Ecological Assessment of the Flora and Fauna of Flinders Reef

Moreton Bay Marine Park, QLD Australia

Authors

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UNIDIVE

FREA

FLINDERS REEF ECOLOGICAL ASSESSMENT

Flinders Reef Ecological Assessment, Moreton Bay Marine Park, Queensland

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Final Report

12 December 2017

This report should be cited as:

Roelfsema C.M., E. Bayraktarov, C. van den Berg, S. Breeze, M.G.G. Grol, T. Kenyon, S. de Kleermaeker, J. Loder, M. Mihaljević, J. Passenger, P. Rowland, J. Vercelloni and J. Wingerd (2017). *Ecological Assessment of the Flora and Fauna of Flinders Reef, Moreton Bay Marine Park, Queensland.* UniDive, The University of Queensland Underwater Club, Brisbane, Australia.

Far and away, the greatest threat to the ocean, and thus to ourselves, is ignorance. But we can do something about that (Sylvia Earle).

Humans are the only creatures with the ability to dive deep in the sea, fly high in the sky, send instant messages around the globe, reflect on the past, assess the present and imagine the future (Sylvia Earle).

Table of Contents

List of Figures

List of Tables

List of Appendices

Acknowledgements

A good news story, the Flinders Reef Ecological Assessment (FREA) project showed again that the UniDive members, supporters, friends and family take "Caring for Local Reefs" seriously. Our team working to piece the puzzle together, resulting in: great adventure, learning curve, detailed ecological description, map, book, video and this report, all presenting a positive story about Flinders Reef. A healthy reef, buzzing with life close to the big smoke of Brisbane.

Surveying Flinders was, as expected, logistically challenging due to its remote and exposed location at the tip of Moreton Island. Giving us a new and challenging experience compared to past UniDive volunteer projects. Each trip was around 12 hours, with the team taking "Down Under", our boat, loaded with divers, dive gear, and survey equipment, 1-2 hours off shore, to Flinders. After two initial training weekends at Point Lookout, we did 15 individual day trips, and two weekend camping trips camping to Moreton Island—a total of 561 dives and over 10,000 hours of volunteer time. The camping trips required additional logistical expertise (thanks Andrew and Trevor), creativity, and acceptance of: long days, sand in your sleeping bag, carrying tanks through the heat of the beach, having a salty shower in the ocean, and sleeping under the stars of the endless sky. Our trips finished by washing the boat on a Sunday night at 7 pm after being awake since 5 am.

This report would not be possible without the data collected by the core divers: Andrew O'Hagan, Andy Holland, Breanne Vincent, Bruce McLean, Catherine Kim, Cedric van den Berg, Clemens Müller, Da King, Dee Passenger, Diana Kleine, Donna Easton, Douglas Stetner, Elisa Bayraktarov, Elisa Girola, Eva Kovacs, Jaap van der Velde, James Mcphearson, Jen Calcraft, Jens Kunze, Josh Passenger, Josh Wingerd, Julie VanDore, Julie Vercelloni, Karen Johnson, Katherine Trim, Liette Boisvert, Lock Pollard, Mark Stenhouse, Mike pheasant , Monique Grol, Morana Mihaljevic, Olivier, Peran Bray, Peter Arlow, Rikki Andersen, Santiago Mejia, Simone De Kleermaeker, Sonja Meier, Stefano Freguia, Tania Kenyon, Tanya Dodgen, and Trevor Barrenger. The boat handler took on the responsibility of bringing the core divers to the reef and back safely - they truly did a fantastic job: Douglas Ster, Jens Kunze, Josh Passenger, Lock Pollard, Mark Stenhouse, Monique Grol, Peran Bray, and Trevor Barrenger. Next to that I'd like to thank the UniDive Management Committee for their ongoing support, and the family of friends of volunteers, who helped with various jobs such as cooking, setting up camp, or loading cars, making life easier for all involved.

For the participants of the FREA project, the scientific project support and training team were crucial for providing the academic basis, practical training, quality control and analysis necessary for such an endeavour. The support team used their own time, experience, and skills to teach others as well as to help analyse the results and write everything up. Thanks to: Elisa Bayraktarov (Substrate, presentations, organizer), Morana Mihaljevic (Inverts, species list, presenter, organiser), Monique Grol (Fish, Substrate, CoralWatch, species lists, reviewer), Julie Vercelloni, (Fish and Statistics), Juan Ortiz (Coral Reefs), Jennifer Loder (Reef Check, Methods, Impacts, Substrate), Christine Dudgeon (Fish), Phebe Rowland (Coral Watch), Tania Kenyon (Impacts, geology), Josh Wingerd (Impacts), Jaap van der Velde (online exam), Megan Saunders (Inverts), Josh Passenger (data base), Simone De Kleermaeker (environmental data), Ryan Booker (pool training, reviewer), Douglas Stetner (reviewer), Melanie Oey (Pool Training) and Sarah Breeze (Methods). Karen Johnson, Phebe Rowland, Sarah Breeze and Eva Kenyon were in charge of the analysis of photos taken.

The FREA project could not have succeeded without the financial support of the Queensland Parks and Wildlife Services, Honourable Minister Dr Steven Miles - Minister of Environment and the Great Barrier Reef, Solar School, Healthy Land and Water, and those who supported the ING Dreamstarter crowd sourcing.

In-kind support came from: Point Lookout SCUBA Charter (Ken) with discounted dives and accommodation for the two training weekends; UQ boating and diving support by Mike Phillips providing access to facilities and tanks; Moreton Adventure for discounted barge prices; Tangatours for free tanks fills; Queensland Parks and Wildlife for in-kind support camping and 4xWD permits; and Geoimage for discounted satellite image of Flinders Reef. Lecture rooms, survey equipment, and hardware & software was provided through the Remote Sensing Research Centre and the School of Earth and Environmental Sciences at the University of Queensland. General support at the University of Queensland was further provided through: Dr Ian Tibbets from the Centre for Marine Science and UQ Sport for the access to the Olympic pool on campus. Reef Check Australia and CoralWatch provided support with methods development, training, data analysis and survey gear.

The thorough external reviews by two local professionals, Nicola Udy and Paul Maxwell with years of experience in management of Moreton Bay and its waterways, helped us to finalise this truly valuable report.

UniDive FREA would like to show their respect and thank the traditional owners for providing us access to the mind-blowing wonders of Flinders Reef.

It feels a bit strange but after many long nights, the FREA project now has come to an end. My main concern has always been the wellbeing and safety of all divers involved, and with their responsible thinking and safe diving techniques, we can truly say we did it again! For those who are asking what's next, yes, , I am already thinking about follow ups, but that will need some time before starting our next citizen science project. It was an honour to lead you to this success, for which you can truly be proud. Thank you!

Lastly, a huge thanks to all the friends and family who also took care of the reef, by letting their loved ones spend hours on the FREA project. I'd especially like to thank; Anouk, Djoy and Diana. The reef is also our family, and we need to take care of it the same we do for our families.

Chris Roelfsema
UniDive FREA Project Organiser
"Caring of Local Reefs"

"The citizen scientists in the Moreton Bay Hope Spot are living proof that the ocean is a big blue magnet that unites people who care. Their important work is benefitting the human and aquatic inhabitants of greater Brisbane by making a strong case for continued protection of this Hope Spot. Thank you to the citizens of Moreton Bay for collaborating and contributing data in the effort to protect and restore the blue heart of the planet. You are a great cause for hope!"
(Sylvia Earle, December 21, 2016, Ocean researcher, founder Mission Blue).

Core FREA Divers during Training Weekend in November and February

FREA Training Weekend Participants November 2016

FREA Training Weekend Participants February 2017

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Executive Summary

Introduction

The Flinders Reef Ecological Assessment (FREA) study was conducted by volunteers of UniDive (The University of Queensland Underwater Club) in 2017, with training starting in 2016. The first detailed habitat map of Flinders Reef was created and 11 sites were surveyed for ecological data over two seasons: autumn (March) and spring (September), using Reef Check, CoralWatch and Reef Health and Impact Survey (RHIS) approaches.

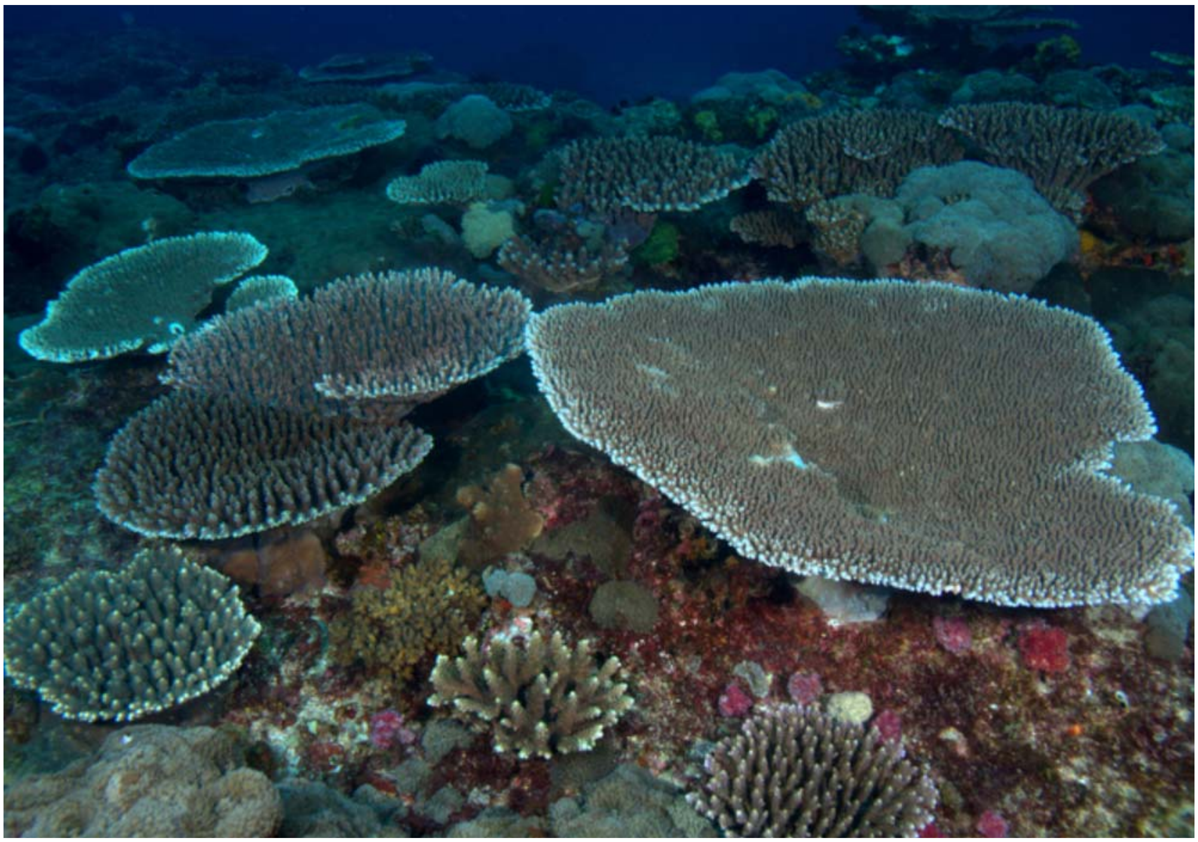
All aspects of the FREA project were conducted on a volunteer basis which included training provided by Reef Check Australia instructors and marine experts, to other UniDive members who had no, or limited, experience in surveying, identifying marine organisms and mapping habitats. Training, subsidised surveys and resulting publications were funded through: Queensland Parks and Wildlife Services; the Honourable Minister Dr Steven Miles - Minister of the Environment for National Parks and the Great Barrier Reef; ING Dreamstarter crowd sourcing; Solar Schools and Healthy Land and Water.

Flinders Reef is located in the northern part of Moreton Bay Marine Park, which is protected as a Marine National Park (green) Zone under a no-take, no fishing, collecting or anchoring policy. A no anchoring area overlaps with the green zone which was re-zoned in 2009. Re-zoning resulted in an improved protection of the biodiversity, unique habitats and wildlife of Moreton Bay Marine Park. It is surrounded by a Conservation Park (yellow) zone (Conservation Status) allowing a limited amount of fishing. Moorings with 2-hour time limits are located around Flinders Reef making it accessible to diving and boating.

Reef Check Australia has been carrying out annual ecological assessment surveys at four sites at Flinders Reef since 2009. CoralWatch and Queensland Parks and Wildlife Services have also conducted opportunistic reef health surveys over time. Additional research projects have been conducted with different focusses by various research groups (e.g. The University of Queensland and Queensland Museum). Unlike the FREA project, most other research studies were focused on a few sites, a specific taxonomic group, and did not provide a comprehensive ecological assessment of fish and invertebrates combined with detailed information on substrate and impacts. The FREA project collected this comprehensive baseline information for 11 sites and throughout different seasons. In addition, this information is accompanied by the first detailed habitat map of Flinders Reef.

The FREA project was initiated by UniDive to establish a detailed characterisation of Flinders Reef in order to highlight its importance within Moreton Bay Marine Park and its similarity with southern reefs of the Great Barrier Reef. The project further acknowledges the value of Flinders Reef as a component of Moreton Bay Marine Park which has recently been identified as a Mission Blue Hope Spot. FREA provides a detailed baseline to help assess potential changes due to local or global environmental impacts. Additionally, the project increased knowledge and skills of UniDive volunteers, and has created and continues to generate community awareness about the biological and cultural value of Flinders Reef.

The ecological assessment surveys were conducted over one weekend during two survey seasons as well as five additional single-day trips. In addition, ten single-day trips were conducted for mapping, photo/video and survey practice. A total of 100+ volunteers have been involved, of which 44 were certified Reef Check divers. The project resulted in 561 dives (421 hours underwater) which included 176 training dives, 239 survey dives, and 146 mapping/photo dives. Four diving days were conducted at Point Lookout, North Stradbroke Island, using a commercial boat for training purposes, and 19 days using "Down Under", the UniDive boat, to operate at Flinders Reef. The FREA project resulted in a habitat map and a detailed dataset for 11 sites at Flinders Reef describing reef composition, inhabitants, impacts, and seasonal variations.



Amazing coral cover around Flinders Reef. Roelfsema© 2017

Key Outcomes

Flinders Reef is a true Hope Spot characterized by a high cover of hard coral, high diversity and relatively low levels of reef health impacts. The findings confirmed an outstanding ecological health state, likely preserved through a full protection status as a green zone and a remote location. Our assessment supports that the coral cover of Flinders Reef is higher than other reefs in South East Queensland and comparable to sites on the Great Barrier Reef.

Rock and hard coral cover were the most abundant substrate and benthic groups surveyed. Average coral cover in 2017 across all sites was 31%, with hard coral cover of up to 79% at the site Coral Garden. The most commonly observed macro algae was the red algae *Asparagopsis* sp, with a strong seasonality as it was more than three times abundant during spring than during autumn. Macro algal *Laurencia* sp. dominated the deeper waters (>15 m) on the east side of the reef. Exposure to wind, waves and currents is suggested as the main driving factor for species distribution between the western sheltered and eastern exposed sides of the reef.

Eight out of the 11 key fish groups were observed at Flinders Reef across seasons, with butterflyfish being the most abundant fish group. Since this fish group feeds upon live corals, its high abundance correlates with our findings of outstanding coral coverage and healthy coral populations. The surveys indicated less fish abundance in spring compared to autumn which may be explained by the difference in water temperature between the two seasons.

The recorded impacts at Flinders Reef were three times lower than those observed for the more accessible reef locations such as Point Lookout. The most common impacts observed at Flinders Reef were coral physical damage, unknown scars and coral disease, which were observed at all sites and during at least one season. *Drupella* scars, fishing gear and general marine debris were found in comparatively lower abundance and at fewer sites than at Point Lookout. No boat anchor damage was recorded at any of the sites in either season. An east-west gradient of total impacts was recorded with higher total impacts on the sheltered western sites.

Environmental data for Flinders Reef supports the data collected during the ecological surveys. The dominant wind and wave direction correlates with the location of different coral types found around the reef. Over the last five years, more than 10 events of increased observed chlorophyll concentration may indicate reduced water quality events, most likely because of eutrophication. The observed daily maximum wind gusts and waves correlate with storms that can explain some observations of damaged coral.

The FREA ecological assessment provided for the first time a comprehensive gain of knowledge about the reef populations for 11 sites over two seasons, in combination with the first habitat map. The high coral cover present at Flinders Reef sites is comparable to other South East Queensland regions surveyed by Reef Check Australia. The Flinders Reef Coral Garden site stands out by its high branching coral coverage with comparable levels observed for similar sites at Heron Reef, Southern Great Barrier Reef. These findings and the previously mentioned outcomes highlight that Flinders Reef stands out as a special place in South East Queensland and re-iterates the importance of ongoing conservation and protection by local management authorities and the community.

Recommendations for Management and Community

The results of the FREA project and the lessons learned implementing this survey led to the following recommendations aimed at conserving the current status and understanding of Flinders Reef:

Continued and Improved Monitoring of Flinders Reef

- Repeating the ecological assessment on an annual basis (e.g. Reef Check, RHIS, CoralWatch surveys) for a selected number of sites and potentially every five years for all sites (e.g. by an ongoing FREA project) will continue to provide a better understanding of the reef communities' changes, thus will help to identify the management interventions required for an effective conservation of Flinders Reef.
- Monitoring should include additional indicator species categories not recorded previously but observed to be present and which are characteristic for sub-tropical and temporal regions.
- Placing cameras at this remote location could provide real-time observations helping authorities to spot illegal activities; cameras could also provide information on the environmental conditions to public recreational users and increase the community awareness about Flinders Reef.

Reduction of Physical Damage to Corals

- Educating divers, snorkelers, fishers and skippers on how to reduce physical damage may help reduce incidental damage to the reef habitat.
- Installing additional moorings on northern and southern sides of Flinders Reef could reduce anchor damage for potential new dive areas with interesting features.

Community Engagement to Create Awareness of the Beauty of the Reefs

- Educating the community about the beauty and importance of Moreton Bay reefs will help preserve these resources for future generations.
- Engaging the community in citizen science can help build further understanding of local reefs.

Support Conservation of the Reefs by Providing Peer-Reviewed Information
Scientific publications, reports and datasets (such as those from the FREA project) should be available to local authorities to help support management decisions and they may include:

- Project documents such as this report, video and the photo book.
- Peer-reviewed scientific papers describing key findings of the research, with one paper based on FREA project results.
- Open access datasets that may be used for additional scientific research and to inform management applications. Survey data collected as part of this project will be uploaded to an open access data repository.

A more complete description of these recommendations is available at the end of the discussion section.

1. Introduction

1.1. Moreton Bay and Flinders Reef

Flinders Reef is a small isolated sandstone platform reef situated three nautical miles north from Moreton Island at the northern borders of the Moreton Bay Marine Park. It is only a 1-2 hour boat ride across from Greater Brisbane (excluding the Gold Coast and Sunshine Coast) with a population of 2.31 million people as counted in June 2015, accounting for nearly half (48%) of the Queensland population and 19% of the national population (Roelfsema et al. 2014). Flinders Reef was first described as an exposed rock by the famous cartographer Matthew Flinders (1774-1814) in his journal on the HM Sloop Investigator on 26 July 1802 and was named after him at a later unknown date.

Moreton Bay was formed when sea levels began to rise following the Last Glacial Maximum (McPhee 2017). Over the past 7,000 years, Moreton Bay has experienced several shifts between coral-dominated and non-coral-dominated states (Lybolt et al. 2011). Today, much of the substrate in Moreton Bay is composed of sand, silt and mud (Jones M.R. et al. 1978, Lockington et al. 2017) and is unsuitable for the settlement of corals, which are largely restricted to small fringing islands.

Moreton Bay is unique for its large biodiversity on land and in the ocean. Marine life present is extraordinary and composed of over 1,600 invertebrates (Bruce 2008, Fautin et al. 2008, Hooper et al. 2008, Li 2008, Lörz and Bruce 2008, Anne-Nina and Bamber 2010, Gershwin L.A. et al. 2010, Healy and Potter 2010, Healy et al. 2010, Johnson 2010, Kott 2010, Preker and Lawn 2010, Morton and Lützen 2008), 125 species of coral (Harrison et al. 1998, Harriott and Banks 2002, Wallace et al. 2008, Sommer et al. 2014), 8 dolphin species including the largest resident population in the world, the largest known aggregation of Leopard sharks (*Stegostoma fasciatum*) in the world (Dudgeon et al. 2013), migrating humpback whale (*Megaptera novaenglia*), large numbers of visiting manta rays (*Manta alfredi*), and grey nurse sharks (*Carcharias Taurus*), and uniquely large herds of dugongs (*Dugong dugon*) considering their proximity to a major city.

Moreton Bay corals experience high turbidity levels, freshwater influx from flooding and large water temperature variations (Lybolt et al. 2011). Flinders Reef is located on the oceanic side of Moreton Bay and is largely protected from these environmental influences (McPhee 2017) thereby supporting a rich coral community. Due to its vicinity to the rapidly expanding population of South East Queensland Greater Brisbane, Flinders Reef is experiencing an increase in both frequency and intensity of commercial and recreational activities (EPA 2008). In addition to anthropogenic effects, Moreton Bay and Flinders Reef have recently been exposed to large-scale natural disasters such as the 2011 Queensland flood (Olds et al. 2014).

Part of Moreton Bay is listed as a Ramsar site, a wetland of international importance under the Ramsar Convention (Queensland Wetlands Program). In 2016, Moreton Bay was identified as a Hope Spot – a special place that is critical to the health of the ocean recognised by Sylvia Earle's Mission Blue Alliance (Chhotray 2016, Blue 2017). In 2009, Moreton Bay Marine Park was re-zoned to better protect the area's biodiversity, unique habitats, and wildlife. In the process of re-zoning the green zones regulated by a no-take, no fishing, collecting or anchoring policy were expanded to 16% of the marine park. Flinders Reef as a centre point with a radius of 500 m is now a Marine National Park (green) zone. This is overlain with a no anchoring area and surrounded by a Conservative Park (yellow) zone with a radius of 2 km (Department of State Development 2010). Moorings are available with a 2-hour limit in both zones for the public to enjoy this jewel, without anchoring.

1.2. History of Indigenous People's Use of Reef Resources in Quandamooka

Quandamooka is commonly defined as the region and indigenous people of Moreton Bay and its islands. Quandamooka indigenous people encompass the Ngugi (Moreton Island) and the Gorenpul and Nunukal clans (North Stradbroke Island) (Ross and Coghill 2000). Collectively they refer to themselves as the people of Quandamooka. The majority of the Quandamooka group are now confined to North Stradbroke Island or the mainland, with a remote community on Peel Island. This group could once be traced back to 600-800 individual tribes on Moreton Island and at least 800 on Stradbroke (Meston 2017). Thus, it is expected that Flinders Reef was first sighted by the Ngugi clan potentially from the high point now known as Cape Moreton at an unknown date. However, no reference was found stating that the Quandamooka people used Flinders Reef or that they visited it to find food resources.

Marine resources formed a high percentage of the diet of local island tribes such as those on Moreton Island (the closest point to Flinders Reef). This allowed them to remain more sedentary and support higher population densities than inland groups (Draper 1978). Remaining sedentary allowed island tribes to retain autonomy longer in the face of European invasion (Whalley 1987). The indigenous people (both islander and coastal) of Moreton Bay also hunted dugongs. They would capture dugongs with a net, restraining them until they drowned or clubbing them to death. All of the animal would be used: its skin would be dried, its meat would be cooked, its bones would be utilised as utensils and its lard would be burned down to oil (Draper 1978, Folkmanova 2015). According to Draper (1978), turtles were killed in a similar way. Short spears were used to kill shellfish and crustaceans in the littoral zone (Draper 1978). Claims by Draper and the accompanying archaeological evidence are consistent with the oral history of the Quandamooka people, which indicates a long history of fishing and coastal resource exploitation (Ross 2001). The historical coastal practices discussed here, probably had minimal impact on the populations of Flinders Reef species. (Whalley 1987) suggests that the introduction of European goods, especially in the form of boating technologies, may have changed the economic behaviours of the islander indigenous people and have taken their hunting practices offshore.

1.3. Past and Ongoing Monitoring of Flinders Reef

Flinders Reef is a particularly important reef in the region due to its unique habitat and species assemblage, yet its isolated location makes it challenging to monitor and map. Beginning in 2009, Reef Check Australia has conducted annual substrate, invertebrate and impact surveys at four sites, namely Alden Cave, Coral Garden, Turtle Cleaning Station and Plateland. Reef Check Australia surveys have reported coral cover as high as 71% at Coral Garden (Pentti et al. 2016). Reef Health Impact Surveys (RHIS) have been conducted by Queensland Parks and Wildlife Services, whereas coral health surveys have been haphazardly undertaken by CoralWatch.

Moreover, the Queensland Museum and The University of Queensland have conducted several research studies at Flinders Reef. These provide additional information on the biodiversity based on collected and lodged specimens, underwater photographs and visual surveys. At least one sea anemone *Stichodactyla haddoni* (largest species known for Moreton Bay), three ascidian species (Harriott and Banks 2002, Kott 2010) and 125 species of hard corals (Harrison et al. 1998, Fautin et al. 2008, Wallace et al. 2008, Sommer et al. 2014) have been reported specifically from Flinders Reef. Over 1,600 invertebrates including molluscs, cnidarians, crustaceans and ascidians have been reported from the Moreton Bay surveys that included Flinders Reef (Bruce 2008, Fautin et al. 2008, Hooper et al. 2008, Li 2008, Lörz and Bruce 2008, Morton 2008, Anne-Nina and Bamber 2010, Gershwin L.A. et al. 2010, Gershwin L.A. et al. 2010, Healy and Potter 2010, Healy et al. 2010, Johnson 2010, Kott 2010, Preker and Lawn 2010, Morton and Lützen 2008). This great variety of invertebrates supports a diverse fish fauna (477 species) of which many are rarely found in areas of the Moreton Bay Marine Park other than Flinders Reef (Johnson 2010). We may see subtropical endemics declining (e.g. the morwongs), more tropical species establishing (Riegl and Piller 2003, Greenstein and Pandolfi 2008, Funk et al. 2012), and temperate species disappearing (Wernberg et al. 2011, Smale and Wernberg 2013).

1.4. Flinders Reef Ecological Assessment (FREA) Project

Flinders Reef plays an important cultural and ecological role for the Moreton Bay Marine Park and detailed ecological assessment has not taken place since mid-1990 (Harrison et al. 1998) nor does a detailed habitat map exist. Hence, a thorough ecological assessment and mapping is warranted to establish baselines from where changes will be deduced. However, local marine authorities lack funding for such projects. The University of Queensland Underwater Club (UniDive) challenged their members in 2016 to take up a new citizen science-based project.

The aim of the 2017 Flinders Reef Ecological Assessment (FREA) project was to:

Conduct a detailed ecological assessment of the flora and fauna at Flinders Reef, map its habitat and compare findings in time and with other local sites

This aim can be further divided into four main objectives in regard to the ecological assessment:

1. Presence of seasonal differences in ecological parameters between autumn and spring
2. Variability in ecological parameters between different areas around the reef
3. Potential changes in ecological parameters on an annual basis since 2009
4. How Flinders Reef compares to other South East Queensland and southern Great Barrier Reef sites

Ecological data was contrasted with data on environmental conditions and habitat characterisation through the habitat map. This report presents data collected by volunteers as part of the FREA project, and where possible draws comparisons with previous Reef Check Australia and CoralWatch surveys

2. General Methods

2.1. Overview

2.1.1. General

UniDive surveyed 11 sites evenly distributed around Flinders Reef (Figure 1) between 5-10 m depth. At each site, surveys were conducted twice in 2017, spring (March) and autumn (September), to ensure that seasonal changes in the marine flora and fauna were captured by the collected data. The site Arus Bale was surveyed only in autumn to help characterise the gap between Stevo and Trevo. Four of the 11 sites were re-surveyed for comparison with annual surveys conducted since 2009 by Reef Check Australia. These included: Alden Cave, Coral Garden, Turtle Cleaning and Plate (aka Turtle Cleaning Station and Plateland as referred to by Reef Check Australia). The remaining seven sites were newly established locations.

