



INSTITUTE FOR
MARINE RESEARCH
DAUIN · PHILIPPINES

DAUIN SUR REEF
(Poblacion I)

STATUS REPORT

2019





INSTITUTE FOR
MARINE RESEARCH
DAUIN · PHILIPPINES

DAUIN SUR REEF
(Poblacion I)

STATUS REPORT

2019

DISCLAIMER

The research reported herein is based on initial analyses of complex datasets as part of the Dauin Reef Long Term Monitoring Project, and should not be considered definitive in all cases. Institutions or individuals interested in the results or applications of the Institute for Marine Research are invited to contact the Director at the Dauin address below.

For additional copies of this report, please phone IMR on (+63) 917 110 0421 or write to us at info@institutemarinereserch.org

This report, along with a range of information about IMR, is available online at www.institutemarineresearch.org

© Institute for Marine Research

Institute for Marine Research
Tugawe, Municipality of Dauin
6217, The Philippines

Front Cover: Poblacion Marine Reserve, Dauin, The Philippines. Image: Tracey Jennings

Full report written by:

Chelsea Waters
Director, Institute for Marine Research
chelsea@institutemarineresearch.org

Oscar Crehan
Head of Science, Institute for Marine Research
science@institutemarineresearch.org

Gabriela Saldanha Blackwood
Research Fellow, Institute for Marine Research

EXECUTIVE SUMMARY

The world's coral reefs are being severely degraded by the activities of humans, and the need to reduce local threats to offset the effects of increasing global pressures is now widely recognized. Major anthropogenic risk factors include mortality and reduced growth of reef-building corals due to their high sensitivity to rising seawater temperatures, ocean acidification, deteriorating water quality, destructive fishing, over-exploitation of key marine species, and the direct devastation of coastal ecosystems through unsustainable coastal development^{38,50}. These anthropogenic risks interact with other large-scale acute disturbances, including tropical storms and population outbreaks of the corallivorous crown-of-thorns starfish (COTS) *Acanthaster planci*, which may also increase in frequency and intensity in response to human activities. Regional policies can no longer protect reefs from global-scale devastation due to climate change-associated heat stress and intensifying tropical storms³⁸. Efforts are therefore shifting toward management of local and regional anthropogenic pressures to strengthen reef resilience. However, assessment of the likely effectiveness of reductions of local anthropogenic pressures requires a sound understanding of the processes that determine ecosystem trajectories.

The Philippines, represents a particularly relevant case to investigate ecosystem trajectories. Over 7,100 islands dominate the Philippine archipelago, which is located within the heart of the incredible biological diversity that is the 'Coral Triangle'. Boasting 76% of the world's total coral species and 37% of the reef fishes of the world³⁹, this incredible biological diversity of the Coral Triangle is associated with some of the highest human population densities and growth rates in the world⁵⁰. Changes to the health of coastal ecosystems are exposing

coastal populations to the erosion of food security and income, deteriorating coastal protection and other challenges. They are affecting people who are already impoverished and are among the least able to respond to the changes that are occurring in their environment⁵⁰. Reef fisheries have estimated to directly contribute to 15 – 30% of the Philippines total known national municipal fisheries (obtained from licenses issued through local-government areas), with nearly 70% of the protein food intake being fish. The stark contrast between poverty, hunger and deprivation amidst this increasing want is rapidly declining reef resources. It is therefore no surprise that it is in the Philippines that reefs are at the highest risk from overexploitation, destructive fishing and other human related impacts such as coastal development and sedimentation. If these processes are allowed to continue, these changes will exacerbate poverty and social instability within the region, with wider consequences for the region and the world. It is imperative that we address the core issue of anthropogenic climate change whilst at the same time addressing the key threats that are rising from local stressors.

ABBREVIATIONS

ABBREVIATION	TERM IN FULL
1-D	Simpsons Index of Diversity
2D	2-Dimensional
3D	3-Dimensional
AIMS	Australian Institute of Marine Science
BBD	Black Band Disease
BrBD	Brown Band Disease
CPCe	Coral Point Count with Excel Extension
COTS	Crown of Thorns Starfish
DEM	Digital Elevation Model
HYP	Hyperplasia
IMR	Institute for Marine Research
LTRMP	Long Term Reef Monitoring Project
NEO	Neoplasia
PP	Porites Pinking
S	Species Richness
SCUBA	Self Contained Underwater Breathing Apparatus
SE	Standard Error
SEB	Skeletal Eroding Band
SfM	Structure from Motion
SVS	Stereo Video System
UVC	Underwater Visual Census

TABLE OF CONTENTS

1. INSTITUTE FOR MARINE RESEARCH	7
2. A MESSAGE FROM THE DIRECTORS	8
3. METHODOLOGY	9
3.1 SURVEY SITES	9
3.2 RESEARCH TECHNIQUES	10
3.2.1 3-DIMENSIONAL REEF MODELLING	10
3.2.2 DIVER OPERATED STEREO VIDEO SYSTEM	11
3.2.3 BENTHIC ASSAYS	11
3.2.4 SCUBA SEARCH	12
4. RESULTS	13
4.1 BENTHIC COVER	13
4.2 REEF IMPACTS & CORAL MORTALITY	13
4.3 FISH	14
4.4 REEF COMPLEXITY	14
5. DISCUSSION	16
6. REFERENCES	18

1. INSTITUTE FOR MARINE RESEARCH

The Institute for Marine Research (IMR) is a grassroots non-profit organization that conducts long-term and fine-scale research on coastal marine ecosystems, using this scientific evidence to educate, transform and encourage locally led marine conservation strategies within the Municipality of Dauin.

The Institute will deliver the science to help realize three key long-term impacts for the Municipality:

1. Improve the health and resilience of marine and coastal ecosystems across the Municipality
2. Ensure economic, social and environmental net benefits for Dauin's marine industries and coastal community
3. Protect Dauin's coral reefs and other tropical marine environments from the effects of climate change and coastal development

The Dauin *Long-Term Reef Monitoring Project (LTRMP)* was established by IMR in February 2019 to track fine-scale changes in the overall reef community of Dauin's fringing reef system, and realize the three key long-term impacts for the Municipality. More specifically, the aims of the Dauin *LTRMP*:

1. Understand how benthic composition (measured as percentage cover, species diversity indices, species abundance, structural complexity, slope and rugosity) influences fish community structure (measured through biomass, species abundance, trophic groups, and species diversity indices)
2. Document the effect of disturbances such as *Acanthaster planci* (Crown of Thorns Starfish, COTS) and *Drupella* spp. outbreaks, typhoons, and

bleaching events. The data will also provide awareness of other threats to the reef (such as coral disease, human activity, illegal poaching, high nutrient outflow, trash) that will be of concern to reef managers

3. Document the effects of temperature, changing light regimes, dissolved oxygen, and pH on the seasonal and annual variability of Dauin's fringing reef

All results collected as part of the *LTRMP* will be used to:

- a) Publish and present annual Outlook reports to policy-makers within the Local Government Unit (LGU)
- b) Determine 'areas of concern' with regards to unsustainable practices occurring within the Municipality
- c) Publish findings on a wider scientific platform to expand our current knowledge of coral reef ecosystems

2. A MESSAGE FROM THE DIRECTORS



What an action-packed and rewarding start to our first research season here in the Philippines! With 19 research sites within the Municipality of Dauin, we have this reef system well monitored!

