holothuroidea	4
Stethojulis interrupta	Actinopterygii	2		***Actinopyga palauensis***	Holothuroidea	2
Stethojulis trilineata	Actinopterygii	2		***Holothuria hilla***	Holothuroidea	2
Sufflamen fraenatum	Actinopterygii	2		***Holothuria scabra***	Holothuroidea	2
Synodus rubromarmoratus	Actinopterygii	2		***Stichopus hermanni***	Holothuroidea	2
Trimma tevegae	Actinopterygii	2		***Synapta maculata***	Holothuroidea	2
Variola albimarginata	Actinopterygii	2		***Thelenota rubrolineata***	Holothuroidea	2
Zoramia viridiventer	Actinopterygii	2		***Actinopyga lecanora***	Holothuroidea	1
Abudefduf bengalensis	Actinopterygii	1		***Holothuria (Semperothuria) cinerascens***	Holothuroidea	1
Abudefduf whitleyi	Actinopterygii	1		***Holothuria fuscopunctata***	Holothuroidea	1

Species	Class	# sites		Species	Class	# sites
Acanthocybium solandri	Actinopterygii	1		***Millepora exaesa***	Hydrozoa	78
Acanthopagrus australis	Actinopterygii	1		***Millepora dichotoma***	Hydrozoa	27
Acanthurus achilles	Actinopterygii	1		***Millepora branching***	Hydrozoa	6
Acanthurus guttatus	Actinopterygii	1		***Millepora tenera***	Hydrozoa	5
Amblyeleotris fasciata	Actinopterygii	1		***Millepora spp.***	Hydrozoa	1
Amblygobius nocturnus	Actinopterygii	1		***Dardanus lagopodes***	Malacostraca	63
Anampses melanurus	Actinopterygii	1		***Calcinus minutus***	Malacostraca	54
Aphareus rutilans	Actinopterygii	1		***Trapezia rufopunctata***	Malacostraca	14
Assessor flavissimus	Actinopterygii	1		***Calcinus lineapropodus***	Malacostraca	12
Assessor macneilli	Actinopterygii	1		***Calcinus morgani***	Malacostraca	7
Atrosalarias holomelas	Actinopterygii	1		***Clibanarius seurati***	Malacostraca	7
Blenniella paula	Actinopterygii	1		***Cymo quadrilobatus***	Malacostraca	6
Calloplesiops altivelis	Actinopterygii	1		***Dardanus guttatus***	Malacostraca	6
Canthidermis maculata	Actinopterygii	1		***Odontodactylus scyllarus***	Malacostraca	6
Chaetodon guentheri	Actinopterygii	1		***Dardanus megistos***	Malacostraca	5
Chaetodon oxycephalus	Actinopterygii	1		***Tylocarcinus styx***	Malacostraca	4
Chaetodon rainfordi	Actinopterygii	1		***Calcinus gaimardii***	Malacostraca	3
Cheilodipterus parazonatus	Actinopterygii	1		***Percnon guinotae***	Malacostraca	3
Chlorurus japanensis	Actinopterygii	1		***Trapezia cymodoce***	Malacostraca	3
Choerodon graphicus	Actinopterygii	1		***Aniculus retipes***	Malacostraca	2
Chromis nitida	Actinopterygii	1		***Calcinus pulcher***	Malacostraca	2
Chrysiptera caesifrons	Actinopterygii	1		***Dardanus gemmatus***	Malacostraca	2
Chrysiptera glauca	Actinopterygii	1		***Paguritta corallicola***	Malacostraca	2
Cirrhilabrus ?scottorum	Actinopterygii	1		***Panulirus longipes***	Malacostraca	2
Cirripectes filamentosus	Actinopterygii	1		***Achaeus japonicus***	Malacostraca	1
Coradion chrysozonus	Actinopterygii	1		***Aniculus erythraeus***	Malacostraca	1
Coris bulbifrons	Actinopterygii	1		***Calcinus elegans***	Malacostraca	1