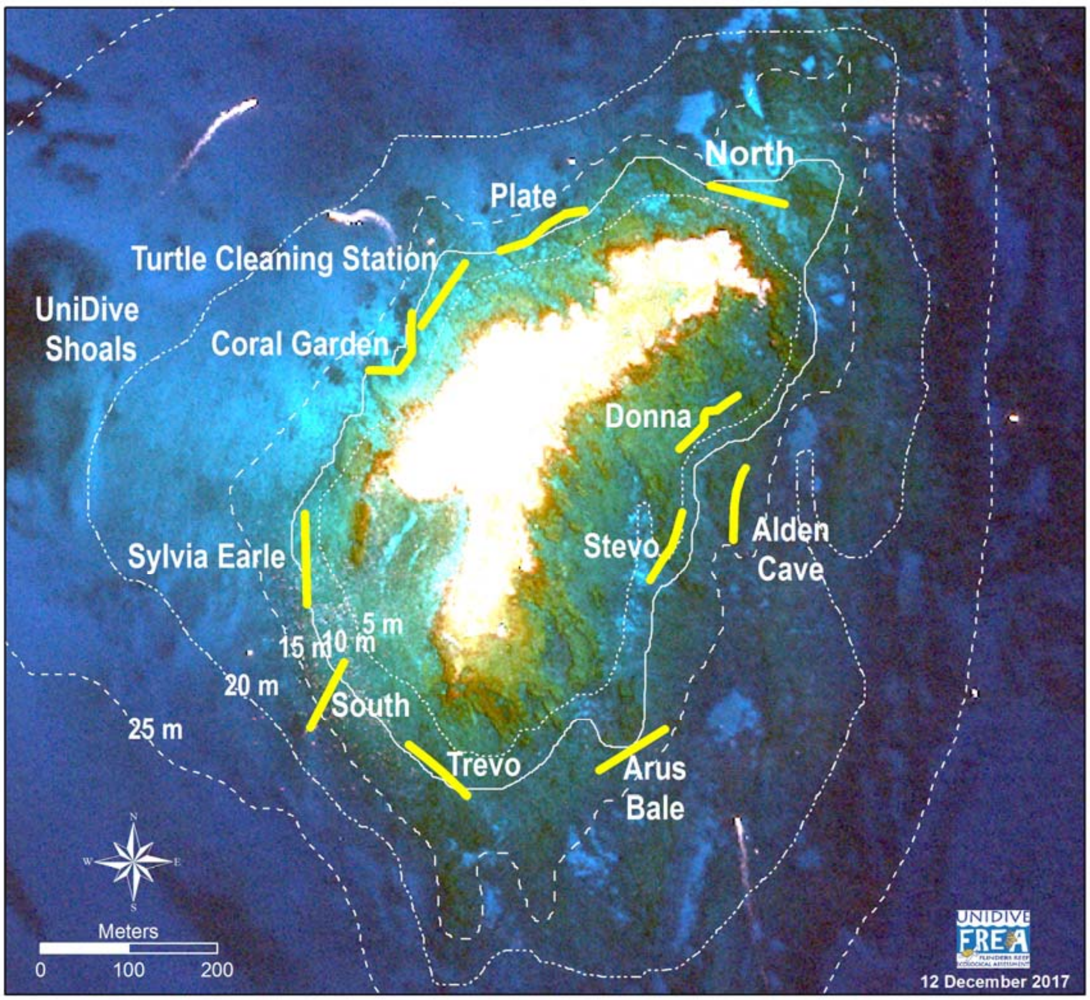


Figure 1: Satellite image of Flinders Reef, approximate transect locations are indicated in yellow. Source image: WorldVIew 2 image Digital Globe (2017), 2 m x 2 m pixels. Water depth is estimated based on image interpretation and water depth recordings during survey visits.

During each survey, a team of 10 divers assessed a site by a broad scale mapping and ecological assessment. Mapping included bathymetric surveys, georeferenced photo transects and roving surveys. Ecological assessment included CoralWatch, RHIS and Reef Check Australia surveys.

Ecological survey methods used were based on Reef Check Australia, Great Barrier Reef Marine Park Authority and CoralWatch methodologies and mapping was consistent with the methodology used in the 2001, 2003, 2014 UniDive (Ford et al. 2003, McMahon et al. 2003, Roelfsema et al. 2016) community projects to ensure comparison of data. Surveys were conducted under a marine parks permit (QS2017/MAN417).

2.1.2. Survey Participants, Training and Quality Control

Participation was voluntary and all participants were members of UniDive. Participants in the program were certified divers and encompassed marine and mapping experts, SCUBA instructors and other enthusiasts interested in learning about the marine environment. See Appendix A for a detailed list of the volunteers and their main tasks during the project.

Over the course of 25 educational lectures, more than 100 UniDive members learned about local reef ecology and Reef Check, CoralWatch and mapping survey protocols. Lecture topics included: coral reef ecology; survey methods; identification of coral, algae, substrate, fish, and invertebrates; causes and assessment of impacts; underwater photography and videography; mapping and buoyancy control. Out of 55 participating experienced divers (50+ dives or more), 24 were previously Reef Check Australia certified and 20 divers became newly certified in Reef Check Australia survey methods. Practical training was assessed in the pool and during two training weekends which helped the participants to put knowledge into practice.

All 44 Reef Check divers taking part in surveys attended the academic sessions, and had to complete an online exam (200+ questions) and all 55 divers had to sit an additional short paper exam with 75 questions (pass mark 75% or higher). In-water survey training consisted of two pool training sessions focussed on buoyancy and survey techniques. Open-water training during two survey weekends was conducted to ensure divers were able to correctly identify the marine life and substrate to be surveyed, and were assessed on competency during a practical exam. The 24 previously certified Reef Checkers were required to participate in a training weekend in which they refreshed their skills through practice surveys. Additionally, 12 of the latter were trained in Reef Check Fish ID. Reef Check training was supervised by one out of three qualified Reef Check instructors and team leaders.

A review lecture was organised before each survey weekend and reviews took place in the evening prior to each survey day. Printed data sheets were used for surveys (Appendix B), which aided in quality control. The data sheets were checked for errors or inconsistencies, both directly after the dives and during the data processing stage. Results derived from the quality controlled data were presented after each survey by UniDive members with experience in Reef Check and CoralWatch survey methods and/or with a marine science background, thus providing additional quality control and expertise.

2.2. Habitat Mapping

Mapping of Flinders Reef was conducted to generate maps of the line features (e.g. major gullies, walls and ridges), point features (e.g. caves, cleaning stations, overhangs) and polygon features (e.g. substrate types) providing a reference for future ecological surveys and planning and zoning of the sites (e.g. installation of mooring buoys). Feature mapping was undertaken by two divers, conducting roving surveys around the transect sites, to a maximum depth of 20 m, and recording characteristic features by producing drawings and taking georeferenced underwater photos. Photos of the seafloor were taken at 1-2 m intervals providing a 1 m^2 footprint, while swimming and drawing the features of the underwater surroundings to produce detailed underwater maps. Feature location was mapped by cross-referencing the time each feature was recorded or photographed, with GPS data recorded by a floating GPS towed by the diver taking georeferenced underwater photos (Figure 2). The lag between diver and GPS float was reduced as much as possible by tighten the line between them.

Photos were linked to GPS coordinates using time synchronisation of GPS and camera. When geo referenced photos were overlaid on the satellite image miss registration was noted through significant features photographed (e.g. edges of sand rock, pinnacles, sandy patches) and manually corrected. Collected images were analysed for benthic composition using the habitat image analysis software Coral Point Count Excel (Kohler and Gill 2006). Twenty-four random points were plotted on each photo taken and manually assigned one of the Reef Check substrate classes (Roelfsema and Phinn 2010). Analysis is still in progress and will not be reported in this report.

Figure 2: Conceptual diagram of the georeferenced photos taken at 1-2 m intervals along the seafloor above the substrate providing a 1 m^2 foot print, while towing a GPS that was logging the track.

High spatial resolution satellite imagery was used as a backdrop to identify areas of interest for surveying. Bottom type was determined based on delineating variation in colour and texture of the satellite imagery and labelled with a bottom type based on assessment of the georeferenced habitat and feature photos. All georeferenced photos that documented each of the reefs were plotted on top of the basic site map for each location to provide additional information for the mapping.

During every visit to Flinders Reef, an echo sounder logged water depth and position while driving around the reef. These were plotted on the satellite imagery and used to find gaps in coverage, which were filled on future surveys. All un-corrected depth readings collected during the dive trips were overlaid on a map and manually depth contours were delineated, representing a rough estimate of a three dimensional shape of the reef.

2.3. Ecological Data

2.3.1. Ecological Survey Methods Overview

Survey design was based on Reef Check methods where a 100 m long transect line was deployed at a depth of 5-10 m at each survey site. Within the 100 m long survey area, four 20 m segments were deployed and surveyed (Figure 3). Each 20 m segment followed the designated depth contour and was separated from the next transect by a 5 m gap.

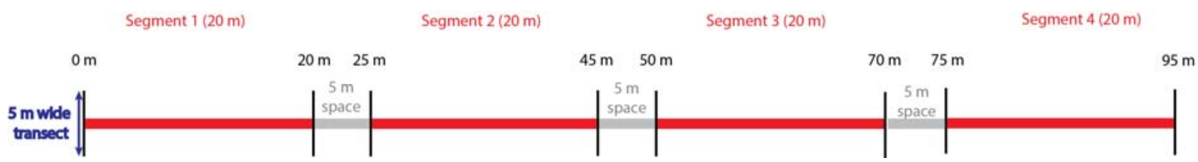


Figure 3: Placement of the survey transect lines.

Fish, invertebrate, impact and substrate categories were surveyed following Reef Check Australia protocols (Hill and Loder 2013) and CoralWatch data was collected using the coral health chart (Siebeck et al. 2006, Marshall et al. 2012). Photos and video of fauna along the segments were taken to support identification of categories. Additional Reef Health and Impact Surveys were conducted at each site and uploaded on the Eye on the Reef, Great Barrier Reef Marine Park Authority website (Beeden et al. 2014). Surveys were conducted following the timing of buddy teams for each survey component as outlined in Figure 4.

For each survey, five diver pairs undertook mapping and/or transect surveys to identify indicator species present and major mapping features at each site. On arrival at each survey site, a marker buoy was deployed using a GPS to mark the start of the transect (Figure 4). A transect line was deployed by one diver, while the second diver conducted a photo transect survey and other teams followed at 5-10 min intervals. As positioning of the transect line for comparison with repeating surveys is crucial, the same three divers were in charge of locating the start of a transect and deploying the line as they were most familiar with the sites. Mapping of the whole reef and/or all sites was undertaken during all survey trips, with new site maps produced for each of the 11 sites surveyed.

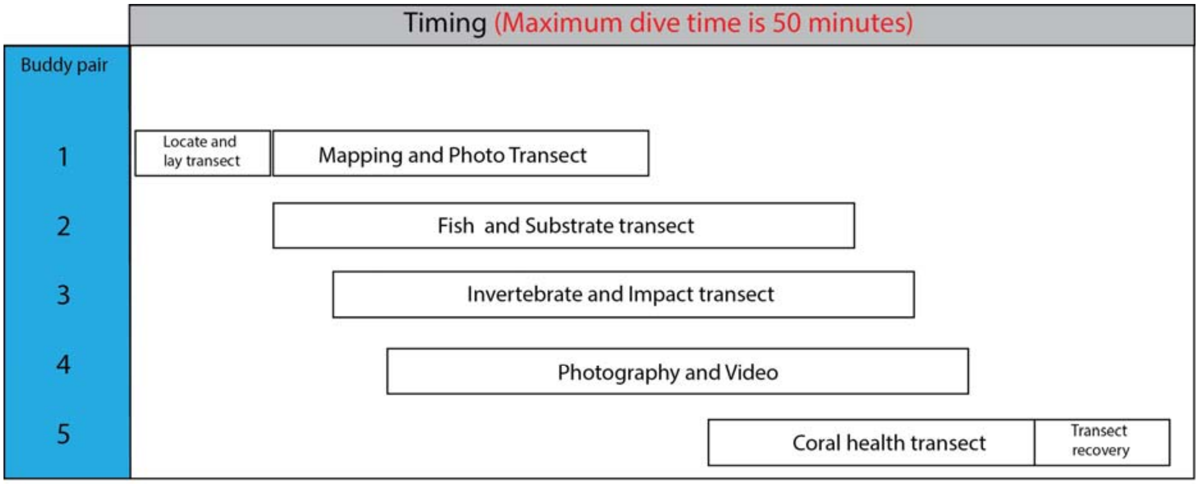


Figure 4: Timing of ecological survey dives, with a small break between buddy pair 1 and 5 so there is always a boat handler and assistant on the boat.

2.3.2. Substrate

Substrate surveys were conducted using the point intercept sampling method, enabling percentage cover of substrate types and benthic organisms to be calculated. The substrate under the transect line was identified at 0.5 m intervals, with a 5 m gap between each of the four 20 m segments (Figure 5). Categories recorded included various growth forms of hard and soft coral, key species/growth forms of algae, other living organisms (i.e. sponges), recently killed coral, and non-living substrate types (i.e. bare rock, sand, rubble, silt/clay). To the list of 23 substrate categories recorded by the Reef Check Australia, a category 'Other Corallimorphs' was added to FREA substrate surveys to capture previously recorded abundance of corallimorphs at Flinders Reef (see Appendix B for data sheet and the categories surveyed). Percentage cover of each substrate category was calculated by counting the occurrence of a category along a segment divided by the total counts.

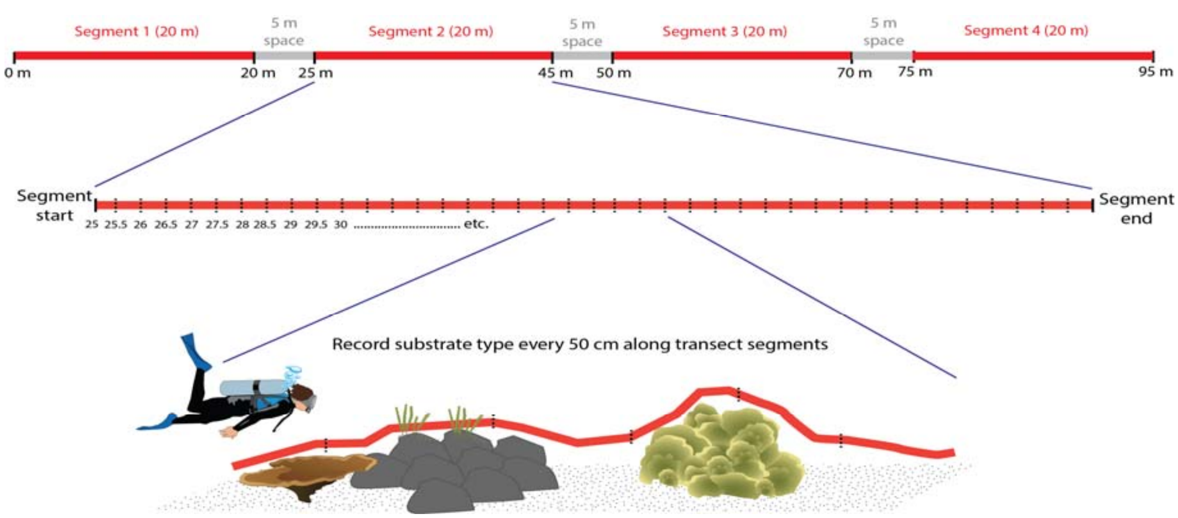


Figure 5: Detail of substrate survey transect. At every 0.5 m, using a plumb line to avoid bias, the benthic category located directly beneath the transect tape was recorded.

2.3.3. Fish

Fish populations were assessed using a visual census along 4 x 20 m segments following Reef Check Australia protocols (Hill and Loder 2013). Each segment was 5 m wide (2.5 m either side of the transect tape), 5 m high, 20 m in length and segments were separated by a 5 m gap (Figure 6). A fish survey diver recorded fish sightings on the data sheet (see Appendix B for data sheet and the fish groups surveyed). Each 20 m segment was completed in 7-10 minutes to ensure a standardisation of the monitoring method and a constant detection probability of fish species.

Fish records were established using the list of 23 fish groups from Reef Check Australia and 4 additional fish groups characteristic for Flinders Reef namely: Blue grouper (*Achoerodus viridis*), Spangled emperor (*Lethrinus nebulosus*), other emperors and Morwongs (*Cheilodactylus fuscus* and *C. vestitus*). A fish group was composed by different fish families and/or fish species and all fish within the 27 groups were recorded. These groups were chosen for their importance and value to recreational or commercial fishing, targeted by aquarium collectors, and easily identified by their body shape or other characteristics by the fish survey diver. Rare or otherwise unusual species such as carpet sharks (family Orectolobidae) were also recorded. In this report, the fish groups were pooled into 11 key fish groups for visualisation purposes. Results are presented in terms of abundance within key fish groups and are expressed as fish abundance per 100 m^2, i.e. average fish number per segment, per site, and per season.

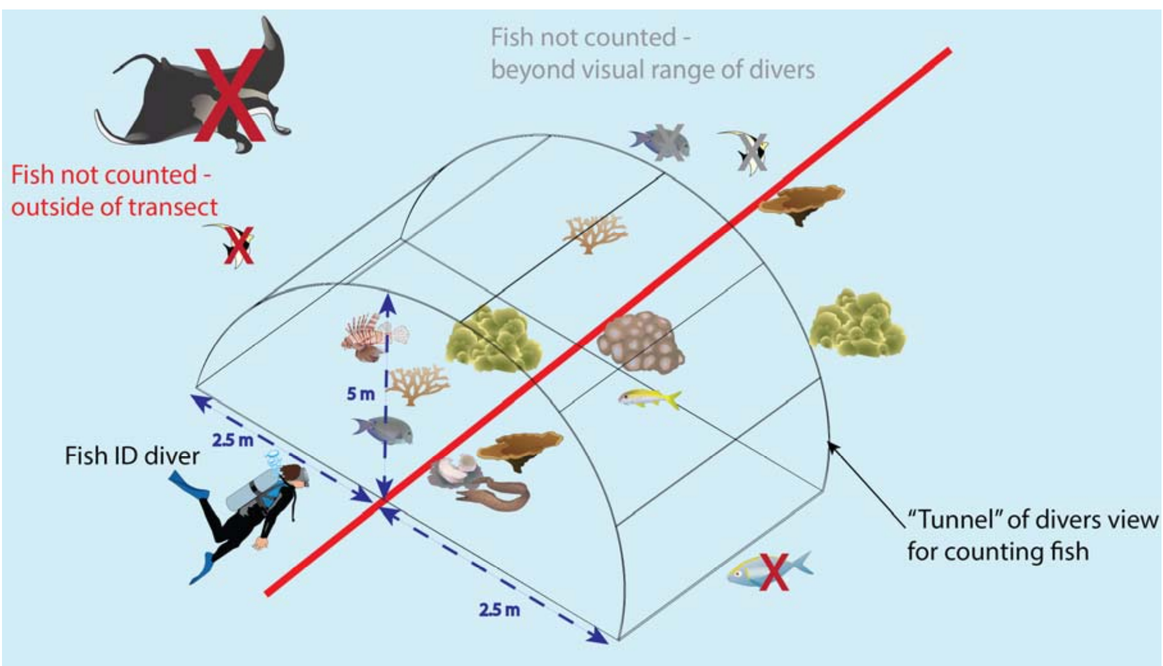


Figure 6: Diagrammatic representation of the fish survey transects showing the imaginary frame of the diver's view within the 2.5 m x 5 m tunnel. Fish outside the tunnel were not counted, e.g. the manta ray in the picture.

2.3.4. Invertebrates

Target invertebrate populations were assessed using visual census along 4 x 20 m segments following Reef Check Australia protocols (Hill and Loder 2013). Each segment was 5 m wide (2.5 m either side of the transect tape), 20 m in length and segments were separated by 5 m. The diver surveying invertebrates conducted a 'U-shaped' search pattern, covering 2.5 m on either side of the transect tape (Figure 7). Each 20 m segment was completed in 7-10 minutes. The invertebrate survey diver recorded invertebrate sightings on the data sheet (see Appendix B for data sheet and the invertebrate categories surveyed).

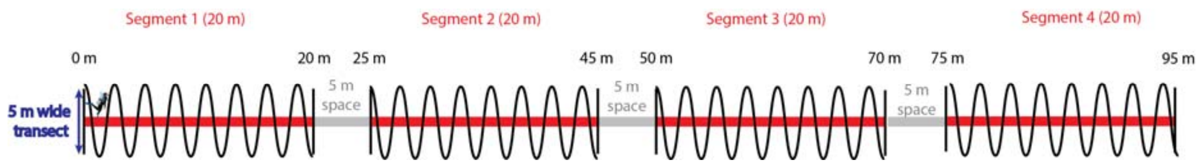


Figure 7: Diagrammatic representation of the invertebrate and reef impact survey transects. Divers swim a 5 m wide transect in a U-shaped pattern along the transect tape.

Invertebrate species were selected based upon their essential role in ecosystem health and functioning and/or their economic value to both commercial and recreational fishing and the aquarium trade. These are aligned with the species selected by Reef Check Australia (Hill and Loder 2013). Abundance of key invertebrate groups is presented per 100 m^2 for the autumn and spring surveys.

2.3.5. Impacts

Target impacts were assessed by a visual census using the same approach as for the invertebrate survey (Figure 7) and included natural and anthropogenic impacts to the reef. The impacts included presence of: physical damage, scars, trash or rubbish, coral disease and bleaching. Damage was assessed for scarring by the gastropod *Drupella* only if the organisms were present. Boat anchor damage to be recorded also required the presence of an anchor or chain. Unknown scars consisted of scraping of tissue around the coralites without damaging the overall structure, while structural breakage of the coral without an obvious source was ranked as unknown damage. Fishing gear consisted of line, hooks, weights or other fishing devices. Any other anthropogenic rubbish found on the reef was classed as general trash or rubbish. Coral disease was identified according to Reef Check protocol. For the analysis of the impacts normalising of abundance was conducted with coral cover to acknowledge that the majority of surveyed reef impacts specifically affect corals, and as such, the ratio of coral cover to impact abundance should be considered when interpreting reef impact data. Photographs of the impacts were taken for archiving purposes.

Coral health was monitored using the coral health chart which is a non-destructive, in-expensive, easy-to-use tool to monitor coral health developed by CoralWatch based at The University of Queensland (Figure 8). For each survey, coral health of 20 corals colonies was assessed along the 4 x 20 m segments using the chart. All observations within 2.5 m of a segment on either side were considered part of the transect. The surveyor swam along the segments accounting for its width and selecting 5 coral colonies per segment at random, i.e. 20 corals in total per transect. The chart was placed next to each chosen coral colony and the colours on the chart were compared with the colours of the coral. The matching codes were identified for the lightest and darkest area of each coral colony and recorded on an underwater data slate. Where necessary, a torch was used to see true colours. Additionally, growth type was identified and recorded, i.e. branching, boulder, plate or soft coral.

The average colour score was calculated for each site and compared between seasons. Per site, the frequency distribution of growth types along each transect was calculated and plotted against the average colour score per site and for each season separately. At last, average colour score values were plotted against the total coral cover (hard and soft coral) extracted from the substrate data, per site and per season.

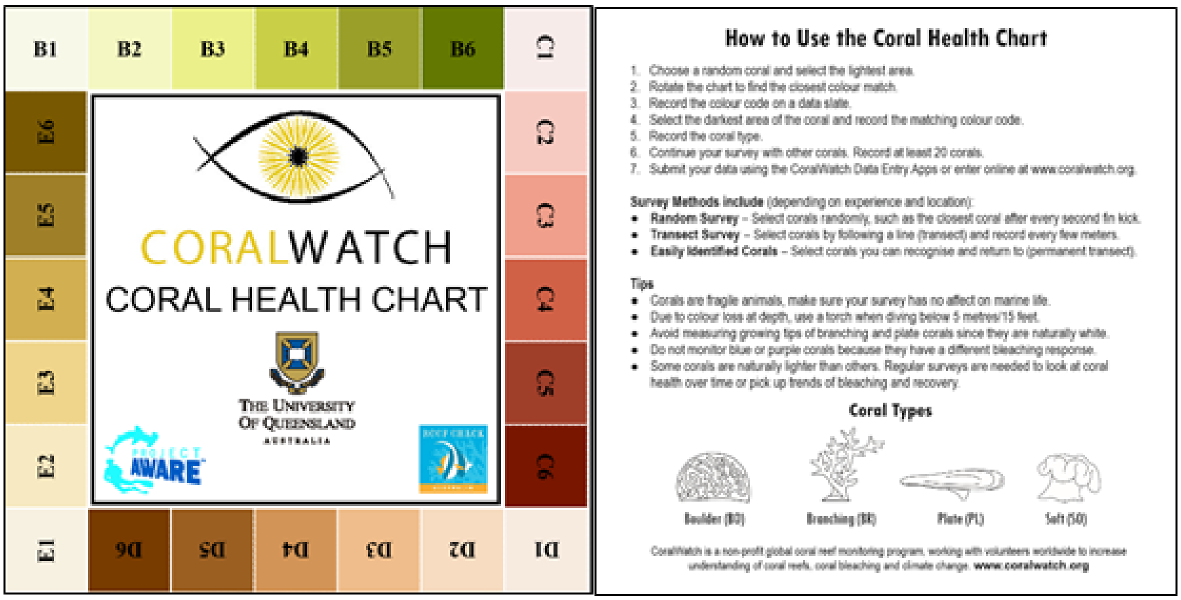


Figure 8: The coral health chart is used to assign a code to coral colours that suggest different levels of coral bleaching (left). Instructions are provided on the back of the chart (right).

2.3.6. Ecological Data Analysis

Analyses of the ecological data focused on four levels to assess:

1. Seasonal variation. A comparative study was conducted in autumn and spring based on using the average of ecological measurements for all sites
2. Spatial variations around the 11 sites distributed around Flinders Reef for the two seasons separately
3. Temporal variations of four sites surveyed as part of the FREA project as well as annually (since 2009) by Reef Check Australia
4. Differences in coral composition between Flinders Reef sites and other regions surveyed by Reef Check Australia in South East Queensland, e.g. Point Lookout, Central Moreton Bay, Mooloolaba, Hervey Bay, and Heron Reef, situated in the southern Great Barrier Reef.

Ecological data was contrasted with data on environmental conditions and habitat characterisation through the habitat map. To characterise each site, the average over the four segments was used for data analyses.

2.4. Environmental Data

2.4.1. Daily Weather Observations – Temperature and Wind

Historical environmental data was collected to understand ambient factors potentially influencing Flinders Reef. The Bureau of Meteorology (BoM) provides daily observations for Cape Moreton Lighthouse that is relatively close to Flinders Reef. This data is freely accessible through http://www.bom.gov.au/climate/dwo/. The BoM also provides statistical information about observed wind speed and direction in the form of wind roses, based on approximately 10 years of daily observations. Daily weather observations were collected for the period of 01/12/2015 until 15/10/2017. The parameters that were included in the temporal analysis are minimum and maximum air temperature, and speed and direction of maximum wind gust. See Appendix G for more detail on all daily weather observations and additional parameters collected. National Oceanic and Atmospheric Administration (NOAA) provides Sea Surface Temperature (SST) information for their product Coral Reef Watch (CRW), which is based on satellite data and is freely available online from current data up to March 2013 (Liu et al. 2014). Observed SST data has been collected for the period of 12/03/2013 until 12/10/2017. This data has been processed to create time series for the location of Cape Moreton Lighthouse, as well as locations on Flinders Reef (Coral Garden and Alden Cave). See Appendix H for more detail on the SST data.

2.4.2. Wave monitoring data– Wave height and direction

Queensland government maintains a network of wave monitoring sites to measure the height and direction of waves along the Queensland coast. These buoys continuously measure wave height, wave direction and wave period. As a wave monitoring buoy floats up and down each passing wave, its motion (or heave) is measured and electronically processed. Data from the wave monitoring buoys are transmitted to a nearby receiver station as a radio signal. Wave buoy monitoring data were collected for the North Moreton Bay wave buoy, for the period of 01/01/2010 until 31/10/2017. The parameters that were included in the temporal analysis are Hmax (the height (in metres) of the highest single wave in a wave record) and direction.

2.4.3. Sea Surface Chlorophyll data

Sea Surface Chlorophyll data was derived from satellite based sensors, through the National Aeronautics and Space Administration (NASA) Ocean Biology Processing Group (OBPG). The sensors view the entire Earth's surface every two days. This data improves our understanding of global dynamics and processes occurring on the land, in the oceans and in the lower atmosphere. The data is freely available online, the set of data covers the entire routine operations period from 04/07/2002 to two weeks before present day (NASA Goddard Space Flight Center et al. 2017). The daily averaged observed chlorophyll concentration has been collected for the period of 01/03/2013 until 07/10/2017 and has been processed to create a time series for the location of Cape Moreton Lighthouse, as well as locations on Flinders Reef (Coral Garden and Alden Cave). The chlorophyll data has gaps at the times where the satellite was not present to make observations. See Appendix H for more detail on the Sea Surface Chlorophyll data. Appendix H

3. Results

3.1. Survey Considerations

Dives were conducted over a total of 23 days between March and October 2017 each under varying conditions (Table 1). Note that the ecological surveys were only conducted in March and September, however, the mapping surveys were conducted from March to October. For the duration of the study, the water temperature at diving depth ranged from 18°C in July to 26°C in February. Of note is that the average visibility was ~14 m and the highest waves (3.1 m) were recorded in July 2017. During 23 days, a total of 561 dives (421 hours underwater) were made, of which 176 were training dives and 239 survey dives, and 146 were for mapping/photo. Four days were at Point Lookout with a commercial boat and 19 days were organised with the UniDive boat (Appendix C).

Table 1: Environmental conditions during each of the survey days, where we differentiate between days where training was conducted, ecological surveys, mapping or photos (Source: Bureau of Meteorology, Wave Rider Buoys, divers participating in the FREA project). In grey highlighted are the two ecological survey season representing autumn and spring. Temperature is in Celsius for the air.

