Australian Government
Great Barrier Reef
Marine Park Authority

Queensland
Government

2018–2023 MONITORING OF REPOSITIONED CORAL BOMMIES AT MANTA RAY BAY, HOOK ISLAND, WHITSUNDAY ISLAND GROUP

July 2026

Maya Srinivasan[1], Daniela M. Ceccarelli[2], Geoffrey P. Jones[1], David Williamson[3] and Neil Mattocks[3]
[1] James Cook University. [2] The Australian Institute of Marine Science. [3] Great Barrier Reef Marine Park Authority.

Published by the Great Barrier Reef Marine Park Authority
ISBN 978-0-6453809-7-2

Disclaimer

While all efforts have been made to verify facts, the Great Barrier Reef Marine Park Authority takes no responsibility for the accuracy of information supplied in this publication.

All images are copyright of the Commonwealth of Australia (Great Barrier Reef Marine Park Authority) unless otherwise stated.

Aboriginal and Torres Strait Islander readers are advised this publication may contain names and images of deceased persons.

A catalogue record for this publication is available from the National Library of Australia.

This publication should be cited as:

Great Barrier Reef Marine Park Authority 2026, *2018–2023 Monitoring of Repositioned Coral Bommies at Manta Ray Bay, Hook Island, Whitsunday Island Group*, Reef Authority, Townsville.

Comments and questions regarding this document are welcome and should be addressed to:

Great Barrier Reef Marine Park Authority
Townsville office (Wulgurukaba and Bindal Country)
235 Stanley Street
(PO Box 1379)
Townsville QLD 4810, Australia

Phone: (07) 4750 0700
Fax: (07) 4772 6093
Email: info@gbrmpa.gov.au
Website: www.reefauthority.gov.au

Acknowledgements

This work was part of the Reef Joint Field Management Program, managed by the Great Barrier Reef Marine Park Authority (Reef Authority) and Queensland Parks and Wildlife Service (Department of the Environment, Tourism, Science and Innovation). This report was prepared by the Great Barrier Reef Marine Park Authority with assistance and contributions from many others, notably James Cook University and the Australian Institute of Marine Science.

The Reef Authority acknowledges the expertise, wisdom and enduring connections of Traditional Owners that have informed the guardianship of the Great Barrier Reef for millennia. We pay our respects to them as the first managers of this Land and Sea Country, and value their traditional knowledge which continues to inform the current management and stewardship of the Reef for future generations.

Background

The Whitsunday Islands, located off Airlie Beach, support around 6,000 hectares of fringing coral reefs and is one of the most highly valued and frequented regions of the Great Barrier Reef Marine Park for tourism and recreational activities. Manta Ray Bay, at the northern end of Hook Island (Figure 1), is especially renowned for its easily accessible fringing reef, its status as a Marine National Park Zone (a no-take 'green zone') and the high density of large reef fish that reside there.

However, the region's coral reefs, including those of Manta Ray Bay, were severely impacted by Cyclone Debbie, which made landfall at Airlie Beach in late March 2017. With wind gusts exceeding 250 km/h and wave heights reaching at least 8 m (Bureau of Meteorology 2018), the cyclone caused significant damage. The island group's northern fringing reefs, in particular, experienced a loss of over 50% of their live hard coral cover (Williamson et al. 2018). In some areas, such as Manta Ray Bay, entire coral bommies were displaced, rolled onto shallow reef flats and beaches.

In response, the Reef Authority worked with Queensland Parks and Wildlife Service (QPWS) rangers to reposition approximately 400 tonnes of displaced bommies from the shallow, intertidal zone of the reef flat at Manta Ray Bay to the deeper, subtidal zone in June 2017, around three months after Cyclone Debbie. The primary objectives of the bommie repositioning were to:

1. restore access for small vessels (tenders) and swimmers
2. partially restore the damaged fringing reef at Manta Ray Bay.

The action was authorised under Section 5.4 of the Great Barrier Reef Marine Park Zoning Plan 2003 (McLeod et al. 2019).

To assess the ecological effects and potential benefits of the bommie repositioning, a rapid baseline ecological survey was conducted in October 2018, about 16 months after the relocation (McLeod et al. 2019). This was followed by re-surveys in 2019, 2021, 2022 and 2023, 12–14 months apart. This report presents the results of these five surveys, compared with monitoring surveys conducted on the reef slope at Manta Ray Bay in 2016 (pre-cyclone), 2017, 2018 and 2022.

Figure 1: Map of the Whitsunday Islands with Manta Ray Bay indicated by the green marker.

Methods

The initial survey of the repositioned bommies at Manta Ray Bay was conducted on 24 October 2018 and follow-up surveys were conducted on 11 December 2019, 19 March 2021, 25 March 2022 and 30 May 2023. Each time, a surface marker buoy was placed at the GPS waypoint for the westernmost bommie (349), and a second surface marker buoy was placed at the easternmost bommie (357) in 2022 and 2023, to locate the bommies. We then completed a short (15–20 min) dive, searching for the bommies and laying out a transect tape, starting from bommie 349, using the map provided by QPWS (Figure 2).

Figure 2: Map of Manta Ray Bay reef flat showing the locations of the repositioned bommies (green markers) and the single 120 m transect deployed from bommie 349 to 364 (blue line).
© Queensland Government

During the initial survey in 2018, we found that there were more bommies than those numbered on the map and selected 22 of the largest ones to survey. To provide a visual record of the bommies, each of the bommies was photographed from two directions, from the north and south. In 2018 and 2019, the top of each bommie was also photographed but this was not possible in subsequent years due to the tidal level, i.e. there was not sufficient water depth above the bommies to photograph them from above. All photographs were labelled with the corresponding bommie number, consistent with those taken in previous years and the direction from which the picture was taken. From 2019 onward, we used the photographs taken of each bommie to help in identifying individual bommies.

Each survey period, after the initial dive when the transect tape was laid out, the divers left the area to allow the mobile fishes to return. Two longer dives were then conducted. In the first of these dives, one diver swam along the transect, surveying fishes and the other diver followed behind, conducting benthic surveys of the bommies. In 2018 and 2022, a third diver took the photos of the bommies. During the next dive, the benthic surveys continued and, in 2019, 2021 and 2023, the diver who surveyed the fishes photographed the bommies.

For benthic surveys, each bommie was treated as an individual sampling unit (replicate). The cover of remnant live coral (*Porites* sp.) tissue on each bommie was estimated visually as a percentage of the exposed surface of the bommie (i.e. not including the part of the bommie resting on the sand). All other corals were identified to genus level and placed in 5 cm size categories (i.e. ≤ 5, 6–10, 11–15, 16–20 and so on). Each non-*Acropora* coral was photographed to verify the genus recorded. In 2021, some of the coral genera were updated to reflect recent changes in coral nomenclature (e.g. the genus *Favia* no longer exists) and since then, Kelley (2021) has been used as the primary identification guide. Other invertebrates such as soft corals, boring clams (*Tridacna crocea*) and trochus were also recorded, and the sizes of soft corals (diameter) and boring clams (length) were placed into 5 cm size categories.

In 2019, one of the bommies surveyed in 2018 was not found, and in 2021, a further three bommies were not found. We believe this is most likely due to a combination of inaccuracies in our map of the bommies and the bommies changing position slightly between survey periods and appearing different to the photos taken in the previous year. In addition, the quality of some of the bommie photos in 2021 was poor due to low visibility, and we were unable to take photos of the tops of many of the bommies in 2021 and 2022 due to the receding tide. In 2021, four bommies that were not found were replaced by four new ones.

In 2022, 21 of the 22 bommies surveyed in 2021 were located and surveyed. Each of these 21 bommies was tagged using plastic plant tags attached with concrete nails to the top surface of the bommie (Figure 3). Each tag had the bommie number both engraved and written on it using an engraving tool and a permanent marker. In 2023, we were unable to locate any of these tags and there had been such rapid growth of many of the corals on the bommies, it was difficult to identify individual bommies using the photos taken in previous years. A total of 18 bommies were surveyed in 2023. Fortunately, 17 of these had been surveyed in each of the four previous survey periods.

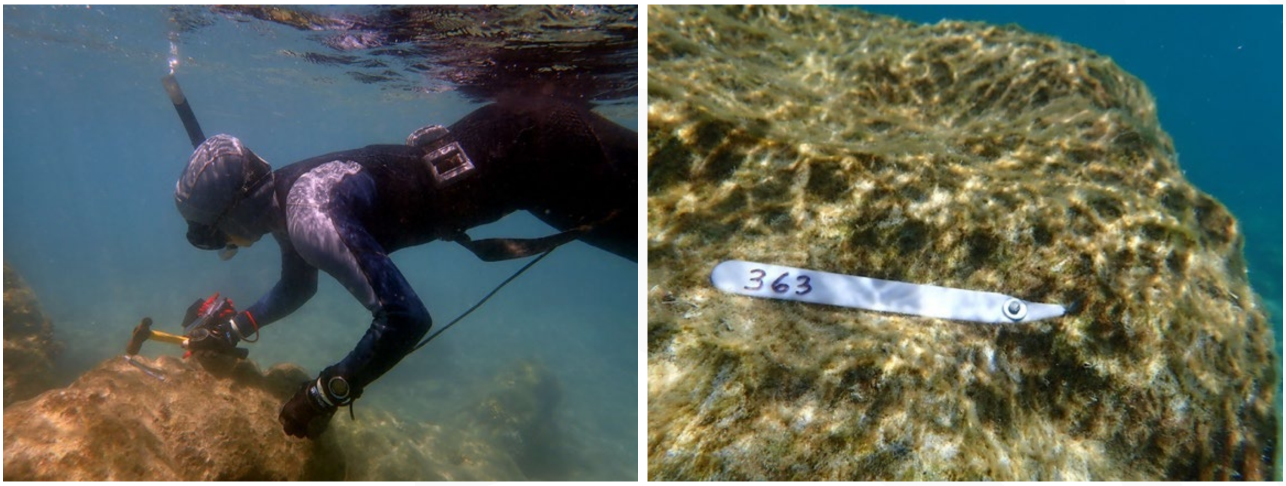

Figure 3: Tagging of bommies in 2022 using plastic plant tags and concrete nails. © Reef Authority | Photographer: Geoffrey P. Jones

The Friedman test was used to test for differences on the 17 bommies that were surveyed across years, including:

1. the number of coral recruits
2. the number of *Acropora* recruits
3. the number of coral genera.

