

2020 OUTLOOK REPORT

DAUIN LONG-TERM REEF MONITORING PROJECT



INSTITUTE FOR
MARINE RESEARCH
DAUIN · PHILIPPINES



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.

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

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OUR MISSION

The Institute for Marine Research is a grassroots non-profit organisation 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 Philippines.

OUR VISION

“We at the Institute for Marine Research strive to be instrumental in the making of an environmentally literate and sustainable community through and evidence-based conservation approach, creating a world that is better and wiser than the one we have now.”

- A message from the Founders

A MESSAGE FROM THE DIRECTORS

What a wild ride 2020 has been!

We started the year strong, celebrating the end of our first full year of operations. Our research base was full of Research Assistants, Fellows, Divemaster trainees, Instructor candidates, and Masters students. We welcomed Becky Tooby (Head of Dive Operations), Jennifer Brand (Head of Science), and Wobby (Golden Retriever) to the team, and said farewell to Oscar Crehan as he would go on to begin a PhD. Oscar joined the team in the infancy of IMR, and we thank him enormously for his passion and dedication to the project!

On March 14th, we were forced to put a pause on our research operations. COVID-19 had officially reached pandemic status, the Philippines was closing its borders to international travellers, and our town went into lockdown. Some of our Research Assistants stayed on base, while others left on scheduled embassy flights. A two week lockdown and dive ban turned into three months, with only one person from our research base allowed to leave to gather essential supplies. Yet amidst this period our staff worked tirelessly, conducting data analysis, and completing several reports showcasing our long term monitoring data. By June we received exemption from our local government to carry on with our monitoring, and with their support our monitoring data remains unaffected by the pandemic.

The completion of this report is a huge achievement for us, and we have many things to be thankful for. Firstly, with the loss of international travel for the remainder of 2020, a serious hit was taken to our income stream and ability to fund our research and base operations. With the support of family and friends, and a couple of Go-Fund-Me campaigns later, the research within this annual report has been obtained. The most sincere thank you goes out to those of you that believed in our work, and supported us with the means to continue this project. Secondly to our staff, Jen and Becky. An entire year into the pandemic, and yet your commitment to the project was unwavering. In addition to conducting data collection and analysis, Becky grew our social media community (@institute.marineresearch) through her photography and a behind the scenes view of life on base, and Jen provided the guidance for Masters students to complete their theses using our data remotely. 2020 would not have been the same without them, and we thank them both immensely! To our Research Assistants and Fellows; Johan, Ella F., Stacey, Jordan, Ella S., Emma, Mark and Kaye. You all made our work achievable during a pandemic year, and we thank you for your assistance and friendship!

Entering a new year, IMR remains committed to our mission of using evidence-based conservation to steer Dauin towards an ecological sustainable path. With two years of research under our belt, we see that it is time to take the necessary next step towards this mission. We will be bringing new techniques, and to do this we will be moving to a new base that will allow us to be oceanfront and obtain seawater for our wet lab facility. We will have an upgraded lab, more classrooms, and a pool for dive training and calibration. We can't wait to share it with you all!

Here's to 2021!

Yours Sincerely,

Rafael Manrique & Chelsea Waters



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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
DLTRMP	Davin Long Term Reef Monitoring Project
DO-SVS	Diver-Operated Stereo Video System
HYP	Hyperplasia
IMR	Institute for Marine Research
MPA	Marine Protected Area
NEO	Neoplasia
PP	<i>Porites</i> Pinking
PUWS	<i>Porites</i> Ulcerative White Spot
SR	Species Richness
SCUBA	Self-Contained Underwater Breathing Apparatus
SE	Standard Error
SEBD	Skeletal Eroding Band Disease
SfM	Structure from Motion

1. INTRODUCTION

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. The Institute for Marine Research aims to use its scientific evidence to educate, transform and encourage locally led marine conservation strategies within the Philippines, ultimately reducing these local threats.

Major anthropogenic threats include 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, which all risk mortality or reduced growth of reef-building corals due to their high sensitivity^{1,2}. These anthropogenic threats interact with 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 storms². Efforts are therefore shifting towards management of local and regional anthropogenic pressures to strengthen reef resilience. A sound understanding of the processes that determine ecosystem trajectories is needed to assess the likely effectiveness of management strategies to reduce local anthropogenic pressures. Long-term and fine-scale monitoring of exemplar ecosystems is therefore essential.

1.1 The Philippines

The Philippines represents a particularly relevant case study to investigate ecosystem trajectories. The Philippine archipelago is comprised of over 7100 islands, located within the heart of the Coral Triangle. With 76% of the world's Scleractinian coral species (over 400 species) and 37% of the reef fishes of the world^{2,3}, this incredible biodiversity is coupled with some of the highest human population densities and growth rates in the world¹.

Changes to the health of coastal ecosystems are exposing coastal populations to food and income insecurity, deteriorating coastal protection among other challenges; they are affecting people who are already impoverished and are amongst the least

able to respond to changes that are occurring in their environment¹. Reef fisheries have been estimated to directly contribute 15-30% of the Philippines total known national municipal fisheries (obtained from licences issued through local government areas), where nearly 70% of the dietary protein intake is from fish. However, the Philippines' main fish species and marine organisms show signs of overfishing, and coastal habitats are degrading due to multiple anthropogenic activities in coastal areas⁴. The stark contrast between poverty, hunger and deprivation amidst this increasing demand is leading to a rapid decline in reef resources. It is therefore no surprise that coral reefs in the Philippines are at very high risk from overexploitation, destructive fishing and other human related impacts such as coastal development, sedimentation, and as a result of anthropogenic climate change coral bleaching and ocean acidification.

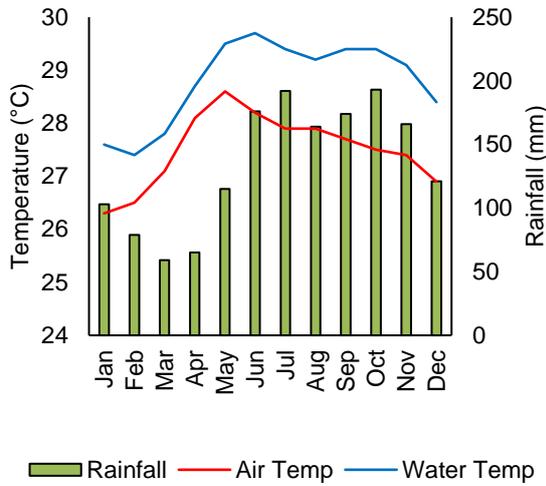
Human activities now threaten an estimated 88 percent of Southeast Asia's coral reefs, with 50 percent of these having a threat level of "high" or "very high"². In the Indo-Pacific, coral cover has dropped from approximately 50 – 22% in just 40 years⁵. If this continues, the changes to the ecosystem will exacerbate poverty and social instability within the region, with wider consequences for the Philippines and globally. It is imperative that we address the core issue of anthropogenic climate change whilst at the same time addressing key threats arising from local stressors.

1.2 Seasonal Weather Patterns

Negros Oriental falls under the Philippines Type III climate, where seasons are not very pronounced, although it is relatively dry from December to May, and relatively wet for the rest of the year. In the Bohol Sea, the lowest monthly average water temperatures are in February, at around 27.20°C, and the highest are in June, at around 30.00°C. The dry season (Filipino: Amihan) is dominated by north-easterly trade winds, bringing moderate temperatures and little rainfall, whereas the wet season (Filipino: Habagat) is dominated by south-westerly winds with hot, humid weather and heavy rainfall.

Whilst this report examines the differences between the data collected from the first four survey seasons (dry and wet 2019 and 2020) of the IMR DLTRMP, it is important to consider that some seasonal fluctuations may not yet be apparent, as several

years of data may be required to highlight these variations.



Average air and water temperature and rainfall of Philippines Type III climate (measurements from Cebu city)⁶. Data from 1982 – 2012.

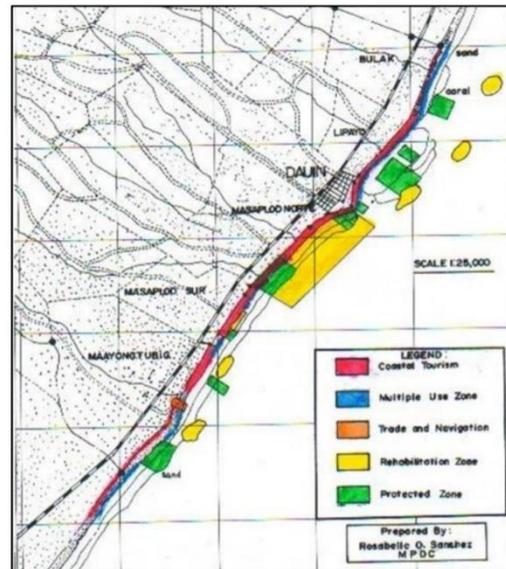
1. 3 Municipality of Dauin

Dauin, a fourth-class municipality in the province of Negros Oriental, is no exception to the critical reliance of reef resources for the wellbeing and subsistence of this coastal community. Together with a steadily growing population, Dauin has experienced first-hand the strain of pushing local fisheries beyond their biological limit – to the reef ecosystem and to the future of social and food security to this small coastal community.

Dauin has since shifted to community led establishment of several coastal management zones

in the form of marine protected areas (MPAs). MPAs have the potential to protect at-risk ecosystems, habitats or species, as well as maintain and enhance coral reef resilience and biodiversity⁷⁻⁹. As such, MPAs have been distributed across the municipality to regulate fishing pressures, abolish destructive practices, and address important issues such as food security, economic growth, and ecosystem resilience. Additionally, one artificial reef site has been constructed (Lipayo II), with the aim of sheltering fauna, increasing structural complexity and promoting juvenile recruitment¹⁰.

This report provides baseline information for Dauin’s reefs after one year of surveying, examining key trends in benthic composition, coral mortality and fish community structure. Seasonal changes are also investigated.



Dauin Coastal Zoning Map; Marine Protected Areas in green.¹¹

Dauin Long-Term Reef Monitoring Project Aims

1. To understand how benthic composition influences fish community structure and invertebrate community composition.
 - a. Will reef fish community structure be influenced by changes to percentage coral cover, habitat structural complexity and rugosity?
 - b. What habitat does the benthic cover of the Dauin Municipal reef employ?
 - c. What is the relative importance of coral cover, structural complexity, and diversity in determining the structure of reef fish communities in Dauin?
 - d. Do structurally complex benthic communities support a greater diversity of fish species, regardless of a low percentage coral cover?
 - e. How do rugose benthic communities support fish and invertebrate communities?

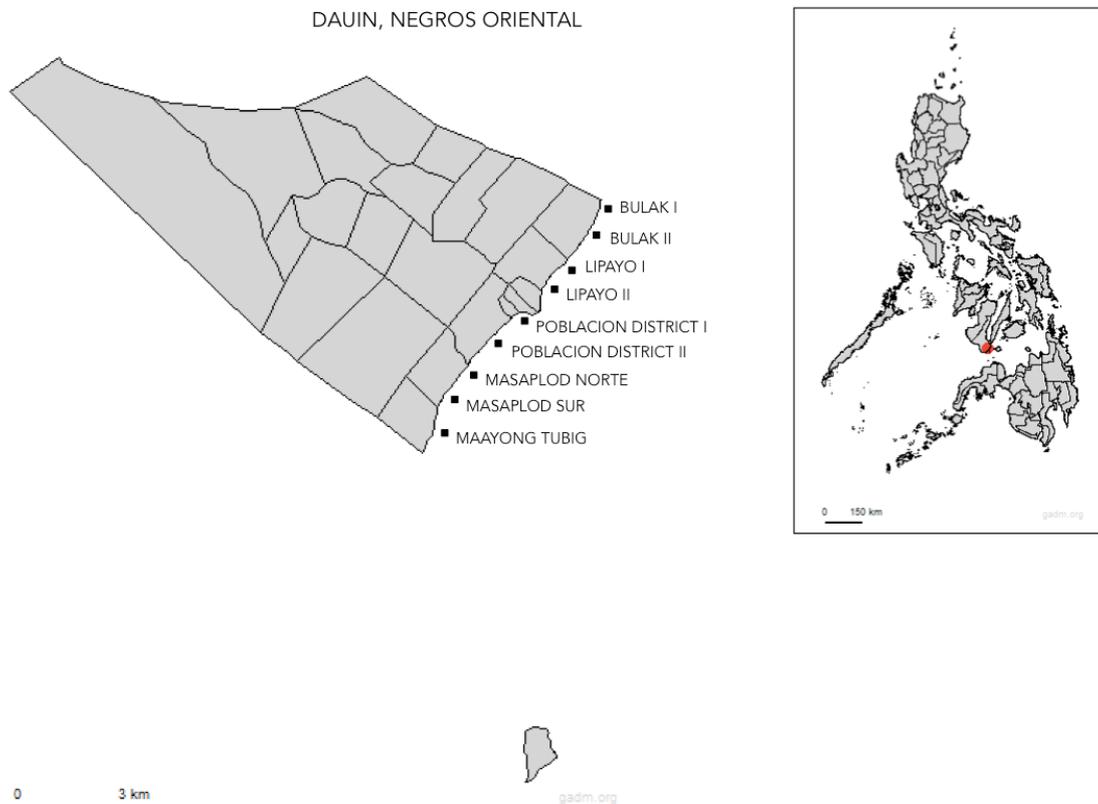
2. To document the effect of disturbances such as crown of thorns outbreaks, typhoons and bleaching events, and to provide awareness of other threats to the reef and other issues of concern to reef managers.
 - a. What is the resiliency factor of ecosystems composed of high structural complexity, rugosity, percentage coral cover and coral diversity in response to storms and bleaching events?
 - b. Is there a relationship between benthic measurement (structural complexity, percentage cover, rugosity, diversity) and the abundance of trash, crown of thorns and disease?
 - c. What are the major localised impacts that affect the Dauin reef system, and where do the major localised impacts originate from?

3. To document the effects of temperature, light and current on the annual and seasonal variability of coral and fish populations.
 - a. How is coral calcification affected between seasons?
 - b. Will coral calcification be higher under high temperature and light regimes, with results dependent on bleaching status and storm intensity?
 - c. Are threats to the Dauin reef system directly influenced by humans, and how will these threats be manipulated by current shifts and storm intensity?
 - d. How do seasonal variations affect benthic cover and fish assemblage?

2. MATERIALS AND METHODS

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. The Dauin coastline was split into three research zones (North, Central and South), each zone 3km long. Nineteen core sites at eleven locations were selected for monitoring. These sites span the variation in coral reef composition, benthic and

fish communities across the Municipality, and account for the zoning history of its associated no-take marine protected areas. The 19 core sites each have one 50m transect that runs parallel to the reef crest, between depth ranges of 1 – 6m and 7 – 12m. 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.



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.

2.1 Benthic Assays

Surveys of sessile benthic organisms were conducted following the Australian Institute of Marine Science (AIMS) LTMP methodology^{12,13}. Images were taken along the transect line using a GoPro camera held approximately 0.5m above the substrate. One image was taken per 1m interval, totalling fifty images per 50m transect. Analysis of benthic assays used CPCe software¹⁴, where underwater images are overlaid by a matrix of 30 randomly distributed

points generated in the full frame of each photo and used for identification. Point overlay was used to characterise the benthos and determine the percentage cover of each type of organism and substrate in the image¹⁵. The species code data for each image is stored in a .cpc file which contains the image filename, point coordinates and the identified data codes.

Points were identified based on a predetermined codec, which contains all Indo-pacific Scleractinian coral genera, octocorals, hydroids, bivalves, other hexacorals (anemones, corallimorphs and zoanths), sponge growth forms, “other live” (ascidian, crown of thorns starfish, cyanobacteria, other e.g. fish), algae, seagrass, dead coral and abiotic (see Appendix 7.1 for full codec). 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 analyse seasonal and temporal trends in cover of benthic organisms at each site, zone, and throughout the municipality as a whole. The non-parametric Kruskal-Wallis (KW) test was used to compare benthic cover between seasons and years. The Dunn test (using Benjamini–Hochberg stepwise adjustment) was used to determine groupings.

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^{16,17}. Coral Point Count with excel extensions (CPCe) is a visual software designed to quickly and efficiently calculate statistical coral coverage over a specified area through the aid of photo-transects¹⁴. 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 results in Microsoft Excel. Thus, CPCe is a highly useful tool, particularly in coral reef monitoring, assessment and conservation.



2.2 SCUBA Search: Reef Impacts & Coral Mortality

The SCUBA search is designed to provide a more detailed picture of the causes and relative scale of coral mortality, and was conducted following a modified version of AIMS LTMP methodology¹². SCUBA searches were conducted along the 50 m transect, with a 2 m belt (1 m either side of the transect line). The following impacts were recorded: direct destruction, trash (general or fishing), *Acanthaster planci* (crown-of-thorns starfish; COTS), COTS feeding scars, *Drupella* spp. feeding scars, unknown scars, coral bleaching and coral disease (black band, brown band, white syndrome, *Porites* pinking, *Porites*

ulcerative white spot, skeletal eroding band, hyperplasia and neoplasia).

For all of the above, images were captured using a GoPro camera and a ruler, to record a) the impact found, b) the affected coral genera, and c) the size of the affected area and the entire colony. Size analysis of the impacts was completed in ImageJ¹⁸. The non-parametric Kruskal-Wallis (KW) test was used to compare impact frequency between seasons and years. The Dunn test (using Benjamini–Hochberg stepwise adjustment) was used to determine groupings.

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).



2.3 Diver Operated Stereo Video System (DO-SVS)

Transects were conducted using a Diver-Operated Stereo Video System (DO-SVS; SeaGIS, Melbourne, Australia), comprised of two GoPro Hero 5 Black cameras. To minimise potential disturbance to the fish community, cameras were set to record and synchronised prior to entry, and the SVS operator was at the front of the survey team. At the start of the 50m transect, the cameras were orientated parallel to the substrate, angled approximately 20° downwards and kept approximately 0.5m above the substrate. The SVS operator moved at a steady pace (adjusting for currents), filming the reef scape along the 50m transect; transects take approximately 5 - 6 minutes.

EventMeasure V5.25 (SeaGIS, Melbourne, Australia) was used to synchronise SVS footage, calibrate camera measurements, and measure fish encountered along the transect. EventMeasure resolves centre points of each individual fish encountered into distances on a three-dimensional coordinate system. This allowed the exclusion of fish outside 2.5m either side of and 5m in front of the camera system; side distance restrictions maintain a consistent survey belt along the transect and front

distance restrictions prevent variations in visibility (e.g. turbidity, light intensity) from influencing data. Each fish encountered within the transect belt was identified to species level. For fish visible in both cameras, measurements are possible; for those only seen in the left-hand side video, a point identifying the fish to species level was recorded. Fish biomass was estimated using the equation:

$$W = aL^b$$

where W is weight (g), L is fish length (cm), and a and b are species-specific allometric constants obtained from FishBase¹⁹. The genus mean was used when allometric constants for a specific species were not available. For points (where length measurements were not possible), the mean length for the species recorded across all depths and survey sites was used. Where fish were unidentifiable to species level (small size, blurry etc.), entries of family/genus were included in abundance data, but not in diversity or biomass data, as no suitable allometric constants were available. Length at first maturity of all fish species (where available) were obtained from FishBase¹⁹.

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 widely used 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 logistically simple, non-destructive, and cost-effective, however the effectiveness 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 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 record fish species with more precision and accuracy than the traditional UVC techniques, and efficiently quantify the abundance and size of reef fish^{20,21}. 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 coverage.



Fish species were classified into functional groups; grazers / detritivores, scrapers / small excavators, browsers, detritivores, obligate corallivores, planktivores, invertivores and piscivores/scavengers²². The invertivores / sessile group was included with the invertivores. Trophic groups were allocated following the FishBase 'Food Items' table, using the Food I-III hierarchical classification of food items consumed by a species, based on diet composition of >20% of recorded items accessed through FishBase^{19,23}. The proportional biomass of each functional group was also calculated at each site. Fish species were also categorised into IUCN Red List Categories²⁴ (Not Evaluated, Data Deficient, Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild and Extinct), as well as their commercial value

(Commercial, Minor, Subsistence fisheries, None) according to FishBase¹⁹.

Statistical analysis methods varied on the dataset. For total fish populations (for Dauin as a whole and separated by survey location), log-transformed abundance and biomass data and untransformed species richness (n) data was used in ANOVAs to compare across survey seasons. Family-level datasets were non-parametric, hence the Kruskal-Wallis (KW) test was used to compare abundance and biomass between seasons and years. The Dunn test (using Benjamini-Hochberg stepwise adjustment) was used to determine groupings. Species accumulation curve was obtained with the function `specaccum` (using "exact" method, which finds the expected (mean) species richness) of the 'vegan'²⁵ package in R²⁶.

2.4 3-Dimensional Reef Modelling

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 food availability. 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^{27,28}.

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^{29,30}.

These 3D models are produced, 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 achieve the same results underwater. With advances in photogrammetry software and high performance hardware, automated analyses of structural complexity across all IMR-monitored reefs in Davin 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 never could before, including the complexity of the reef scale.

A 3D camera rig consisting of two GoPro Hero 5 Black cameras placed 0.9m apart on a one-metre long aluminium pole³¹ was used to obtain video footage of the survey transect. The cameras were set to wide-angle, resolution of 1080 pixels and 60 frames per second. The principles for this method of stereo-video measurement are described in Harvey and Shortis (1995)³². The cameras were faced directly down at the substratum³³ at the beginning of the 50m transect, with the rig approximately 2m above the substrate. A lawnmower pattern was followed at a steady pace, covering 1m either side of the transect line, along the 50m transect. The operator aimed for at least 60% overlap of the path to ensure images can be aligned; preliminary testing indicates this method decreases alignment errors over single passes or higher image intervals³⁴.

Stills were extracted at a rate of one per 30 frames from both camera videos, which were used to

generate a 3D model (Agisoft Metashape Standard 9), using Structure from Motion (SfM) software and photogrammetry principles. Images were aligned with a high accuracy, generic preselection, key point limit of 40,000, tie point limit of 1000, and with an adaptive camera model fitting. The alignment was optimised to fit k4 and a dense cloud was created with medium quality, mild depth filtering, with point colours calculated.

2.5 Metadata

Before every survey dive, air temperature (°C), wind speed (kts), tidal state (low/high, rising/falling), sea state (calm/ slight/ moderate/ rough) and boat activity (number of fishing and diving boats present) were recorded. This can be used in conjunction with any other data collected when needed.

3. RESULTS

3.1 Benthic Composition

Benthic cover across Dauin’s reefs show abiotic substrate types dominate (48%), followed by hard coral cover (21%), algae (12%), dead coral (8%) and sponges (5%) (Fig 3.1.1). The Dauin benthos has changed significantly over the course of the DLTRMP (Fig 3.1.2). Although abiotic cover continues to dominate the benthos, it decreased significantly from dry to wet season of 2019 and from wet 2019 to dry 2020, although from dry to wet 2020 it remained consistent. Coral cover has remained unchanged for the duration of the DLTRMP. Algae cover steadily increased from dry 2019 to dry 2020, before significantly decreasing in wet 2020. Sponge cover remained consistent from dry 2019 until wet 2020, which saw a marked increase. No clear trend is apparent in dead coral cover as yet, although non-parametric testing shows a decline in percent cover followed by a significant increase in 2020 wet compared to all other survey seasons. Seagrass cover declined slightly from 2019 dry to wet, but increased in 2020 to return to similar

levels. Cyanobacteria cover has steadily and significantly increased across survey seasons. Octocoral, hydroid other hexacoral and bivalve cover have remained unchanged for the duration of the DLTRMP.

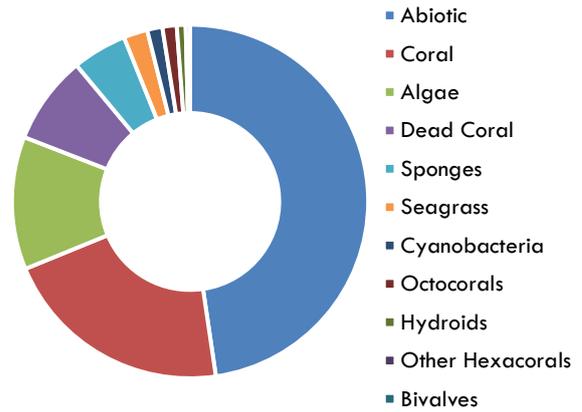


Fig 3.1.1: Relative mean transect cover of major benthic categories along Dauin Reef for the duration of the DLTRMP.

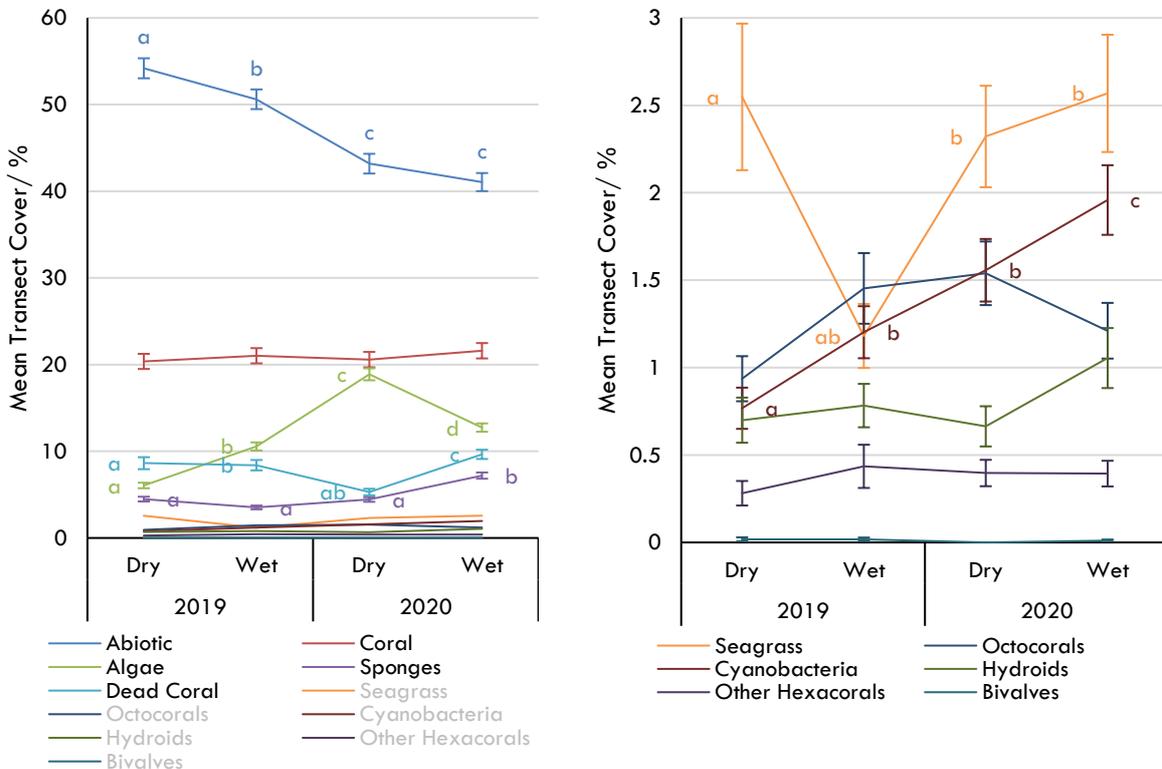
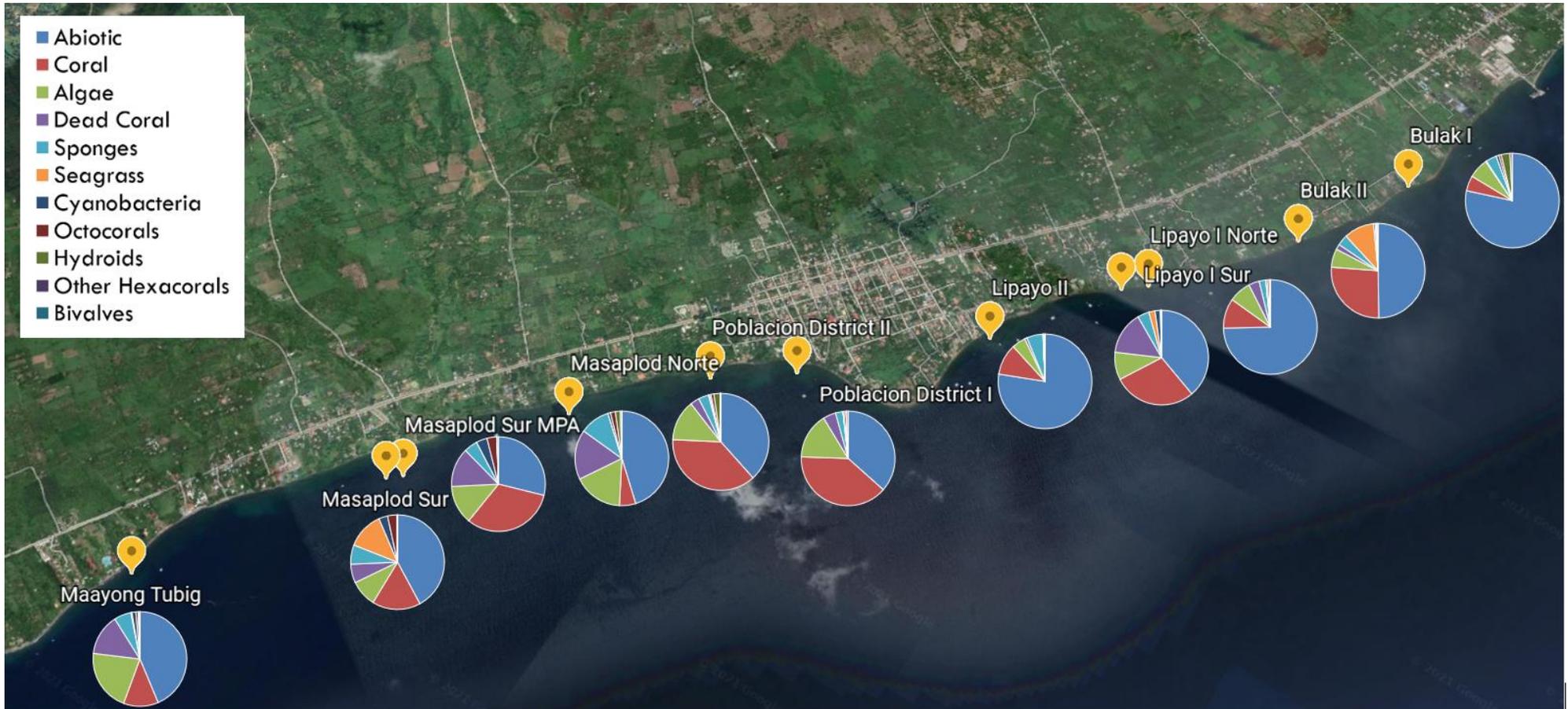


Fig 3.1.2: Mean transect cover (% ± SE) of major benthic categories along Dauin Reef separated by survey season. Letters represents significant differences within a category between survey seasons; seasons with different letters are significantly different from each other (p < 0.05). Graph on right is a zoom on the minor categories (grey categories in legend on left graph).



Satellite map of survey locations with major benthic category proportions averaged for the course of the DLTRMP.

3.1.1 Scleractinian Coral

Coral cover has remained significantly unchanged during the DLTRMP ($H(3) = 5.036, p = 0.17$). A total of 50 Scleractinian coral genera have been recorded. The genera *Acropora*, *Porites*, *Anacropora*, *Echinopora* and *Pocillopora* dominate the Dauin reef system, contributing to 78% of all coral cover between them (31%, 18%, 14%, 8% and 7% respectively) (Fig 3.1.3), with the remaining coral genera contributing 3% or less each.

Coral cover varies significantly according to site ($H(18) = 1175.9, p < 0.01$). Poblacion District II at 10m (Site 1), Masaplod Sur MPA at 10m (Site 13) and Poblacion District I at 5m (Site 6) and 10m (Site 5) have the highest coral cover along the Dauin coastline, all with mean coral cover of over 38%, followed by Poblacion District II at 5m (Site 2) and Lipayo I Sur at 10m (Site 9). Sites with the lowest coral cover (<10%) are Bulak I at 5m (Site 12) and 10m (Site 11) and Masaplod Norte at 5m (Site 4) and 10m (Site 3) (Fig 7.1.1, 7.1.2).

Most survey sites along the Dauin coastline follow the same trend for coral cover over the course of the DLTRMP, remaining largely unchanged with minor fluctuations (Fig 3.1.4). However, notable exceptions include Poblacion District I at 10m (Site 5) and Lipayo I Sur at 10m (Site 9), which show large increases in coral cover, whereas Masaplod Sur within the MPA boundary at both 10m (Site 13) and 5m (Site 14) show slight declines in coral cover (Fig 3.1.4).

Diversity indices for the Dauin coastline as a whole show improvements to Scleractinia diversity, richness and evenness (Table 3.1). Looking at diversity metrics for individual sites along the Dauin coastline, some sites have much higher diversity, richness and evenness than others (Fig 3.1.5). Poblacion District II at 10m (Site 1), Poblacion District I at 5m (Site 6) and 10m (Site 5), Masaplod Norte at 10m (Site 3), Maayong Tubig at 10m (Site 19) and Lipayo I Norte at 10m (Site 17) all have high diversity measures. Although genus richness at Masaplod Norte at 5m (Site 4) and Bulak I at 5m (Site 12) is low, all other diversity metrics are relatively high. Sites with consistently low diversity measures include Bulak II at 10m (Site 7), Lipayo I Sur at 10m (Site 9) and 5m (Site 10) and Masaplod Sur MPA at 10m (Site 13) (Fig 3.1.5).

Of the 15 coral genera with highest percent cover, long term trends show *Acropora* and *Echinopora* cover gently increasing, *Anacropora* declining and *Pocillopora* remaining relatively consistent (Fig 3.1.6). *Porites* was the only genus in the top 5 that had significant changes in percent cover over the course of the DLTRMP ($H(3) = 14.046, p < 0.01$), which remained consistent for the first three survey

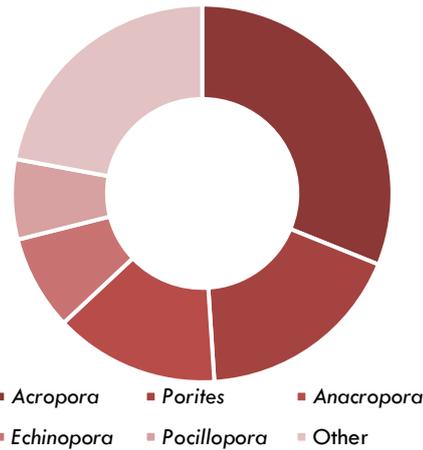


Fig 3.1.3: Relative mean transect cover of most common coral genera along Dauin Reef, where the colour gradient from dark to light represents descending percentage cover.

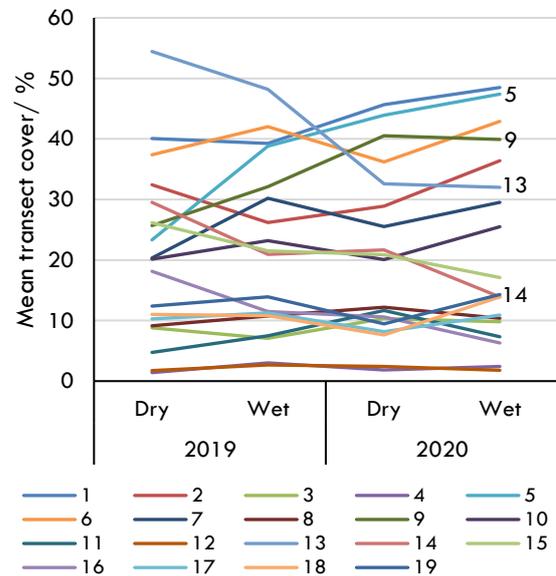


Fig 3.1.4: Mean Scleractinian coral transect cover (%) for each of the 19 survey sites along Dauin Reef separated by survey season. Labels indicate the site number of notable breaks from the overall trend along the coastline.

Table 3.1: Scleractinian diversity for the DLTRMP separated by season. Mean genera richness refers to per transect, whereas total richness refers to the whole Dauin study area.

