Assessment of the 2024 marine heatwave on five reefs in the central Coral Sea Marine Park

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In responding to a request from Parks Australia, a team of researchers representing the College of Science and Engineering at James Cook University (JCU) completed an assessment of shallow coral reef habitats across five reefs in the central Coral Sea Marine Park.

On the cover – a completely bleached branching *Acropora* in front of a healthy massive *Porites*. Image: Victor Huertas

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We are indebted to the skipper and crew and staff of RV Escape for enabling this work in a safe and professional manner.

1 Executive Summary

Despite the significant heat stress experienced throughout much of the Coral Sea Marine Park (CSMP) in March 2024 (up to 16 Degree Heating Weeks), there appears to have been minimal or low levels of bleaching and mortality of corals across the five reefs surveyed in July 2024.

Surveys of eight sites from five reefs in the central CSMP in July 2024 revealed that coral cover on most reefs and sites has increased since February 2023. The only exception being Chilcott Islet where coral cover had declined from 22.9% in 2021 (the last time this reef was surveyed) to 18.7% in 2024. Overall, live coral cover had increased from 10.2% (February 2023) to 11.6% (July 2024); a relative increase of 14.4%. These data were consistent with qualitative observations of the health of shallow water corals at Osprey Reef, northern CSMP, in June 2024 where the incidence of bleaching and bleaching-induced mortality was highly variable among sites.

Despite the apparent limited effects of the 2024 marine heatwave on shallow coral communities across the four reefs surveyed (excluding Chilcott Islet), these findings are unlikely to represent conditions across the entire CSMP. All reefs surveyed had low coral cover (mean = 11.6%) and as such, many of the bleaching-susceptible taxa may have already been lost to previous heat stress events (e.g., 2020, 2021, and/or 2022). Several other reefs within the CSMP have considerably higher coral cover, including high cover of bleaching-susceptible taxa (e.g., *Acropora*), and may have been adversely affected by the 2024 marine heatwave (e.g., bright spot reefs such as Mellish and Moore Reefs). Surveys in the next 6-12 months will be critical to determine the broader impacts of this heatwave on shallow coral communities within the CSMP.

Alternatively, these reefs may not have experienced the heat stress as predicted by the NOAA satellite products. Temperature loggers were deployed across most large reef systems within the CSMP in February 2023 and February 2024, and as such were recording *in situ* temperatures in shallow reef habitats throughout this marine heatwave. Retrieving these loggers and comparing *in situ* temperatures to those from NOAA's satellite-derived products should be a high priority, if not an essential target, of future monitoring within the CSMP.

Recommendations:

- Surveys in the next 6-12 months will be critical to determine the broader impacts of this heatwave on shallow coral communities within the CSMP, and the potential recovery of coral populations from previous bleaching events.

- Retrieving the temperature loggers deployed throughout the CSMP in February 2023 and February 2024 is critical to determine the levels of heat stress corals experienced throughout the region, and understand the responses of these communities to these disturbances. This would also enable us to groundtruth satellite-derived temperature data with *in situ* recordings of water temperatures.

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2 Background

Coral reefs are one of the world's most biodiverse ecosystems, yet they are also one of the most threatened. The effects of local anthropogenic stressors (e.g., fishing, and declining water quality due to terrestrial run-off) are being greatly compounded by the effects of climate change and have led to declines in coral cover across most tropical regions (Gardner et al. 2003; Bellwood et al. 2004; Hughes et al. 2017; Stuart-Smith et al. 2018; Souter et al. 2021). Declines in coral cover are invariably accompanied by shifts in the composition of coral assemblages due to the differential susceptibility of coral taxa to heat stress (e.g., Loya et al. 2001; Burn et al. 2023), shifts in benthic communities as a range of organisms rapidly colonise the dead coral skeletons (Diaz-Pulido and McCook 2002), and declines in physical structure as the dead coral skeletons are broken down by a range of processes (Alvarez-Filip et al. 2009). These changes in the composition and structure of benthic communities on coral reefs invariably affect the associated fish and invertebrate communities (Stella et al. 2011; Hoey et al. 2016; Richardson et al. 2018), and the goods and services they provide (Graham & Nash 2013, Woodhead et al. 2019). Projections of the increased frequency and intensity of climate-induced disturbances, in particular increased seawater temperatures, have raised concerns for the persistence of coral reef ecosystems into the future (Hughes et al. 2018; Emslie et al. 2024; Mellin et al. 2024).

Remote oceanic reefs, often considered to be 'near pristine' due to their isolation from human populations and hence local anthropogenic pressures (Graham and McClanahan 2013), are impacted by climate change (e.g., Sandin et al. 2008; Gilmour et al. 2013; Lange and Perry 2019; Hoey et al. 2020). Importantly, the recovery of coral populations on these isolated reefs can be protracted due to their limited connectivity with other nearby reef systems and their reliance on self-recruitment (Gilmour et al. 2013). It is becoming increasingly apparent that these isolated reef systems are structured by processes that are fundamentally different to those of nearshore and highly-connected reef systems (e.g., Great Barrier Reef). Understanding how these isolated reef systems respond to climate-induced heat stress, and the degree to which they are able to recover from these disturbances is critical to predicting their future configurations.