This test is a non-parametric alternative to the one-way repeated measures ANOVA (Kassambara 2019) and was used due to the data violating the assumption of normality of ANOVA even after transformation. When the Friedman test was significant, pairwise Wilcoxon signed-rank tests were used to identify which pairs of years had significant differences between them.

Fishes were surveyed along a single 120 m transect that was run alongside the bommies beginning at bommie 349 and ending at bommie 363 (Figure 2). During each survey, all fishes that were observed within a 4 m wide band along the transect (total survey area of 480 m^2) were recorded to species.

Figure 4: Repositioned bommies and colonising organisms: (a) surveyed *Porites* sp. bommie; (b) bommie with *Acropora* recruits of several species and sizes in 2022 and a large (>30 cm) soft coral; (c) parrotfish damage to an *Acropora* recruit; (d) older *Acropora* recruit growing into a corymbose or plating form; (e) encrusting *Porites* species (dark brown patch in the lower half of the photo) competing with remnant live *Porites* tissue; (f) boring clam (*Tridacna crocea*) on a bommie. Photos: Geoff Jones (panels a–b) and Maya Srinivasan (panels c–f). © Reef Authority

Results and discussion

Percent cover of remnant *Porites* tissue

All surveyed bommies were massive *Porites* sp. colonies ranging from approximately 1–3 m in diameter (Figure 4a). The percent cover of remnant live *Porites* on each bommie ranged from 0–30% (Figure 5), with the mean ranging from 4–5.5 across the five years (Figure 6). In 2023, most of the bommies had a similar percent cover of remnant coral tissue as they had in 2018 and 2019, however, several bommies had a slight increase in *Porites* cover in the last three years (Figure 6). For example, bommie 354 had an increase from 15% in 2018 and 2019 to 20% in 2021, and 2022 to 25% in 2023 (Figure 6). Similarly, bommie 354C had an increase from 20% in 2018, 2019 and 2021, to 25% in 2022, and 30% in 2023 (Figure 6). Bommie 355 had no *Porites* tissue visible in the first four surveys, but in 2023, a small amount (roughly 1% of the bommie) was visible. Five bommies have had no *Porites* tissue on them in all five surveys, four of which are the ones that are in the shallowest water, closest to shore (360–363).

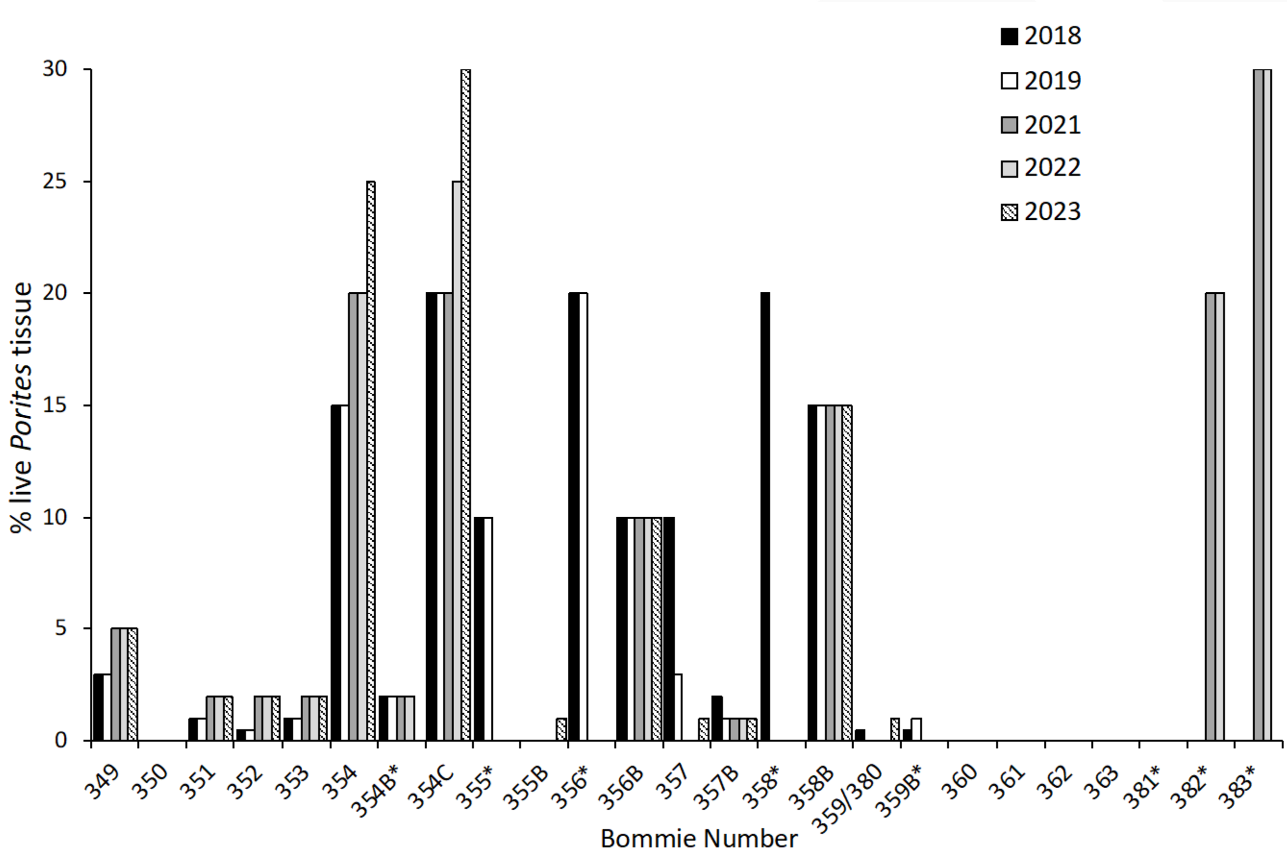

Figure 5: Percent cover of remnant live coral tissue on each of the surveyed bommies. Asterisks indicate bommies that were not surveyed in all five years (i.e. 358 was only surveyed in 2018; 355 and 356 were only surveyed in 2018 and 2019; 359B was surveyed in 2018, 2019 and 2021 but not in 2022 and 2023; and 382–383 were only surveyed in 2021 and 2022). Bommie 359 was not identified in 2021 but we realised in 2022 that this was likely the same bommie that we surveyed as a new bommie in 2021 (and given the number 380) that had been flipped over between the 2019 and 2021 surveys.

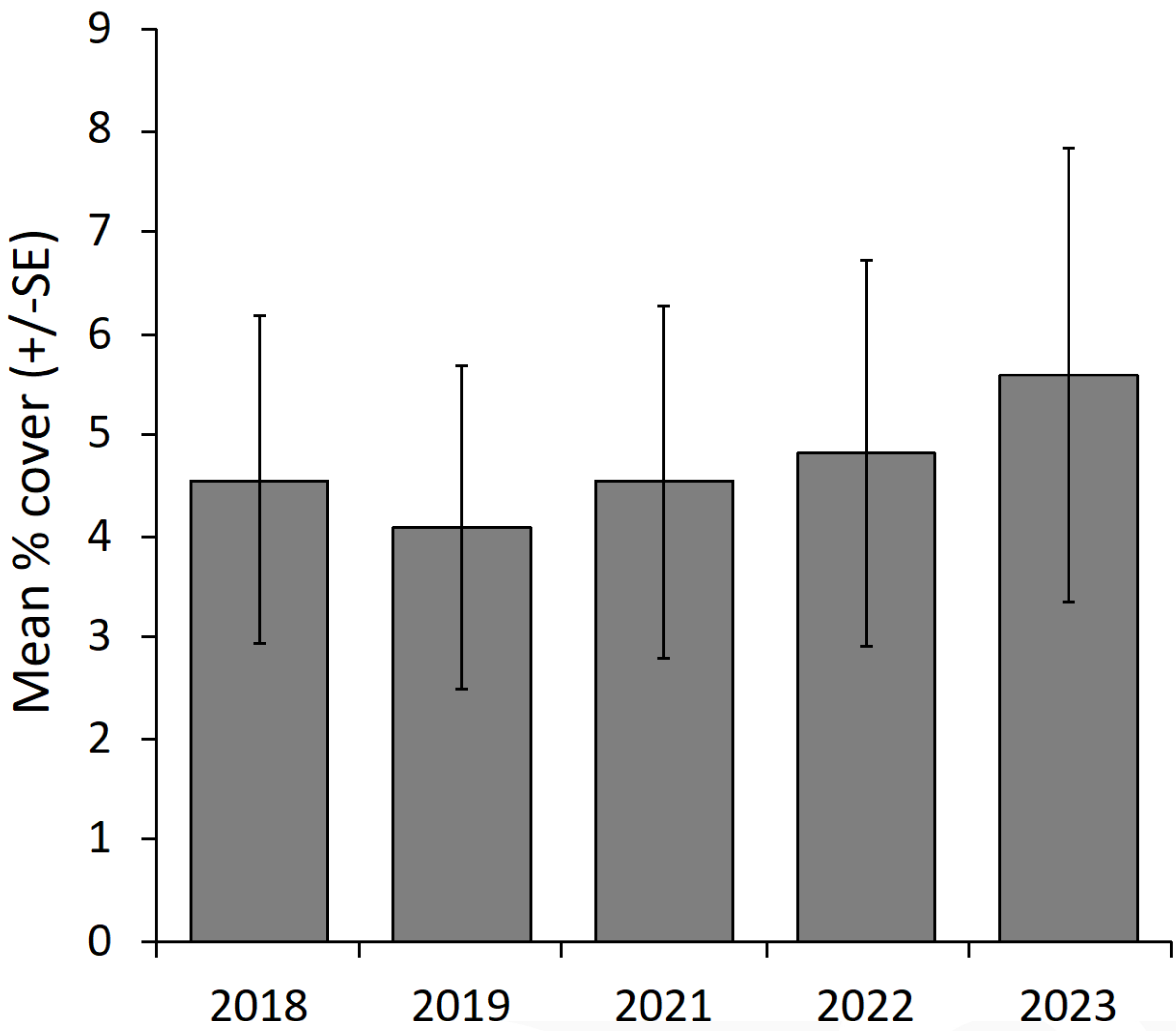

Figure 6: Mean percent cover of remnant live *Porites* tissue on the surveyed bommies in each year. These means were calculated using only the bommies that were surveyed in all 5 years (n = 17).