With that being said, these results are just the beginning.

We have a long road to go with deepening our research to understand the resiliency state of our reef system towards the threats and challenges associated with our changing climate. On a localised platform, our results are catching a glimpse of the negative, human-induced practices that are exacerbating coral mortality within the region.

Our first step towards reef conservation is awareness and partnership. We are proudly partnering not only with Dauin's Local Government Unit (LGU), but with various local resorts, NGOs and other local stakeholders who wish to share our common goal of preserving Dauin's coastal ecosystem.

We would also like to take this opportunity to say how proud and thankful we are of our Research Assistants and Fellows who have not only assisted the Institute in meeting our seasonal research objectives, but for everything that comes both afterwards and in-between. From the months of data analysis, to the weeks of interpretation of findings into site reports. From creating school lesson plans, and environmental awareness initiatives. You have helped to take IMR to a whole new level. Our heartfelt thanks to you all.

- Chelsea Waters & Rafael Manrique

3. METHODOLOGY

3.1 SURVEY SITES

Dauin is a fourth class Municipality in the province of Negros Oriental, Philippines. The Municipality stretches across nine kilometres of coastline, bordered in the north by Bacong, and Zamboanguita in the south. Nineteen core sites were selected for seasonal and annual monitoring. These sites span the variation in the coral reef composition of benthic and fish communities across the Municipality, and account for the zoning history of its associated no-take marine protected areas. The nineteen core sites consist of fifty metre transects that are laid out parallel to the reef crest, between

depth ranges of 1 – 6 metres and 7 – 12 metres. Surveys are conducted bi-annually to account for seasonal variability, with “dry” season surveys running from February to July, and “wet” season surveys running from August to January. Sites will be surveyed at the same time each year.

Dauin Sur reef is located within Barangay Poblacion I. Four fifty metre replicates (n = 4) were conducted between the months of February and July.

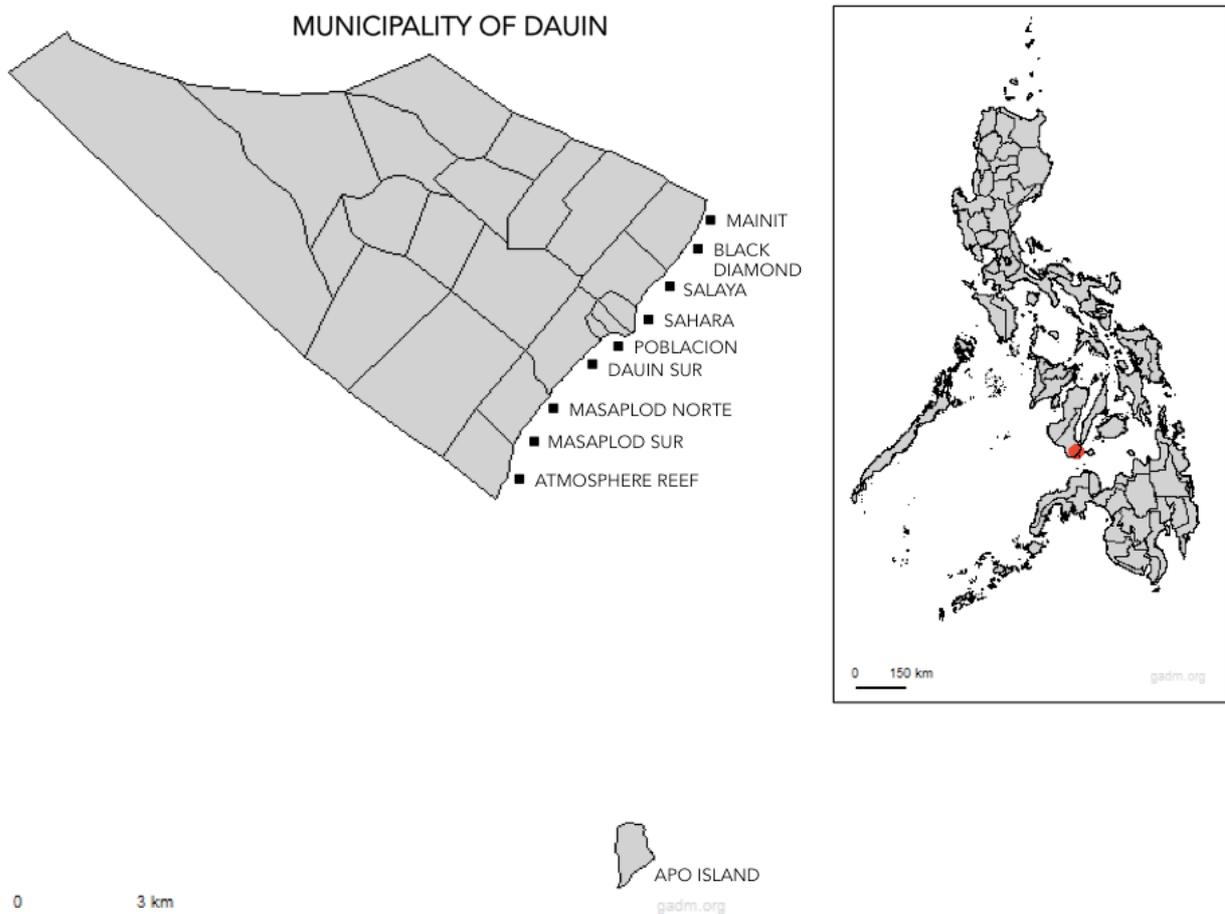


Figure 3.1. Location of the Municipality of Dauin and IMRs survey sites on Negros Oriental, the Philippines. Maps sourced from GADM database of Global Administrative Areas (2015) under a CC BY licence, used with permission.

3.2 RESEARCH TECHNIQUES

3.2.1 3-Dimensional Reef Modelling

A 3D camera rig consisting of two *GoPro Hero 5 Black* cameras attached to a one-metre long aluminium pole is assembled. The cameras are placed 90 centimetres apart, having one on each end of the pole⁴⁴. The cameras are placed in a downward facing position at the beginning of the 50 metres. The aim of the diver is to get over 60% overlap from pictures to ensure they can be aligned,

with preliminary testing indicating this method decreases alignment errors over single passes or higher image intervals⁵⁹. The rig is kept approximately 2 meters above the substrate with the cameras always aimed straight down at the substratum, the lens moving in one plane rather than following the contours of the scene⁶². A lawnmower pattern is conducted at a steady pace, 1 metre either side of the transect.

