Recovery of the Great Barrier Reef

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May-September, 2018

LETTER TO VOLUNTEERS

Dear Earthwatch volunteers,

Our team at James Cook University and Earthwatch Australia wish to thank you for the continued field support during our 12th and 13th field trip expeditions. Again with great weather conditions, this season has been especially successful in fulfilling our missions in the field. In February 2011, a severe tropical cyclone (Yasi) struck the coast of North Queensland and caused catastrophic damage to reefs in the study area around Orpheus Island located in the central sector of the Great Barrier Reef. In 2016 and 2017 the Great Barrier Reef was also hit by the largest bleaching events on recorded resulting in unprecedented coral mortality in some areas of the reef. Finally coral populations at the study sites have previously suffered from outbreaks of a coral disease, black-band disease (BBD). Our goals of the field work were; 1) monitor the recovery of coral populations extensively damaged following cyclone Yasi; 2) Assess the impacts of the bleaching events in 2017 and 2017 on these recovering populations; 3) study how coral disease outbreaks influence this reef recovery processes; 4) elucidate the microbial mechanisms of BBD; and 5) conduct pilot surveys of benthic cover for future algal removal research.

We are grateful for the hard work of the Earthwatch volunteers during the field trips in 2018 and appreciated the fantastic sunny days that volunteers brought with them. Favourable conditions allowed us to efficiently collect coral data from all the study sites that we have been monitoring. This year was critical for our understanding of the effects severe impacts will have on coral reefs as 2016 and 2017 saw the most serious back to back bleaching events on record. Based on in-water monitoring surveys, coral mortality was over 50% for the entire Great Barrier Reef. The long-term impact of this event on the recovery process of the reef is unknown but is starting to appear in our current dataset at Orpheus Island. We suspect that a number of critical knock-on effects are occurring following these bleaching events, including increased disease outbreaks and decreased reproduction output of corals. The data collected in the current 2018 season will be vital to accurately determine how such a large bleaching event influences the recovery process of coral reefs. This highlights that our continued attention and efforts are necessary to fully understand reef recovery and resilience questions. We would like to express our gratitude for your hard work in obtaining this invaluable data.

All team members have been in good spirits and your enthusiasm in helping our coral reef science was truly contagious. In addition to the monitoring associated tasks, we successfully collected coral samples for many different experimental projects, exploring novel aspects of corals on the Great Barrier Reef and their associated microbes, and coral disease-causing microorganisms. Knowledge that can be derived from these studies will significantly improve our fundamental understanding about what is involved in maintaining healthy coral reefs in the environment. We appreciate everyone's participation in these difficult tasks underwater and in the accompanying laboratory tasks.

As scientists, one of our important missions is to communicate our scientific findings to as many people as possible. The Earthwatch activities provide a great opportunity to facilitate these communication efforts for us. We truly wish that all participants enjoyed their field experience and feel enthusiastic to share what you saw, heard, learnt and felt during the scientific expedition with your family and friends. Thank you for what you have given to us, and we wish to see you back on the reef again!

Best wishes,
David Bourne

SUMMARY

Recovery of the GBR has undertaken 13 field-based research trips to Orpheus Island resulting in nearly 10,000 m^2 of reef substrate surveyed over the last 7 years. This year has been important not only to continue our investigation into the patterns of recovery following the cyclone disturbance of 2011, but also to document the fine-scale patterns of recovery following two consecutive mass-bleaching events.

Prior to the first bleaching event in 2016, we reported that the abundance of adult coral colonies had reached between 73 to 122% of pre-cyclone levels. Following the two extreme bleaching events, we observed a decrease in abundance between 10 and

36% of pre-bleaching levels. In this field season, we document ongoing recovery from bleaching, with a 35-53% increase in coral cover in May, followed by an 11% loss of coral cover by September. This year's data will continue to form an important baseline for continued investigation into how the Great Barrier Reef will recover from repeated disturbances and how coral communities may change in light of rapid climate change.

In addition to our usual survey activities, in May our team rescued a green sea turtle with floating syndrome. The estimated 60+ year old turtle was named Theresa and spent a long time in recovery at the Townsville turtle hospital at Reef HQ Aquarium.

GOALS, OBJECTIVES, AND RESULTS

Introduction

Our research in the inshore Great Barrier Reef (GBR) region is focused on recording the fine scale dynamics of coral reefs recovering from environmental disturbances around Orpheus Island. A major disturbance event occurred on the GBR in 2011 with the tropical cyclone Yasi causing widespread and devastating destruction of reef ecosystems. The study site at Orpheus Island was heavily impacted with a dramatic loss of coral cover. The cyclone disturbance allows us to investigate coral recovery following such a major disturbance and investigate the dynamics of disease within this recovering coral population. Importantly, in 2016 and 2017 the Great Barrier Reef experienced another significant disturbance, the most widespread and severe bleaching events ever recorded, and it's still unfolding. Based on in-water monitoring surveys, coral mortality following the 2016 bleaching event was estimated at 29% for the entire Great Barrier Reef, with the 2017 bleaching event causing up to 97% coral mortality at some reefs. The impact of these events on the recovery process of the reef is unknown and we suspect that a number of critical knock-on effects will occur over the next several years, including increased disease outbreaks and decreased reproduction output of corals. The reef is still recovering from cyclone Yasi and it is unknown how this regeneration will be affected by the recent bleaching events. The baseline data that we have accumulated over the last 7 years will provide an ongoing opportunity to capture reef resilience data when multiple disturbances impact a reef system. In addition, infectious diseases have been identified as a major contributor to declines in coral reef ecosystems worldwide. On the GBR, patterns of increasing coral disease prevalence have been reported, indicating an urgent need to understand potential impacts of disease outbreaks on GBR coral populations. Black Band Disease (BBD) is a virulent disease that causes rapid loss of coral tissue. Its outbreak was observed on reefs around Orpheus Island, the project's study site in the central GBR in 2006. An ongoing monitoring program has recorded recurring summer outbreaks, causing significant mortality in susceptible coral populations. Research in this project unravels the fundamental mechanisms responsible for BBD pathogenesis through a combination of field- and laboratory-based approaches which investigates the environmental and microbial drivers of developing BBD lesions. In addition,

Past seasons' achievement

To document recovery of the reef and variability in the prevalence of BBD over time, obtaining baseline data was essential. The first year's (2012) field trips based out of the Orpheus Island Research Station established six permanent 10 m x 10 m quadrats at 3-5 m depth, covering a total area of 600 m^2 at two sites, Northeast and Southeast Pelorus Island ('NE Pelorus' and 'SE Pelorus' sites; see Site Map). With the help of Earthwatch volunteers, the quadrats were permanently marked by metal stakes in each corner. These plots have been used in recurring field trips to monitor the coral populations.

Eighteen 3 m x 3 m quadrats were also established at sheltered ('West Pelorus', 'Cattle Bay', 'Pioneer Bay'; 3 quadrats each) and exposed ('NE Pelorus', 'SE Pelorus', 'Channel'; 3 quadrats each) sites around Orpheus and Pelorus Islands. These smaller plots have been surveyed to follow coral recruitment back to the reef following the devastating cyclone Yasi in February 2011.

Initial coral surveys were conducted in the 2012 season and have continued in conjunction with the Earthwatch volunteer teams. All coral colonies within surveyed areas were recorded with morphological types and colony sizes. Any diseased coral was mapped, photographed and tagged with numbered plastic cattle-ear tags. In the 3m x 3m quadrats, newly-settling coral juveniles were counted to assess coral recruitment. These data collected between 2012 and 2018 form a unique long-term dataset for monitoring coral recovery dynamics following multiple disturbances.