Porites sp. colonies have the capacity to recover through asexual reproduction of remnant coral polyps, which overgrow and recolonise dead sections of the colony, provided that these sections are not overgrown by macroalgae or other sessile organisms (Roff et al. 2014). So far, the tissue on the surveyed bommies has not expanded significantly, which is likely a reflection of the slow growth rates typical of *Porites* species (Lough et al. 2016). The rate of remnant live tissue expansion is variable and is influenced by numerous factors, including water quality; rates of algal grazing and coral scraping by reef fishes; disturbances such as coral bleaching, flood plumes or cyclones; and by contact damage from divers and snorkellers. It can also be influenced by coral juveniles settling on the dead sections of the bommies and the growth and expansion of these new colonies, inhibiting the growth of the host coral. On one of the bommies, we observed an encrusting species of *Porites*, which has likely recruited to the bommie, in active competition with the remnant *Porites* tissue of the bommie (Figure 4e). Tracking the total percent cover of remnant *Porites* coral tissue on each of the bommies will continue to be a crucial component of future monitoring, providing information on the potential for coral colonies to survive and recover after cyclone damage and being repositioned. Due to the small amount of remnant tissue on these colonies combined with slow growth rates of massive growth forms of *Porites*, and overgrowth by other faster growing benthic organisms (e.g. sponges, soft corals and hard corals such as *Acropora* species), it is possible that there will not be a significant increase in the amount of live *Porites* tissue on these bommies.

Coral recruitment to the repositioned bommies

There has been an increase in the total number of corals recruiting to the bommies in each survey, from just 17 coral recruits on 22 bommies in 2018, to 201 in 2019, 320 in 2021, 516 in 2022 and 457 in 2023. The lower number of recruits in 2023 compared with 2022 is likely due to three fewer bommies surveyed, or to less vacant space on the bommies as recruit numbers increase. The number of recruits per bommie ranged from 0–6 in 2018, 0–29 in 2019, 0–37 in 2021, 1–65 in 2022 and 2–56 in 2023, mostly *Acropora* species (Figure 7). From 2019 onwards, bommie 356B, the largest bommie surveyed, had the highest number of recruits (Figure 7).

The mean number of coral recruits increased significantly between 2018 and 2023 (Friedman test, $c^2(4) = 56.848$, $p < 0.001$), with pairwise comparisons showing that the mean number of recruits per bommie in 2019 and 2021 was significantly higher than in 2018, and the mean number of recruits in 2022 and 2023 was significantly higher than in 2019 and 2021 (Figure 8a). As the coral recruits consisted mostly of *Acropora* recruits, the results were similar when the number of *Acropora* recruits was analysed separately, with a significant difference across all years (Friedman test, $c^2(4) = 55.015$, $p < 0.001$), the mean number in 2019–2021 being significantly higher than in 2018, and the mean number in 2022 and 2023 being significantly higher than the earlier three years (Figure 8b).

Four of the five bommies (360–363) with the fewest recruits were closest to shore. These four bommies had no coral recruits in 2018, between 0–3 *Acropora* recruits in 2019, no coral recruits in 2021 (i.e. the few recruits recorded in 2019 did not survive) and 1–9 recruits in 2022 (Figure 7). These bommies' proximity to shore and vulnerability to snorkellers may explain the low recruitment. Manta Ray Bay usually has many snorkellers visiting and these bommies are shallow enough to stand on at low tide. From our observations, made while searching for the bommies, other smaller bommies nearby were equally bare. This suggests that these bommies should have been placed further from shore.

The number of coral genera per bommie ranged from 1–4 in 2018, 1–5 in 2019 and 2021, and 1–7 in 2022 and 2023. The mean number of genera differed significantly among years (Friedman test, $c^2(4) = 29.457$, $p < 0.001$) with 2018 showing significantly fewer genera than 2019–2023, and 2019 having significantly fewer than 2022 when the number of genera was the highest (Figure 8c). The number of genera was similar among 2019, 2021 and 2022.

Over the last five years, 16 coral genera have been recorded on bommies: *Acropora*, *Acanthastrea*, *Coeloceris*, *Cyphastrea*, *Dipsastraea*, *Favites*, *Goniastrea*, *Hydnophora*, *Leptastrea*, *Lobophyllia*, *Montipora*, *Pocillopora*, *Platygyra*, *Psammocora* and encrusting *Porites* species (Figure 7). Sometimes, a genus recorded in one year was not recorded the following year. For example, one *Coeloceris* recruit was recorded in 2019 on bommie 354B, but this recruit was not recorded in 2021 and 2022. One *Leptastrea* recruit was recorded on bommie 353 in 2022 but not in any of the other years. The disappearance of these recruits could be due to predation or some other disturbance. In 2021 and 2022, just over 90% of coral recruits were *Acropora* species, compared with 78% in 2019 and 12% in 2018 (Figure 7). Cyclone Debbie likely had a disproportionate effect on *Acropora* corals, which are most susceptible to storm damage due to their branching growth forms and it is possible that the low percentage of *Acropora* recruits in initial surveys is due to the supply of recruits being very low immediately after the cyclone.

The bommies were repositioned in June 2017, subjecting them to six coral spawning seasons prior to the latest survey in 2023. The rapid increase in recruit numbers suggests that Manta Ray Bay receives a healthy supply of coral larvae and the bommies offer suitable settlement substratum for arriving coral recruits. After five years of surveys, this is likely to be a representative post-cyclone assemblage for this area, with fast-growing *Acropora* corals tending to dominate in early stages of recovery following a disturbance (Emslie et al. 2008, Johns et al. 2014, Tebbet et al. 2021). Other coral genera had much lower abundances (Figure 7) and some genera have been recorded just once. We have observed that *Acropora* corals also dominate the surrounding areas of reef flat, indicating that coral recruitment on the bommies is part of the natural recolonisation process following a major disturbance. However, it will take longer to establish what is likely to be a typical mature assemblage, the composition of which will only become apparent with further, long-term monitoring. Although the adjacent areas of reef have not been monitored, it would be useful to start monitoring these to compare coral communities on the bommies with those in adjacent areas of hard, pavement-like substrate.

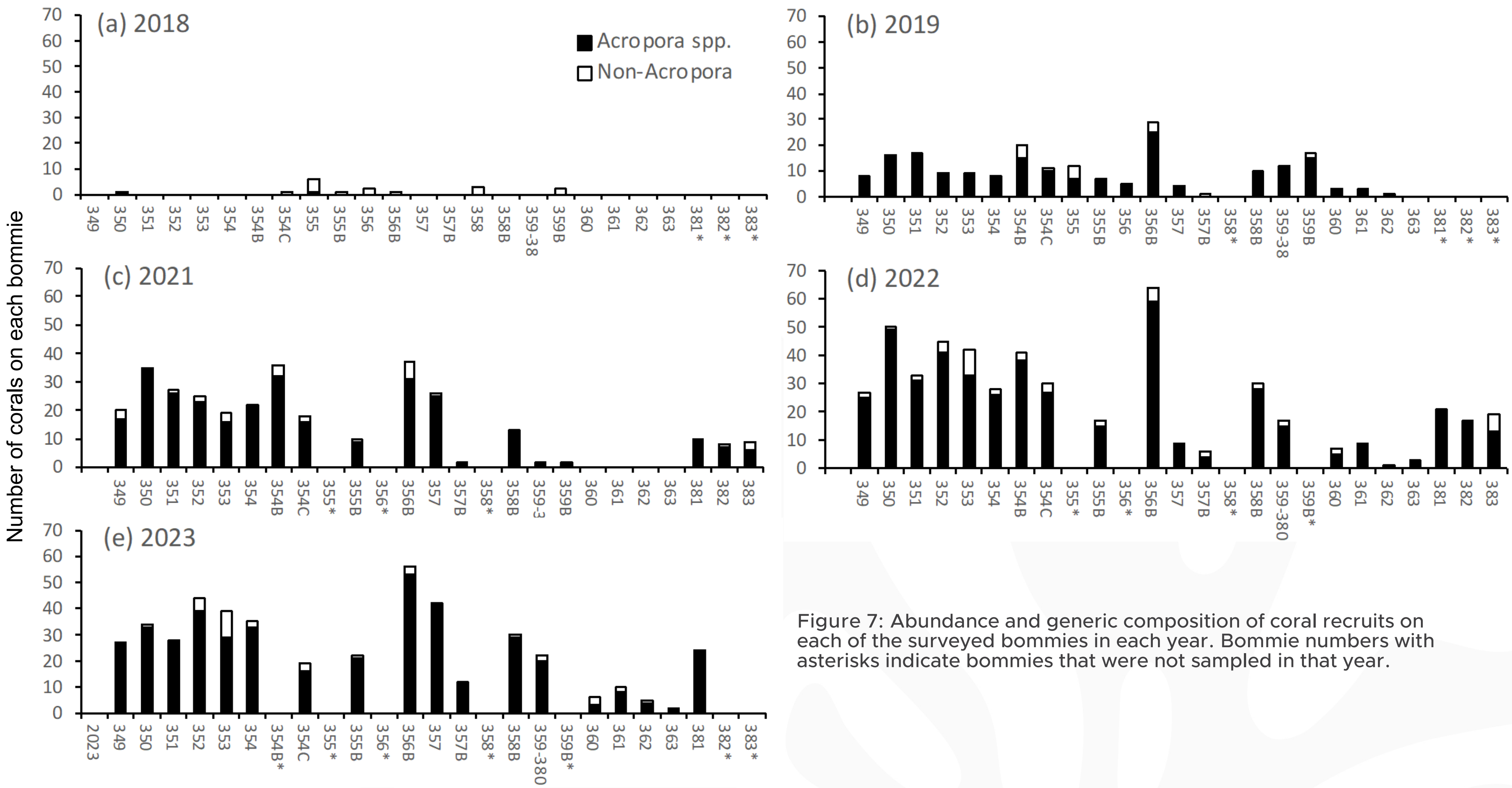

Figure 7: Abundance and generic composition of coral recruits on each of the surveyed bommies in each year. Bommie numbers with asterisks indicate bommies that were not sampled in that year.