Diversity Index	2019		2020	
	Dry	Wet	Dry	Wet
Shannon (H)	1.29	1.45	1.56	1.60
Simpson's (SDI)	0.54	0.60	0.65	0.65
Inverse Simpson's (1/D)	2.97	3.39	3.89	3.84
Pielou's evenness (J')	0.52	0.58	0.61	0.61
Mean genus richness (G)	12.68	13.32	13.95	15.00
Total genus richness	41	41	46	43

seasons, but significantly increased in wet 2020. Other genera that changed significantly include *Goniopora* ($H(3) = 19.641, p < 0.01$), *Montipora* ($H(3) = 15.172, p < 0.01$), *Merulina* ($H(3) = 16.917, p < 0.01$) and *Pavona* ($H(3) = 38.627, p < 0.01$), which all show significant increases during the DLTRMP (Fig 3.1.6). Looking at the five most dominant coral genera across sites, it is clear that most sites with higher coral cover tend to be dominated by one, or a few, coral genera (Fig

3.1.7). For example, Poblacion District II at 10 (Site 1) and 5m (Site 2), are sites with proportionally very high *Porites* cover. *Echinopora* dominates Poblacion District I at 10m (Site 5). *Anacropora* dominates Masaplod Sur and Masaplod Sur MPA, both at 5 and 10m (Sites 13-16). Many sites are dominated by *Acropora*, such as Bulak II at 10m (Site 7), Lipayo I Sur at 10 (Site 9) and 5m (Site 10), and Maayong Tubig at 5m (Site 18).

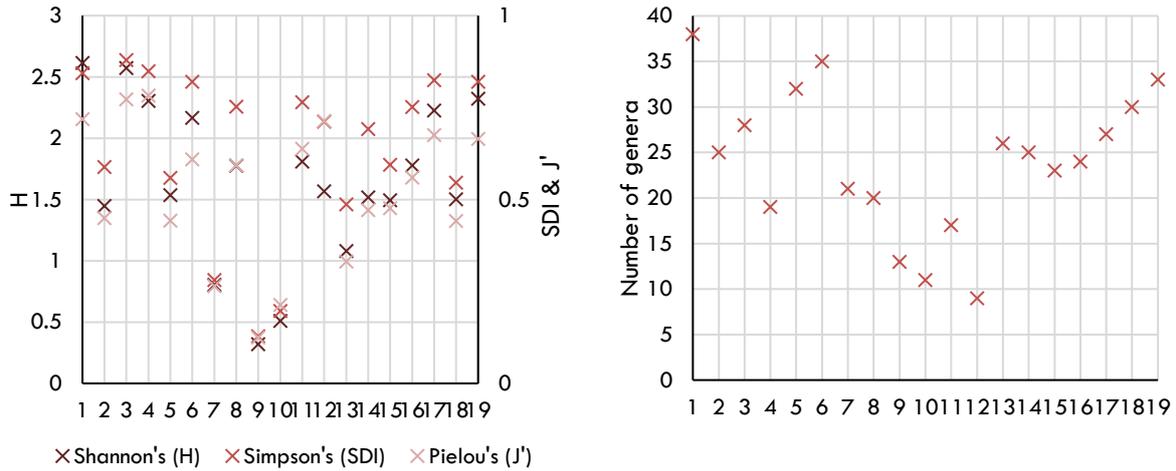


Fig 3.1.5: Diversity metrics (left: Shannon diversity index (H), Simpson's diversity index (SDI) and Pielou's evenness index (J'), right: genus richness (number of genera)) for each study site along the Dauin coastline for the duration of the DLTRMP.

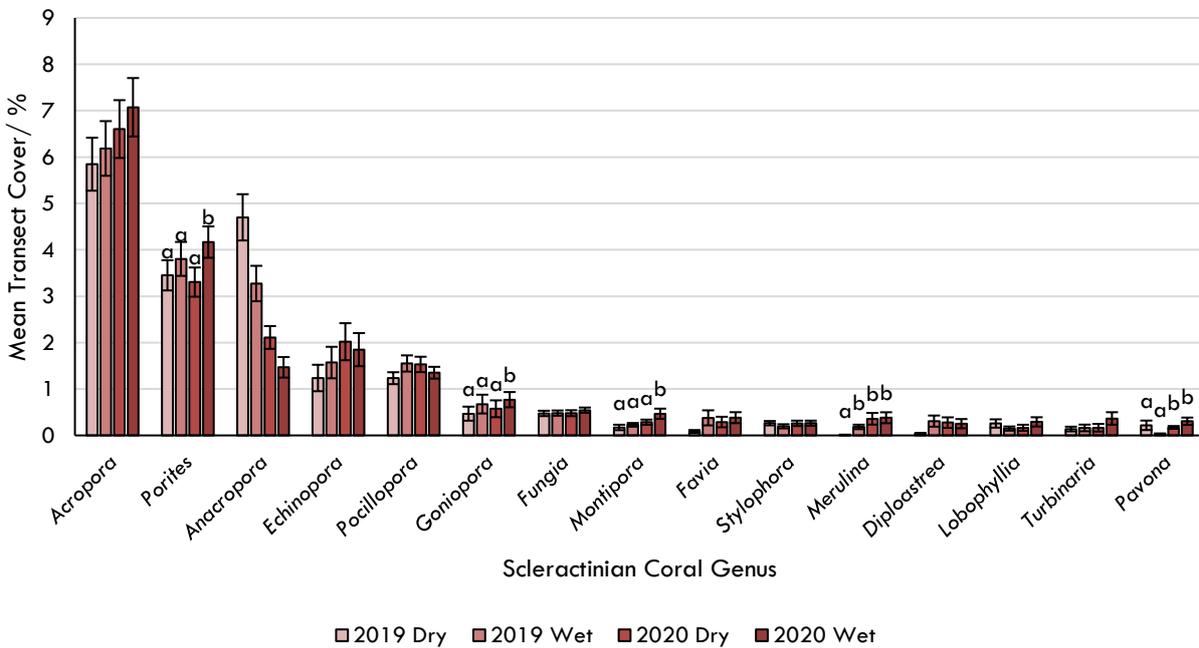


Fig 3.1.6: Mean transect cover (% \pm SE) of 15 most common coral genera along Dauin Reef separated by survey season. Letters represents significant differences within a genus between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

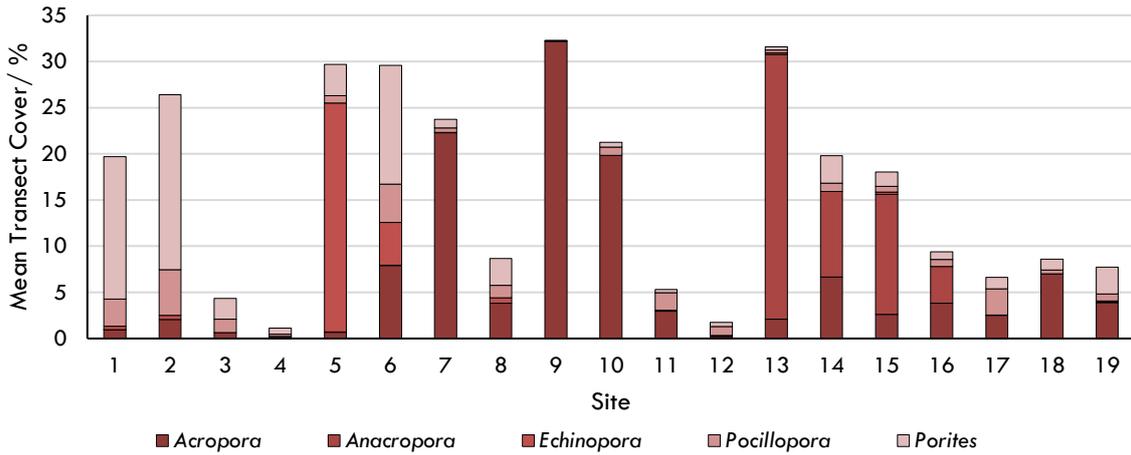


Fig 3.1.7: Mean transect cover (%) of 5 most common coral genera along Dauin Reef survey sites for the duration of the DLTRMP

3.1.2 Abiotic Substrate

Sand, rubble and rock comprise 99.91% of abiotic coverage, with shell, trash and fishing gear as the remaining 0.08% (Fig 3.1.8). Abiotic substrate cover shows significant changes during the DLTRMP ($H(3) = 80.322, p < 0.01$); decreasing from dry 2019 to wet 2019 and from wet 2019 to dry 2020, although no significant change is seen from dry to wet of 2020 (Fig 3.1.2). The three dominant abiotic substrates (rock, rubble and sand) show different relationships between season and site. The most notable trend are the significant and consistent declines in sand ($H(3) = 11.166, p = 0.01$) and rubble ($H(3) = 247.43, p < 0.01$) (Fig XX). There appears to be a trend of increasing rock cover ($H(3) = 85.23, p < 0.01$), although longer-term data is needed to confirm this trend (Fig 3.1.9).

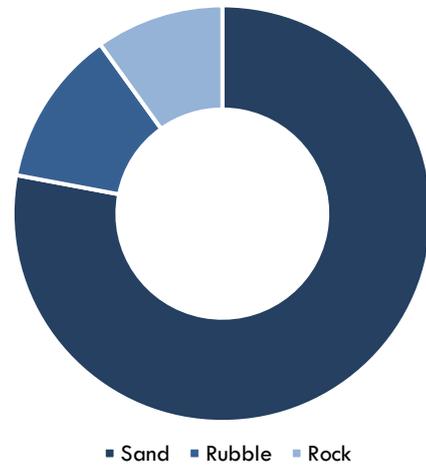


Fig 3.1.8: Relative mean transect cover (%) of abiotic categories along Dauin Reef for the duration of the DLTRMP, where colour gradient from dark to light represents descending percentage cover.

Sites with highest abiotic percent cover include Bulak I 5m (Site 12) and 10m (Site 11), with 85.6% and 69.6% respectively, Lipayo II at 10m (Site 8), with 77.1% and Lipayo I Norte at 10m (Site 17), with 74.1%. Sites with lowest abiotic cover include Masaplod Sur MPA at 10m (Site 13), Lipayo I Sur at 10m (Site 9), Poblacion District II at 10m (Site 1) and Poblacion District I at 5m (Site 6), with 13.1%, 28.3%, 29.1% and 30.6% respectively (Fig 7.1.3, 7.1.4). Most survey sites along the Dauin coastline follow the same trends over the course of the DLTRMP, for both total abiotic cover and the individual components within this category (Fig 3.1.10). However, notable exceptions include severe declines in abiotic cover at Poblacion District I at 10m (Site 5) and Lipayo I Sur at 10m (Site 9). Lipayo I Sur at 10m (Site 9) has the greatest decrease in sand cover. Poblacion District I at 10m (Site 5) shows the greatest decline in rubble cover, followed by Poblacion District I at 5m (Site 6). Poblacion District II at 10m (Site 1) shows much greater fluctuations in rock cover than all other sites along the coast (Fig 3.1.10).

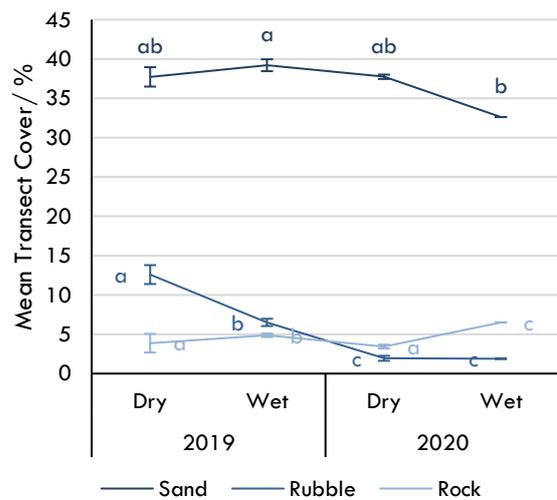


Fig 3.1.9: Mean abiotic substrate transect cover (% ± SE) along Dauin Reef separated by survey season and abiotic type. Letters represents significant differences within a substrate type between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

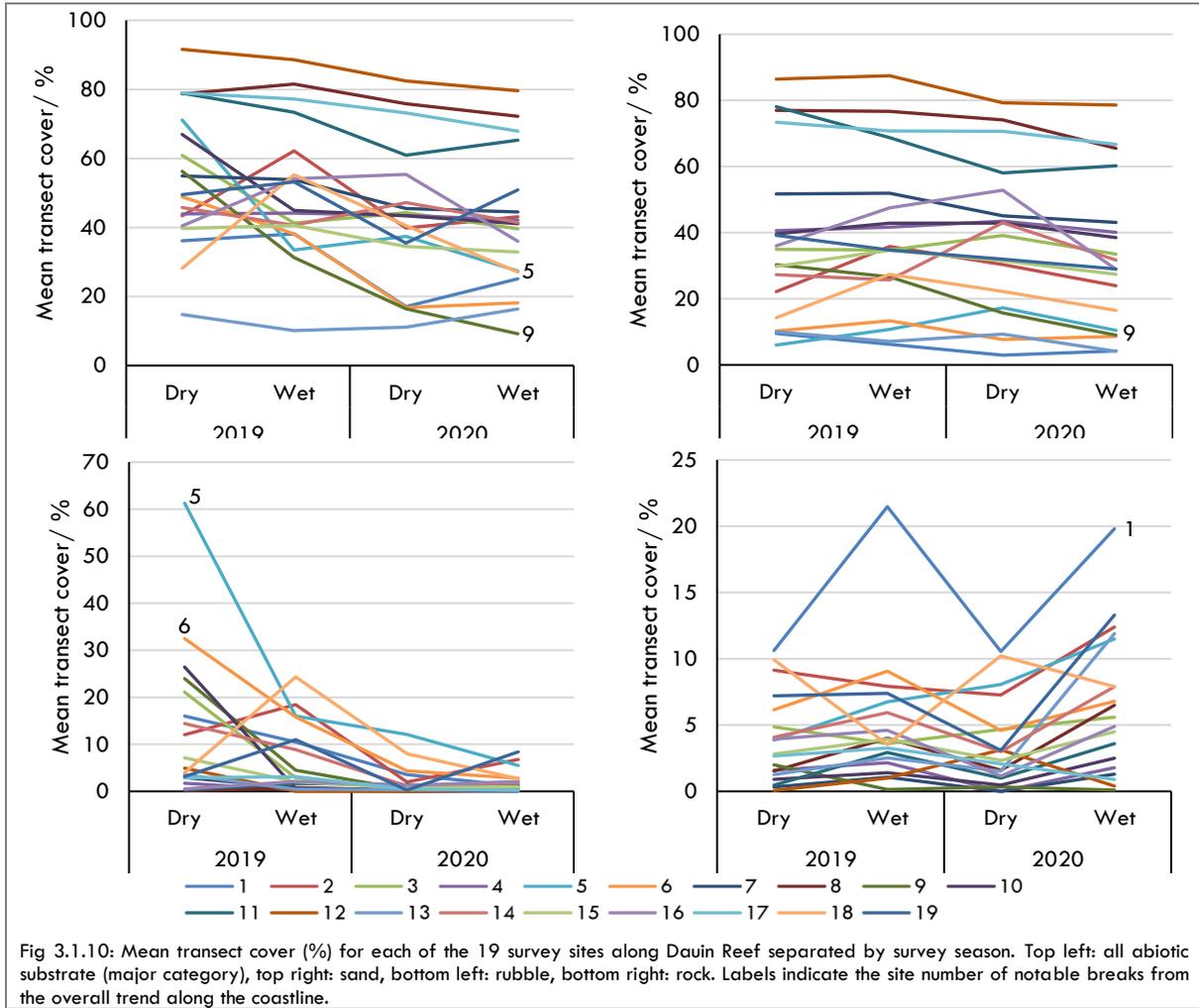


Fig 3.1.10: Mean transect cover (%) for each of the 19 survey sites along Dauin Reef separated by survey season. Top left: all abiotic substrate (major category), top right: sand, bottom left: rubble, bottom right: rock. Labels indicate the site number of notable breaks from the overall trend along the coastline.

3.1.3 Algae

Turf algae, coralline algae and other algae combined contribute to 96.0% of algae recorded, with *Halimeda* contributing 4.0% and sargassum contributing <0.01% (Fig 3.1.11). Algae cover shows significant changes during the DLTRMP ($H(3) = 257.86, p < 0.01$); increasing significantly each survey season until 2020 wet, which shows a significant decrease (Fig 3.1.2). This trend in total algae transect cover observed over the course of the DLTRMP is mirrored in that of turf algae (Fig 3.1.12). Coralline algae cover increases significantly from 2019 dry to wet, but has not changed significantly since. Other algae cover is significantly higher in dry season than wet ($H(1) = 51.756, p < 0.01$) and *Halimeda* shows a gentle yet significant decrease in percentage cover over the survey seasons (Fig 3.1.12).

Sites with the highest overall algae percent cover are Maayong Tubig at 5m (Site 18), Poblacion District I at 5m (Site 6) and Masaplod Norte at 5m (Site 4), with 26.0%, 20.5% and 20.0% respectively. Sites with the lowest overall algae percent cover are

Lipayo II at 10m (Site 8), Bulak I at 5m (Site 12), Masaplod Sur at 5m (Site 16) and Bulak II at 10m (Site 7), with 4.7%, 5.7%, 5.8% and 6.3% respectively (Fig 7.1.5, 7.1.6).

Most survey sites along the Dauin coastline follow the same trends over the course of the DLTRMP, for both total algae cover and the individual components within this category (Fig 3.1.13). Masaplod Norte at 5m (Site 4) and Poblacion District I at 5m (Site 6) show a more elevated spike in total algae cover in the 2020 dry season than all other sites, which is attributable to the spike in turf algae. Maayong Tubig at 5m (Site 18) shows large and consistent increases in total algae compared to all other sites, which is attributable to the only minor decline in turf algae and a large surge in coralline algae cover. Maayong Tubig at 10m (Site 19) also shows a spike in coralline algae, but in 2020 dry season, which then drops to levels consistent with other sites along the coast. Other sites that show notable increases in coralline algae are Lipayo I Sur at 10m (Site 9) and Poblacion District I at 10m (Site 5) and 5m (Site 6).

Sites that show different trends to the majority of sites along the coast for 'other algae' include Poblacion District II at 10m (Site 1) and Masaplod

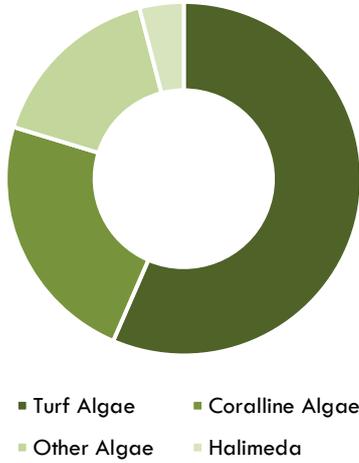


Fig 3.1.11: Relative mean transect cover (%) of algae categories along Dauin Reef for the duration of the DLTRMP, where colour gradient from dark to light represents descending percentage cover.

Sur at 10m, both within the MPA boundary (Site 13) and outside (Site 15).

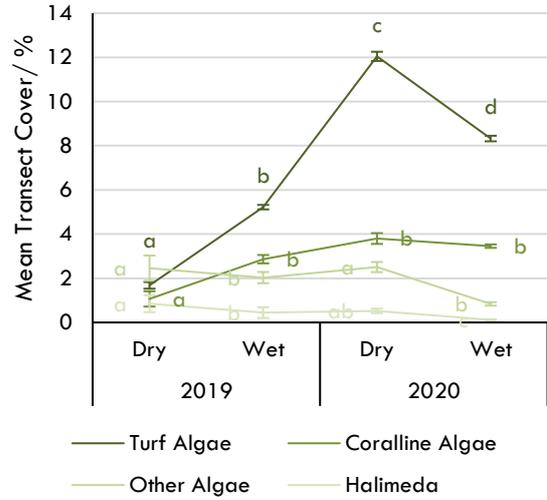


Fig 3.1.12: Mean algae transect cover (% ± SE) along Dauin Reef separated by survey season and algae type. Letters represents significant differences within an algae type between survey seasons; seasons with different letters are significantly different from each other (p<0.05).

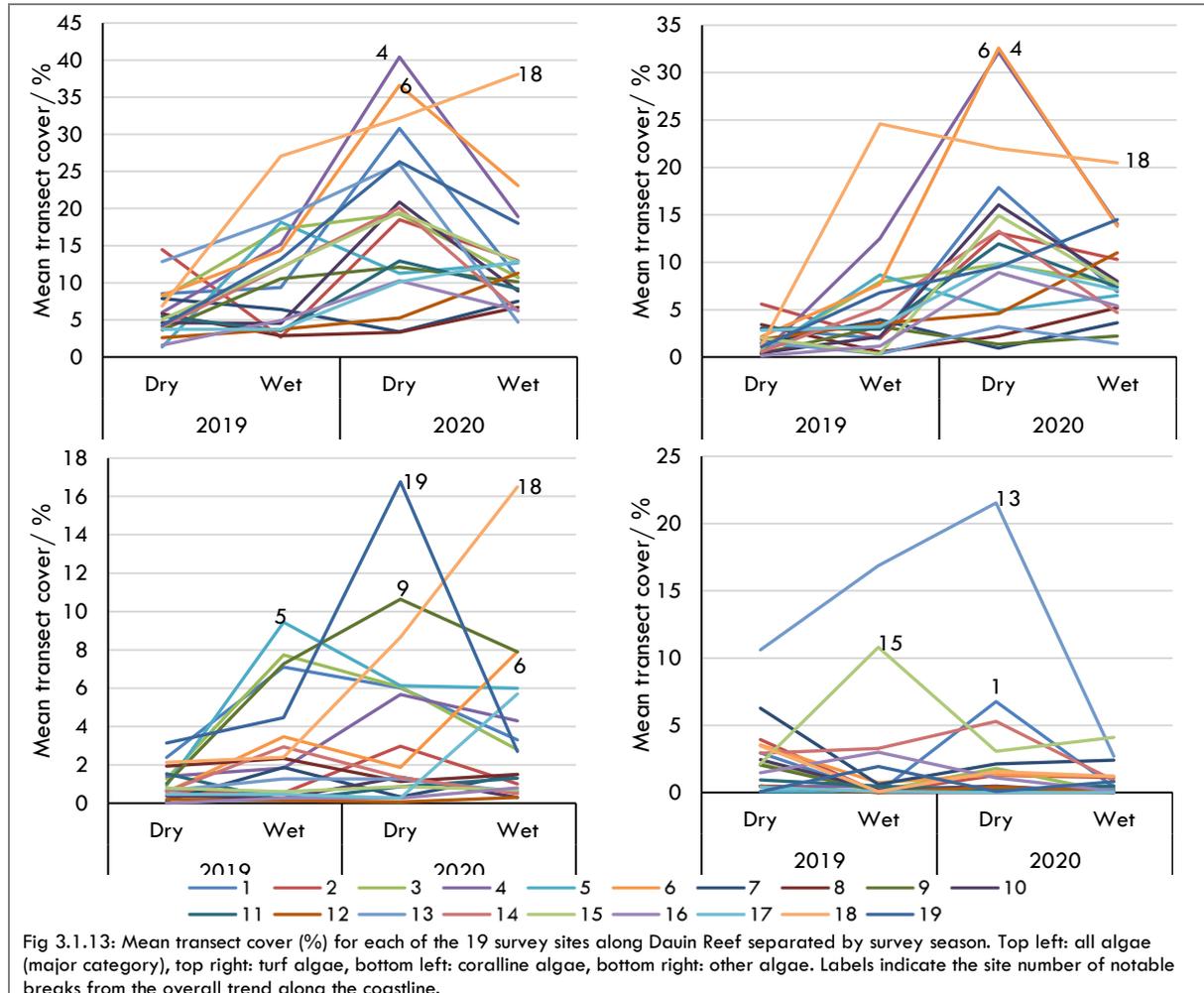


Fig 3.1.13: Mean transect cover (%) for each of the 19 survey sites along Dauin Reef separated by survey season. Top left: all algae (major category), top right: turf algae, bottom left: coralline algae, bottom right: other algae. Labels indicate the site number of notable breaks from the overall trend along the coastline.

3.1.4 Dead Coral

Coral rubble contributes to on average 88.7% of dead coral, whereas dead coral with algae and recently dead coral contribute 9.3% and 2.0% respectively (Fig 3.1.14).

Although dead coral cover changes significantly throughout the DLTRMP ($H(3) = 66.705, p < 0.01$), no clear trend is apparent as yet in the category as a whole, possibly as a result of varying trends in the dead coral types within the major category (Fig 3.1.15). Coral rubble appears to be consistently increasing, excluding a significant decline in cover in 2020 dry, dead coral with algae is stable, excluding a significant decline in 2019 dry after which percent cover returned to pre-existing levels, and recently

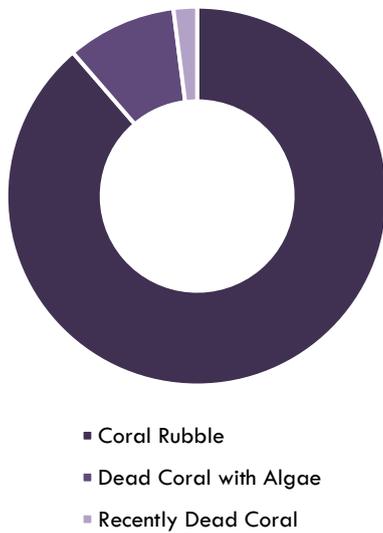


Fig 3.1.14: Relative mean transect cover (%) of dead coral categories along Dauin Reef for the duration of the DLTRMP, where colour gradient from dark to light represents descending percentage cover.

3.1.5 Sponges

Encrusting, branching and rope sponge combined contribute to 90.7% of sponge recorded, with tube sponge contributing 5.5% and ball, barrel and fan sponges contributing 3.8% combined (Fig 3.1.16). Sponge cover remained consistent from dry 2019 until wet 2020, which increased significantly ($H(3) = 77.487, p < 0.01$). This trend in total sponge cover is mirrored in that of encrusting sponge (Fig 3.1.17). Branching sponge cover significantly increased from 2019 dry to wet, before decreasing slightly and levelling out in 2020. Rope sponge decreased from 2019 dry to wet, but significantly increased in the following two survey seasons. Tube sponge decreased significantly from 2019 dry to wet, but

dead coral appears to be gently increasing as time progresses (Fig 3.1.15).

Sites with highest overall dead coral percent cover are Masaplod Norte at 5m (Site 4), Masaplod Sur MPA at 5m (Site 14), Lipayo I Sur at 10m (Site 9) and Maayong Tubig at 5m (Site 18) and, with 25.7%, 20.9%, 18.9% and 17.6% respectively. All other sites have overall average dead coral percent cover below 15%. Sites with the lowest overall percent dead coral cover include Bulak I at 5 (Site 12) and 10m (Site 11), Lipayo II at 10m (Site 8) and Bulak II at 10m (Site 7), with 0.1%, 0.5%, 0.8% and 1.8% respectively (Fig 7.1.7, 7.1.8).

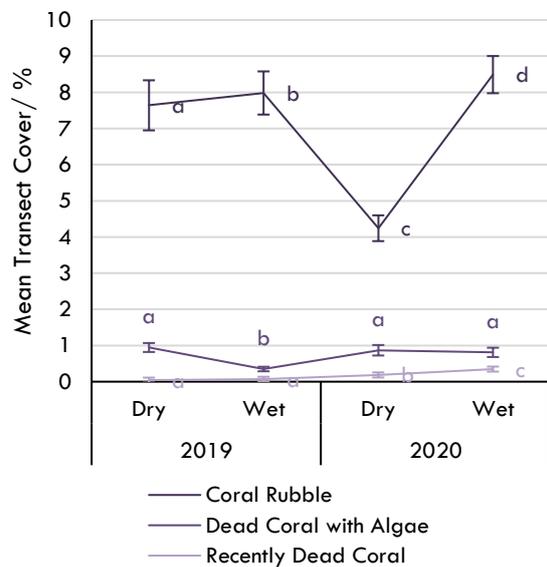


Fig 3.1.15: Mean dead coral transect cover (% ± SE) along Dauin Reef separated by survey season and dead coral type. Letters represents significant differences within a dead coral type between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

has remained consistent since. Ball sponge cover fluctuated around the mean, but has continued to have very low coverage, of 0.1% or less (Fig 3.1.17).

Masaplod Norte at 10m (Site 3) and Masaplod Sur at 10m (Site 15) have the greatest mean sponge cover, significantly higher than all other sites, with 13.7% and 10.7% respectively. Sites with the lowest sponge cover are Masaplod Sur MPA at 5m (Site 14) and Bulak I at 5 (Site 12), with sponge covers of 2% or less (Fig 7.1.9, 7.1.10). Most survey sites along the Dauin coastline follow similar trends over the course of the DLTRMP, for both total sponge cover and the individual components within this category (Fig 3.1.18). Masaplod Norte at 10m (Site 3) and

Masaplod Sur at 10m within the MPA boundary (Site 13), followed by Masaplod Sur at 10m outside the MPA boundary (Site 15), Maayong Tubig at 10m (Site 19) and Masaplod Norte at 5m (Site 4), all show greater increases in total sponge cover over time than other sites along the Dauin coastline (Fig 3.1.18).

These increases are attributable to the increases in different sponge types for different sites (Fig 3.1.18). For Masaplod Norte, both at 10m (Site 3) and 5m (Site 4), encrusting sponge cover is much higher than at all other sites, and it greatly increases throughout the DLTRMP. For Masaplod Sur at 10m, both within (Site 13) and outside the MPA (Site 15), rope sponge cover is much higher than at all other sites, and it greatly increases throughout the DLTRMP. This is true also for outside the MPA at 5m (Site 16), although to a lesser extent. Masaplod Sur at 10m, both within (Site 13) and outside the MPA (Site 15) also show elevated branching sponge cover, during 2019 wet and 2020 dry season respectively, although these decrease to levels consistent with the rest of the coastline by 2020 wet season, whereas Maayong Tubig at 10m (Site 19) shows a consistently increasing percent cover of branching sponge during the course of the DLTRMP.

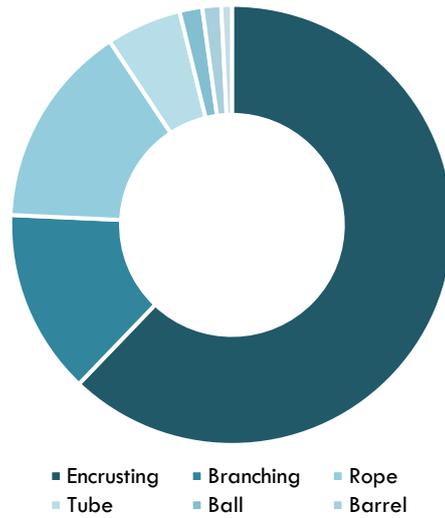


Fig 3.1.16: Relative mean transect cover (%) of sponge morphologies along Dauin Reef for the duration of the DLTRMP, where colour gradient from dark to light represents descending percentage cover.

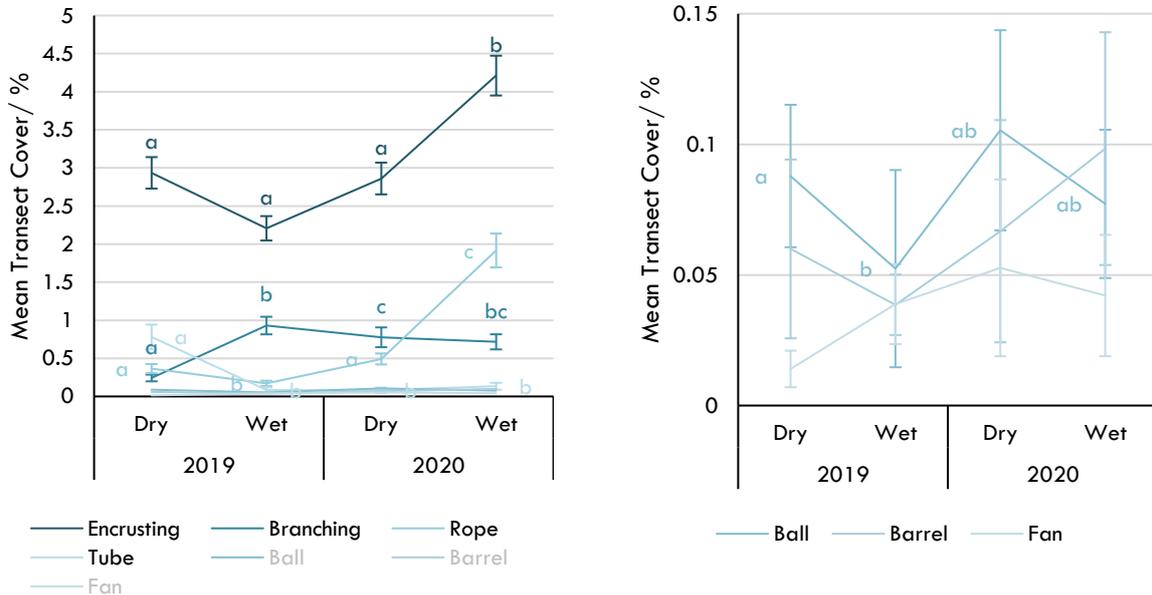


Fig 3.1.17: Mean sponge transect cover (% ± SE) along Dauin Reef separated by survey season and sponge morphology. Letters represents significant differences within a sponge type between survey seasons; seasons with different letters are significantly different from each other (p<0.05). Graph on right is a zoom on the minor categories (grey categories in legend on left graph).

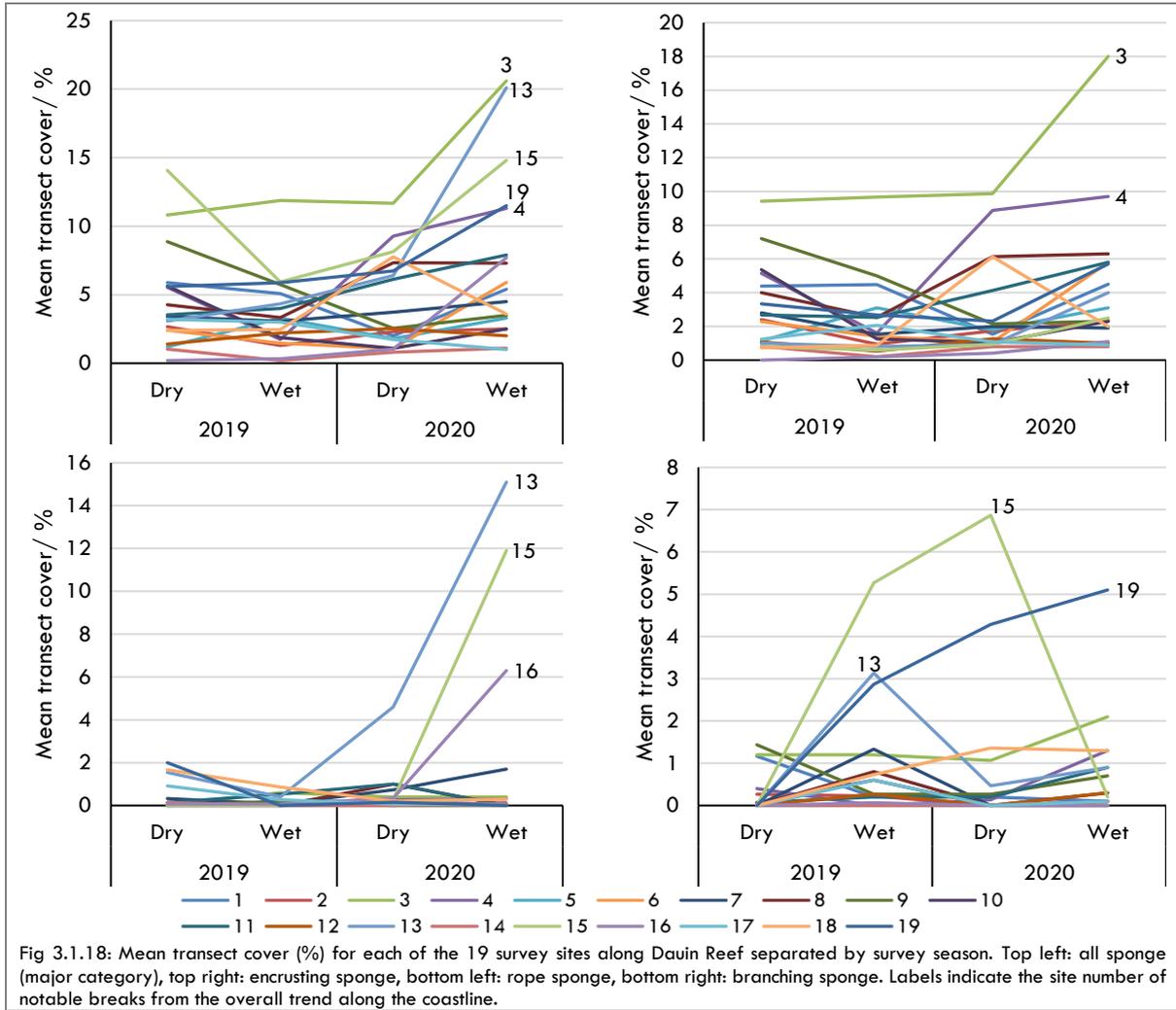


Fig 3.1.18: Mean transect cover (%) for each of the 19 survey sites along Dauin Reef separated by survey season. Top left: all sponge (major category), top right: encrusting sponge, bottom left: rope sponge, bottom right: branching sponge. Labels indicate the site number of notable breaks from the overall trend along the coastline.