				Day						Morning 9am		Afternoon 3pm	
#	Dive Date	Dive Type	Number of dives	SST	Temp min	Temp max	Wave height	Cloud cover	Rain	Wind direction	Wind Speed	Wind direction	Wind Speed
1	Saturday, 12 November 2016	Training	4	24	23.1	28.2	<1m	8		NNW	26	999	999
2	Sunday, 13 November 2016	Training	4	24	22.7	999	<1m	7		NNW	22	999	999
3	Saturday, 4 February 2017	Training	4		25.5	999		5		NNE	9	999	999
4	Sunday, 5 February 2017	Training	4		999	999		0		0	0	999	999
5	Sunday, 12 March 2017	Ecology	2	28	22.1	28.9	<1m	0	1.4	N	13	NE	24
6	Saturday, 25 March 2017	Ecology	3	27	22.2	27.3	<1m	0	6.8	SE	43	ESE	31
7	Sunday, 26 March 2017	Ecology	2	27	22.9	28.4	<1m	0	0.2	SE	15	E	17
8	Sunday, 16 April 2017	Ecology	2	25	20.6	25.4	1-2m	0	0	SE	24	ESE	19
9	Monday, 1 May 2017	Ecology	2	24	18	22.9	1-2m	0	6	S	28	SE	24
10	Saturday, 27 May 2017	Mapping	2		17.5	23.7		0		S	11	ESE	9
11	Saturday, 10 June 2017	Mapping	2	21	15.5	22.1	1m	0		S	33	SSE	39
12	Saturday, 24 June 2017	Mapping	2	24	16.2	22.8	<1m	0		W	19	SW	13
13	Monday, 26 June 2017	Mapping	2		16.6	22.4		0		W	11	SSE	15
14	Tuesday, 27 June 2017	Mapping	2		18.4	22.9		0		NNW	11	NNE	20
15	Saturday, 8 July 2017	Mapping	2		15	20.6		0		WSW	13	SW	15
16	Saturday, 15 July 2017	Mapping	2	22	17.8	22.1	?	0		WNW	15	N	22
17	Saturday, 5 August 2017	Mapping	2		13.2	22		0		WSW	20	E	13
18	Sunday, 13 August 2017	Mapping	2		17.5	23.2		0		S	20	ESE	24
19	Sunday, 27 August 2017	Ecology	2	23	14.5	22	<1m	0	0	WSW	9	NNE	22
20	Friday, 1 September 2017	Ecology	2	22	14.8	20.6	1m	0	0	SSE	26	ESE	28
21	Saturday, 2 September 2017	Ecology	4	22	15.4	22.9	1m	0	0	SSE	13	ENE	19
22	Sunday, 3 September 2017	Ecology	4	22	16.9	23.3	1m	0	0	WNW	17	NNE	30
23	Saturday, 7 October 2017	Photos	2	22	19.8	24.9	<1m	0		SE	50	SE	37

3.2. Mapping

Georeferenced habitat maps (UTM-WGS84) were created for Flinders Reef and describe the substrate type, water depth and significant features (Figure 9 and Figure 10). A noticeable feature mapped were the branching coral beds at Coral Garden which are similar to those present on the southern Great Barrier Reef such as Heron Reef. Additionally, at several locations, plate corals were observed with up to a 2 metre diameter. Encrusting and plate corals were observed mostly on the south eastern side, with branching and soft corals on the western side. *Asparagopsis* sp. was the dominant macro algae observed and hardier species such as *Sargassum sp.* or *Turbanaria sp.* were not observed nor any significant amount of kelp like species such as *Ecklonia sp.*. *Laurencia sp*. dominated the deeper waters (>15 m) on the east site of the reef. Most rock and rubble surfaces were mainly covered by macro algae but also by sponges, corals or a fine layer of turf algae.

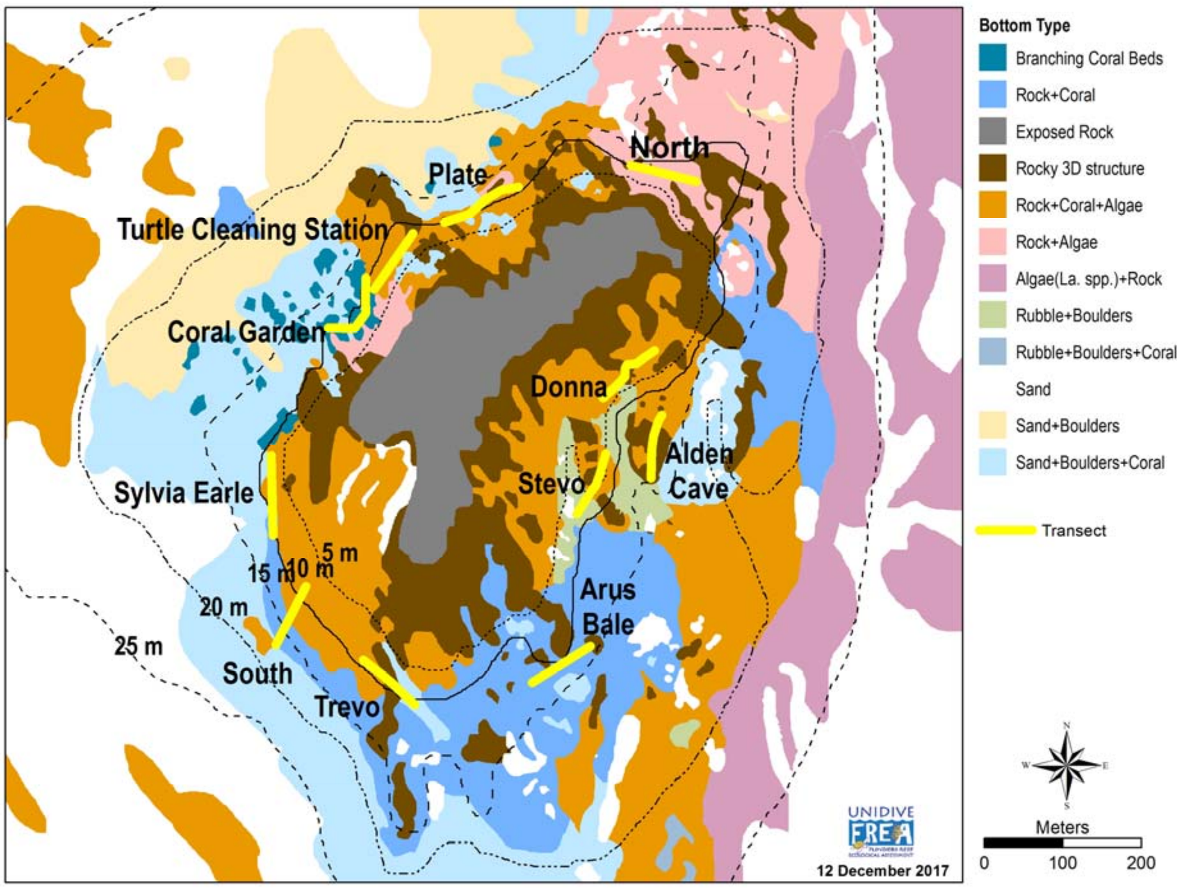


Figure 9: Prominent substrate and benthic features, and locations of survey transects at Flinders Reef, north of Moreton Island, Australia.

Three dimensional structures were found mostly on the eastern side of the reefs with various overhangs and swim through, and one collapsed cave known as Alden Cave (Figure 10). Ridges and gullies characterise the eastern areas and they are more common in a north-south direction. Sandy areas are present in the deeper water in the east and shallower water in the more sheltered west. Large areas of sand and boulders overgrown with algae and coral are present in the northwest. Newly named UniDive shoal, further to the west, turns to a rocky bottom covered by coral and algae.

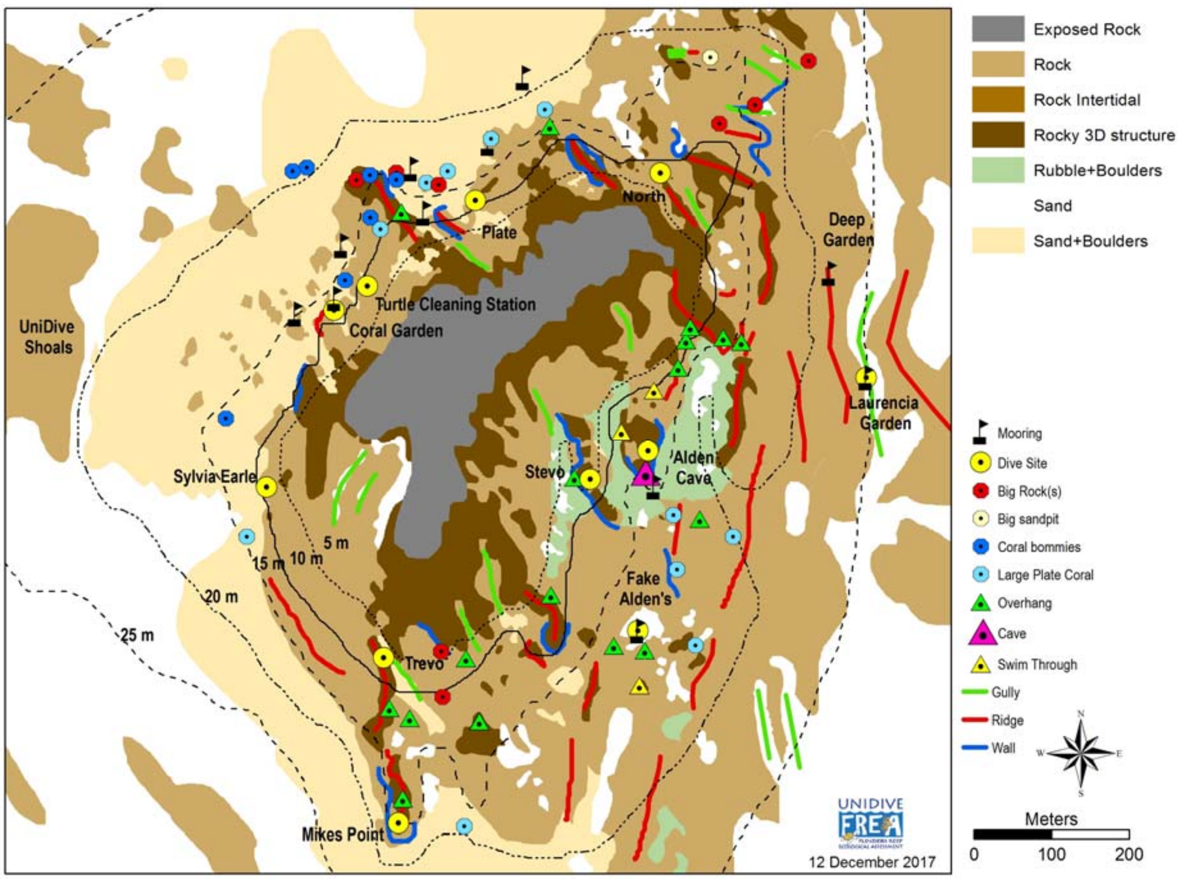


Figure 10: Prominent point and line features at Flinders Reef, north of Moreton Island, Australia.

Refer to Appendix D for a detailed location of survey transects and to Appendix E for coordinates of the start and end points of each transect.

3.3. Ecological Data

3.3.1. Substrate

Substrate data collected showed that hard coral cover (e.g. massive, branching, plate, foliose and encrusting growth forms) and rock (e.g. bare rock, rock with crustose coralline algae and rock with turf algae) are the most dominant cover types (between 11% and 79% for hard coral cover and between 16% and 62% for rock, respectively) at all sites throughout the year.

Seasonal Patterns of Substrate Key Groups at Flinders Reef

Rock was the category with the highest percentage cover for both seasons with 41.0% in autumn and 36.5% in spring 2017 (Figure 11) based on all 10 sites surveyed in autumn and 11 sites surveyed in spring hard coral was the next most abundant benthic category with 29.9% cover in autumn and 32.4% in spring. Differences in hard coral cover less than 10% are due to survey methods and deemed acceptable (Done et al. 2017).

The second most abundant benthic category was soft coral with 11.3% cover in autumn and 8.6% in spring. The overall average number of the macro algae *Asparagopsis* sp. tally was more than two times higher in spring than in autumn, with an averaged tally number of 2.3 and 7.3 per transect, respectively. The dominant hard coral growth form at Flinders Reef was encrusting coral with 15.8% in autumn and 13.6% in spring. This was followed by branching corals with 9.4% in autumn and 13.7% in spring (Figure 11).

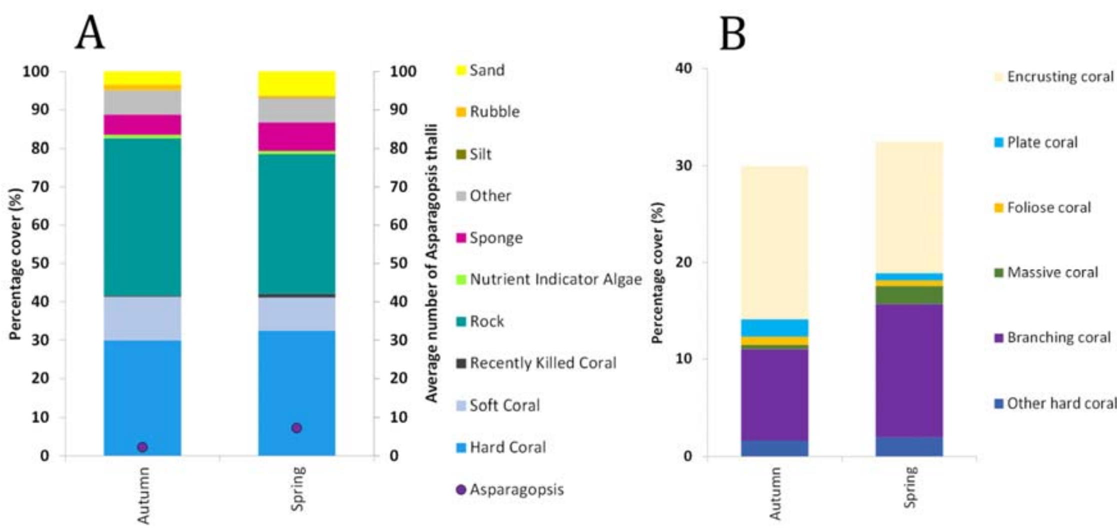


Figure 11: Seasonal patterns of substrate categories at Flinders Reef (A) and hard coral growth forms (B). Results are based on the aggregation of n=4 x 20 m segments (except for the site Sylvia Earle where n=3 in autumn) from 10 sites in autumn and 11 sites (including the site Arus Bale) in spring.

Seasonal and Spatial Patterns of Substrate Key Groups at Survey Sites

Hard coral cover had a difference of <10% between autumn and spring surveys for the sites North, Alden Cave, Stevo, South, Sylvia Earle, Turtle Cleaning and Plate. The largest difference of 23.8% was present for Coral Garden with 55.0% hard coral cover measured in autumn as compared to 78.8% in spring (Figure 12). This deviation in average coral cover indicates that the repeated survey in spring was carried out at a slightly different location to the site previously surveyed as hard coral cover would not increase significantly in a six month period. Averaged hard coral cover between seasons varied by around 10% which is common due to survey methods (Done et al. 2017).

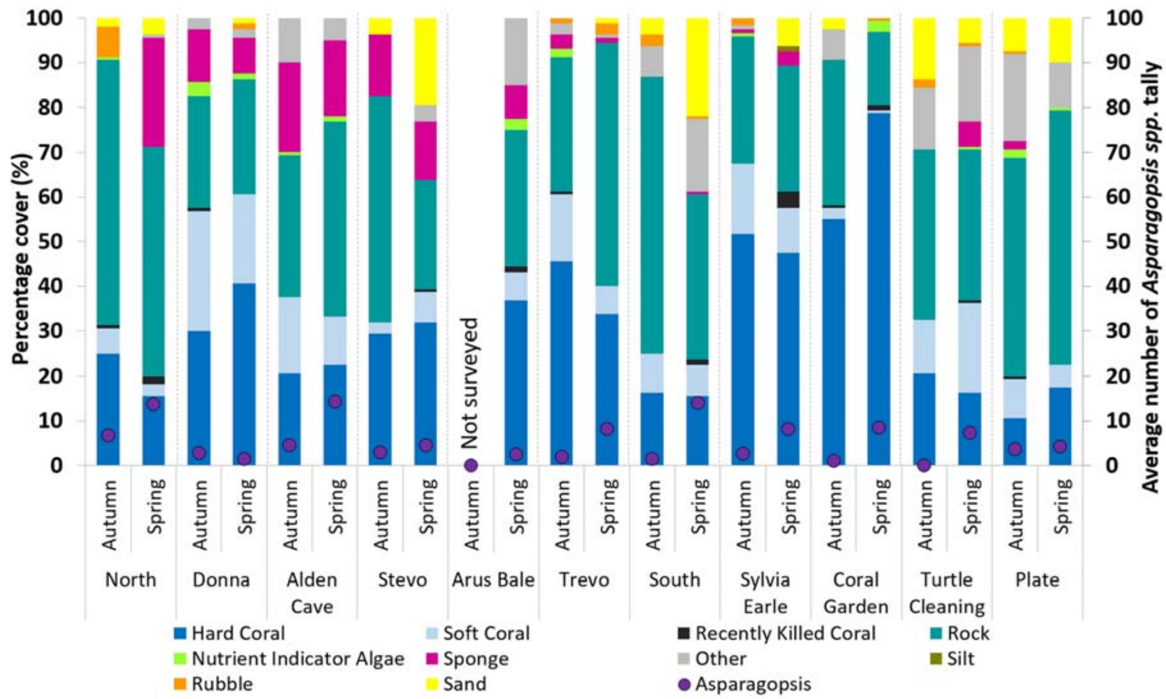


Figure 12: Seasonal cover percentage of substrate categories at Flinders Reef for autumn and spring. The purple dot represents average coral bleaching levels of the coral population.

Hard coral cover varied between the sites and was highest for the site Coral Garden. In spring, hard coral cover at Coral Garden averaged 78.8% (n=4) across all n=4 segments, and mainly consisting of branching corals (77.5%) (Figure 12 and Figure 13). Soft coral cover at this site and season was negligible with 0.6% leathery soft coral cover. Sylvia Earle had the second highest hard coral cover which was comparable between the two seasons autumn (51.7%) and spring (47.5%) and the dominant coral type was encrusting (25.0% for both seasons) followed by branching (11.7% and 13.8% for respectively autumn and spring) and soft coral (15.8% and 10.0%). The lowest content of hard coral cover (≤25%) was observed for North (25.0 and 15.6% for respectively autumn and spring), Turtle Cleaning (20.6 and 16.3%), Plate (10.6 and 17.5%) and South (16.3 and 15.6%).

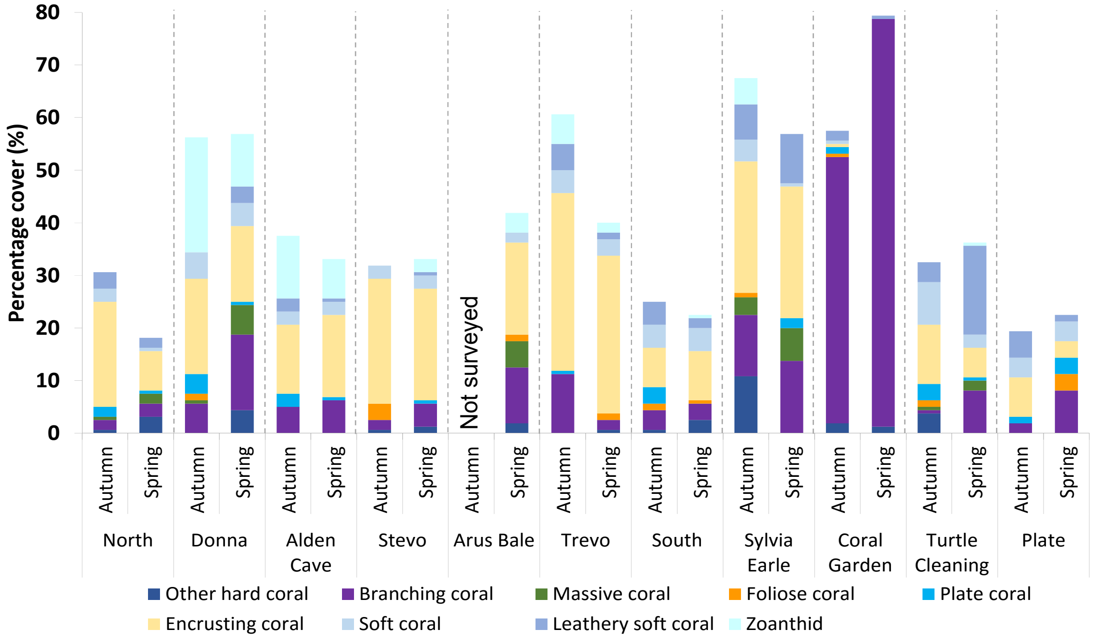


Figure 13: Seasonal percentage cover of coral growth types at Flinders Reef for autumn and spring. Results are based on the aggregation of n=4 x 20 m segments (n=4) (except for the site Sylvia Earle where n=3 in autumn) from 10 sites in autumn and 11 sites (including the site Arus Bale) in spring.

3.3.2. Fish

Fish Key Groups at Flinders Reef

A total of 8 key fish groups were encountered at Flinders Reef among the 11 key fish groups monitored, i.e. wobbegong, sweetlip, morwong, emperor, snapper, parrotfish >20 cm, moray eel and butterflyfish. The 3 key fish groups that were included in the surveys but have not been observed on the transects during autumn and spring were grouper >30 cm, wrasse: blue grouper and humphead wrasse.

Seasonal Patterns of Fish Key Groups at Flinders Reef

Surveys were conducted at two different times of the year revealing temporal patterns in terms of key fish group abundance. Overall, less fish was observed in spring compared to autumn (Figure 14A). Average fish abundance per 100 m^2 in autumn was 9.45 (n = 378 fish) and 6.00 (n = 264 fish) in spring. This pattern is mainly due to a decrease in the butterflyfish and snapper key groups between the two seasons, average fish abundance per 100 m^2 decreased from 7.80 in autumn to 4.82 in spring for butterflyfish and from 0.83 in autumn to 0.16 in spring for snapper (Figure 14). Results show that abundance of the other fish groups remained relatively constant with the exception of the wobbegong group which increased in abundance from 0.03 per 100 m^2 in autumn to 0.14 per 100 m^2 in spring (Figure 14b). Note that the two wrasse and grouper groups were omitted in the results as they were not seen during the surveys.

Butterflyfish were the most common key fish group observed at Flinders Reef with an average abundance of 7.80 and 4.82 fish per 100 m^2 in autumn and spring respectively (Figure 14A). In autumn, the snapper group was the second most abundant key fish group with 0.83 fish per 100 m^2 and in spring the morwong was the second most abundant group with an average fish abundance of 0.41 per 100 m^2 (Figure 14B).

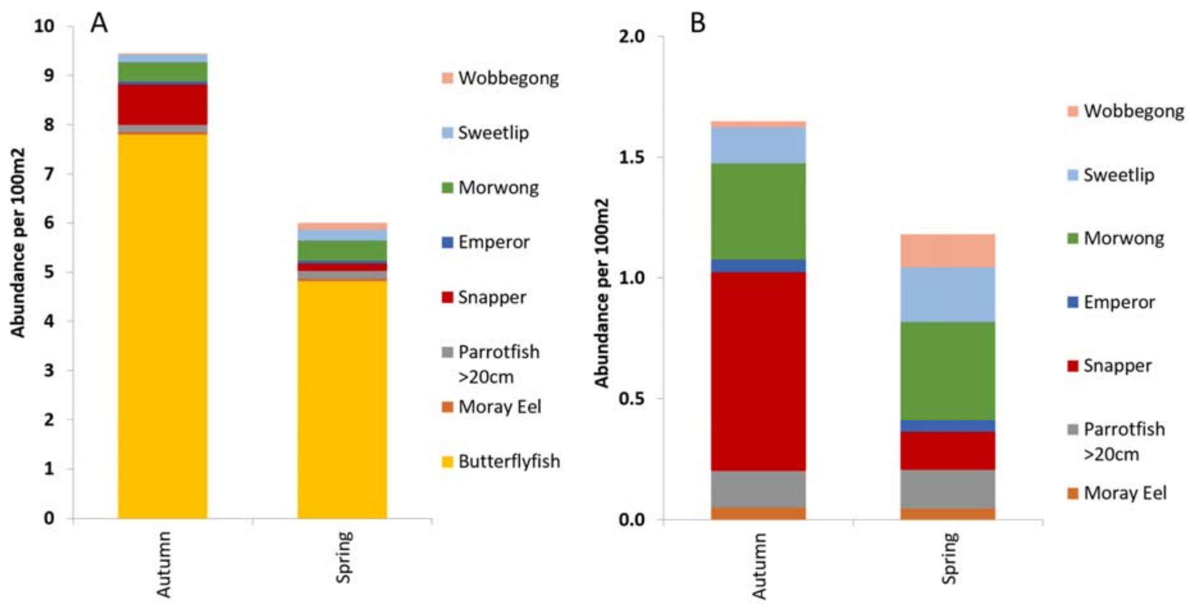


Figure 14: Seasonal abundance per 100 m^2 of key fish groups at Flinders Reef for (A) all eight key fish groups and (B) zoomed in on the seven less represented key fish groups, i.e. minus the butterflyfish.

Seasonal Patterns of Fish Key Groups at Survey Sites

Surveys per site show that at each site butterflyfish were the most abundant key fish group in autumn and in spring (Figure 15). Additionally, less fish per site were observed in spring compared to autumn (Figure 15). Turtle Cleaning showed the highest on average fish abundance per 100 m^2 in autumn and Donna the lowest in spring, 19.75 and 3.00 respectively. Turtle Cleaning also showed the highest overall abundance of butterflyfish, 18.00 per 100 m^2 in autumn and Donna the lowest, 1.75 per 100 m^2 in spring (Figure 15). The decrease in fish abundance between autumn and spring surveys was particularly pronounced for the sites Stevo and Turtle Cleaning where the total fish abundance dropped by more than 50%, from 13.25 to 4.75 per 100 m^2 at Stevo and from 19.75 to 7.50 per 100 m^2 at Turtle Cleaning (Figure 15). The butterflyfish abundance at those sites dropped by 77% at Stevo and 65% at Turtle Cleaning between autumn and spring (Figure 15).
The fish abundance for the sites of Sylvia Earle, Donna and North remained constant between the two seasons (Figure 15). Note that for the site Arus Bale no data was collected during the autumn surveys.

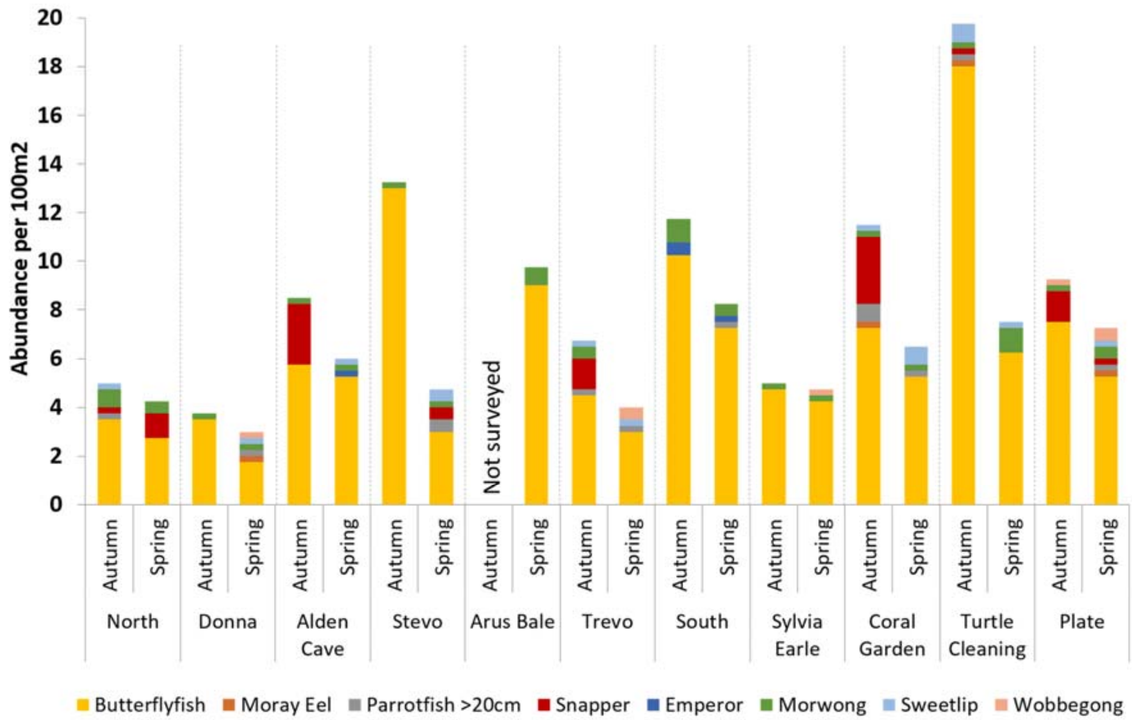


Figure 15: Seasonal abundance of key fish groups per 100 m² per survey site at Flinders Reef.

