**Ella FERRANDIS**

# Baseline assessement of Dauins Marine Protected Areas, Philippines

**UNIVERSIDADE DO ALGARVE**

Faculdade de Ciências e Tecnologia

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**Mestrado em Biologia Marinha**

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**UNIVERSIDADE DO ALGARVE**

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**<u>Declaração de autoria de trabalho</u>**

Declaro ser oa autora deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída

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# ABSTRACT

No-take Marine Protected Areas (MPAs) have been established as a management strategy to conserve biodiversity and sustain fisheries. When properly managed, such areas can maintain or increase reef productivity. A total of seven Marine Protected Areas have been established on the coastline of Dauin, Negros Oriental, Philippines. These seem to have been successful in reducing fish stock exploitation by local and international fishermen. Each MPA, however, covers an average of 6.69Ha, far smaller than is recommended for effective MPAs. This is compounded by the common practice of fishers placing longlines at the MPA boundaries. This thesis project would compare fish diversity, size, and biomass in addition to coral diversity and coral cover within and outside the MPA systems. In parallel, an assessment of the external risks and impacts that reefs within these MPAs are exposed to will be performed during the study. In total, one dry season (February to July 2019) and one wet season (August 2019 to January 2020) of data were analyzed. Coral Point Count with Excel extensions (CPCe) were used to investigate substrate composition. Diver Operated Stereo Video System (SVS) and EventMeasure measured fish biomass, diversity, and abundance. 3-Dimensional reef modeling, using AgiSoft were applied to obtain values of rugosity and slope. SCUBA helped search to identify the root causes of coral mortality (coral bleaching, coral disease, trash, corallivorous invertebrates). The data collection was carried out by researchers from the Institute for Marine Research (IMR) located in Dauin, Negros Oriental, and by myself, under their supervision. A high variability between the study sites have been noted. Added to the underrepresentation of the unprotected sites (three vs fourteen MPAs), this report constitute therefore a descriptive overview more than a proper significant comparison between Dauin's MPAs and non-MPAs. The results obtained underline the need to continue studies on the Dauin coast in order to assess the effectiveness of MPAs and to guide the stakeholders towards better enforcement measures and respect for the protection status of MPAs already implemented. Indeed, make a case for the unification of MPAs to create a much larger area seems to be an option that would benefit not only marine biodiversity, but also the local population who depend heavily on the reef for their livelihood.

*Keywords* : Philippines, marine protected areas, coral reef, fish diversity, coral cover

## RESUMO

As Áreas Marinhas Protegidas (AMPs) foram criadas como uma estratégia de gestão para conservar a biodiversidade e sustentar a pesca. Quando geridas adequadamente, essas áreas podem manter ou aumentar a produtividade dos recifes. A expansão de áreas marinhas individuais estabelecidas localmente para formar redes é vista como um meio de atingir os objetivos de conservação e acelerar a melhoria dos recursos naturais e ecossistemas costeiros. Esses objetivos são considerados alcançados através da melhoria do desenho (tamanho, localização) e gestão das AMPs, que geralmente são dificultados tanto pela governança como pelas restrições financeiras. A criação de AMPs nas Filipinas implica uma cooperação real entre comunidades, governos e outras instituições. Um total de sete Áreas Marinhas Protegidas foram estabelecidas na costa de Dauin, Negros Oriental, Filipinas. Estas áreas parecem ter tido sucesso na redução da exploração de peixes por pescadores locais e internacionais. Cada AMP, no entanto, cobre uma média de 6,69 Ha, muito menor do que o recomendado para AMPs eficazes. Isto é agravado pela prática comum dos pescadores usarem palangres nas fronteiras do MPA. Este projeto de tese compara a diversidade, tamanho e biomassa de peixes, além da diversidade e cobertura de corais dentro e fora das MPAs. Em paralelo, uma avaliação dos riscos e impactos externos aos quais os recifes dentro dessas AMPs estão expostos foi realizada durante o estudo. Apenas o efeito sobre a biodiversidade local foi avaliado. Isto significa que a dimensão socioeconómica (efeitos no turismo ou nas receitas da pesca) ou governação, que são as duas outras dimensões a investigar quando se avalia a eficácia das AMPs, não foram incluídas neste relatório. Os resultados fornecerão percepções sobre a eficácia das AMPs, que são essenciais para avaliar as necessidades futuras, adaptar as práticas e otimizar a alocação de recursos governamentais e privados para as AMPs. No total os dados de uma estação seca (Fevereiro a Julho de 2019) e uma estação chuvosa (Agosto de 2019 a Janeiro de 2020) foram analisados. O software Coral Point Count com extensões Excel (CPCe) foi usado para investigar a composição do substrato. O sistema de vídeo estéreo operado por mergulhador (SVS) e o software EventMeasure permitiram calcular a biomassa, a diversidade e a abundância dos peixes. Modelagem de recife tridimensional, usando AgiSoft, foi aplicada para obter valores de rugosidade e declive. A observação directa usando SCUBA permitiu identificar as causas básicas da mortalidade do coral (branqueamento do coral, doença do coral, lixo, invertebrados coralívoros). A recolha de dados foi realizada por investigadores do Institute for Marine Research (IMR) localizado em Dauin, Negros Oriental, e por mim, sob sua supervisão.