3.1.6 Cyanobacteria

Cyanobacteria percent cover has significantly increased during the DLTRMP ($H(3) = 39.347, p < 0.01$); significantly increasing from dry to wet season of 2019, and from dry to wet of 2020, although there was no significant change between 2019 wet and 2020 dry (Fig 3.1.2, 3.1.19).

Cyanobacteria has been recorded at 18 survey sites, although it accounts for on average only 1.4% of the benthic composition of Dauin’s reefs, as 11 of 19 sites show negligible percent cyanobacteria cover (<1%). The highest cyanobacteria percentage cover was recorded at Masaplod Sur MPA at 10m (Site 13), at 6.6%, followed by Masaplod Sur at 10m (Site 15) and Lipayo I Sur at 10m (Site 9), with 4.3% and 3.0% respectively (Fig 7.1.11, 7.1.12).

Most survey sites along the Dauin coastline follow the same trends of cyanobacteria cover over the course of the DLTRMP (Fig 3.1.20), however, notable spikes are seen at Masaplod Sur at 5m outside the MPA boundary (Site 15) during 2019 wet season, Masaplod Sur at 5m inside the MPA boundary (Site

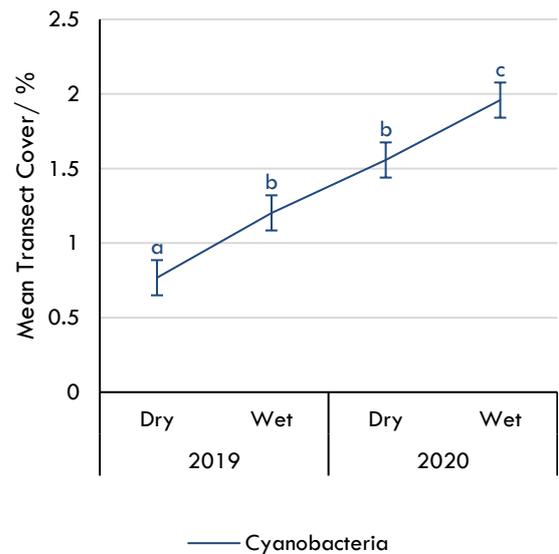


Fig 3.1.19: Mean cyanobacteria transect cover (% ± SE) along Dauin Reef separated by survey season. Letters represents significant differences between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

13) during 2020 dry season, and Lipayo I Sur at 10m (Site 9) during 2020 wet season (Fig 3.1.20). These rare spikes are high enough to give these three sites the highest mean cyanobacteria cover over the course of the DLTRMP (Fig 7.1.11), as well as separating these sites from all others in the cluster dendrogram (Fig 7.1.12).

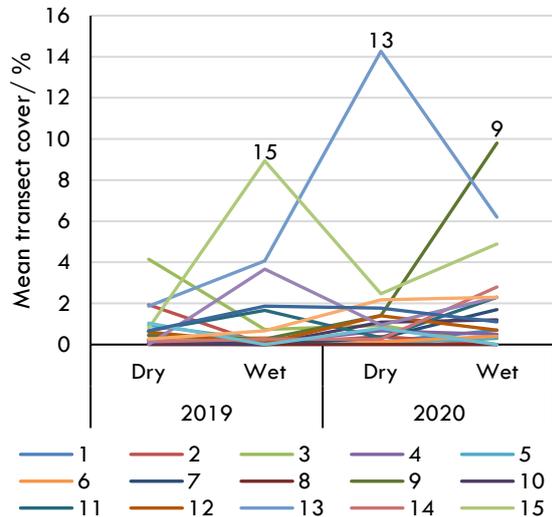


Fig 3.1.20: Mean cyanobacteria transect cover (%) for each of the 19 survey sites along Dauin Reef separated by survey season. Labels indicate the site number of notable breaks from the overall trend along the coastline.

3.1.7 Seagrass

Seagrass cover has changed significantly over the course of the DLTRMP ($H(3) = 11.824$, $p < 0.01$); declining slightly from 2019 dry to wet, but increasing in 2020 to return to similar levels (Fig 3.1.2). Seagrass was recorded along the transects of 8 survey sites, although it accounts for on average only 2.2% of the benthic composition of Dauin's reefs, as 15 of 19 sites show negligible percent seagrass cover ($<1\%$). The highest seagrass percentage cover was recorded at Masaplod Sur at 5m (Site 16), at 22.8%, significantly higher than all other sites (Fig 7.1.13, 7.1.14). Other sites with significantly greater average percent cover of seagrass include Bulak II at 10m (Site 7) with 10.7%, Lipayo I Sur at 5m (Site 10) with 4.3% and Masaplod Sur at 10m (Site 15), with 2.2% (Fig 7.1.13, 7.1.14).

3.1.8 Hydroids

Hydroid cover has not changed significantly during the course of the DLTRMP ($H(3) = 3.473$, $p = 0.32$) (Fig 3.1.2). Hydroids represent a minor component of the benthic composition of Dauin's reefs, averaging a coverage of 0.8% and most sites have negligible hydroid coverage ($<1\%$). Sites with highest percentage cover are Bulak I at 10m (Site 11), Poblacion District II at 10m (Site 1) and Masaplod Norte at 10m (Site 3), which have average hydroid coverage of 4.1%, 3.4% and 2.9% respectively, significantly higher than most other sites (Fig 7.1.15, 7.1.16).

3.1.9 Bivalves

Bivalve cover has not changed significantly during the course of the DLTRMP ($H(3) = 3.00$, $p = 0.39$) (Fig 3.1.2). Bivalves contribute on average 0.01% to the benthic composition of Dauin's reefs, as the least prevalent major category (Fig 3.1.1). Bivalves were recorded at only 7 of the 19 survey sites and all sites show negligible coverage ($<1\%$). Masaplod Norte at 10m (Site 3) has the highest bivalve coverage. Other site with bivalves recorded were Poblacion District II at 10m (Site 1), Lipayo I Sur at 10m (Site 9), Poblacion District I at 5m (Site 6), (Site 14), (Site 2) and Masaplod Norte at 5m (Site 4) (Fig 7.1.17, 7.1.18).

3.1.9 Other hexacorals and octacorals

Other hexacoral cover has not changed significantly during the course of the DLTRMP ($H(3) = 7.08$, $p = 0.07$). Other hexacoral cover is greatest at Bulak I at 10m (Site 11) and 5m (Site 12), both with mean coverage of 0.8% (Fig 7.1.19, 7.1.20). Octocoral cover has not changed significantly during the course of the DLTRMP ($H(3) = 6.174$, $p = 0.10$). Octocoral cover is greatest at Masaplod Sur at 10m, both inside (Site 13) and outside (Site 15) the MPA boundary, with coverage of 5.9% and 4.9% respectively (Fig 7.1.21, 7.1.22).

3.2 Reef Impacts & Coral Mortality

A total of 373 impacts were recorded throughout the 2019 (dry: 152, wet: 221) survey year across Dauin’s reefs, compared to 759 in 2020 (dry: 247, wet: 512), with the mean count of impacts per transect of 9.8 in 2019, compared to 20.0 in 2020. Coral bleaching has been the most prevalent impact during the DLTRMP, followed by unknown scarring, *Drupella* spp. feeding activity, and fishing trash (Fig 3.2.1).

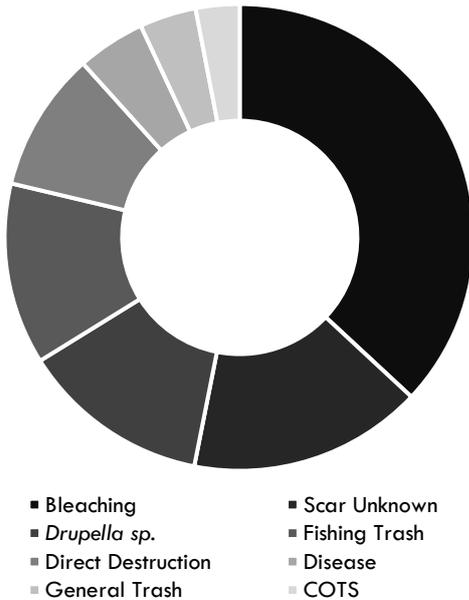


Fig 3.2.1: Relative frequency of different impacts along Dauin Reef for duration of DLTRMP, where the colour gradient from dark to light represents descending frequency.

The frequency of coral bleaching, unknown scarring, *Drupella* spp. feeding activity, fishing trash and disease per transect have all increased significantly

since the beginning of the DLTRMP (Fig 3.2.2). Bleaching frequency was consistent throughout 2019, but incrementally increased during 2020. The frequency of unknown scarring remained unchanged until the most recent survey season (2020 wet), which saw a significant and sharp increase. For *Drupella* spp. feeding activity, fishing trash and disease, the changes in frequency over time are consistent; slight increases/fluctuations for the first three survey seasons, followed by sharp increases in 2020 wet. The trend of direct destruction (now including damage from stone fishing) frequency is similar, although the changes are not statistically significant. General trash and Crown of Thorns Starfish (COTS) frequency show minor but insignificant changes (Fig 3.2.2).

3.2.1 Coral Bleaching

A total of 149 incidences of bleaching were recorded throughout the 2019 (dry: 72, wet: 77) survey year across Dauin’s reefs, compared to 268 in 2020 (dry: 120, wet: 148), with the mean count of impacts per transect of 3.9 in 2019, compared to 7.1 in 2020. Bleaching frequency has changed significantly throughout the DLTRMP ($H(3) = 11.837, p < 0.01$); it was consistent throughout 2019, but increased significantly from wet 2019 to wet 2020, with a transitional period in dry 2020 (Fig 3.2.2). The depth of the site does not significantly affect the frequency of bleaching ($H(1) = 0.013, p = 0.91$) (Fig 3.2.3).

The number of coral genera affected by bleaching has increased slightly during the DLTRMP (2019: 19 (dry: 11, wet: 18), 2020: 23 (dry: 17, wet: 20)). The mean colony area affected by bleaching has stayed

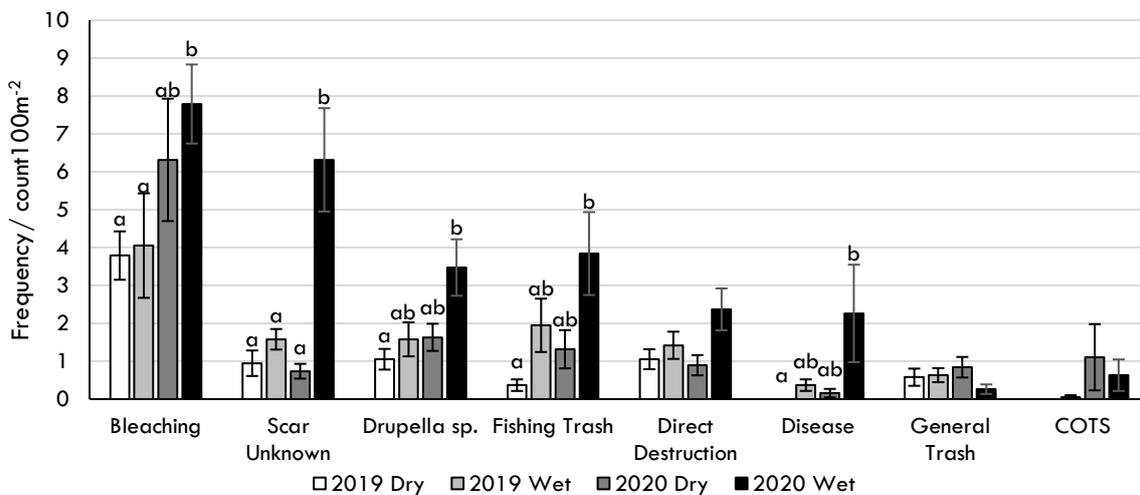


Fig 3.2.2: Mean frequency (count/100m² ± SE) of recorded impacts along Dauin Reef separated by survey season. Stone fishing impacts are included within the category Direct Destruction. Letters represents significant differences within a category between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

consistent (2019: 96.7% (dry: 95.0%, wet: 98.4%), 2020: 92.8% (dry: 97.5%, wet: 89.0%)). The frequency of bleaching and area of colony affected are genera specific (Fig 3.2.4); *Fungia* had much higher incidences of bleaching than all other genera (41% of all bleaching incidences), and *Fungia*, *Pavona*, *Ctenactis*, *Montastrea* and *Favia* had the highest percentage areas of colony affected.

Bleaching by coral morphology shows solitary corals to be the most frequently bleached (primarily *Fungia*), followed by encrusting, massive and branching corals (Fig 3.2.5). Size groupings show smaller corals more frequently bleach than larger colonies (Fig 3.2.5), although it is important to note genus bias in size groupings; 52% of bleaching records within the 5-10cm category are *Fungia*.

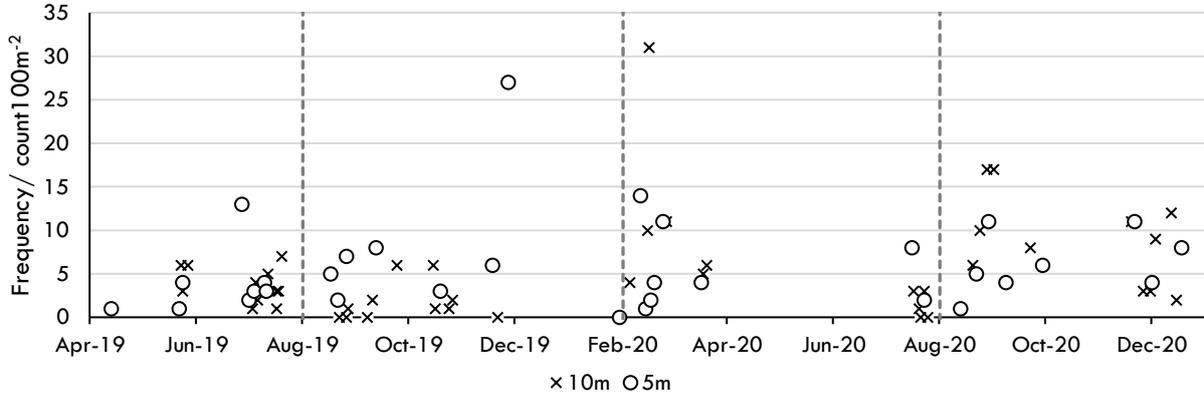


Fig 3.2.3: Frequency (count/100m²) of recorded bleaching impacts along Dauin Reef for every survey conducted, separated by depth of site and survey season (represented by the dotted vertical lines).

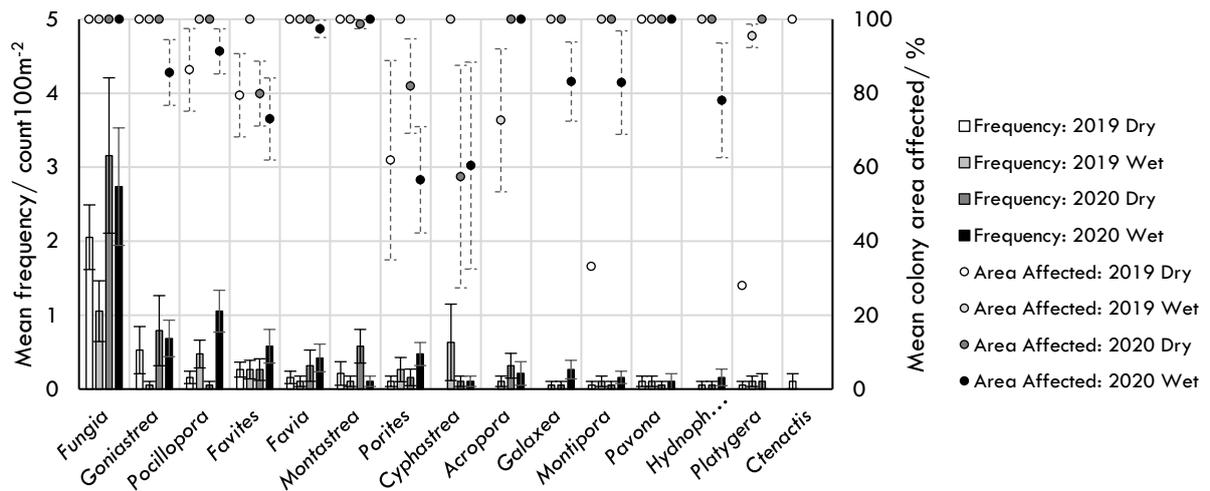


Fig 3.2.4: Mean frequency (count/100m² ± SE) and the percentage size of the affected area (Colony Size Affected/ % ± SE) of bleaching events on 15 most frequently bleached coral genera along Dauin Reef separated by survey season.

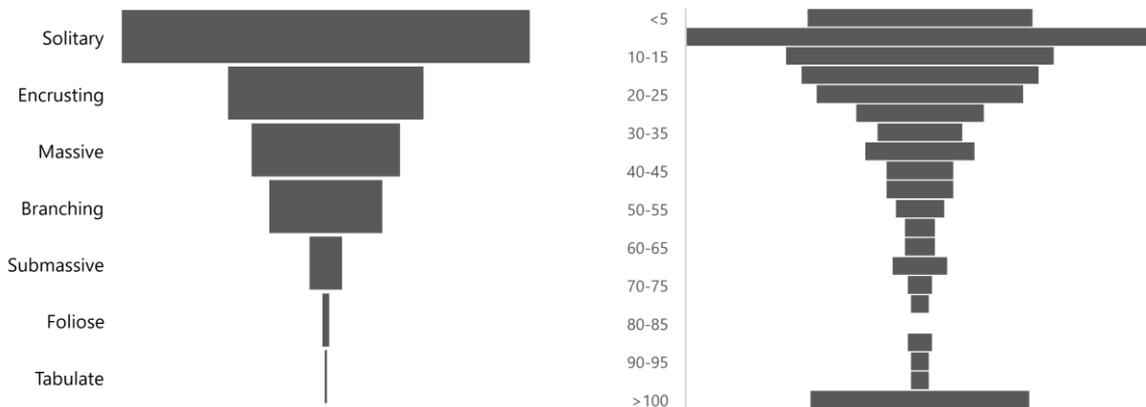


Fig 3.2.5: Total frequency of bleaching records on different coral (left) morphologies and (right) size groupings, for duration of DLTRMP.

3.2.2 *Drupella* spp. Feeding Activity

Drupella spp. feeding activity has changed significantly throughout the DLTRMP ($H(3) = 8.776, p = 0.03$); counts per transect increased significantly from dry 2019 to wet 2020, with a transitional period of wet 2019 to dry 2020 (Fig 3.2.2). The total coral area affected by *Drupella* spp. feeding activity per 100m² transect has also significantly increased over time, again from dry 2019 to wet 2020, with a transitional period of wet 2019 to dry 2020 (Fig 3.2.6). Looking at individual colonies, the mean area affected per colony follows a similar trend, whereas the mean percent area affected per colony decreases slightly over time (Fig 3.2.6). From the most recent survey season (2020 wet), the mean total coral area affected per 100m² transect was 1037cm² (Fig 3.2.6). The majority of *Drupella* spp. feeding activity records are on *Acropora* spp. (n=102, 69.4% of records), followed by *Pocillopora* spp. (n=28, 19.0% of records). All other genera had a total of five or less records for the course of the DLTRMP.

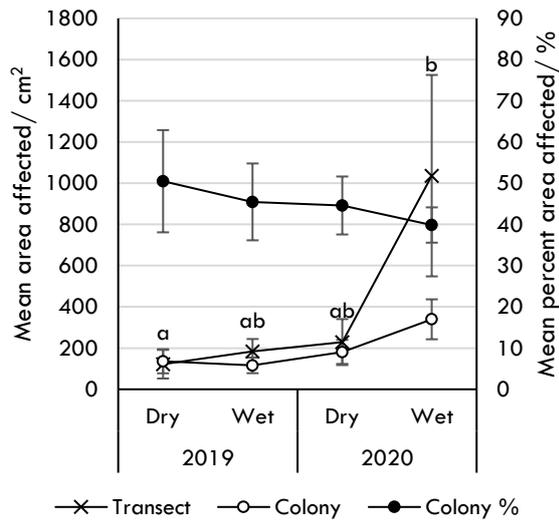


Fig 3.2.6: Mean total coral area affected per 100m² transect (cm²100m⁻² ± SE), mean area affected per colony (cm² ± SE), and mean percent area affected per colony (% ± SE) by *Drupella* spp. feeding activity along Dauin Reef separated by survey season. Letters represents significant differences for mean total coral area affected per 100m² transect (cm²100m⁻² ± SE) between survey seasons; seasons with different letters are significantly different from each other (p<0.05).

3.2.3 Trash

Fishing trash has significantly increased throughout the DLTRMP ($H(3) = 9.666, p = 0.02$); counts per transect increased significantly from dry 2019 to wet 2020, with a transitional period from wet 2019 to dry 2020 (Fig 3.2.2). General trash has remained consistent throughout the DLTRMP ($H(3) = 3.346, p = 0.34$). Significant differences are also seen in the number of trash items at different locations along the Dauin coastline, for both fishing trash ($H(10) =$

27.454, $p < 0.01$) and general trash ($H(10) = 31.189, p < 0.01$). Locations with greater numbers of fishing trash include Bulak I and II, Lipayo I and Masaplod Norte (Fig 3.2.7). Locations with greater numbers of general trash include Lipayo I Sur, Bulak I, Maayong Tubig and Masaplod Norte (Fig 3.2.8).

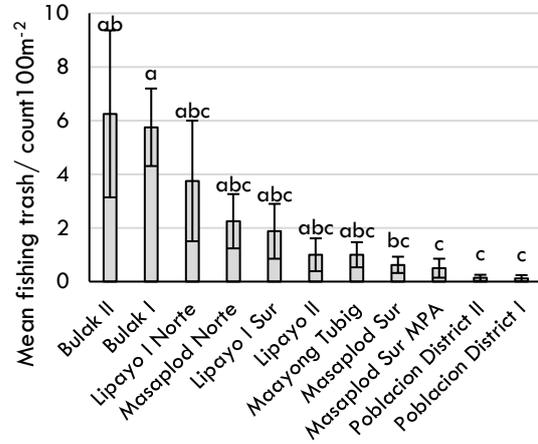


Fig 3.2.7: Mean number of fishing trash items per 100m² transect (count100m⁻² ± SE) for the duration of the DLTRMP, separated by location along the Dauin coastline. Letters represents significant differences between locations; locations with different letters are significantly different from each other (p<0.05).

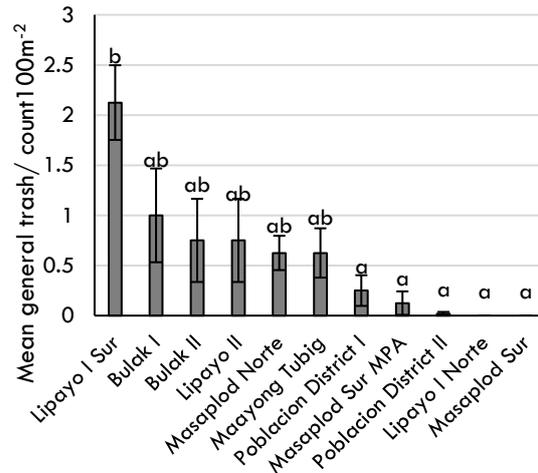


Fig 3.2.8: Mean number of general trash items per 100m² transect (count100m⁻² ± SE) for the duration of the DLTRMP, separated by location along the Dauin coastline. Letters represents significant differences between locations; locations with different letters are significantly different from each other (p<0.05).

3.2.4 Direct Destruction

Direct destruction recordings have not changed significantly over the course of the DLTRMP ($H(3) = 4.473, p = 0.21$), although a slight increase is seen from dry to wet of 2020 (Fig 3.2.2). There are no significant correlations between the frequency of direct destruction and the number of fishing or dive boats; although direct destruction increased in wet 2020, the number of fishing boats remained

consistent and the number of dive boats declined (Fig 3.2.9).

Of the 109 direct destruction incidences recorded since the beginning of the DLTRMP, 9 (8%) were as a result of stone fishing practices (2019 dry: 4 wet: 2, 2020 dry: 1 wet: 3) (3 at Lipayo I Sur, 5 at Masaplod Sur and 1 at Masaplod Sur MPA).

Branching coral morphologies are the most frequently impacted by direct destruction, followed by tabulate and foliose (Fig 3.2.10). *Acropora* is the genus most frequently impacted by direct destruction, followed by *Pocillopora*, *Stylophora* and *Porites* (Fig 3.2.10).

Secondary impacts from direct destruction have been recorded in 40% of direct destruction cases; most commonly predation, followed by bleaching and disease (Fig 3.2.11).

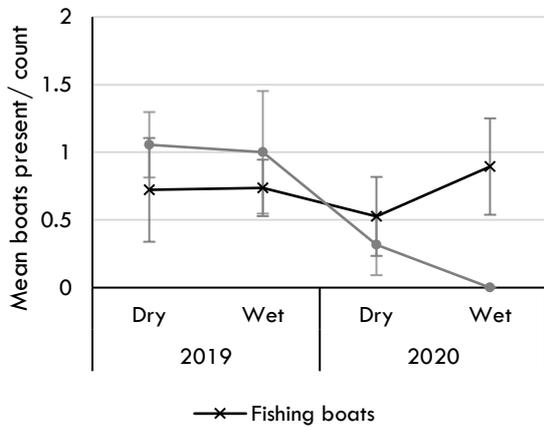


Fig 3.2.9: Mean number of boats present per survey (count ± SE) along Dauin Reef separated by survey season.

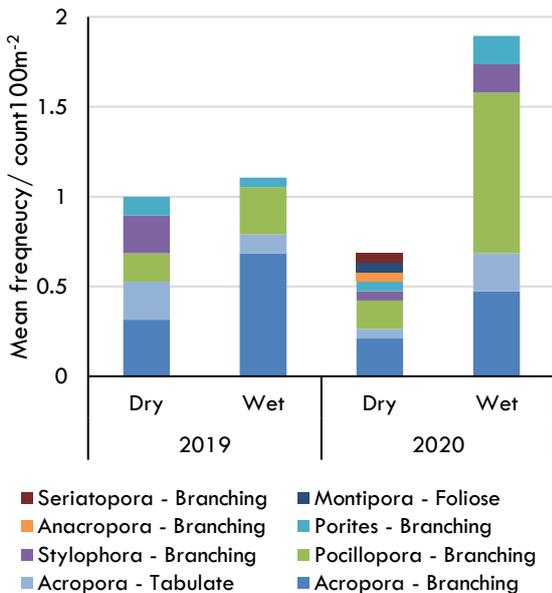


Fig 3.2.10: Mean frequency of direct destruction incidences (count/100m² ± SE) along Dauin Reef separated by coral genus, morphology and survey season.

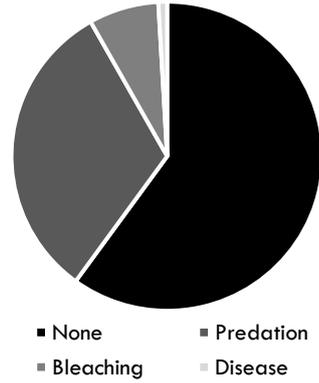


Fig 3.2.11: Relative frequency of secondary impacts after direct destruction along Dauin Reef for duration of DLTRMP.

3.2.5 Disease

Disease prevalence remained stable for the first three survey seasons, before significantly increasing in wet 2020 ($H(3) = 10.812, p = 0.01$), as a result of a large spike in *Porites* Ulcerative White Spot (PUWS) (Fig 3.2.12). Two counts of skeletal eroding band disease (SEBD) have been recorded, both during 2019 wet on branching *Pocillopora*, affecting a mean colony area of 42cm² (27% of colony). Two counts of white syndrome (WS) have been recorded, both during 2020 wet, also on branching *Pocillopora*, with a mean colony area affected of 158cm² (55% of colony). Two counts of *Porites* pinking (PP) have been recorded, one during 2019 wet and the other 2020 wet, both on massive *Porites*, with a mean colony area affected of 636cm² (100% of colony).

Porites is also affected by *Porites* ulcerative white spot (PUWS), which has been recorded on the Dauin coastline since 2019 wet but saw a significant increase from 2020 dry to wet. PUWS has been recorded on both branching (45% of records) and massive (55% of records) *Porites* colonies. The mean colony area affected is 573cm² (100% of colony).

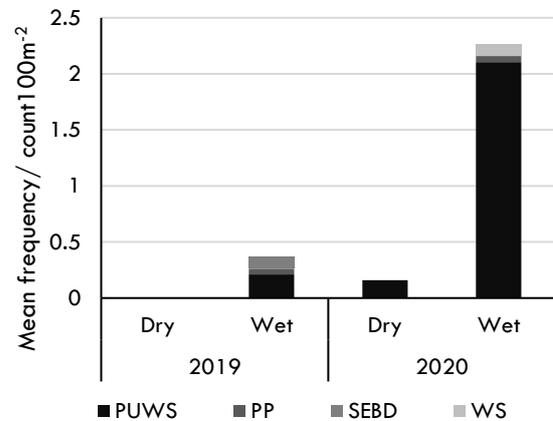


Fig 3.2.12: Mean frequency of disease incidences (count/100m²) along Dauin Reef separated by disease type (PUWS = *Porites* Ulcerative White Spot, PP = *Porites* Pinking, SEBD = Skeletal Eroding Band Disease, WS = White Syndrome) and survey season.

3.2.6 Crown of Thorns Starfish (COTS)

Throughout 2019, only one COTS individual was recorded along the Dauin coastline, during wet season at Poblacion District I 10m (Site 5). Actively feeding COTS numbers remained low in 2020 across most of the coastline (2020 dry: Poblacion District I 5m (Site 6) n= 1 and Lipayo I Sur 10m (Site 9) n=3, 2020 wet: Masaplod Sur MPA at 10m (Site 13) n=2 and Masaplod Norte 10m (Site 3) n=1 and 5m (Site 4) n=1). Exceptions to these low numbers of COTS were found in 2020 dry at Masaplod Sur 5m (Site 16), with 17 actively feeding individuals recorded and in 2020 wet at Masaplod Sur MPA 5m (Site 14), with 8 actively feeding individuals; Masaplod Sur both inside and outside the MPA boundary account for 82% of COTS records (Fig 3.2.13). Of the total 34 individuals recorded throughout the DLTRMP, 13 were found on their associated coral colony (others were found with nearby scars). *Acropora* is the most frequently impacted genus (n=9), followed by *Pavona* (n=2), *Anacropora* (n=1) and *Porites* (n=1). *Acropora* also has the largest mean area affected by COTS predation (498cm²), followed by *Anacropora* (363cm²), *Porites* (95cm²) and *Pavona* (10cm²), however note for all genera excluding *Acropora*, only one record of affected area is available (a measurement for one of the *Pavona* records was unattainable).

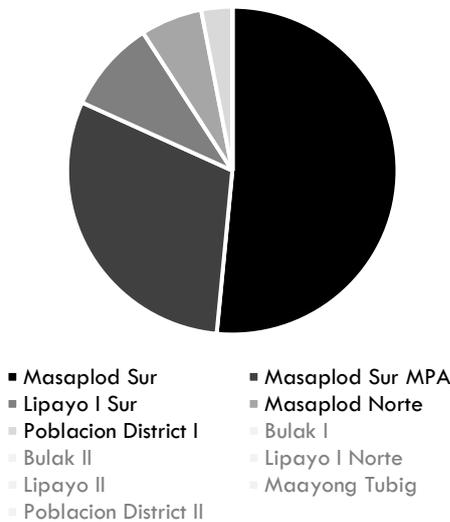


Fig 3.2.13: Relative frequency of COTS records at different survey locations along Dauin Reef for duration of DLTRMP. Locations in grey have zero COTS records.

3.2.7 Genera breakdown

Acropora is the most frequently impacted genera recorded, followed by *Fungia*, *Pocillopora* and *Porites* (Fig 3.2.14). Over the course of the DLTRMP, only three genera (*Pocillopora*, *Porites* and *Montipora*) of the 15 most frequently impacted show significant changes in the number of impacts recorded across seasons. All three exhibit the same trend, remaining consistent for the first three survey

seasons, followed by a significant increase in 2020 wet season – *Pocillopora* ($H(3) = 29.901, p < 0.01$), *Porites* ($H(3) = 13.901, p < 0.01$) and *Montipora* ($H(3) = 10.900, p = 0.01$).

Acropora is affected mostly by *Drupella* spp. feeding activity (47%), followed by direct destruction, unknown scarring, bleaching and COTS predation. *Anacropora* is mostly recorded impacted by unknown scarring (43%), followed by *Drupella* spp. feeding activity. *Pavona* is mostly impacted by bleaching (58%), followed by unknown scarring and COTS predation. *Pocillopora* is mostly impacted by unknown scarring (37%), bleaching, *Drupella* spp. feeding activity and direct destruction. *Porites* is affected mostly by disease (predominantly PUWS) (53%), followed by bleaching, unknown scarring and direct destruction. *Seriatopora* is mostly impacted by unknown scarring (88%), with a few counts of bleaching and direct destruction. *Stylophora* is mostly affected by direct destruction (42%), followed by unknown scarring, *Drupella* spp. feeding activity and bleaching. The following genera are all mostly impacted by bleaching; *Cyphastrea* (89%), *Favia* (90%), *Favites* (96%), *Fungia* (92%), *Galaxea* (88%), *Goniastrea* (91%) and *Montastrea* (100%), followed by unknown scarring as the only other impact recorded for these genera (Fig 3.2.15).

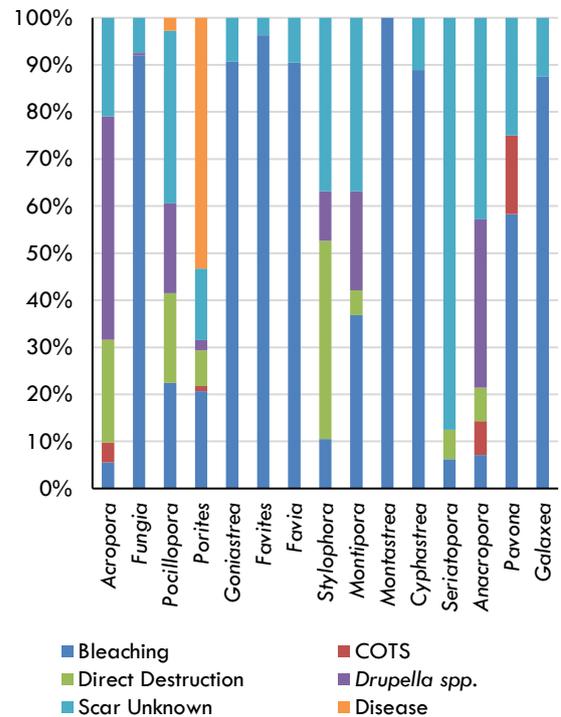


Fig 3.2.15: Proportional frequency of different impacts recorded for each of the 15 most frequently impacted coral genera along Dauin Reef. Total number of impacts recorded for each; *Acropora* n=215, *Anacropora* n=14, *Cyphastrea* n=18, *Favia* n=21, *Favites* n=27, *Fungia* n=186, *Galaxea* n=8, *Goniastrea* n=43, *Montastrea* n=19, *Montipora* n=19, *Pavona* n=12, *Pocillopora* n=92, *Porites* n=92, *Seriatopora* n=16, *Stylophora* n=19.