Spatial Patterns of Fish Key Groups at Survey Sites

Results show different spatial patterns as a function of the fish key group per season. Butterflyfish and morwong groups were present at each survey site in autumn and spring and the sweetlip and parrotfish >20 cm key groups were found at most sites (Figure 16). However, the sites and proportion of fish encountered within sites varied through the seasons. In contrast, moray eel and emperor only represented one or two sites in autumn and spring with the moray eel key group found on two different survey sites in autumn compared to spring; Coral Garden and Turtle Cleaning in autumn (Figure 16), sites close to each other on the western side of Flinders Reef, and Plate and Donna in spring (Figure 16). This pattern was also observed for the snapper group which was present in autumn in North, Alden Cave, Trevo, Coral Garden, Turtle Cleaning and Plate, while in spring it was only found in North, Stevo and Plate (Figure 16). Wobbegong and emperor were only spotted at one site in autumn (Figure 16), while in spring they represented two and four sites respectively (Figure 16). Butterflyfish were present at each site and the most abundant fish key group at Flinders Reef.

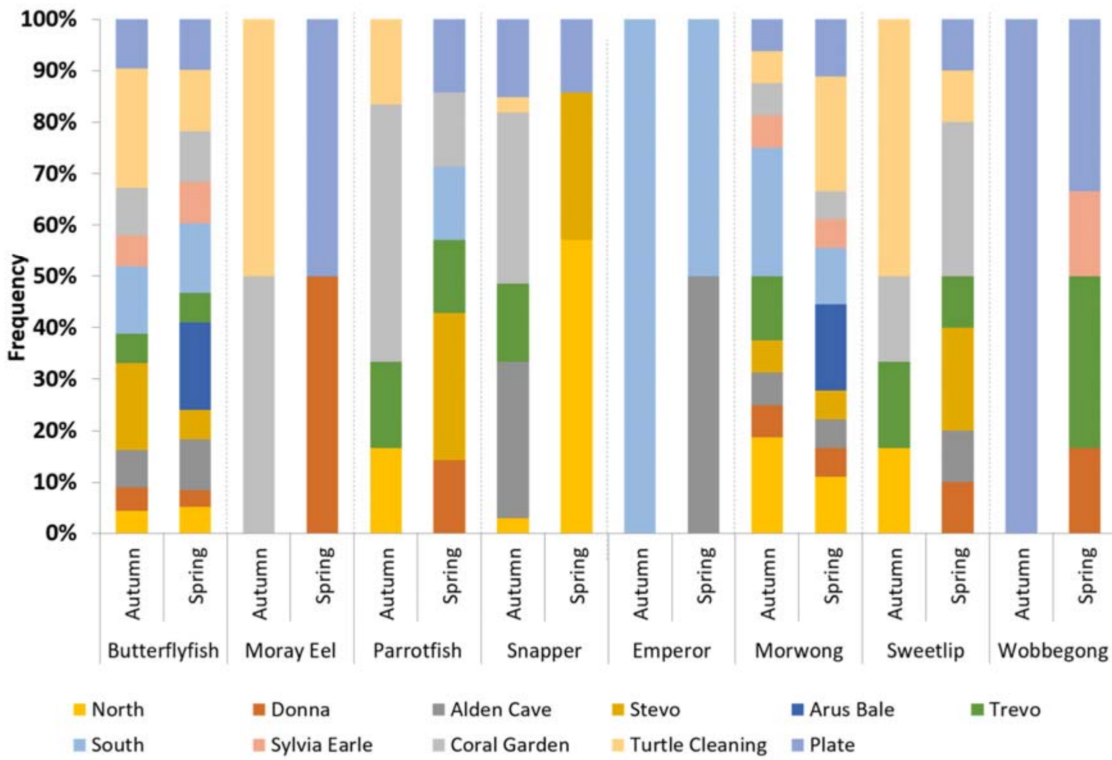


Figure 16: Proportion of the key fish groups encountered at each survey site per season.

Rare Animals at Survey Sites

Not many rare animals were observed at Flinders Reef and more often encountered during spring than in autumn (Appendix F). When encountered in both seasons, the number of rare animals per 100 m^2 was highest in autumn (Coral Garden, Turtle Cleaning and Plate). No rare animals were observed at Stevo, Trevo and South; Arus Bale was not surveyed in autumn and therefore not included in the latter. Turtle Cleaning showed the highest number of rare animals in autumn, mainly consisting of trevally. Turtles were found at six of the 11 survey sites in both autumn and spring.

3.3.3. Invertebrates

Seasonal Patterns of Invertebrate Key Groups at Flinders Reef

Flinders Reef's invertebrate diversity and abundance seems to be relatively constant over the two seasons (Figure 17). In both seasons, eight taxa have been recorded. The only difference lies in the abundance of collector sea urchins (*Tripneustes* sp.), which were found only in autumn.

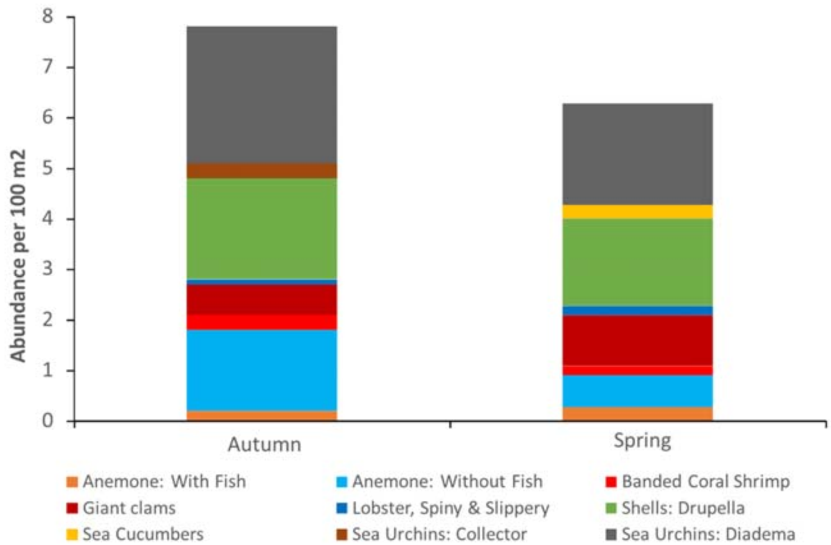


Figure 17: Seasonal abundance per 100 m² of key invertebrate groups at Flinders Reef for autumn and spring surveys. Crown-of-thorn starfish, triton, trochus, prickly greenfish and redfish sea cucumbers, and pencil sea urchins were not seen during surveys.

Seasonal Patterns of Invertebrate Key Groups at Survey Sites

Diversity and abundance of recorded indicator invertebrate taxa varied strongly between the Flinders Reef survey sites (Figure 18). Most diverse sites with five out of 14 taxa recorded (two anemone categories counted as one) were North, South and Plate. Most common taxon recorded is the sea urchin *Diadema* sp. which is observed in nine out of 11 sites. Most abundant taxa were corallivorous gastropod *Drupella* sp. and anemones. Crown-of-thorn starfish (*Acanthaster planci*), gastropods triton (*Charonia tritonis*) and trochus (*Tectus niloticus*), sea cucumbers prickly greenfish (*Stichopus chloronotus*) and prickly redfish (*Thelenota ananas*) as well as pencil sea urchin (*Heterocentrotus mammillatus* or *Phyllacanthus parvispinus*) were not observed at any of the sites.

Spatial Patterns of Invertebrate Key Groups at Survey Sites

Strong variation both in invertebrate diversity and abundance have been observed between the two surveyed seasons (Figure 18). All sites show a difference in taxa recorded in the two seasons. The most striking differences are found in North, Stevo and Sylvia Earle where the set of taxa recorded in autumn is completely different from the set of taxa observed in spring, i.e. none of the recorded taxa are found in both seasons. Additionally, in autumn surveys none of the indicator invertebrates were recorded in at Trevo, whereas in spring three taxa (anemone, *Drupella* sp. and *Diadema* sp.) were observed. Most diverse sites in autumn are Coral Garden and Turtle Cleaning with four taxa recorded. In spring, these sites had two and a single taxon recorded respectively. South was the most diverse site in spring surveys with five taxa recorded, while in autumn only three taxa were recorded.

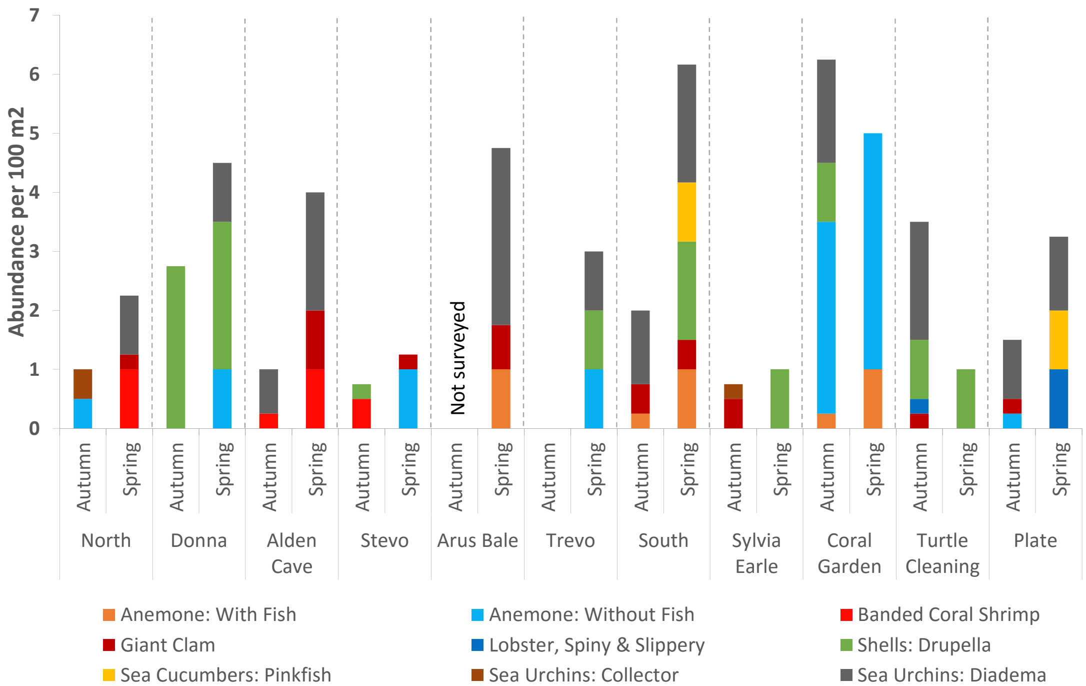


Figure 18: Seasonal abundance of indicator invertebrate taxa per 100 m² recorded at Flinders Reef on all sites during autumn and spring. Crown-of-thorn starfish, triton, trochus, prickly greenfish and redfish sea cucumbers and pencil sea urchins were not seen during our surveys.

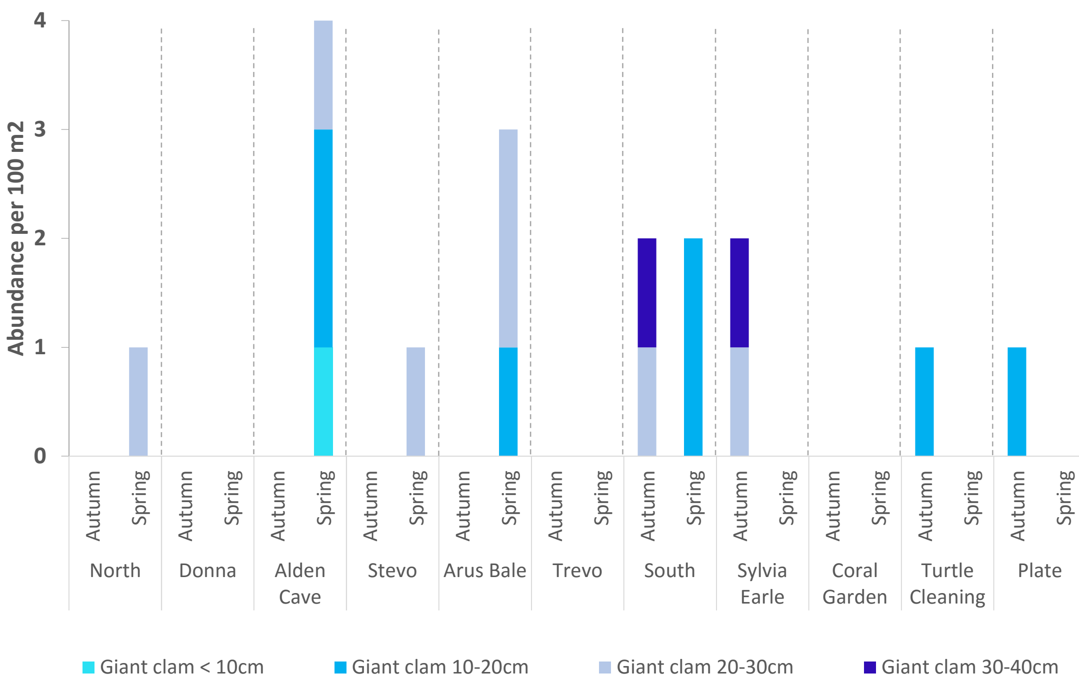


Figure 19: Seasonal abundance per 100 m² of giant clam size categories for autumn and spring at Flinders Reef. Giant clams with sizes superior or equal to 40 cm were not seen during our surveys.

The recorded abundance of taxa in the same site in two different seasons also varies. However, the abundance of some taxa seems to be relatively constant in particular sites: (a) anemone in Coral Garden, (b) *Drupella* sp. in Donna and Turtle Cleaning, (c) giant clams in South, and (d) *Diadema* sp. in Plate. Most observed invertebrates are mobile, with the exception of giant clams. Therefore, the difference in abundance of giant clam size categories is most notable (Figure 19). Giant clams with sizes ≥40 cm were not seen during our surveys.

3.3.4. Impacts

Seasonal Patterns of Reef Health Impacts for all Survey Sites combined

Reef health impacts observed in autumn and spring were generally higher in spring compared to autumn (Figure 20). Overall, this was especially true for coral disease, with incidence almost five times higher in spring (1.31/100 m^2) compared to autumn (0.27/100 m^2) across all sites combined. The presence of unknown scars were over two times more abundant in spring (1.42/100 m^2) compared to autumn (0.58/100 m^2). Conversely, *Drupella* scars were over two times more abundant in autumn (0.19/100 m^2) compared to spring (0.07/100 m^2)**.** This was the only impact recorded in a higher abundance in autumn. However, the abundance of *Drupella* scars was not reflective of recorded *Drupella* abundance, which was equal across seasons (Figure 17).

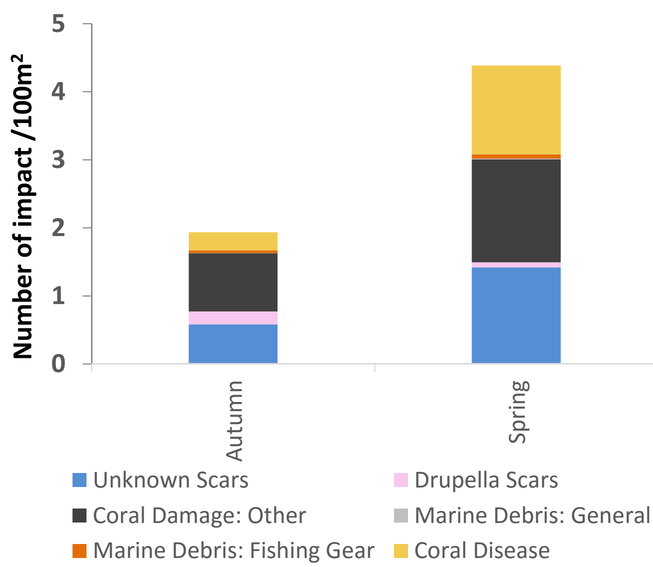


Figure 20: Seasonal abundance of reef health impacts per 100 m^2 normalised by the percentage of coral cover per season across all Flinders Reef survey sites combined. Anchor damage was not seen during surveys.

Physical coral damage can result from natural causes such as storms, or anthropogenic factors such as boat anchoring, poorly trained divers, snorkelers and fishing. The low abundance of discarded fishing gear on Flinders Reef was apparent. Although recorded during the impact survey, coral bleaching was not included in this section as it is addressed in the coral health section below.

Seasonal Patterns of Reef Health Impacts at Survey Sites

The average abundance of reef impacts per 100 m^2 and normalised by percentage coral cover generally increased from autumn to spring for each site (Figure 21). However, Plate had almost equally high damage in both seasons (autumn: 0.52/100 m^2; spring: 0.54/100 m^2). The highest abundance of impacts was found at Plate in autumn and at Trevo in spring (0.66/100 m^2), followed closely by South (0.66/100 m^2) (Figure 21).

The healthiest sites across seasons with a summed total of less than 0.50 impact counts per 100 m^2 included North, Donna, Stevo, Sylvia Earle and Coral Garden (Figure 21). North had the lowest abundance of reef impacts in autumn (0.08/100 m^2) and also exhibited one of the lowest abundances of reef impacts in spring (0.19/100 m^2), together with Donna (0.19/100 m^2). Despite having the highest coral cover in both autumn (55%) and spring (78.8%) (Figure 13), Coral Garden exhibited some of the lowest abundances of total impacts in both seasons (autumn: 0.15/100 m^2; spring: 0.22/100 m^2).

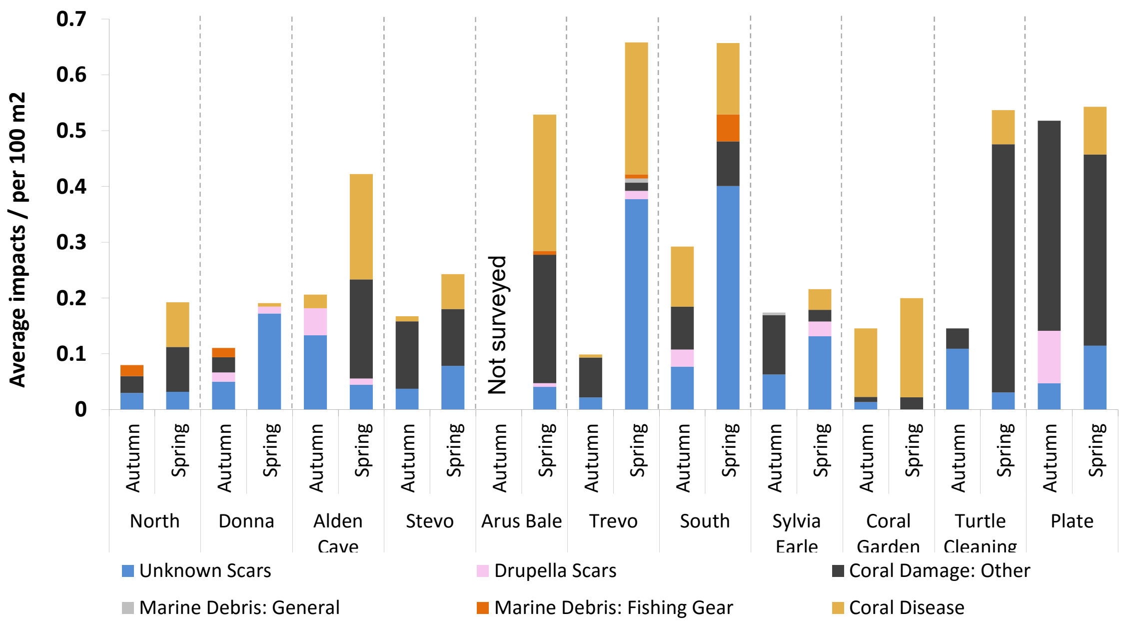


Figure 21: Seasonal abundance of reef health impacts per 100 m^2 at Flinders Reef normalised for coral cover for each survey site per season.

In terms of specific impacts, all sites exhibited some degree of coral disease, coral physical damage and unknown scars in at least one season (Figure 21). Although total impact abundance was relatively low in Coral Garden, this site experienced the highest abundance of coral disease compared to other sites in autumn (0.12/100 m^2). The incidence of coral disease at this site was also high compared to other impacts across both seasons. In spring, Arus Bale and Trevo displayed an even higher abundance of disease (both 0.24/100 m^2). Interestingly, however, Trevo experienced the lowest abundance of disease in the autumn (0.01/100 m2) and in spring, Donna had the lowest abundance of coral disease (0.01/100 m^2).

Plate displayed high abundances of coral physical damage in both seasons (autumn: 0.38/100 m^2; spring: 0.34/100 m^2), exceeded only by Turtle Cleaning in spring (0.44/100 m^2) (Figure

21). While Coral Garden displayed a high incidence of coral disease, there was a low abundance of coral damage across seasons (autumn: 0.01/100 m^2; spring: 0.02/100 m^2), with minimal unknown scars at this site in autumn (0.01/100 m^2) and none reported in spring. Conversely, Trevo (0.38/100 m^2) and South (0.40/100 m^2) had the highest abundances of unknown scars, both present in spring.

Although *Drupella* scars were found at most sites, total counts were low (Figure 21). The highest abundance of *Drupella* scars in autumn and spring were found at Plate (0.09/100 m2) and Sylvia Earle (0.03/100 m2), respectively. Fishing gear was encountered in five sites, with the highest incidence recorded at South in Spring (0.05/100 m^2). Fishing gear was also found in this season at Arus Bale and Trevo, and in autumn fishing gear was found at North and Donna.

Coral Health (coral bleaching)

For the period of observation, the recorded coral health was relatively stable with no obvious coral bleaching (Figure 22) on a scale from 1 to 6 (1 unhealthy, 6 very healthy). Overall, the lightest scores were observed in autumn, when the water temperature was highest (Figure 22). As data was consistent and similar for the 11 survey transects, they were pooled to create an average for the Flinders Reef dive site region. Figure 22 shows that the average score ranges from 3.5 in autumn to 4 in spring.

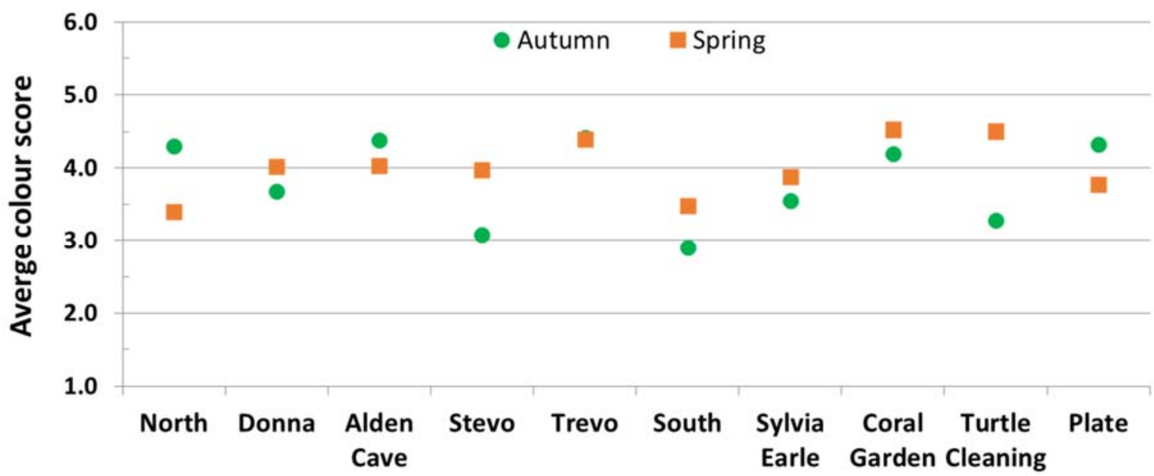


Figure 22: Average colour score for randomly surveyed corals per site separately for autumn and spring.

The average colour score as an indicator for coral health ranged between 2.9 at South in autumn and 4.5 at Turtle Cleaning and Coral Garden in spring. On six out of the 11 survey sites, the average colour score was lower in autumn than in spring, i.e. corals showed higher degree of health in spring.

In general, the average colour score per site and per season follows the same trend as the percentage hard coral cover, i.e. when a high coral cover is measured, the average colour score is higher than when a low coral cover is measured (Figure 23).

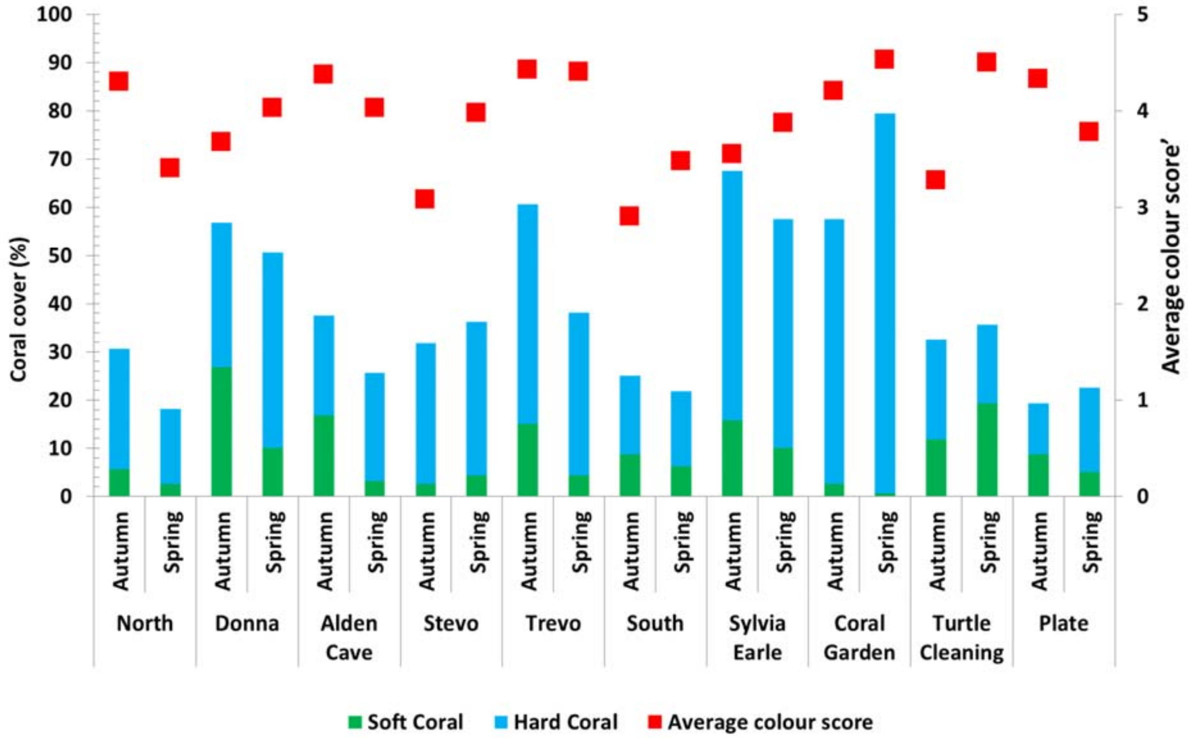


Figure 23: Seasonal average colour score of randomly surveyed corals at Flinders Reef per site (2nd y-axis) and the soft and percentage hard coral cover per site per season (1st y-axis).

In general, the lowest colour scores were measured at most sites and seasons for the growth type soft coral (Figure 24). The average colour score per growth type did not vary much between seasons per site, but a larger variation was found between sites. The lowest average colour score values were recorded for soft and boulder types in spring at North and Stevo (both average a colour score of 2.5) and highest average colour scores were recorded for branching and plate in spring at Turtle Cleaning and in autumn at Plate (both average a colour score of 5.3) (Figure 24).

No soft corals were randomly selected in the surveys in spring at Donna and in autumn at Alden Cave, and no plate corals were randomly surveyed in spring at Plate. Therefore, no bar is shown for these sites/seasons (Figure 24).

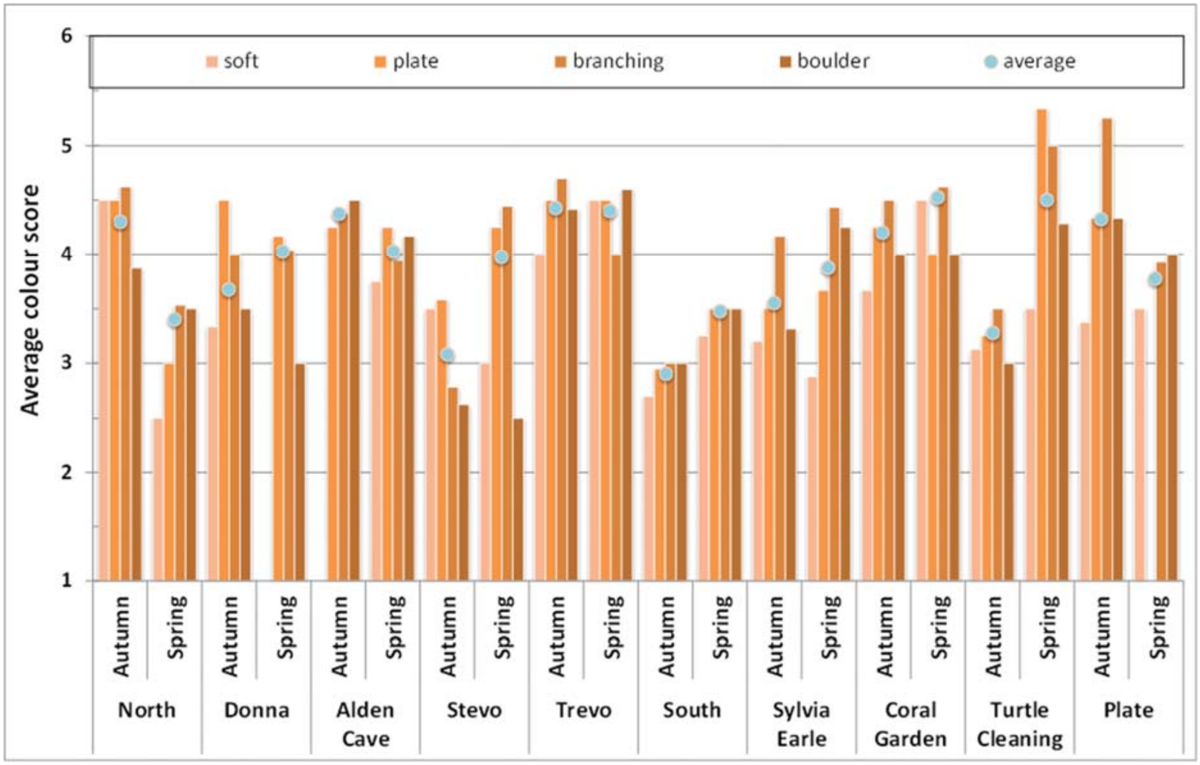


Figure 24: Seasonal average colour score of randomly surveyed corals per site per season per growth type (bars) and average per site per season (blue dot) at Flinders Reef.