Uma alta variabilidade entre os locais de estudo foi observada. Somado à sub-representação dos locais desprotegidos (três vs catorze MPAs), este relatório constitui, portanto, uma visão geral descritiva mais do que uma comparação significativa adequada entre MPAs de Dauin e não MPAs. Em relação à composição bêntonica, metade da cobertura de Dauin é composta por componentes abióticos, principalmente areia; enquanto os componentes bióticos são principalmente corais, algas e esponjas. Os géneros Acropora, Anacropora, Porites, Echinopora e Pocillopora são os corais dominantes relatados. A população de algas é composta principalmente por algas Turf, Coraline e Halimeda. As esponjas incrustantes são os principais gêneros relatados. Os estressores locais estão causando a mortalidade dos corais no recife de Dauin. Os impactos mais frequentes foram o branqueamento, Drupella spp. alimentação e destruição direta. Acropora, o principal coral presente em Dauin, foi o gênero mais impactado. Não é possível concluir que as AMPs têm um efeito benéfico nos impactos dos corais em Dauin, visto que foram relatados mais impactos em locais protegidos do que em locais não protegidos, concomitante à presença de barcos de mergulho e actividades de pesca nas MPAs. Foram registadas 36 famílias de peixes com uma riqueza de espécies de 244; quase a metade representada por três espécies: Labridae, Pomacentridae e Chaetodontidae. A estrutura trófica suporta uma alta prevalência de generalistas de habitat. Nenhuma conclusão pode ser feita para a eficiência dos AMPs da Dauin no aumento da abundância e biomassa de peixes e nenhuma diferença nas espécies comercialmente importantes foi encontrada, no entanto, as AMPs podem ter um impacto positivo nas espécies ameaçadas. Finalmente, a correlação entre rugosidade e estrutura da comunidade de peixes, abundância ou biomassa não foi significativa. No entanto, este estudo destaca diferenças locais claras que podem orientar estudos futuros. O sul de Dauin é caracterizado pelo domínio de corais Anacropora, corais mortos altos e coberturas de algas e branqueamento de corais. Ao comparar as populações na AMP Masapold Sul com as zonas fora da AMP, as populações de corais Porites spp. e algas mortas foram superiores na AMP; enquanto Anacropora spp. e as populações de esponjas eram inferiores na zona protegida. A zona Central Dauin é caracterizada pela dominância de corais Porites, uma alta cobertura de algas, presença de cicatrizes de alimentação de COT no Distrito I de Poblacion e ausência de Drupella spp.. A zona Norte de Dauin é caracterizada pelo domínio dos corais Acropora e a menor cobertura de coral morto. Ao comparar as populações na AMP Bulak com zonas fora da MPA, Porites spp. e hidroides estiveram mais presentes, enquanto Acropora spp. estavam menos presentes na zona protegida.