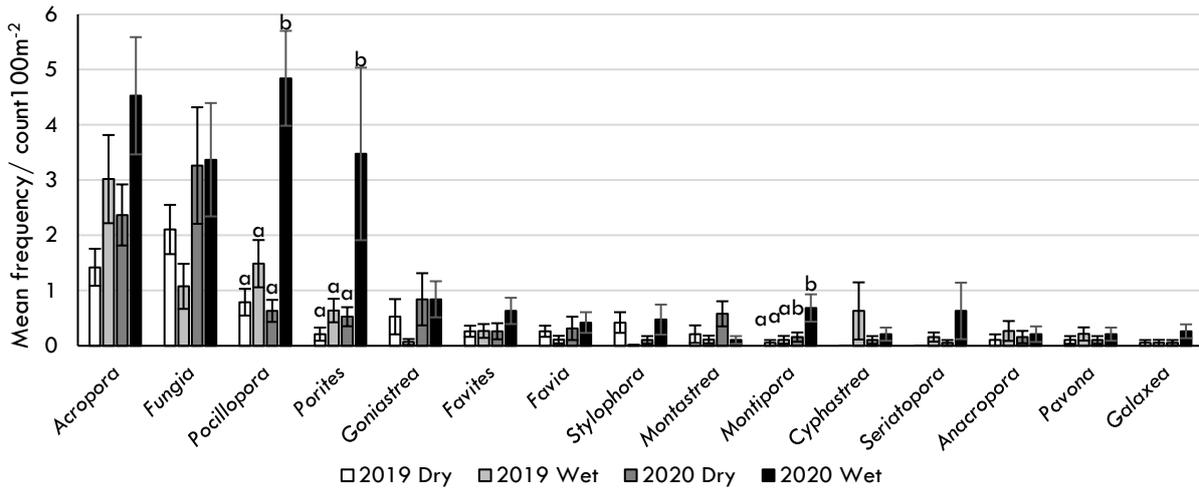


Fig 3.2.14: Mean frequency (count/100m² ± SE) of all recorded impacts on 15 most frequently impacted coral genera along Dauin Reef, separated by survey season. Letters represents significant differences within a genus between survey seasons; seasons with different letters are significantly different from each other (p<0.05).

3.2.8 Location breakdown

Impacts such as bleaching, direct destruction, unknown scarring, trash and *Drupella* spp. feeding activity have been recorded consistently along the Dauin coastline, although some impacts are more site specific (Table 3.3). For example, COTS have only been recorded at Masaplod Sur (inside and outside MPA) and Poblacion District II, direct destruction as a result of stone fishing has only been recorded at Lipayo I Sur and Masaplod Sur (inside and outside MPA), and disease tends to be limited to the Barangays Bulak and Poblacion.

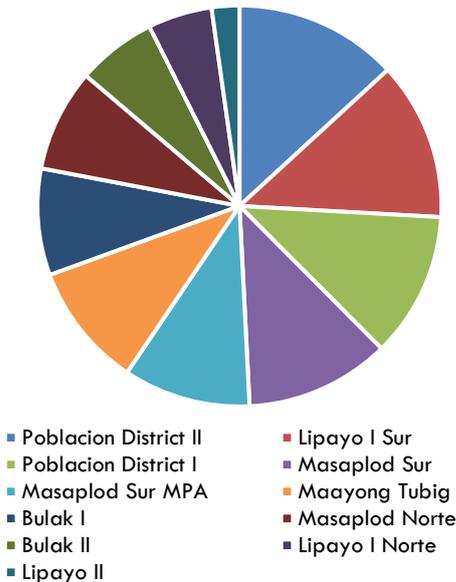


Fig 3.2.16: Relative mean total impact count per 100m² transect for the duration of the DLTRMP, separated by survey location along Dauin Reef.

Most locations show consistent counts of impacts, with a mean for the Dauin reef system of 26 impacts per 100m² transect, although a few sites have notably

higher or lower impact counts; Poblacion District II has 37 per 100m² and Lipayo I Sur has 36, whereas Lipayo II and Lipayo I Norte have 6 and 15 per 100m² respectively (Fig 3.2.16). It is important to consider however that the number of impacts is likely to be higher when coral cover is greater, as shown by the positive relationship between coral cover and mean number of impacts (Fig 3.2.17). The only impact irrespective of coral cover is trash, both fishing and general.

Looking at the changing rank per location from 2019 to 2020 (Table 3.2), the greatest increase in mean number of impacts per transect from 2019 to 2020 is seen at Poblacion District I, followed by Masaplod Sur and Bulak I. The greatest decrease (decrease in rank) of impacts per transect are seen at Bulak II and Maayong Tubig.

Table 3.2: Rank of each survey location according to mean number of impacts recorded at that location for each survey year and the change in rank from 2019 to 2020.

	2019 Rank	2020 Rank	Rank Change
Poblacion District II	8	1	7
Lipayo I Sur	1	2	-1
Poblacion District I	4	3	1
Masaplod Sur	6	4	2
Masaplod Sur MPA	5	5	0
Maayong Tubig	3	6	-3
Bulak I	9	7	2
Masaplod Norte	7	8	-1
Bulak II	2	9	-7
Lipayo I Norte	10	10	0
Lipayo II	11	11	0

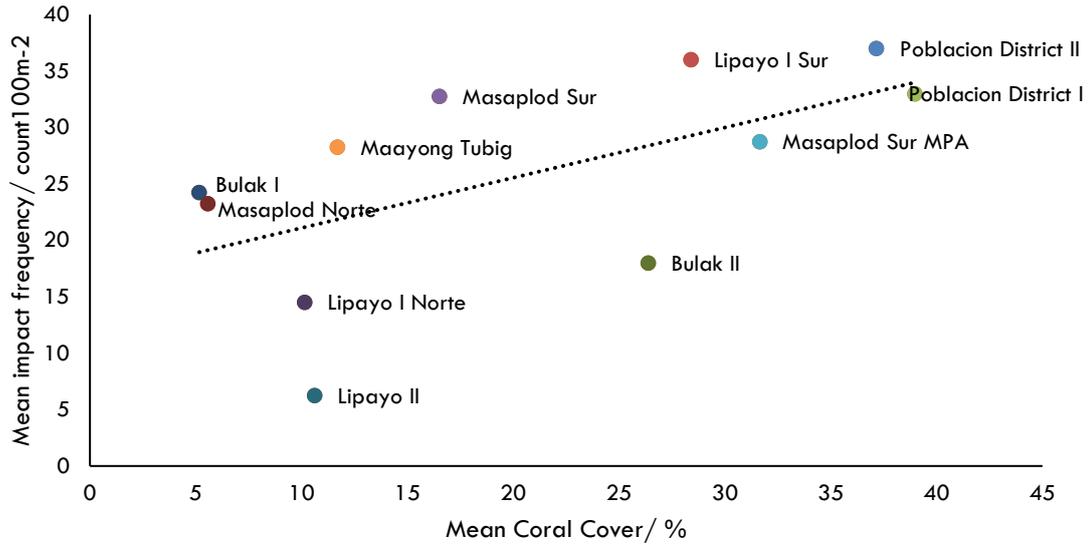


Fig 3.2.17: Mean coral cover of and mean number of impacts recorded at each survey location with trendline ($y = 0.4447x + 16.648$, $r^2=0.3417$).

	<i>Acanthaster planci</i> (COTS)					Bleaching					Direct Destruction					Disease				
	2019		2020		Trend	2019		2020		Trend	2019		2020		Trend	2019		2020		Trend
Bulak I	0	0	0	0	→	3	0	2.5	3.5	↗	0	2	0.5	2	↗	0	0	0	1	↗
Bulak II	0	0	0	0	→	2	1	0	9	↗	1	2	0	3	↗	0	0	0	6	↗
Lipayo I Norte	0	0	0	0	→	1	1	0	12	↗	0	1	1	0	→	0	0	0	1	↗
Lipayo I Sur	0	0	1.5	0	↗	3.5	4.5	16.5	7	↗	1.5	3	1	1	↘	0	0	0	0	→
Lipayo II	0	0	0	0	→	4	1	1	3	↗	0	0	0	2	↗	0	0	0	0	→
Maayong Tubig	0	0	0	0	→	3	14.5	5.5	5	→	2.5	1	0.5	1.5	→	0	0.5	0	0	→
Masaplod Norte	0	0	0	1	↗	5	5	5	10.5	↗	0	0.5	0	2.5	↗	0	0	0	0	→
Masaplod Sur	0	0	8.5	0	↗	1.5	3.5	5.5	10.5	↗	2	2.5	3	2.5	→	0	0	0	0	→
Masaplod Sur MPA	0	0	0	5	↗	4.5	1	11	5.5	↗	0.5	1.5	1	2	↗	0	0.5	0	1.5	↗
Poblacion District I	0	0.5	0.5	0	→	10	5.5	9	9	↗	1	0.5	1.5	4	↗	0	1.5	0	2	→
Poblacion District II	0	0	0	0	→	2	3	4.5	11	↗	2	1	0.5	4.5	↗	0	1	1.5	13.5	↗

	Drupella					Fishing Trash					General Trash					Scar Unknown				
	2019		2020		Trend	2019		2020		Trend	2019		2020		Trend	2019		2020		Trend
Bulak I	0	0	2	0	→	1	6	5.5	10.5	↗	0.5	0.5	3	0	→	0.5	0.5	1	3	↗
Bulak II	1	5	2	9	↗	2	3	3	17	↗	0	2	1	0	↘	0	2	0	1	→
Lipayo I Norte	0	0	3	6	↗	0	0	4	11	↗	0	0	0	0	→	5	2	1	9	↗
Lipayo I Sur	2.5	5	3	1	↘	0	5	1	1.5	↘	3	2	2.5	1	↘	0	2.5	0	2.5	→
Lipayo II	0	0	0	2	↗	0	1	0	3	↗	0	0	2	1	↗	0	0	2	3	↗
Maayong Tubig	0.5	1	3	4.5	↗	1	0	1.5	1.5	→	0.5	1	0.5	0.5	→	0	0.5	1.5	5	↗
Masaplod Norte	0.5	0	0	0.5	→	0.5	4	0	4.5	→	1	1	0	0.5	↘	0	1.5	0.5	2.5	↗
Masaplod Sur	0	1	1	4.5	↗	0	1	0.5	1	→	0	0	0	0	→	2	2	1	12	↗
Masaplod Sur MPA	2	3	2.5	7.5	↗	0	0	0.5	1.5	↗	0	0	0.5	0	→	1.5	2.5	0	2	→
Poblacion District I	1.5	1.5	1.5	2.5	↗	0	0.5	0	0	→	0.5	0.5	0	0	↘	2	2.5	1	7	↗
Poblacion District II	2.5	1	0	4	↗	0	0	0	0.5	→	0	0	0	0	→	0.5	1	0.5	19.5	↗

 Table 3.3: Mean incidence per location (count/100m²) of each recorded impact along Dauin Reef separated by survey season.

3.3 Reef Fish Community Structure

A total of 73676 fish have been recorded since the beginning of the DLTRMP; 21593 fish during the 2019 survey year (dry: 7148, wet: 14445), compared to 52083 during the 2020 survey year (dry: 21034, wet: 31049). This equates to a total fish biomass for the duration of the DLTRMP of 1326.91kg; 451.73kg in 2019 (dry: 178.70kg, wet: 273.02kg) and 875.18kg in 2020 (dry: 495.79kg, wet: 379.40kg). A total of 346 fish species, within 42 families, have been recorded since the beginning of the DLTRMP; 247 in 2019 (dry: 178, wet: 218) and 301 in 2020 (dry: 249, wet: 223).

Mean abundance, biomass and species richness have all increased significantly since the beginning of the DLTRMP (Fig 3.3.1) (abundance: $F(3,72) = 29.69$, $p < 0.01$, biomass: $F(3,72) = 7.54$, $p < 0.01$, species richness: $F(3,72) = 6.55$, $p < 0.01$). Mean fish abundance has significantly increased twice since the beginning of the DLTRMP; although the difference between 2020 dry and wet was not significant, mean abundance still increased. Mean fish biomass and species richness follow the same trend; significantly increasing from 2019 dry to 2020 dry (with a transitional period of 2019 wet), and not significantly changing from 2020 dry to wet (Fig 3.3.1). The species accumulation curve is gently moving towards a plateau (Fig 3.3.2).

Looking at sites along the coastline, Bulak I, Poblacion District II and Lipayo II have the highest mean fish abundance, although there are no significant

differences in fish abundance across the different locations ($F(10,65) = 1.14$, $p = 0.35$). Fish biomass does differ significantly across locations ($F(10,65) = 4.16$, $p < 0.01$); Masaplod Sur and Masaplod Sur MPA (lowest biomass) have significantly lower fish biomass than Lipayo II, Lipayo I Sur and Masaplod Norte (highest biomass) (Fig 3.3.6). Species richness is highest at Masaplod Norte, Lipayo I Sur, Poblacion (both districts) and Maayong Tubig (Fig 3.3.3).

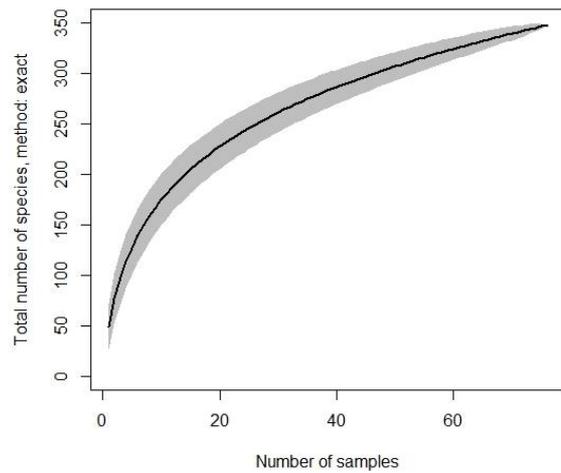


Fig 3.3.2: Species accumulation curve for the current 76 samples of the DLTRMP, obtained with the function specaccum of the 'vegan' R package. Confidence intervals (from standard deviation) are represented by shaded area around curve. Calculated using "exact" method, which finds the expected (mean) species richness.

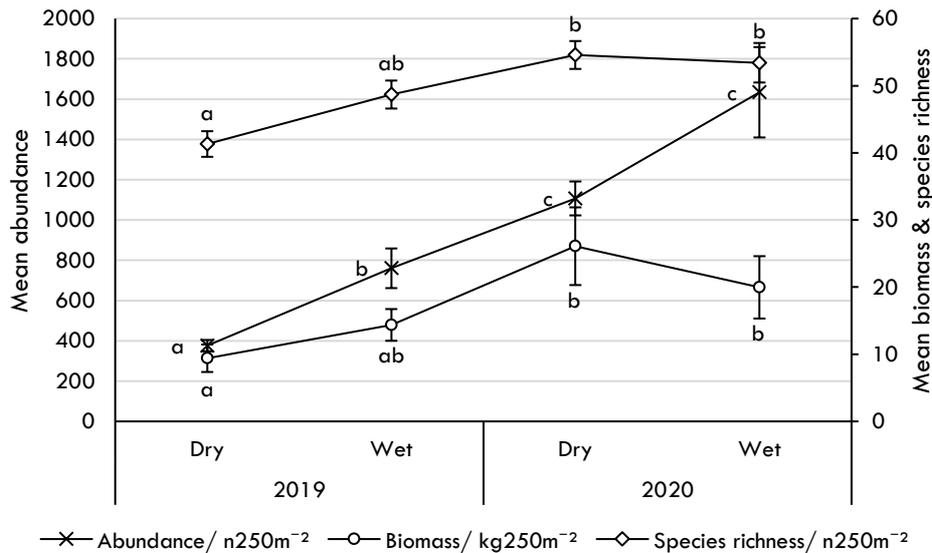


Fig 3.3.1: Mean fish abundance ($n250m^{-2} \pm SE$), biomass ($kg250m^{-2} \pm SE$) and species richness ($n250m^{-2} \pm SE$) along Dauin Reef separated by survey season. Letters represents significant differences within each metric (abundance, biomass and species richness) between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

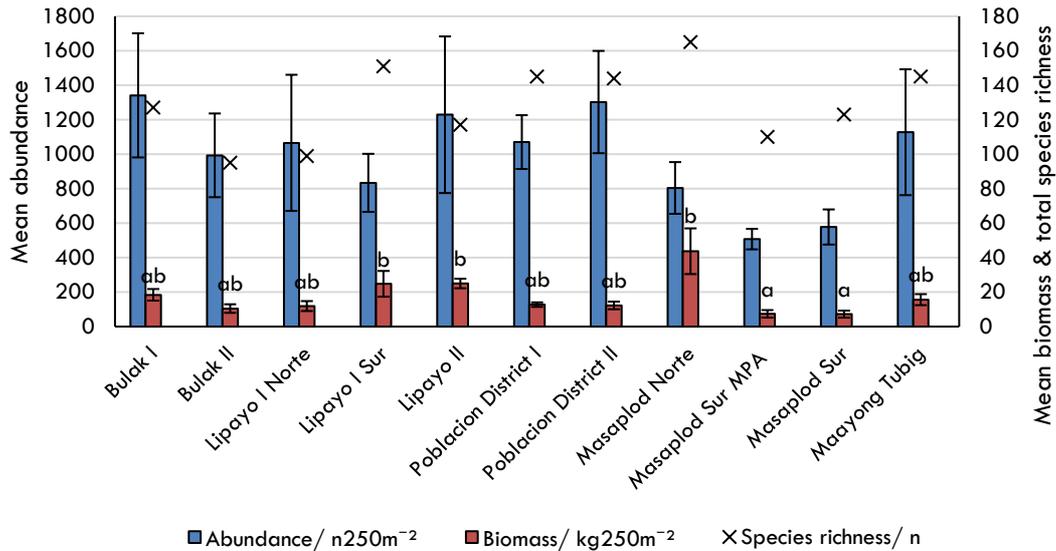


Fig 3.3.3: Mean abundance (n250m⁻² ± SE), biomass (kg250m⁻² ± SE) and total species richness (n) per transect for the duration of the DLTRMP at the different locations surveyed along Davin Reef. Letters represents significant differences in biomass between survey locations; locations with different letters are significantly different from each other (p<0.05).

Most species recorded during the DLTRMP are IUCN Red List²⁴ species of Least Concern (244 species, 72%), followed Not Evaluated (85 species, 25%) (Fig 3.3.4, 3.3.5). Five species recorded are listed as Data Deficient; *Aeoliscus strigatus*³⁵ (Razorfish), *Chaetodon ocellicaudus*³⁶ (Spot-tail Butterflyfish), *Lutjanus xanthopinnis*³⁷ (Yellowfin Snapper), *Siganus unimaculatus*³⁸ (Blotched foxface) and *Epinephelus bleekeri*³⁹ (Duskytail grouper).

Three species recorded during the DLTRMP are Near Threatened; *Taeniura lymma*⁴⁰ (Bluespotted ribbontail ray), *Chlorurus bowersi*⁴¹ (Bower's Parrotfish) and *Scarus hypselopterus*⁴² (Yellow-tail Parrotfish). *T. lymma* has been recorded twice, both during 2020 wet season and at 10m, once at Masaplod Norte and once at Lipayo II. *C. bowersi* has been recorded twice, both during 2020 wet season and at 10m, once at Maayong Tubig and

once at Poblacion District I. *S. hypselopterus* has been recorded five times; four in 2019 wet season and one in 2020 dry, at both 5 and 10m, and at Poblacion District I and II and Masaplod Sur inside and outside the MPA.

Two species recorded are listed as Vulnerable; *Oxymonacanthus longirostris*⁴³ (Orange spotted filefish), and *Epinephelus fuscoguttatus*⁴⁴ (Brown-marbled grouper). *O. longirostris* was recorded twice during the 2019 survey year and twice during 2020, all during the dry season and at 5m; in 2019 at Poblacion District I and in 2020 at Lipayo I Sur. *E. fuscoguttatus* was recorded twice during the 2019 survey year (once during dry season at Lipayo II at 10m and once during wet season at Masaplod Norte at 10m) and once during 2020 (during wet season at Masaplod Norte at 10m).

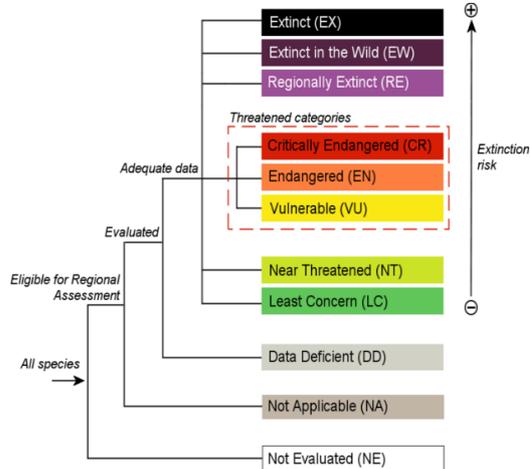


Fig 3.3.4: Structure of IUCN Red List categories⁴⁵

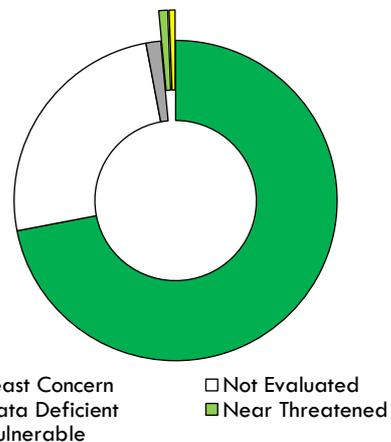


Fig 3.3.5: Relative number of species within each IUCN Red List Category for the DLTRMP. Highlighted outside of pie are Near Threatened and Vulnerable species

3.3.1 Fish Families

Pomacentridae accounts for 61% of fish by abundance, and 25% of fish biomass. The next most abundant families are *Labridae*, *Serranidae*, *Caesionidae* and *Apogonidae*, accounting for 15%, 4%, 4% and 4% respectively (Fig 3.3.6). The relatively high abundance of the *Serranidae* family is due to two species; *Pseudanthias huchtii* (Threadfin anthias) and *Pseudanthias tuka* (Yellow striped fairly basslet), which combined comprise 95% of the *Serranidae* family by abundance. By biomass, *Pomacentridae* is followed by *Lutjanidae*, *Caesionidae*, *Acanthuridae*, *Serranidae* and *Labridae*, accounting for 16%, 11%, 7%, 5% and 5% respectively (Fig 3.3.7). By abundance, *Lutjanus biguttatus* accounts for

56% of all *Lutjanidae*, whereas by biomass this species accounts for 23%, with *Macolor macularis* accounting for the most within the *Lutjanidae* at 40%. Families with the highest species richness include *Labridae* (64), *Pomacentridae* (55), *Apogonidae* (24), *Chaetodontidae* (22), *Acanthuridae* (20), *Scaridae* (19), *Lutjanidae* (16), *Serranidae* (15), and *Mullidae* (10) (Fig 3.3.8).

There is no significant correlation between mean coral cover with total fish abundance ($r^2= 0.0026$), total fish biomass ($r^2= 0.024$), total *Pomacentridae* abundance ($r^2= 0.0001$) or total *Pomacentridae* biomass ($r^2= 0.0006$) (Fig 3.3.9).

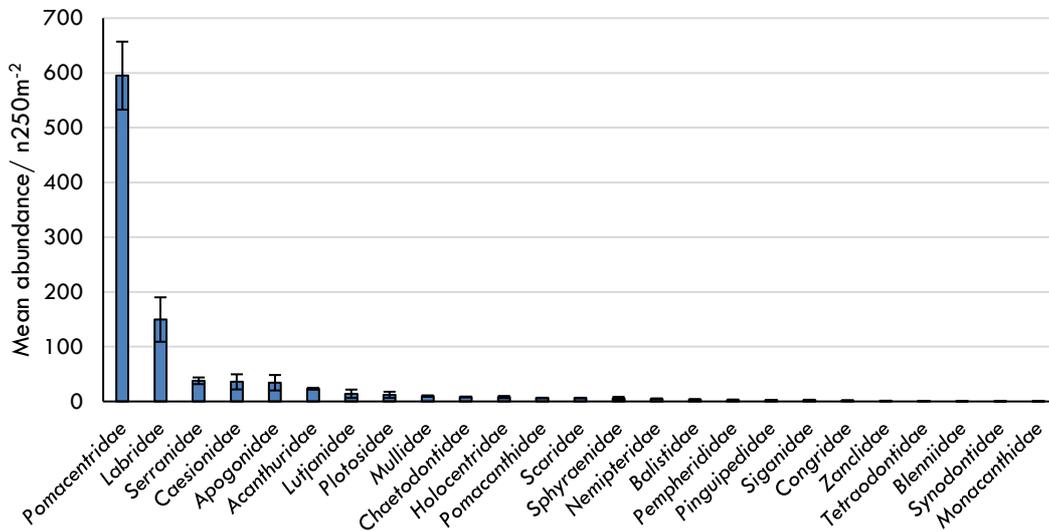


Fig 3.3.6: Mean abundance per transect ($n250m^{-2} \pm SE$) of 25 most abundant fish families recorded along Dauin Reef for the duration of the DLTRMP.

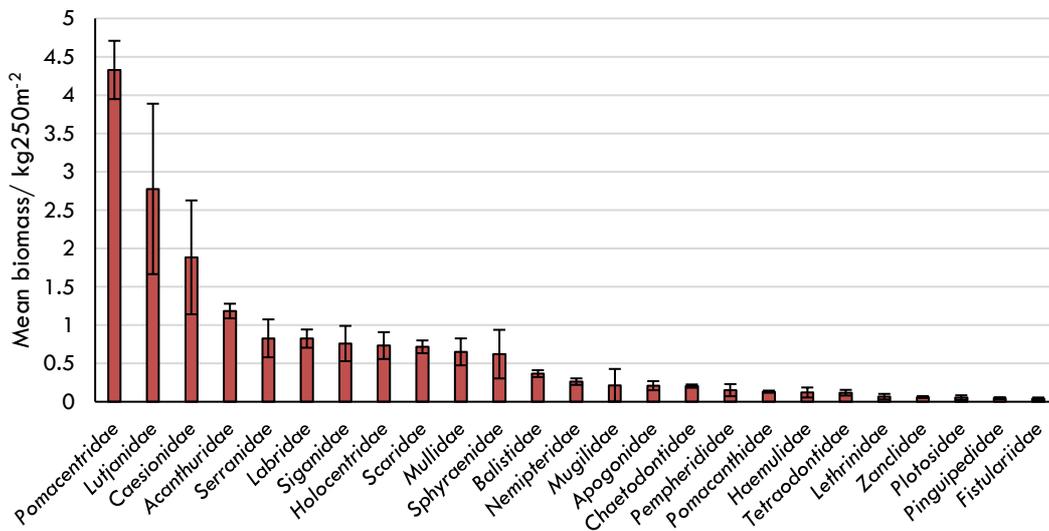


Fig 3.3.7: Mean biomass per transect ($kg250m^{-2} \pm SE$) of 25 most abundant fish families recorded along Dauin Reef for the duration of the DLTRMP.

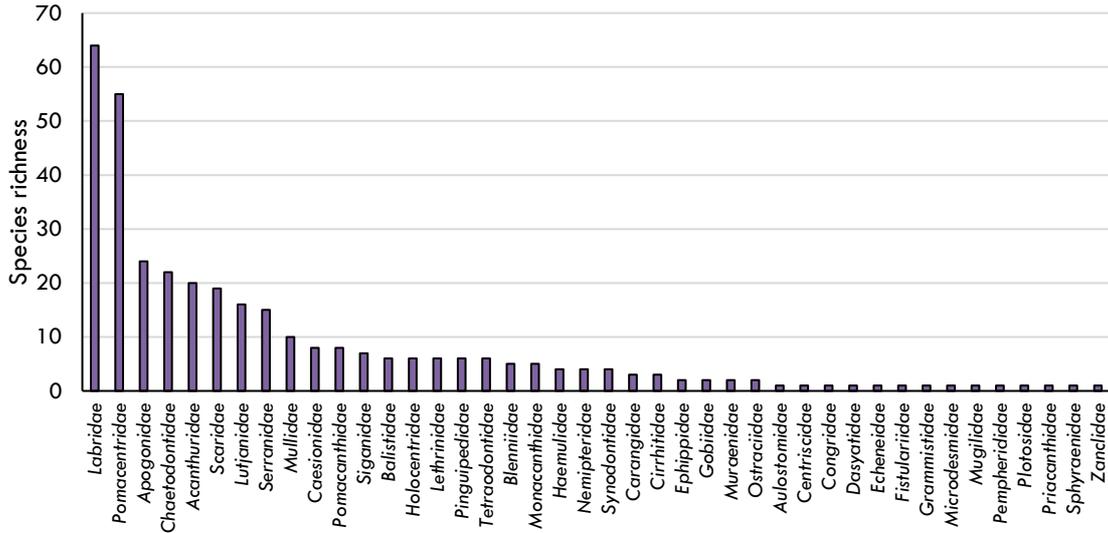


Fig 3.3.8: Total species richness of all fish families recorded along Dauin Reef for the duration of the DLTRMP.

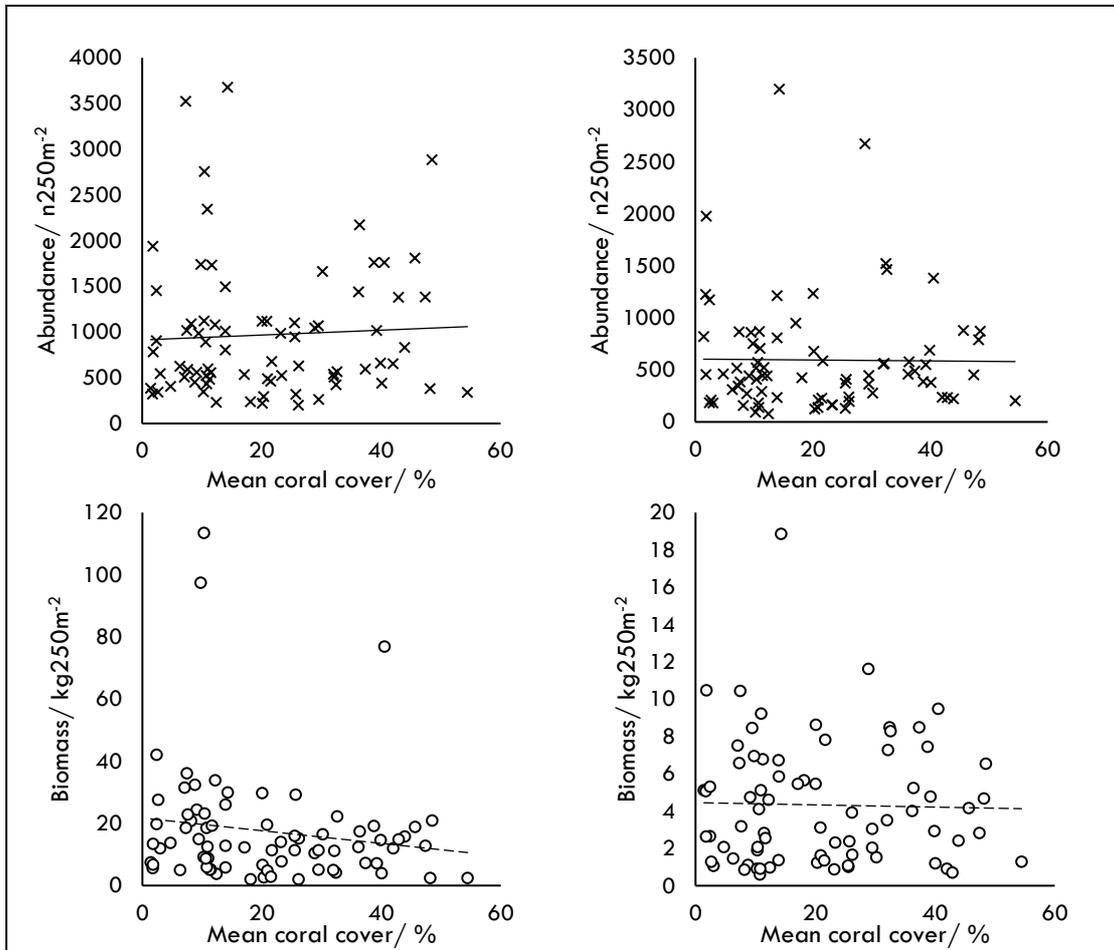


Fig 3.3.9: Mean coral cover per transect and left) total fish abundance and biomass and right) *Pomacentridae* abundance and biomass. Total abundance trendline $y = 2.6772x + 913.47$, $r^2 = 0.0026$, biomass trendline $y = -0.204x + 21.723$, $r^2 = 0.024$. *Pomacentridae* abundance trendline $y = -0.4401x + 604.25$, $r^2 = 0.0001$, biomass trendline $y = -0.006x + 4.453$, $r^2 = 0.0006$.

As *Pomacentridae* is the major contributor to fish abundance (69%), it follows that this family is responsible for the majority of abundance increases between seasons. From 2019 dry to wet, *Pomacentridae* accounts for 80.7% of the increase in fish abundance, followed by *Labridae* (4.6%), *Serranidae* (4.4%) and *Plotosidae* (4.2%). From 2019 wet to 2020 dry, *Pomacentridae* accounts for only 26.7% of the increase in fish abundance, with *Labridae* accounting for 32.0%, *Caesionidae* accounting

for 11.2%, *Lutjanidae* accounting for 9.1% and *Serranidae* accounting for 7.0%. From 2020 dry to wet, *Pomacentridae* accounts for 65.1% of the increase in fish abundance, followed by *Labridae* (30.2%) and *Apogonidae* (15.6%). The only families with significant changes to abundance over the course of the DLTRMP are *Pomacentridae* ($H(3) = 30.518, p < 0.01$) and *Scaridae* ($H(3) = 17.468, p < 0.01$) (Fig 3.3.10).

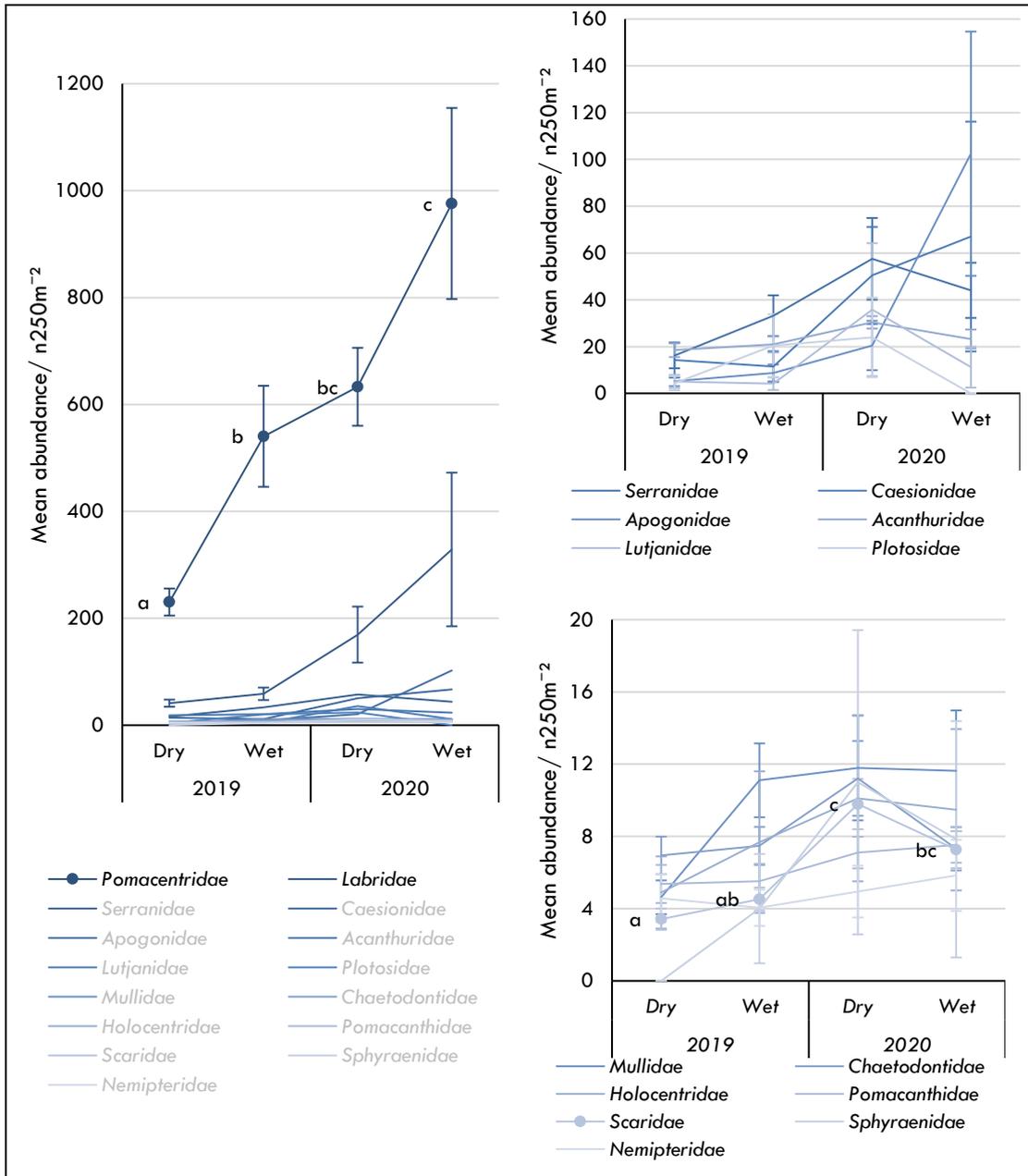


Fig 3.3.10: Mean abundance per transect (n250m⁻² ± SE) of 15 most abundant fish families recorded along Dauin Reef separated by survey season. Lines with circle markers and letters represents significant differences in abundance between survey seasons; seasons with different letters are significantly different from each other (p<0.05). Graphs on right are a zoom on the less abundant fish families (grey families in legend on left graph).