Introduction to 3-Dimensional Reef Modelling

Structural complexity is a key habitat feature that influences ecological processes by providing a set of primary and secondary resources to organisms, such as shelter from predators and availability of food. The spatial configuration and morphology of corals create complex structures that serve as habitats for a large number of species inhabiting coral reefs. As such, structural complexity of coral reefs drives numerous functions directly linked to the resilience of these ecosystems^{41,66}.

Despite the importance of reef structure in the long-term functioning of these systems, quantifying its complexity is a time-consuming exercise. Therefore, advancing our understanding of how structural complexity influences reef dynamics requires improving our efficiency and ability to quantify multiple metrics of 3D structural complexity in a repeatable way, across spatial extents, whilst maintaining a high resolution.

IMR researchers are making use of rapid advances in technology to monitor reef structural complexity by recreating and measuring reefs in 3D. Using off-the-shelf cameras, the 3D structure of the reef is accurately reconstructed by underwater images taken at pace across a reef transect. These images are aligned and referenced using a technique called photogrammetry, which allows the recovery of the exact position of each pixel in the images, recreating the 3D structure of the reef^{40,41}.

These 3D models are produced at scale, allowing IMR scientists to measure different attributes associated with the structural complexity of coral reefs, such as surface complexity (3D/2D surface area), curvature, volume and slope, across large extents in a fraction of the time that takes to do it underwater. With the advances in photogrammetry software and high performance computing hardware, automated analyses of structural complexity across all IMR-monitored reefs in Dauin is now possible and at a minimal cost. Characteristics of the reef surface are believed to play an important part in the early life of corals and subsequent reef recovery. We can now measure things we could never measure before, including being able to see how complex the surface of the reef is.

3.2.2 Diver Operated Stereo Video System

Transects are conducted using a diver-operated Stereo-Video System (SVS; SeaGIS, Melbourne, Australia), comprised of two GoPro Hero 5 Black video cameras. Transects are 50 metres long following the reef contour. Surveys are conducted by two people; the SVS operator and a second diver responsible for distance measurements. To minimise potential disturbance to the fish community, cameras are set to record and synchronised prior to entry. Transects begin with the cameras pointing vertically down. The SVS operator is alerted via a fin tug to indicate the start of the transect. At this point cameras are now pointed along the reef, with another fin tug indicated the end of the transect after a further 50 metre. Cameras are angled approximately

20° downwards, and kept approximately 0.5 metres above the substrate, filming the reef scape along the transect. Transects take approximately 5 - 6 minutes to film using SCUBA. Footage is analysed in EventMeasure software v3.51 (SeaGIS, Melbourne, Australia) allowing the calibrated SVS footage to be synchronised and fish total lengths to be measured. EventMeasure also resolves centre points of each individual fish encountered into distances on a three-dimensional coordinate system, allowing the exclusion of fish outside 2.5 metres either side and 5 metres in front of the camera system. Side distance restrictions maintains a consistent belt along the transect, while a front distance restriction prevents variations in visibility (e.g. turbidity, light intensity) from influencing data.

Introduction to the Diver Operated Stereo Video System

Understanding of fish ecology, and our ability to effectively manage fish populations requires accurate data on diversity, abundance and size. Underwater visual census (UVC) surveys have been a widely used method to collect data on coastal fish assemblages. UVC requires divers to identify and count fishes within a predetermined area, or by distance-based sampling. This is a logistically simple, non-destructive, and cost-effective method of surveying fish. However, the effectiveness of UVC for reliable long-term monitoring is influenced by inter-observer variability and inaccuracies in estimating the length of fish and sampling areas. In addition, a combination of the identification, counting and size estimations of fish requires extensive training and experience.

IMR utilises a Diver Operated Stereo Video System, an innovative technology which allows our researchers to not only record fish species with more precision and accuracy than the traditional Underwater Visual Census (UVC) techniques, but efficiently quantifies the abundance and size of reef fish^{67,68}. Rather than relying on in situ identification and length estimates, collected video data can be annotated in the lab reducing time in the field and/or enabling greater spatial coverage.

3.2.3 Benthic Assays

Benthic surveys of stationary benthic organisms are conducted following the technique of the Australian Institute of Marine Science (AIMS) LTMP. Benthic

surveys are conducted along the transect line. At each site, single frames are shot at 1 metre intervals using a GoPro camera. Fifty still frames are shot along each 50 metre transect, with the camera held approximately 50 centimetres above the

substrate. Photographs are analysed through the use of CPCe software by Kohler and Gill (2006). Underwater photographic frames are overlaid by a matrix of randomly distributed points. In this case, thirty random points are overlaid and generated in the whole frame of each photo and used for identification. Point overlay is used to characterise the benthos, and estimate percentage type of organism and substrate in the image⁴⁶. The species code data for each frame is stored in a .cpc file which contains the

image filename, point coordinates and the identified data codes. The data from individual frames can be combined to produce inter and intra transect and site comparisons via automatically generated Excel spreadsheets. For each category of benthic organism, the mean values for percent cover at each site are used to estimate seasonal and temporal trends in cover of benthic organisms at each site, zone, and throughout the municipality as a whole.

Introduction to Benthic Assays

With the world's coral reefs being severely degraded by the activities of humans, there is a need to efficiently assess and monitor reefs even at the regional and local level^{69,70}. Coral Point Count (CPCe) is a visual basic software designed to quickly and efficiently calculate statistical coral coverage over a specified area through the aid of photo-transects⁷¹. These transect images are assigned with spatial random points for user's further identification. It can also perform both image calibration and area analysis of the benthic features, and has the ability to automatically generate analysis in Microsoft Excel. Thus, CPCe is a highly significant useful tool, particularly in coral reef monitoring, assessment and conservation.

3.2.4 SCUBA Search

SCUBA searches are designed to provide a more detailed picture of the causes and relative scale of coral mortality, and are conducted following a modified version of AIMS LTMP. SCUBA searches are made along a fixed 50 m transect, with a 2 m belt (1 metre either side of the central tape measure). Numbers are recorded for

the following: crown-of-thorns starfish (COTS), COTS feeding scars, *Drupella* spp., *Drupella* spp. feeding scars, unknown scars, coral bleaching and coral disease (black band disease, white syndrome, brown band disease, porites pinking, skeletal eroding band disease, hyperplasia and neoplasia).

Introduction to Reef Impacts and Coral Mortality

SCUBA searches have been used by the LTMP to provide information on sources of coral mortality, which assist in examining the reef in greater detail and interpreting trends in benthic cover at permanent sites. SCUBA searches enable:

- I. The detection of low-level populations of COTS. At low densities they are cryptic and more difficult to detect by methodologies such as the manta tow.
- II. SCUBA searches provide a method for the detection of juvenile COTS, which because of their small size and cryptic behaviour, are not easily seen in benthic or 3-Dimensional modelling assays.
- III. SCUBA searches enable the diver to detect other factors that may be causing coral mortality such as *Drupella* spp., bleaching or disease (e.g. white syndromes and black band disease).