During May and September 2018, field trips were conducted to revisit the six 10 m x 10m permanent quadrats at NE and SE Pelorus and eighteen 3m x 3m quadrats around Orpheus and Pelorus Islands. Previous results clearly indicated that coral communities at both sites at NE and SE Pelorus were in the process of accelerated recovery; however in the previous field season we documented a drop in adult coral abundance, likely due to the effects of back to back bleaching events. This year we observed a sharp increase in adult coral abundance at both NE and SE Pelorus (35 and 55%, respectively) in May, followed by an 11%

decrease in September (Figure 1). The unexpected drop in coral abundance between May and September may possibly be explained by the bleaching event as well. Smaller size classes (4-20cm) were more affected by bleaching, showing drastic declines following the 2017 bleaching event (Figure 2). These size classes showed impressive rebound in May 2018, which may suggest that more heat resilient coral individuals successfully settled. However, there may be a trade-off, as these smaller size classes also experienced the greatest decline in abundance from May to September, suggesting they were not able to withstand the cooler winter temperatures. Indeed, the Townsville region experienced record cold days in winter 2018.

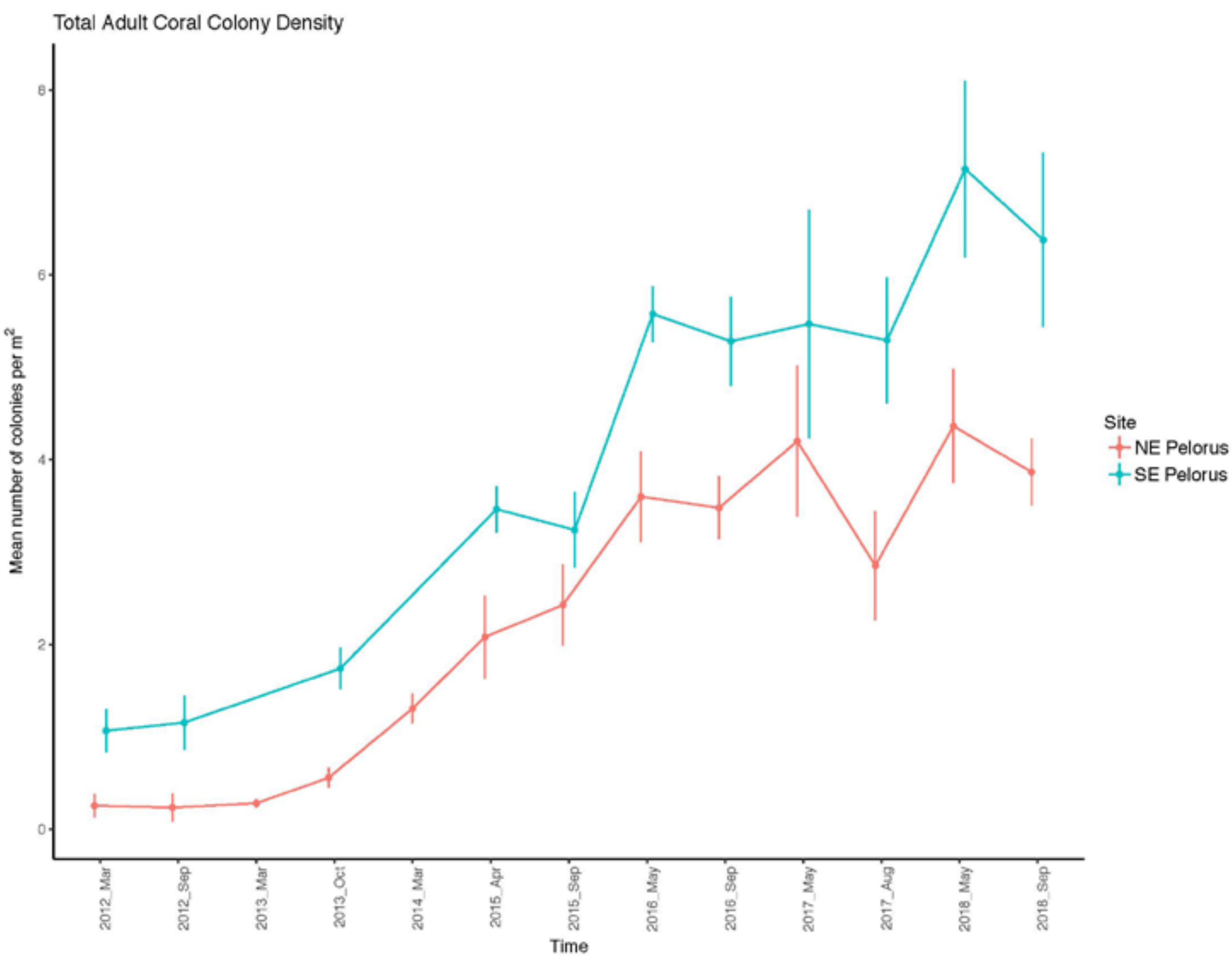

Figure 1 The increase in coral abundance over the course of the project.

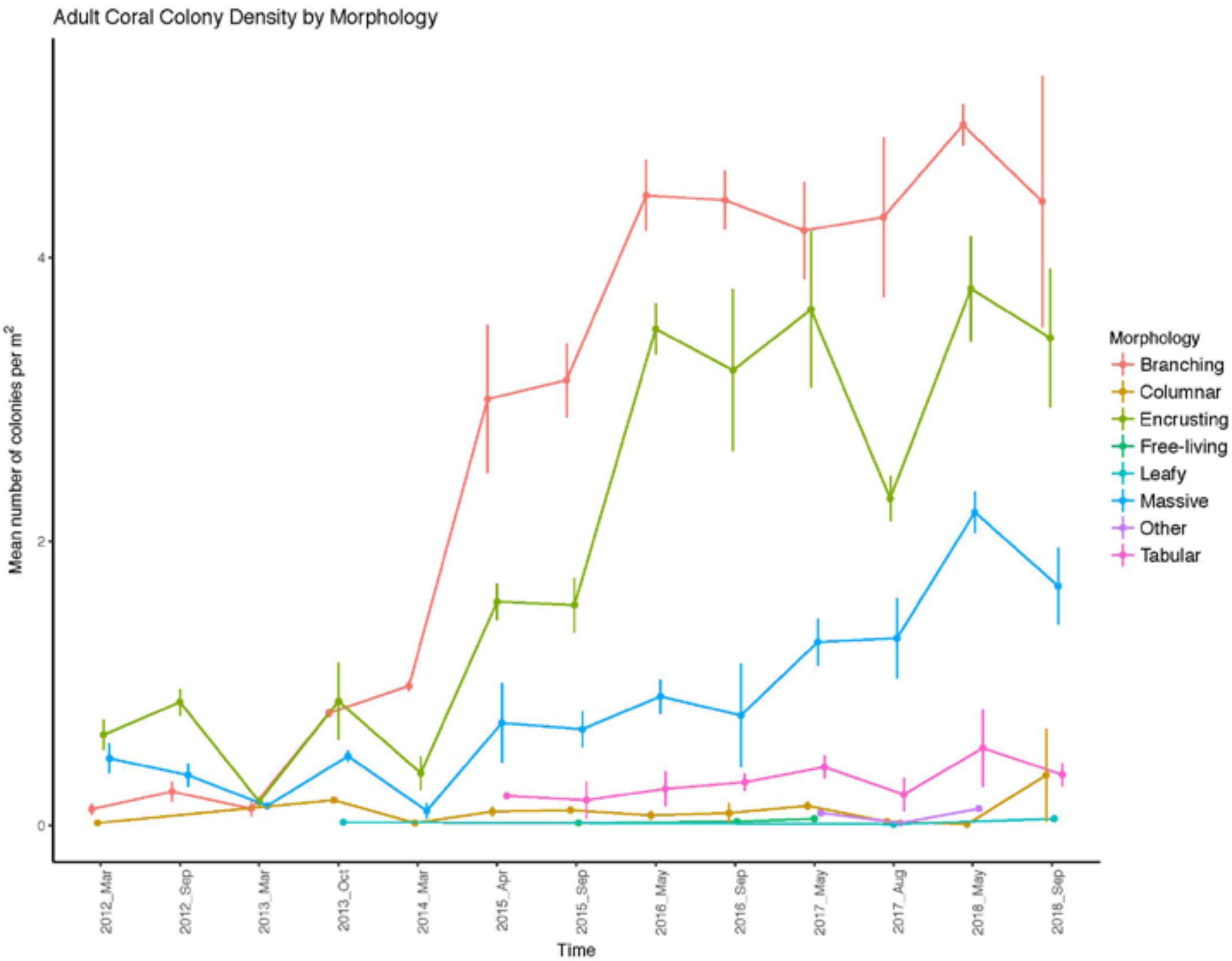

Figure 2 The difference in coral abundance by coral morphology types.