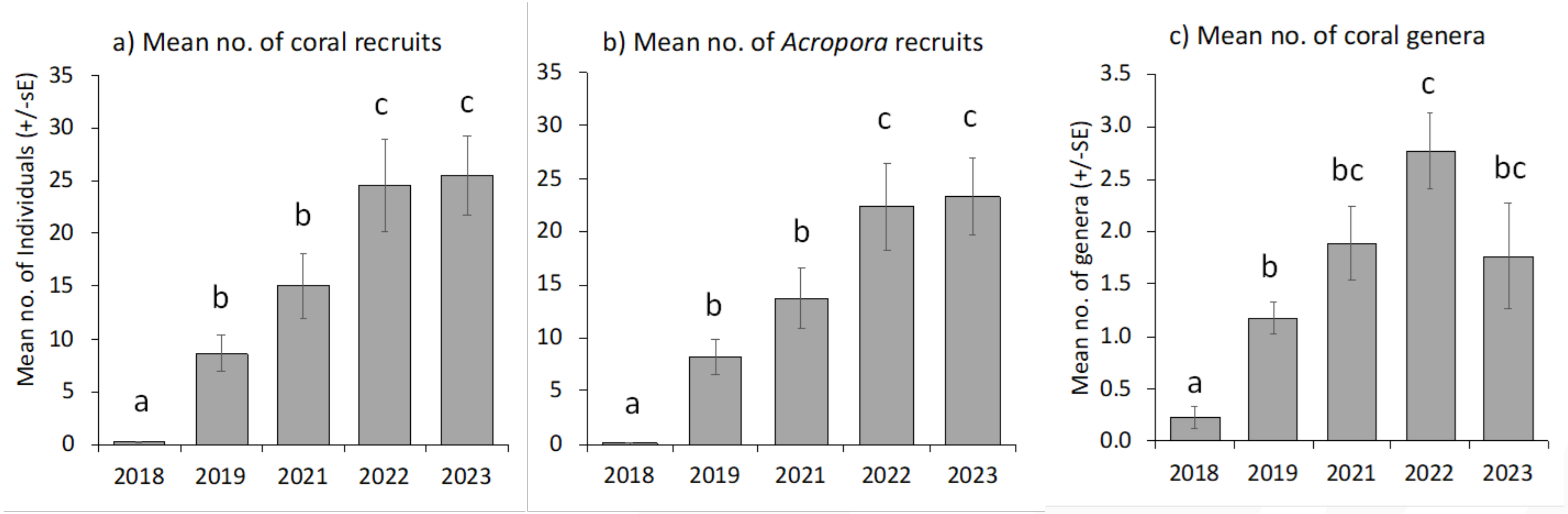

Figure 8: Mean number of (a) coral recruits of all genera, (b) *Acropora* recruits and (c) coral genera per bommie in each of the four years surveyed. Note that the mean was calculated using only the bommies surveyed in all five years. Significant differences between pairs of means are indicated by the letter(s) above each bar.

Growth of coral recruits on the repositioned bommies

In 2018 and 2019, all the *Acropora* recruits on the bommies were very small, between 1–10 cm (Figure 9). In 2021 and 2022, the *Acropora* recruits were larger on average, with a higher percentage in the 6–10 cm size class and several individuals measuring between 11–20 cm (Figure 9). In 2023, it was apparent that many of the *Acropora* recruits had grown rapidly (Figures 10 and 11). Over 50% were small, relatively recent recruits between 1–10 cm, but the older corals had grown to up to 31–40 cm. Prior to 2023, the largest *Acropora* corals were in the 16–20 cm size class (Figure 9). In 2023, almost 10% of the *Acropora* corals were larger than 16–20 cm, and eight colonies were over 30 cm.

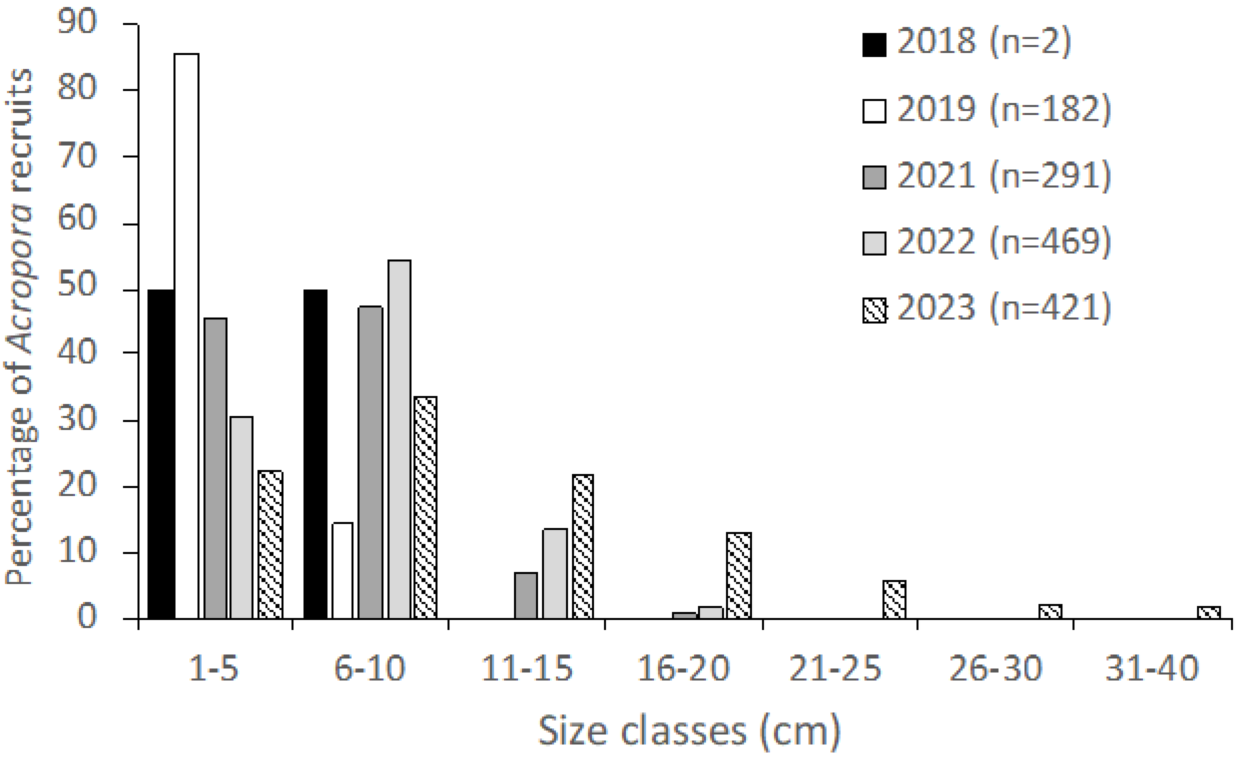

Figure 9: Percentage of *Acropora* recruits in each 5 cm size class each year. In 2023, the largest two 5 cm size classes were combined into one (31–40 cm).

In 2019 and 2021, some of the *Acropora* recruits on the bommies had missing branch tips, evidence of damage from parrotfish grazing (Figure 4c) and most of the *Acropora* recruits with branching structure were found in crevices where the branches were protected from grazing. This sort of damage was much less apparent in 2022 and 2023, compared to previous surveys. There are now many *Acropora* colonies with well-developed branching structure and no sign of damage from grazing fishes. Immediately after the cyclone, *Acropora* cover on the reef would have been extremely low and any new recruits would have been targeted by corallivores (e.g. parrotfish). As more *Acropora* recruits colonised and grew in subsequent years, this will have reduced predation pressure per colony. Some of the larger colonies have now developed into plating, corymbose or bushy growth forms (Figures 10 and 11) and are large enough to be reproductively mature (Bette Willis, personal communication). Some of them are likely to have spawned in the last mass coral spawning event in 2022 and many of them would have been expected to spawn in 2023. Overall, we believe that if favourable conditions persist during the next five years or so, these coral colonies should have the chance to grow further and reproduce. Future surveys of the repositioned bommies should continue to include measures of the mean diameter of all coral colonies recorded growing on the bommies.

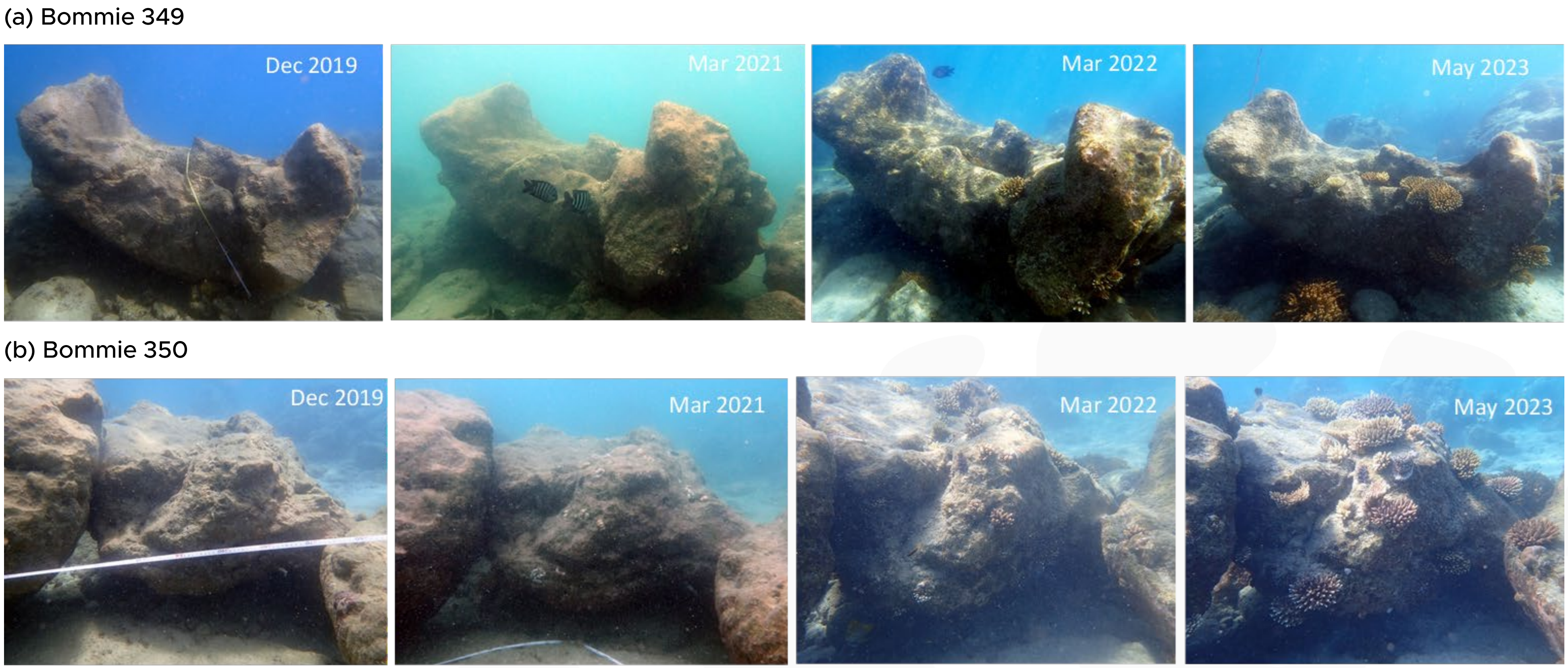

Figure 10: Photos of two of the bommies from four of the survey periods showing the increase in the number and size of *Acropora* corals that have recruited to them.