4. RESULTS

4.1 Benthic Cover

It was found that at Dauin Sur Reef, abiotic categories (rock, rubble and sand) were the most prevalent substrate types at 40% followed by coral (34%) and algae (9%) (fig. 4.1). A total of 31 Scleractinian coral genera were recorded across both survey depths, with Simpson's Index of Diversity (1-D) ranking this system at 8th within the Dauin inshore reef. Both diversity and richness indices favoured deeper depths (5m; S = 18, 1-D = 0.59) (10m; S = 28, 1-D = 0.8). Evenness of this coral spread also improved with depth (10m; J' = 0.71) (5m; J' = 0.54). *Porites* spp. was distinctively the most prevalent coral genus (16.7%), followed by *Pocillopora* spp. (4.02%) and *Fungia* spp. (2.08%) (fig 4.2).

4.2 Reef Impacts & Coral Mortality

Coral bleaching affected an average of 15% of the tissue of the affected colonies across 10 separate coral genera. Coral disease was also present within the surveyed space, with 1 count of white syndrome affecting *Porites* spp.

General and fishing trash was absent from this surveyed space (Table 1). One account of *Acanthaster plancii* (COTS) was recorded affecting 4 different coral genera, and an additional 2 counts of suspected feeding activities. 7 cases of *Drupella* spp. were recorded at Dauin Sur. Additional impacts recorded include 2 counts of coral damage due to direct destruction (e.g. damage inflicted by anchors or fins).

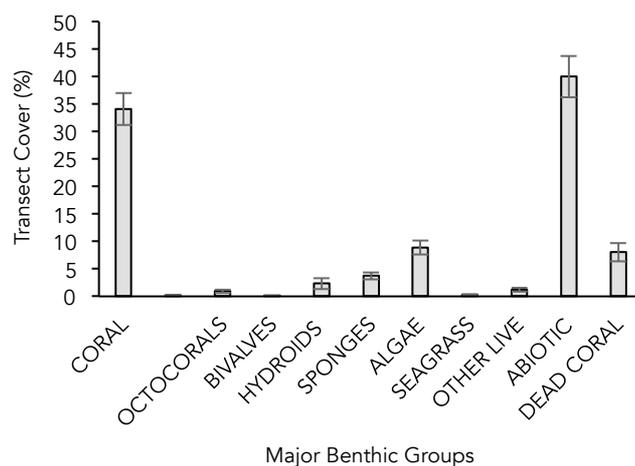


Figure 4.1 Average percentage cover of all major benthic categories with standard error (\pm SE) recorded at Dauin Sur reef during the dry season of February to July 2019.

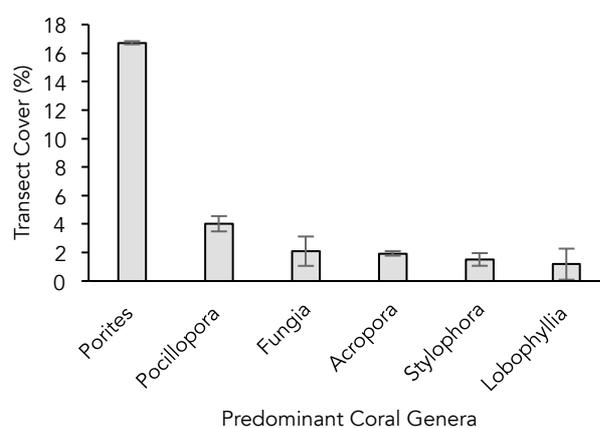


Figure 4.2 Average percentage cover of the five major coral genera with standard error (\pm SE) recorded at Dauin Sur reef during the dry season of February to July 2019.

Table 1. Reef impacts recorded at Dauin Sur reef during the dry season of February to July 2019 with ranking and trends.

Measurement	Current Value	Ranking	Last Season Value	Trend
Coral Bleaching (count/100m ²)	5	2 nd	n/a	n/a
Disease (incidences/100m ²)	1	2 nd	n/a	n/a
<i>Acanthaster plancii</i> (count/100m ²)	0.5	3 rd	n/a	n/a
<i>Drupella</i> spp. (count/100m ²)	1.75	2 nd	n/a	n/a
Trash (count/100m ²)	0	10 th	n/a	n/a

4.3 Fish

Dauin Sur reef recorded a total fish abundance of $n = 862$, an average species richness of $S = 48.5$, and a total biomass of $4.39 \text{ kg}/250\text{m}^2$. *Pomacentridae* (damselfish) had both the highest recorded abundance and species richness ($n = 639$, $S = 20$), followed by *Labridae* (wrasse) ($n = 104$, $S = 23$), and *Acanthuridae* (surgeonfish) ($n = 32$, $S = 3$).

Greatest biomass correlated with most abundant species present, as *Pomacentridae* (damselfish) and *Labridae* (wrasse) had the greatest biomass across survey depths. Grouping fish into trophic groups, collectively across depths, showed that invertivores to have the greatest biomass ($1.59 \pm 0.2 \text{ kg}/250\text{m}^2$) followed by planktivores ($1.2 \pm 0.055 \text{ kg}/250\text{m}^2$). Fish that fit within two trophic groups were counted separately in each group. Those within three or more groups were counted as omnivores (figure 4.4).

Commercially important families recorded at Dauin Sur reef include *Labridae* ($0.53 \text{ kg}/250\text{m}^2$), *Acanthuridae* ($0.48 \text{ kg}/250\text{m}^2$), *Lutjanidae* ($0.46 \text{ kg}/250\text{m}^2$), *Scaridae* ($0.42 \text{ kg}/250\text{m}^2$), *Serranidae* ($0.35 \text{ kg}/250\text{m}^2$) and *Mullidae* ($0.12 \text{ kg}/250\text{m}^2$). No *Haemulidae* (sweetlips) or *Lethrinidae* (emperor) were found across the transects.

4.4 Reef Complexity

Results from our 3-Dimensional reef reconstructions reveal an average rugosity index of 2.19, and a slope value of 0.0811. Figure 4.5 and 4.6 shows the rugosity and slope across the site.

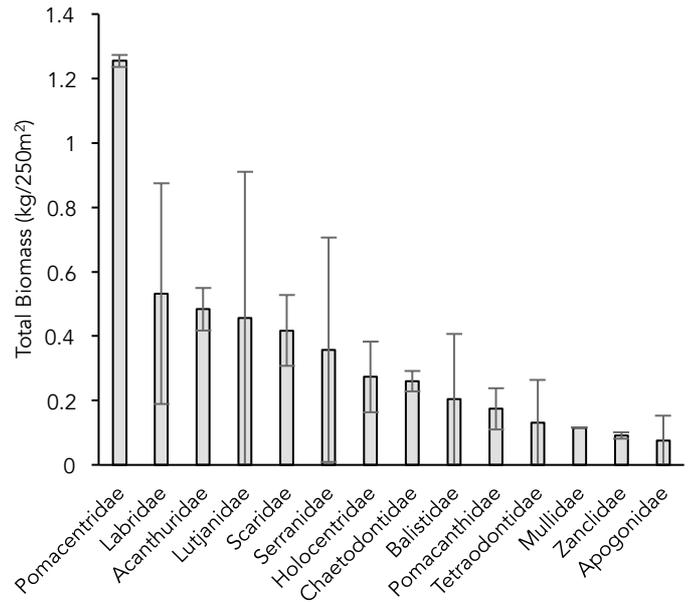


Figure 4.3 Total biomass ($\text{kg}/250\text{m}^2$) of fish families recorded at Dauin Sur reef during the dry season of February to July 2019.