Surveys at the eighteen 3m x 3m quadrats showed a drastic drop in the abundance of coral juveniles and recruits immediately following the 2017 bleaching event (May 2017), with a decrease of 36% and 31% of pre-bleaching abundances at exposed and sheltered sites, respectively (Figure 3). Previously, we observed signs of early recovery, especially at sheltered sites, in August of 2017. However, this field season documented ongoing declines in coral juvenile abundances, with a decrease in recruit abundance of 57% at exposed sites and 54% at sheltered sites since August 2017 (Figure 3). It is possible that knock-on effects of the dual bleaching events have manifested in long-term lower reproductive output. Our results demonstrate that the consecutive bleaching events have ongoing impacts and will continue to impede the recovery of the cyclone-impacted reefs at Orpheus and Pelorus Islands, and that while short term studies may document initial recovery, longer term studies are required to delineate the true effects of such devastating natural events.

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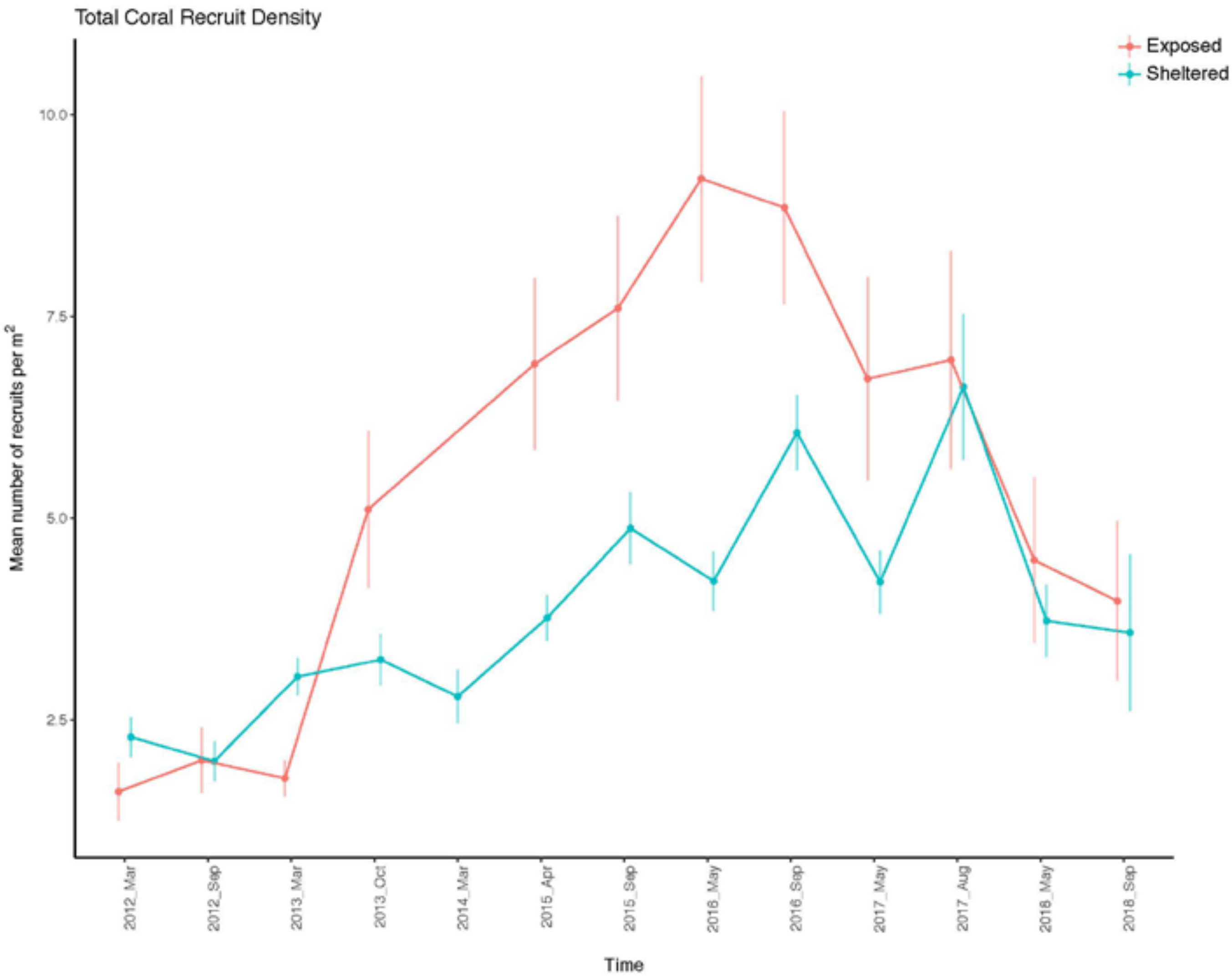

Figure 3 The abundance or coral juveniles at different types of sites around Orpheus and Pelorus Islands.

1. Coral community dynamics in 2018

(a) Transition in morphological compositions during the initial recovery of coral communities

During the 2018 field expedition in May and September, we revisited all the permanent monitoring plots at the NE and SE Pelorus sites (three 10m x 10m quadrats at each site). The number of adult corals (larger than 4cm in the largest dimension) per plot increased compared to the previous years, with a greater relative increase in abundance observed at SE Pelorus (Figure 1). SE Pelorus quadrats displayed higher coral density than at NE Pelorus throughout the study period, likely due to a greater abundance of corals that survived the cyclone event at SE Pelorus and greater recruitment potential into this site (see the following section on coral demography). Mean density of coral colonies increased to ~386 and 638 colonies per 100 m^2 quadrat at NE Pelorus and SE Pelorus, respectively. Colony density at both NE and SE Pelorus remained above the estimated density levels before the cyclone event (360 and 421 colonies per 100 m^2 quadrat, respectively). Interestingly, a small decrease in the abundance of corals from the May to September 2018 field trips was observed and this pattern was consistent with what was observed in 2015, 2016, and 2017 field season surveys.

During the initial recovery of coral communities, morphological compositions at NE and SE Pelorus underwent a transition characterised by a gradual increase of branching corals after 2012 and a noticeable increase of encrusting corals after 2015 (Figure 2). A notable decline in both branching and encrusting corals was observed in 2017 at NE Pelorus, and while encrusting corals appear to have recovered to pre-bleaching abundance, branching corals continue a downward trajectory at NE Pelorus

(Figure 4). Interestingly, there was an increase in branching morphology corals following the 2017 bleaching event at SE Pelorus, and this trend has continued in 2018 (Figure 4). This can likely be explained by the fast-growing life history strategy of branching corals and their ability to settle opportunistically following a disturbance. Abundance of massive corals has slowly increased at both sites throughout the study period.