Este estudo foi o primeiro a abranger as sete zonas protegidas de Darin e teve o objetivo de relatar uma visão geral da paisagem recifal em termos de caracterização bentônica e comunidades de peixes. A subdivisão em três zonas, ou seja, Dauin Norte, Central e Sul foi usada para investigar se a linha costeira estaria sujeita ao efeito local. Diferentes dinâmicas nessas três zonas foram claramente observadas, sugerindo processos ecológicos locais e fatores antrópicos impactando a paisagem recifal. As diferenças entre as AMPs podem ser consideráveis, mesmo entre locais próximos. Portanto, mais estudos devem avaliar a eficácia dos AMPs um por um, já que a combinação de parâmetros da população de peixes e medidas bentônicas de locais heterogêneos pode ser enganosa. Além disso, cada AMP deve ser emparelhada com uma zona próxima não protegida, para garantir uma boa representatividade de ambos os grupos de estudo. Esses parâmetros deveriam aumentar a representatividade e a significância das medidas, que faltaram neste estudo. Finalmente, um monitoramento por vários anos aumentaria a compreensão do funcionamento e da dinâmica das zonas protegidas de Dauin. Isso serviria ainda como um feedback para a eficiência das medidas de fiscalização ou forneceria argumentos para melhorá-las e talvez defender a unificação das AMPs para criar uma área muito maior que beneficiaria não apenas a biodiversidade marinha, mas também a população local que depende muito do recife para seu sustento.

## ABBREVIATIONS

| Abbreviation | Term in full |
| --- | --- |
| **1-D** | Simpsons Index of Diversity |
| **2 D** | 2-Dimensional |
| **3 D** | 3-Dimensional |
| **AIMS** | Australian Institute of Marine Science |
| **ANOSIM** | Analysis of Similarities |
| **BBD** | Black Band Disease |
| **BrBD** | Brown Band Disease |
| **CPCe** | Coral Point Count with Excel Extension |
| **COTS** | Crown of Thorns Starfish |
| **DEM** | Digital Elevation Model |
| **DO-SVS** | Diver-Operated Stereo Video System |
| **HYP** | Hyperplasia |
| **IMR** | Institute for Marine Research |
| **MIF** | Mobile Invertebrate Feeder |
| **MPA** | Marine Protected Area |
| **NEO** | Neoplasia |
| **NMDS** | Non-metric Multidimensional Scaling |
| **PP** | Porites Pinking |
| **SR** | Species Richness |
| **SCUBA** | Self-Contained Underwater Breathing Apparatus |
| **SE** | Standard Error |
| **SEB** | Skeletal Eroding Band |
| **SED** | Standard Deviation |
| **SfM** | Structure from Motion |
| **WS** | White Syndrome |

## TABLE OF CONTENTS

# 1. INTRODUCTION

Coral reefs are being significantly degraded by human activities all around the world. It is now internationally recognized that there is an urgent need to reduce local threats in order to compensate impacts of growing global pressures. As a consequence of main anthropogenic risk factors, mortality and reduced growth of reef-building corals were found. They are indeed highly sensitive to rising seawater, ocean acidification, deteriorating water quality, destructive fishing, over-exploitation of key marine species, and the direct devastation of coastal ecosystems through unsustainable coastal development (Burke et al., 2002, Hoegh-Guldberg et al., 2009). These anthropogenic risks interplay with other large-scale serious disturbances, such as tropical storms and outbreaks of the corallivorous crown-of-thorns starfish (COTS) *Acanthaster plancii*. Human activities may also increase these perturbations in frequency and intensity. Coral reefs can no longer be only protected by regional policies because of climate change, particularly associated with an increase in storms (Burke et al., 2002). More attention must therefore be given to managing local and regional anthropogenic pressures to enhance reef resiliency. However, to measure the effectiveness of reducing these pressures, it is necessary to understand the processes that determine the trajectories of the ecosystem.

## 1.1. The Philippines

The Philippine archipelago, with its 7,100 islands located in the center of the coral triangle, is a marine conservation priority (Cabral et al., 2014) and a relevant place to study ecosystem trajectories. With 76% of all coral species and 37% of the world's reef fish (Allen, 2007), this incredible biological diversity, one of the largest in the world, is associated with some of the highest human population densities and growth rates (Hoegh-Guldberg et al., 2009).

Coastal populations are now exposed to food and income insecurity as a result of changes in the health of coastal ecosystems. It leads to a deterioration of coastal protection. The insecurity affects already impoverished people that are not able to respond to changes in their environment.