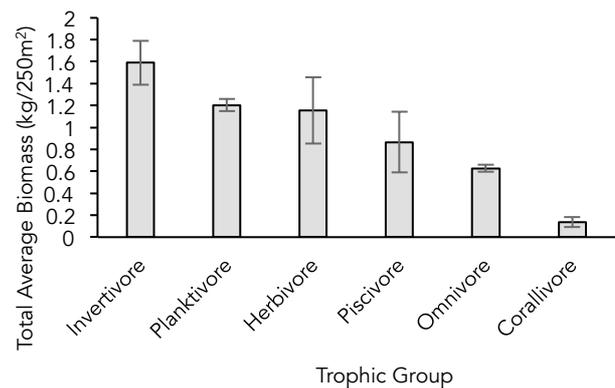


Figure 4.4 Total biomass ($\text{kg}/250\text{m}^2$) of fish trophic groups recorded at Dauin Sur reef during the dry season of February to July 2019.

Table 2. Summary of findings at Dauin Sur reef during the dry season of February to July 2019 with ranking and trends.

Measurement	Current Value	Ranking	Last Season Value	Trend
Coral Cover (%)	34.7	2 nd	n/a	n/a
Algal Cover (%)	8.86	4 th	n/a	n/a
Coral 1-D	0.7	8 th	n/a	n/a
No. of Fish (count/250kg ²)	431	3 rd	n/a	n/a
Fish Biomass (kg/250m ²)	4.39	7 th	n/a	n/a
Fish 1-D	0.9	4 th	n/a	n/a
Rugosity (RQ)	2.19	10 th	n/a	n/a

Figure 4.5 a) Average slope along the transect at 5m (replicate A). Scale is in mega pixels with 300MP being equal to 50 meters on the transect. b) Average rugosity along the transect at 5m (replicate A). Scale is in mega pixels with 300MP being equal to 50 meters on the transect. b) Digital Elevation Model (DEM) produced with SfM photogrammetry techniques at 5m (replicate A).

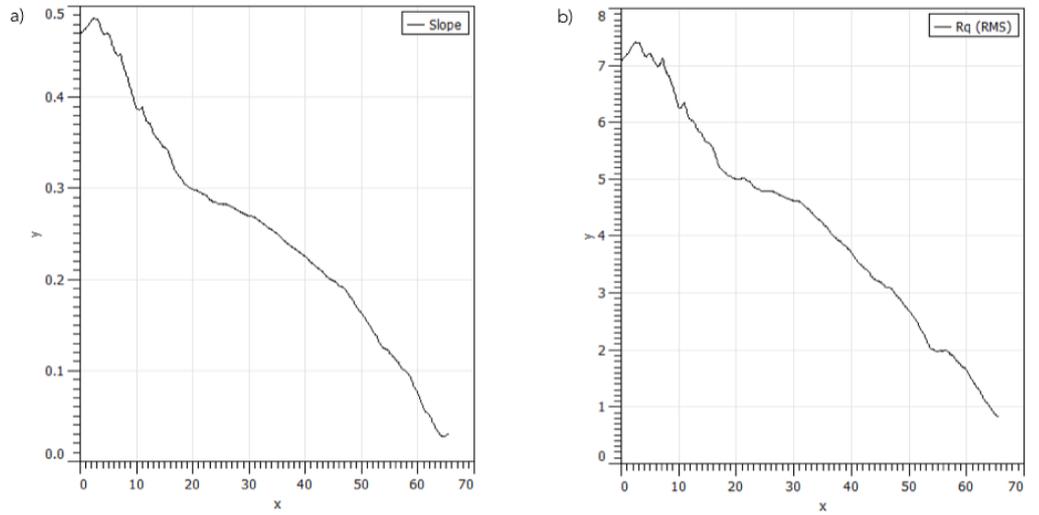
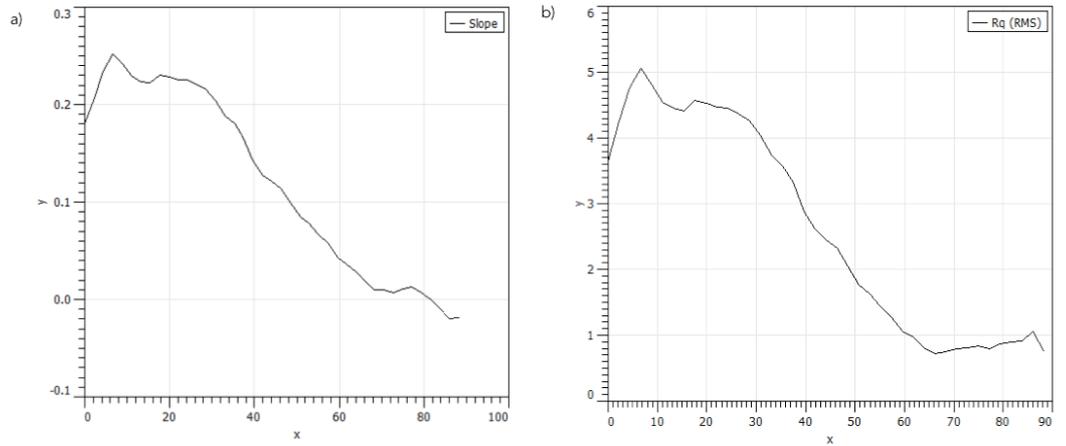


Figure 4.6 a) Average slope along the transect at 5m (replicate B). Scale is in mega pixels with 300MP being equal to 50 meters on the transect. b) Average rugosity along the transect at 10m (replicate B). Scale is in mega pixels with 300MP being equal to 50 meters on the transect. b) Digital Elevation Model (DEM) produced with SfM photogrammetry techniques at 10m (replicate B).



5. DISCUSSION

Coral cover at Dauin Sur is ranked 2nd out of all surveyed sites across the Dauin coast. This coral cover was dominated by corals from the genus *Porites* spp., reducing the overall coral diversity of this site. *Porites* spp. was primarily recorded in its branching form. This is a demonstration of *Porites* spp. phenotypic plasticity, where the coral alters its structure from dome shaped to branching in response to high light⁷². Low diversity of coral makes this site vulnerable to disease, as a disease devastating *Porites* spp. could lower the coral cover to just 17%.