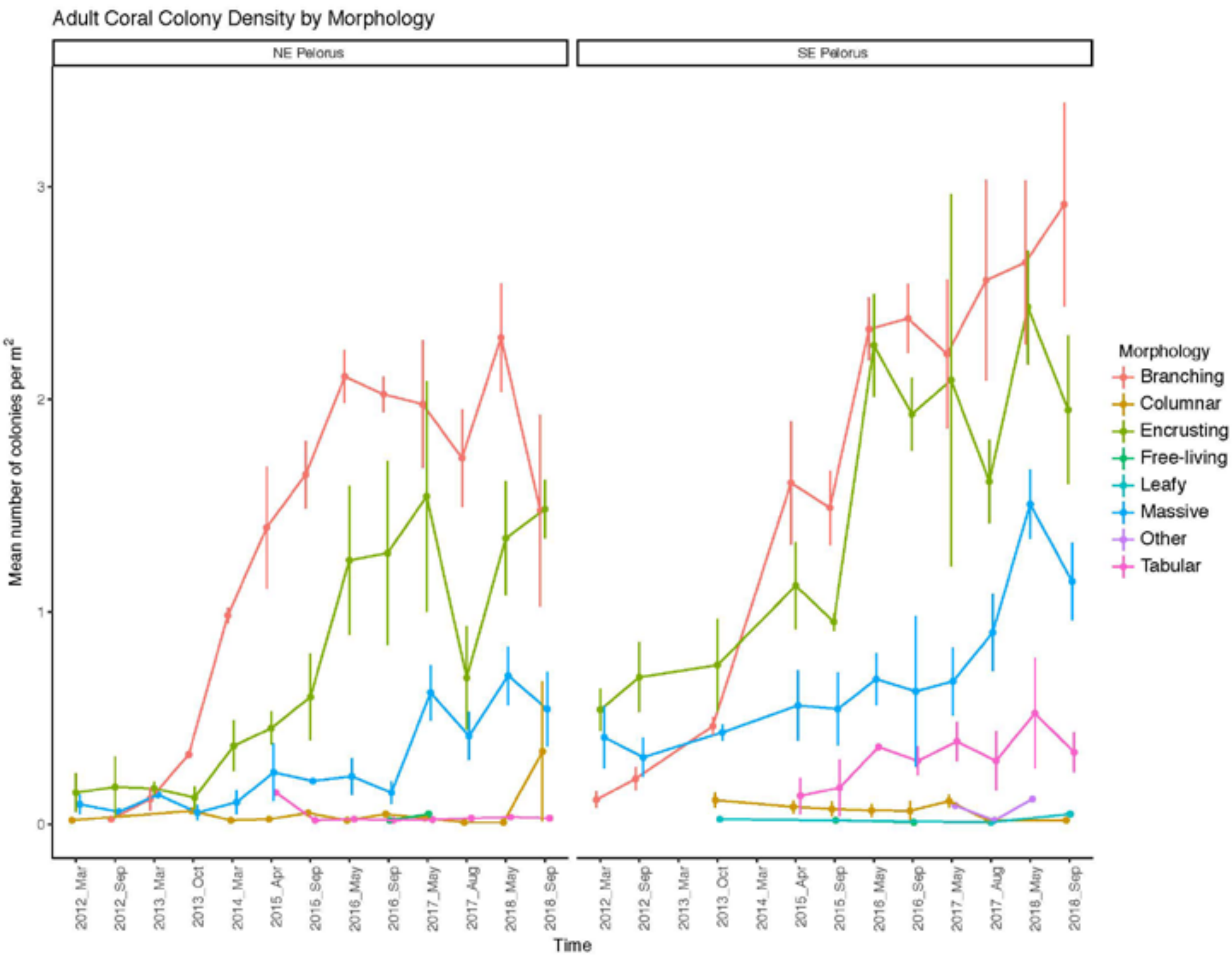

Figure 4 The density of different types of corals at different sites around Pelorus Island.

(b) Dynamics in coral demography during the initial recovery of the coral communities

Temporal patterns in coral demography, indicated by the size-distribution of colonies over time, clearly illustrate that the recruitment of small, recently-colonised colonies drive the recovery of coral communities (Figure 5). This pattern is particularly apparent from October 2013 onwards, when the smallest size class (4 – 10 cm) accounted for the largest component of the community at both NE and SE Pelorus. Between March and September 2012, the second smallest size class (10 – 20 cm) accounted for the largest proportions of the coral communities at both sites, indicating that there were corals in this size class that survived the storm-related disturbances, and that surviving corals in various size-classes were more abundant at SE Pelorus than at NE Pelorus. Reef substratum at the SE Pelorus site mostly consists of stable rocky structures, which likely allowed some coral colonies to remain attached during the major storm event. In contrast, the majority of coral communities at the NE Pelorus site had developed on a loose substratum consisting of dead branching coral skeletons on the top of a rocky bottom. As a result, these loosely attached corals were entirely dislodged by wave surges during the cyclone. Temporal comparisons of size distributions among the three most prevalent morphological categories (branching, encrusting and massive forms) also indicated that more encrusting and massive corals survived the storm event at SE Pelorus than at NE Pelorus (Figure 5). Establishment of recently colonised populations, indicated by a large increase and dominance of the smallest size class (4 – 10 cm), was observed first for branching corals, followed by encrusting and massive corals (Figure 5), reflecting the faster growth rates of branching species. Across all morphologies it can be demonstrated that a shift in distribution has occurred, with larger size classes gradually becoming more abundant. This is further evidence that recruitment and growth is occurring.