In the Philippines, nearly 70% of protein food consumption comes from fish; and reef fishing accounts for 15-30% of total fisheries. Species of fish and marine organisms are presenting signs of overfishing and coastal habitat degradation, due to multiplied human activities (FAO 2014-2020). A rapid decline in reef resources is caused by the contrast between poverty, hunger, and deprivation in

this growing need. A massive decline in reef resources is observed in the Philippines, due to overexploitation of destructive fishing and other human-induced impacts such as coastal development, coral sedimentation and bleaching, and ocean acidification due to anthropogenic climate change (Honda et al., 2016, Nañola Jr. et al., 2011).
Human activities currently threaten 88% of the coral reefs in Southeast Asia, 50% of which are at a « high » or « very high » threat level (Burke et al., 2002). Coral cover has decreased from around 50% to 22% in 40 years in the Indo-Pacific (Bruno et al., 2007). Coastal populations, already impoverished, are particularly affected by climate change. Without any evolution, this will lead to an increase of poverty and social instability in the region, but also in the global Philippines and worldwide. It seems imperative to undertake the issue of man-made climate change while addressing the main threats to local stressors.

### 1.1.1 Marine Protected Areas in Philippines

Marine protected areas (MPAs) are usually used as biodiversity conservation tools throughout the world. They help to preserve biodiversity by increasing the richness, biomass, and density of fish in coral reefs through the effect of larval recruitment or adult spillover (Honda et al., 2016, Muallil et al., 2015, Abesamis et al., 2006, Russ and Alcala, 1996). In the Philippines, more than 1 600 MPAs have been established. These MPAs support small-scale fisheries when they are properly managed (Alcala and Russ, 2006, Indab and Suarez-Aspilla, 2004, Maliao et al., 2004), particularly by establishing no-catch zones surrounded by managed fishing areas (White et al., 2014).
Only 1% of coral reefs appear to be optimally protected (White et al., 2014), as only 30% of MPAs are well managed and include only 3.4% of coral reefs. This poor management of MPAs is mainly due to the size of these areas; they are generally small (< $1km^2$) and do not take into account ecological connectivity (Weeks et al., 2010). They could not make a significant contribution to broader objectives, such as combating climate change, because they do not take into account regional ecological processes and far-reaching gaps and objectives in biodiversity conservation (White et al., 2014). The expansion of individual locally established marine areas to form networks is seen as a means of achieving conservation objectives and accelerating the improvement of coastal natural resources and ecosystems. These goals are considered achieved by improving the design (size, location) and management of MPAs, which are generally hampered by both governance and financial constraints (Horigue et al., 2012). Create MPAs in the Philippines implicates a real cooperation between communities, governments, and other institutions (Maypaab et al., 2012).

### 1.1.2 Seasonal Weather Patterns

The climate in the Philippine archipelago, maritime and tropical, is characterized by a relatively high temperature combined with high humidity and abundant rainfall. There are different types of climate recognized in the Philippines, based on the distribution of rainfall. In Negros Oriental, the climate is referred to as type III: the seasons are only slightly pronounced. The weather is dry in the early months of the year, until April-May, then wet the rest of the year. During the dry season (Amihan in Filipino), trade winds come from the northeast, which induces moderate temperatures and little precipitation. In the wet season (Habagat in Filipino), winds are found from the southwest, bringing warm and humid weather and heavy rainfall. Regarding water temperature, it is lowest in February with about 27.20°C and highest in June with about 30.00°C (**Figure. 1.1.1; measurements taken in the Bohol Sea**).

This master thesis does not look at the differences observed between the dry and wet seasons over the year 2019/2020 since several years may be required to observe seasonal fluctuations. Thus, monitoring over several years will be necessary to determine whether changes are the result of seasonal fluctuations or long-term trends.