The reefs of Australia's Coral Sea Marine Park are one such isolated reef system. Australia's marine estate within the Coral Sea is managed through the Coral Sea Marine Park (CSMP). The CSMP extends from the eastward margin of the Great Barrier Reef Marine Park (GBRMP) to the outer extent of Australia's Exclusive Economic Zone, some 1,200km offshore (Figure 1.1). The CSMP is among the world's largest and most isolated marine parks, encompassing an area of 989,836km^2. The CSMP includes approximately 56 islets and cays and 20 widely separated shallow reef systems. Reefs in the CSMP have been exposed to increasing heat stress within the past two decades, with five major coral bleaching events occurring in eight years from 2016-2023 (i.e., 2016, 2017, 2020, 2021, and 2022; Stuart-Smith et al. 2018; Harrison et al. 2019; Hoey et al. 2020, 2021, 2022). In 2024, the reefs within the CSMP were again exposed to extreme heat stress, with the greatest heat stress recorded in late March 2024 (Figure 1.2), several weeks after the most recent surveys of the shallow reef communities in the southern and central CSMP (Hoey et al. 2024). Although considerable levels of heat stress were recorded across the seven southern and central CSMP reefs surveyed in February 2024 (Hoey et al. 2024), much of the CSMP was exposed to heat stress of 12 Degree Heating Weeks (DHW), and some areas exceeded 16 DHW by late March (Figure 1.2). Levels of heat stress exceeding 8 DHW are expected to cause severe bleaching and mortality (Hughes et al. 2017).

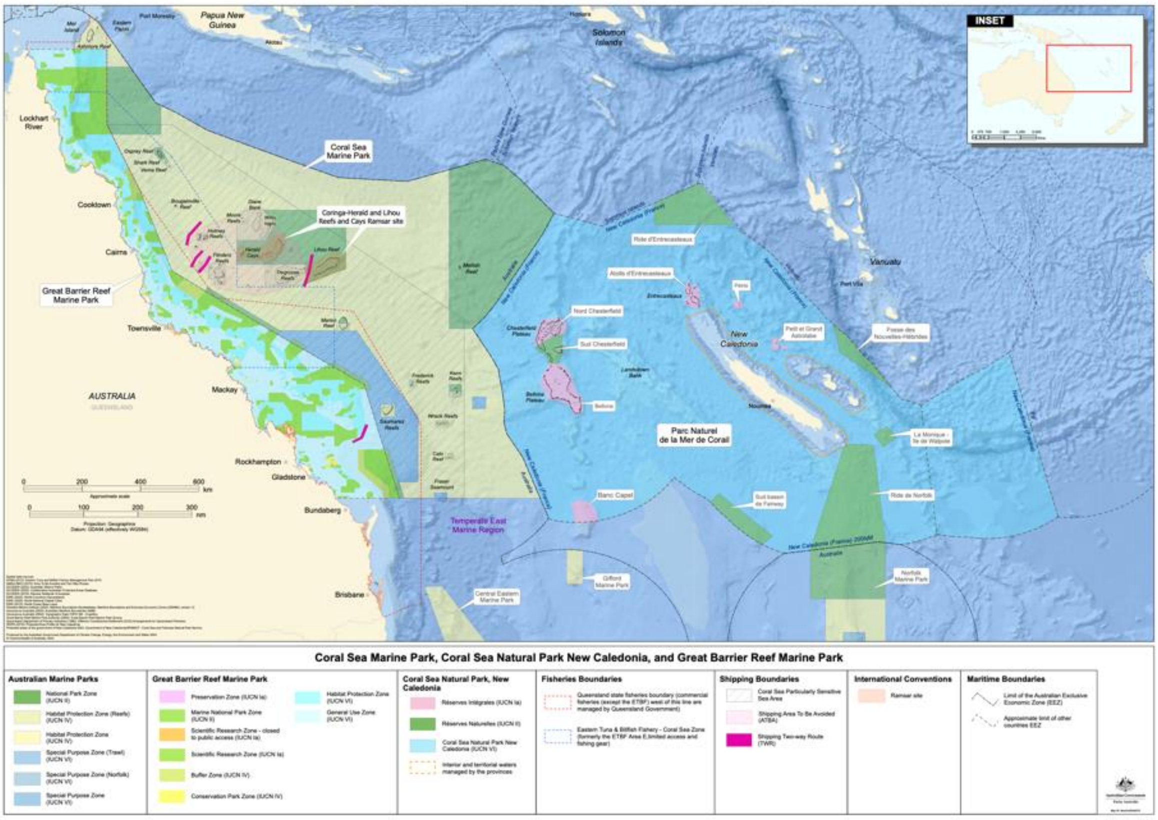

Figure 1.1. Map of the Coral Sea showing the location of the Coral Sea Marine Park and Parc Naturel de la Mer de Corail (Natural Park of the Coral Sea, New Caledonia). Together, these two Marine Parks represent the world's largest protected area. The management zones shown were implemented in the Coral Sea Marine Park in July 2018, and in the Parc Naturel de la Mer de Corail in April 2024. (Source: parksaustralia.gov.au)

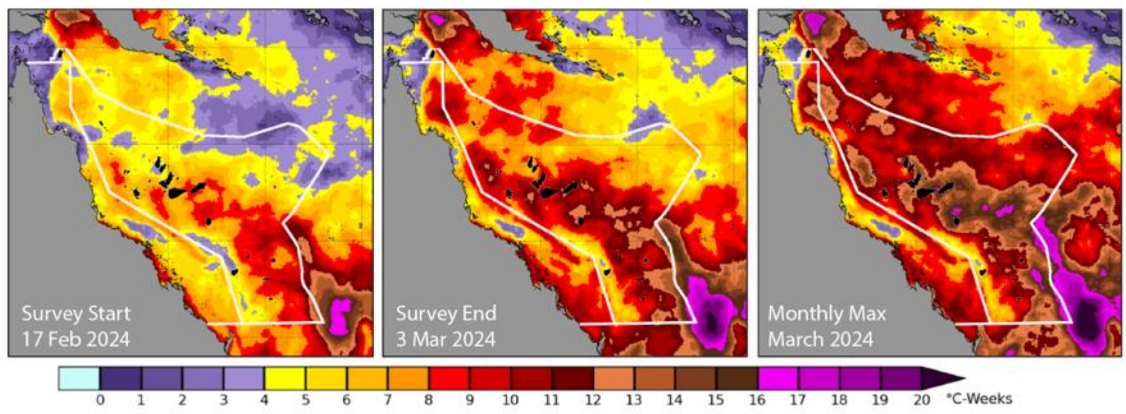

Figure 1.2 Degree heating weeks (DHW) in the Coral Sea Marine Park for February – March 2024 showing the progression of heat stress from the start of the coral reef health surveys (17th February) to the end of the surveys (3rd March), and the monthly maximum heat stress for March 2024. Images produced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