Porites spp., along with *Fungia* spp., are known to be particularly tolerant to thermal stress (unlike *Acropora* spp., *Stylophora* spp. and *Pocillopora* spp.)⁷³. This means Dauin Sur should be relatively resilient to a bleaching event, and could also indicate that this coral community may thus be structured as a response to a bleaching event. This is further supported by the relatively high number of bleached corals recorded on the survey, indicating this site may be subject to warmer water temperatures than others. The adjacent sites of Dauin Sur, Poblacion and Masaplod Norte, recorded the three highest cases of bleaching out of all of the sites surveyed in Dauin. Poblacion also recorded the second highest *Porites* cover (after Dauin Sur) at 6%, whereas all other sites had covers of less than 2%. Dauin Sur also recorded the highest cover of dead coral with algae, which would also occur post-bleaching event. The percentage cover of *Fungia* spp. was also highest at Dauin Sur, followed by Poblacion. These sites are known for being areas of low current, which could allow bodies of warm water to accumulate. As a result, the surrounding water temperature may influence the coral make-up of these sites.

A high number of fish were found within the transect (ranked 3rd), yet these were all relatively small, leading to a lower biomass (ranked 7th). It is likely these small fish are able to find refuge within the branching arms of the *Pocillopora* spp. and some *Porites* spp. colonies. Fish sheltering within branched corals tend to be of the genera *Pomacentridae* (damselfish)⁷⁴, with Dauin Sur recording the highest abundance, species richness and biomass of this genera. *Pomacentridae* tend to fall into the trophic groups of herbivores, planktivores and omnivores, therefore it is interesting to note that despite a large abundance of *Pomacentridae*, invertivorous fishes recorded the greatest biomass. These larger bodied fish (such as *Labridae*), exploit invertebrates hiding within the sand, and are thus likely to be found in the sites with a high sand cover. Invertivores and herbivores are also rarely targeted by fisherman, unlike piscivores such as grouper and snapper. Reefs located within a close proximity to human populations tend to be dominated by invertivorous and herbivorous fish⁷⁵. Over time, if the MPAs are controlled effectively it can be expected that larger piscivores can recover over time.

A number of studies have shown that 3D complexity is positively correlated with fish abundance and diversity^{76,77,78}. It is therefore surprising to note that for a site with such a high fish abundance, the site had a low 3D complexity. This is likely due to the large expanses of sand, with a rugosity value close to 0. This may well be where few large bodied invertivores were found, but the explosion in fish abundance occurred around the branching corals.

Dauin Sur is located in between the sites of Poblacion and Masaplod Norte. All three of these sites are designated MPAs, recording 1st, 3rd and 4th highest abundance of fish. It has been calculated that for fish with a body size of 20cm, an

optimum MPA size would be around 1.8km² in area⁷⁹. This high number of fish found within these MPAs could be due to the fact that together they are reasonably large areas of protection, however it could also be that they were designed as MPAs due to having high coral cover and fish abundance. This chicken and egg situation is common when studying MPAs where before MPA establishment studies are not available for comparison. To assess the effectiveness of these MPAs, they will need to be monitored over time and compared to non-MPA sites.

Despite the evidence indicating that Dauin Sur has been recovering from a bleaching event, the site is doing well with a high coral cover and high number of fish. The site should, however, be closely monitored as it is in a prime location for coral bleaching events, due to the fact that it has a low coral diversity and smaller than average fish, making it vulnerable to disturbances.

6. REFERENCES

1. Harmelin-Vivien, M. L. The Effects of Storms and Cyclones on Coral Reefs: A Review. *J. Coast. Res.* 211–231 (1994).
2. Fabricius, K. E. et al. Disturbance gradients on inshore and offshore coral reefs caused by a severe tropical cyclone. *Limnol. Oceanogr.* **53**, 690–704 (2008).
3. Done, T. J. Effects of tropical cyclone waves on ecological and geomorphological structures on the Great Barrier Reef. *Cont. Shelf Res.* **12**, 859–872 (1992).
4. Gardner, T. A., Côté, I. M., Gill, J. A., Grant, A. & Watkinson, A. R. Hurricanes and Caribbean Coral Reefs: Impacts, Recovery Patterns, and Role in Long-Term Decline. *Ecology* **86**, 174–184 (2005).
5. Hongo, C., Kawamata, H. & Goto, K. Catastrophic impact of typhoon waves on coral communities in the Ryukyu Islands under global warming. *J. Geophys. Res. Biogeosciences* **117**, (2012).
6. Marshall, P. Skeletal damage in reef corals: relating resistance to colony morphology. *Mar. Ecol. Prog. Ser.* **200**, 177–189 (2000).
7. Andersson, A. J. & Gledhill, D. Ocean Acidification and Coral Reefs: Effects on Breakdown, Dissolution, and Net Ecosystem Calcification. *Annu. Rev. Mar. Sci.* **5**, 321–348 (2013).
8. Hoegh-Guldberg, O. et al. Coral Reefs under Rapid Climate Change and Ocean Acidification. *Science* **318**, 1737–1742 (2007).
9. Mollica, N. R. et al. Ocean acidification affects coral growth by reducing skeletal density. *Proc. Natl. Acad. Sci.* **115**, 1754–1759 (2018).
10. De'ath, G., Lough, J. M. & Fabricius, K. E. Declining Coral Calcification on the Great Barrier Reef. *Science* **323**, 116–119 (2009).
11. Dullo, W. Coral growth and reef growth: a brief review. *Facies Dordr.* **51**, 33–48 (2005).
12. Comeau, S., Edmunds, P. J., Spindel, N. B. & Carpenter, R. C. Fast coral reef calcifiers are more sensitive to ocean acidification in short-term laboratory incubations. *Limnol. Oceanogr.* **59**, 1081–1091 (2014).
13. Knutson, T. R. et al. Tropical cyclones and climate change. *Nat. Geosci.* **3**, 157–163 (2010).
14. Rasser, M. & Riegl, B. Holocene coral reef rubble and its binding agents. *Coral Reefs* **21**, 57–72 (2002).
15. Heyward, A. J. & Negri, A. P. Natural inducers for coral larval metamorphosis. *Coral Reefs* **18**, 273–279 (1999).
16. Wulff, J. L. Sponge-mediated coral reef growth and rejuvenation. *Coral Reefs* **3**, 157–163 (1984).
17. Foster, T., Falter, J. L., McCulloch, M. T. & Clode, P. L. Ocean acidification causes structural deformities in juvenile coral