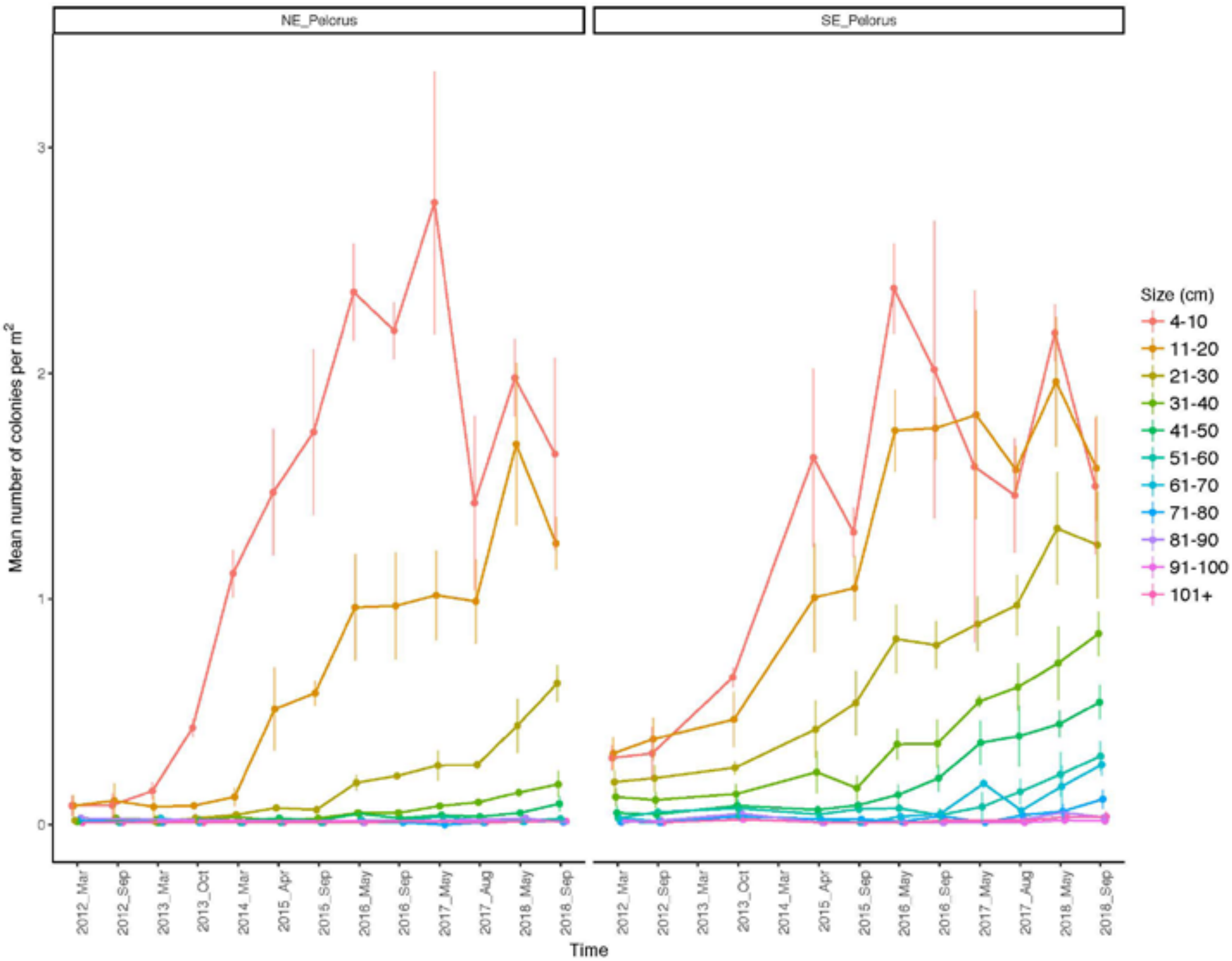

Figure 5 The increase of corals of different size classes over the course of the project, demonstrating coral recovery over time.

Following the 2017 mass-bleaching event, we observed a 48% decrease in the smallest size class of corals at NE Pelorus, which will likely have run-on effects on the distribution of adult coral sizes and recovery of adult populations at this site (Figure 5). This also demonstrates that small size-class corals are more susceptible to stress events, as there was no change in abundance of corals with a minimum size of 20cm following the 2017 bleaching event. Corals in the two smallest size classes displayed some recovery, with increases at both sites between August 2017 and May 2018 (Figure 5). Interestingly, we observed a subsequent crash of both size classes at both sites from May to September, suggesting these smaller corals did not over-winter.

Recruitment was overall less abundant in 2012 compared to the following years at both the exposed and sheltered sites (Figure 3). The effect of wave-exposure (i.e. exposed vs. sheltered sites) for different time-points specifically indicated that there was no significant difference in the recruit abundance in September 2012, while exposed sites had significantly more recruits than sheltered sites at every survey time point until September 2016. Following September 2016, a steep decline in recruit abundance was observed at both exposed and sheltered sites (Figure 3), with recruitment levels nearing the low levels observed immediately post-cyclone, a clear reflection of the delayed effects of the 2016 bleaching on coral reproduction. While we observed an initial increase in recruit abundance in 2017, further declines in recruit abundance were observed at all sites in 2018 (Figure 6), reflecting ongoing effects of the 2017 bleaching event on spawning and reproduction.

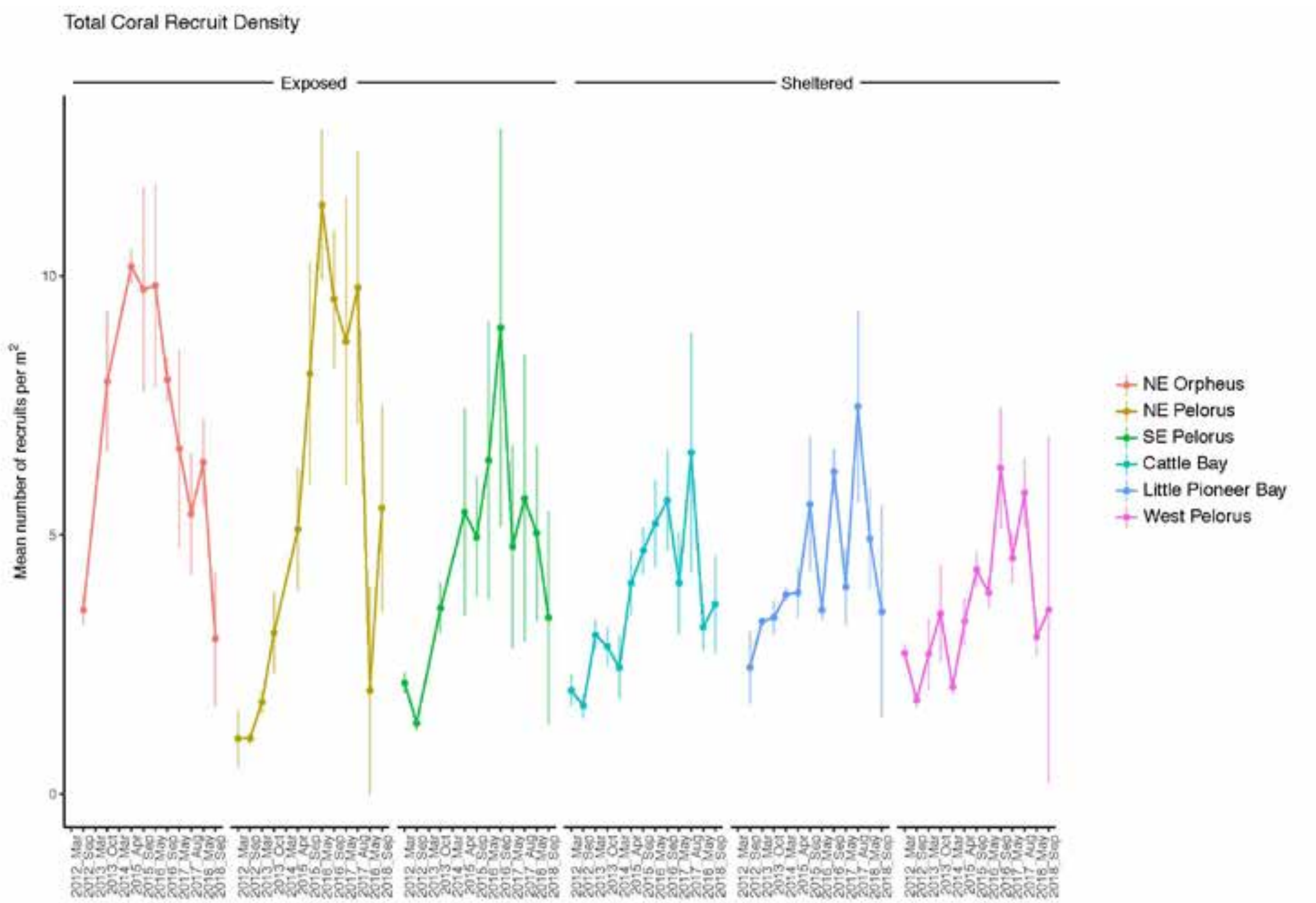

Figure 6 The density of coral recruits at various sites around Orpheus and Pelorus Islands over the course of the project.

(d) Summary of coral dynamics

The density of coral colonies at the cyclone-impacted NE and SE Pelorus Island sites 7 years post-cyclone was 107% and 152% of pre-cyclone estimated levels, respectively. Despite this recovery in coral density, the low coral cover in 2016 (16% and 31% of the pre-cyclone levels at NE and SE Pelorus, respectively) indicates that density of coral colonies *per se* does not accurately represent the status of coral recovery because the dimensions of each colony are not captured. However, our study approach based on individual coral colonies provides insights into community dynamics during coral recovery, especially when demographic data are temporally compared among different morphological groups. Results showed that branching corals were the first to establish newly-colonised communities after the cyclone and that the establishment of encrusting and massive corals followed 1 – 2 years later (Figure 2). These observations are directly related to coral life history traits among different colony morphologies such as larval dispersal and settlement rates, and/or growth rates. Coral recruitment is a particularly important driver in recovery and maintenance of reef communities and the detailed monitoring of young coral communities before substantial increase in coral cover is useful to capture early signs of reef resilience. Therefore the present approach based on coral demography has potential management applicability in reef conservation by providing a baseline dataset that is essential to model coral recovery processes after major disturbances, not only by storms, but also by other large-scale disturbances including coral bleaching, which is becoming a focus of field based activities at this site.