Bleaching-induced mortality can, however, be spatially and temporally variable (Burn et al. 2023; Winslow et al. 2024), with previous exposure to heat stress reducing the incidence of bleaching and associated mortality when exposed to subsequent heat stress (Hughes et al. 2019). There are some suggestions that the increased frequency and severity of bleaching events within the last five years may have resulted in an increased thermal tolerance of corals, potentially enhancing their resilience to marine heatwaves (Lachs et al. 2023).

2.1 Objectives

The objective of this project was to provide comprehensive assessments of the current condition of benthic communities across five reefs within the central CSMP. Specifically, we quantified the cover of live corals during this voyage to compare it with previous surveys at the same sites to provide an indication of any mortality due to the 2024 marine heatwave.

Surveys were conducted at five reefs in the central CSMP following methods of Hoey et al. (2020). At each site, diver-based surveys were conducted along three replicate transects within each of two habitats (reef crest: 1-3m depth; reef slope: 7-10m depth) to provide quantitative information on temporal patterns in benthic cover and composition, including the percentage cover for hard (Scleractinian) and soft (Alcyonarian) corals, macroalgae, and other sessile organisms.

3 Methods

Surveys were undertaken at eight sites across five reef systems (Chilcott, Diamond, and Willis Islets, Herald Cays, and Lihou Reef) within the central CSMP during a 10-day voyage, 8th – 17th July 2024 (Figure 2.1). The majority of these reefs and sites had previously been surveyed in February 2023, the only exception being Chilcott Islet where the previous most recent surveys were conducted in February 2021. Previously surveyed sites were relocated using GPS waypoints and a bearing that provided the direction of the transects from that waypoint.

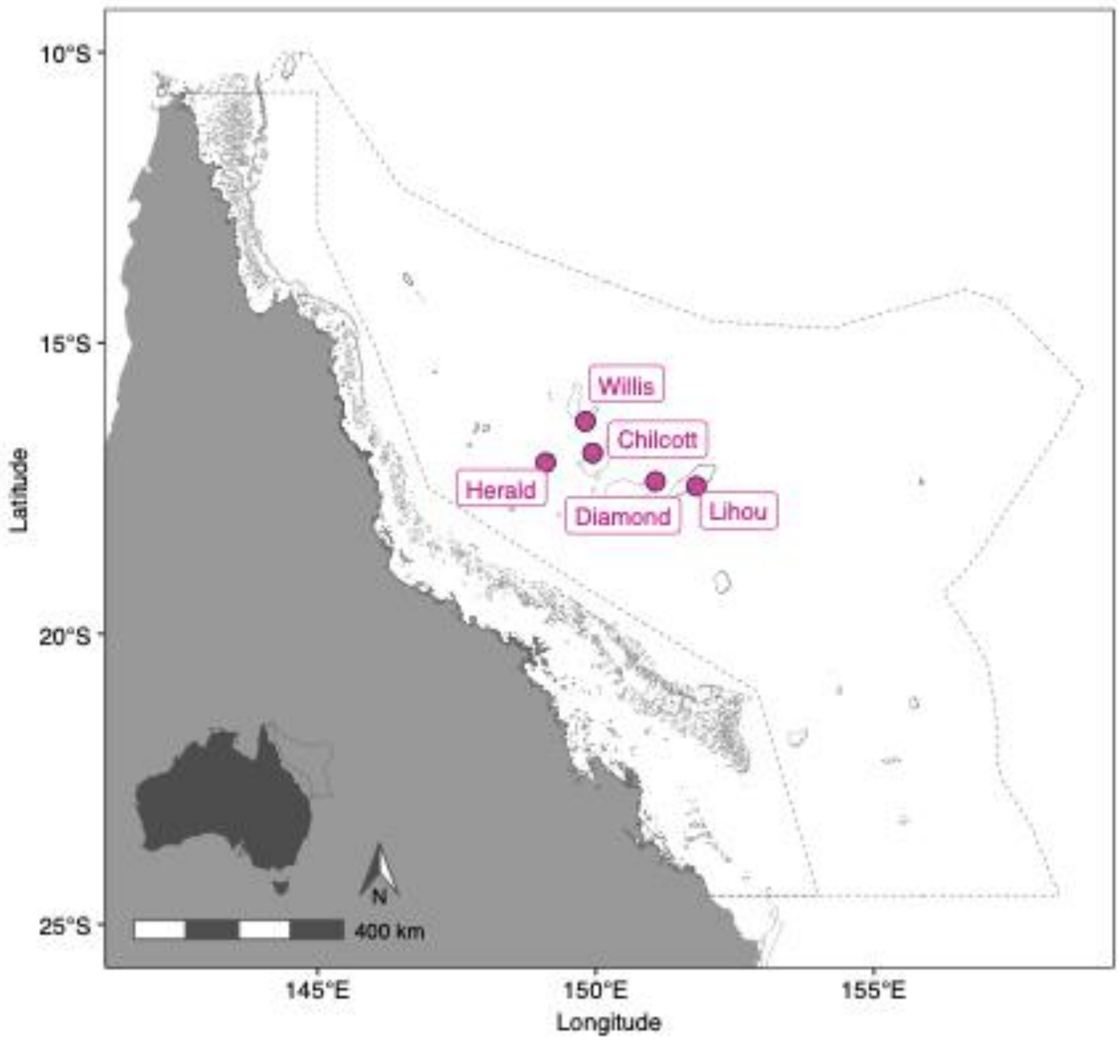

Figure 2.1 Map of the CSMP showing the location of the five reefs in the central CSMP surveyed during the July 2024 voyage. The dashed line indicates the boundary of the CSMP.