Coris pictoides	Actinopterygii	1		***Ciliopagurus strigatus***	Malacostraca	1
Ctenogobiops maculosus	Actinopterygii	1		***Dardanus scutellatus***	Malacostraca	1
Dendrochirus zebra	Actinopterygii	1		***Gonodactylus platysoma***	Malacostraca	1
Diodon holocanthus	Actinopterygii	1		***Notosceles serratifrons***	Malacostraca	1
Diodon liturosus	Actinopterygii	1		***Panulirus versicolor***	Malacostraca	1
Diplogrammus goramensis	Actinopterygii	1		***Tetralia cinctipes***	Malacostraca	1
Ecsenius bicolor	Actinopterygii	1		***Trapezia flavopunctata***	Malacostraca	1
Ecsenius yaeyamaensis	Actinopterygii	1		***Aipysurus laevis***	Reptilia	59
Enneapterygius tutuilae	Actinopterygii	1		***Chelonia mydas***	Reptilia	11
Epinephelus cyanopodus	Actinopterygii	1		***Eretmochelys imbricata***	Reptilia	9
Epinephelus howlandi	Actinopterygii	1		***Aipysurus duboisii***	Reptilia	7
Eviota punctulata	Actinopterygii	1		***Acalyptophis peronii***	Reptilia	6
Exyrias akihito	Actinopterygii	1		***Emydocephalus annulatus***	Reptilia	5
Gorgasia galzini	Actinopterygii	1		***Caretta caretta***	Reptilia	1
Gymnocranius microdon	Actinopterygii	1		***Hydrophis elegans***	Reptilia	1
Gymnothorax eurostus	Actinopterygii	1		***Natator depressus***	Reptilia	1

Species	Class	# sites		Species	Class	# sites
Gymnothorax favagineus	Actinopterygii	1		***Pseudobiceros bedfordi***	Rhabditophora	1
Gymnothorax flavimarginatus	Actinopterygii	1		***Pseudoceros gravieri***	Rhabditophora	1
Gymnothorax thrysoideus	Actinopterygii	1		***Pseudoceros liparus***	Rhabditophora	1
Gymnothorax undulatus	Actinopterygii	1		***Thysanostoma flagellatum***	Scyphozoa	1
Halichoeres hartzfeldii	Actinopterygii	1		***Pseudoceros monostichos***	Turbellaria	2
Halichoeres leucurus	Actinopterygii	1		***Pseudobiceros gloriosus***	Turbellaria	1
Halichoeres scapularis	Actinopterygii	1		***Pseudoceros bimarginatus***	Turbellaria	1
Lethrinus rubrioperculatus	Actinopterygii	1		***Pseudoceros dimidiatus (cf)***	Turbellaria	1
Lethrinus xanthochilus	Actinopterygii	1		***Pseudoceros ferrugineus***	Turbellaria	1
Lutjanus argentimaculatus	Actinopterygii	1		***Pseudoceros sapphirinus***	Turbellaria	1
Lutjanus semicinctus	Actinopterygii	1		***Zebrasoma velifer***	Actinopterygii	162
Macropharyngodon choati	Actinopterygii	1		***Ctenochaetus cyanocheilus***	Actinopterygii	97
Meiacanthus grammistes	Actinopterygii	1		***Centropyge flavissima***	Actinopterygii	80
Myrichthys maculosus	Actinopterygii	1		***Parapercis australis***	Actinopterygii	14
Myripristis hexagona	Actinopterygii	1		***Canthigaster papua***	Actinopterygii	6
Myripristis pralinia	Actinopterygii	1		***Centropyge loricula***	Actinopterygii	4
Naso caeruleacauda	Actinopterygii	1		***Iniistius pavo***	Actinopterygii	1
Neoglyphidodon polyacanthus	Actinopterygii	1		***Oxycercichthys veliferus***	Actinopterygii	1
Neopomacentrus azysron	Actinopterygii	1				