Density of coral recruits was higher in wave-exposed sites than sheltered sites with the exception of the first year of the study (2012). In general, the rate of coral recruitment is considered proportional to the availability of suitable substrata and larval supply. Therefore our results suggest that (1) more substrata were available for larval settlement after substantial coral loss at the exposed sites, and/or (2) larval supply increased as a result of predominant waves and currents from reproductive coral communities in the vicinity (i.e. at deep depths) of the exposed sites. However, similar levels of coral recruits were observed in exposed and sheltered sites in September 2012, suggesting that these effects were not effective immediately after the cyclone event. Widespread blooms of turf-like and fleshy fan-like algae were observed covering the bare rocky substrata in the exposed sites shortly after the cyclone (July 2011 – September 2012), which may have limited suitable substrata for coral larval settlement even if sufficient coral larvae were supplied to these areas. It is worthwhile to note that the algae gradually diminished during the study period.

In our study, seven years after cyclone Yasi, coral communities at the exposed sites had fewer encrusting corals and more branching corals than at pre-cyclone levels. It remains to be seen whether these communities will return to pre-cyclone morphological compositions, which were dominated by encrusting corals. Our observations at NE and SE Pelorus showed the establishment of branching coral communities earlier than encrusting and massive communities. Despite this initial trend, future growth of branching corals may be size-limited in wave-exposed sites as wave surges can dislocate physically unstable growth forms from the reef, and thus corals with more stable morphologies, including encrusting and massive forms, may dominate the substratum in the future. Indeed, we have documented steady increases in massive morphology corals since September 2016.

We are beginning to document the changes in community structure and abundance as a result of the bleaching events of 2016 and 2017. Following Cyclone Yasi, we observed a gradual increase in recruitment at both exposed and sheltered sites. While sheltered sites have displayed an unstable yet increasing trajectory from 2012 to 2017, exposed sites have displayed a steadily decreasing trend in recruitment since September 2016 (Figure 3). The delayed effect can be attributed to the dominant coral reproductive strategy (i.e. spawning) which only occurs once per year. Disturbances to corals in summer can have long-term stressful effects, preventing successful reproduction in the following spawning season. Interestingly, however, all sites except one (NE Orpheus) showed initial increases in recruit abundance after both bleaching events, followed by a crash in recruitment in 2018 at all sites (Figure 6). This may indicate that some corals maintained reproductive capacity immediately after the bleaching events, but there may be longer term effects on the health and reproduction of corals following extreme stress. Revisits are needed to determine if this trend persists or if we observe a recovery in 2019. The initial increases and subsequent crash in recruitment may also be an artefact of juvenile coral survey techniques: recruits under 1cm are not usually visible to the naked eye, and thus the temporal patterns of recruitment may be skewed due to a necessary growth period for juvenile corals to be counted in our surveys.

The adult populations underwent a decrease in abundance following the bleaching events, with branching and encrusting corals being the most affected. Encrusting corals seem to have recovered to pre-bleaching abundances at both sites. Branching corals, however, have further dropped in abundance at NE Pelorus. Massive corals were not affected as much and continue to show a rising trend. A drop in abundance of small coral colonies (diameter 4-20cm) is indication that juveniles were more susceptible to the bleaching events, and did not survive (Figure 2). It is hopeful that the abundance of larger size classes did not change significantly, and suggests that larger, established adult corals both survived and recovered from the event.

This field based study has provided new insights into coral population dynamics during the recovery of coral communities and identifies the establishment of new coral populations as an important driver for replenishing cyclone-impacted coral communities. The frequency and severity of large-scale disturbances to coral communities are predicted to increase as climate change progresses and the recent 2016/2017 bleaching events are evidence of this phenomenon. Recovery of coral communities is thus becoming an increasingly important key to the resilience of reef ecosystems. The documentation of early recovery dynamics within coral populations will contribute to predicting coral recovery rates and inform the role that effective management of these ecosystems can have in aiding reef recovery.

2. Pilot macroalgae survey

Activities associated with this Earthwatch project are expanding with a new project looking at the effects of macroalgal abundance on reefs around Magnetic Island. To facilitate a transition in project activities, we also performed pilot surveys relating to our new project objectives, the role of macroalgae in coral recruitment and growth. Volunteers characterised the substrate of two sites, Little Pioneer Bay and West Pelorus, using 20m point transects to determine the feasibility of using these sites for future algae removal trials. We found that the substrata at these sites are not suitable for future macroalgal research, as they are characterised by mostly rock, sand, or dead coral (Figure 7). Because macroalgae did not occur, we can use this data as a benchmark for possible expected outcomes from algal removal treatments.

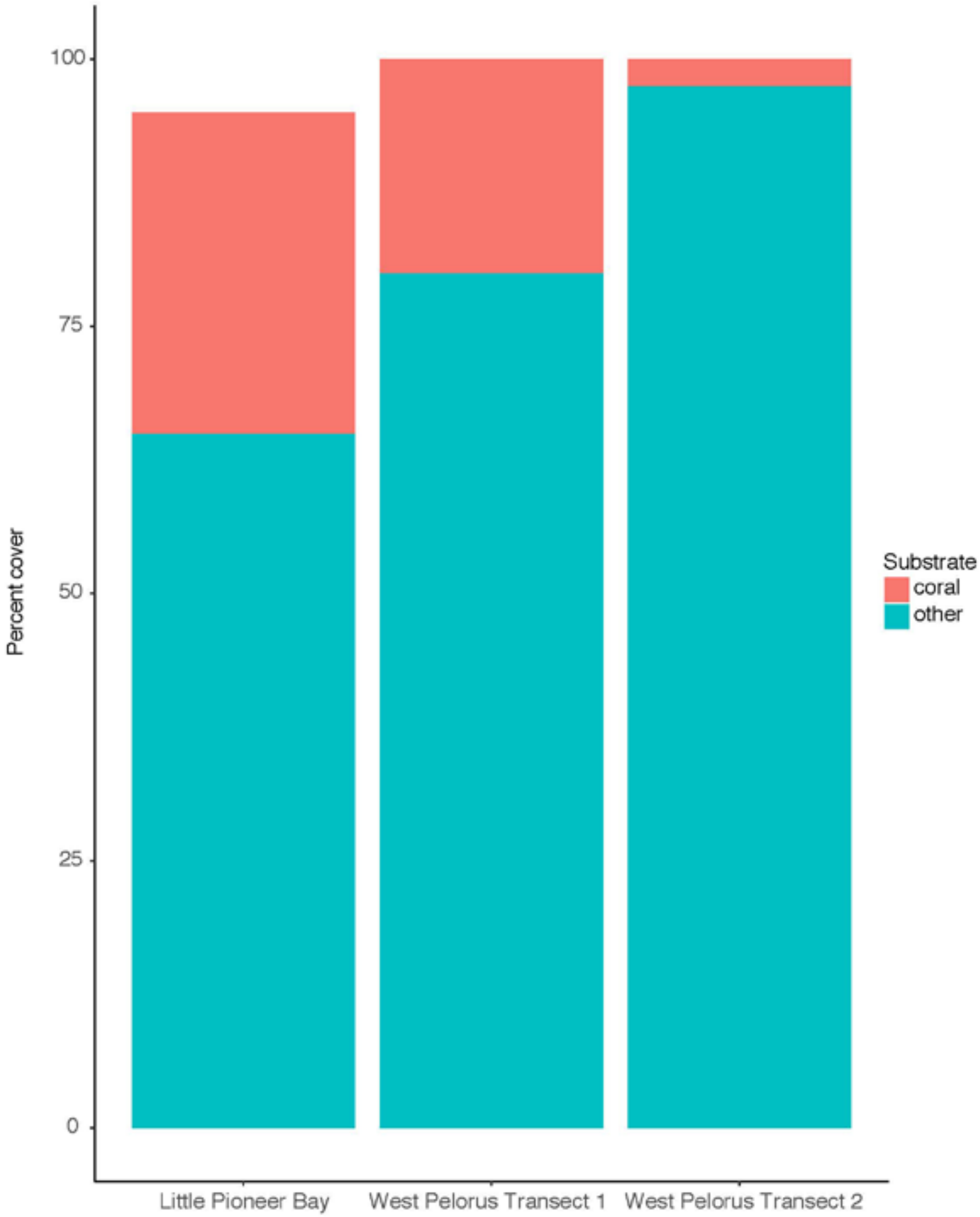

Figure 7 The characterisation of substrate at sites around Orpheus and Pelorus Islands.