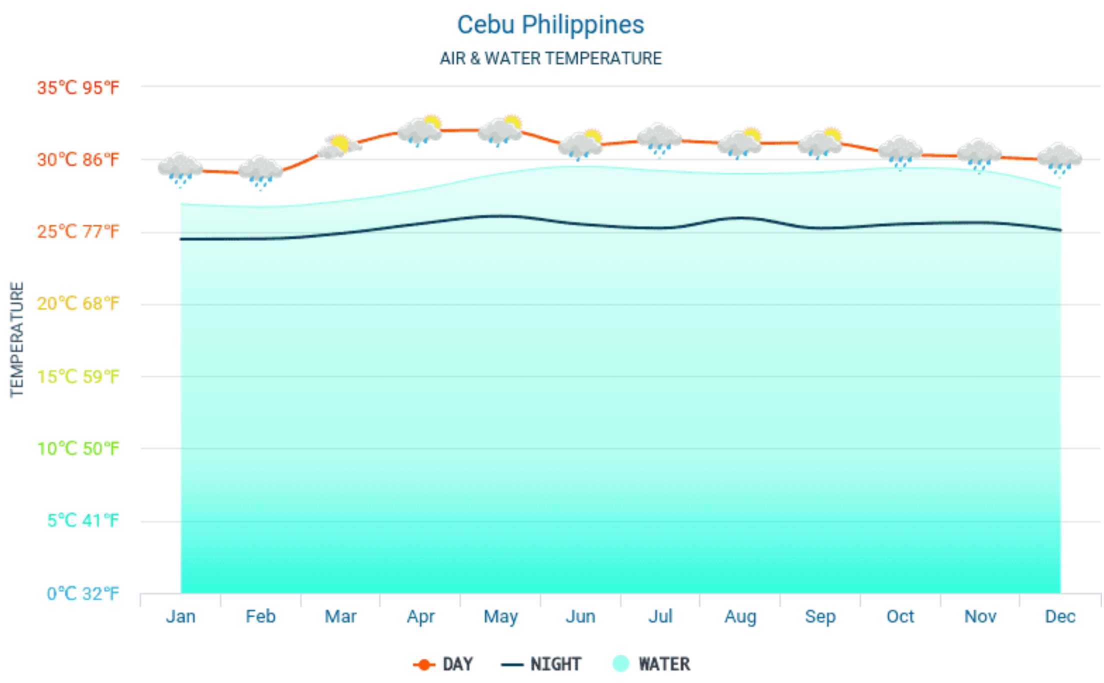



***Figure. 1.1.1*** Average air and water temperature of Philippines Type III climate (measurements from Cebu city). Data from 2020.

### 1.1.3 Typhoons impacts on coral reefs

Coral reefs are continually being shaped in composition and distribution by storms and typhoons. Thus, branches and heads of coral can be broken or overturned by the strong waves and currents caused by cyclones, causing entire reefs to suffocate under the sand. In this way, massive corals such as Favia or Porites will be much more resistant than branched corals like Acropora or Pocillopora. This leads to a collapse of the hard coral cover; the dead skeletons are then covered by faster-growing species of algae or seaweed.

The Philippines has seen major storms in the past. Numerous typhoons such as Milenyo, Ondoy, Pablo, Pepeng, Yolanda (international name Haiyan) and many more have already caused heavy damage, both financially and humanly (WWF, 2013). Injuries to the reefs are often neglected. However, it is important to take this into account in a developing country that has to produce more and more food for its growing population.

About 30 to 40 tons of fish per square kilometer are produced each year by healthy Philippine coral reefs. Unfortunately, only 1% of these reefs are still in good condition, meaning hard coral cover is at 75% or higher (Licuanan et al., 2017). The Philippine population is estimated at 110 million and is growing at an annual rate of about 2% (World Population Prospects, 2019). Thus, Philippine reefs are threatened by sedimentation, overfishing, and pollution, but storms are a huge menace too (**Figure. 1.1.2**).

***Figure. 1.1.2.*** Picture by *Steve de Neef* of the reefs in Apo Island's Marine Sanctuary (located 7 km southeast off the coast of Dauin) severely damaged by typhoon Sendong in 2011 and Typhoon Pablo in 2012. Researchers estimate coral damage at 99%. Coral reef fish abundance also declined by 50%.

## 1.2. Municipality of Dauin

Dauin, a municipality located in the province of Negros Oriental, is critically dependent on reef resources for the well-being and livelihood of its coastal community. Due to its large population increase, this city has put significant pressure on these local fisheries, pushing them outside their biological limits. This highlighted the future of Dauin's social and food security, but also the sustainability of the reefs (Zupan *et al*., 2018).