- skeletons. *Sci. Adv.* **2**, e1501130 (2016).
18. Foster, T., Gilmour, J. P., Chua, C. M., Falter, J. L. & McCulloch, M. T. Effect of ocean warming and acidification on the early life stages of subtropical *Acropora spicifera*. *Coral Reefs* **34**, 1217–1226 (2015).
 19. Albright, R., Mason, B., Miller, M. & Langdon, C. Ocean acidification compromises recruitment success of the threatened Caribbean coral *Acropora palmata*. *Proc. Natl. Acad. Sci.* **107**, 20400–20404 (2010).
 20. Smith, L. D. & Hughes, T. P. An experimental assessment of survival, re-attachment and fecundity of coral fragments. *J. Exp. Mar. Biol. Ecol.* **235**, 147–164 (1999).
 21. Knowlton, N., Lang, J. C. & Keller, B. D. Case study of natural population collapse: post-hurricane predation on Jamaican staghorn corals. (1990).
 22. Dollar, S. J. & Tribble, G. W. Recurrent storm disturbance and recovery: a long-term study of coral communities in Hawaii. *Coral Reefs* **12**, 223–233 (1993).
 23. Bruckner, A. W., Link to external site, this link will open in a new window, Coward, G., Bimson, K. & Rattanawongwan, T. Predation by feeding aggregations of *Drupella* spp. inhibits the recovery of reefs damaged by a mass bleaching event. *Coral Reefs Heidelb.* **36**, 1181–1187 (2017).
 24. Turner, S. J. Spatial variability in the abundance of the corallivorous gastropod *Drupella cornus*. *Coral Reefs* **13**, 41–48 (1994).
 25. Bennett, E. M., Carpenter, S. R. & Caraco, N. F. Human Impact on Erodeable Phosphorus and Eutrophication: A Global Perspective Increasing accumulation of phosphorus in soil threatens rivers, lakes, and coastal oceans with eutrophication. *BioScience* **51**, 227–234 (2001).
 26. Marshall, P. Skeletal damage in reef corals: relating resistance to colony morphology. *Mar. Ecol. Prog. Ser.* **200**, 177–189 (2000).
 27. Carroll, A. G., Harrison, P. L. & Adjeroud, M. Susceptibility of coral assemblages to successive bleaching events at Moorea, French Polynesia. *Mar. Freshw. Res.* **68**, 760 (2017).
 28. Hoeksema, B. W. Control of bleaching in mushroom coral populations (Scleractinia: Fungiidae) in the Java Sea: Stress tolerance and interference by life history strategy. *Mar. Ecol. Prog. Ser. Oldendorf* **74**, 225–237 (1991)
 29. Baker, A. & Cunning, R. Coral “Bleaching” as a Generalized Stress Response to Environmental Disturbance. in 396–409 (2015). doi:10.1002/9781118828502.ch30
 30. Douglas, A. E. Coral bleaching—how and why? *Mar. Pollut. Bull.* **46**, 385–392 (2003)

31. Jones, R. Zooxanthellae loss as a bioassay for assessing stress in corals. *Mar. Ecol. Prog. Ser.* **149**, 163–171 (1997).
32. Harland, A. D. & Brown, B. E. Metal tolerance in the scleractinian coral *Porites lutea*. *Mar. Pollut. Bull.* **20**, 353–357 (1989).
33. Henry, L.-A. & Hart, M. Regeneration from Injury and Resource Allocation in Sponges and Corals – a Review. *Int. Rev. Hydrobiol.* **90**, 125–158 (2005).
34. Ateweberhan, M. *et al.* Climate change impacts on coral reefs: Synergies with local effects, possibilities for acclimation, and management implications. *Mar. Pollut. Bull.* **74**, 526–539 (2013).
35. Selig, E. R. & Bruno, J. F. A Global Analysis of the Effectiveness of Marine Protected Areas in Preventing Coral Loss. *PLOS ONE* **5**, e9278 (2010).
36. Soler, G. A. *et al.* Reef Fishes at All Trophic Levels Respond Positively to Effective Marine Protected Areas. *PLOS ONE* **10**, e0140270 (2015).
37. Edgar, G. J. *et al.* Global conservation outcomes depend on marine protected areas with five key features. *Nature* **506**, 216–220 (2014).
38. Burke, Lauretta & Selig, Elizabeth & Spalding, Mark & authors, other & McManus, John. (2002). Reefs at Risk in South East Asia. *Freshw. Ecosyst.* DOI: 10.1002/aqc.880.
40. Snavely, Seitz & Szeliski (2008) Snavely N, Seitz SN, Szeliski R. Modeling the world from internet photo collections. *International Journal of Computer Vision.* 2008;80:189–210. doi: 10.1007/s11263-007-0107-3.
41. Westoby *et al.* (2012) Westoby MJ, Brasington J, Glasser NF, Hambrey MJ, Reynolds JM. ‘Structure-from-Motion’ photogrammetry: a low-cost, effective tool for geoscience applications. *Geomorphology.* 2012;179:300–314.
42. Fisher *et al.* (2007) Fisher WS, Davis WP, Quarles RL, Patrick J, Campbell JG, Harris PS, Hemmer BL, Parsons M. Characterizing coral condition using estimates of three-dimensional colony surface area. *Environmental Monitoring and Assessment.* 2007;125:347–360.
43. Done (1997) Done TJ. Decadal changes in reef-building communities: implications for reef growth and monitoring programs. *Proceedings of the 8th International Coral Reef Symposium.* 1997;1:411–416.
44. Figueira W, Ferrari R, Weatherby E, Porter A, Hawes S, Byrne M. Accuracy and Precision of Habitat Structural Complexity Metrics Derived from Underwater Photogrammetry. *Remote Sensing.* 2015;7(12):16883–16900.
45. Holmes, Thomas & Wilson, Shaun & Travers, Michael & Langlois, Tim & Evans, Richard & Moore, Glenn & Douglas, Ryan &

- Shedrawi, George & Harvey, Euan & Hickey, Kate. (2013). A comparison of visual-and stereo-video based fish community assessment methods in tropical and temperate marine waters of Western Australia. *Limnology and oceanography, methods*. 11. 337-350. 10.4319/lom.2013.11.337.
46. Stopnitzky S. 2014. Studying Reefs, Staying Dry. Khaleb bin Sultan Living Oceans Foundation. <https://www.livingoceansfoundation.org/studying-reefs-staying-dry/>
47. Kohler KE, Gill SM. 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers & Geosciences*, 32: 1259-1269
48. Rogers CS, Garrison G, Grober R, Hillis ZM, Franke MA. 1994. Coral reef monitoring manual for the Carribean and Western Atlantic. Virgin Islands National Park, St. John, US Virgin Islands, 107, USA
49. Rogers CS. 1988. Recommendations for long-term assessment of coral reefs: US National Park initiates regional program. *Proc 6th Int. Coral Reef Symposium, Australia*, 2: 339-403.
50. Hoegh-Guldberg, O., Hoegh-Guldberg, H., Veron, J.E.N., Green, A., Gomez, E. D., Lough, J., King, M., Ambariyanto, Hansen, L., Cinner, J., Dews, G., Russ, G., Schuttenberg, H. Z., Peñaflor, E.L., Eakin, C. M., Christensen, T. R. L., Abbey, M., Areki, F., Kosaka, R. A., Tewfik, A., Oliver, J. (2009). *The Coral Triangle and Climate Change: Ecosystems, People and Societies at Risk*. WWF Australia, Brisbane, 276 pp.
51. Jonker, M. (Michelle) II. Australian Institute of Marine Science III. Title (Series: Long-term monitoring of the Great Barrier Reef standard operational procedure; 10).
52. Komyakova, V., Munday, P.L., Jones, G.P. (2013). Relative importance of coral cover, habitat complexity and diversity in determining the structure of reef fish communities. *PLoS ONE*, 8(12), e83178.
53. Kostylev VE, Erlandsson J, Ming MY, Williams GA. 2005. The relative importance of habitat complexity and surface area in assessing biodiversity: fractal application on rocky shores. *Ecological Complexity* 2:272–286
54. Luckhurst BE, Luckhurst K. 1978. Analysis of the influence of substrate variables on coral reef fish communities. *Marine Biology* 49:317–323
55. McCormick M. 1994. Comparison of field methods for measuring surface topography and their associations with a tropical reef fish assemblage. *Marine Ecology Progress Series* 112:87–96
56. Miller, I. R. (2003) *Crown-of-thorns starfish and coral surveys using the manta tow and scuba search techniques*. Long-term Monitoring of the Great Barrier Reef. Standard Operational Procedure, No. 8, Australian Institute of Marine Science, Townsville, 43pp.
57. Pittman SJ, Brown KA. 2011. Multi-scale approach for predicting fish species