Pomacentridae is also the main contributor to fish biomass (24%), hence it follows that this family is also a large contributor to the trends of biomass change between seasons (although not as large a portion as for abundance). From 2019 dry to wet, *Pomacentridae* accounts for 38.2% of the increase in fish biomass, followed by *Mugilidae* (16.8%), *Siganidae* (10.4%), *Mullidae* (10.2%) and *Labridae* (9.9%). From 2019 wet to 2020 dry, *Pomacentridae* accounts for only 21.8% of the increase in total fish biomass, with *Lutjanidae* accounting for 57.4% and *Caesionidae* accounting for 12.3%. From 2020 dry to wet, overall biomass slightly

decreases, which is attributable to large decreases in *Lutjanidae* (which decreased 75.1% from the previous season) and *Acanthuridae* biomass (37.5% decrease from the previous season), although *Mullidae* show a substantial increase (179% increase from the previous season). The families with significant changes to biomass over the course of the DLTRMP are *Pomacentridae* ($H(3) = 35.709, p < 0.01$), *Acanthuridae* ($H(3) = 18.04, p < 0.01$), *Scaridae* ($H(3) = 15.451, p < 0.01$) and *Balistidae* ($H(3) = 7.8785, p < 0.05$) (Fig 3.3.11).

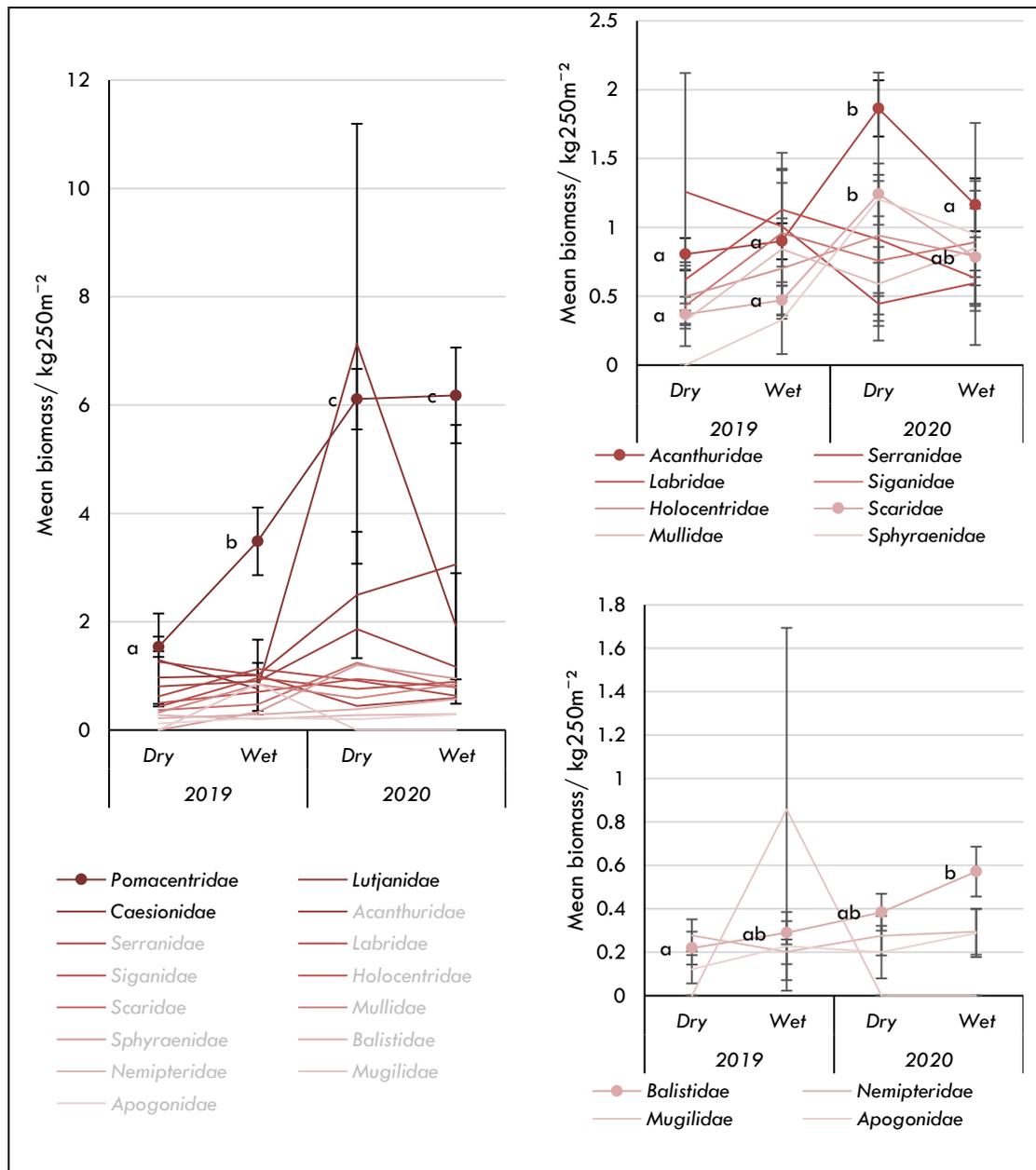


Fig 3.3.11: Mean biomass per transect (kg250m⁻² ± SE) of 15 fish families with the highest total biomass recorded along Dauin Reef separated by survey season. Lines with circle markers and letters represents significant differences in biomass between survey seasons; seasons with different letters are significantly different from each other (p < 0.05). Graphs on right are a zoom on the smaller biomass fish families (grey families in legend on left graph).

3.3.2 Trophic Structure

Mean Omnivore abundance (259 individuals per 250m²) and biomass (4.46kg per 250m²) is greatest across Dauin’s reefs, followed by Planktivores (249 individuals and 3.93kg per 250m²) and Herbivore & Planktivores (245 individuals and 2.97kg per 250m²) (Fig 3.3.12). The fourth most abundant trophic group is Invertivores (127 individuals), but by biomass the fourth group is Invertivore & Piscivores (2.52kg per 250m²) (Fig 3.3.12). Omnivores are also the most speciose functional group, followed by invertivores, invertivore & piscivores, herbivore & planktivores and planktivores (Table 3.4). All other trophic groups have mean abundances of less than 40 individuals and less than 1kg per 250m². Consistently the lowest contributors to fish community structure in terms of both abundance and biomass are Detritivores, Corallivore & Invertivores, Corallivore & Herbivores, Detritivore & Invertivores and Detritivore & Herbivores (Fig 3.3.12).

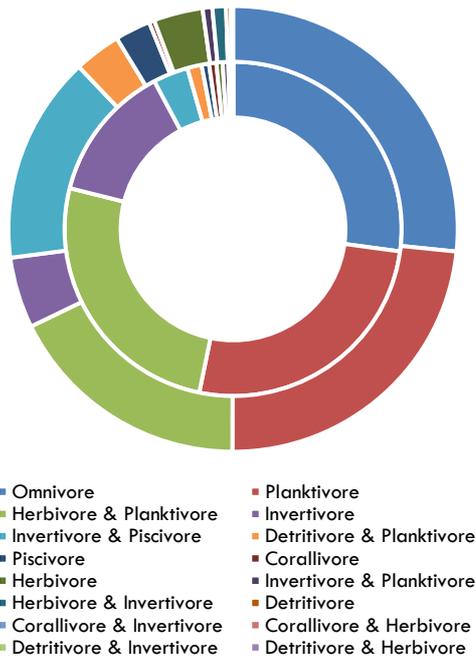


Fig 3.3.12: Relative mean abundance (inside) (n/250m²) and biomass (outside) (kg/250m²) per transect of fish functional groups recorded along Dauin Reef for the duration of the DLTRMP.

The trends in most abundant fish and highest contributors to biomass are largely consistent with each other across the survey seasons of the DLTRMP. The three most abundant trophic groups are the same for each survey season (Omnivores, Planktivores and Herbivore & Planktivores), although the ranking between these three varies (Fig 3.3.13). The abundance of all other trophic groups are consistently much

Table 3.4: Species richness (SR) of all trophic groups recorded during the DLTRMP.

Trophic Group	SR
Omnivore	67
Invertivore	60
Invertivore & Piscivore	60
Herbivore & Planktivore	33
Planktivore	33
Herbivore	24
Herbivore & Invertivore	14
Corallivore	11
Piscivore	11
Invertivore & Planktivore	10
Corallivore & Invertivore	5
Detritivore & Herbivore	2
Detritivore & Invertivore	2
Detritivore & Planktivore	2
Corallivore & Herbivore	1
Detritivore	1

(an order of magnitude) lower than the top three, with the exception of Invertivores which reach a similar mean abundance to the top three trophic groups by 2020 wet season. Significant changes in mean abundance throughout the DLTRMP are seen in Omnivores ($F(3,72) = 18.937, p < 0.01$), Planktivores ($F(3,72) = 9.53, p < 0.01$), Herbivore & Planktivores ($H(3) = 18.352, p < 0.01$), Invertivores ($H(3) = 10, p < 0.05$), Herbivores ($F(3,72) = 3.846, p = 0.01$) and Corallivores ($F(3,72) = 2.99, p < 0.05$) (Fig 3.3.13). Significant changes are seen in the proportional abundance of Invertivore & Piscivores ($H(3) = 11.579, p < 0.01$), Detritivore & Planktivores ($H(3) = 12.586, p < 0.01$) and Herbivores ($H(3) = 14.656, p < 0.01$) (Fig 3.3.15). During the DLTRMP, omnivores show a consistent increase in abundance, increasing significantly from 2019 dry to wet and from 2019 wet to 2020 dry; although another increase occurs from 2020 dry to wet, it is not statistically significant. Herbivore & Planktivores and exclusive Planktivores increase in abundance significantly from 2020 dry to wet, and although they continued to increase steadily since, the differences are not statistically significant. Invertivores remained consistent in 2019 but steadily increased throughout 2020, although variation (standard error) is much greater between sites, hence statistical trends are unclear as yet. Herbivores show minor increases from 2019 dry to wet and 2019 wet to 2020 dry, followed by a significant decrease in abundance and biomass from 2020 dry to wet. Corallivores show minor increases from 2019 dry to wet and 2019 wet to 2020 dry, followed by a significant increase from 2020 dry to wet.

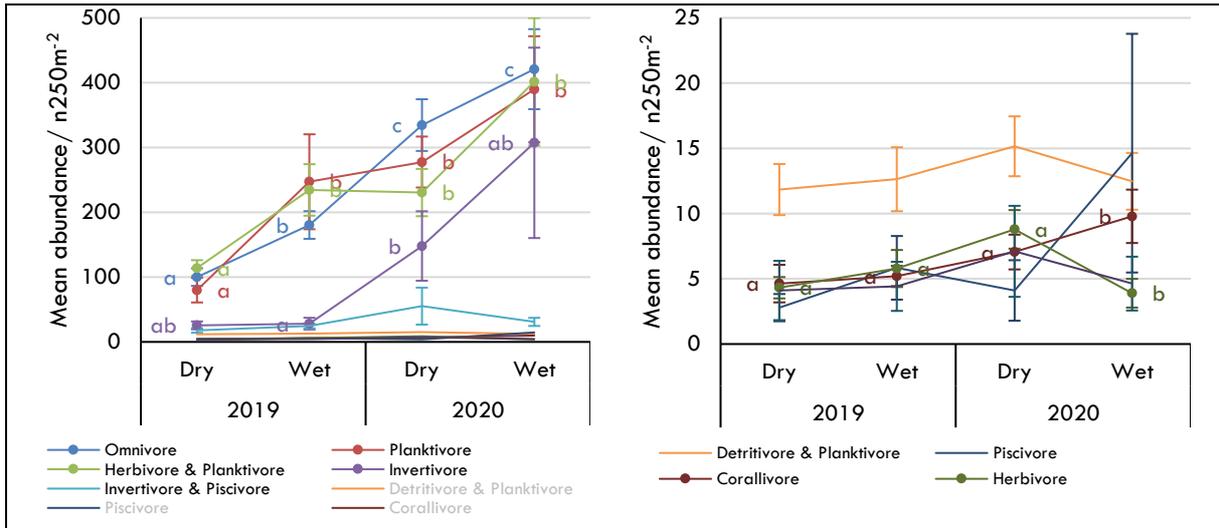


Fig 3.3.13: Mean abundance per transect ($n250m^{-2} \pm SE$) of 10 most abundant fish trophic groups recorded along Dauin Reef separated by survey season. Lines with circle markers and letters represents significant differences in abundance between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$). Graph on right are a zoom on the less abundant fish trophic groups (grey groups in legend on left graph).

The top four trophic groups in terms of biomass are the same for each survey season (Omnivores, Planktivores, Herbivore & Planktivores and Invertivore & Piscivores), although the ranking between these three varies (Fig 3.3.14). The biomass of all other trophic groups are consistently much lower than the top four. Significant changes in mean biomass throughout the DLTRMP are seen in Omnivores ($H(3) = 22.168, p < 0.01$), Planktivores ($H(3) = 8.976, p < 0.05$), Herbivore & Planktivores ($H(3) = 17.819, p < 0.01$) and Herbivores ($H(3) = 9.8563, p < 0.05$). There are no significant changes to the proportional biomass of any functional group during the DLTRMP (Fig 3.3.15). Omnivores show an overall significant increase in biomass; although a

notable decrease is seen in 2020 wet season this is not significant. Planktivores also show an overall increase in biomass, with 2020 dry season biomass being significantly higher than 2019 dry, although high variation (standard error) leads to the high biomass of planktivores in 2020 wet season to not be significantly higher than 2019 values. Herbivore & Planktivores increased steadily throughout the DLTRMP, with a significant increase from 2019 dry to wet season, followed by a gentle incline. Herbivore biomass shows a similar trend to omnivores; increasing substantially in 2020 dry season from 2019 levels, before decreasing significantly in 2020 wet season, to marginally below 2019 levels.

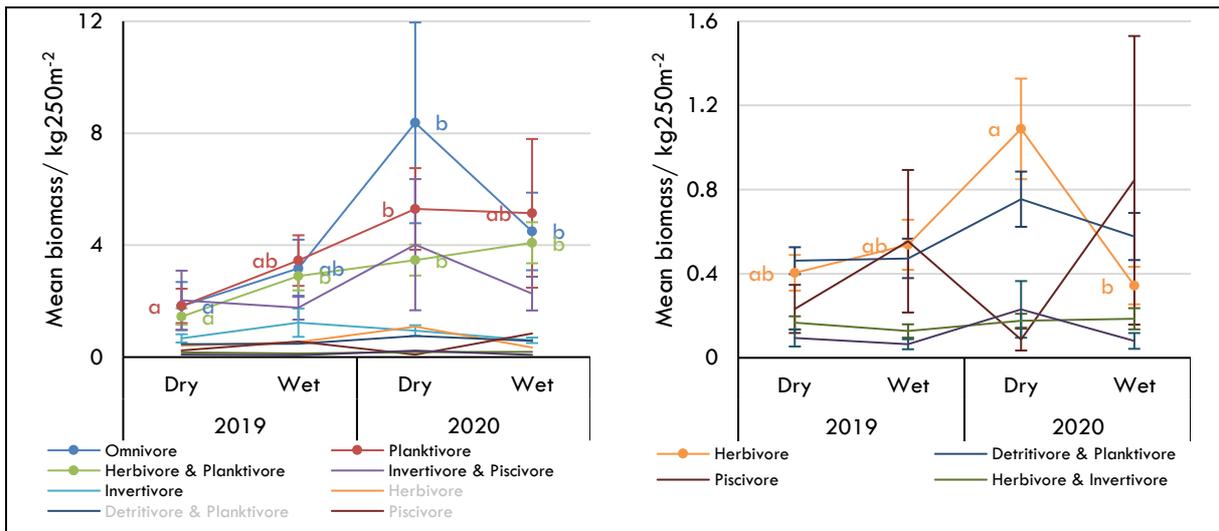


Fig 3.3.14: Mean biomass per transect ($kg250m^{-2} \pm SE$) of 10 fish trophic groups with the highest total biomass recorded along Dauin Reef separated by survey season. Lines with circle markers and letters represents significant differences in biomass between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$). Graphs on right are a zoom on the smaller biomass fish trophic groups (grey groups in legend on left graph).

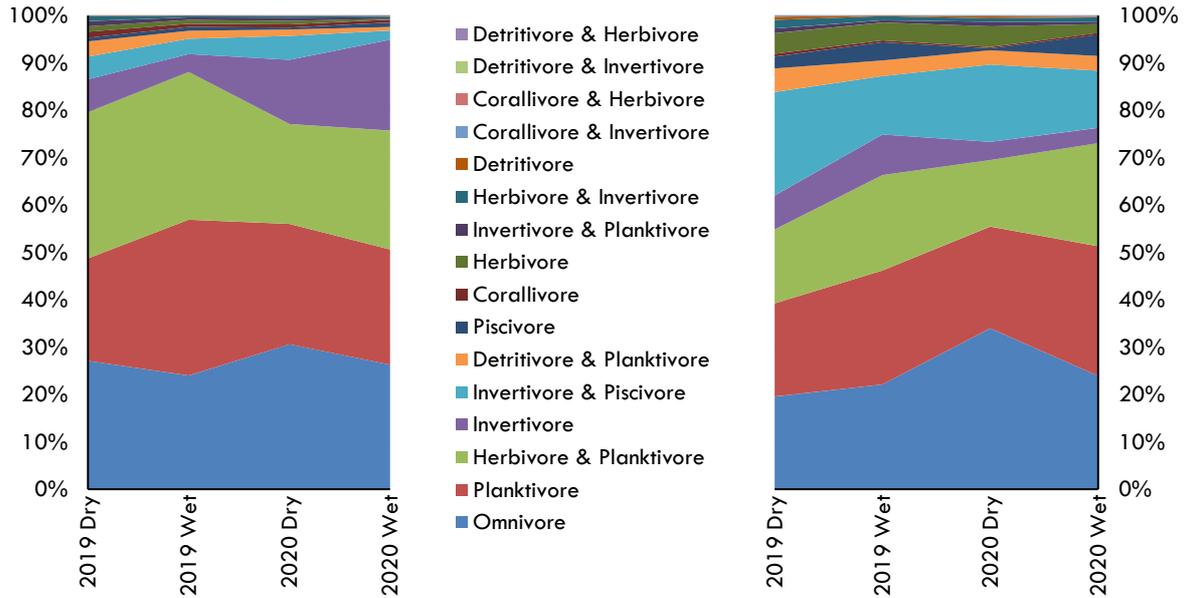


Fig 3.3.15: Relative mean abundance (left) and biomass (right) (%) of fish functional groups per transect recorded along Dauin Reef separated by survey season.

3.3.3 Commercially Important Fish

Over the course of the DLTRMP, a total of 6696 commercially important fish individuals were recorded; 2841 fish during the 2019 survey year (dry: 1188, wet: 1653), compared to 3855 during the 2020 survey year (dry: 2564, wet: 1291). This equates to on average 9.2% of the fish abundance across Dauin’s reefs. By weight, the total biomass of commercially important fish recorded throughout the DLTRMP is 550.63kg; 234.65kg during the 2019 survey year (dry: 103.95kg, wet: 130.70kg), compared to 315.98kg during the 2020 survey year (dry: 216.00kg, wet: 99.97kg). This equates to a mean per 250m² transect of 88 commercially important fish individuals, weighing 7.25kg.

Non-commercially important fish account for 76.1% of the fish population across Dauin’s reefs by abundance, followed by fish with minor commercial importance (14.5%), commercially important fish (9.2%) and subsistence fisheries fish (0.2%). However, by biomass, commercially important fish represent the majority of the fish population (42.6%), followed by non-commercially important fish (36.5%), fish with minor commercial importance (20.6%) and subsistence fisheries fish (0.3%) (Fig 3.3.16).

94 commercially important fish species were recorded (27% of total species richness), across 20 different fish families. *Labridae* has the most commercially important fish species recorded during the DLTRMP (17), followed by *Lutjanidae* (14), *Acanthuridae* (11), *Serranidae* (10) and *Mullidae* (9) (Fig 3.3.17). The families with the highest abundance of commercially important fish are *Labridae*,

Acanthuridae, *Plotosidae*, *Lutjanidae* and *Mullidae*; commercially important fish represent 11.5%, 63.0%, 100%, 77.9% and 95.3% respectively of the total fish abundance of the family (Fig 3.3.18). Families with the highest biomass of commercially important fish are *Lutjanidae*, *Acanthuridae*, *Siganidae* and *Mullidae*; commercially important fish represent 89.8%, 68.8%, 98.7% and 96.5% respectively of the total fish biomass of the family (Fig 3.3.19).

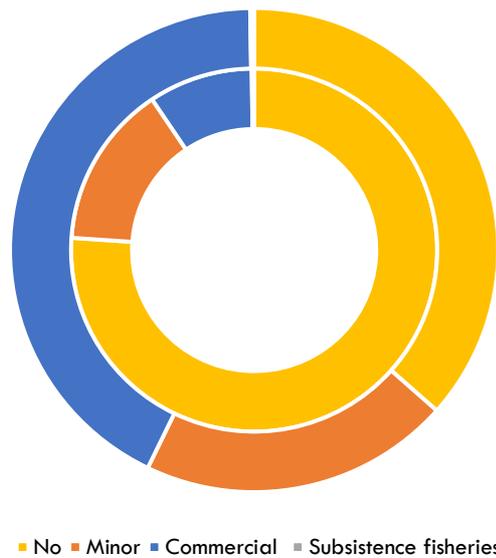


Fig 3.3.16: Relative mean abundance (inside) (n250m²) and biomass (outside) (kg250m²) per transect of fish separated by commercial importance recorded along Dauin Reef for the duration of the DLTRMP.

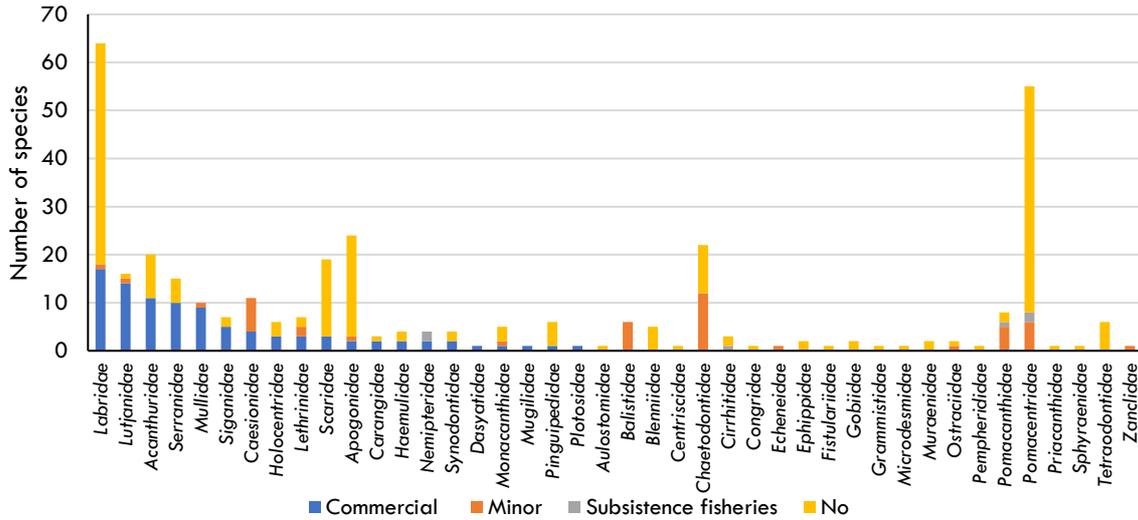


Fig 3.3.17: Total number of species of all fish families recorded along Davin reef for the duration of the DLTRMP, separated by commercial importance.

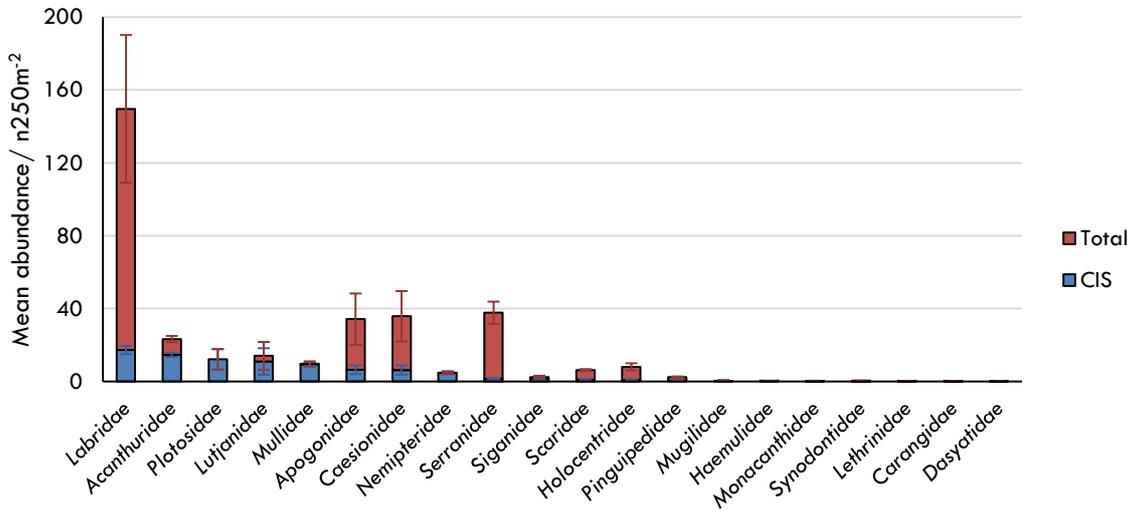


Fig 3.3.18: Mean abundance per transect ($n250m^2 \pm SE$) of commercially important fish (CIS) and total fish (Total) recorded along Davin reef for the duration of the DLTRMP, separated by fish family and sorted from left to right with family with most to least abundant of commercially important fish.

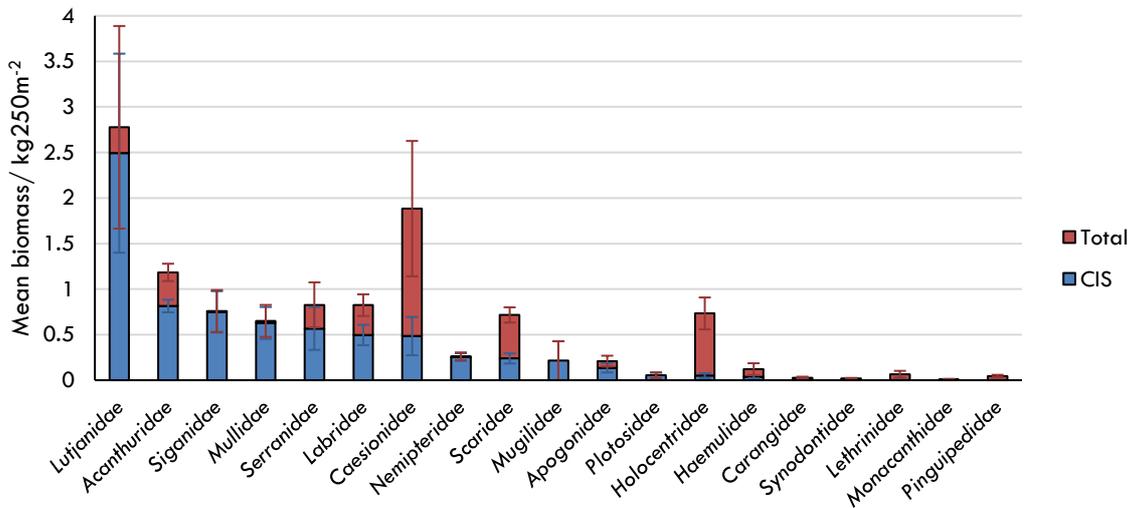


Fig 3.3.19: Mean biomass per transect ($kg250m^2 \pm SE$) of commercially important fish (CIS) and total fish (Total) recorded along Davin reef for the duration of the DLTRMP, separated by fish family and sorted from left to right with family with most to least biomass of commercially important fish.

The abundance and biomass of fish within different groups of commercial importance varies throughout the course of the DLTRMP. The abundance of non-commercially important fish increases significantly ($H(3) = 38.057, p < 0.01$); increasing significantly from 2019 dry to wet, from 2019 wet to 2020 dry, and although not significantly, another increase in abundance is seen from 2020 dry to wet. The abundance of fish with minor commercial importance also increases significantly ($F(3,72) = 5.851, p < 0.01$); increasing significantly from 2019 dry to 2020 dry, with a transitional period of 2019 wet, and a slight increase (although not significant) is seen in abundance from 2020 dry to wet (Fig 3.3.20). The abundance of commercially important fish and subsistence fisheries fish (negligible abundance) remains statistically unchanged throughout the duration of the DLTRMP ($F(3,72) = 1.741, p = 0.166$ and $H(3) = 1.263, p = 0.74$ respectively).

Regarding biomass, the trends are similar; the biomass of non-commercially important fish increases significantly throughout the DLTRMP ($F(3,72) = 9.33, p < 0.01$), as does the biomass of fish with minor commercial importance ($H(3) = 23.356, p < 0.01$). The biomass of non-commercially important fish increases significantly from 2019 dry to 2020 dry, with a transitional period of 2019 wet, before declining slightly (although not significantly) from 2020 dry to wet. The biomass of fish with minor also increases significantly from 2019 dry to 2020 dry, before levelling off in 2020 wet (Fig 3.3.20). The biomass of commercially important fish and subsistence fisheries fish (negligible biomass) remains statistically unchanged throughout the duration of the DLTRMP ($H(3) = 3.007, p = 0.39$ and $H(3) = 0.240, p = 0.97$ respectively).

As the abundance of total fish, non-commercially important fish and fish with minor commercial importance all significantly increase, it follows that in terms of community structure the relative abundance and biomass of commercially important fish show significant declines (abundance $H(3) = 3.007, p = 0.39$ and biomass $H(3) = 0.240, p = 0.97$). The relative abundance of commercially important fish declines gently from 2019 dry to 2020 dry, before decreasing significantly from 2020 dry to 2020 wet. Biomass of this group shows a similar trend, declining significantly from 2019 dry to 2020 wet, although with transitional periods of 2019 wet and 2020 dry (Fig 3.3.21). The relative contribution of subsistence fisheries fish to the Davin fish assemblage is consistently negligible (< 1%), hence the proportional abundance and biomass remains statistically unchanged during the DLTRMP.

The abundance and biomass of commercially important fish species varies significantly between locations ($F(10,65) = 7.551, p < 0.01$ and $F(10,65) = 7.71, p < 0.01$ respectively) (Fig 3.3.22 and Fig 3.3.23). For example, Lipayo II, Lipayo I Sur and Masaplod Norte have the greatest abundance of commercially important fish, whereas Masaplod Sur both inside and outside the MPA have the least. For biomass, the three locations with the most are consistent with that of abundance (although in a different order); Masaplod Norte, Lipayo II and Lipayo I Sur. Sites with the lowest biomass of commercially important fish is consistent with that of abundance; Masaplod Sur both inside and outside the MPA.