3.3.5. Substrate over Time, Annually from 2007 to 2017

In this study, the data collected at Coral Garden, Turtle Cleaning, Plate and Alden Cave were compared with long-term Reef Check Australia data for these sites previously collected. Overall, recorded hard coral cover was found to be lower on FREA surveys than on long-term Reef Check Australia averages, except at Turtle Cleaning (Figure 25), potentially suggesting slightly different survey locations.

From 2007 to 2016, sites were dominated by rocky substrate (long-term site averages 21-30%) and hard coral (22-65%). Plate has the highest average cover of soft coral over time (20%) and "other" (mostly corallimorphs) (14%), but the lowest average hard coral cover (22%). Coral Garden has an average coral cover of 65% over the course of monitoring, which is almost exclusively branching coral. There appears to be an upward trend in hard coral cover, due to relatively fast-growing branching coral and what appears to be limited major disturbances. Alden Cave on the windward side of the reef has consistently higher sponge cover than sites on the leeward side (16%). Turtle Cleaning has a more limited monitoring regime, but also shows high cover of "other" (mostly corallimorphs) (12%) and soft coral (11%).

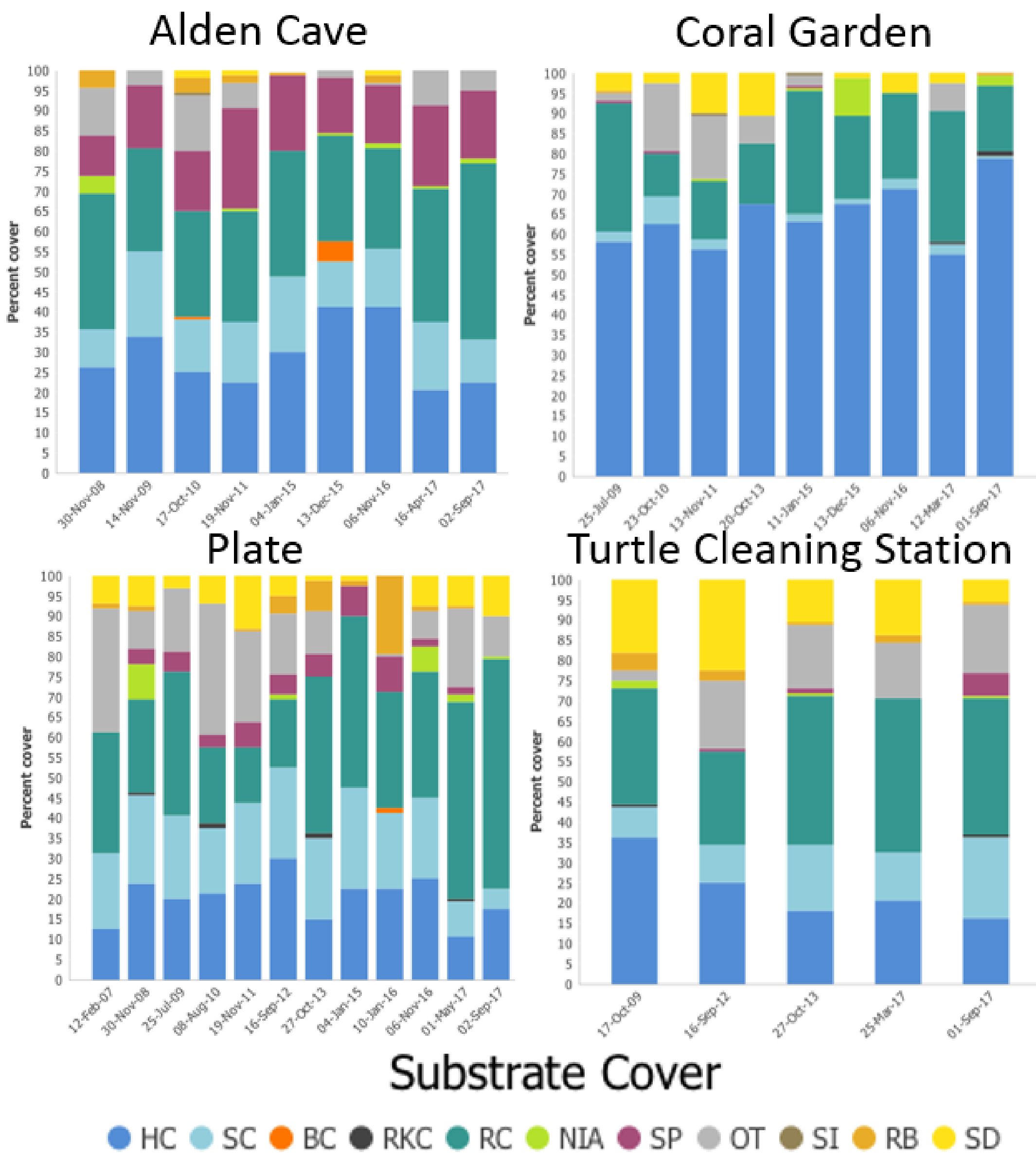


Figure 25: Comparison of 2009 to 2017 substrate data for four sites previously surveyed at Flinders Reef by Reef Check Australia, these include Coral Garden, Alden Cave, Plate and Turtle Cleaning (here named as Turtle Cleaning Station). HC=Hard Coral, SC=Soft Coral, BC=Bleached Coral, RKC=Recently Killed Coral, RC=Rock, NIA=Nutrient Indicator Algae, SP=Sponge, OT=Other, SI=Silt, RB=Rubble, and SD=Sand.

3.3.6. Substrate Compared to South East Queensland and Southern Great Barrier Reef

Based on average hard coral cover recorded by trained volunteers at long-term Reef Check Australia monitoring locations in the southern section of Queensland (2007-2017), Flinders Reef demonstrates itself as a standout location for coral, with 36% hard coral cover averaged across all sites over the course of monitoring (Reef Check Australia 2017, Reef Health Database www.reefcheckaustralia.org/data.html). This is higher than the Fraser Coast (22%), Sunshine Coast (28%), Point lookout (17%), and Inshore Moreton Bay (20%). Within Flinders Reef, Coral Garden with its extensive stand of branching *Acropora* spp. corals, is a particularly unique location for hard coral cover, with a cumulative average of 64% cover. This is comparable to cover at well-known dive sites at Heron Reef (Heron Bommie and Coral Gardens, 65% cover), and the southern Great Barrier Reef, which also host similar habitats of mostly branching coral. Other slope sites at Heron Reef have 51% coral cover and include plate, massive and branching corals, where on the shallow reef flat at Heron Reef hard coral cover is around 17% (Salmond et al. 2016).

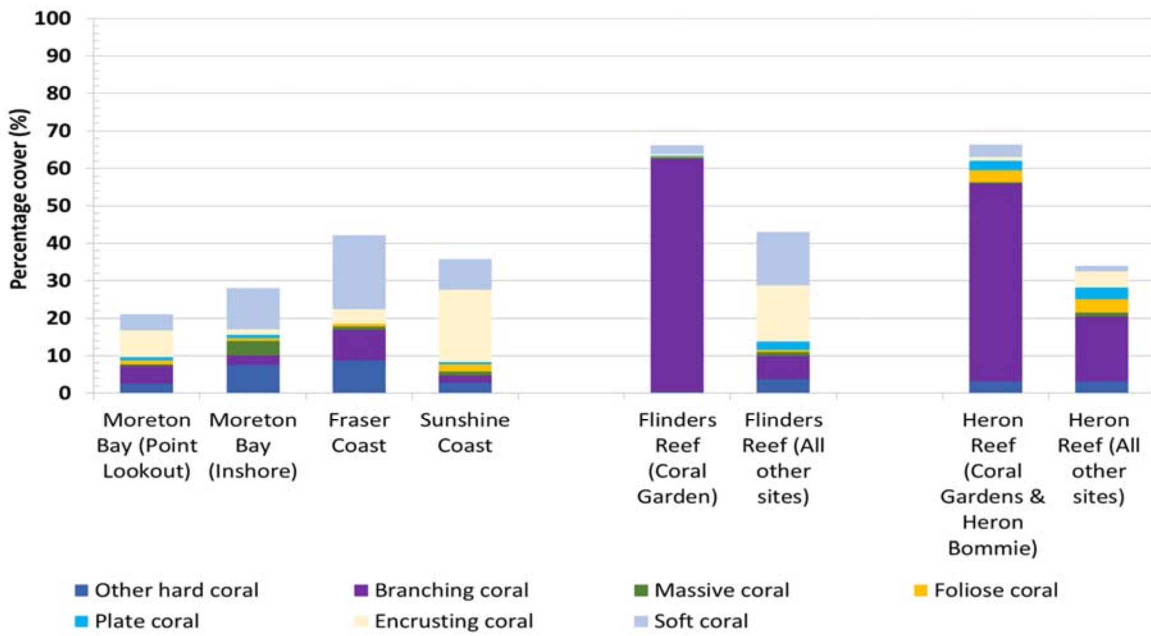


Figure 26: Percentage cover of coral growth forms at Flinders Reef compared with other South East Queensland sites and Heron Reef at the southern extent of the Great Barrier Reef.

3.4. Environment

3.4.1. Daily Weather Observations – Temperature and Wind

The air temperature at Cape Moreton Lighthouse shows a clear seasonal pattern, with the highest temperatures in February and March and the coolest months in July and August (Figure 27). The difference between the minimum and maximum daily temperature is on average 5.6°C, varying between 0.7 and 10.8°C.

When the observed Sea Surface Temperature (SST) is compared with the observed air temperature, the SST shows less variability and is closer to the maximum observed air temperature. However, it is not clear how the air temperature could be used as a proxy for the SST. Therefore, we should rely on observed SST if we want to correlate for example observed coral bleaching to water temperatures or fish abundance at Flinders Reef.

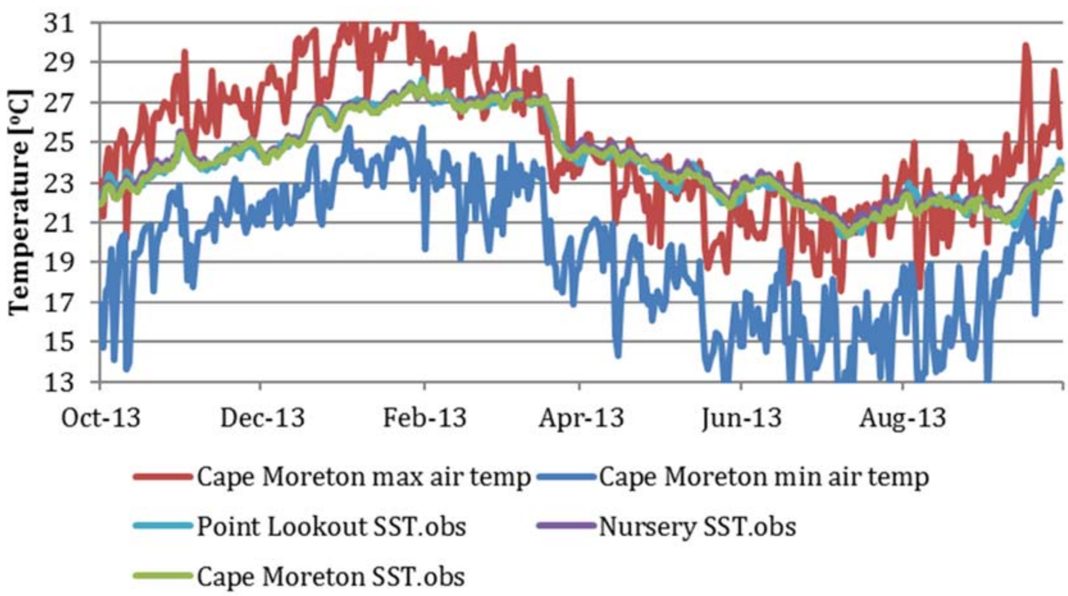


Figure 27: Daily observed minimum and maximum air temperature at Cape Moreton Lighthouse (source: http://www.bom.gov.au/climate/dwo/) combined with the observed Sea Surface Temperature at 3 locations based on NOAA processed satellite data (source: Liu et al. 2014).

If we look at a longer time series for the observed SST at Cape Moreton Lighthouse, we can identify the summer of 2014/2015 as a warmer summer. The average temperature for this season was up to 1.3°C warmer than the same season in the other years in our data set (Figure 28. Table 1 shows the complete time series, together with the moving average taken over 4 weeks.

Table 2: Seasonal average Sea Surface Temperature in the period 03/03/2013 until 12/10/2017 at Cape Moreton Lighthouse. Note: spring average for 2017 is based on partial data set from BOM.

Average SST	2013	2014	2015	2016	2017
Autumn	24.69	25.10	25.45	25.76	25.27

Winter	21.21	21.65	21.74	21.88	22.10
Spring	23.03	22.89	23.02	22.71	22.21
Summer	25.38	26.70	26.09	26.15	

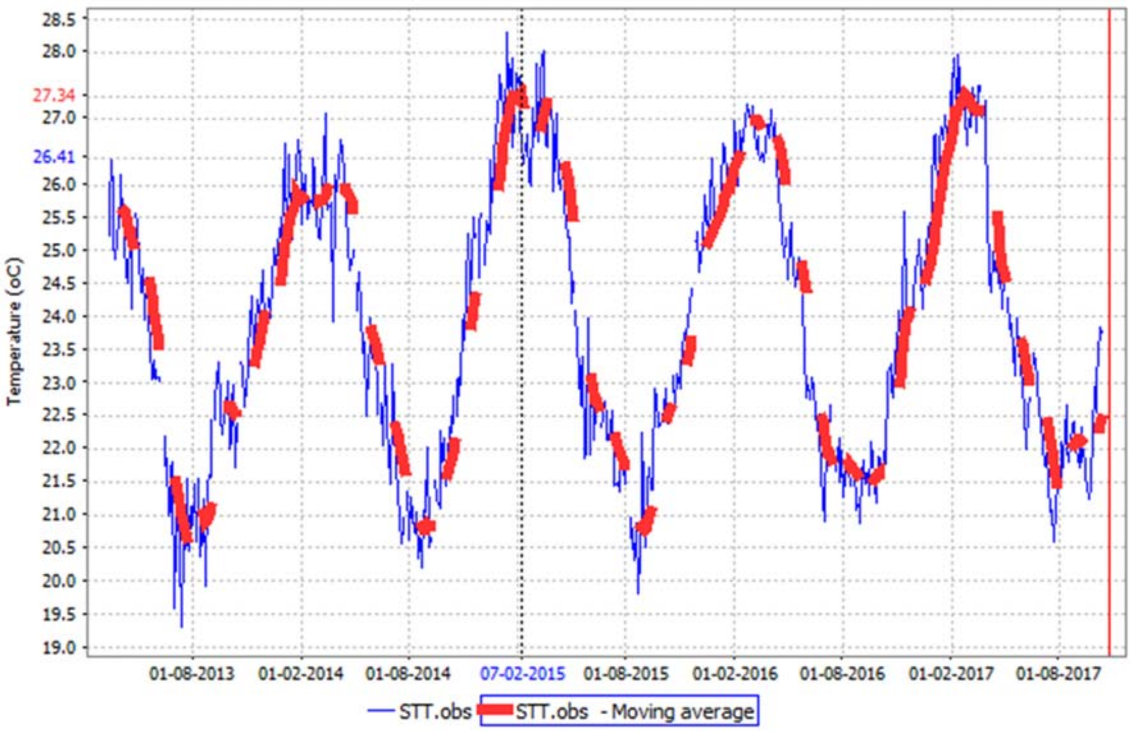


Figure 28: Observed Sea Surface Temperature at off Cape Moreton Lighthouse based on NOAA processed satellite data (source: Liu et al. 2014) over a period of 4 years, together with the moving average taken over 4 weeks (in red).

The wind climate near Flinders Reef can be characterised as mild, with wind speeds generally less than Beauport 5. The dominant wind direction at Cape Moreton Lighthouse is southeast, occurring for about 30% of the time. The relatively high position of Cape Moreton Wind gauge compared to Flinders Reef the wind speeds are known to be considerably higher but will provide a good representation of direction. Figure 29 shows wind roses for the morning and afternoon, averaged for the entire year. In the morning a calm westerly wind is present, but not in the afternoon.

The wind speeds and directions at Cape Moreton Lighthouse show a distinct seasonal variation (Figure 29). In autumn, the predominant 9 AM wind direction is SE, moving towards S/SW going into winter (Figure 29). In spring, the predominant 9 AM wind is either SE or NW.

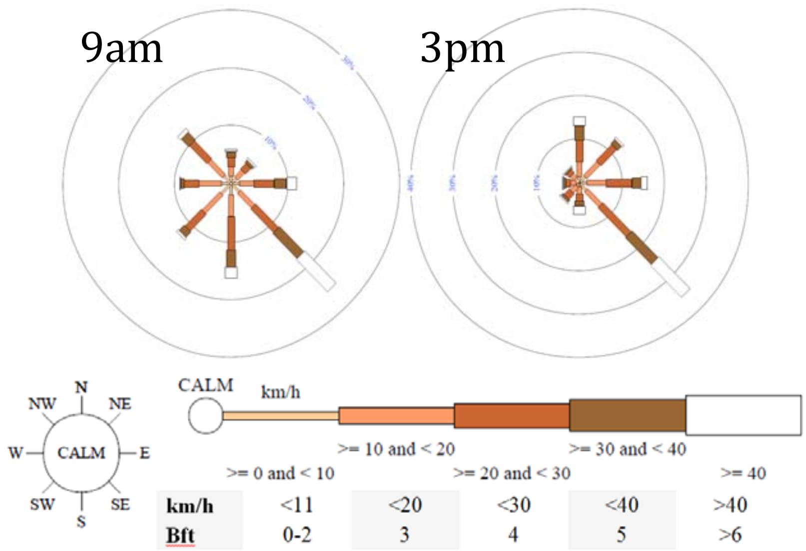


Figure 29: 9 AM and 3 PM wind roses at Cape Moreton Lighthouse averaged over the period 01-01-1957 to 10-08-2017 (source http://www.bom.gov.au/climate/data: http://www.bom.gov.au/climate/data/).

The predominant wind directions at Point Lookout (Figure 30) are different, therefore this data is less relevant when looking at the wind conditions at Flinders Reef. The wind roses for autumn and spring have been included in (Appendix I).

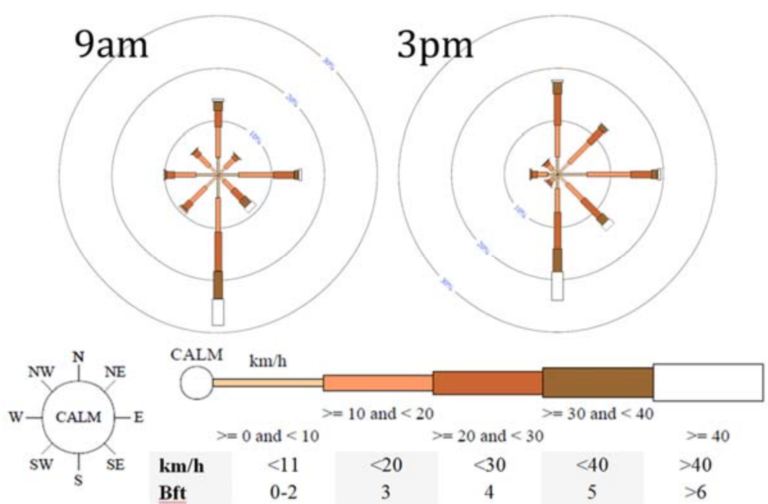


Figure 30: 9 AM and 3 PM wind roses at Point Lookout averaged over the period 06-02-1997 to 11-08-2017 (source: http://www.bom.gov.au/climate/data/).

The recording of the maximum daily wind gust gives an indication of storm events, which may cause damage to the reef. This information can be related to unusual swell and therefore potential observations of damaged coral (e.g. branching coral). Figure 31 shows dates for the days when the maximum recorded wind gust was 80 km/h or more, together with the corresponding wind direction.

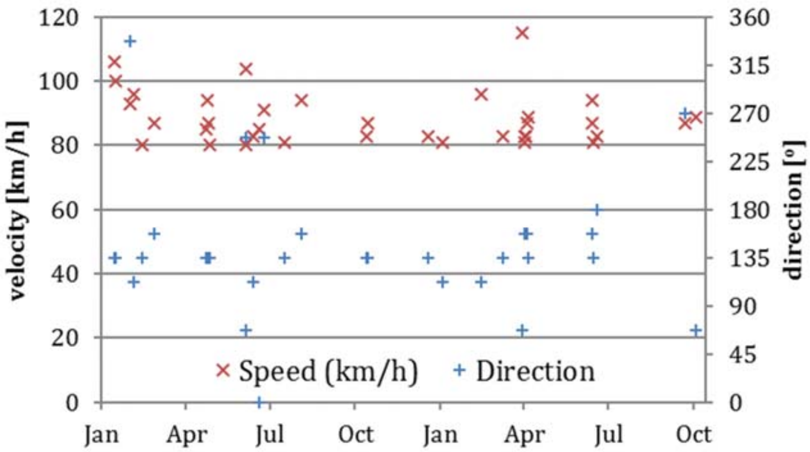


Figure 31: Daily maximum wind gust (velocity and direction) at Cape Moreton Lighthouse for days when maximum recorded wind gust was 80 km/h or more (source: http://www.bom.gov.au/climate/dwo/)

3.4.2. Wave monitoring data

The recorded maximum wave height and direction at the North Moreton Bay wave buoy show some correlation to the observed maximum wind gusts at Cape Moreton Lighthouse. Figure 32 shows the events where the recorded maximum wave height (Hmax) was 4 m or higher, together with the corresponding direction for the same period as used in Figure 31.

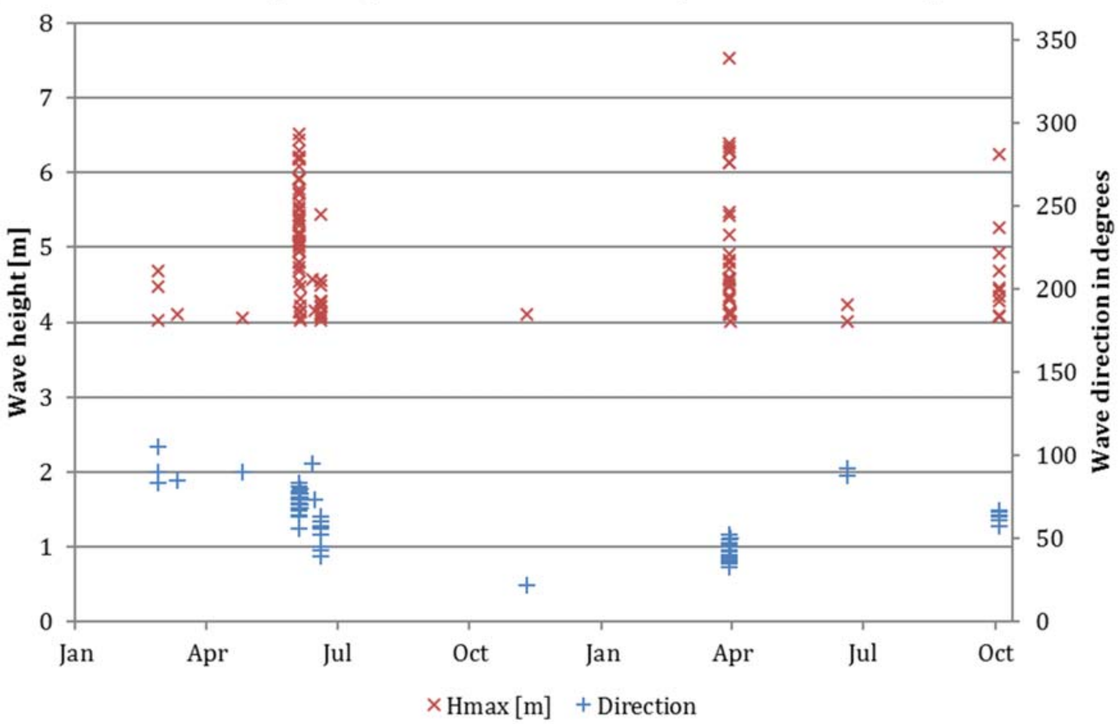


Figure 32: Maximum wave height (Hmax) and direction at North Moreton Bay wave buoy for days when maximum wave height was 4 m or more (source: https://data.qld.gov.au/dataset/)

3.4.3. Chlorophyll

High chlorophyll concentration values are an indication of a lower water quality likely due to eutrophication and by consequence, potential stress on the reef. Over a period of almost five years, several peaks can be identified, the biggest being 10 µg/l on 26/09/2013 (Figure 33). Other peaks (with values higher than 1 µg/l) have been observed and are listed in Table 3.

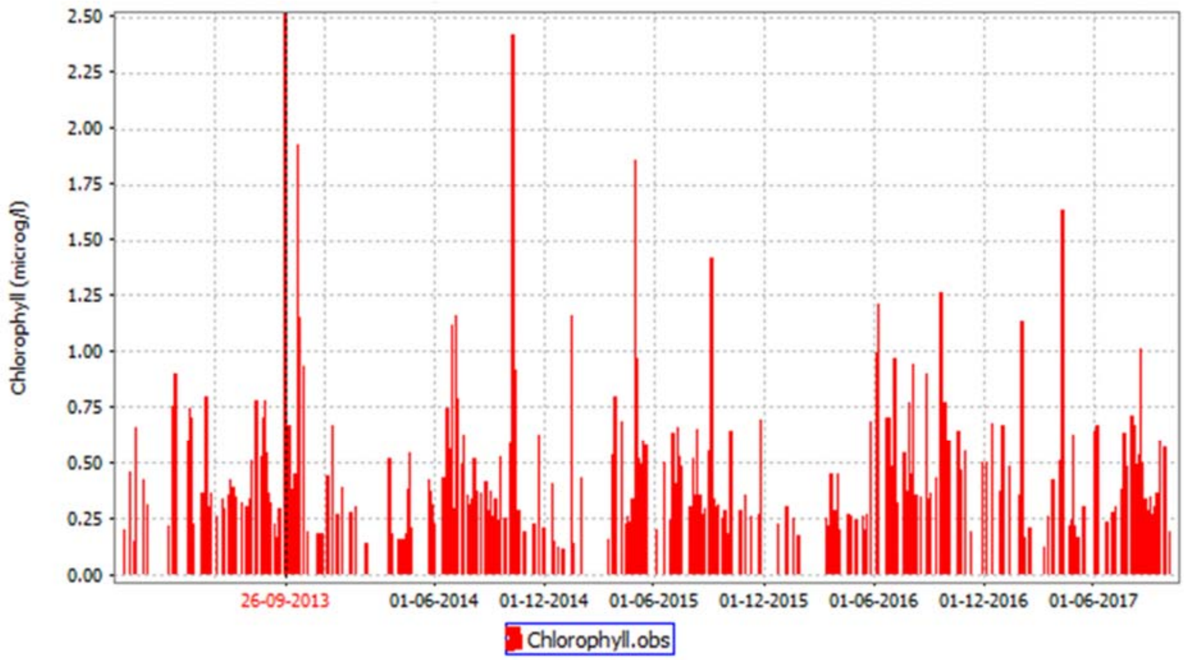


Figure 33: Daily averaged observed chlorophyll concentration at Cape Moreton Lighthouse based on NASA gathered satellite data (source: NASA Goddard Space Flight Center et al. 2017) over a period of more than four years. The high concentration observed on 26-09-2013 of 10 µg/l is off the scale.

Table 3: Peak events in observed daily average chlorophyll concentrations in the period 01-01-2013 until 05-10-2017 at Cape Moreton Lighthouse.