3.1 Sampling design

At each site, diver-based surveys were generally conducted within each of two different habitats, i) the reef crest (approximately 1-3m depth) and ii) the reef slope (9-10m depth, where possible). The only exception to this was one site where the reef crest could not be safely accessed due to excessive surge and wave action at the time of the surveys (Lihou site 1). In shallow reef environments (mainly inside lagoons or in back reef environments), where maximum depths were less than 9m, the reef slope transects were run along the deepest margin of contiguous reef habitats, avoiding extensive areas of sand or rubble.

3.2 Coral and reef habitats – Benthic cover and composition

In each depth zone at each site, three replicate 50m point-intercept transects were run parallel to the depth contour, with a minimum of 5m between successive transects. Surveys were conducted by a two-person dive team whereby the lead diver deployed the transect tape along the depth contour, and the second diver took photographs of the benthos every 50cm along the transect (i.e., 100 photographs per transect). The photographs were taken at a height of ~50-70cm above and perpendicular to the substratum.

Each photograph was viewed and the substratum immediately under the transect tape at 50cm intervals was recorded. Whenever possible, corals were identified to genus (using contemporary, molecular-based classifications for scleractinian corals), though some of the less abundant genera were pooled to ‘other’ for analyses. We also distinguished major growth forms for *Acropora* (tabular, staghorn, and other) and *Porites* (massive versus columnar or branching). Macroalgae were identified to genus where possible. For survey points that did not intersect corals or macroalgae, the underlying substratum was categorised as either crustose coralline algae (CCA), sponge, sand/ rubble, carbonate pavement, or other (including gorgonians, hydroids, anemones).

3.3 Data handling and analysis

Data from the 2024 surveys was combined with those of the previous voyages (2023, and 2021 for Chilcott Islet) into a single database and analysed using R version 4.3.2 with RStudio interface version 2023.09.1+494 (R Core Team 2023).

Data were wrangled and visualised using the *tidyverse* environment (Wickham 2017). Maps of the GBRMP and CSMP boundaries were reproduced from shapefiles contained in the data package *gisaimsr* (Barneche and Logan 2021) and *dataaimsr* (AIMS Datacentre 2021), with datasets courtesy of the Great Barrier Reef Marine Park Authority and Geoscience Australia. Two-dimensional maps of CSMP reefs and reef boundaries were reproduced from shapefiles generated by Project 3DGBR (Beaman 2012). These maps were produced in R using the package *sf* (Pebesma 2018) and *ggspatial* (Dunnington 2021) using the GDA2020 coordinate system.

All survey data were averaged across independent transects to obtain a site, or where appropriate a zone (i.e., crest, slope) average prior to summarising data at the level of reefs or regions. For comparisons among years, eight sites in the central CSMP were identified that were surveyed in 2024 that had been surveyed at least once between 2021-2023.

Data are generally presented using box and whisker plots (i.e., box plots). The box plots represent the distribution of the data based on the minimum, first quartile, median, third quartile and maximum values. The lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles). The upper whisker extends from the hinge to the largest value no further than 1.5 * IQR from the hinge (where IQR is the inter-quartile range, or distance between the first and third quartiles). The lower whisker extends from the hinge to the smallest value at most 1.5 * IQR of the hinge. Data beyond the end of the whiskers (i.e., outliers) are plotted individually.

4 Findings

4.1 Temporal changes in coral cover

The mean coral cover of the five reefs surveyed in July 2024 was relatively low in 2024 (11.6 ±1.0% SE), although was slightly greater than the previous surveys at the same sites (2021/2023: 10.2 ±0.6%). This represents an increase of 1.4% in absolute coral cover, and a relative increase of 14.4%. Excluding Chilcott Islet from these comparisons resulted in a slightly greater increase in coral cover from 2023 (7.1%) to 2024 (10.7%; Figure 3.1). This small increase in coral cover was relatively consistent among the four reefs surveyed in both 2023 and 2024 (Figure 3.2), and sites within each reef (Figure 3.3). In contrast, coral cover declined on Chilcott Reef from 22.9% in 2021 to 18.7% in 2024 (a relative decline of 18.5%; Figure 3.2). Given the broader timeframe between consecutive surveys at Chilcott Islet it is difficult to attribute the cause of this decline, and may have been related to heat stress experienced during the 2021, 2022 and/or 2024 summers (Figure 1.1). Regular surveys of at least some reefs are essential to determine the causes of any declines in coral cover and reef health.