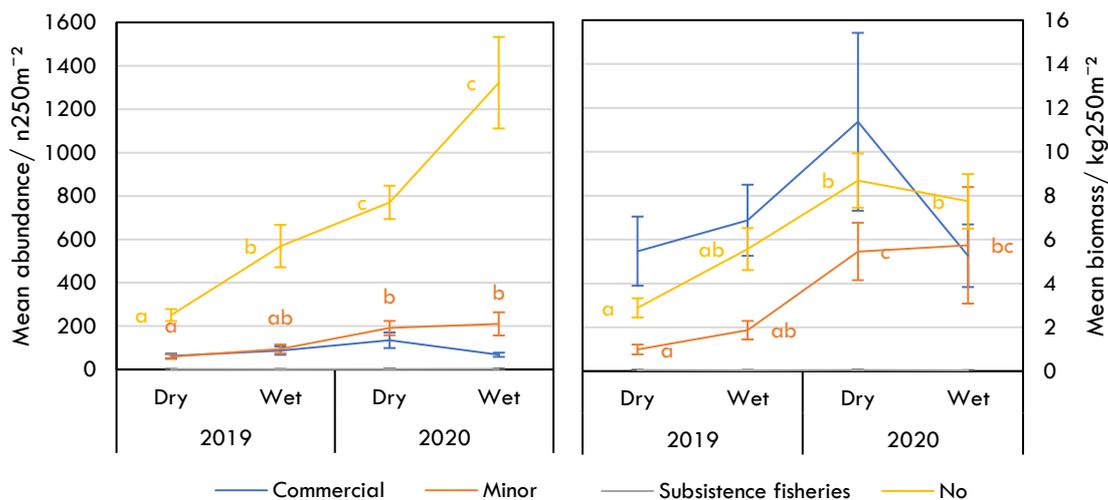


Fig 3.3.20: Mean fish abundance (left; $n/250m^{-2} \pm SE$) and biomass (right; $kg/250m^{-2} \pm SE$) per transect recorded along Davin Reef separated by commercial importance and survey season. Letters represents significant differences in abundance/biomass within a commercial importance group between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

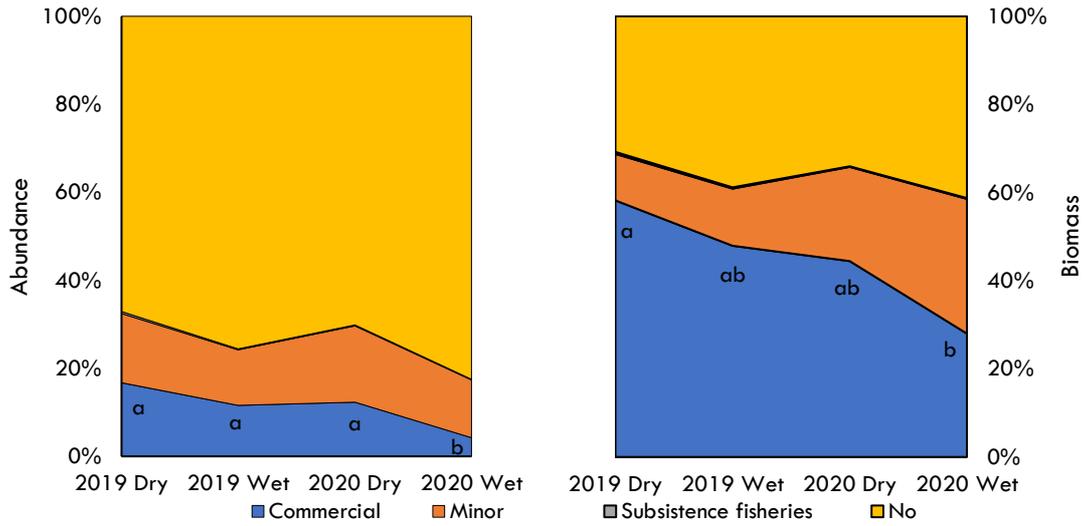


Fig 3.3.21: Relative mean abundance (left) and biomass (right) (%) per transect of fish recorded along Dauin Reef separated by commercial importance and survey season. Letters represents significant differences in abundance/biomass for the commercially important group between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

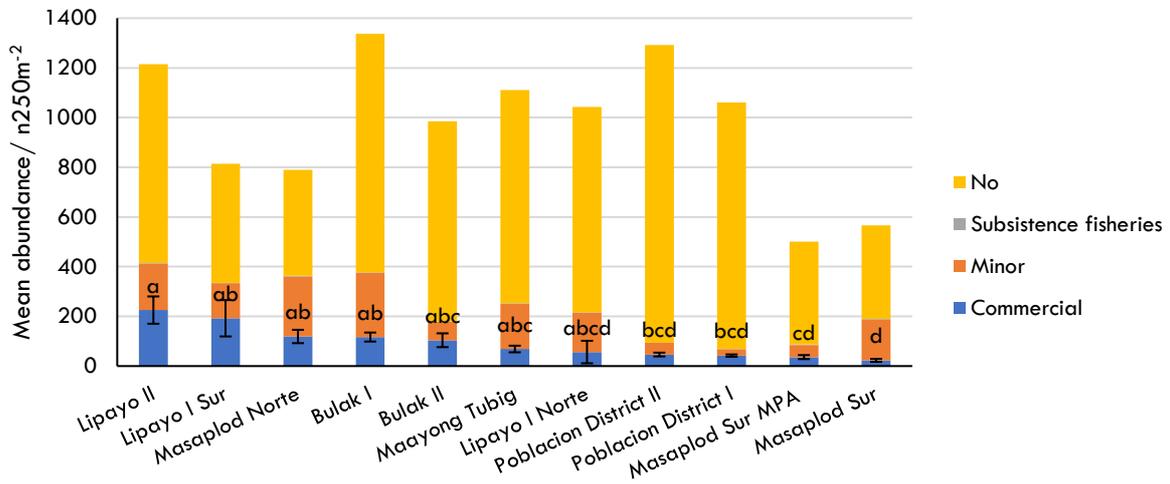


Fig 3.3.22: Mean fish abundance ($n250m^2 \pm SE$) per transect recorded along Dauin Reef separated by commercial importance and survey location. Letters represents significant differences in abundance within the commercially important fish group between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

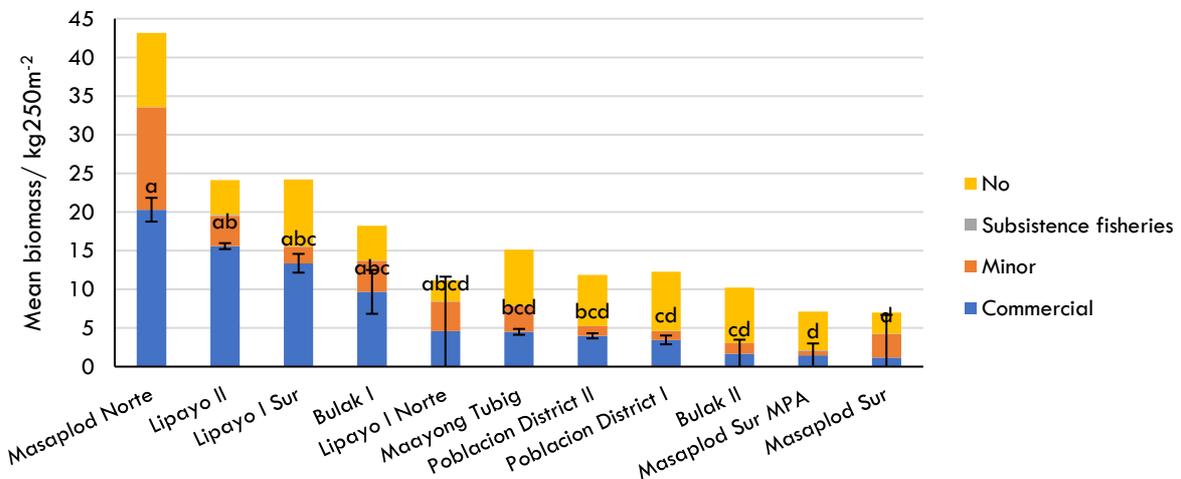


Fig 3.3.23: Mean fish biomass ($kg250m^2 \pm SE$) per transect recorded along Dauin Reef separated by commercial importance and survey location. Letters represents significant differences in biomass within the commercially important fish group between survey seasons; seasons with different letters are significantly different from each other ($p < 0.05$).

As CIS fish represent a relatively small portion of the fish assemblage, it follows that for most trophic groups the majority of the abundance and biomass is non-CIS (Fig 3.3.24). However, for the trophic group detritivore & planktivores, CIS account for almost all fish abundance (99.6%) and biomass (99.4%) (Fig 3.3.24). CIS also account for the

majority of fish abundance (75.7%) and biomass (87.4%) for the invertivore & piscivore trophic group (Fig 3.3.24). Most exclusively herbivorous fish species are not commercially important, with CIS representing 29.3% of herbivores by abundance, but by biomass they comprise 49.2% of the herbivore population (Fig 3.3.24).

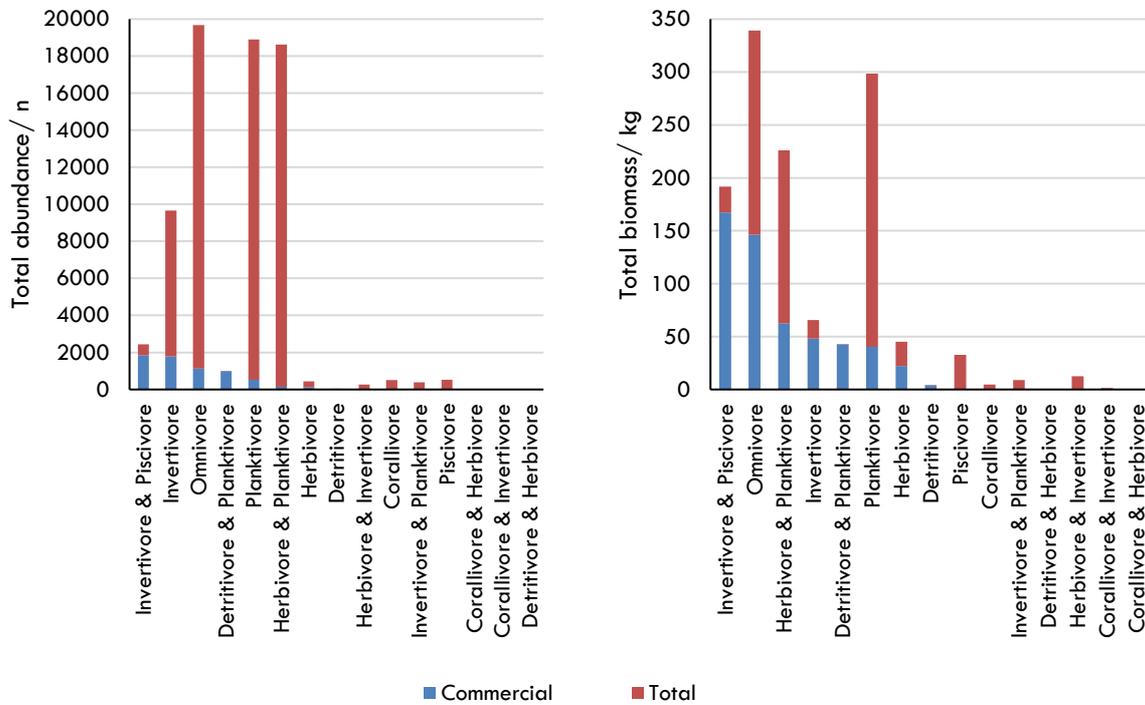


Fig 3.3.24: Total fish abundance (n) (left) and biomass (kg) (right) of commercially important fish and total fish recorded along Dauin Reef, separated by trophic group.

The size distribution of the commercially important fish population in Dauin is heavily skewed towards small individuals, with very few records of CIS individuals above 40cm in length (Fig 3.3.25). Of the commercially important fish species that have been recorded and measured during the DLTRMP, information on the length at first maturity (obtained from FishBase) is unavailable for most. For species where this information is available, the size distribution of the population can be examined, to determine the proportion of juveniles to adults. Species with mostly juvenile populations are (in order of most recorded measurements per species) *Plotosus lineatus*, *Lutjanus fulvus*, *Myripristis murdjan*, *Neoniphon samara* and *Lutjanus argentimaculatus* (Fig 3.3.26). Populations of *Parupeneus multifasciatus* and *Mulloidichthys flavolineatus* have an even distribution of juveniles and adults, whereas populations of *Thalassoma hardwicke*, *Siganus guttatus*, *Lutjanus vitta* and *Epinephelus merra* are more skewed towards mature adults (Fig 3.3.26). However, it is important to note sample sizes of these populations – with one third of these species having 10 or less recorded

measurements, overall size distributions of many CIS species cannot be easily described at this point in the IMR Dauin LTRMP.

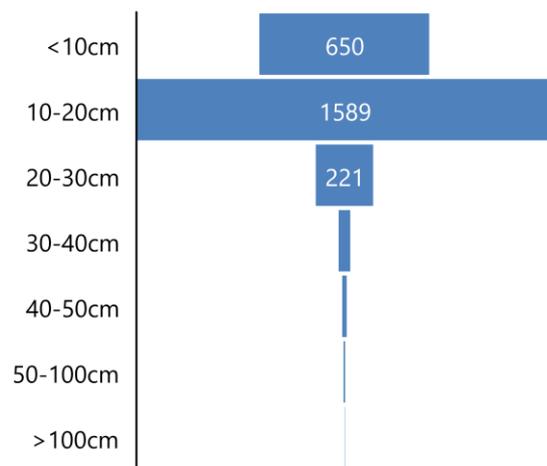


Fig 3.3.25: Total number of commercially important fish in each size class that have been measured along Dauin Reef during the DLTRMP.

The Dauin small-scale fishing community project

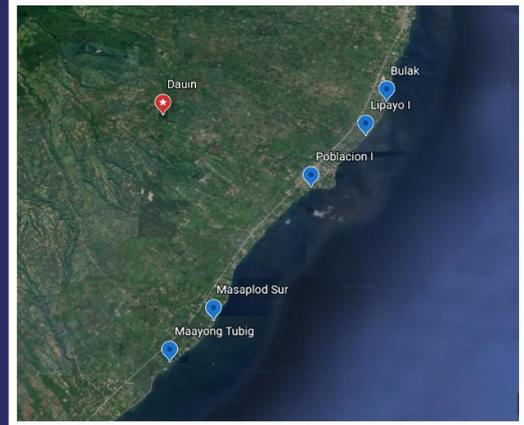


INSTITUTE FOR MARINE RESEARCH
DAUIN - PHILIPPINES

Introduction

Dauin has a thriving fishing community that spans back many generations. The aim of this project was to gather information from fishers and market vendors about small-scale fishing in the area.

We conducted social surveys across five coastal barangays in Dauin: Bulak, Lipayo, Maayong Tubig, Masaplod Sur and Poblacion I. Data was gathered about fishing methods, how much is being fished and where, which fish families are the most commercially valuable, and finally, to understand the community's perspective of sustainability and their opinions on current fishing restrictions.



Who did we survey?

Participants were chosen at random by approaching fisherfolk at their homes and on the beachfront, and market vendors at fish markets. We conducted detailed interviews with a sample size of 10 fishers and 10 market vendors.

Fishers



100%
were male



25-78
range of age



219
collective years fishing

Market vendors



80%
were female



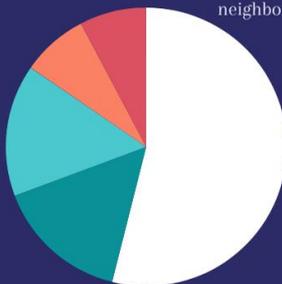
30-64
range of age



169
collective years selling fish

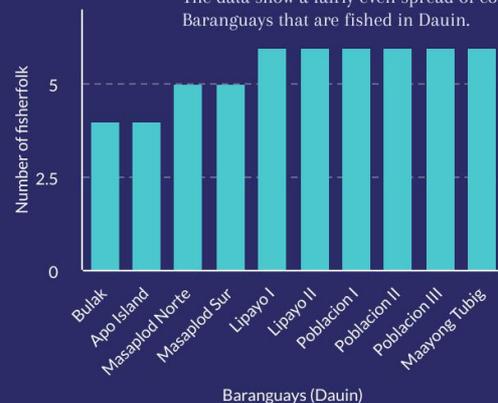
Where are they fishing?

Over half (53.92%) of our fishers survey participants fish in Dauin only. The rest fish in neighboring waters too.



- Dauin only (53.92%)
- Mindinao (15.36%)
- Siquijor (15.36%)
- Sumilon Island (7.68%)
- Cebu (7.68%)

The data show a fairly even spread of coastal Barangays that are fished in Dauin.



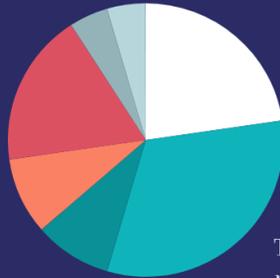
Where is it sold?



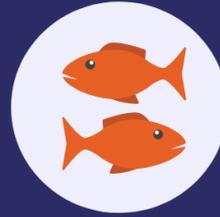
Many of the fishermen here already have their own suki (regular customers), so I'm forced to buy my fish from elsewhere.

Market Vendor, Brgy Poblacion I

- Dauin (22.73%)
- Siaton (31.82%)
- Zamboanguita (9.09%)
- San Miguel (9.09%)
- Bayawan (18.18%)
- Tambobo (4.55%)
- Dumaguete (4.55%)



Market vendors struggle to compete with the demand for Dauin fish, as only around 23% of their produce is from Dauin.



20%

of fishers sell their catch to Dauin market vendors



40%

of market vendors say that Dauin fish are more expensive than other areas.

The survey shows that many Dauin fishers do not rely on the market to buy their catch, instead most have regular customers that wait on the beachfront or their homes, and even reserve specific fish in the hope of a good catch that day.

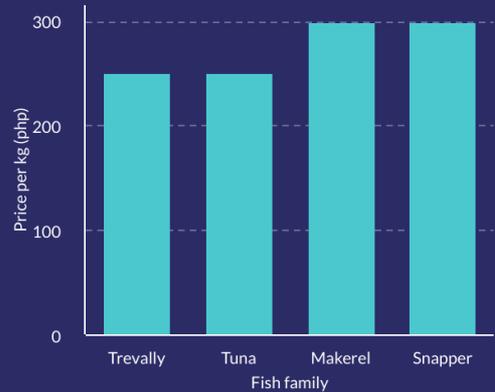
What is being fished?



23

different fish families are caught in Dauin

Small-scale fishing is largely opportunistic as fishers will catch what they can that day to make a living - this is why there is a huge range of fish caught (23 different families).



The four most commercially valuable fish (above) are trevally, tuna, makerel and snapper, all making over 250php per kg.

How it is fished?

The most popular distance from shore to fish was 0-100m (50%). Interestingly, 10% of survey participants drive their boat over 10km from shore to catch fish - that is all the way to the Mindanao border!



- 0-100m (50%)
- 101-200m (30%)
- 1-5km (10%)
- 10km+ (10%)



100%

go fishing every day (weather permitting)



80%

start fishing between 4am-8am



30% of fisher participants will go fishing for over 9 hours every single day. However, half of the participants fish between 1-4 hours.



Which fishing methods are used?

Hook and line (Palangre) 80%

This is the most popular method and also the cheapest: the only equipment needed are fishing line and a lure.



Fishing rod (Pasol) 10%

This method is similar to *palangre*, but instead involves a wooden 'rod' attached to the fishing line.

Fishing cage (Bobo) 0%

Despite none of our survey participants using *bobo*, they can be frequently found underwater. The cages are set and left until enough fish become trapped before retrieval.

Spearfishing (Pamana) 20%

Pamana requires a snorkeller or diver to shoot a speargun underwater to catch the fish.

Gillnet (Pukot) 40%

Large nets are placed underwater to trap fish. This method is for fishers who are not exclusive about what they catch. When lost, these become 'ghost nets' and can sometimes smother corals.



Surface net with lights (Kayagkag) 20%

Specifically used for night fishing, the bright lights attract fish into the net.

Fishing net over seagrass (Sahid) 50%



Sahid requires a whole team of people to pull the net into shore. This method is often used to catch large quantities of small fish, such as anchovies.



Fishing restrictions

Marine Protected Areas (MPAs)

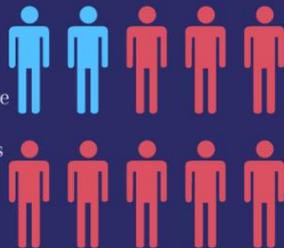
Ten MPAs have been established in Dauin since 1986. These areas are legally no-take zones, but have varying levels of enforcement.



80%

of fishers say the biggest impact from the MPAs are reduced fishing grounds

20% of fishers said that the MPA is beneficial to them, whereas 80% say the MPAs are problematic to their livelihood



■ Positive (20%) ■ Negative (80%)

The MPA is good for us as the area is a breeding ground for the fish. That way there will be more fish for us to catch in the long run.

Pedro, Brgy Poblacion I



institutemarineresearch.org

Commercial fishing

To maintain fish populations and protect the livelihoods of small-scale fishing, it is illegal for commercial fishing vessels (*Cob cob*) to fish within 15km from the shore in the Philippines.



The small fisherman cannot compete with the hi-tech equipment on the cob cob. It takes all the fish in one go and leaves us with nothing.

Arsenjo, Brgy Lipayo I

20%

of fisher survey participants say they have seen *Cob cob* within 8km of the shoreline.



Community Project by Emma Levy, Research Fellow

4. DISCUSSION

Characterizations of small-scale temporospatial patterns over the two years of the DLTRMP have been used to explore factors that drive population structure within the Dauin Municipal reef ecosystem (Negros Oriental, Philippines).

4.1 Benthic Composition

Reefscapes are often a mixture of stable consolidated habitat and unconsolidated reef rubble⁴⁶. Physically unstable reef rubble can cause abrasion and burial of juvenile coral⁴⁷; consolidation of this unstable substrate is therefore essential in establishing a solid framework for coral settlement and growth. The Dauin coastline has a history of typhoon disturbance; particularly category 5 Typhoon Pablo, which hit the coast in November 2012, causing partial destruction of coral skeletons and reef rock. As such, much of the Dauin coastline fringing reef is comprised of unconsolidated substrate, hence limiting reef accretion rates. The fate of these destroyed framework components is affected by subsequent wave action, erosion and redeposition, as well as taphonomic and successional processes including framework growth, sedimentation, burial, recruitment, colonisation and marine diagenetic cementation^{48,49}. Post-disturbance recovery of coral reefs is complex and varies temporospatially⁵⁰. It usually occurs through recolonisation of bare substrate by settlement of coral larvae⁵¹, although following severe storm damage, benthic algal blooms generally develop first⁵⁰. Depending on the extent of damage and the history of the reef, recovery can take anywhere from a few years to centuries⁵⁰. Shifts to algal-dominated systems may occur if the reef cannot recover⁵⁰.

Abiotic components (predominantly sand and rubble) contribute most to the benthos of this fringing reef ecosystem, followed by coral, algae and sponge (Fig 3.1.1). During the DLTRMP, bare abiotic substrate significantly decreased, whereas algae and sponge cover increased and coral cover remained unchanged (Fig 3.1.2). No consistent trend is apparent in dead coral cover, highlighting the lack of mass mortality events (as confirmed by coral mortality assays as discussed below). The reduced abiotic cover is attributable largely to declining bare rubble (Fig 3.1.9). The increase in algae cover is owed to increasing turf and coralline algae (Fig 3.1.12). The increase in sponge cover is attributable largely to encrusting and rope sponge (Fig 3.1.17). It is likely that rubble along Dauin's reefscape is

becoming increasingly colonised by algae and sponges; biogenic constructional processes that provide preliminary stabilization.

The high percentage of coral cover has remained stable during the DLTRMP (Fig 3.1.2). Net reef growth depends on the balance of calcification (and subsequent colony extension) and decalcification (erosion) processes⁵². These processes are determined by water quality parameters including temperature, salinity, pH, nutrient load, light availability, pCO₂ and aragonite saturation state⁵³⁻⁵⁶. Seawater biochemistry and hydrodynamics fluctuate naturally across various timescales (diurnal, seasonal)^{57,58}, but many of these aforementioned parameters are also affected by anthropogenic activity (e.g. water temperature increases and ocean acidification as a result of climate change)^{52,59}. Studies have demonstrated coral calcification responds negatively to rapid changes in temperature on time scales of weeks or less due to thermal stress^{55,56} or more gradually to seasonal changes in water temperature⁶⁰. Discrimination of calcification cycles (or lack thereof) is essential in the identification of long-term trends in Dauin's reef accretion rates⁴⁶. Further data on light, temperature, carbonate chemistry, water motion, and/or nutrient uptake rates are therefore required for predicting the effects of resource management actions on the health of this coastal ecosystem.

Acropora spp., *Echinopora spp.*, *Porites spp.*, *Anacropora spp.* and *Pocillopora spp.* are the dominant coral genera across the Dauin reefscape, contributing to 78% of total recorded coral cover (Fig 3.1.3). These genera (and coral diversity) are not evenly distributed across surveyed locations; rather genera growth and diversity shows site specificity (Fig 3.1.5, 3.1.7). A plethora of research, sometimes conflicting, exists on the role of disturbances on biodiversity⁶¹⁻⁶⁵. Nonetheless, it is widely accepted that disturbances can maintain diversity by changing species composition, whereas reef regeneration after disturbances is dependent on various abiotic and biotic factors⁶⁶. Although many sites show high coral diversity (Fig 3.1.5), the dominance of a single genera and overall lack of diversity at certain reef sites is concerning, such as *Acropora spp.* dominance at Bulak II at 10m (Site 7) and Lipayo I Sur at 10m (Site 9) and 5m (Site 10). These concerns are validated by results of impact and coral mortality assays, which reveal some of the most dominant genera (*Acropora spp.*, *Porites spp.* and *Pocillopora spp.*) to be most susceptible to impacts such as bleaching, disease, predation from

corallivorous invertebrates and direct destruction (Fig 3.2.15). The capacity for this reef ecosystem to absorb recurrent disturbances or shocks and adapt to change whilst maintaining ecosystem functions and structure is the core research focus of the DLTRMP. With sparse data on Dauin's fringing reef disturbance history and environmental conditions, the long-term research of the DLTRMP becomes the first of its kind to understand both the ecological ability of Dauin's reef to resist or survive disturbance, as well as the rate of recovery for this reef assemblage to return to its original condition.

Turf algae cover increased significantly each survey season of the DLTRMP until 2020 wet season, which shows a significant decline (Fig 3.1.2) Turf algae is classified as short (<2cm), multispecies filamentous macroscopic algae that covers hard substrate on coral reefs⁶⁷. It is one of the first colonisers of bare substrate⁶⁸, bleached coral⁶⁹ and dead coral⁷⁰⁻⁷². Turf algae occupy available space quicker, grow faster and are less vulnerable to grazing and water turbulence compared to other algal groups such as macroalgae and coralline algae^{69,73}. The dominance of turf algae over coralline algae (which is fundamental for coral settlement⁷⁴) may inhibit coral settlement in the long term, potentially contributing to a phase shift to an algal-dominated system⁷⁵. Previous research has shown that colonisation of bare substrate by different organisms is dependent on pre-existing conditions; filamentous turf algae establishes faster in previously and/or currently algal-dominated habitats^{76,77} (indicating a higher supply of propagules from the direct surrounding environment⁷⁶), whereas healthy coral-dominated habitats are more often colonised by coralline algae and other calcifiers⁷⁷. It is therefore expected that turf algae targets areas with disturbance history.

A rise in algal turfs as a result of increasing anthropogenic disturbances has been widely reported globally⁶⁷. Turf algae has the capacity to weaken or overgrow neighbouring corals, through space competition and/or reducing effective photochemical efficiency of neighbouring corals⁷⁸. The outcomes of these interactions depends on the coral species and morphology involved⁷⁹; encrusting corals most frequently interact with turf algae, but also compete the most successfully against turf algae, whereas branching corals rarely interact with turf algae but also rarely win interactions⁸⁰. Additionally, turf algae readily traps and accumulates sediment, significantly altering reef processes such as coral settlement and herbivory⁶⁷. Herbivorous fish in the "scrapers" functional group (i.e. *Scaridae*) should provide the capacity to remove algae and sediment by close cropping, in turn facilitating settlement,

growth and survival of coralline algae and corals⁸¹. Herbivorous fish contribute relatively little to the Dauin reef fish assemblage (Fig 3.3.12), potentially posing concern over the capacity for algal removal from disturbed sites. However, the decline in other algae cover (Fig 3.1.12) suggests the relatively small herbivorous fish population may not be of concern (as discussed below); rather finer classification of herbivores within their functional group (i.e. large excavators, small excavators, scrapers, grazers, browsers and grazers/ detritivores) along the Dauin reefscape requires deeper understanding.

Other algae cover shows seasonal variation (significantly higher in dry season than wet) and a long term trend of gentle decline (Fig 3.1.12). The 'other algae' category includes macroalgae such as *Turbiniaria*, *Dictyota* and *Udotea* spp.. Macroalgae biomass varies spatiotemporally due to many biotic and abiotic factors, such as competition, herbivory, wave action and temperature⁸²⁻⁸⁴. Key driving factors behind seasonal fluctuations are natural variability of temperature and light (photosynthetic active radiation)⁸⁵⁻⁸⁷. The long term gentle decline in macroalgae cover observed so far from the DLTRMP is promising for the condition of the Dauin reefscape. Increasing macroalgae abundance increases the number of coral-algal competitive interactions⁸⁸, which under limited resources (light and space) can lead to decreases in coral growth and survival⁸⁹ as macroalgae shades and smothers corals, thereby hindering its photosynthetic capabilities^{90,91}. However, macroalgae can also beneficially shade corals, reducing the extent of coral bleaching under environmentally stressful conditions⁹². Globally, increasing macroalgae cover has led to a phase shift in many reefs from a coral-dominated system to assemblages with higher proportions of macroalgae⁹³⁻⁹⁵.

Anthropogenic stressors such as eutrophication and overfishing contribute to the proliferation of macroalgae⁹⁵⁻⁹⁷. Overfishing can change the reef fish trophic community structure, with potential for trophic cascade effects (as discussed below). The herbivorous fish population increased gently from 2019 dry to 2020 dry, but declined significantly from 2020 dry to wet (Fig 3.3.13). It therefore appears that the relationship between herbivores and macroalgae cover aren't closely linked, although finer classification of herbivores within this functional group will elucidate these ecosystem relationships. Understanding the relationship between herbivores and macroalgae and continuing to monitor macroalgae cover on the Dauin reef is key in predicting future potential shifts to algal-dominated systems in order to identify necessary management

actions, both on a fine-scale at individual sites and across Dauin as a whole.

Coralline algae cover increased significantly from 2019 dry to wet season, but has not changed significantly since (Fig 3.1.12, Fig 3.1.13 for site-specific changes). Coralline algae has two main functional roles on coral reefs, 1) as a reef builder by contributing to reef calcification, and 2) inducing larval settlement of benthic organisms^{98,99}. The calcification of its cell walls, its heavy fixation to substrate and thick crusts that bind loose substrate, enable rigid binding of coral reef frameworks^{100,101}. Reef rubble stabilisation and substrate cementation are crucial in shallow reef environments with high wave action, to provide suitable substrate for larval settlement and reducing turnover and burial of established juvenile corals^{47,102}. Coralline algae also provide chemical cues that induce coral larvae settlement^{103,104}; an essential step in increasing coral cover and continuing reef recovery. Tebben *et al.* (2011) found a specific microbe strain from the genus *Pseudoalteromonas* (cultured from the surface of coralline algae) produces the small molecule tetrabromopyrrole (TBP) that induces both coral attachment and metamorphosis¹⁰⁵. Growth of coralline algae depends on its morphotype and environmental conditions, particularly water motion, depth, light intensity and temperature¹⁰⁶. Calcification rates are directly related to photosynthetic rate¹⁰⁷, hence growth rates vary greatly, from 0.3mm to 30mm per year¹⁰⁶. Thus, whilst calcification of coralline algae results in rigid binding and recovery of Dauin's inshore reefs, it is a gradual process.

Coralline algae, with high-magnesium calcite skeletons, is highly susceptible to increased dissolution as a result of ocean acidification¹⁰⁸ and increased runoff (particularly increased phosphate levels, which inhibits coralline algae growth and calcification¹⁰⁹). Furthermore, increased fishing pressure can affect coralline algae cover; removal of predatory fish in Kenyan reef lagoons led to a trophic cascade with an urchin-dominated community that intensely graze coralline algae, leading to a decline in coralline algae cover and a subsequent reduction in coral recruitment and juvenile abundance¹¹⁰. As such, it is essential to monitor coralline algae cover in the event of any declines, to rapidly identify and manage the cause, preventing further decline of this crucial reef component.

Sponge cover along the Dauin inshore reef remained consistent from dry 2019 until wet 2020, which saw a marked increase (Fig 3.1.17). Sponges have a

variety of functional roles in a coral reef ecosystem, including binding live corals to the reef frame, temporarily stabilising reef rubble, recycling dissolved nutrients via the sponge loop and improving water clarity^{111,112}. Due to their resilience under environmental stress and disturbance, their role on coral reefs may become increasingly pronounced¹¹³. Studies have found sponges to settle and stabilize rubble piles within a month of rubble production¹¹⁴⁻¹¹⁶. This temporary stabilisation allows for further encrustations and rigid binding by coralline algae; succession from temporary binding of rubble by sponges, consolidation by coralline algae and subsequent colonisation by corals can take as little as ten months¹¹⁵. Encrusting sponges "glue together" of rubble pile interiors to 2m below the rubble surface, while erect sponges (such as branching and rope sponge) bind adjacent rubble pieces through superficial overgrowth¹¹⁵. Along the Dauin inshore reefs, sponge cover is increasing whilst bare abiotic substrate, particularly rubble, decreases (Fig 3.1.2); demonstrating the occurrence of this temporary binding of loose rubble.

It is important to monitor the relative benthic coverage of sponges and Scleractinian coral to elucidate any direct competition between these two; on the Dauin reef sponge cover is increasing, but coral cover is not decreasing as a result, as it remains unchanged throughout the DLTRMP (Fig 3.1.2). Many sponges have been found to be superior to Scleractinian corals in space acquisition, although this depends on the presence of 'aggressive' sponge species, and sponges found on coral reefs vary greatly in their competitive abilities¹¹⁷. Spongivores also have a crucial role in limiting coral overgrowth by sponges. Experimental research found that exclusion of sponge predators, primarily angelfish, led to increased sponge overgrowth and subsequent decline in coral cover¹¹⁸. Invertivores (which includes spongivores) are the fourth-most abundant trophic group found along the Dauin coast, although by biomass they represent a much smaller proportion of the fish community (Fig 3.3.12). These invertivores may assist in limiting overgrowth of coral by sponges, maintaining consistent coral cover on the Dauin coast. Further classification of invertivores within their functional group (i.e. spongivores, crustacivores, molluscivores) along the Dauin reefscape will further our understanding of the importance of spongivores in regulating sponge cover.

Cyanobacteria cover has increased steadily throughout the DLTRMP (Fig 3.1.19). Cyanobacteria are a key component of coral reef ecosystems in their formation of microbial mats and epiphytic, epilithic and endolithic communities. They are a significant

food source for grazing reef organisms, and provide nitrogen to coral reef ecosystems through fixation^{119,120}. However, cyanobacteria are becoming increasingly abundant on declining reefs as their proliferation is supported by changes in water chemistry (dissolved organics, iron, and phosphorus levels) as a result of changing land use and runoff¹²¹. On reefs experiencing phase shifts or short-term algal blooms, restocking adult coral populations may be slowed by cyanobacteria due to recruitment inhibition, in turn reducing coral cover and limiting community recovery. Additionally, cyanobacterial mats can also poison Scleractinian corals, killing live coral tissue¹²². Cyanobacteria are also closely linked with coral disease, particularly Black Band Disease (BBD). Although the causative agent of BBD is identified as the cyanobacterium *Phormidium corallyticum*, previous studies found a variety of species and strains of cyanobacteria can co-exist in the same infection, altering the pathobiology and toxin production during the course of the disease^{123,124}. Although the cyanobacteria recorded during the DLTRMP cannot be directly implicated for disease incidences, the increasing cyanobacteria cover suggests the reef is responding to anthropogenic activity (i.e. eutrophication). Although cyanobacteria cover is very low along the Dauin reef (Fig 3.1.19), it is nonetheless essential to continue monitoring of cyanobacteria levels, to quantify any threats to coral recovery on the inshore Dauin reefs and identify possible management solutions.

Within the Dauin fringing reef, temporal changes in benthic composition are site-specific, indicating that recovery and succession varies along the coast. For example, Poblacion District II at 10m (Site 5) shows bare abiotic substrate declining (Fig 3.1.10), being colonised by Scleractinian coral (Fig 3.1.4) and coralline algae (Fig 3.1.13). Poblacion District II at 5m (Site 6) has declining rubble cover (Fig 3.1.10), as it is increasingly covered with coralline algae and turf algae (Fig 3.1.13). Conversely, Masaplod Sur within the MPA boundary at 10m (Site 13) shows declining coral cover (Fig 3.1.4), with increasing rope sponge, branching sponge (Fig 3.1.18) and a spike in other (macro-) algae (Fig 3.1.13). Maayong Tubig at 10m (Site 19) shows increases in both coralline algae (Fig 3.1.13) and branching sponge (Fig 3.1.18), whereas at 5m (Site 18) turf algae and coralline algae show notable increases (Fig 3.1.13). Reef recovery and early succession will vary greatly according to abiotic and biotic conditions such as the extent of initial damage, wave action and larval availability¹²⁵, hence it should not be assumed that recovery is synchronous across affected reef sites;

monitoring and management strategies must reflect this.

4.2 Reef Impacts & Coral Mortality

Assessments of coral health within the Dauin reefscape indicate a variety of localised stressors are causing direct mortality to the coral holobiont. Records of coral impacts and mortality have approximately doubled from 2019 to 2020 along the Dauin reef ecosystem. The foundation of reef ecosystems are the corals themselves; they play crucial roles in calcium carbonate dynamics, food provisioning for corallivores, herbivore-algae interactions, predator-prey interactions and nutrient cycling. Consequently, the loss of this ecosystem foundation (coral mortality) has severe consequences; phase shifts to algal-dominated systems and reef flattening are only a few of the widely documented effects of coral loss^{94, 126-131}.

Coral bleaching is the most prevalent impact recorded during the DLTRMP, followed by unknown scarring, *Drupella* spp. feeding activity and fishing trash (Fig 3.2.1). The frequency of coral bleaching, unknown scarring, *Drupella* spp. feeding activity, disease, fishing trash and direct destruction have all significantly increased throughout the DLTRMP (Fig 3.2.2). *Acropora* is the most frequently impacted Scleractinian genera, followed by *Fungia*, *Pocillopora* and *Porites* (Fig 3.2.14), which is consistent with the most prevalent coral genera along the Dauin reefscape (Fig 3.1.3). Fortunately, the current disturbances facing these predominant coral genera along the Dauin reef ecosystem are mostly small and localised lesions (with the exception of *Fungia* spp., for which 92% of recorded impacts are bleaching).