As a result, coastal management areas, in the form of Marine Protected Areas (MPAs), have been established under community leadership. Ecosystems, habitats, and endangered species are therefore protected, and MPAs also help maintain and enhance the biodiversity of coral reefs. These areas are found throughout the territory to regulate fishing and abolish destructive practices. It also covers economic growth in food security and resistance in ecosystems (***Figure. 1.2.1***).

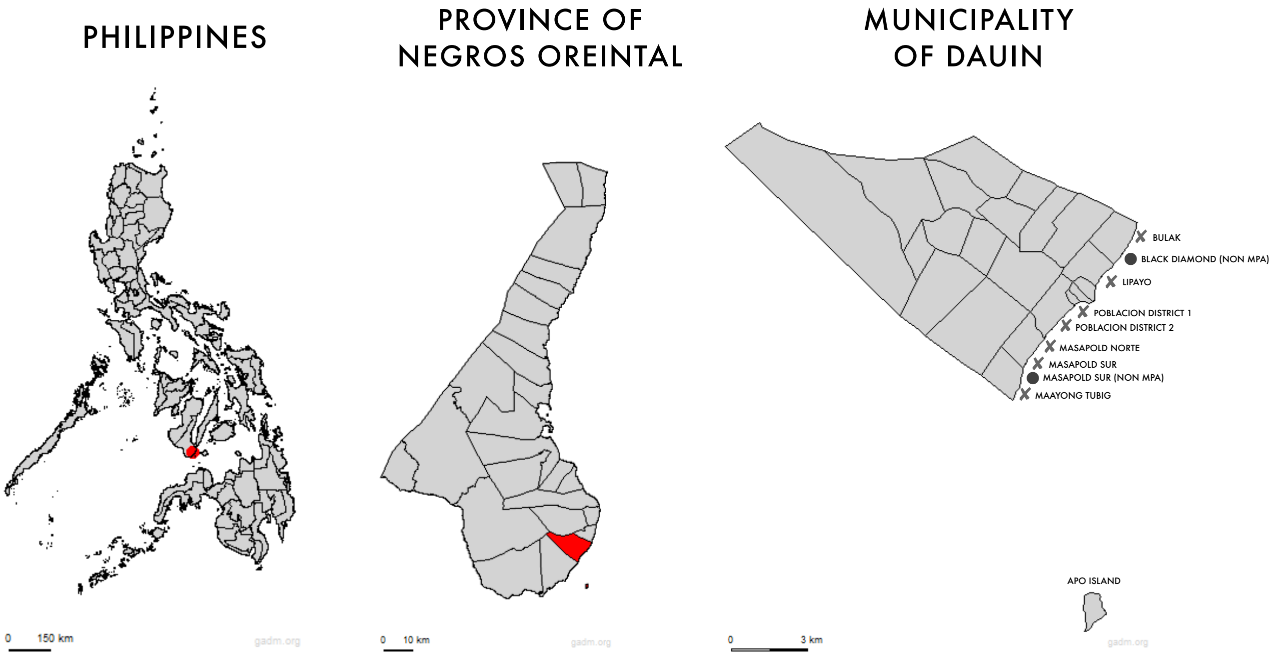



***Figure. 1.2.1.*** Location of the Municipality of Dauin and IMRs survey sites on Negros Oriental. Maps sourced from GADM database of Global Administrative Areas (2015) under a CC BY licence.

Implementing multiple MPAs along the coast ensured that each community had their own area to protect and to benefit from (Dauin MPA draft management plan, 2008-2012*)*. The introduction of a ticketing system marked a turning point in the history of Dauin. Thus, one of the main sources of income for local residents is the tourist fees collected by the MPAs' Fishers Associations. These revenues were the key to the acceptance of MPAs by the local community (**Figure. 1.2.2**); indeed, MPAs are now seen as a « reliable source of income » rather than « a restriction of fishing areas ».