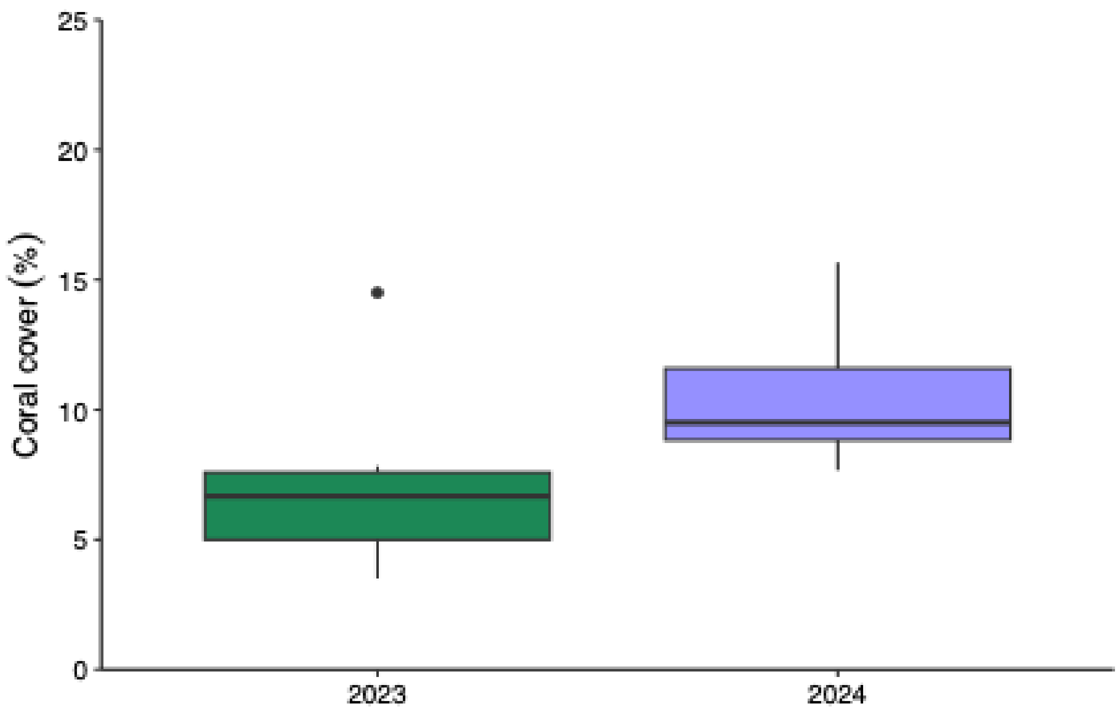

Figure 3.1 Variation in coral cover between February 2023 and July 2024 on four reefs the Central CSMP. Data are based on 50m point intercept transects. Reefs surveyed were Diamond Islets, Herald Cays, Lihou Reef, and Willis Islets.

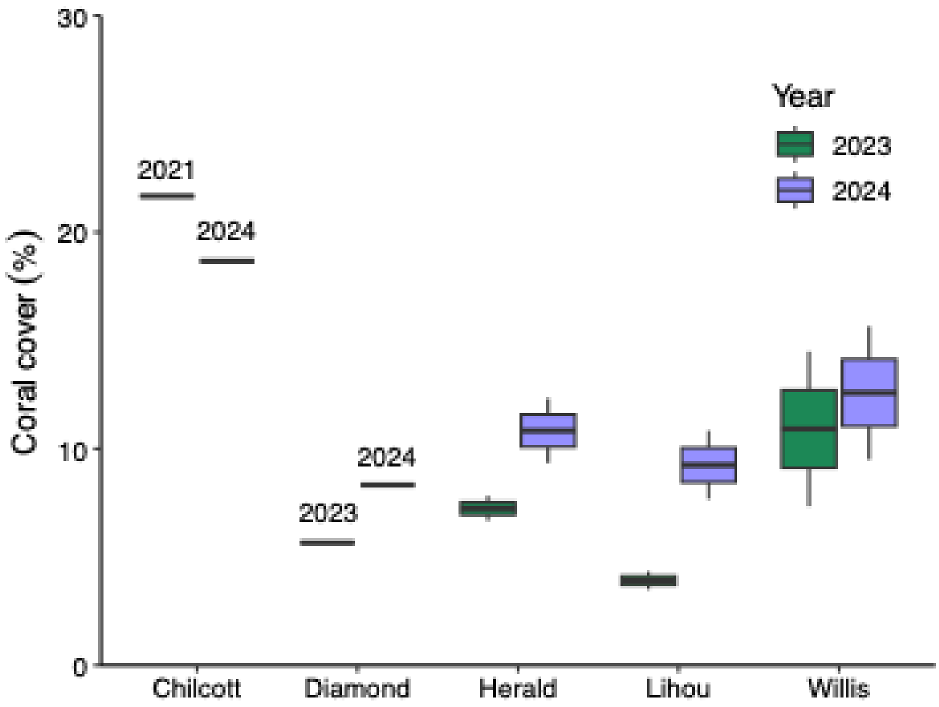

Figure 3.2 Temporal variation in coral cover among five reefs in the CSMPthat were surveyed at least once in February 2021 or February 2023 and resurveyed in July 2024. Data are based on surveys of matching sites in each year and pooled between habitats (reef slope and reef crest) and sites within each reef.