The health of a coral reef is often jeopardised by multiple stressors, both natural and anthropogenic¹³². Reefs within 10km of the coast are directly influenced by run-off (freshwater, sediment, nutrient and organic carbon)¹³³; the Dauin fringing reef ecosystem is located well-within this boundary (often less than 100m from the shoreline), hence it is directly affected by land-based activities including coastal development, waste management and tourism. When a coral is damaged or weakened, its susceptibility to secondary stressors such as disease increases¹³⁴. Secondary stressors can have synergistic or antagonistic effects if acting simultaneously^{132,135}. For example, nutrient enrichment has been seen to increase prevalence and severity of coral disease^{136,137} and bleaching¹³⁷. It is likely that some of these stressors are acting synergistically in Dauin, such as temperature stress, predation and nutrient

enrichment, which may be exacerbated due to the proximity of this reef to shore. Further research is required to determine the relationship between stressors and to quantify their interactions, in order to subsequently reduce their impact on the reef.

Bleaching is consistently the most frequently recorded impact to Scleractinian coral along the Davin reef (Fig 3.2.1, 3.2.2). Coral bleaching (loss of colour) occurs when symbiotic zooxanthellae are expelled from the Scleractinian host. The coral host may survive and regain zooxanthellae, or it may die. In Davin, bleaching was consistent throughout 2019, but increased significantly throughout 2020 (Fig 3.2.2). Triggers of coral bleaching include extreme temperatures, high irradiance, prolonged darkness, heavy-metal exposure and pathogens¹³⁸. However, most of the recent large-scale bleaching events are attributed to increased sea water temperature, combined with increased solar radiation (although other stressors may act synergistically)¹³⁸. Global climate change is widely accepted as the driving force behind these mass bleaching events¹³⁹.

Understanding the factors that determine coral bleaching sensitivity and severity (such as depth, location of colonies relative to the reef edge, microhabitat, colony size and morphology) is important in predicting future events¹⁴⁰. Bleaching of corals can be highly size-dependent and largely connected to their life histories¹⁴¹. Previous research has found the bleaching susceptibility of juvenile corals to vary by genus; *Acropora* spp. and *Goniastrea* spp. juveniles were less susceptible to bleaching than adults, but the reverse was true for *Pocillopora* spp. and *Merulina* spp.¹⁴². The surrounding benthos can also play a key role. Carbonate sand is highly reflective and can amplify light intensity to neighbouring corals; massive corals surrounded by sand have been shown to be more susceptible to bleaching¹⁴³. The high sand coverage at some locations along the Davin fringing reef may therefore affect the frequency and intensity of bleaching events.

The frequency and extent of bleaching per colony are genera specific (Fig 3.2.4); *Fungia* spp. has much higher incidences of bleaching than all other genera (41% of all bleaching records), and *Fungia* spp., *Pavona* spp., *Ctenactis* spp., *Montastrea* spp. and *Favia* spp. all have the highest percentage areas of colony affected. *Fungia* spp. has been found to be one of the coral genera most susceptible to bleaching, along with *Acropora* spp. and *Pocillopora* spp.¹⁴⁴. Of the bleached corals recorded throughout the DLTRMP, *Fungia* represent a large portion of the smaller colony size groupings (Fig 3.2.5). Previous research has found conflicting results as to whether fast growing (branching, tabular etc.) coral genera

are more or less susceptible to bleaching¹⁴⁵⁻¹⁴⁷. Results from the DLTRMP show that following solitary corals, it is the encrusting and massive growth forms that are the most frequently bleached, with branching corals following these (Fig 3.2.5).

The frequency of direct destruction has not changed significantly throughout the DLTRMP, although a notable increase is seen from dry to wet season of 2020 (Fig 3.2.2). Direct destruction is acutely detrimental to coral health, both directly through fragmentation (which is particularly detrimental for slower growing species) and indirectly through reduced fitness and susceptibility to secondary stressors. When a coral is damaged or weakened, energy is diverted to tissue repair and regeneration¹⁴⁸. Wound healing is achieved by rapidly repairing the epithelial breach and regenerating lost polyps and the surrounding tissue¹⁴⁹. This important process protects the coral from invasion by pathogens. However, the energetic cost of repair may increase susceptibility to secondary stressors such as disease, by lowering the immune responses of the coral¹³⁴. Lesions may also attract corallivores, also potentially acting as vectors for disease¹⁵⁰⁻¹⁵⁶. During the DLTRMP, secondary impacts have been recorded in 40% of direct destruction cases; most commonly predation, followed by bleaching and disease (Fig 3.2.11). Additionally, under harsh environmental conditions, the corals ability to recover from physical injuries becomes compromised¹⁵⁷.

Resistance of corals to physical forces depends on several factors; the shape, size and skeletal density of the coral, as well as the nature of the physical force being exerted (direction, strength and area over which it is applied)^{158,159}. In Davin, branching corals are the most frequently impacted by direct destruction, followed by tabulate and foliose growth forms (Fig 3.2.10). *Acropora* (branching and tabulate) is the genus most frequently damaged, followed by *Pocillopora* (branching), *Stylophora* (branching) and *Porites* (branching) (Fig 3.2.12). Branching corals are less able to withstand mechanical stress than massive or encrusting forms, as a result of form rather than skeletal properties¹⁶⁰. Moreover, colonies with thicker branches are able to withstand more mechanical stress than those with thinner branches¹⁵⁸. Branching corals have strong gradients of skeletal density, with high skeletal density at the base of the colony and lower density axially¹⁵⁹, meaning branch tips are highly susceptible to breakages. It is important to note however that many other factors also affect skeletal density of branching corals, such as species, depth and polyp/corallite spacing¹⁵⁹, so some branching corals

may be able to withstand physical forces better than others.

Causes of direct destruction can be natural (storms, wave action) or anthropogenic (boat anchors, recreational use from snorkelling/diving, destructive fishing practices). The 2012 category 5 Typhoon Pablo caused widespread damage to parts of the Dauin fringing reef, however the aforementioned colonisation of reef rubble has been occurring for years since, hence any recent direct destruction cannot be attributed to this extreme weather event. Strong wave action can damage the more brittle branching corals, but much of the Dauin fringing reef is sheltered from strong winds and waves by the shape of the coastline, hence rough seas (sufficient to damage corals) are rare in the area. As such, anthropogenic causes cannot be underestimated. The widespread recreational use of coral reefs for snorkelling and SCUBA diving is known to damage reefs^{161,162}, damaging coral skeletons directly (fins) and indirectly (boat anchors). Disease prevalence has also been recorded increasing three-fold at coral reef sites with high use compared to low use¹⁶³. Direct destruction recordings in Dauin fluctuate seasonally (Fig 3.2.2), potentially linking with the number of tourist visitors from low to high season.

Eight percent of direct destruction recordings are from stone fishing practices, which have been recorded at three DLTRMP survey sites, two of which are MPAs (Lipayo and Masaplod Sur). “Muro-ami is a Japanese fishing method used in reef fishing, consisting of a moveable bagnet, detachable wings and scarelines with plastic strips and iron/steel/stone weights”¹⁶⁴. Fish are caught by “spreading the net in an arc around reefs or shoals and, with the use of scarelines, a cordon of fishermen drive the fish towards the waiting net while pounding the corals by means of heavy weights like iron/steel/stone or rock, making it highly destructive to corals”¹⁶⁴. “Kayakas is the local version of the *muro-ami* but smaller in size using bamboo or tree trunks as scare devices aside from coconut or other leaves or materials as scarelines to drive fish out of the coral reefs”¹⁶⁵. Both have been prohibited in all Philippine waters since 1986 through the passing of an administrative order¹⁶⁵. An alternative, *pa-aling*, was introduced, which uses “bubbles generated by surface-supplied air through plastic hoses, to scare fish toward a set-net”¹⁶⁶. Although *pa-aling* is not prohibited, its use is spatially restricted through another administrative order¹⁶⁷. The records of stone fishing in Dauin’s MPAs, whether from *muro-ami* or *kayakas*, is concerning; these illegal practices are still being used instead of the less destructive *pa-aling*. This suggests the marine reserves of Lipayo and Masaplod Sur have forgone enforcement measures and are weakly-functioning “paper parks”¹⁶⁸.

No significant correlations were found between the frequency of direct destruction and the number of fishing or dive boats present during DLTRMP surveys. Although the trends of fishing trash and direct destruction frequency appear to mirror each other, statistical testing does not confirm a relationship between these. As such, at this point in the DLTRMP the cause of direct destruction cannot be attributed to either recreational use or fishing activity; more research on the causes of direct destruction of coral across the Dauin coastline is needed.

Fishing trash has significantly increased throughout the DLTRMP, whereas general trash has remained consistent (Fig 3.2.2). A plethora of research exists on the effects of marine litter on a variety of marine taxa and ecosystems, including coral reefs¹⁶⁹⁻¹⁷³. Impacts include entanglement, ingestion, substrate damage and assisting in the transportation of invasive species, as well as the range of impacts associated with microplastics. A study in the Gulf of Mannar in 2020 found 48% of corals in contact with debris were fragmented, and 34% had tissue loss¹⁷⁴. The prevailing currents, proximity to shore and fringing nature of the Dauin reef may contribute to the influx and subsequent retention of trash¹⁷⁵. Substrate composition will also influence trash retention, as structurally-complex corals such as *Acropora spp.* and *Montipora spp.* are more often in contact with marine debris¹⁷⁴.

The abundance of each type of trash (fishing or general) varies along the Dauin coastline; hotspots for general trash are Lipayo, Bulak, Maayong Tubig and Masaplod Norte (Fig 3.2.9), whereas fishing trash is higher at Bulak, Lipayo and Masaplod Norte (Fig 3.2.8). The identification of these hotspots is essential in determining best management actions to reduce this trash, as actions for land-based litter management are very different to that of fishing activities. Fishing trash abundance is also greater during wet seasons than dry (Fig 3.2.2), whereas general trash (also known as “land-based”) doesn’t fluctuate seasonally. This implies that increased rainfall during wet season does not lead to a greater influx of trash on the Dauin reef, hence an increase in fishing trash is more likely attributable to an increase in fishing activity (perhaps as a result of improved weather conditions for fishing) rather than weather patterns.

Coral disease prevalence was consistently low for the first three survey seasons, before significantly increasing in 2020 wet season, as a result of a large spike in Porites Ulcerative White Spot (Fig 3.1.12). Skeletal Eroding Band Disease and White

Syndromes have been recorded during the DLTRMP with very low frequencies, found only on branching *Pocillopora* spp.. *Porites* trematodiasis (also known as *Porites* pinking) has also been recorded at low frequencies. Factors previously found to increase disease outbreaks include temperature stress^{176,177}, lesions from direct destruction¹⁵⁰, nutrient enrichment^{136,137}, high coastal human population¹⁷⁸, reef fish abundance and functional diversity alterations¹⁷⁹ and proximity to algae¹³⁷. Increased runoff during wet seasons and subsequent nutrient enrichment may account for increases in disease, as a result of reduced host fitness or increased pathogen virulence due to increased nutrients and organic matter¹⁸⁰. Lesions may attract corallivores such as *Drupella* spp.^{152,181} and corallivorous fish¹⁵³, which in turn may act as vectors for disease¹⁵⁴⁻¹⁵⁶.

Little is known about disease dynamics specific to the Philippines, with few studies and reviews available^{182,183}. However, *Porites* is known as a dominant disease host within the Philippines, particularly in the Central Visayas¹⁸⁴. Across the Dauin reefscape, *Porites* was the most affected genus, by *Porites* trematodiasis (PP) and *Porites* Ulcerative White Spot (PUWS) (Fig 3.2.12). *Porites* trematodiasis has been recorded to drastically reduce growth rates of *Porites* colonies, up to 50% reductions^{185,186}, hence potentially reducing the capacity of the infected colony to compete for space on the reef¹⁸⁷. However, it has been postulated that a high prevalence of *Porites* trematodiasis is indicative of a healthy reef ecosystem, as the disease (caused by a parasitic flatworm) requires multiple hosts (molluscs, coral and fish) during its life cycle¹⁷⁸. As such, although the disease will have negative impacts on individual *Porites* hosts, the presence of this disease in Dauin, combined with its low prevalence, may infer a healthy reef ecosystem.

“White syndrome” is a term that has been used for a range of diseases characterised by acute tissue loss, exposing white skeleton in the absence of other disease signs or established causation, causing either partial or whole colony mortality as the disease progresses^{188,189}. These “white syndromes” are some of the most prevalent diseases on coral reefs¹⁹⁰ and severe white syndrome outbreaks can affect coral cover and reef composition¹⁸⁸. In spite of this, white syndromes are some of the least well-defined¹⁹¹. Little information is available on white syndromes specific to Pocilloporidae, whereas the white syndrome PUWS is better understood. PUWS is prevalent in the Philippines, however mortality is generally low²⁵. It is indiscriminate to coral morphology, affecting both branching and massive *Porites* spp., with prevalence per species correlated with species density (host availability), not morphology¹⁹². Although the rate of tissue loss for

PUWS is slower than other white syndromes, recovery from PUWS is rare, limited only to colonies with low-intensity infections¹⁹². PUWS prevalence is positively correlated with human population density, and outbreaks of PUWS are driven by elevated nutrient levels and organic carbon¹⁸³. Warmer sea temperatures also increase incidence of PUWS, suggesting their virulence increases under these conditions¹⁸³. Previous research has documented links between sewage-derived nitrogen pollution and white syndrome severity in *Porites* spp.¹⁹³. It is possible that the Dauin fringing reef is exposed to these diseases as a result of sewage outfall and nutrient enrichment from increased runoff. Continued monitoring of the prevalence of this disease is needed, as well as examining its severity and subsequent mortality of *Porites* spp.; as one of the dominant coral genera on the Dauin reef, widespread loss of this genus could have significant ecological impacts.

Skeletal Eroding Band Disease (SEBD) is rare along the Dauin reef, but has been recorded during the DLTRMP (Fig 3.2.12). SEBD is a ciliate infection associated with tissue loss in corals and is strongly linked with coral damage and injuries¹⁹⁴. The Dauin reef ecosystem may be more susceptible to SEBD due to the higher frequency of direct destruction and predation (*Drupella* spp., COTS and unknown scarring), both of which leave behind exposed coral skeleton. The putative agent of SEBD has been shown to readily colonise recently exposed coral skeleton in the absence of a vector, but did not colonise intact coral tissue¹⁹⁵. Although it can readily colonise exposed skeleton, it is not able to cause tissue mortality alone; it requires additional agents or factors (stressors) to increase the virulence of the putative agent or to lower the disease resistance of the coral host in order to cause tissue loss¹⁹⁵. A study on the Great Barrier Reef found 12 Scleractinian families were affected by SEBD, with Pocilloporidae and Acroporidae as the most susceptible¹⁹⁵; the only incidences of SEBD recorded during the DLTRMP were on *Pocillopora* spp.. Although the presence of this disease can be concerning, prevalence is low. Additionally, both of these records were from the 2019 wet season, with no records of this disease during any other survey season; further monitoring will highlight any future occurrences and the potential need for management.

Crown-of-thorns starfish (COTS, *Acanthaster planci*) are found at low abundances across the Dauin reef ecosystem (Fig 3.2.2). Only one individual was recorded in 2019 and although the mean number of individuals per transect remained low in 2020 for Dauin as a whole, some sites had large increases in the number of COTS present. 82% of COTS

recorded during the DLTRMP in 2020 were at Masaplod Sur (Fig 3.2.13). Outbreaks of COTS are one of the most destructive disturbances on coral reefs⁵, causing mass coral mortality, long-term changes to community structure^{197,198}, reef structural complexity collapse and declining biodiversity and productivity^{199,200}. A corallivore 'outbreak' is commonly described as "brief episodes of unsustainably high densities"²⁰¹, or "increases (often rapid) in their abundance above threshold densities that can be sustained by local coral assemblages, which in turn depends on the abundance and turnover of coral prey"²⁰². Pratchett *et al.* summarised the variability and subsequent difficulty in defining COTS outbreak thresholds, as well as the importance in defining thresholds for management actions²⁰³. As such, a threshold for an 'outbreak' must be defined locally, which is one of the research aims of the DLTRMP. Causes of rapid increases in COTS population densities are thought to be as a response to 1) natural disturbances²⁰⁴, 2) nutrient enrichment²⁰³ and 3) predator removal²⁰³. However, as COTS are highly fecund with enormous reproductive potential²⁰⁵, small changes in recruitment may be enough to initiate outbreaks²⁰¹. Additionally, post-settlement survival of COTS is highest in relatively shallow waters, obliquely exposed fore reef habitats and areas with high coral rubble cover²⁰⁶; parts of the Dauin coastline closely match this description. Identifying the causes of COTS outbreaks along the Dauin coastline is essential in predicting and preventing future COTS outbreaks.

Acropora spp. is the most commonly impacted genus by COTS on the Dauin fringing reef, followed by *Pavona spp.*, *Anacropora spp.* and *Porites spp.*. *Acropora spp.* also has the largest mean area affected by COTS predation. Previous research has found *Acropora spp.* to be one of the most preferred Scleractinian genera^{203,207} for COTS, consistent with the DLTRMP findings. Tabular forms are also favoured over branching, submassive, foliose and massive (the least preferred)²⁰⁷. This study also found these results to be consistent over many reefs, suggesting starfish size, density, time of day and depth are not significant factors in prey preferences²⁰⁷. Larval survivorship is also greater when maternal diets include *Acropora spp.*²⁰⁸, indicating that COTS outbreaks may be more likely on reefs with high *Acropora spp.* cover. The high proportion of *Acropora spp.* across Dauin's reef ecosystem is therefore conducive to COTS outbreaks, highlighting the need for effective management of potential causes for COTS population outbreaks.

Coral mortality as a result of corallivorous *Drupella spp.* (marine snails) predation has increased throughout the DLTRMP, both in terms of the number of impacted colonies per transect and the size of the area affected per colony and per transect (Fig 3.2.6). *Drupella spp.* outbreaks are associated with

high coral mortality^{181,209-2014} and reduced reef resilience and recovery²¹⁵ leading to phase shifts. Additionally, links have been observed between *Drupella spp.* outbreaks and coral damage (direct destruction)²¹⁶, disease¹⁸¹, mass bleaching²¹⁷, mechanical and salinity stress¹⁵², chronic overfishing of predators e.g. triggerfish and wrasse²¹⁸, eutrophication²¹¹ and seasonality (particularly water temperature and increased runoff input)^{211,219}. Many of these stressors have been recorded along the Dauin coastline, potentially acting synergistically and hence exacerbating the effects of *Drupella spp.* predation.

Drupella spp. primarily feed on fast-growing corals with high recruitment rates, such as *Acropora spp.*, *Pocillopora spp.* and *Montipora spp.*²²⁰, although they may change feeding preferences according to taxon abundance²¹⁹. The majority of *Drupella spp.* feeding activity records from the DLTRMP are on *Acropora spp.* (69.4% of records), followed by *Pocillopora spp.* (19.0% of records), which are two of the most dominant coral genera in the area.

Whilst *Drupella spp.* are most frequently observed at low densities, the damage caused by *Drupella spp.* outbreaks in terms of intensity, extent and biological features of the damage is similar to that of *Acanthaster planci* (COTS)^{209,210}. To understand the threat of observed *Drupella spp.* abundances to coral cover on Dauin's reefs, it is essential to determine the density of *Drupella spp.* that can be sustained based on coral cover and growth; quantifying *Drupella spp.* feeding rates is key in this. Bessey *et al.* (2018) defined outbreak densities of *Drupella cornus* as a function of coral cover and growth and *Drupella* consumption rates²⁰². Using this model, with Dauin's mean coral cover of 21% (Fig 3.1.1), *Drupella spp.* densities of 1.1 individual m⁻² would be considered an outbreak. This could be further refined to examine site-specific coral cover to determine highly-localised outbreak densities of *Drupella spp.*; coral cover ranges from 2-43%, which would equal outbreak densities of 0.3-2.1 individuals m⁻². However, the applicability of this model to Dauin's reef ecosystem will need validating, ideally with *in situ* measurements of *Drupella spp.* consumption rates and coral growth rates.

Management actions to curb coral mortality should be prescriptive, as different areas along the coastline have different primary concerns. Coral bleaching, the most prevalent impact across Dauin's reef, cannot be solved locally; it is a global threat that requires global action. However, many other threats facing the Dauin reef ecosystem can be effectively managed at a local scale, either by the municipality of Dauin or more specifically by

individual barangays. Local efforts could be concentrated on the following threats at these locations:

- Fishing trash: Bulak, Lipayo and Masaplod Norte
- Stone fishing: Lipayo and Masaplod Sur
- General trash: Lipayo
- Direct destruction (whether from fishing or recreational use): Lipayo, Poblacion, Maayong Tubig and Masaplod Sur

Abating some of these localised threats will aid in curbing the synergistic effects of multiple stressors, enabling Dauin's reefs to become more resilient and recover from other, more widespread threats such as bleaching.

4.3 Fish community structure

Fish abundance, biomass and species richness along the Dauin reef ecosystem have all increased significantly throughout the DLTRMP (Fig 3.3.1), suggesting the conditions along the Dauin coastline are beneficial to the reef fish assemblage. 42 fish families have been recorded along the Dauin inshore reef with a total species richness of 346, increasing from 2019 with 248 species in 37 families. The species accumulation curve (Fig 3.3.2) is gently moving towards a plateau, which combined with the significant increase in species richness between survey seasons, suggests that the fish community of Dauin's reefs have not yet been surveyed representatively after the 76 replicates of the DLTRMP thus far, but will be after another few survey seasons. Within the Dauin reef fish community, two species recorded are classified as Vulnerable according to the IUCN Red List (Orange spotted filefish and Brown-marbled grouper), and three are Near Threatened (Bluespotted ribbontail ray, Bower's Parrotfish and Yellow-tail Parrotfish). The long term monitoring of the Dauin fish assemblage, including any rare species that are a priority for conservation, is crucial in determining suitable and effective management actions if required, whilst ensuring the reef provisioning needs of the local community continue to be met.

The Dauin fish assemblage is dominated by *Pomacentridae* (damselfish) and *Labridae* (wrasse); damselfish and wrasse are the most abundant and speciose fish families (Fig 3.3.6,3.3.8). Damselfish also are the biggest contributors to fish biomass, followed by *Lutjanidae* (Snapper) and *Caesionidae* (fusiliers) (Fig 3.3.7). Globally, damselfish and wrasse are ubiquitous and abundant components of reef fish assemblages, and often the most speciose families^{221,222}. Wrasse are the second-most speciose

reef fish family (second to *Gobiidae*)²²³, with huge variety in body shape, size, feeding strategies and mating systems²²⁴. Both damselfish and wrasse exhibit strong relationships with coral cover and habitat complexity²²⁵. *Acropora spp.*, the most dominant coral in Dauin (Fig 3.1.3), provides shelter for and therefore sustains abundant populations of small-bodied fish such as damselfish^{226,227}. Damselfish are able to occupy a vast array of niches within the reef ecosystem due to their high degree of variation and specialisation, in terms of feeding, habitat and shelter selection²²⁸. They are also able to withstand environmental change by adapting these strategies²²⁸, explaining their high prevalence on coral reefs globally amidst severe environmental changes as a result of frequent and intense disturbances. The abundance and biomass of damselfish increases significantly throughout the DLTRMP, (Fig 3.3.10) indicating the conditions are favourable for this family, perhaps as a result of an absence of predators, an abundance of food and/or habitat.

Overall fish abundance does not differ significantly along the coast, but biomass does (Fig 3.3.3), indicating that larger-bodied fish are more prevalent at some locations. Reef fish community structure is strongly shaped by responses to a vast number of biotic and abiotic factors, such as temperature, depth, current direction and intensity, benthic composition, topographic complexity, food availability, competition, recruitment patterns^{221,229-231}. These factors can vary considerably even at a patch-reef scale, potentially explaining the significant differences in size structure of the fish assemblage. Temporal fluctuations can also affect fish community structure, such as variation in physical conditions (temperature, currents etc.), biological traits (mortality, growth etc.) and behavioural patterns (migration, spawning etc.)²³². Ecological processes such as ontogenetic migration²³³ (where fish occupy different sites at different life stages based on habitat features such as complexity or food availability), and niche partitioning²³⁴ (where different species occupy different habitats as a result of natural selection and resource competition) can also shape the fish assemblage. Coral reef ecosystems are increasingly subjected to disturbances, natural and anthropogenic, which can reduce habitat quality, quantity and connectivity^{235,236}. Anthropogenic factors such as fishing pressures and disturbances may also play a significant role in the size structure of the Dauin fish assemblage²³⁷. Further investigation into the community composition, size structure of the fish populations and the external forces affecting these at different sites along the Dauin fringing reef will shed more light on the driving forces behind these differences in reef fish communities along the coast.

The Dauin reef ecosystem supports a high proportion of trophic generalists over specialists, as shown by the high abundance, biomass and species richness of omnivores in comparison to specialists such as corallivores, piscivores, herbivores and detritivores (Fig 3.3.12, Table 3.4). The major trophic guilds along the Dauin fringing reef ecosystem correlate directly with the high abundance and biomass of *Pomacentridae* (damselfish), *Labridae* (wrasse), *Serranidae* (*Anthiinae*) (groupers, anthias) and *Caesionidae* (fusiliers). The guilds omnivore, planktivore, herbivore & planktivore and invertivore remain dominant throughout the DLTRMP (Fig 3.3.13, 3.3.14). Strong positive relationships between fish abundance and live coral cover are widely reported in literature, particularly with regards to specialists (such as obligate coral-dwelling species, corallivorous fishes, or species reliant on coral habitat for recruitment)^{231,238-240}. The lack of a strong relationship between live coral cover and fish abundance and biomass in Dauin (Fig 3.3.9) further supports the premise of a fish assemblage dominated by generalists.

The loss of specialists and subsequent replacement by generalist species, known as biotic homogenisation, is an emerging global phenomenon²⁴¹, which can have severe impacts on ecosystem functioning and community structure²⁴², particularly if the generalist replacements are invasive species²⁴¹. Ecological theory predicts that generalists (trophic or habitat) are less susceptible to disturbances than specialists²⁴³. As such, examining functional group community structure (trophic level, ecological role, body size, home range, habitat associations, or a combination of these factors²⁴⁴) can indicate how reef fish assemblages will respond to these disturbances. Many studies have demonstrated the susceptibility of habitat and feeding generalists versus specialists following disturbances, such as bleaching and severe tropical storms on coral reefs^{243,245,246}; fish assemblages in post-bleaching communities on the Great Barrier Reef are dominated by generalist planktivores, benthic omnivores and detritivores⁸¹. The strong foundation of trophic generalists in the fish assemblages of Dauin is promising (in terms of resilience to future disturbances), but frequent and/or intense disturbances will cause reef fish communities to become further dominated by trophic generalists, whilst specialists become depauperate. The evolution of the Dauin reefscape benthos is indicative of early stages of recovery post-disturbance. Thus far in the DLTRMP, there have been few significant changes to the fish trophic community structure (relative abundance and biomass of functional groups) (Fig 3.3.15). It is crucial however to continue monitoring fish community structure along the Dauin reef ecosystem, to elucidate any trends in trophic

community structure shifts both post-disturbance and in response to any future disturbance events.

Following generalist omnivores, planktivores are the most abundant and greatest contributors to fish biomass along the Dauin coastline (Fig 3.3.12). This is consistent with the high proportion of *Pomacentridae* (damselfish) (and *Anthiinae*, *Labridae* and *Caesionidae* (anthias, wrasse and fusiliers), although at an order of magnitude less abundant). Planktivores are a dominant feeding guild on coral reefs globally, accounting for up to 50% of fish biomass in reef assemblages²⁴⁷. They are a crucial component of the reef ecosystem, transferring particulate organic matter from the water column to the benthos and higher up the oligotrophic coral reef food web²⁴⁸. Planktivorous fishes are also a common prey item for piscivores and invertivores²⁴⁹, their faeces are consumed by detritivores, contributing to the detrital food web²⁵⁰, and excreted nutrients are taken up by sessile organisms such as corals and anemones²⁵¹. Niche partitioning²⁵² (specialisation within the trophic guild) occurs in planktivores, with some species having significant differences in dietary composition despite similar feeding strategies, and some genera having more diverse diets whilst others are more selective^{253,254}. The Dauin fringing reef is situated very close to the shore, hence run-off and increased suspended sediment may alter nutrient dynamics, planktonic communities and therefore the planktivorous fish assemblage²⁵⁵⁻²⁵⁷. Additionally, planktivores have been shown to dramatically decline in abundance, biomass and body size in heavily exploited reefs²⁴⁷. As such, it is important to monitor the populations of this vital trophic guild, to maintain ecosystem functioning of the reef assemblage in the event of disturbances.

Exclusive herbivores have relatively low abundance along the Dauin reef ecosystem, however they contribute a reasonable portion to overall fish biomass (4%, Fig 3.3.12). These exclusive herbivores are comprised of mostly large-bodied fishes (*Scaridae*, *Acanthuridae*, *Siganidae* and *Pomacentridae*), explaining the low abundance but relatively high contribution to biomass. The trophic guild herbivore & planktivore has many more *Pomacentridae* species, as well as some *Acanthuridae* and *Siganidae* species – the high proportion of damsels in this functional group explains the very high abundance of this trophic group, whereas the relatively high contribution to biomass is from the *Acanthuridae* and *Siganidae*.

The abundance of exclusive herbivores is consistent throughout the DLTRMP except for a significant decrease in 2020 wet season (Fig 3.3.13), whereas biomass remains consistent except for a spike in 2020 dry season, which then returns to baseline

levels (Fig 3.3.14). Relative to other functional groups, a significant proportional decrease is seen in 2020 wet season in the abundance of the exclusive herbivore group (Fig 3.3.15). Herbivorous fish are crucial in limiting algal growth on coral reefs and preventing phase shifts to algae-dominated systems⁹⁴. At this point of the DLTRMP, the population of herbivores is not declining below baseline levels identified in 2019, however close monitoring of this is essential to identify any significant future declines, as a loss of this group in the fish assemblage may lead to a phase shift to an algal-dominated system if unimpeded.

The trends in the herbivorous fish population and benthic algae cover appear to mirror each other, suggesting that the system is a self-regulating predator-prey feedback loop²⁵⁸; whereby more algae provides a more abundant food source for the herbivores, which then graze the algae to lower levels leading to a drop in the herbivorous fish population, and so on. However, niche partitioning within the herbivore functional group has led to further classification into specific niches (browsers, grazers, scrapers and croppers²⁵⁹), which translate to different ecological roles. As such, all herbivores cannot be grouped together in determining their role in limiting algal overgrowth on coral reefs. For example, two damselfish species (*Stegastes nigricans* and *Stegastes obreptus*) in Japan have been found to promote algal growth through 'intensive and extensive farming' in order to maintain a stable food supply²⁶⁰. Conversely, bioassays have confirmed *Siganidae* are the main fish family responsible for removing macroalgal biomass on coral reefs²⁶¹. As such, the further classification of herbivores recorded in Dauin is a high priority for the DLTRMP (and a research goal for 2021-2022), to determine which fishes are crucial for inhibiting algal overgrowth on the reef and therefore are a high priority for conservation. This will also allow us to better understand the population dynamics, seasonal migrations or fishing pressures that affect these keystone species, in order to effectively manage and maintain their role in the reef fish assemblage.

Similar to herbivores, exclusive piscivores have low abundance along the Dauin reef ecosystem but relatively high biomass (3%, Fig 3.3.12). There are only 11 species classified as exclusive piscivores, but when including the invertivore & piscivore functional group, abundance, biomass and species richness all contribute much more to the overall Dauin reef fish community (Fig 3.3.12, Table 3.4). Piscivores are apex predators in coral reef ecosystems and play a vital role in top-down community structuring^{262,263}. Removal of piscivores leads to prey release and potentially trophic cascades²⁶², whereby the removal of keystone species causes significant changes to the

ecosystem community structure, often with devastating effects on ecosystem functioning. On coral reefs, the removal of apex predators (piscivores) by intensive fishing has complex and varying effects on community structure and functioning (see Boaden & Kingsford, 2015 for a review). However, exclusion studies on small patch reefs (similar to the Dauin fringing reef ecosystem) have consistent findings; the removal or exclusion of predators leads to changes in abundance, species richness and mortality of prey species^{264,265}.

During the course of the DLTRMP, the abundance and biomass of the two main piscivorous functional groups (exclusive piscivore and invertivore & piscivore) remains unchanged (Fig 3.3.13, Fig 3.3.14), however as the abundance of other functional groups increases, a significant relative decrease is seen in the functional group invertivore & piscivore (Fig 3.3.15). Many ecological factors may influence the relative abundance of piscivores, such as daily foraging movements, seasonal migrations and ontogenetic shifts^{232,247}, however the relative decline in piscivorous fish may also be as a result of targeted fishing pressures^{58,266,267}. A deeper understanding of the driving forces behind this decline is needed, in order to effectively implement any management solutions if required; targeted fishing restrictions on certain piscivores could be an effective measure, as it would allow surrounding areas to benefit from 'spill over' effects in the future²⁶⁸.

Commercially important fish species (CIS) although few in number, contribute greatly to the biomass of the fish assemblage in Dauin (Fig 3.3.16). 94 commercially important fish species (27% of total species richness) across 20 different fish families have been identified during the DLTRMP. *Labridae* (wrasses), *Lutjanidae* (snapper), *Acanthuridae* (surgeonfish) and *Siganidae* (rabbitfish) are the main commercially important fish families in the Dauin reef fish assemblage in terms of abundance, biomass and species richness (Fig 3.3.17-3.3.19). No significant changes have been recorded in the abundance and biomass of CIS throughout the DLTRMP (Fig 3.3.20), however the abundance and biomass of non-commercially important fish and fish with minor commercial importance have significantly increased, so a significant relative decrease is seen in the population (abundance and biomass) of CIS (Fig 3.3.21). The lack of an increase in commercially important fish when the rest of the fish assemblage population is increasing highlights the fishing pressure on this group. Throughout the tropics and subtropics, tens of millions of people rely on coral reef fisheries for food and livelihood²⁶⁹. The Philippines is highly reliant on fish as a protein source²⁷⁰, so productivity and fishing pressures on the reefs of the Philippines are an important issue. The majority of the world's

coral reefs are found in areas where human populations are expected to double within the next 30–50 years, so pressure on these ecosystems will undoubtedly increase^{271,272}. Coral reef fishes are vulnerable to intense fishing pressures due to their life history traits, which are not adapted for the high adult mortality associated with fishing²⁷³.

The relative abundance and biomass of commercially important fish varies greatly between sites along the Dauin coastline (Fig 3.3.22-3.3.23), which will affect fishing pressures on individual reef patches and hence influence any required management actions. Coral reef fisheries can be categorised into three states; manageable, ecosystem-overfished, and Malthusian-overfished²⁶⁹. Manageable states are sustainable fisheries that support large bodied fish that are easy to harvest²⁶⁹. Ecosystem-overfished states refer to more heavily fished areas where large and high-value predators such as grouper and snapper are rare and lower-value species such as parrotfish, wrasse and rabbitfish are targeted²⁶⁹; a shift in both the ecosystem and market from high to lower valued species indicates ecosystem overfishing²⁷⁴. Malthusian-overfished states exist under intense coastal crowding, where the number of fishers increases to a point where the average fisher receives very little or no net income and often destructive fishing practices are adopted to maintain catches²⁷⁵. Manageable coral reef fisheries have little to no effect on the fish community other than reducing the abundance and biomass of target species. However, intense fishing causes reduced species diversity²⁷², localised extinctions of both target and non-target species^{276,277}, the loss of larger, often apex predator species²⁷³, entire functional groups²⁷² and subsequent significant shifts in the reef ecosystem structure^{126,273,278,279} and reduced resilience to disturbances²⁷². As such, overfishing is one of the most significant threats to reef ecosystems²⁸⁰. It is not yet clear where the Dauin reef ecosystem fits along this scale of overfishing, and in all likelihood different locations along the coast will fall into different categories. It is therefore essential to monitor the populations of CIS within the fish assemblage across different locations along the Dauin coastline, as well as changing fishing pressures. This will allow the identification any areas that are exhibiting signs of overfishing and subsequent implementation of necessary management actions to prevent the aforementioned consequences of overfishing.