GMT	Chlorophyll.obs (µg/l)	GMT	Chlorophyll.obs (µg/l)
26-09-13 12:00	1.20	02-05-15 12:00	1.85
17-10-13 12:00	1.92	05-09-15 12:00	1.41
19-10-13 12:00	1.15	09-06-16 12:00	1.21
30-06-14 12:00	1.11	22-09-16 12:00	1.26
08-07-14 12:00	1.16	03-02-17 12:00	1.13
10-10-14 12:00	2.41	11-04-17 12:00	1.63
15-01-15 12:00	1.15	18-08-17 12:00	1.01

4. Discussion

Flinders Reef and the surrounding rocky reefs host temperate, tropical and sub-tropical species co-existing to form an important transitional marine habitat (Perry and Larcombe 2003). South East Queensland is exhibiting rapid population growth and coastal development, with potentially corresponding impacts upon its marine environments such as found around Flinders Reef. Climate change induced impacts due to rising sea level and warming ocean, have resulted in mass coral bleaching events in the Great Barrier Reef and increased occurrence and severity of cyclones (Pandolfi et al. 2005). Previous studies have recognised the importance of South East Queensland reefs for biodiversity and its unique species assemblages (Harrison et al. 1998), and ongoing long-term monitoring is driven by various citizen science initiatives filling in data gaps (Loder et al. 2010). The FREA survey project is one of those initiatives and has contributed effort to the documentation and monitoring of Flinders Reef.

4.1. Interpretation of Findings

Substrate

The surveys carried out in autumn and spring identified rock as the most dominant substrate type at Flinders Reef, followed by the benthic category hard coral. The encrusting growth form was the most abundant hard coral growth form, followed by branching corals. Coral Garden had the highest hard coral cover in comparison to all 11 sites surveyed around Flinders Reef. This more sheltered site features a large monospecific of branching coral. Plate and encrusting coral are more dominant on the windward side of the reef which aligns with findings from the Great Barrier Reef (Done et al. 2017, Ortiz et al. in press). At various locations around the reef, large plate corals of more than two meters in diameter were found. Mushroom, foliose, massive and sub-massive coral morphologies were also observed at Flinders Reef.

The FREA project further expands on site representation at Flinders Reef and supports Reef Check Australia data showing that hard coral cover at this reef is the highest for South East Queensland. With hard coral cover of up to 79% recorded at Coral Garden, Flinders Reef is comparable to and even exceeds coral cover recorded for reef sites at Heron Reef, southern Great Barrier Reef (up to 63% coral cover). This high cover of coral is likely supported by the location of this offshore reef, with well-flushed water regimes (Dennison and Abal 1999).

The red algae *Asparagopsis* sp. as the dominant macro algae observed at Flinders Reef showed a strong seasonal trend, with two times higher abundance in spring than in autumn. Seasonality of macro algae is known for the southern Great Barrier Reef (Rogers 2009) and also from upwelling regions where seawater temperature (Diaz-Pulido and Garzon-Ferreira 2002) and the availability of nutrients (Bayraktarov et al. 2014) were proposed as drivers of seasonality. For Flinders Reef, exposure to wind and water currents is a likely driver for the abundance and distribution of macro algae. *Laurencia* sp. dominated the deeper waters (>15 m) on the east side of the reef. Here, a limited number of the hardier species such as *Sargassum* sp. or *Turbanaria* sp. were observed while no kelp-like species like *Ecklonia* sp. were found. Most rock and rubble surfaces were either overgrown with macro algae or covered by sponges, corals or a fine turf algae layer.

Fish

Fish surveys were conducted using the Reef Check protocol to match the fish categories targeted in previous surveys by Reef Check Australia. Only a few new species were added specifically for the FREA project, mainly including fish from sub-temperate regions. The absence of three main key fish groups (grouper larger than 30 cm, blue grouper and humphead wrasse) suggests that the reef environment of Flinders Reef may not be optimal for these groups. The absence of groupers greater than 30 cm in size is likely related to the role of the shallower areas of Flinders Reef that were included in this study and they may function as nurseries. Smaller sized groupers as well as smaller parrotfishes were observed during the surveys (personal communication M. Grol). Similarly, smaller sized surgeon fishes were very abundant on the transects, while larger surgeon fishes and angelfishes were present on the survey sites. The size restriction followed by the Reef Check protocol may have influenced the apparent absence of some key fish groups from our results. Notably, volunteers observed more fish species and high fish abundances, however these were no indicator fish species, hence were not accounted for within the surveys.

Our surveys revealed spatio-temporal variations between the different study sites and key fish key groups. Overall, less fish were observed in spring compared to autumn, mainly driven by a drop in the abundance of the two most abundant key fish groups represented by butterflyfish and snapper. The main difference in environmental conditions between the two seasons was the temperature that varied between 22.2° and 25.3°C in spring and autumn, respectively. Most of the fish species included in the butterflyfish and snapper groups are known as residents of tropical coral reefs, and hence may prefer the warmer temperatures recorded in autumn.

Despite a difference in abundance between seasons, the butterflyfish group was the most abundant key fish group for all sites and across both seasons. Attempts to explain their high abundance using percentage of coral cover and coral growth form as explanatory factors were made without any clear correlation. It will be interesting to expand this analysis to more reefs in South East Queensland which are similar to Flinders Reef, such as Point Lookout or Mooloolaba. Comparing these relationships between rocky reefs and well-known tropical coral reefs will allow managers to better understand the value of rocky reefs for the conservation of reef fish diversity.

Invertebrates

Diversity of invertebrates at Flinders Reef was very similar in both surveyed seasons. However, their abundance was higher in autumn than in spring. This difference in abundance between the two seasons appears to be a result of high abundance of anemones in autumn (Figure 17). Anemones are not strictly sessile organisms. It is possible that they may have relocated or died out as a response to an environmental factor. However, a more likely explanation is that the transect line varied in position between the two seasons. Different positioning of transect lines can be proven by inconsistent numbers of sessile and easily-recognisable giant clams between the two seasons (Figure 19). The seasonal differences per site are more pronounced for some sites (North, Stevo and Sylvia Earle) where the diversity of taxa recorded between the two seasons is completely different (Figure 18). In contrast, some sites showed seasonal consistency in both diversity and abundance (Figure 18). The differences in diversity and abundance between the two seasons could be a result of: (a) mobility of organisms, i.e. most of the invertebrates recorded are mobile animals that change their location in response to time of the day and diverse environmental factors (e.g. temperature, sunlight and water energy); (b) inconsistency of transect position between the two seasons; (c) observers bias. The Reef Check protocol was followed and its indicator invertebrates counted on the transects are typical for tropical reef environments, thus a variety of other invertebrates observed on the dives such as different sea cucumbers, nudibranchs or flatworms were not recorded.

Impacts

The reef impacts at Flinders Reef were low, three times lower to than observed for other local reefs, such as Point Lookout (Roelfsema et al. 2016). Point Lookout has less management protection and more visitors due to its close proximity to North Stradbroke Island. Of the impacts present, coral physical damage, unknown scars and coral disease were observed at least once during every season and at each site. *Drupella* scars, fishing gear and general marine debris were found in comparatively low abundances and at few sites.

Despite being exposed to the prevailing southeast winds, east-facing Donna, Stevo and North had a very low impact abundance compared to other sites at Flinders Reef. The higher number of moorings and the more sheltered waters at the western side of the reef may explain the less frequent visits of the eastern side and why they are less affected by recreational activities. Physical damage to the coral (including unknown scars) was generally more abundant at western sites including Plate and Turtle Cleaning which have more branching coral that tend to grow fast easily but are very fragile.

Overall, impact abundance generally increased from autumn to spring, which was especially true for coral disease. Coral disease is generally caused by either biological factors or abiotic stresses including increased seawater temperatures, salinity variations and changes in water quality (Hayes and Goreau 1998, Bruno et al. 2003, Sutherland and Ritchie 2004).

Fishing gear was encountered in small quantities at only a few sites, even though illegal fishing was observed within the 500 m exclusion green zone during the survey trips. The availability of moorings most likely contributes to preventing anchor damage at this highly-trafficked site. Fishing gear was removed from the reef after each survey when possible.

Between sites and seasons, the average colour score measured by the coral health chart did not very much and all scores were 3 or higher which suggests a healthy reef. Growth types measured did not vary much between sites and seasons. Soft corals were lighter in colour on average with the lowest colour score of 2.5 indicating potential bleaching. However, most soft coral present on the sites were leathery soft corals which in general are lighter in colour, especially when their tentacles are retracted. Hard coral growth types scored healthy colour scores. Coral colour scores had similar values as recorded at Point Lookout in the past (Roelfsema et al. 2016).

Environmental Data

The dominant wind and wave direction correlates with the location of different coral types found around the reef. Historical data can also help to identify potential stressors to the reef community at Flinders Reef. In the summer of 2014/2015 there was an increased sea surface temperature observed, which could point towards a coral bleaching event. In the last five years, more than 10 events of increased observed chlorophyll concentration could indicate reduced water quality events. The observed daily maximum wind gusts correlate to storms that can explain some observations of damaged coral.

4.2. Project and Data Limitations

The FREA project and data limitations are similar as for the previous citizen science project conducted by the volunteer team, e.g. the PLEA project (Roelfsema et al. 2014).

The large number of volunteers involved in the project resulted in a higher chance of measurement errors and brought variability in the data that could be misinterpreted as real ecological differences. To reduce this variation, divers were trained to a high standard in Reef Check and CoralWatch survey methods (pass mark ≥75% on written survey ID exams) and if possible, divers were appointed consistent survey activities. Furthermore, all Reef Check divers, previously certified or not, had to participate in an academic exam. In addition, certified Reef Check divers had a practical review session during the training weekends and newly certified Reef Check divers did undertook practice surveys during the individual day trips. All of the 24 previously certified divers had survey experience gained during the PLEA project. The newly certified divers had to submit knowledge reviews, complete an academic online and paper exam, participate in survey technique and buoyancy pool training, as well as do ID training and an exam in the open water.

Within the FREA project differences have been observed between survey dates that are expected to be due to misalignment of transects over time for the same sites. Differences in transect location between surveys for the same site are allowed to vary as long as the different transects fall within the representative area of that specific site. A Reef Check site represents the different areas of a reef, each site itself is chosen to represent its direct surroundings. Slight differences in transect location are known to vary in the observations made, which are most notable with the substrate transect, as here observations are made every 50 cm along each of the four segments. Improving the relocation of a transect is therefore reliant on good start and end points, which can be achieved by using: 1) permanent markers for each segment or 2) good maps and start GPS locations. Placement of permanent markers as done for PLEA could impact the reef, hence FREA chose to use the second option and try to relocate the same survey transect areas. Additionally, environmental conditions such as waves and surge also result in misalignment of transects, specifically for the detailed substrate survey, explaining some variation in the identified substrate between surveys.

Ecological surveys were carried out in two seasons over six months apart where surveys were completed over one weekend and additional day trips to fill in the gaps (see Appendix I). The environmental conditions (e.g. wind, swell, tides, and temperature) during the surveys varied due to normal weather patterns, which had some influence on the flora and fauna present.

5. Recommendations for Management and the Community

Continued and Improved Monitoring of Flinders Reef

Repeating the ecological assessment on an annual basis for a select number of sites and every five years for all 11 sites would be beneficial for further understanding and management for conservation. The results of the study show both seasonal and spatial differences. The existing annual Reef Check monitoring of these reefs is important and should continue, as it documents changes over time. The data documents potential ecological changes and enables us to better understand if they are natural variations or caused by external factors such as fishing, pollution or physical damage. The FREA project report is the first detailed ecological assessment for 11 sites at Flinders Reef, creating a baseline for the whole reef. As this was a logistical challenge to complete at these isolated and exposed sites. Therefore, it is advised to conduct this level of assessment on a five-yearly basis.

Adjustment of indicator categories for ecological assessment. The FREA surveys included additional fish and substrate category indicators to those of Reef Check Australia advised by local scientists. These were mainly indicators for sub-tropical and temperate regions and relevance. Observations by the FREA team suggest considering the addition of other indicators for the invertebrate category such as nudibranchs and additional types of sea cucumbers.

Improved monitoring through live camera feed. It is advised that ongoing monitoring of recreational activities is conducted through regular visits by Queensland Parks and Wildlife Services rangers and/or the placement of a remote camera at Cape Moreton Lighthouse or on a structure on the exposed part of Flinders Reef. The camera could provide live information to authorities and public recreational users about the reef and its visitors' activities. For authorities, the camera could be used to potentially reduce illegal anchoring and/or fishing in the protected waters around Flinders Reef, which was observed during the FREA project and has been observed by other reef visitors. For the public, permanent camera footage can be used to assess environmental conditions, helping with planning of recreational activities at Flinders. It is our recommendation that a combination of increased penalties and stricter enforcement be applied to deter further fishing in this protected marine reserve.

Detailed maps of transect locations and deploying a drop buoy at the start of transects provide the best option to repeat the same transect location and improve the quality and reliability of survey result comparisons between sites and years. Based on the lessons learned from the PLEA project, the FREA project used GPS coordinates and drop buoys to locate the start of each transect, then used a detailed map and local knowledge to deploy the transect line. This approach is favourable as it is fast and has a high chance of positioning the transect in a representative area for that site, without placing permanent transect markers.

Reducing Physical Damage to Corals by Snorkelers and Divers

Educating divers, spear fishers, snorkelers, fishers and vessel skippers could help to reduce incidental physical damage to the reef. While recorded impacts at Flinders Reef were relatively low, it is important to encourage best practice at such unique locations. Snorkelers and divers should be encouraged not to touch anything or get close to the bottom, reducing their impact.

Additional moorings are recommended to provide access to northern and southern areas of the reef. As no anchor damage was recorded on the reef during the FREA project even though the reef is frequently visited by snorkelers and divers, it is concluded that moorings function successfully. Based on the ecological assessment and mapping activities the project found that both the North and South site are favourable for diving, however they do not have moorings and anchoring is wisely not allowed. Hence, we suggest adding additional moorings or moving one of the six moorings from the Nursery to these areas.

No anchor damage was recorded in any survey. This could be attributed to the presence of permanent moorings. However, high amounts of physical damage was present at the highly trafficked sites of Plate and Turtle Cleaning, which are frequented by both snorkelers and divers. However, Coral Garden, which is adjacent to the above-mentioned sites and also frequented by recreational divers, remained minimally affected by coral damage. Therefore, damage may be unrelated to diver frequency (e.g. turtles cleaning their body on coral) and should be a metric investigated in future studies. At the actual turtle cleaning station, divers observed that the tops of the branching coral area are eroded due to frequent visits of turtles purposely cleaning their belly by moving over the corals (personal observation).

Community Engagement to Create Awareness of the Importance of the Reefs

Educating the community about the Moreton Bay reefs will help preserve these resources for the future. A community survey undertaken by Reef Check in 2010 indicated that 1 in 4 people don't know about South East Queensland's sub-tropical reefs (Reef Check Australia 2010). As indicated in previous UniDive projects, increasing awareness about the importance of these habitats and how personal actions can support their protection is critical to help in the conservation of these ecosystems for the future.

Due to Flinders Reef's remote location it is even harder to access. Hence, to make the South East Queensland community aware of this special reef, we produced a photo book *"Flinders Reef, A Marine Flora and Fauna Description of Local Dive Sites"* and a video which will assist in increasing community awareness about the existence of the reefs around South East Queensland and showcase the value, beauty and diversity of these reefs.

The community can help build an understanding of Moreton Bay reefs through citizen science. The broader community can get involved in numerous citizen science initiatives to support increased understanding of Moreton Bay reefs: Reef Check Australia (http://www.reefcheckaustralia.org/), CoralWatch (http://www.coralwatch.org/)
Grey Nurse Shark Watch (http://www.reefcheckaustralia.org/grey-nurse-shark-watch.html)
Spot the Leopard Shark (http://www.uq.edu.au/whale/spot-the-leopard-shark)

Support Conservation of the Reefs by Providing Peer-Reviewed Information

The scientific community, non-governmental organisations, management authorities, local area councils and interested citizens can use the findings of this research and future research projects to help support management decisions and guide further monitoring of the reefs. The results and data from this project will be made publicly available, and include:

Project Documents

- Roelfsema C.M., E. Bayraktarov, C. van den Berg, S. Breeze, M.G.G. Grol, T. Kenyon, S. de Kleermaeker, J. Loder, M. Mihaljević, J. Passenger, P. Rowland, J. Vercelloni and J. Wingerd (2017). Ecological Assessment of the Flora and Fauna of Flinders Reef, Moreton Bay Marine Park, Queensland. UniDive, The University of Queensland Underwater Club, Brisbane, Australia.(this report)

  The document was reviewed by two coastal region managers, both having over fifteen years of experience with monitoring and managing the coastal regions and national parks in South East Queensland.

- Roelfsema C.M. and A.D. Kleine (2017). *Flinders Reef, Flora and Fauna of Flinders Reef, North Moreton Island, Queensland.* Unidive, The University of Queensland Underwater Club, Brisbane, Australia.

  Photo book (100 pages) created with the help of UniDive volunteers capturing 200+ photos taken by UniDive volunteers at Flinders Reef.

Peer-Reviewed Scientific Papers

- Roelfsema C.M. E. Bayraktarov, C. van de Berg, S. Breeze, M.G.G. Grol, T. Kenyon, S. de Kleermaeker, J. Loder, M. Mihaljević, J. Passenger, P. Rowland, J. Vercelloni and J. Wingerd (manuscript in preparation). *Flora and Fauna of Flinders Reef, a detailed Citizen Science assessment in time and space, Moreton Bay Marine Park, Queensland.* Journal of Ecosystem and Echography

Peer-Reviewed Data Set

- The by FREA collected *Reef Check and CoralWatch 2017 Data Set* will be accessible through their online data portals from either organisation*.*
- Roelfsema C.M. T. Barenger, R. Anderson, A. O'Hagen, M. Grol, T. Kenyon, P. Arlow, M. Pheasent, P. Bray, J. Passenger and D. King, *Georeferenced Photos collected in 2017 of the Flinders Reef Dive Sites at North Moreton Island, Queensland. UniDive FREA Project.* Pangea or Coastal Data Portal.
- Kovacs E.K., S. Breeze, P. Rowland, K. Johnson and C.M. Roelfsema. Benthic composition derived from the *Georeferenced Photos collected in 2017 of the Flinders Reef Dive Sites at North Moreton Island, Queensland. UniDive FREA Project.* Pangea or Coastal Data Portal.
- Roelfsema C.M., M.G.G. Grol, T. Barrenger, M. Pheasant, P. Arlow, J. Kunze, A. O'Hagen, R. Andersen (in preparation). *Habitat Maps Created as part of the Ecological Assessment of the Flinders Reef Dive Sites at North Moreton Island, Queensland. UniDive FREA Project*. Pangea or Coastal Data Portal.

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Appendices

Appendix A: Participating Divers

OWD=Openwater, ADV=Advanced, RES=Rescue, DM=Dive Master, INS=Instructor, RCA= Reef Check Certified, RCA+Fish= RCA certified including fish.

Name	Points	Training dives	Survey dives	Cert	Training	Boat Handling	RCA Survey	Mapping	Coral Watch	Organisation	Science	Analysis	Book	Video
Alex Burt	8	4		RES	RCA+Fish									
Andrew O'Hagan	29	4	12	DM	RCA-new		x	x	x	x				
Andy Holland	17	4	4	DM	RCA-new		x	x	x					
Breanne Vincent	32	4	12	DM	RCA+Fish	x	x		x	x	x		x	x
Bruce McLean	7	4	2	DM	RCA	x		x	x	x				
Catherine Kim	11	4		RES	Non			x	x					
Cedric van den Berg	25	4	20	RES	RCA-new		x				x	x	x	x
Chris Roelfsema	45	16	19	INS	RCA	x	x	x	x	x	x	x	x	x
Clemens Müller	18	4	4	RES	RCA-new			x	x	x				
Da King	3		5	DM	Non			x	x					
Dee Passenger	10	4	2	DM	RCA+Fish		x							
Diana Kleine	20	4	3	INS	RCA+Fish		x		x	x	x	x	x	
Djoy Roelfsema	3			RES	Non								x	x
Donna Easton	22	4	9	RES	RCA		x			x				
Douglas Stetner	27	8	10	INS	RCA	x	x	x	x		x	x	x	
Elisa Bayraktarov	31	4	15	RES	RCA-new		x			x	x	x	x	
Elisa Girola	6	4		DM	RCA-new			x	x					
Emily Purton	7	4		DM	RCA-new									
Eva Kovacs	10	4	4	DM	RCA+Fish			x	x	x	x	x		
Jaap van der Velde	15	4	1	RES	RCA-new		x		x	x				
James Mcphearson	1		2	OWD	Non			x						
Jen Calcraft	27	4	24	RES	RCA+Fish		x		x	x			x	x
Jen Loder	5			DM	RCA+Fish					x	x	x	x	
Jens Kunze	28	4	15	RES	RCA-new	x	x	x	x	x		x		
Josh Passenger	22	8	16	DM	RCA+Fish	x	x	x	x	x	x	x		
Josh Wingerd	18	4	6	RES	RCA-new		x	x	x		x	x		
Julie VanDore	24	4	9	RES	RCA-new		x		x				x	
Julie Vercelloni	15	4	2	RES	RCA-new			x	x		x	x		
Justin Marriner	6			DM	Non					x				
Karen Johnson	28	4	19	DM	RCA+Fish	x	x		x	x		x		
Katherine Trim	6	4		RES	RCA+Fish		x							
Liette Boisvert	20	4	4	RES	RCA		x		x	x				
Lock Pollard	6	4	2	DM	RCA	x		x	x	x			x	
Mark Stenhouse	24	4	13	DM	RCA	x	x	x	x	x			x	x
Melanie Oey	19	4		DM	Non					x				
Mike pheasant	18	4	12	DM	RCA	x		x		x		x		
Monique Grol	34	4	15	RES	RCA+Fish	x	x	x	x	x	x	x	x	
Morana Mihaljevic	26	4	4	RES	RCA-new		x			x	x	x		
Olivier	10	4	3	RES	RCA-new				x					
Peran Bray	22	4	9	INS	RCA	x	x	x						
Peter Arlow	10		8	RES	Non			x						
Phebe Rowland	10			OWD	Non						x	x		
Rikki Andersen	24	4	11	RES	RCA-new		x	x	x	x				
Robert Cook	9			DM	Non					x				
Ryan Booker	16	4		INS	RCA					x				
SANTIAGO MEJIA	11	4	2	RES	RCA		x							
Sarah Breeze	8			RES	RCA-new						x	x		
Simone De Kleermaeker	20	4	8	RES	RCA-new				x		x	x		
Sonja Meier	24	4	11	RES	RCA-new		x			x				
Sophie Remond	10	4		RES	Non									
Stefano Freguia	9	4	5	RES	RCA+Fish		x							
Tania Kenyon	19	4	6	DM	RCA+Fish		x	x	x	x	x	x	x	
Tanya Dodgen	21	4	6	RES	RCA-new		x			x				
Trevor Barrenger	32	4	18	DM	RCA	x	x	x		x	x	x	x	
Yu Pei Tan	10	4		RES	RCA-new									

Appendix B: Data Sheets

Reef Check Belt Transact – Substrate SEQ	
Dive site name:	Reef name:
Date:	Depth
Time:	Habitat:
Data recorded by:	Site number:
Camera ID:	Team leader:

HC – Hard Coral
HCB – Bleached hard coral
HCBR – Branching hard coral
HCM – Massive hard coral
HCF – Foliose hard coral
HCP – Plate hard coral
HCE – Encrusting hard coral

SC – Soft Coral
SCL – Leathery soft coral
SCZ – Zoanthids
SCB – Bleached soft coral

RKC – Recently Killed Coral
RKCNIA – Recently killed coral & NIA
RKCTA – Recently killed coral & turf algae

OT – Other
OTC - Corallimorph

NIA – Nutrient Indicator Algae

SP – Sponge
SPE – Encrusting sponge

RC – Rock
RCTA – Turf algae
RCCA – Coralline algae

SI – Silt/Clay
RB – Rubble
SD – Sand

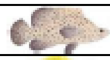
0-20m				25-45m				50-70m				75-95m			
0		10		25		35		50		60		75		85	
0.5		10.5		25.5		35.5		50.5		60.5		75.5		85.5	
1		11		26		36		51		66		76		86	
1.5		11.5		26.5		36.5		51.5		66.5		76.5		86.5	
2		12		27		37		52		62		77		87	
2.5		12.5		27.5		37.5		52.5		62.5		77.5		87.5	
3		13		28		38		53		63		78		88	
3.5		13.5		28.5		38.5		53.5		63.5		78.5		88.5	
4		14		29		39		54		64		79		89	
4.5		14.5		29.5		39.5		54.5		64.5		79.5		89.5	
5		15		30		40		55		65		80		90	
5.5		15.5		30.5		40.5		55.5		65.5		80.5		90.5	
6		16		31		41		56		66		81		91	
6.5		16.5		31.5		41.5		56.5		66.5		81.5		91.5	
7		17		32		42		57		67		87		92	
7.5		17.5		32.5		42.5		57.5		67.5		87.5		92.5	
8		18		33		43		58		68		88		93	
8.5		18.5		33.5		43.5		58.5		68.5		88.5		93.5	
9		19		34		44		59		69		84		94	
9.5		19.5		34.5		44.5		59.5		69.5		84.5		94.5	
MA Tally				MA Tally				MA Tally				MA Tally			
Air		Time		Air		Time		Air		Time		Air		Time	

Asparagopsis Padina Saragassum Turbinaria

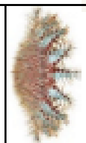
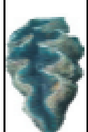
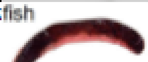
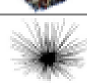
Comments about 'other' category

Circle SI category for site: N L M H
N – None
L – Low some SI
M – Medium, Surface have thin SI layer
H – High, Surface have thick SI layer

	Reef Check Belt Transect – Fish SEQ	
	Dive site name:	Reef name:
	Date:	Depth
	Time:	Habitat:
	Data recorded by:	Site number:
	Camera ID:	Team leader:

		0-20m	25-45m	50-70m	75-95m	Photo No.*
Barramundi Cod *(Chromileptes Altivelis)* 						
Butterfly *(Chaetodontidae)* 						
Grouper: Coral Trout *(Plectropomus leopardus)* 	30-40cm					
	40-50cm					
	50-60cm					
	>60cm					
Grouper: Grouper *(Epinephelinae)* 	30-40cm					
	40-50cm					
	50-60cm					
	>60cm					
Grouper: Queensland Grouper *(Epinephelus lanceolatus)* 						
Grouper: Blue Grouper *(Achoerodus viridis)* 						
Humphead Wrasse *(Cheilinus undulatus)* 						
Morey Eel *(Muraenidae)* 						
Parrotfish: Bumphead Parrotfish *(Bolbometopon Muricatum)* 						
Parrotfish: Other Parrotfish *(Scaridae)* (count only > 20cm) 						
Snapper/ Emperor: Snapper (generic) *(Lutjanidae)* 						
Snapper/ Emperor: Pink Snapper *(Chrysophrys auratus)* 						
Snapper/ Emperor: Emperor (generic) *(Lethrinus)* 						
Snapper/ Emperor: Spangled Emperor *(Lethrinus nebulosus)* 						
Morwong *(Cheilodactylus)* Crested  Red 						
Sweetlips *(Haemulidae)* 						
Wobbegong *(Orectolobus)* 						
Rare animals (turtle, shark, ray, octopus, etc)						
	Air					
	Time					

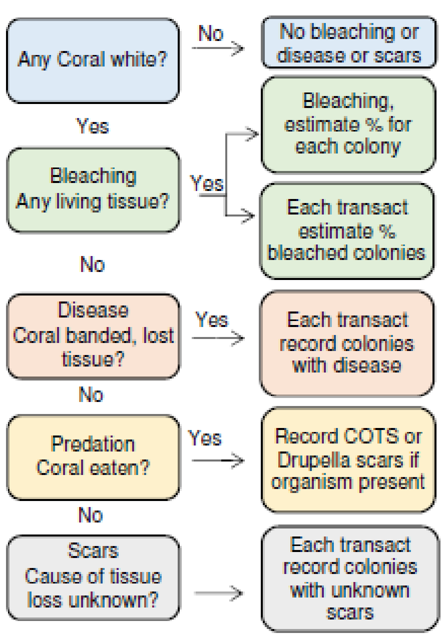
UNIDIVE FREA / Reef Check Australia	Reef Check Belt Transact – Inverts SEQ	
	Dive site name:	Reef name:
	Date:	Depth
	Time:	Habitat:
	Data recorded by:	Site number:
	Camera ID:	Team leader:

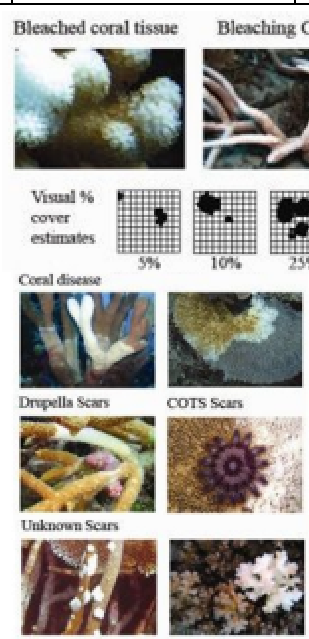
			0-20m	25-45m	50-70m	75-95m	Photo No.*
Anemone		With Fish					
		Without Fish					
Banded Coral Shrimp							
COTS		< 6cm					
		6-15cm					
		15-25cm					
		>25cm					
Giant Clam		<10cm					
		10-20cm					
		20-30cm					
		30-40cm					
		40-50cm					
		>50cm					
Lobster, spiny & slippery							
Shells	Drupella						
	Triton						
	Trochus						
Sea Cucumbers	Pinkfish						
	Prickly Greenfish						
	Prickly Redfish						
Sea Urchins	Collector						
	Diadema						
	Pencil						
		Air					
		Time					