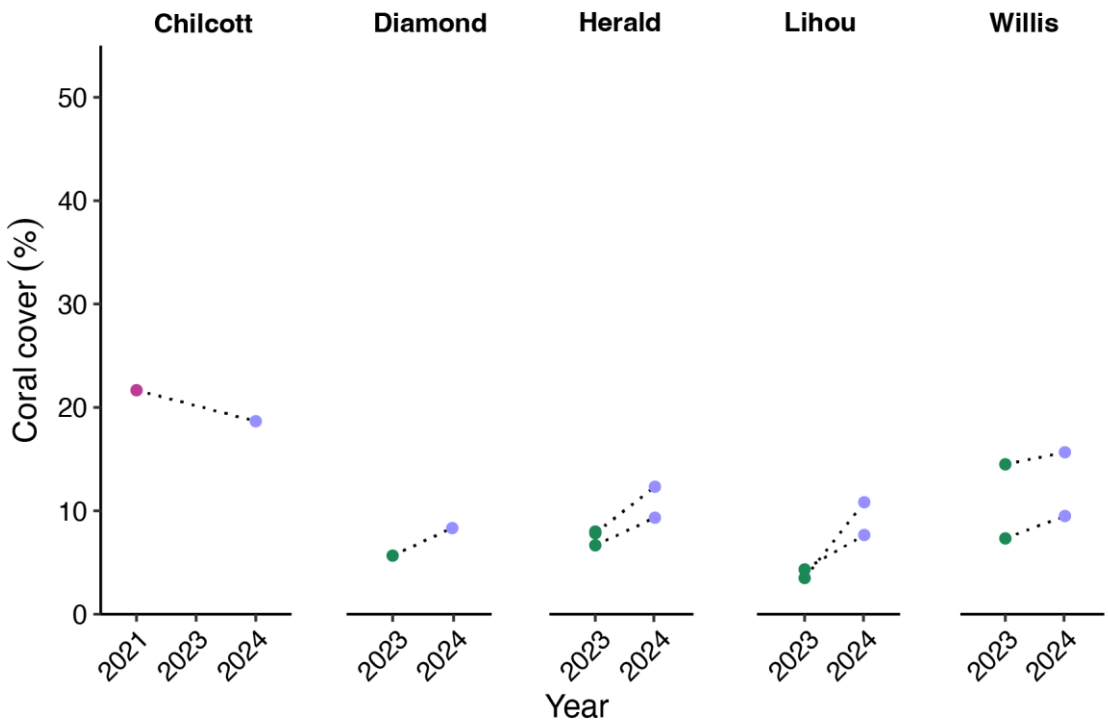

Figure 3.3 Temporal variation in coral cover among eight sites in the CSMP that were surveyed at least once in February 2021 or February 2023 and again in July 2024. Data

are based on replicate point-intercept transects of sites in each year and pooled between habitats (reef slope and reef crest) within each site.

Changes in coral cover varied among habitats with the greatest increases recorded on the reef crest at Herald Cays (2023 5.4%; 2024: 11.5%) and Lihou Reef (2023 3.1%; 2024: 11.3%), whereas coral cover on the reef slope of these reefs remained relatively stable over the same period (Figure 3.4). In contrast, the greatest increase on Diamond and Willis Islets were recorded on the reef slope, while only small increases were recorded on the reef crest (Figure 3.4). The decline in coral cover at Chilcott Islet was solely attributable to a decrease in coral cover (2021: 23.7%; 2024: 15.7%) on the reef crest, while there was a small increase in coral cover on the reef slope over the same period (2021: 19.7%; 2024: 21.7%; Figure 3.4).

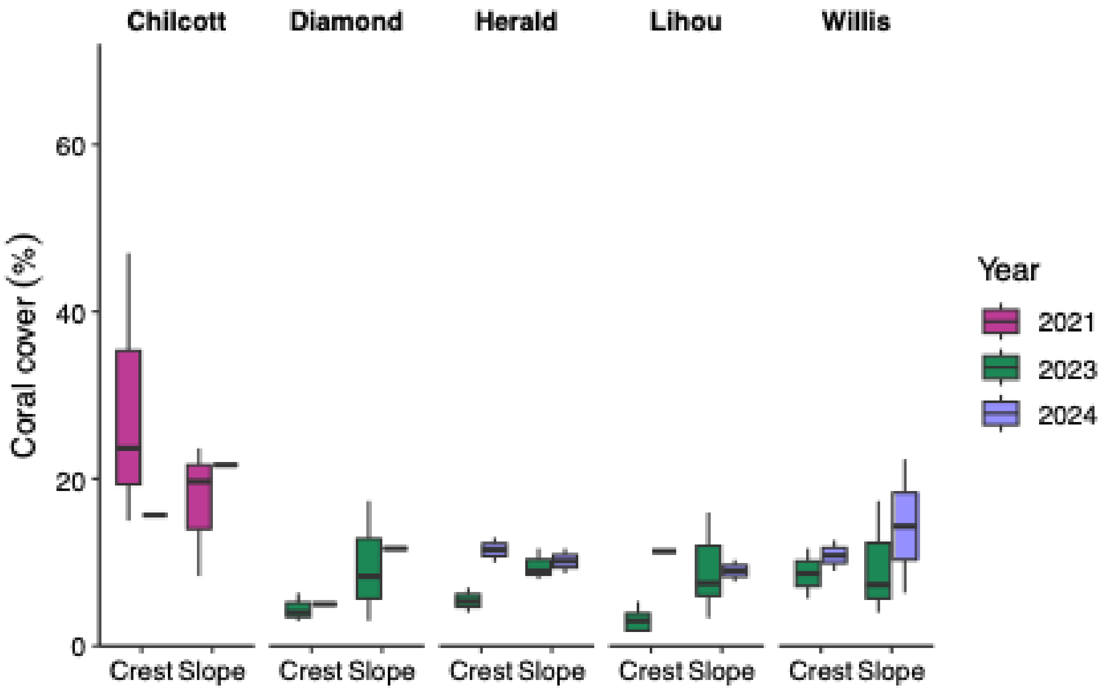

Figure 3.4 Temporal variation in coral cover between shallow reef habitats (reef crest and reef slope) within five reefs of theCSMP. Data are based on surveys of 8 matching sites in 2021 (Chilcott Islet), 2023 (Diamond Islets, Herald Cays, Lihou Reef, and Willis Islets), and 2024 (all reefs) and pooled between habitats (reef slope and reef crest) within each site.

Comparisons of the change in cover of the eight most abundant coral taxa reveal marked differences among taxa, ranging from a ~197% increase in the cover of

Pocillopora to a 55% decline in the cover of *Leptastrea* (Figure 3.5). Overall, six of the eight most abundant coral taxa increased in cover (*Pocillopora, Goniastrea,* massive *Porites*, *Cyphastrea, Psammacora,* and 'other' *Acropora*), while one taxa (*Montipora*) showed no change in cover and one taxa (*Leptastrea*) experienced a decline in cover (Figure 3.5).