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PROJECT IMPACTS

Report contributions in the categories below for the past fielding year.

1. Increasing Scientific Knowledge

a) Total citizen science research hours

Provide an estimate for the number of hours per day that volunteers spent collecting data, being trained to collect data in the field, and performing data entry. Include in this estimate transportation from housing site to the field site, and all sorts of activity for which you would typically pay a technician.

8 hours/day for 7 days for two weeks (May and September) of 2018, with avg. of 5 volunteer participants per trip = 560 volunteer hours in 2018.

For the following items, provide full references for publications and material resulting from or supported by your Earthwatch project, indicate the status of the publication (in press, published, etc.) and whether Earthwatch was acknowledged. Include papers/material from all staff, whether or not the PI is a co-author.

b) Peer-reviewed publications

Sato, Y., Ling, E, Turaev, D., Laffy, P., Weynberg, K.D., Rattei, T., Willis, B.L., Bourne, D.G. (2017) Unraveling the microbial processes of black band disease in corals through integrated genomics. Scientific Reports 7: 40455. doi: 10.1038/srep40455.

Chen, C., Bourne, D.G., Drovandi, C., Mengersen, K., Willis, B.L., Caley, M.J., Sato, Y., (2017) Modelling environmental drivers of black band disease outbreaks in populations of foliose corals in the genus *Montipora*. Peer J 5:e3438. doi: 10.7717/peerj.3438

Sato, Y, Bell, S., Nichols C, Fry K, Menéndez, P., Bourne DG (2018). Early-phase dynamics in coral recovery following cyclone disturbance on the inshore Great Barrier Reef, Australia. Coral Reefs 37 (2), 431-443. doi: 10.1007/s00338-018-1668-z

Torda, G., Sambrook, K., Cross, P., Sato, Y., Bourne, D.G., Lukoschek, V., Hill, T., Torras Jorda, G., Moya, A., Willis, B.L. (2018). Decadal erosion of coral assemblages by multiple disturbances in the Palm Islands, central Great Barrier Reef. Scientific Reports 8: 11885.

Ceccarelli, D.M., Loffler, Z., Bourne, D.G., Al Moajil-Cole, G.S., Boström-Einarsson, L., Evans-Illidge, E., Fabricius, K., Glasl, B., Marshall, P., McLeod, I., Read, M., Schaffelke, B., Smith, A.K., Jorda, G.T., Williamson,D.H., Bay, L. (2018). Rehabilitation of coral reefs through removal of macroalgae: state of knowledge and considerations for management and implementation. Restoration Ecology 26(5), 827-838.

Yang, C., Tan, S., Bourne, D.G., O'Brien, P.A., Meng, G., Xu, J., Liao, S., Chen, A., Chen, X., Liu, S. (2019) Access COI barcode efficiently using high throughput Single-End 400 bp sequencing. Submitted.

c) Non-peer reviewed publications:

Technical reports, white papers, articles, sponsored or personal blogs

Recovery of the Reef project activities have been highlighted in Yui Sato's personal Twitter (@Yui_Sato1) posts with a link to Earthwatch Australia and Earthwatch Institute.

The Recovery of the reef project was also highlighted on the internal AIMS communication publication WayPoint. "AIMS celebrates achievements of Successful Earthwatch partnership"

d) Books and book chapters

e) Presentations:

Indicate if this was an invited paper, panel presentation, keynote speech, plenary address, or other.

David Bourne was invited onto the Academy of Sciences Ocean Studies Board ad hoc committee, assembled to investigate Interventions to Increase Resilience of Coral Reefs. Membership of the committee was obtained through nomination and selection based on knowledge and skills in coral ecology and coral microbiomes and disease processes. The committee is tasked with reviewing the science and assessing potential risks and benefits of ecological and genetic interventions that have potential to enhance the recovery and persistence of coral reefs threatened by rapidly deteriorating environmental conditions that are warmer, less favourable for calcification, have impaired water quality, and pose continuing disease threats. The first task of this committee was to produce a review that summarizes scientific research on a range of intervention strategies, either designed specifically for coral or with the potential to be applied to coral, including evaluation of the state of readiness. This review was released on the 28th November 2018. As part of this committee process there were 4 planned committee meetings in the United States in 2018. A second report that provides i) a risk assessment framework for evaluating the likelihood of potential ecological benefits and harms of the novel interventions, ii) a decision pathway to implementation and monitoring of the potential interventions and iii) Identifies the research needs to refine the intervention strategies and reduce uncertainties in the environmental risk assessments is currently underway and due for release in mid-2019. These tasks and both reports represent a significant investment of time and energy.

David Bourne has been in ongoing discussions with the Great Barrier Reef Marine Park Authority contributing to policy-making discussion on coral disease management plans.

David Bourne presented work associated with the evolving Earthwatch Macroalgal removal project at the Coral reef restoration Symposium held in Cairns in July 2018. The talk was titled "Removal of macroalgae for reef restoration; state of knowledge and considerations for implementation"

2. Mentoring

a) Graduate students

Student Name	Graduate Degree	Project Title	Anticipated Year of Completion
Paul O'Brien (JCU)	PhD	Host-microbial coevolution in marine invertebrates	2021
Maria Andersen (JCU)	MSc	Two degrees of separation: Vertical transmission as a potential driver for transgenerational acclimatization in a GBR sponge	2018
Margot Bligh (UQ)	Honours	Metagenomics tools to probe coral microbiome function	2018
Ole Brodnicke (U of Copenhagen)	MSc	Augmented coral health - Linking coral physiology, energetics and microbial factors to enhance coral resilience	2019
Rachel Johns (JCU)	MSc	Influence of acrylate on coral calcification	2019
Marie Thomas (AIMS)	MSc	Toxicity of herbicides to tropical microalgae for guideline development and risk assessments	2018

b) Community outreach

Provide details on how you have supported the development of environmental leaders in the community in which you work.

Name of school, organization, or group	Education level	Participants local or non-local	Details on contributions/ activities
Mitsubishi Corporation	Various	Both	As a funder of the research program, Mitsubishi Corporation employees are encouraged to join the expedition to comprehensively understand their company's sustainability programs.
Olivia Penman	Bachelors	Local - Marine Park Ranger	Participation enhanced her understanding of GBR coral science, which is relevant to her position as a ranger of the Great Barrier Reef Marine Park.
Steve Robbins (UQ)	Post-doctoral researcher	Local	Steve Robbins is a Post-Doctoral researcher based in the Australian Centre for Ecogenomics at the University of Queensland, supervised by Dr. Gene Tyson. Samples collected in both May and September 2018 are being used to establish two model species for coral microbial investigations.