- distributions across coral reef seascapes. *PLoS ONE* 6(5):e20583
58. Pittman SJ, Costa BM, Battista TA. 2009. Using lidar bathymetry and boosted regression trees to predict the diversity and abundance of fish and corals. *Journal of Coastal Research* 25(6):27–38
 59. Raoult et al. (2016), GoPros™ as an underwater photogrammetry tool for citizen science. *PeerJ* 4:e1960
 60. Sweatman, H., Burgess, S., Cheal, A., Coleman, G., Delean, S., Emslie, M., McDonald, A., Miller, I., Osborne, K., and Thompson, A. (2005) Long-term Monitoring of the Great Barrier Reef Status Report, No. 7, Australian Institute of Marine Science, Townsville, 266 pp.
 61. Verhoeven G. 2012. Getting computer vision airborne: using structure from motion for accurate orthophoto production. In: RSPSoc archaeology special interest group meeting spring 2012. 4–6
 62. Young GC, Dey S, Rogers AD, Exton D (2018) Correction: Cost and time-effective method for multi-scale measures of rugosity, fractal dimension, and vector dispersion from coral reef 3D models. *PLOS ONE* 13(7): e0201847.
 63. Snavely, Seitz & Szeliski (2008) Snavely N, Seitz SN, Szeliski R. Modeling the world from internet photo collections. *International Journal of Computer Vision*. 2008;80:189–210. doi: 10.1007/s11263-007-0107-3.
 64. Westoby et al. (2012) Westoby MJ, Brasington J, Glasser NF, Hambrey MJ, Reynolds JM. 'Structure-from-Motion' photogrammetry: a low-cost, effective tool for geoscience applications. *Geomorphology*. 2012;179:300–314.
 65. Fisher et al. (2007) Fisher WS, Davis WP, Quarles RL, Patrick J, Campbell JG, Harris PS, Hemmer BL, Parsons M. Characterizing coral condition using estimates of three-dimensional colony surface area. *Environmental Monitoring and Assessment*. 2007;125:347–360.
 66. Done (1997) Done TJ. Decadal changes in reef-building communities: implications for reef growth and monitoring programs. *Proceedings of the 8th International Coral Reef Symposium*. 1997;1:411–416.
 67. Holmes, Thomas & Wilson, Shaun & Travers, Michael & Langlois, Tim & Evans, Richard & Moore, Glenn & Douglas, Ryan & Shedrawi, George & Harvey, Euan & Hickey, Kate. (2013). A comparison of visual-and stereo-video based fish community assessment methods in tropical and temperate marine waters of Western Australia. *Limnology and oceanography, methods*. 11. 337-350. 10.4319/lom.2013.11.337.
 68. Andradi-Brown, D.A., Gress, E., Wright, G., Exton, D.A., Rogers, A.D. (2016). Reef fish community biomass and trophic structure changes across shallow to upper-mesophotic reefs in the Mesoamerican Barrier Reef, Caribbean. *PLoS ONE* 11(6): e0156641.

69. Rogers CS, Garrison G, Grober R, Hillis ZM, Franke MA. 1994. Coral reef monitoring manual for the Caribbean and Western Atlantic. Virgin Islands National Park, St. John, US Virgin Islands, 107, USA
70. Rogers CS. 1988. Recommendations for long-term assessment of coral reefs: US National Park initiates regional program. Proc 6th Int. Coral Reef Symposium, Australia, 2: 339-403.
71. Kohler KE, Gill SM. 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. Computers & Geosciences, 32: 1259-1269
72. Muko, Soyoka, Kohkichi Kawasaki, Kazuhiko Sakai, Fugo Takasu, and Nanako Shigesada. "Morphological plasticity in the coral *Porites sillimaniani* and its adaptive significance." Bulletin of Marine Science 66, no. 1 (2000): 225-239.
73. Hutchings, Pat, Michael Kingsford, and Ove Hoegh-Guldberg, eds. The Great Barrier Reef: biology, environment and management. Csiro publishing, 2019
74. Holbrook, Sally J., Graham E. Forrester, and Russell J. Schmitt. "Spatial patterns in abundance of a damselfish reflect availability of suitable habitat." *Oecologia* 122, no. 1 (2000): 109-120.
75. DeMartini, E.E., Friedlander, A.M., Sandin, S.A. and Sala, E., 2008. Differences in fish-assemblage structure between fished and unfished atolls in the northern Line Islands, central Pacific. Marine Ecology Progress Series, 365, pp.199-215.function." *Environmental biology of Fishes* 55, no. 1-2 (1999): 65-79.
76. Knudby, Anders, Stacy Jupiter, Chris Roelfsema, Mitchell Lyons, and Stuart Phinn. "Mapping coral reef resilience indicators using field and remotely sensed data." *Remote Sensing* 5, no. 3 (2013): 1311-1334.
77. Purkis, Samuel J., N. A. J. Graham, and B. M. Riegl. "Predictability of reef fish diversity and abundance using remote sensing data in Diego Garcia (Chagos Archipelago)." *Coral reefs* 27, no. 1 (2008): 167-178.
78. Purkis, Samuel J., N. A. J. Graham, and B. M. Riegl. "Predictability of reef fish diversity and abundance using remote sensing data in Diego Garcia (Chagos Archipelago)." *Coral reefs* 27, no. 1 (2008): 167-178.
79. Kramer, Donald L., and Matthew R. Chapman. "Implications of fish home range size and relocation for marine reserve function." *Environmental biology of Fishes* 55, no. 1-2 (1999): 65-79.