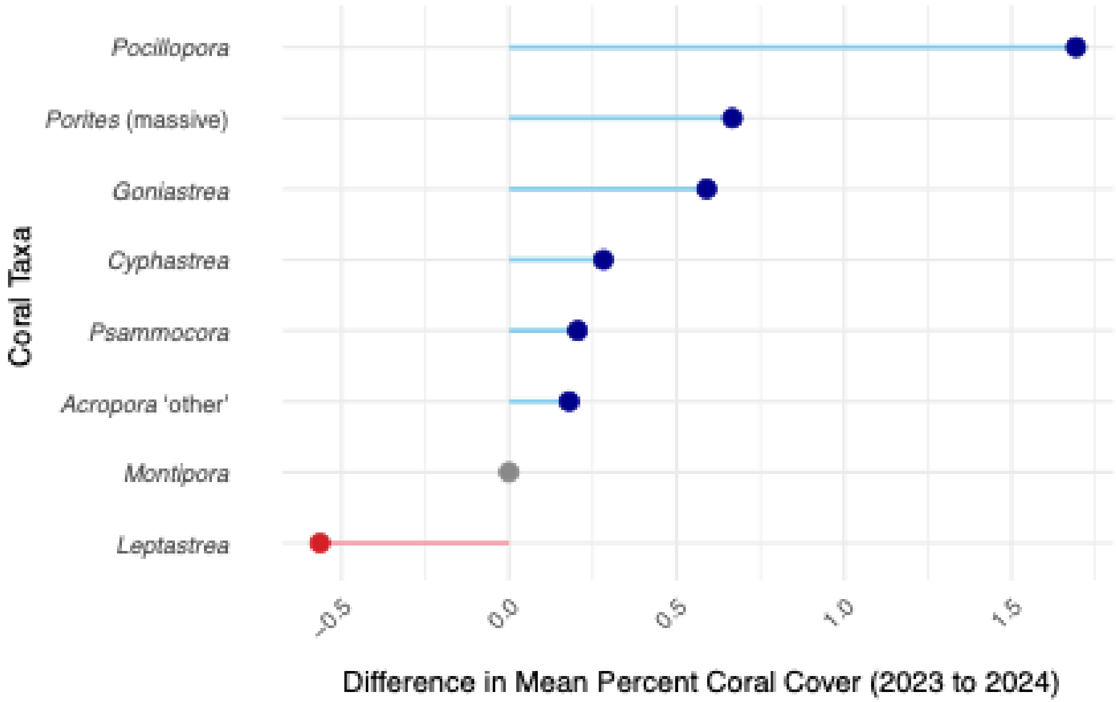

Figure 3.5 Difference in mean percent cover of the eight most abundant coral taxa between February 2023 and July 2024 in the CSMP. Data are based on surveys across four reefs (Diamond Islets, Herald Cays, Lihou Reef, Willis Islets).

5 Conclusions

The surveys conducted on the five reefs in the central CSMP in July 2024, suggest that bleaching-driven coral mortality during the February/March 2024 marine heatwave on shallow water coral assemblages was low. Despite a decline in the abundance of some coral taxa (namely *Montipora* and *Leptastrea*), and observations of recent mortality of some coral colonies, we did not detect widespread declines in coral cover across the eight sites and five reefs surveyed. Rather, between February 2023 and July 2024 we observed small increases in coral cover across ~~the~~ four reefs surveyed. This is surprising given this area in the CSMP experienced heat stress of up to 16 DHW in late March 2024. Previous studies have shown that heat stress of 8 DHW or greater is expected to result in extensive bleaching and mortality of corals (e.g., Hughes et al. 2017).

These data were consistent with qualitative observations of the health of shallow water corals at Osprey Reef, northern CSMP in June 2024 where the incidence of bleaching and bleaching-induced mortality was highly variable among sites (V. Huertas pers. obs.). No bleaching or mortality was observed at sites along the western and north-western aspect of Osprey Reef. The only site in which bleaching and recent mortality was observed, was at a shallow embayment known as 'False Entrance', where primarily branching *Acropora* corals were showing signs of heat stress, from pale to fluorescing and some colonies completely bleached. There was evidence of recent mortality with some colonies being recently overgrown by turf communities (Figure 4.1).

We caution that the apparent limited effects of the 2024 marine heatwave on shallow coral communities across the five reefs surveyed, may not be representative of other sites and reefs within the CSMP. In addition, it is important to note that all reefs surveyed had low coral cover (mean = 11.6%) and low cover of many of the bleaching susceptible taxa that were lost to previous heat stress events (e.g., Hoey et al. 2020, 2022). Several other reefs within the CSMP have considerably higher coral cover, including high cover of bleaching-susceptible taxa (e.g., *Acropora*), and may have been adversely affected by the 2024 marine heatwave (e.g., bright spot reefs such as Mellish and Moore Reefs; Hoey et al.

2022). Surveys in the next 6-12 months will be critical to determine the broader impacts of this heatwave on shallow coral communities within the CSMP.

Alternatively, these reefs may not have experienced the heat stress as predicted by the NOAA satellite products. In February 2023 and February 2024, we deployed temperature loggers across most large reef systems within the CSMP to record *in situ* water temperatures on shallow coral reefs. These loggers recorded temperature data during the 2024 marine heatwave. Retrieving these loggers and comparing *in situ* temperatures to those from NOAA's satellite-derived products should be a high priority, if not an essential target, of future monitoring within the CSMP.