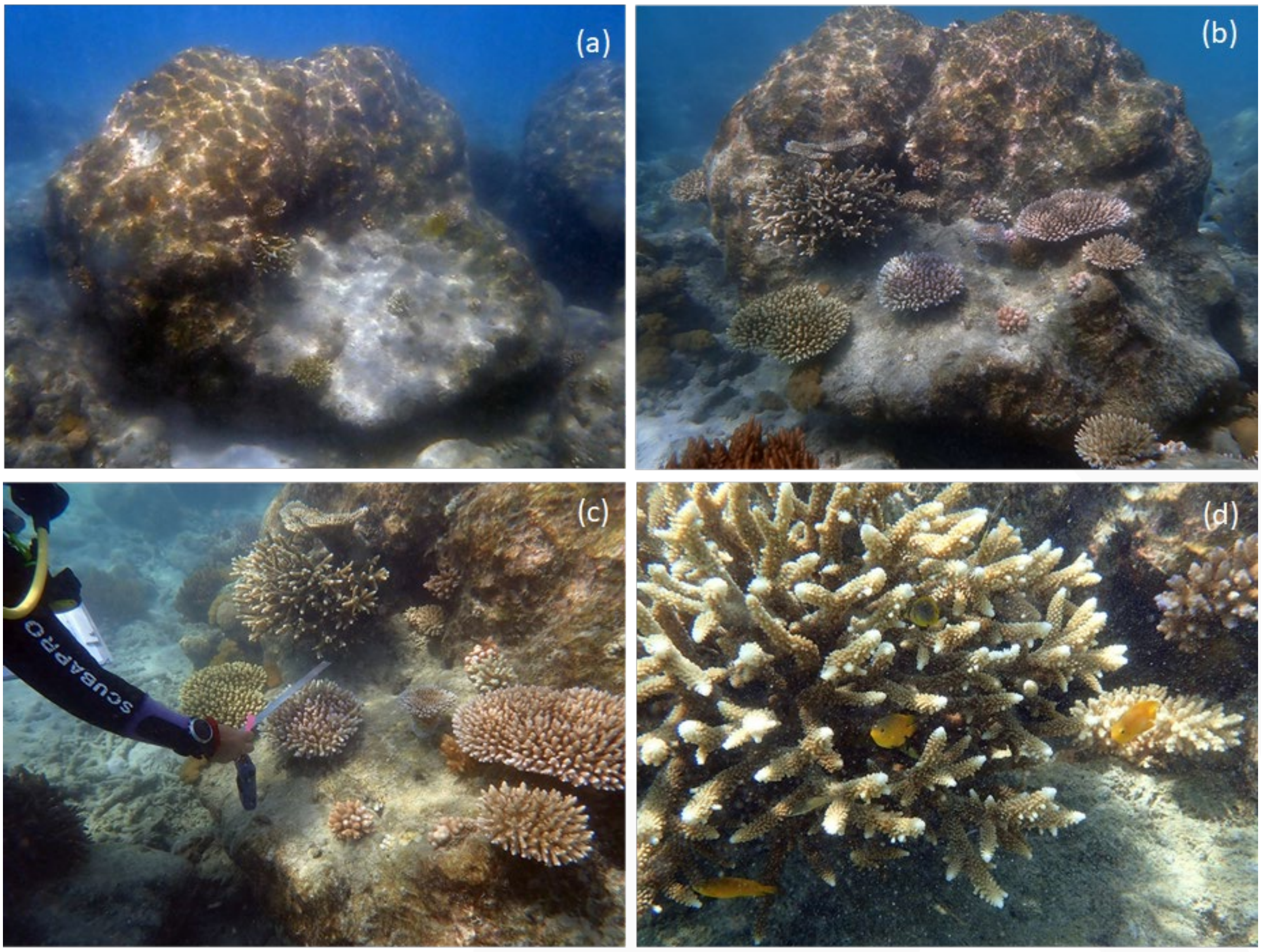

Figure 11: Photos of bommie 381 from (a) 2022 and (b) 2023 showing the increase in the number and size of *Acropora* corals in just 14 months, (c) measuring the corals on the bommie in 2023, and (d) one of the *Acropora* colonies had fish living in it, including a lemon damselfish, a juvenile golden butterflyfish and a juvenile tail spot wrasse.

Coral cover on the reef slope

James Cook University's Inshore Reef Zoning Monitoring Program conducted surveys at several island groups, including the Whitsunday Islands, every 1–2 years from 1999–2018. A new Great Barrier Reef Foundation-funded monitoring project, the Inshore Island Reef Fish Monitoring Project, is continuing to monitor the same locations for at least two further years, from July 2022. Manta Ray Bay is one of the sites surveyed, with fish and benthic surveys conducted at a depth of 8–9 m on the reef slope using five replicate 50 m transects. The percent cover of benthic organisms and substrates was estimated by recording the benthic organism or substrate at each metre mark along the transect tape (i.e. 50 points per transect). There was one survey conducted in September 2016, seven months prior to Cyclone Debbie, and there have been three surveys following the cyclone in November 2017, October 2018 and October 2022. Total live hard coral cover declined from 38.4% in 2016 to less than half that (17.2% and 18.8% respectively) in 2017 and 2018 (Figure 12a). There has been a further decline to 12.6% in 2023. In 2016, about 30% of the hard corals consisted of *Acropora* corals and other corals with complex growth forms (i.e. branching, digitate, foliose and plate) and 70% were massive and encrusting growth forms, however in 2017 and 2018, the hard corals consisted of mostly massive and encrusting corals and the cover of *Acropora* species and other corals with complex growth forms was between 0–0.4% (Figure 12b).

This project's data will make it possible to compare benthic and fish communities on the repositioned bommies with post-cyclone reef slope communities in Manta Ray Bay and other bays nearby. It is important to note that coral community structure is known to vary with reef zone (e.g. reef flat, crest, slope and base) and depth, so benthic surveys of the natural areas of reef flat around the bommies would be a useful addition to this project. In the long-term monitoring project, surveys are conducted at the mid-depth of the reef slope at each site. From observations at 44 survey sites around the Whitsunday Islands, it appears that there has been greater coral recovery in shallower areas, i.e. the reef flats and reef crests.

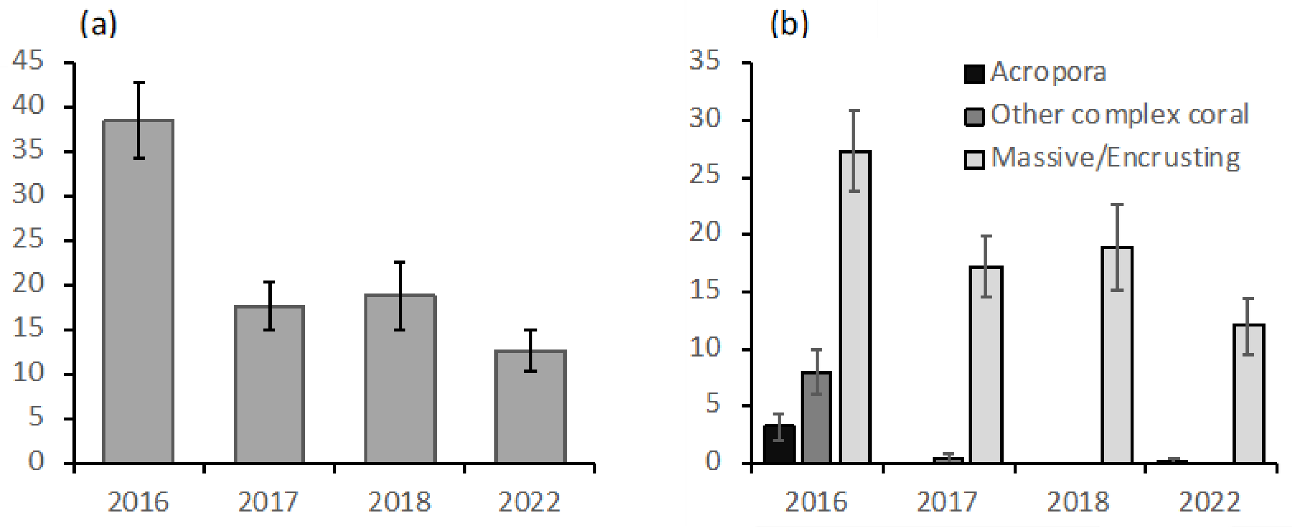

Figure 12: Manta Ray Bay reef slope mean percent cover of (a) all live, hard corals and (b) live, hard corals separated into *Acropora* corals, other corals with complex morphologies (i.e. branching, digitate, foliose and plate) and massive or encrusting corals.