3. Partnerships

List your current active professional partnerships that contribute to your project and indicate the type of support these partners provide

Partner	Support Type(s)[1]	Years of Association (e.g. 2006-present)
Mitsubishi Corporation	Funding	2012-present

[1]. Support type options: funding, data, logistics, permits, technical support, collaboration, academic support, cultural support, other (define)

4. Contributions to management plans or policies

List the management plans/policies to which your project contributed this year

Plan/Policy Name	Type[2]	Level of Impact[3]	New or Existing?	Primary goal of plan/policy[4]	Stage of plan/policy[5]	Description of Contribution
Report for Coral Reef Expert Group: S3. Synopsis of current coral reef monitoring on the Great Barrier Reef	Report, management plan	To Reef Management authority for Government overview; Regional	New	Reviews current coral reef monitoring programs on the GBR, addressing three objectives: •Collate information about indicators measured, techniques used, spatio-temporal design, and reporting processes • Identify which of the candidate indicators are not covered in existing programs; •Discuss potential limitations of current designs.	Submitted to GBRMPA and under consideration	This project represent one of the current monitoring studies on the GBR

2. Type options: agenda, convention, development plan, management plan, policy, or other (define)
3. Level of impact options: local, regional, national, international
4. Primary goal options: cultural conservation, land conservation, species conservation, natural resource conservation, other
5. Stage of plan/policy options: proposed, in progress, adopted, other (define)

5. Conserving natural and sociocultural capital

a) Conservation of taxa

i. List any focal study species that you did not list in your most recent proposal

Species	Common name	IUCN Red List category	Local/regional conservation status	Local/regional conservation status source

ii. In the past year, has your project helped conserve or restore populations of species of conservation significance? If so, please describe below.

The AIMS long-term monitoring project reports that coral cover across the Great Barrier Reef has declined by approximately 50% during the last 30 years. Our study focuses on obtaining baseline data on Scleractinian corals (reef-building corals) specifically related to the recovery of coral abundance following a major tropical cyclone disturbance and the influences of coral black-band disease within the recovering coral population. This data has been used to inform management on the capacity of reefs to recover and their trajectory in population size and health in relations to other environmental impacts. Long-term trends in population size, density and health will be modelled to allow informed information on corals reefs and the threat that they face. This information has been transferred to the management agencies such as the Great Barrier Reef Marine Park Authority to help developing better management strategies for threatened coral species.

Species	IUCN Red List category	Local/regional conservation status	Local/regional conservation status source	Description of contribution	Resulting effect[6]

6. Resulting effect options: decreased competition, improved habitat for species, range increased, population increase, improved population structure, increased breeding success, maintained/enhanced genetic diversity, other

b) Conservation of ecosystems

In the past year, has your project helped conserve or restore habitats? If so, please describe below.

The AIMS long-term monitoring project reports that coral cover across the Great Barrier Reef has declined by approximately 50% during the last 30 years. Our study focuses on obtaining baseline data on Scleractinian corals (reef-building corals) specifically related to the recovery of coral abundance following a major tropical cyclone disturbance and the influences of coral black-band disease within the recovering coral population. This data has been used to inform management on the capacity of reefs to recover and their trajectory in population size and health in relations to other environmental impacts. Long-term trends in population size, density and health will be modelled to allow informed information on corals reefs and the threat that they face. This information has been transferred to the management agencies such as the Great Barrier Reef Marine Park Authority to help developing better management strategies for threatened coral species.

Habitat type	Habitat significance[7]	Description of contribution	Resulting effect[8]

[7]. Habitat significance options: nursery, breeding ground, feeding site, corridor, migration path, refuge, winter range, summer range, spring range, fall range or other (define)

[8]. Resulting effect options: extent maintained, condition achieved, restored, expanded, improved connectivity or resilience

c) Ecosystem services

Indicate which ecosystem service categories you are **directly studying** in your Earthwatch research and provide further details in the box below.

☐Food and water

☐Flood and disease control

☐Spiritual, recreational, and cultural benefits

☐Nutrient cycling

Details:

d) Conservation of cultural heritage

Provide details on intangible or tangible cultural heritage components that your project has conserved or restored in the past year.

Cultural heritage component[9]	Description of contribution	Resulting effect

[9]. Cultural heritage component options: traditional agriculture, artifacts, building(s), hunting ground or kill site, traditional ecological knowledge and practices, monument(s), oral traditions and history, spiritual site, traditional subsistence living

RESEARCH PLAN UPDATES

In early 2016 PI on the project David Bourne moved across to James Cook University accepting a position as Senior Lecturer in the College of Science and Engineering. Field based activities since 2017 have been run through James Cook University. The activities associated with this project would not be possible without the support of Orpheus Island Research Station of James Cook University. The logistical support from the station is vital and their well-equipped field and laboratory facilities which are essential to our underwater research activities and aquarium experiments on site.

Activities associated with this Earthwatch project have also contributed to sample collection and processing for a large project called ReFuGe2020 co-ordinated through the Great Barrier Reef Foundation. The aims of the project are to fast-track management-relevant genomics-based coral reef climate adaptation research. During field activities, collection of corals has occurred and sampled coral fragments have been processed at the research station for later sequencing activities of the coral microbiomes, viromes and transcriptomes. The project links with Prof Gene Tyson at the University of Queensland and activities included collections for corals associated with a joint ARC discovery project (Tyson and Bourne).

The project has also helped facilitate collections associated with the PhD project of Paul O'Brien which is partnered with the Beijing Genome Institute (BGI) and looks at the coevolution of host microbial associated in marine invertebrate species.

Due to increasing impacts on corals reefs in a GBR marine park, reef restoration is emerging as a future research priority for the Great Barrier Reef Marine Park Authority. A collaborative initiative with Dr Ian McLeod (JCU and NESP leader) and Reef Ecologic (Dr Adam Smith and Dr Paul Marshall) involving community groups, scientists and industry in Townsville are investigating potential restoration of reefs around Magnetic Island. A project for macroalgal removal is currently in its early phases with the proposed methodology and measures of success being developed and tested through an honours project. The project at fringing reefs of Magnetic Island will act as a pilot study for a more comprehensive program. The reefs at Magnetic Island have high cover of brown macroalgae, are easily accessible for a research program and are highly visible to the local community, the scientific community and international tourists. It is also indicative of other inshore reefs of the Great Barrier Reef, and ideal for a pilot project that could be expanded to other similar reef systems. The program would run citizen science activities to aid removal of algae and underpin key scientific questions around the approach and measured indicators of success.

The existing Earthwatch project led by David Bourne will be merged into activities around Magnetic Island and source additional funds through NESP and ARC linkage to build a large focused program on reef restoration. Such a project would have large local community engagement plus high national and international impact. David Bourne is proposing to lead an ARC linkage project in 2019 that further grows this work.

Report any changes in your research since your last proposal/annual report. For any 'yes' answers, provide details on the change in the 'Details' box. This section will not be published online.

1) Have you added a new research site or has your research site location changed? ☐ Yes ☒ No
2) Has the protected area status of your research site changed? ☐ Yes ☒ No
3) Has the conservation status of a species you study changed? ☐ Yes ☒ No
4) Have there been any changes in project scientists or field crew? ☐ Yes ☒ No

Details – provide more information for any 'yes' answers

5) Provide details on any changes to your objectives, volunteer tasks, or methods, include reason for the change.

ACKNOWLEDGEMENTS

We thank Earthwatch Institute for this funded project "the Recovery of the Great Barrier Reef" and the staff of Earthwatch Australia for their assistance and professionalism which has largely contributed to the smooth field based operations and the enjoyment and outcomes of the project.

LITERATURE CITED

EARTHWATCH INSTITUTE

ANYTHING ELSE

Is there any other information you would like to provide Earthwatch?

APPENDICES

Include appendices in this document or include as attachment(s) with your submission. Include the following:

- PDFs of papers published or in press (see attached)