UNIDIVE FREA / Reef Check Australia	**Reef Check Belt Transact – Impacts SEQ**	
	Dive site name:	Reef name:
	Date:	Depth
	Time:	Habitat:
	Data recorded by:	Site number:
	Camera ID:	Team leader:

		0-20m	25-45m	50-70m	75-95m	Photo No.*
Bleaching	Estimate % impact for each bleached colony					
	Estimate % totals coral population					
Damage	Boat / Anchor					
	Dynamite					
	Other					
Coral Disease						
Coral Scars	Crown of Thorns					
	Drupella					
	Unknown/Other					
Trash	Fishing Line					
	Fish Nets					
	General					
Rare Animals						
	Air					
	Time					

Three dominant algae	1. Photo #	2. Photo #	3. Photo #





Other Photos

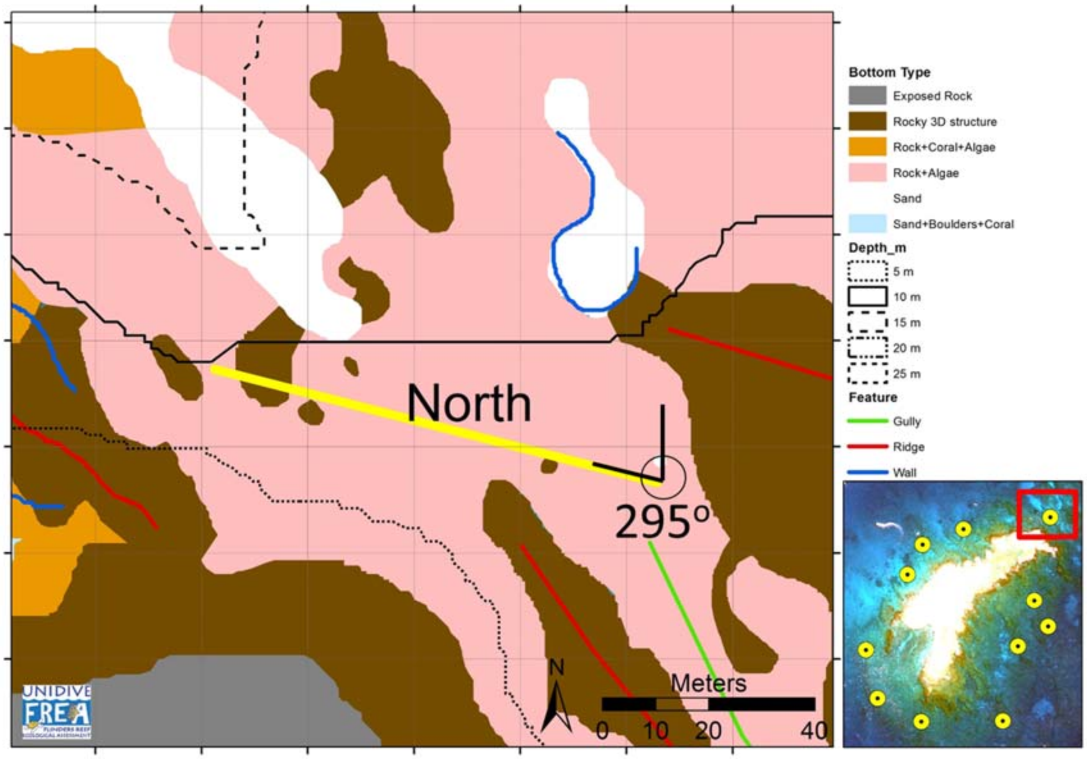
Subject	Photo #

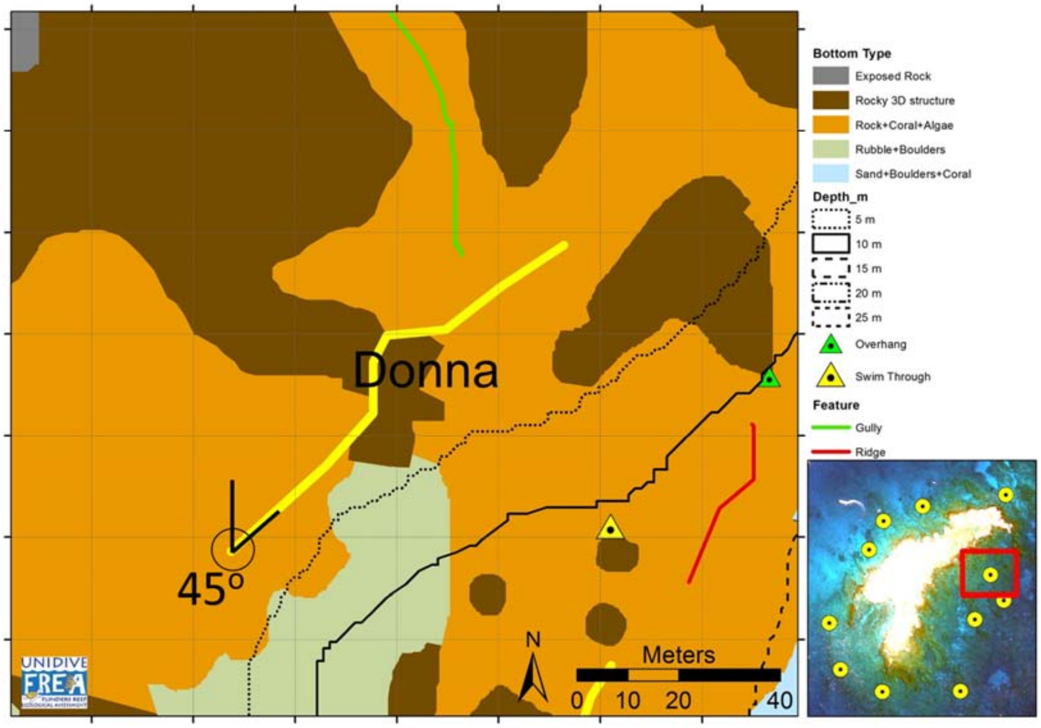
Appendix C: Diving Statistics

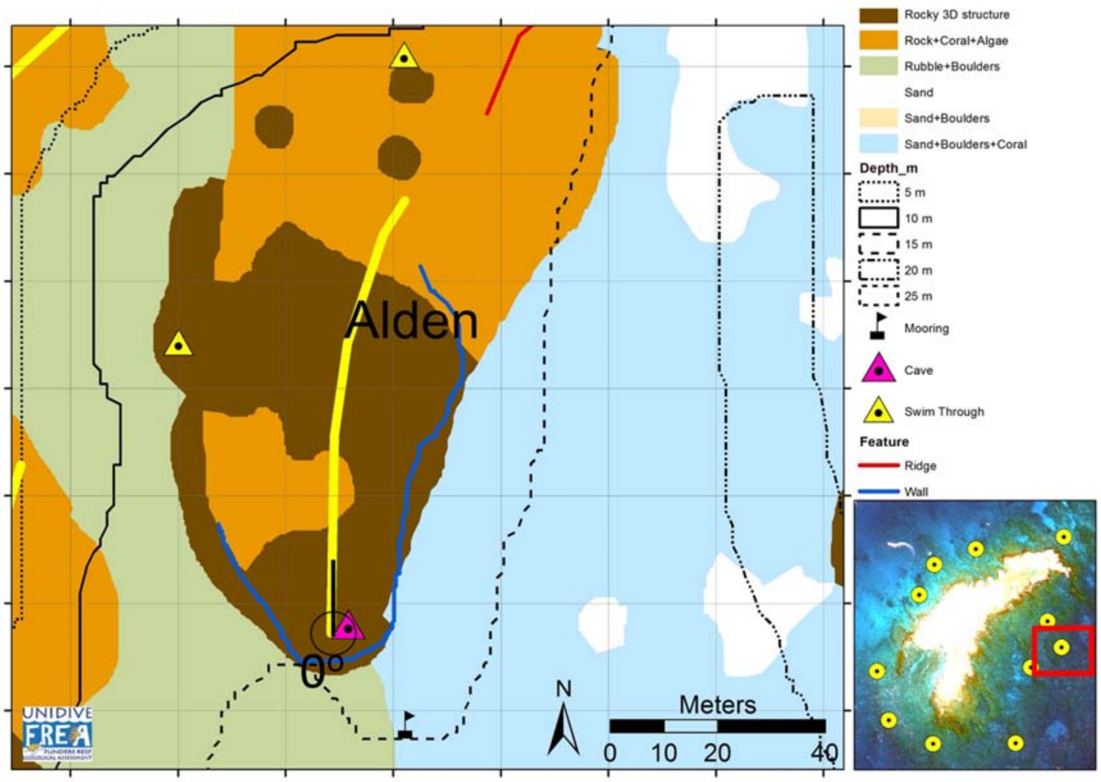
#	Dive Date	Number of Divers	Total dives	Bottom Time (hrs.)	Dive location	Type of Dive
1	12/11/2016	22	44	33	Shag Rock	Training
2	13/11/2016	22	44	33	Shag Rock	Training
3	4/02/2017	22	44	33	Shag Rock	Training
4	5/02/2017	22	44	33	Shag Rock	Training
5	12/03/2017	10	20	15	Coral Garden/North	Survey
6	25/03/2017	26	31	23	Sylvia Earl/Alden/Turtle	Survey
7	26/03/2017	25	30	23	Donna's/Stevo/South	Survey
8	16/04/2017	10	20	15	Plate/Alden	Survey
9	1/05/2017	10	20	15	Plate/Trevo	Survey
10	27/05/2017	10	20	15	Stevo/Trevo	Mapping
11	10/06/2017	10	20	15	Plate/Coral Garden	Mapping
12	24/06/2017	10	20	15	North/Alden	Mapping
13	26/06/2017	2	4	3	All around	Mapping
14	27/06/2017	2	4	3	All around	Mapping
15	8/07/2017	10	20	15	North/DeepGarden/South/Trevo	Mapping
16	15/07/2017	10	20	15	Fake Alden	Mapping
17	5/08/2017	10	20	15	Alden/Coral Garden	Mapping
18	13/08/2017	9	18	14	North/Plate/UniDive Shoal	Mapping
19	27/08/2017	8	16	12	North/Stevo	Survey
20	1/09/2017	16	16	12	Coral Garden/Turtle Cleaning	Survey
21	2/09/2017	16	36	27	Plate/Alden/Sylvia Earle/Donna	Survey
22	3/09/2017	16	36	27	South/Trevo/Arus Bale	Survey
23	7/10/2017	7	14	11	South/Trevo/Arus Bale	Survey

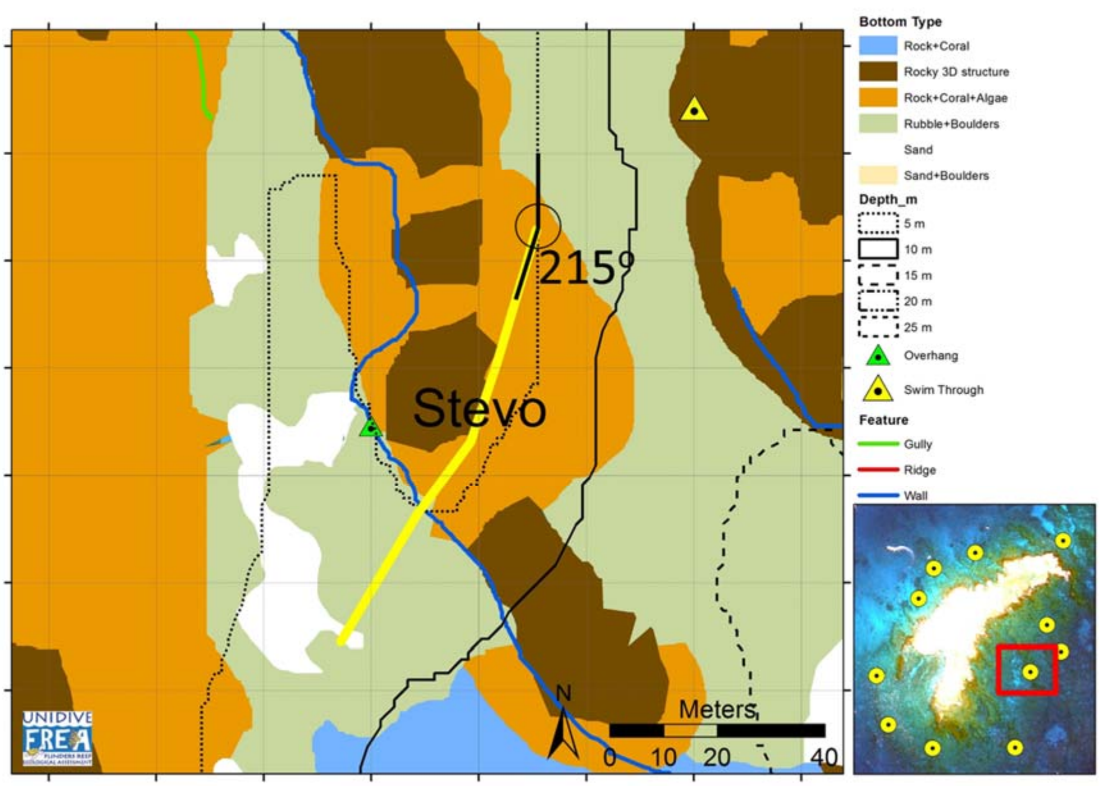
	Dive Days	Number Dives	Bottom Time (hr)
Training	4	176	132
Survey	10	239	179
Mapping	9	146	110
Total	**23**	**561**	**421**

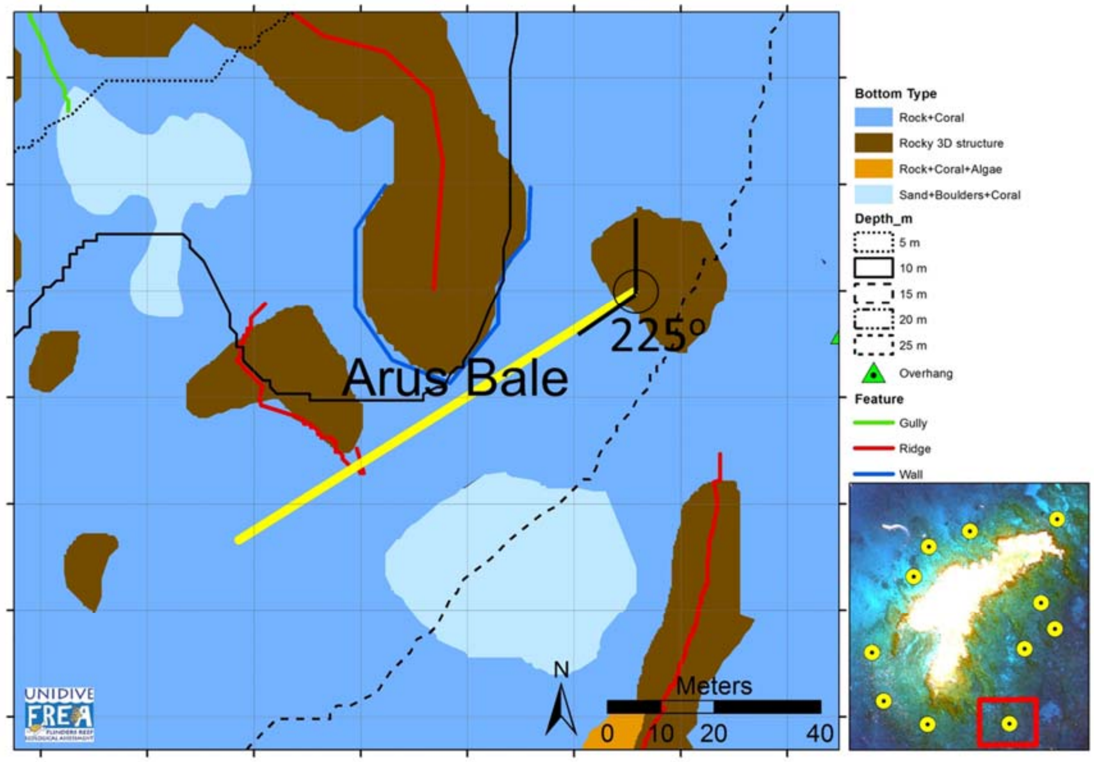
Appendix D: Transect Locations

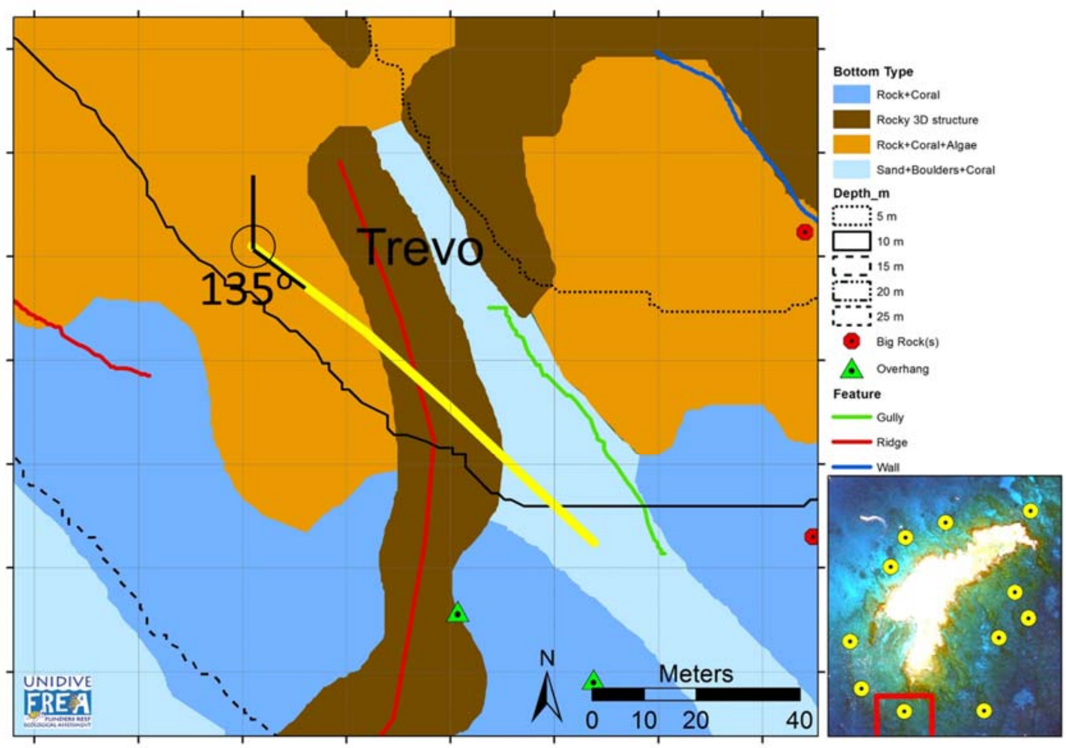


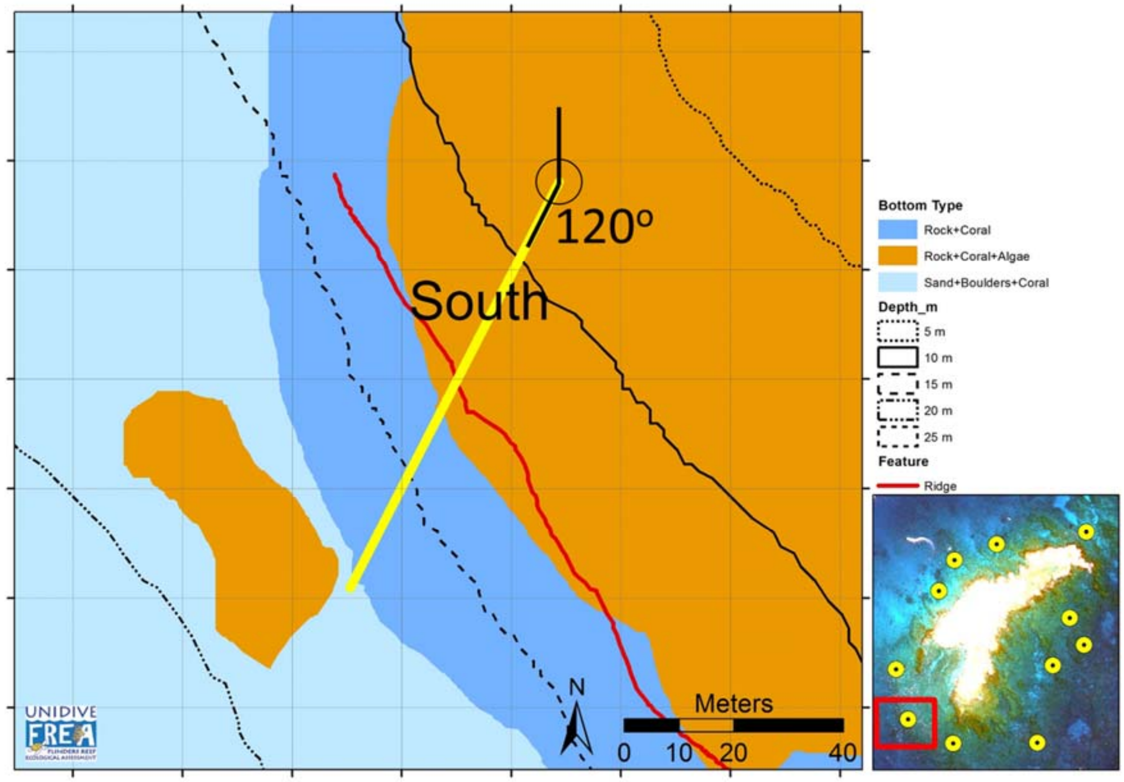


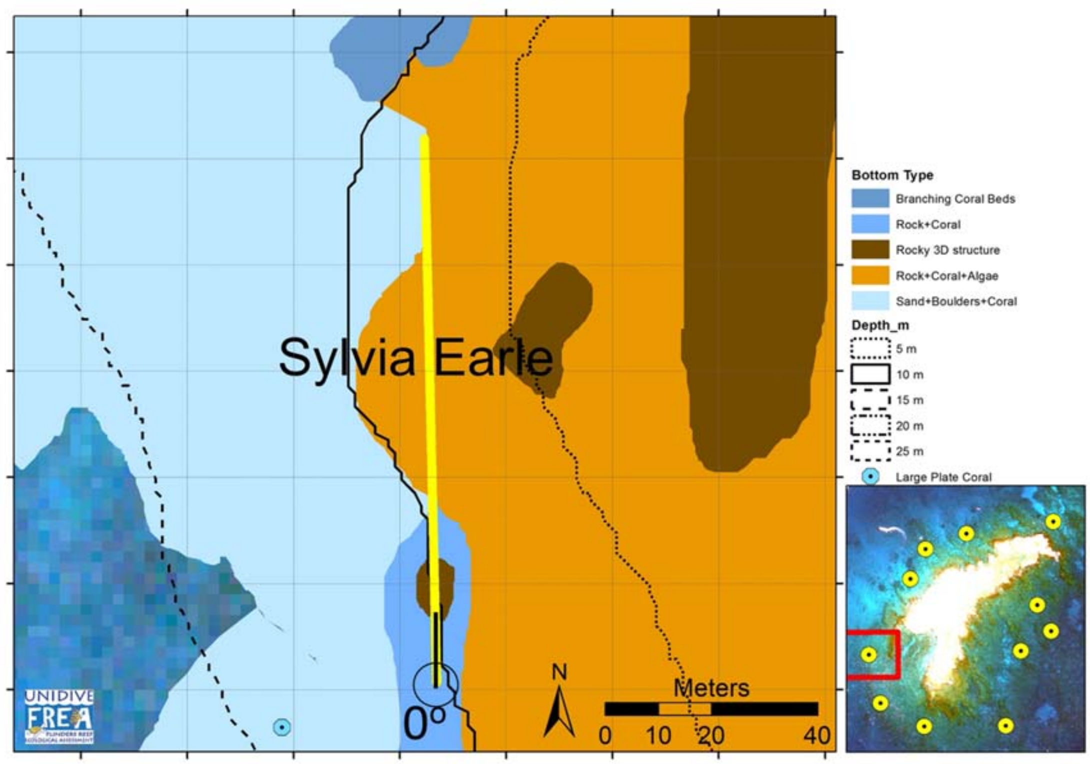

Rocky 3D structure
Rock+Coral+Algae
Rubble+Boulders
Sand
Sand+Boulders
Sand+Boulders+Coral
Depth_m
5 m
10 m
15 m
20 m
25 m
Mooring
Cave
Swim Through
Feature
Ridge
Wall
Alden
0°
N
Meters
0 10 20 40
UNIDIVE FREA

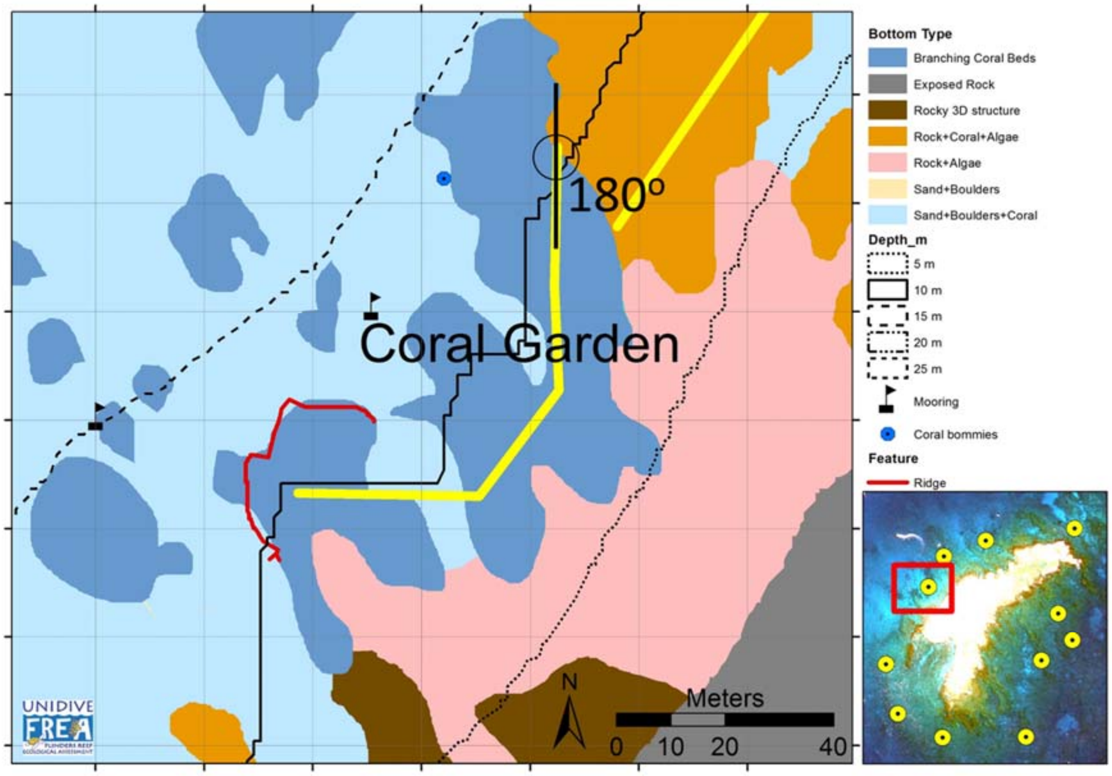

Bottom Type
Rock+Coral
Rocky 3D structure
Rock+Coral+Algae
Rubble+Boulders
Sand
Sand+Boulders
Depth_m
5 m
10 m
15 m
20 m
25 m
Overhang
Swim Through
Feature
Gully
Ridge
Wall
Stevo
215°
N
Meters
0 10 20 40
UNIDIVE FREA