5.1 Recommendations

- Surveys in the next 6-12 months will be critical to determine the broader impacts of this heatwave on shallow coral communities within the CSMP, and the potential recovery of coral populations from previous bleaching events

- Retrieving the temperature loggers deployed throughout the CSMP in February 2023 and February 2024 is critical to understanding the heat stress experienced on reefs throughout the region, and hence the resilience of these communities to these events. This would also facilitate comparisons of *in situ* temperatures to those derived from the NOAA satellite products to inform management.

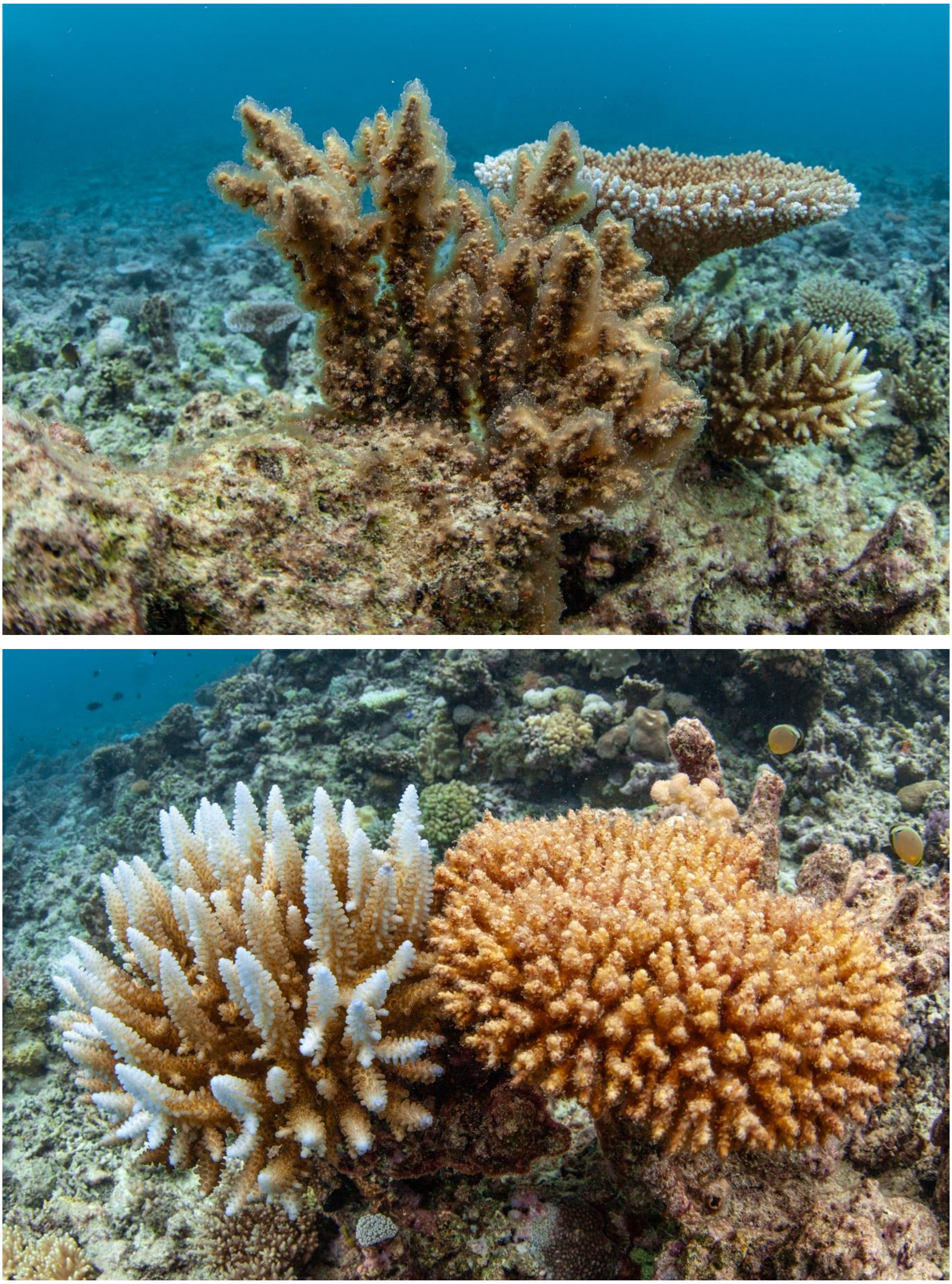

Figure 4.1 Photographs showing the differential effects of heat stress on branching *Acropora* corals at Osprey Reef, northern Coral Sea Marine Park in June 2024. Top: A recently dead branching *Acropora* colony in the foreground with healthy tabular and branching *Acropora* in the background. Bottom: A partially-bleached *Acropora* (left) next to a recently dead *Acropora* that is being overgrown by a turfing community (right). Image credits: V. Huertas.

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7 APPENDIX 1 – Sites surveyed.

List of the eight sites surveyed across five reefs in the central Coral Sea Marine Park (CSMP) during July 2024.

Reef	Site	Habitat/s	Exposure	Aspect	Lat	Long
Chilcott	Chilcott 2	Reef slope and crest	Sheltered	NW	-16.93962	149.99644
Diamond	Diamond 2	Reef slope and crest	Sheltered	W	-17.43684	151.06972
Herald	Herald 1	Reef slope and crest	Semi-exposed	E	-16.94348	149.18565
	Herald 6	Reef slope and crest	Sheltered	E	-16.99189	149.13075
Lihou	Lihou 1	Reef slope	Sheltered	NW	-17.59707	151.48956
	Lihou 2	Reef slope and crest	Sheltered	N	-17.59065	151.50027
Willis	Willis 2	Reef slope and crest	Sheltered	W	-16.28728	149.95930
	Willis 4	Reef slope	Semi-exposed	NE	-16.28256	149.96570