Comparing photographs taken among years, it appears that although most bommies have remained in the same position, several had moved slightly. However, the amount of movement was not measured. We believe the bommies that were surveyed in 2018 and 2019 were not found in 2021 and 2022 because they likely moved or tipped over to the point of being unrecognisable from the photos taken in 2018–2019. After the most recent survey, we are now certain that bommie 359, which was surveyed in 2018 and 2019, but not 'found' in 2021, is the 'new' bommie we surveyed in 2021, bommie 380. While comparing the photos, and after looking at the bommie closely in the latest survey, we realise that this bommie seems to have been turned over sometime between the 2019 and 2021 surveys (Figure 13). Although the bommies are quite large, as they are no longer attached to the seafloor (due to being thrown up onto the beach during Cyclone Debbie), it is highly likely that a severe storm or cyclone could move them around or possibly throw them up onto the beach again.

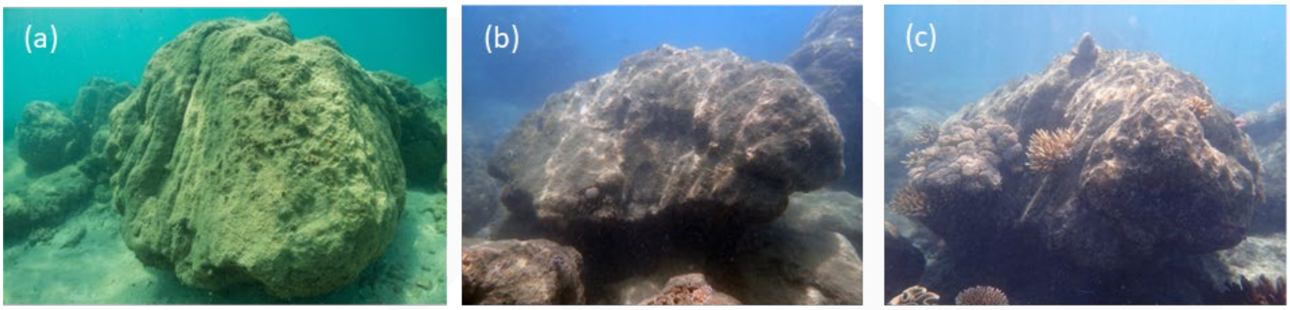

Figure 13: Bommie 359/380 in (a) 2019, (b) 2021 and (c) 2023. This bommie appears to have been turned over completely sometime between 2019 and 2021.

Benthic fauna other than hard corals

The abundance and diversity of benthic fauna other than hard corals have increased since 2018. In 2018, a single trochus (*Rochia nilotica*) was the only non-coral animal recorded, and in 2019, four soft coral colonies and one fire coral (*Millepora* sp.) colony were the only fauna other than hard corals recorded. In 2019, just four soft coral colonies in the 11–15 cm size class were recorded across all bommies. There has been a substantial increase in both the number and size of soft corals since then, with a total of 15 colonies ranging in size from the smallest size class (1–5 cm) to 16–20 cm in 2021, a total of 61 and 46 colonies in 2022 and 2023 respectively, ranging in size from 1–5 cm to 51–80 cm (Figure 14). The coral boring clam, *Tridacna crocea* was first recorded in 2021, with a total of 54 individuals that were mostly in the two smaller size classes 1–5 and 6–10 cm (Figure 15). In 2022 and 2023, there were almost twice this number, with 95 individuals in 2022 and 103 individuals in 2023, with an increase in the percentage in the 6–10 cm size class between 2021 and 2022, and an increase in the 11–15 cm size class between 2022 and 2023 (Figure 15), indicating that the clams that have recruited to the bommies have been growing.

Other sessile fauna recorded on the bommies include one fire coral (*Millepora* sp.), sponges, ascidians, anemones, the zoanthid *Palythoa* sp., cone shells, trochus, boring mussels and crayfish. Repeated monitoring of these bommies will provide a rare insight into the development and succession of shallow water benthic communities on coral reefs.

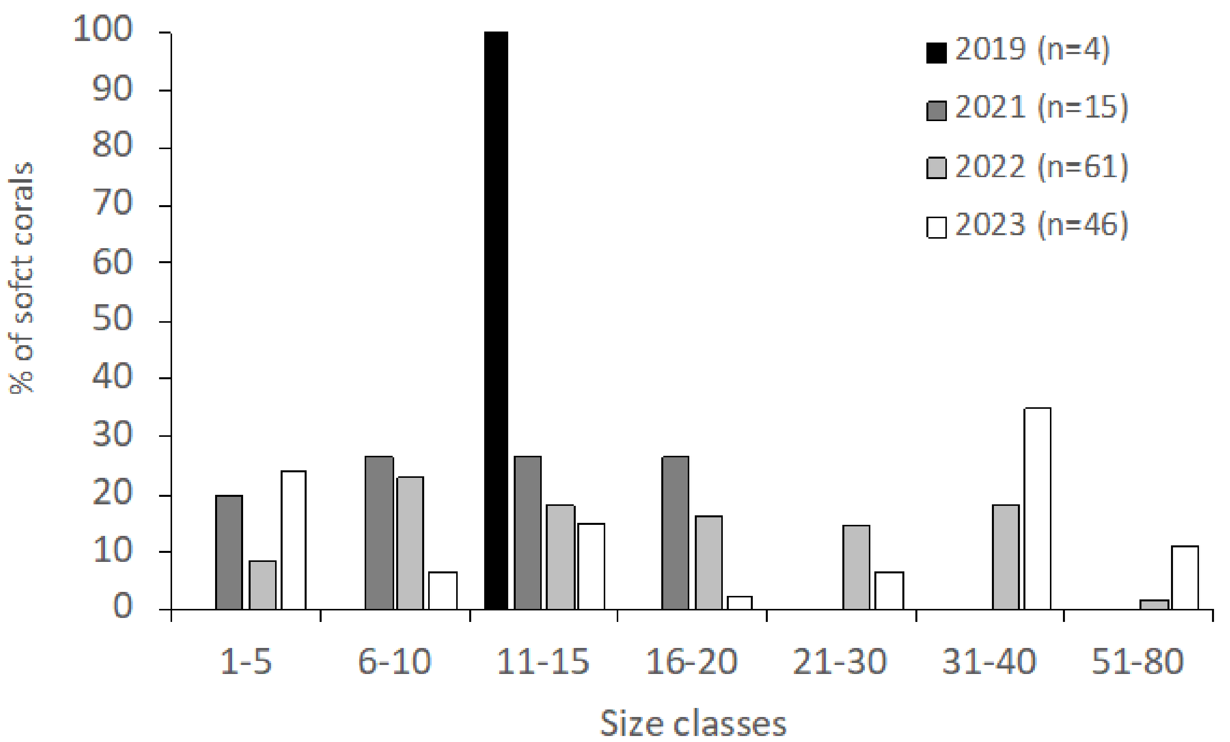

Figure 14: Percentage of soft corals in each of seven size classes each year. Due to the small number of individuals in the larger size classes, they were combined (to 21–30, 31–40 and 51–80).

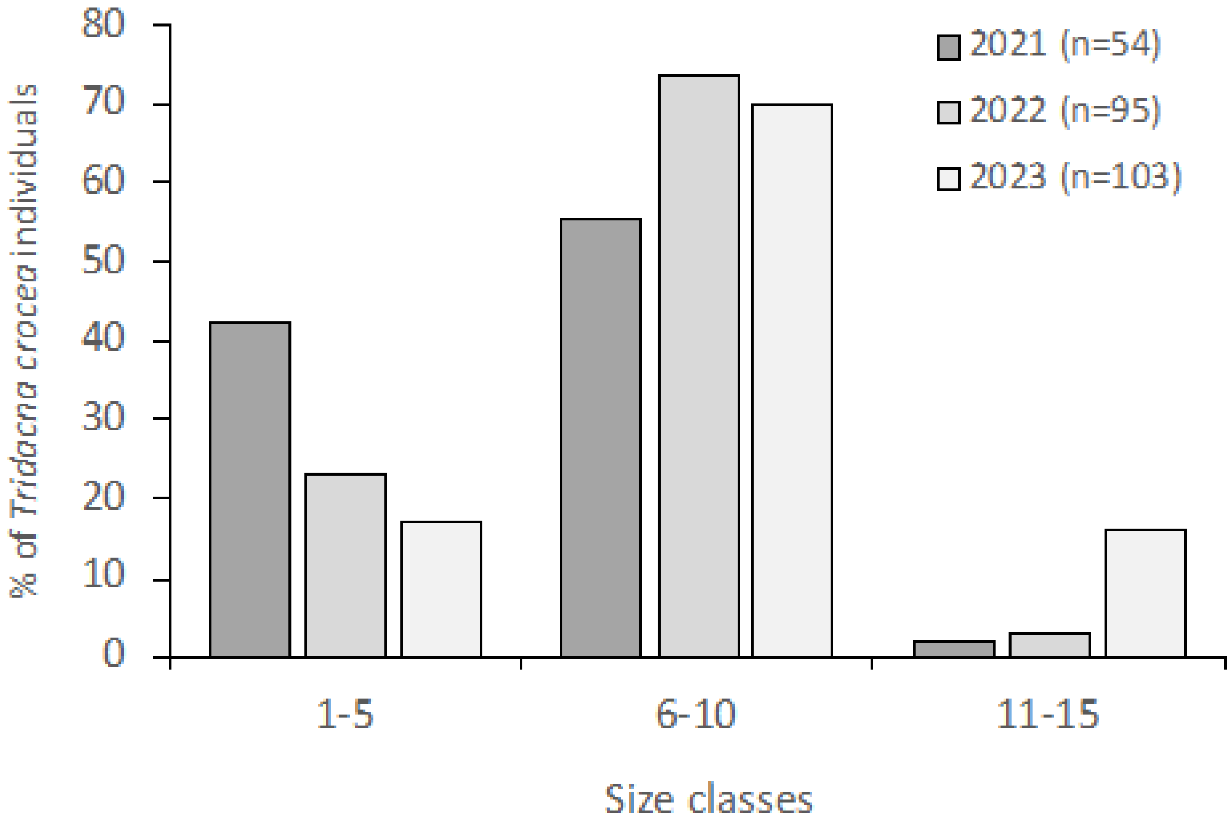

Figure 15: Percentage of boring clam (*Tridacna crocea*) individuals in each of three size classes each year.

Reef fishes associated with the repositioned bommies

The total density of all fish species, the number of species and number of families recorded in the single transect through the repositioned bommies has increased steadily, from a total density of 894 individuals per 1,000m^2 representing 20 species and seven families in 2018 to a total density of 1,442 individuals per 1,000m^2 representing 57 species and 13 families in 2023 (Table 1).