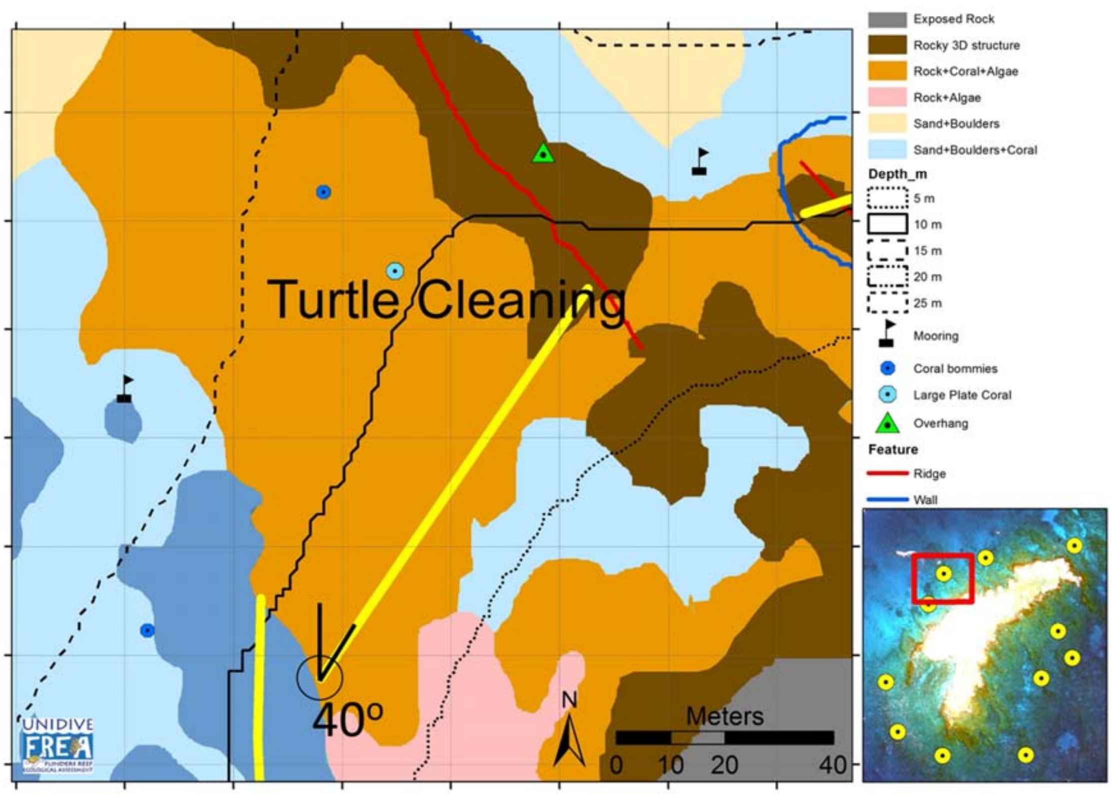

Arus Bale
225°
Bottom Type
Rock+Coral
Rocky 3D structure
Rock+Coral+Algae
Sand+Boulders+Coral
Depth_m
5 m
10 m
15 m
20 m
25 m
Overhang
Feature
Gully
Ridge
Wall
N
Meters
0 10 20 40
UNIDIVE FREA

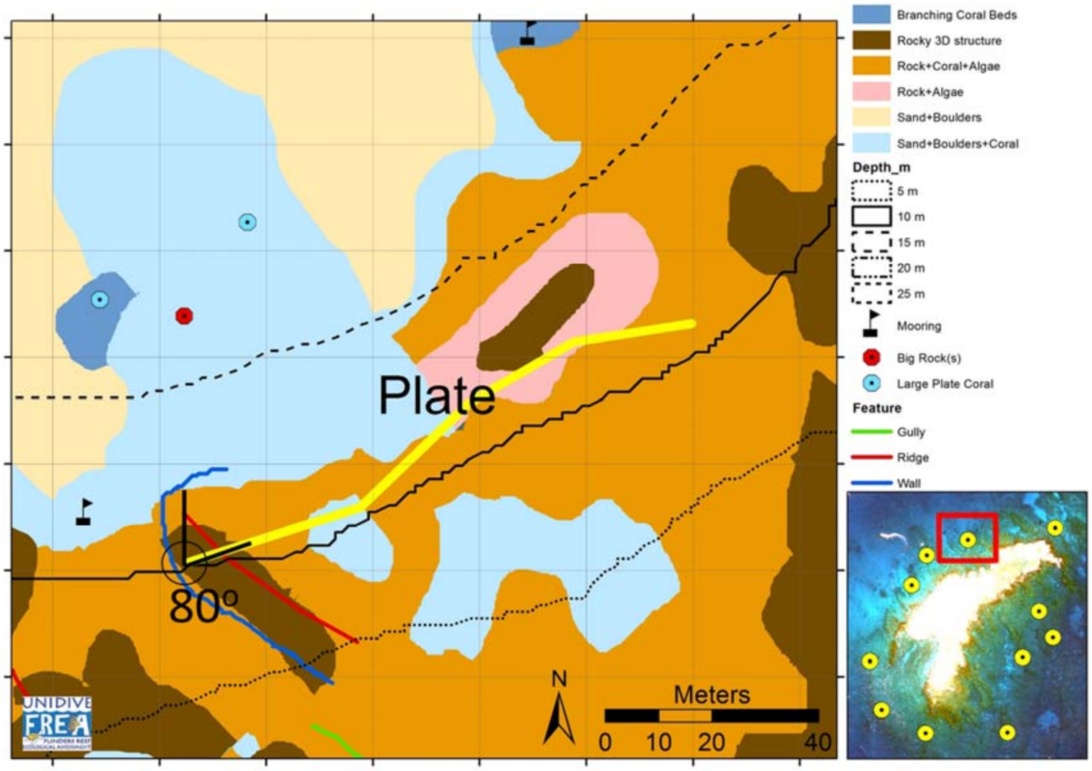

Trevo
135°
Bottom Type
Rock+Coral
Rocky 3D structure
Rock+Coral+Algae
Sand+Boulders+Coral
Depth_m
5 m
10 m
15 m
20 m
25 m
Big Rock(s)
Overhang
Feature
Gully
Ridge
Wall
N
Meters
0 10 20 40
UNIDIVE FREA


120º
South
Bottom Type
Rock+Coral
Rock+Coral+Algae
Sand+Boulders+Coral
Depth_m
5 m
10 m
15 m
20 m
25 m
Feature
Ridge
N
Meters
0 10 20 40
UNIDIVE
FREA


Sylvia Earle
0º
Bottom Type
Branching Coral Beds
Rock+Coral
Rocky 3D structure
Rock+Coral+Algae
Sand+Boulders+Coral
Depth_m
5 m
10 m
15 m
20 m
25 m
Large Plate Coral
N
Meters
0 10 20 40
UNIDIVE
FREA


Bottom Type
Branching Coral Beds
Exposed Rock
Rocky 3D structure
Rock+Coral+Algae
Rock+Algae
Sand+Boulders
Sand+Boulders+Coral
Depth_m
5 m
10 m
15 m
20 m
25 m
Mooring
Coral bommies
Feature
Ridge
180°
Coral Garden
Meters
0 10 20 40
N
UNIDIVE
FREA

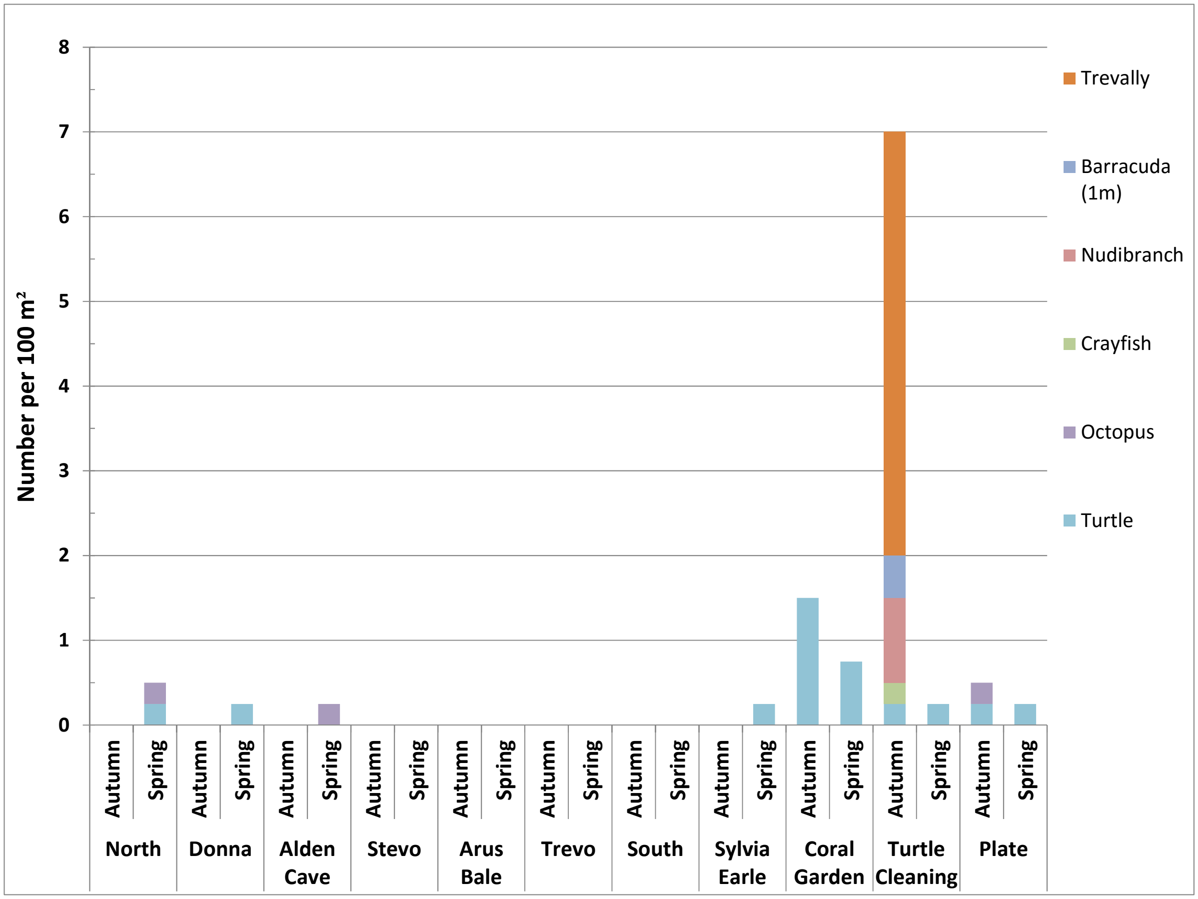

Exposed Rock
Rocky 3D structure
Rock+Coral+Algae
Rock+Algae
Sand+Boulders
Sand+Boulders+Coral
Depth_m
5 m
10 m
15 m
20 m
25 m
Mooring
Coral bommies
Large Plate Coral
Overhang
Feature
Ridge
Wall
Turtle Cleaning
40°
Meters
0 10 20 40
N
UNIDIVE
FREA


Branching Coral Beds
Rocky 3D structure
Rock+Coral+Algae
Rock+Algae
Sand+Boulders
Sand+Boulders+Coral
Depth_m
5 m
10 m
15 m
20 m
25 m
Mooring
Big Rock(s)
Large Plate Coral
Feature
Gully
Ridge
Wall
Plate
80º
N
Meters
0 10 20 40
UNIDIVE
FREA

Appendix E: Transect Coordinates

Site order clock wise	LatWGS84	LongWGS84
North	-26.9762411	153.4882308
Donna	-26.9785476	153.4877905
Alden Cave	-26.9792699	153.4881746
Stevo	-26.9798167	153.4873367
Arus Bale	-26.9818838	153.4869192
Trevo	-26.9819093	153.4846653
South	-26.9812589	153.4834533
Sylvia Earle	-26.9799209	153.4831341
Coral Garden	-26.9778264	153.4842843
Turtle Cleaning	-26.9770000	153.4846961
Plate	-26.9765690	153.4858299

Appendix F: Rare animals at Flinders Reef



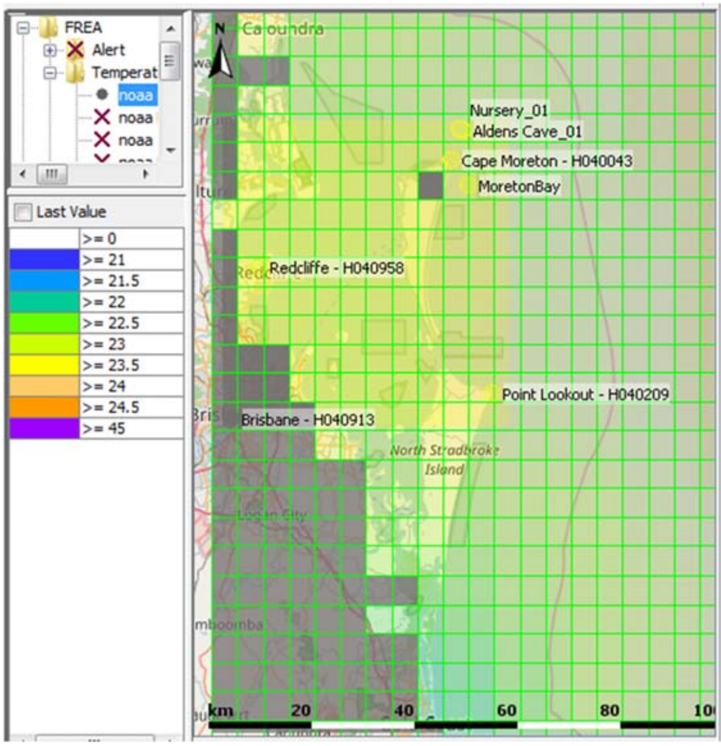
Number of rare animals per 100 m² at Flinders Reef study sites during autumn and spring surveys in 2017.

Appendix G: Collected daily weather observations

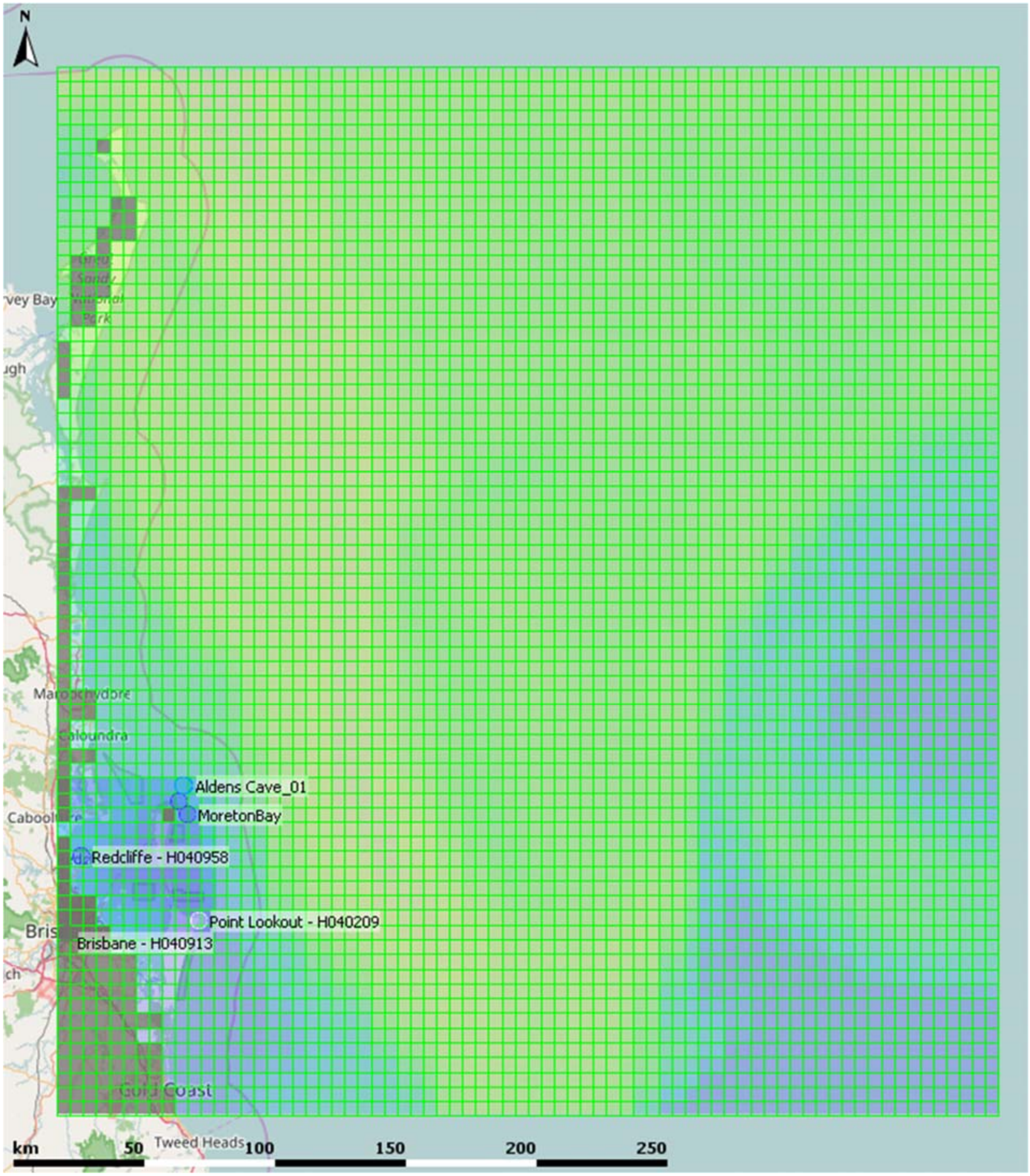
Collected daily weather observations for 2015-12-01 until 2017-08-31.

	Cape Moreton lighthouse	Point Lookout	Redcliff	Brisbane & Brisbane Aero
BoM station number	040043	040209	040958	040913 & 040842 (Aero)
Minimum temperature (− C)	X	X	X	X
Maximum temperature (− C)	X	X	X	X
Rainfall (mm)	X	x	X	X
Evaporation (mm)				Aero
Sunshine (hours)				Aero
Direction of maximum wind gust	X		X	X
Speed of maximum wind gust (km/h)	X		X	X
Time of maximum wind gust	X		X	X
9am Temperature (− C)	X	X	X	X
9am relative humidity (%)	X	X	X	X
9am cloud amount (oktas)		X		Aero
9am wind direction	X	X	X	X
9am wind speed (km/h)	X	X	X	X
9am MSL pressure (hPa)	X		X	X
3pm Temperature (− C)	X		X	X
3pm relative humidity (%)	X		X	X
3pm cloud amount (oktas)				Aero
3pm wind direction	X		X	X
3pm wind speed (km/h)	X		X	X
3pm MSL pressure (hPa)	X		X	X

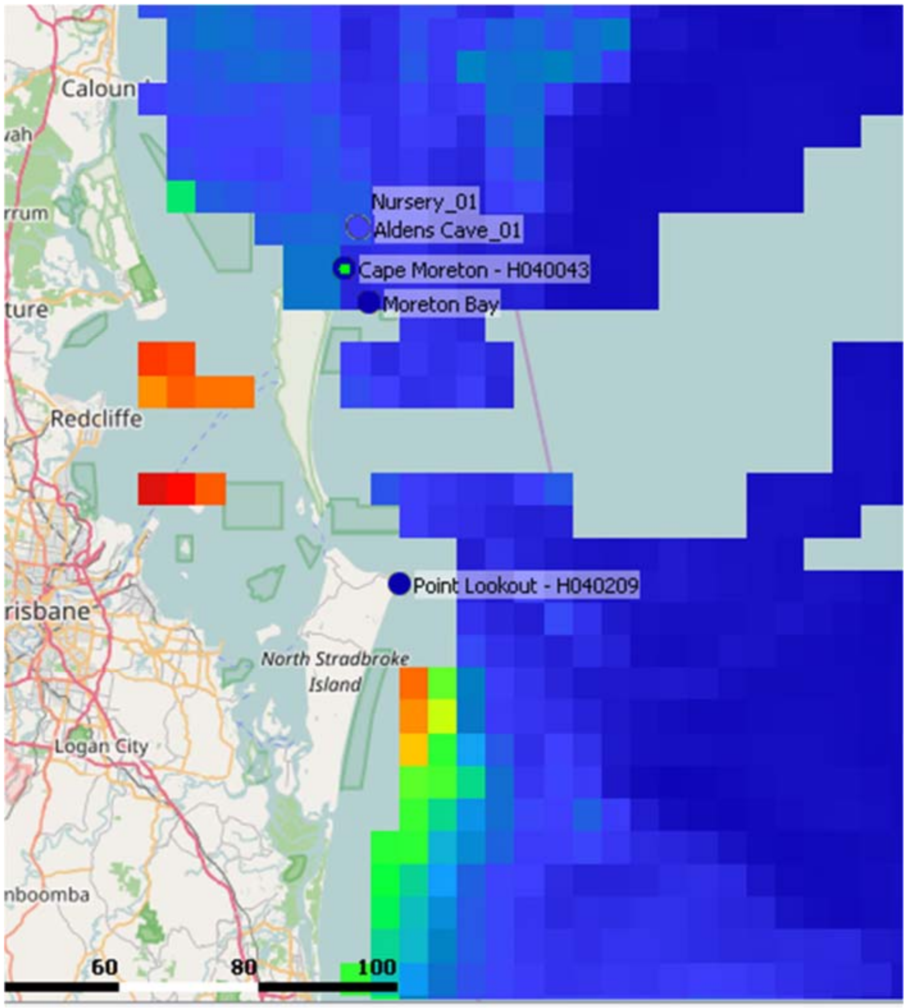
Appendix H: Observed Sea Surface Temperature and Sea Surface Chlorophyll



Observed Sea Surface Temperature (SST) based on processed satellite data for a cut out of approximately 300 x 300 km of the global data sets from NOAA (source: Liu et al. 2014). For the marked locations, scalar time series have been extracted for analysis.

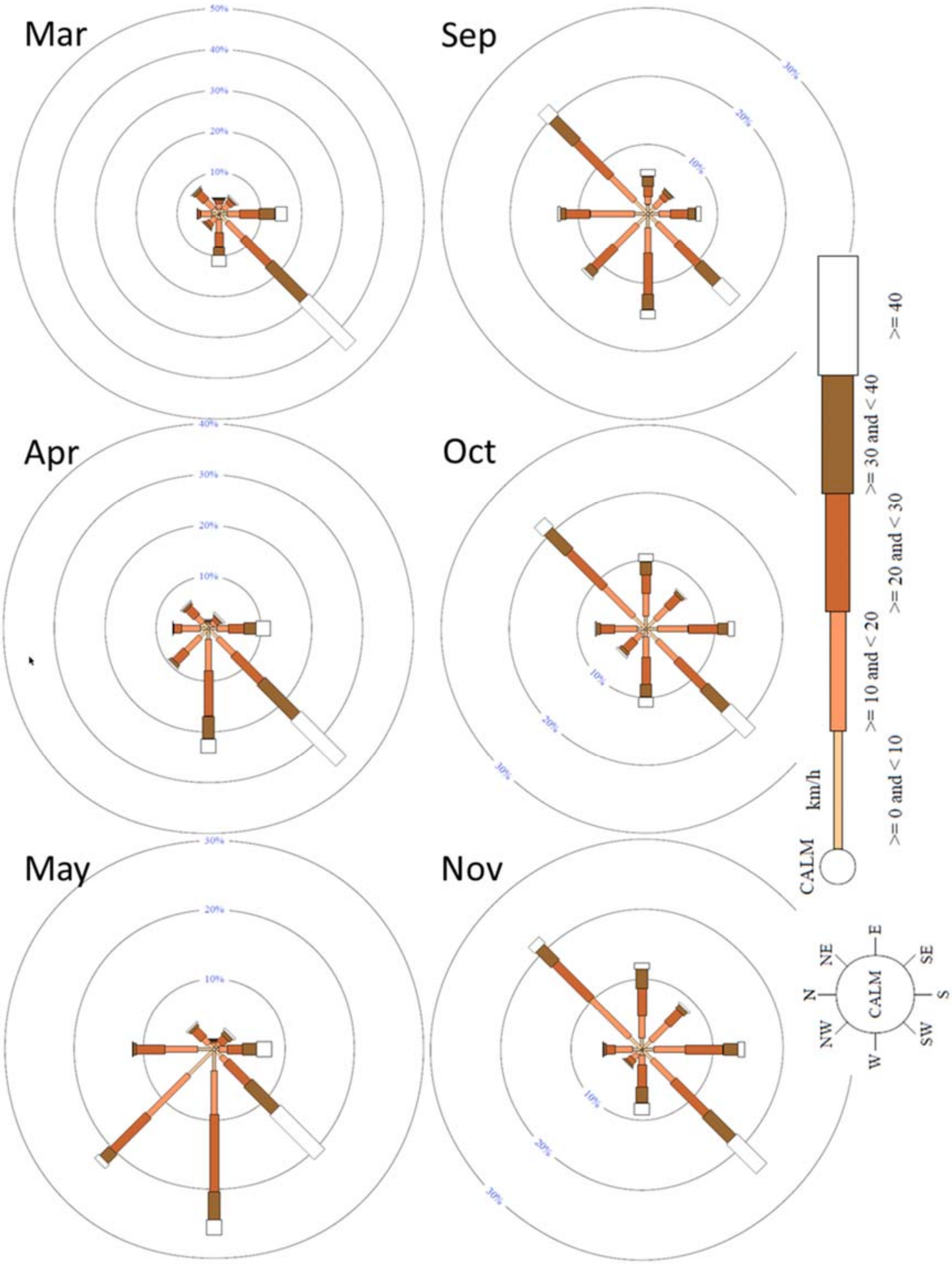


Observed Sea Surface Temperature (SST) based on processed satellite data for a cut out of the global data sets from NOAA (source: Liu et al. 2014). Each grid cell is approximately 5 km x 5 km.

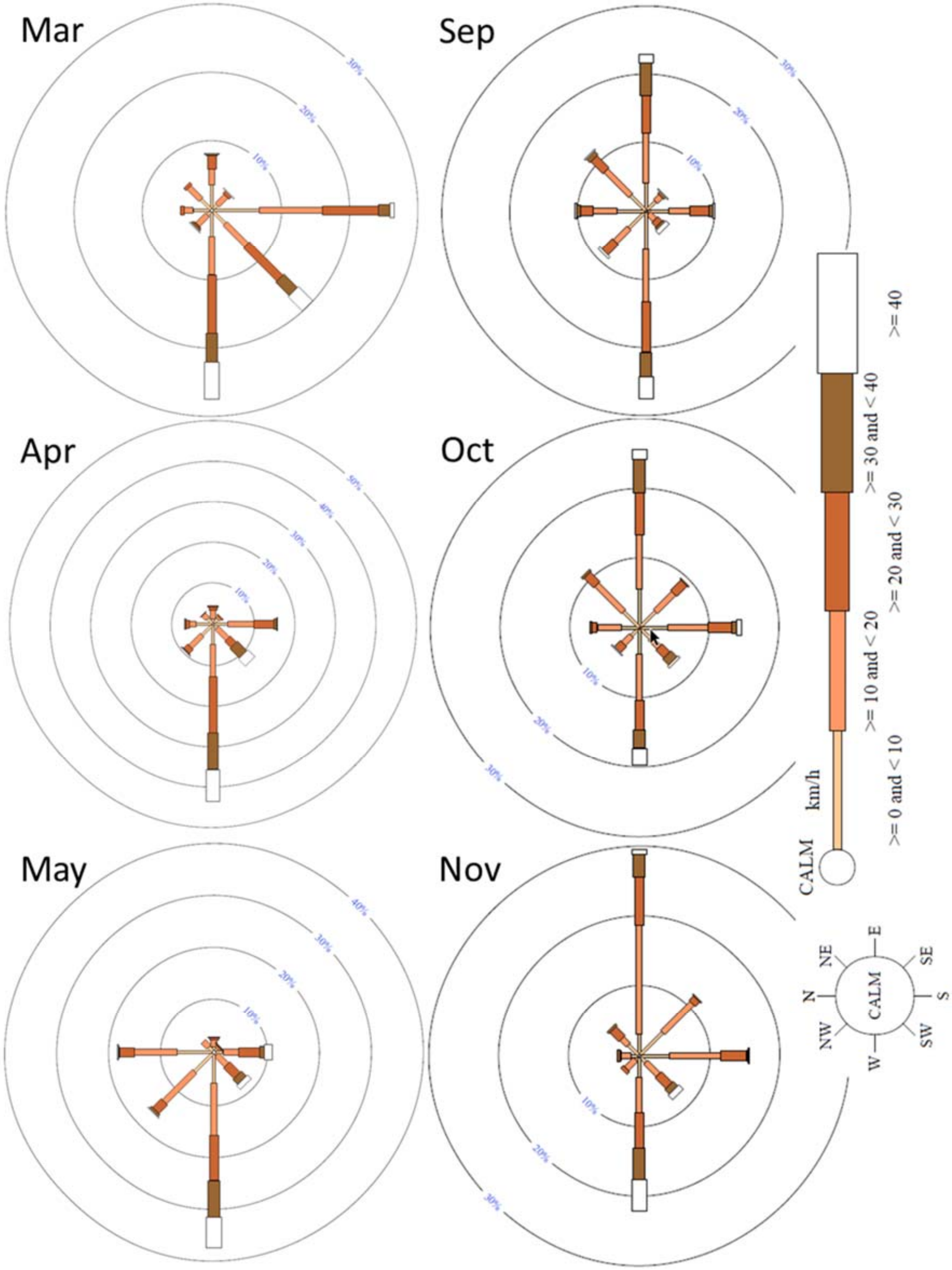


Observed daily average chlorophyll (Sea Surface Chlorophyll) concentration based on processed satellite data for a cut out of the global data sets from NASA (source: Nasa 2017). For the marked locations, scalar time series have been extracted for analysis.

Appendix I: Monthly Wind Roses



9 AM wind roses at Cape Moreton Lighthouse averaged per month over the period 01-01-1957 to 12-08-2017. Left: autumn (Mar-May), right: spring (Sept-Nov) (Source: http://www.bom.gov.au/climate/data/).



9 AM wind roses at Point Lookout averaged per month over the period 01-01-1957 to 12-08-2071. Left: autumn (Mar-May), right: spring (Sept-Nov) (Source: http://www.bom.gov.au/climate/data/).

This study was possible by the support and assistance of the following contributing agencies and organisations:

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