The proportion of commercially important species to species with minor/no commercial importance varies greatly between trophic groups in Dauin (Fig 3.3.24). For omnivores, the abundance of CIS is low (5.7% of all omnivores), but their biomass accounts for 43.1% of omnivores, highlighting the targeted selection of heavy-bodied omnivores by fishermen. Effects of the

feeding behaviour of trophic generalists are dissipated throughout the food web²⁸¹, hence removal of omnivores from the ecosystem by fishermen will have less damaging effects than that of trophic specialists, who maintain specific ecological functions on the reef, as aforementioned. CIS represent only 29.3% of exclusive herbivores by abundance but 49.2% by biomass, again highlighting the targeting of larger-bodied fish by fishermen. However, the abundance and biomass of this crucial trophic group remains consistent throughout the DLTRMP, so currently no management actions on the harvesting of these fishes is needed. Fish in the detritivore & planktivore trophic guild are almost exclusively CIS (Fig 3.3.24). There are only two species within this trophic guild, *Ctenochaetus binotatus* and *C. striatus*, the latter being the CIS. Although planktivores are abundant along the Dauin reef ecosystem, detritivores are depauperate (Fig 3.3.12). The fishing pressure on this niche and on *C. striatus* is therefore in need of consistent monitoring. Currently, the abundance and biomass of this species has remained consistent throughout the DLTRMP, indicating that the pressure exerted on this species is currently sustainable.

The commercially important fish population in Dauin is heavily skewed towards smaller individuals (Fig 3.3.25). The size structure of a fish assemblage is key in maintaining its sustainability; exploited fish communities shift toward smaller individuals, truncating its size structure as a result of size-selective fishing²⁸². Generally, larger-bodied animals are preferentially harvested as they are more valuable and more obvious and easy to catch²⁸³. Body size is largely correlated with trophic level, hence the targeted removal of large-bodied fish coincides with the removal of apex predators^{276,284} and the knock-on effects of this, as discussed above. This size-selective fishing hinders the reproductive potential of the fish community by removing sexually-mature individuals²⁸⁵, potentially causing recruitment failure²⁸⁶ and altering the stability of the community, increasing its sensitivity to other disturbances and stressors such as ocean warming²⁸². If coral reef fish communities continue to be heavily fished, fishermen target smaller individuals (as the largest have already been exploited to local extinction)²⁸⁷, further exacerbating the aforementioned effects of fishing out the species highest up the food web. However, it is important to note that the scarcity of these large-bodied CIS during DLTRMP surveys does not guarantee that these fish are functionally extinct in the Dauin reef community. It is consistent with ecological theory that in an ecosystem, the abundance of a species decreases as body size increases^{288,289}, hence these large-bodied CIS are naturally rarer in the ecosystem than small-bodied fish such as damselfish (Fig 3.3.6). Additionally, larger-bodied fish such as *Lutjanidae* (snapper), *Haemulidae* (sweetlips) and *Serranidae* (grouper)

tend to have larger home ranges²⁹⁰, hence capturing them in a survey is less likely. Nonetheless, avoiding the shift to a size-truncated fish assemblage is crucial in maintaining healthy and effective ecosystem functioning; continued monitoring and management action where required is key in this.

Data on the body size at which sexual maturity is reached is lacking for most CIS found in Dauin. The rarity (abundance) of these CIS compounds the problem; it is challenging to obtain a representative sample of the size structure of fish species populations when they are rarely encountered on surveys. Of the three species that have over 50 measurements from the DLTRMP, *Parupeneus multifasciatus* and *Mulloidichthys flavolineatus* appear to have normally-distributed size structures, whereas *Plotosus lineatus* is undersized (Fig 3.3.26). However, more measurements on the body size (hence sexual maturity) are needed on all CIS, as well as determining the size of sexual maturity for more CIS, to effectively monitor the sustainability of fishing activities for individual species.

5. CONCLUSION & FUTURE WORK

Results thus far from the DLTRMP are promising overall, although the increase in impacts to coral health and mortality is concerning. There are site-specific variations in benthic composition, disturbance history, recovery and succession, anthropogenic use and fish community structures. Continued long-term monitoring will be required to confirm trends with regards to benthic recovery, impacts to corals (and their causes such as nutrient loading and anthropogenic use) and changes to the fish assemblage. Key areas of management action have been highlighted, as well future research required by the Institute to better understand the current findings of the DLTRMP.

5.1 Management Action

1. Readdress the conservation goals of the Lipayo and Masaplod Sur marine reserves as a result of the continued recordings of fishing line and the destructive *muro-ami* fishing technique.
2. Tighten enforcement on Poblacion District I, Lipayo, Maayong Tubig, Masaplod Sur and Masaplod Norte marine reserves due to the presence of “Vulnerable” and “Near Threatened” IUCN Red Listed species.
3. Improve management of the sources of trash (both general and fishing) and work towards the provisioning of infrastructure to reduce littering, particularly in Lipayo, Bulak, Maayong Tubig and Masaplod Norte.

5.2 Future Research

1. Deepen the understanding (perhaps quantitatively) of the resilience of Dauin’s reef to disturbance and the rate of recovery in returning to its original condition.
2. Determine rates of biogenic carbonate sediment production, and the presence (or absence) of calcification cycles as influenced by anthropogenic and/or environmental processes (e.g. seasonality, water temperature, nutrients, pCO₂, light availability); monitoring water quality will be key in determining suitability of conditions for coral growth.
3. Explore the relationships between different stressors (impacts), determine any synergistic/antagonistic interactions, and the effects of these multiple stressors on the subsequent susceptibility of corals to further impacts and therefore the resilience of the reef to future disturbances.
4. Understand what environmental factors explain bleaching severity within Dauin, such as depth, microhabitat, colony size and morphology.
5. Examine the causes of direct destruction along the Dauin reef, in order to develop effective management actions and advice for the community to reduce damage to the reef.
6. Continue to monitor the presence of Porites Ulcerative White Spot along the Dauin reef, to determine if 2020 saw a spike in this disease that returns to baseline levels or if the increase continues into 2021 – if the latter, further investigation into the local cause of this outbreak and subsequent management action will be necessary.
7. Identify the factors driving the abundance and spread of *Drupella* spp. and *Acanthaster planci*, as well as determine a locally-relevant threshold (quantitative) above which population densities are deemed ‘outbreaks’. Determining feeding rates, combined with our data on coral cover, is essential in this.
8. Determine the abundance and distribution of herbivores within their trophic niche (i.e. large excavators, small excavators, scrapers, grazers, browsers and grazers/detritivores), and the effects of this on algal cover.
9. Determine the abundance and distribution of invertivores within their trophic niche (i.e. spongivores, crustaceans, molluscivores), and the effects of this on regulating sponge cover and coral-sponge competition.
10. Continue to examine the size structure of commercially important reef fish within the Dauin inshore reef to determine their species-specific reproductive potential.

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7. APPENDIX

7.1 CPCe codec

ACAN	ACR	ALV	ANAC	ASTR	AUS	CATA	CAUL	COEL	COSC	CTEN	CYC	CYN	CYPH	DIPL	DUNC	ECHI	ECHP	EUPH	FAV	FAVI	FUN	GALA	GARD	GONI
GONO	HALO	HELI	HERP	HET	HETP	HYDN	ISOP	LOBO	LEP	LEPT	LEPTA	LITH	MON	MONT	MERU	MOSE	MYC	OULO	OXY	PACH	PARA	PAVO	PECT	PHYS
PLAT	PLER	POC	PODA	POLY	POR	PSAM	SAN	SCAP	SCOL	SER	STY	SYMP	TRAC	TUBA	TURB	ZOO	UC	GG	SC	SP	TP	HEL	LC	MP
STH	DRU	GC	SL	AM	CM	Z	SPB	SPBL	SPBR	SPE	SPF	SPR	SPT	ASC	COT	CY	O	HM	SA	TA	CA	DA	SG	RDC
DCA	CR	R	RB	S	SH	T	FG	UNK	TAPE	WAND	SHAD	BL	BBD	BLBD	WSD	NEO	HYP	SEBD	PP	FS	IVB	OD		

<i>Acanthastrea</i> (ACAN)	<i>Leptoria</i> (LEPTA)	Anemone (AM)	Sand (S)
<i>Acropora</i> (ACR)	<i>Leptoseris</i> (LEPT)	Corallimorph (CM)	Shell (SH)
<i>Alveopora</i> (ALV)	<i>Lithophyllon</i> (LITH)	Zoanthid (Z)	Trash (T)
<i>Anacropora</i> (ANAC)	<i>Lobophyllia</i> (LOBO)	Gorgonian (GG)	Coral Rubble (CR)
<i>Astreopora</i> (ASTR)	<i>Merulina</i> (MERU)	Heliohora (HEL)	Dead Coral with Algae (DCA)
<i>Australogyra</i> (AUS)	<i>Montastrea</i> (MONT)	Sea Pen (SP)	Recently Dead Coral (RDC)
<i>Catalaphyllia</i> (CATA)	<i>Montipora</i> (MON)	Soft Coral (SC)	Unknown (UNK)
<i>Caulastrea</i> (CAUL)	<i>Moseleya</i> (MOSE)	Tubipora (TP)	Shadow (SHAD)
<i>Coeloseris</i> (COEL)	<i>Mycedium</i> (MYC)	Drupella (DRU)	Tape (TAPE)
<i>Coscinaraea</i> (COSC)	<i>Oulophyllia</i> (OULO)	Giant Clam (GC)	Wand (WAND)
<i>Tenactis</i> (CTEN)	<i>Oxypora</i> (OXY)	Scallop (SL)	Bleached coral point (BL)
<i>Cycloseris</i> (CYC)	<i>Pachyseris</i> (PACH)	Lace Coral (LC)	Brown Band Disease (BBD)
<i>Cynarina</i> (CYN)	<i>Paraclavaria</i> (PARA)	Millepora (MP)	Black Band Disease (BLBD)
<i>Cyphastrea</i> (CYPH)	<i>Pavona</i> (PAVO)	Stinging Hydroid (STH)	White Syndrome Disease (WSD)
<i>Diploastrea</i> (DIPL)	<i>Pectinia</i> (PECT)	Sponge Ball (SPBL)	Neoplasia (NEO)
<i>Duncanopsammia</i> (DUNC)	<i>Physogyra</i> (PHYS)	Sponge Barrel (SPBR)	Hyperplasia (HYP)
<i>Echinophyllia</i> (ECHI)	<i>Platygyra</i> (PLAT)	Sponge Branching (SPB)	Skeletal Eroding Band Disease (SEBD)
<i>Echinopora</i> (ECHP)	<i>Plerogyra</i> (PLER)	Sponge Encrusting (SPE)	Porites Pinking (PP)
<i>Euphyllia</i> (EUPH)	<i>Pocillopora</i> (POC)	Sponge Fan (SPF)	Feeding Scar (FS)
<i>Favia</i> (FAV)	<i>Podabacia</i> (PODA)	Sponge Rope (SPR)	Invertebrate Burrow (IVB)
<i>Favites</i> (FAVI)	<i>Polyphyllia</i> (POLY)	Sponge Tube (SPT)	Other disease (OD)
<i>Fungia</i> (FUN)	<i>Porites</i> (POR)	Coralline Algae (CA)	
<i>Galaxea</i> (GALA)	<i>Psammocora</i> (PSAM)	Halimeda (HM)	
<i>Gardineroseris</i> (GARD)	<i>Sandalolitha</i> (SAN)	Other Algae (OA)	
<i>Goniastrea</i> (GONI)	<i>Scapophyllia</i> (SCAP)	Sargassum (SA)	
<i>Goniopora</i> (GONO)	<i>Scolymia</i> (SCOL)	Turf Algae (TA)	
<i>Halomitra</i> (HALO)	<i>Seriatopora</i> (SER)	Seagrass (SG)	
<i>Heliofungia</i> (HELI)	<i>Stylophora</i> (STY)	Ascidian (ASC)	
<i>Herpolitha</i> (HERP)	<i>Symphyllia</i> (SYMP)	Crown of Thorns (COT)	
<i>Heterocyathus</i> (HET)	<i>Trachyphyllia</i> (TRAC)	Cyanobacteria (CY)	
<i>Heteropsammia</i> (HETP)	<i>Tubastrea</i> (TUBA)	Other (O)	
<i>Hydnophora</i> (HYDN)	<i>Turbinaria</i> (TURB)	Fishing Gear (FG)	
<i>Isopora</i> (ISOP)	Unknown Coral (UC)	Rock (R)	
<i>Leptastrea</i> (LEP)	<i>Zoopilus</i> (ZOO)	Rubble (RB)	

7.2 Additional Figures

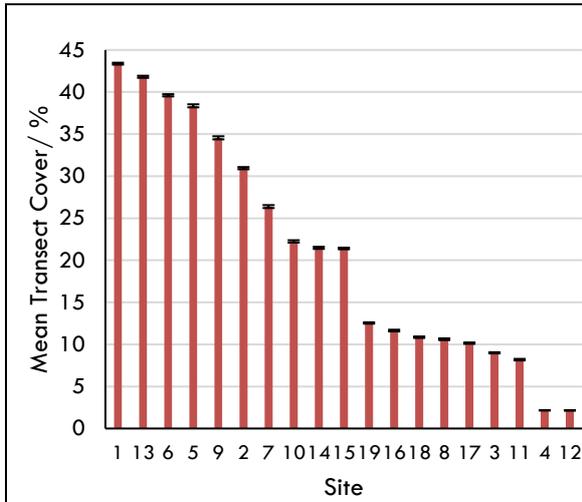


Fig 7.1.1: Mean transect cover (% ± SE) of Scleractinian coral cover along Davin Reef survey sites for the duration of the DLTRMP.

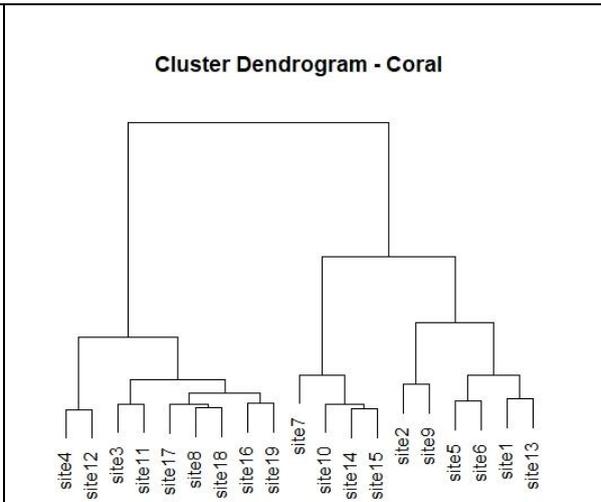


Fig 7.1.2: Cluster dendrogram showing similarities between Scleractinian coral cover of different sites.

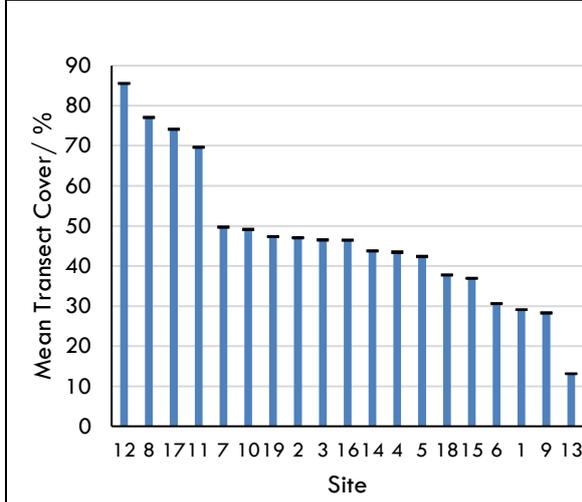


Fig 7.1.3: Mean transect cover (% ± SE) of abiotic substrate cover along Davin Reef survey sites for the duration of the DLTRMP.

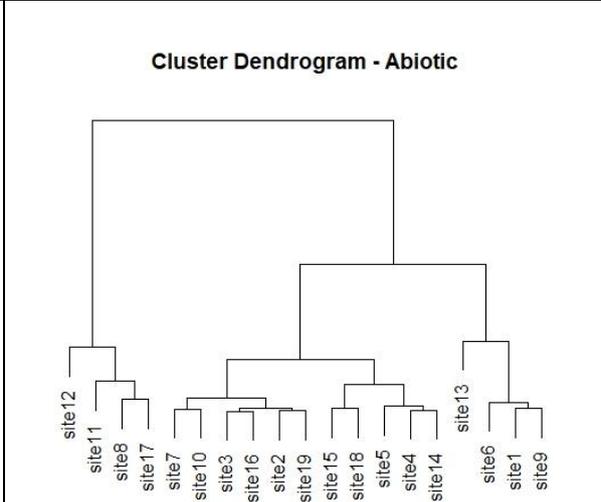


Fig 7.1.4: Cluster dendrogram showing similarities between abiotic substrate cover of different sites.

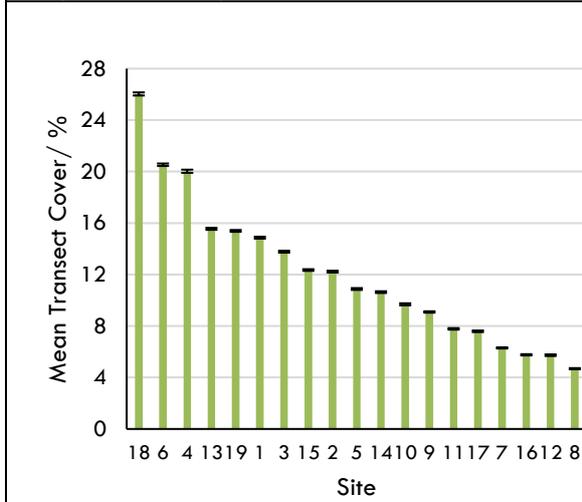


Fig 7.1.5: Mean transect cover (% ± SE) of algae cover along Davin Reef survey sites for the duration of the DLTRMP.

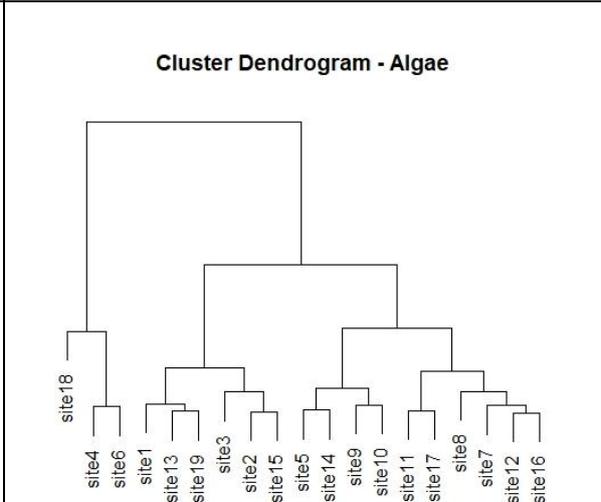


Fig 7.1.6: Cluster dendrogram showing similarities between algae cover of different sites.

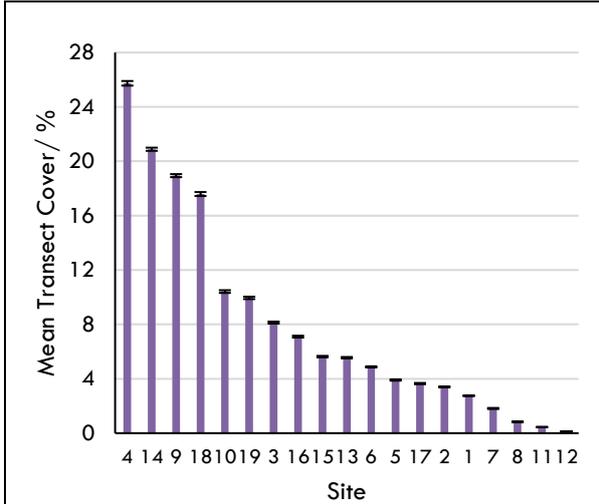


Fig 7.1.7: Mean transect cover (% ± SE) of dead coral cover along Davin Reef survey sites for the duration of the DLTRMP.

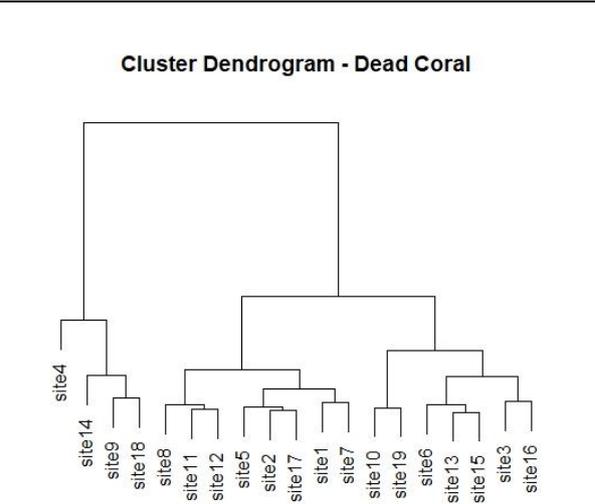


Fig 7.1.8: Cluster dendrogram showing similarities between dead coral cover of different sites.

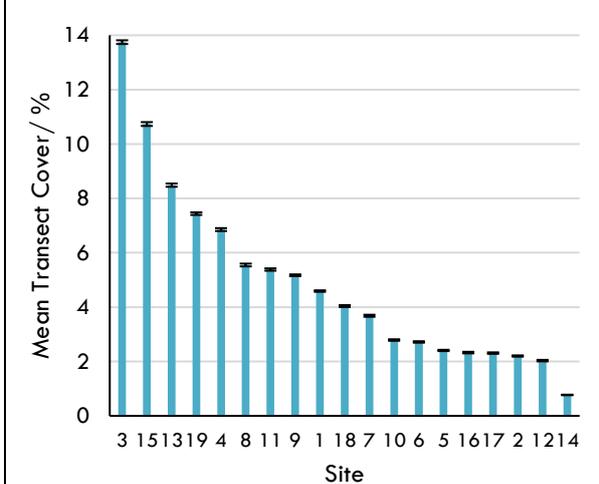


Fig 7.1.9: Mean transect cover (% ± SE) of sponge cover along Davin Reef survey sites for the duration of the DLTRMP.

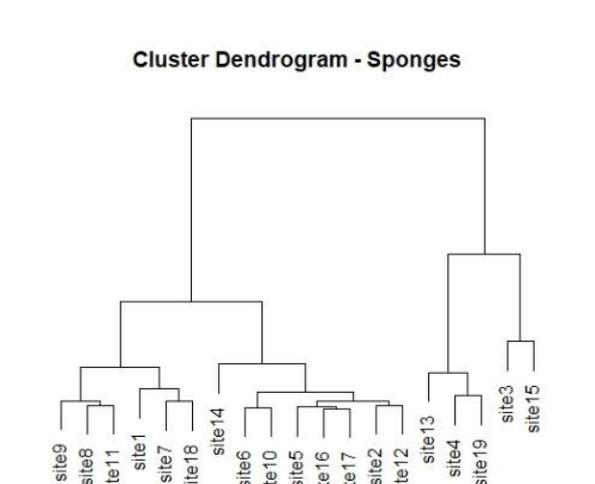


Fig 7.1.10: Cluster dendrogram showing similarities between sponge cover of different sites

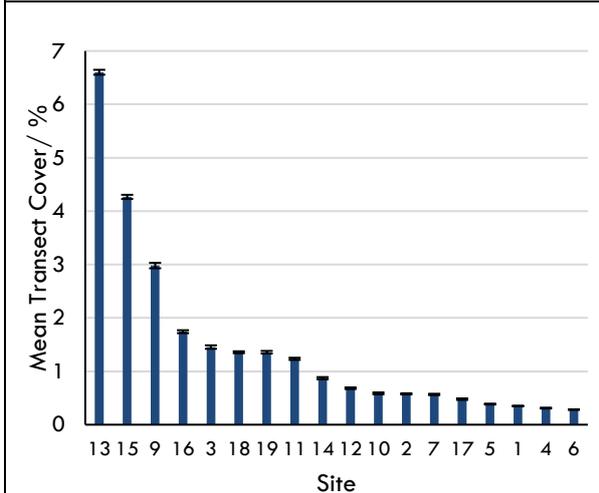


Fig 7.1.11: Mean transect cover (% ± SE) of cyanobacteria cover along Davin Reef survey sites for the duration of the DLTRMP.

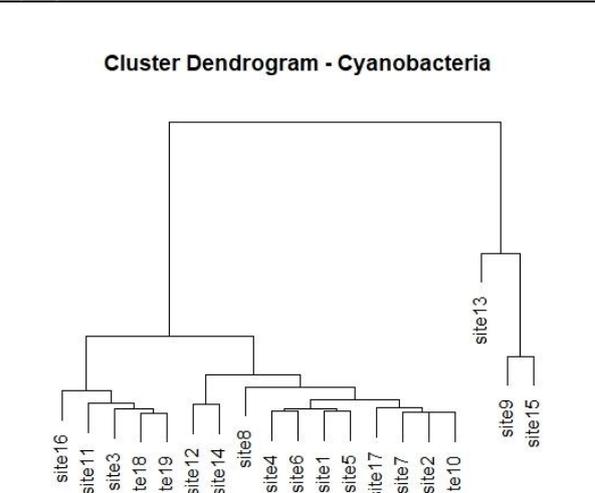


Fig 7.1.12: Cluster dendrogram showing similarities between cyanobacteria cover of different sites.

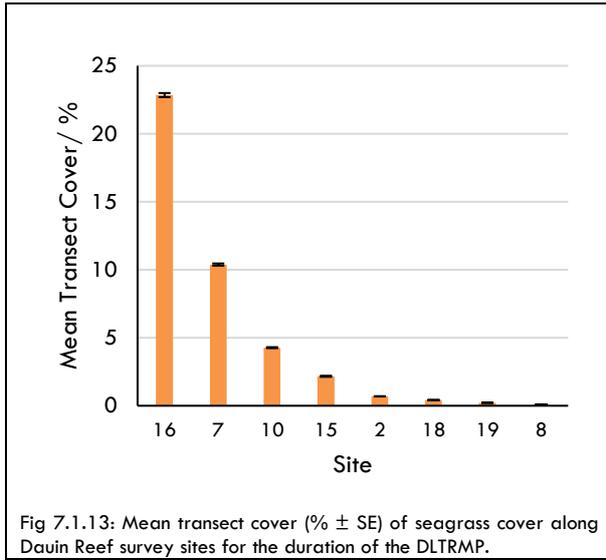


Fig 7.1.13: Mean transect cover (% ± SE) of seagrass cover along Dauin Reef survey sites for the duration of the DLTRMP.

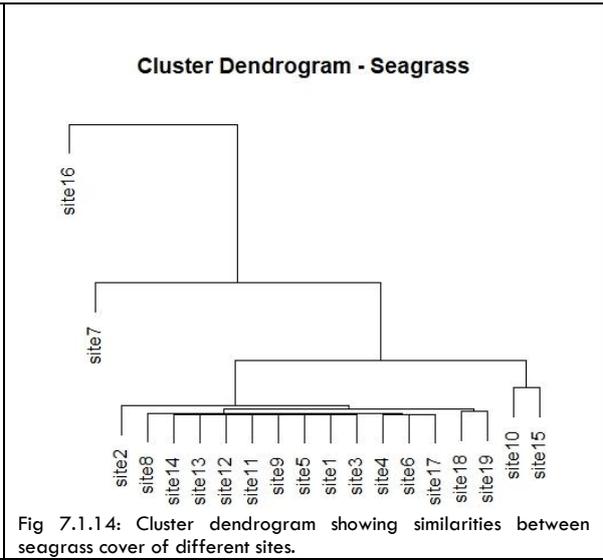


Fig 7.1.14: Cluster dendrogram showing similarities between seagrass cover of different sites.

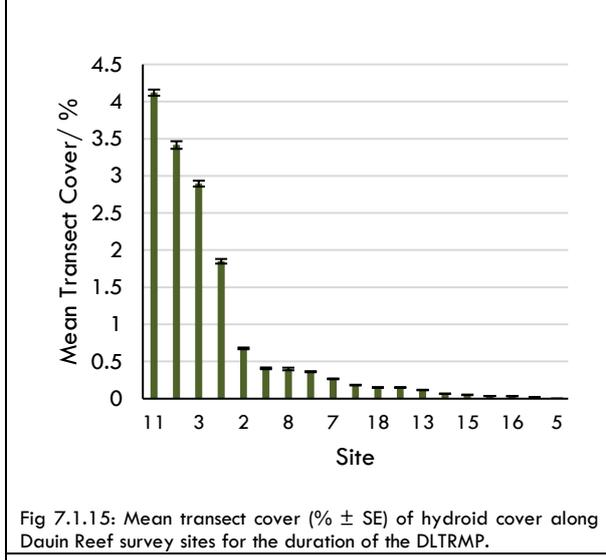


Fig 7.1.15: Mean transect cover (% ± SE) of hydroid cover along Dauin Reef survey sites for the duration of the DLTRMP.

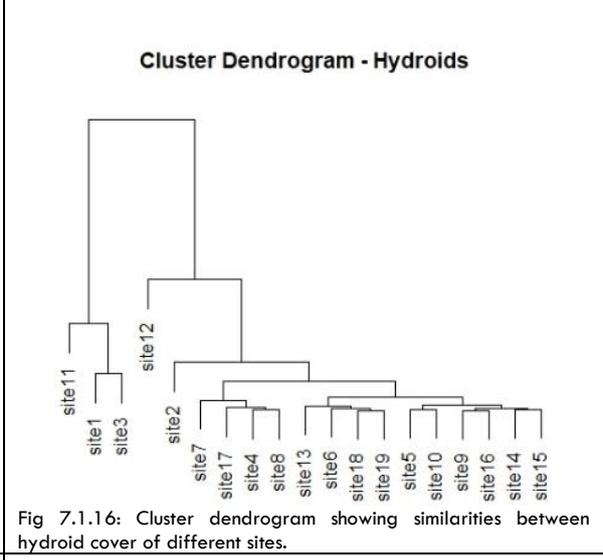


Fig 7.1.16: Cluster dendrogram showing similarities between hydroid cover of different sites.

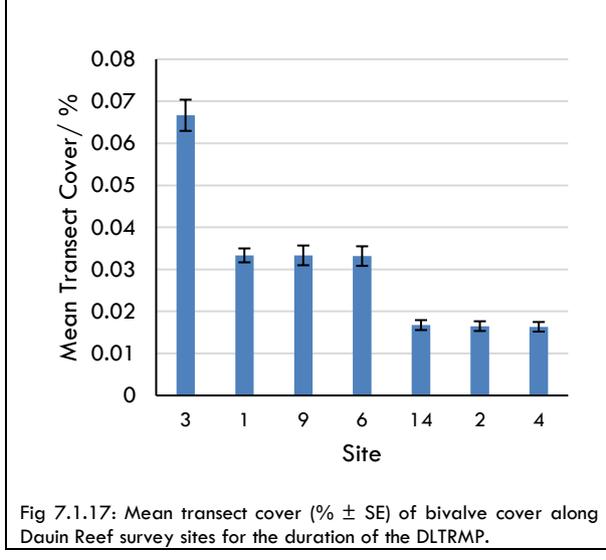


Fig 7.1.17: Mean transect cover (% ± SE) of bivalve cover along Dauin Reef survey sites for the duration of the DLTRMP.

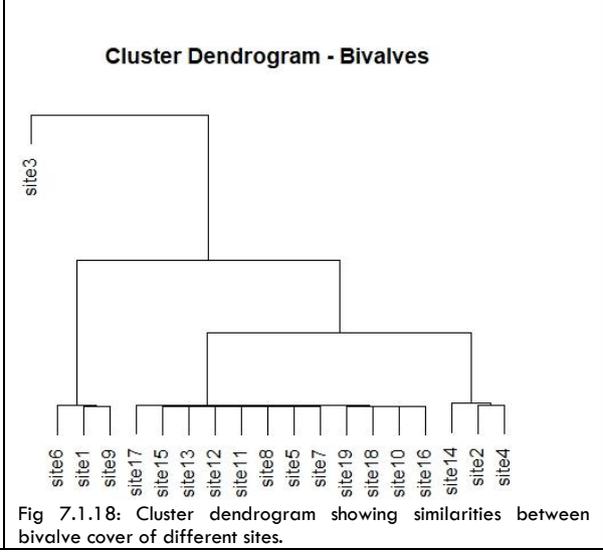


Fig 7.1.18: Cluster dendrogram showing similarities between bivalve cover of different sites.

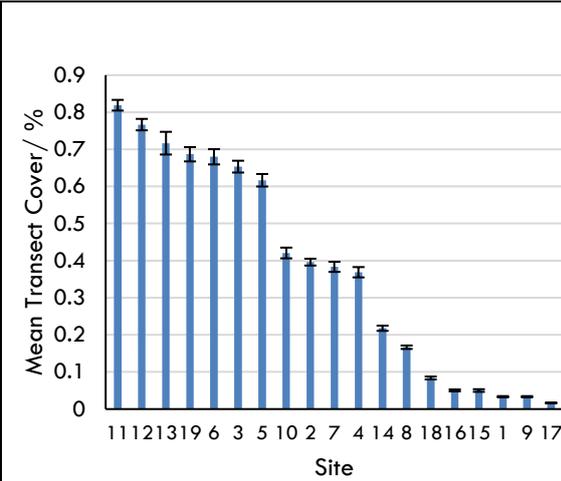


Fig 7.1.19: Mean transect cover (% ± SE) of 'other hexacoral' cover along Dauin Reef survey sites for the duration of the DLTRMP.

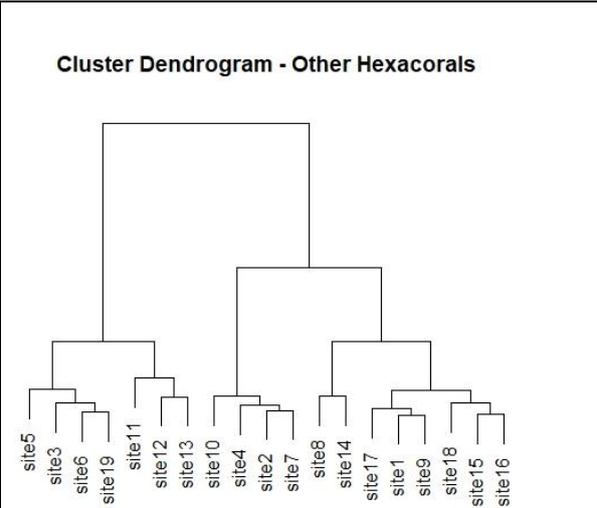


Fig 7.1.20: Cluster dendrogram showing similarities between 'other hexacoral' cover of different sites.

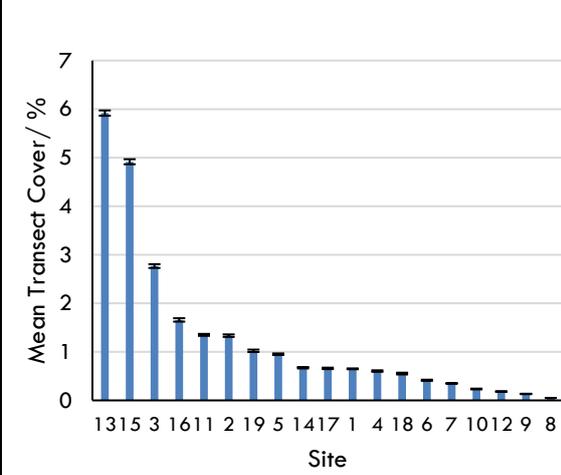


Fig 7.1.21: Mean transect cover (% ± SE) of octocoral cover along Dauin Reef survey sites for the duration of the DLTRMP.

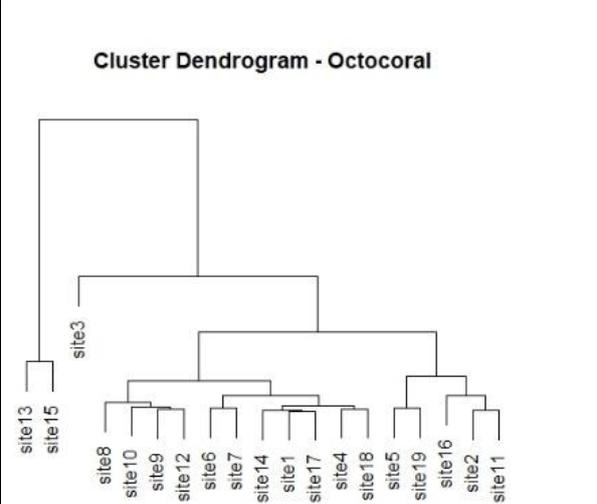


Fig 7.1.22: Cluster dendrogram showing similarities between octocoral cover of different sites.