Table 1: Numbers of fish families, species and individuals surveyed in each year.

Year	No. of families	No. of species	Fish density (per 1,000m^2)
2018	7	20	894
2019	8	44	1,275
2021	9	38	1,218
2022	13	55	927
2023	13	57	1,442

The overall abundance of reef fishes in 2022 was 927 individuals per 1,000 m^2, which is lower than the previous two survey periods, i.e. 1,218 individuals per 1,000 m^2 in 2021 and 1,275 individuals in 2019, but higher than in 2018 (894 individuals per 1,000 m^2) (Figure 16a). The highest number of fish recorded so far was in the latest survey in May 2023. The large increase in fish density between 2022 and 2023 is likely to be at least partly due to the greater number and size of *Acropora* corals (Figures 8 and 9). For example, one of the species that has contributed to this increase is *Neopomacentrus azysron*, a schooling damselfish, which typically hovers above live branching corals and other branching structures. This species increased in abundance from 300–340 individuals per 1,000 m^2 in 2021 and 2022 to 588 individuals per 1,000 m^2 in 2023. *Pomacentrus moluccensis*, another damselfish species that lives in live branching coral, was recorded for the first time in 2023. However, there were several species that do not associate with live coral, e.g. the damselfishes *Pomacentrus australis* and *Stegastes apicalis* and the wrasse *Halichoeres chloropterus* that also increased in abundance between 2022 and 2023. This suggests that the increase in fish abundance is likely to also be due to natural colonisation to the area following the cyclone. Studies on the recovery of exploited fish species in marine reserves have shown that their populations increase to a point where resource limitation and density-dependent processes limit their abundance (Sanchez Lizaso et al. 2000). This point does not seem to have been reached by the fish community living around the bommies, as fish density has had a steady increase to a maximum in 2023.

Survey data from James Cook University's Inshore Reef Zoning Monitoring Program and Inshore Island Reef Fish Monitoring Project showed that total fish density on the reef slope at Manta Ray Bay in the two years after Cyclone Debbie (2017 and 2018) was less than half the total fish density prior to Cyclone Debbie in 2016 (Figure 16b). Total fish density in 2023 had increased to over 2,500 individuals per 1,000 m^2, which is slightly higher than the pre-cyclone density.

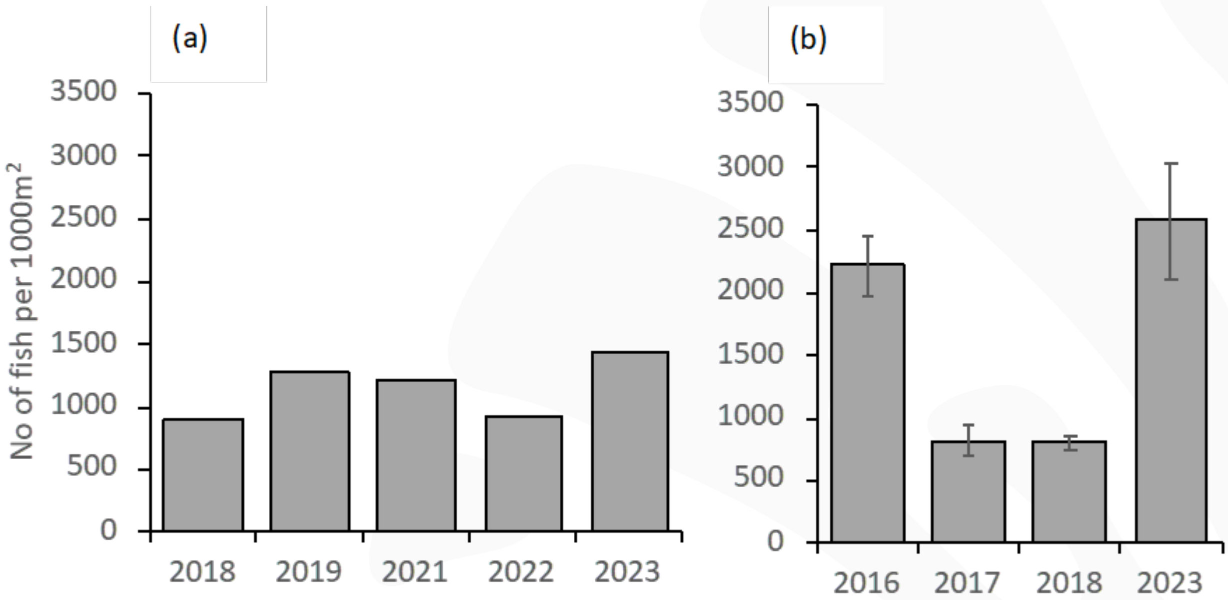

Figure 16: Total density of all reef fish species (a) associated with the repositioned bommies along a single 120 m transect (480 m^2 survey area) during each of survey year and (b) on the reef slope at Manta Ray Bay in the last three years of the Inshore Reef Zoning Monitoring Program (2016, 2017 and 2018) and the first year of the Inshore Island Reef Monitoring Project (2023). Error bars are standard error.

The fish families represented were the *Acanthuridae* (surgeonfishes), *Caesionidae* (fusiliers), *Chaetodontidae* (butterflyfishes), *Ephippiidae* (batfishes), *Gobiidae* (gobies), *Labridae* (wrasses and parrotfishes), *Lutjanidae* (snappers), *Microdesmidae* (dartfishes), *Nemipteridae* (threadfin breams), *Mullidae* (goatfishes), *Pomacanthidae* (angelfishes), *Pomacentridae* (damselfishes), *Serranidae* (groupers), *Siganidae* (rabbitfishes) and *Pinguipedidae* (sandperches). Damselfishes were the most abundant family, with the planktivorous *Neopomacentrus azysron* and *Neopomacentrus bankieri* dominating the fish community numerically (Figure 17). The *Labridae* (wrasses and parrotfishes) had the highest number of species, with a total of 26 species, i.e. 21 species of wrasses and five species of parrotfishes. As the number and sizes of coral colonies on the bommies has increased, the abundance of corallivorous fish has increased, from none in 2018 and 2021, low densities in 2019 and 2022 (4–6 individuals per 100 m^2) to 29 individuals per 1,000 m^2 in 2023 (Figure 17). The corallivores recorded in these surveys include the golden butterflyfish (*Chaetodon aureofasciatus*), Rainford's butterflyfish (*Chaetodon rainfordi*), the copperband butterflyfish (*Chelmon rostratus*) and the highfin coralfish (*Coradion altivelis*).

During the latest survey in May 2023, some of the *Acropora* colonies had grown large enough to host fish, and for the first time, we observed several *Acropora* colonies occupied by fish. These included the lemon damselfish (*Pomacentrus moluccensis*), a clown goby (*Gobiodon sp.,* either *G. erythrospilus or G. histrio*), a juvenile golden butterflyfish (*Chaetodon aureofasciatus*) and a juvenile tail spot wrasse (*Halichoeres melanurus*) (Figure 11d). This latest survey was the first time we have recorded the lemon damselfish and a clown goby on the bommies. Both species are coral specialists, the lemon damselfish typically lives in live branching coral, preferring *Acropora* corals, and clown gobies are highly specialised on *Acropora* corals and are only ever found in a small number of *Acropora* species, with the most specialised clown goby species only occupying one *Acropora* species (Munday 2004). Fish species that are reliant on live coral for food and shelter are the most vulnerable to declines in coral cover, and the more specialised a species is, the more vulnerable it is to population declines and, ultimately, extinction (Munday 2004).

Increased habitat complexity can lead to an increase in reef fish diversity (Friedlander and Parish 1999, Gratwicke and Speight 2005) and it is likely that as the benthic communities on the bommies grow and develop, the increased complexity of the habitat will enhance fish diversity so continued monitoring is essential. The fish species associated with the bommies were a subset of the species found on the reef slope, however as many of the wrasses were recorded to genus level in the Inshore Reef Zoning Monitoring Program, it was not possible to directly compare the densities of individual species between the two monitoring programs.

Roving grazers, particularly *Scarus* species, *Acanthurus* species and *Siganus doliatus* were observed grazing on the repositioned bommies and on the surrounding substrate. Numerous fish grazing scars were observed on all the surveyed bommies (Figure 4c). Although algal turfs were growing on most dead areas of the bommies (Figure 4), as noted in previous years, these turfs remained short, indicating that the level of grazing pressure by reef fishes has been effectively limiting the growth of macroalgae. Furthermore, no macroalgae species were observed growing on the repositioned bommies or on the surrounding reef flat at Manta Ray Bay. As macroalgae compete with corals for space, having a healthy community of grazers to keep the macroalgae in check is essential for coral recovery (Mumby et al. 2007, Mumby 2009).

Continued monitoring of the reef fishes will reveal whether this assemblage is at a stable stage with changes reflecting stochastic movement and recruitment events or still developing towards a more established fish community.

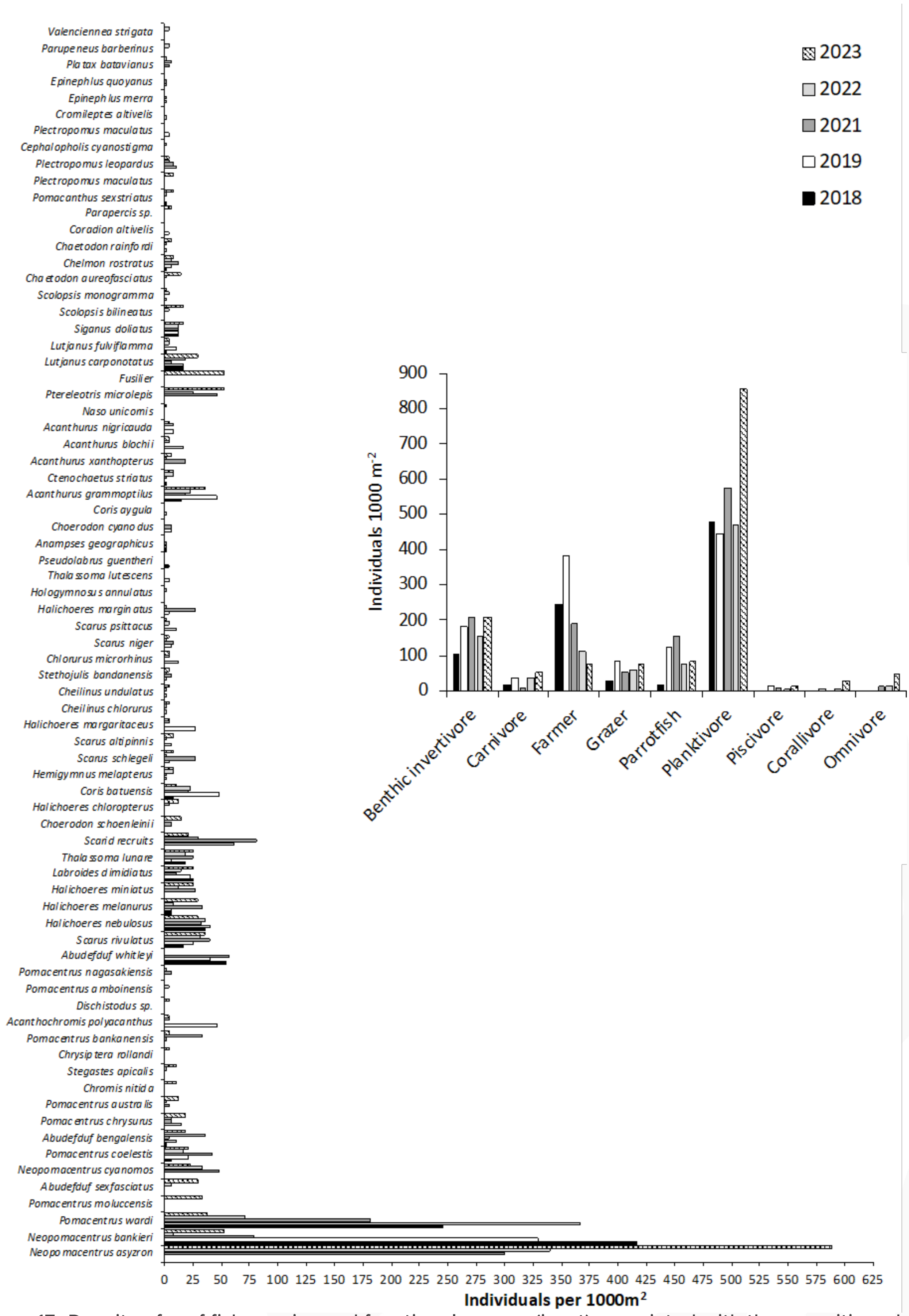

Figure 17: Density of reef fish species and functional groups (inset) associated with the repositioned bommies along a single 120 m transect (480 m² survey area) during each survey year.

Conclusion

The repositioning of the *Porites* bommies displaced at Manta Ray Bay during Cyclone Debbie had the following key objectives: the replacement of structure for future coral settlement, re-established visitor access and safety, and improved site aesthetics.

It has already been established that these original objectives have been achieved (2021 monitoring survey). The site is frequently visited and accessible, and ecological surveys to date indicate that the replaced bommies are supporting new coral recruits and other benthic life forms.

Although the coral communities on the bommies have yet to develop into larger and more complex habitats for the smaller, coral-associated reef fish species, the structure provided by the bommies and the increasing amount of *Acropora* coral has led to an initial increase and the first signs of stabilisation in the abundance and diversity of reef fishes in the area. In the latest survey in 2023, fish were observed to be living in a small number of the larger *Acropora* corals for the first time. The increased habitat complexity and fish diversity will have enhanced the shallow-water snorkelling experience for tourists.

The replacement (installation) of over 100 m^3 of almost completely bare hard structure offers a relatively unique opportunity to study fringing reef recovery. Unlike many other monitoring programs, this project has allowed us to track the development and succession of a benthic community and associated fish assemblage from a 'blank slate' stage following severe cyclone damage.

It is widely understood that reef communities require 10–15 years to recover following a severe disturbance and continued monitoring will provide valuable insights into the trajectories of benthic and fish assemblages in a high-use but no-take fringing reef. Given the increasing interest in reef rehabilitation using structures (e.g. reef stars or other hard structure options being investigated by the Reef Restoration and Adaptation Program), this project provides an early test case and opportunity to monitor habitat change and recovery on introduced structures.

Recommendations

Continued monitoring of the site

Continued monitoring will allow us to examine patterns of succession in the benthic community and the development of a relatively stable fish community. This will provide valuable insights into the recovery trajectories of benthic and fish assemblages in a high-use but no-take fringing reef.

Ongoing annual surveys will help to determine whether surviving *Porites* tissue is able to grow and how coral assemblages may change as the corals that have recruited to the bommies grow larger and begin to compete with one another, while new corals continue to settle.

This project can be considered the largest experiment on the Great Barrier Reef in adding hard structure to a degraded reef, albeit the replacement of natural structures. The ongoing monitoring of the site will provide valuable insights into the consideration and management of future similar projects.

Undertaking similar monitoring of suitable adjacent sites

In addition to a planned continuation of a long-term monitoring program, in which fish and benthic communities will be surveyed on the reef slope of Manta Ray Bay, future monitoring should also include areas of natural reef flat adjacent to the bommies to compare the successional stage of the bommies to that of natural, unmanipulated habitats.

Improved imagery to monitor possible bommie movements

The tagging of 21 bommies in 2022 was unsuccessful as none of the tags were found in 2023. One possible reason for the disappearance of these tags is that they were pulled out by large parrotfish. It is also possible that tourists may have pulled out tags, under the impression they were doing a good deed by removing plastic from the reef. In future, numbered cattle tags tied to a piece of reinforcing bar or star picket hammered into the sand next to each bommie could be used to tag the bommies. Our existing imagery of the bommies has been useful in identifying the bommies and for following the number and growth of coral recruits over time. However, the imagery could be improved. The bommies have each been photographed on three sides (north-facing, south-facing and top) each time they have been monitored but it has not been possible to photograph the tops of all or some of the bommies in some years, as the tide was too low. Ideally, 3D photogrammetry of each bommie could be used to identify the bommies and track them through time. If this is not possible due to time or funding constraints, simply photographing the bommies from additional angles would be an improvement.

A better understanding of how and why specific bommies might move will improve potential future projects. For example, it may be that placing smaller, unsecured bommies back to an area too close to shore carries the risk of future uncontrolled movement (either from storms or from being stood on or kicked by snorkellers) and a lower chance of new coral recruits surviving.

References

Bellwood DR, and Hughes TP (2001) Regional-scale assembly rules and biodiversity of coral reefs. Science 292:1532–1535.

Bureau of Meteorology (2018) Cyclone Debbie. URL: http://www.bom.gov.au/cyclone/history/debbie17.shtml

Clements KD, German DP, Piche J, Tribollet A, and Choat JH (2017) Integrating ecological roles and trophic diversification on coral reefs: multiple lines of evidence identify parrotfishes as microphages. Biological Journal of the Linnean Society 120:729–751.

Emslie MJ, Cheal AJ, Sweatman H and Delean S (2008) Recovery from disturbance of coral and reef fish communities on the Great Barrier Reef, Australia. Marine Ecology Progress Series, 371, 177–190.

Friedlander AM and Parish JD (1998) Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. Journal of Experimental Marine Biology and Ecology, 224, I–30.

Gratwicke B and Speight MR (2005) The relationship between fish species richness, abundance and habitat complexity in a range of shallow tropical marine habitats. Journal of Fish Biology, 66, 650–667.

Johns KE, Osborne KO and Logan M (2014) Contrasting rates of coral recovery and reassembly in coral communities on the Great Barrier Reef. Coral Reefs, 33, 553–563.

Kassambara A (2019) Practical Statistics in R II - Comparing Groups: Numerical Variables. Datanovia, Montpellier.

Kelley R (2021) Coral Finder 2021. BYO Guides, Townsville.

Lough JM, Cantin NE, Benthuysen JA, and Cooper TF (2016) Environmental drivers of growth in massive Porites corals over 16 degrees of latitude along Australia's northwest shelf Limnology and Oceanography 61:684–700.

McLeod IM, Williamson DH, Taylor S, Srinivasan M, Read M, Boxer C, Mattocks N and Ceccarelli DM. (2019) Bommies away! Logistics and early effects of repositioning 400 tonnes of displaced coral colonies following cyclone impacts on the Great Barrier Reef. Ecological Management and Restoration, 20, 262–265.

Mumby P.J., Harborn A.R., Williams J., Kappel C.V., Brumbaugh D.R., Micheli F., Holmes K.E., Dahlgren C.P., Paris C.B., Blackwell P.G. (2007) Trophic cascade facilitates coral recruitment in a marine reserve. Proceedings of the National Academy of Sciences, 104: 8362–8367.

Mumby P.J. (2009) Phase shifts and the stability of macroalgal communities on Caribbean coral reefs. Coral Reefs, 28: 761–773.

Munday P.L. Habitat loss, resource specialization, and extinction on coral reefs. Global Change Biology, 10, 1642–1647.

Roff G., Bejarano S., Bozec Y-M., Nugues M., Steneck R.S., Mumby P.J. (2014) Porites and the Phoenix effect: unprecedented recovery after a mass coral bleaching event at Rangiroa Atoll, French Polynesia. Marine Biology, 161, 1385–1393.

Russ GR, Questel S-LA, Rizzari JR, and Alcala AC (2015) The parrotfish–coral relationship: refuting the ubiquity of a prevailing paradigm. Marine Biology 162:2029–2045.

Sanchez Lizaso JL, Goni R, Renones O, Garcia Charton JA, Galzin R, Bayle JT, Sanchez Jerez P, Perez Ruzafa A and Ramos AA (2000) Density dependence in marine protected populations: a review. Environmental Conservation, 27, 144–158.

Tebbet S, Morais J and Bellwood DR (2021) Spatial patchiness in change, recruitment and recovery on coral reefs at Lizard Island following consecutive bleaching events. Marine Environmental Research, 173, 105537.

Williamson D.H., Ceccarelli D.M., Jones G.P., Russ G.R. (2018) Assessing the ecological effects of management zoning on inshore reefs of the Great Barrier Reef Marine Park. Reef 2050 Integrated Monitoring and Reporting Program (RIMReP). Milestone Report 2, September 2018.