| Dauin MPA USER FEES | |
|---|---|
| DIVING | |
| Scuba diving | P150.00/dive |
| Scuba diving w/ still camera | P200.00/dive |
| Scuba diving w/ video camera | P250.00/dive |
| SNORKELING | P50.00/day |
| SNORKELING WITH CAMERA | P100.00/day |
| SWIMMING WITHIN THE DESIGNATED AREA | P20.00/day |
| SWIMMING WITH GOGGLES WITHIN THE DESIGNATED AREA | P10.00/day |
| MOORING (NEAR THE MPA) | P50.00/day |
| ANCHORING ONLY AT DESIGNATED AREA | P1,00.00/day |
| DOCKING/REPAIR AS A SPECIAL PERMIT | P500.00/day |
| RESEARCH, SPECIAL PERMIT | P500.00 |
| REGISTRATION OF FISHING PARAPHERNALIA | P30.00/item |
| MOORING | |
| Private/Family use | P3,000.00 |
| Commercial/Buisness use | P20.00/day |
| OUTSIDE THE MPA BUT BY CLIENTELE | |
| Day time diving | P50.00 |
| Night diving | P500.00 |

**SYSTEM FOR SHARING OF INCOME FROM USERS FEES**

User fees are divided as follows:

a. 40% - Municipal LGU

b. 40% - Fishermen's Association

c. 20% - Barangay fronting the Municipal Water where the MPA is located

Note: Income shares for the FA's and the Barangay's shall only be released upon submission of work and financial plan duly approved by all its members not later than 15 days after every end of the month.

***Figure. 1.2.2.*** The Dauin MPA user fees (left) and the system for sharing of revenue from the fees (right) as listed in the Unified CRM ordinance.

Heavy sanctions for illegal MPA users are in place, therefore few violations of these rules have been identified since the system was created.

A fishing license system was also introduced to foster a sense of belonging of the inhabitants of Dauin to its municipal waters (up to 15 km wide). Large commercial trawlers and destructive fishing are strictly prohibited. Fishing rights have been granted to residents, known as Territorial Use Rights in Fisheries (TURF). Non-local people can still obtain a license at the LGU's discretion. These various mechanisms create a sense of ownership and a collective incentive to protect municipal waters from illegal fishers from neighboring towns. The community informs systematically the law enforcement team about illegal fishing .

To evaluate the success of the MPA network and the Coastal Resource Management (CRM) program, different indicators are used. The adoption of Dauin's MPAs was made possible by taking into account socio-economic parameters: incomes from fines and fees for recreational users, the number of members of the Fishers Associations, and the percentage of community members supporting MPAs (Dauin MPA draft management plan, 2008-2012*)*.

In the early years of the MPAs' establishment, in the 1990s, the provincial program of the Environment and Natural Resources Division (ENRD), in collaboration with the German Development Service (DED), established a system to collect fish catch data from local fishermen in two of the Dauin MPAs (Aliňo *et al* 2011). The monitoring has provided valuable baseline data and helped fishers obtain support for the areas. An underwater monitoring control system has been implemented in some of the Dauin maritime protected areas. The survey has highlighted the possible changes in these regions if protection is properly implemented.

One of the major and direct benefits of good oversight of these management areas is the improvement of coral and fish health within and near the MPAs, and thus an increase in fish catch in adjacent waters. Long-term coastal monitoring in all the areas appears to be the most reliable way to assess the success of MPAs, based on available studies on the relationship between coral cover, fish biomass, and the number of years of protection. A local NGO, the Dauin Marine Research Institute, has made this project possible.

## 1.3. Institute for Marine Research (IMR)

The Institute for Marine Research (IMR) is a grassroots non-profit organization founded in February 2019 that conducts long-term and fine-scale research on coastal marine ecosystems. They use scientific evidence to educate, transform, and encourage locally-led marine conservation strategies within Dauin Municipality. IMR address the science to help achieve three key long-term impacts for the municipality: a) enhance the health and resilience of marine and coastal ecosystems across the Municipality, b) assure the economic, social, and environmental net profits for Dauin's marine industries and coastal community, and c) preserve and protect Dauin's coral reefs and other tropical marine environments from the impacts of climate change and coastal development.

## 1.4. Study aims and objectives

Understanding MPAs and their effectiveness is essential to assess future needs, adapt practices, and to optimize the allocation of government and private resources to MPAs.

This thesis constitutes a baseline assessement of the seven MPAs that have been established on the coastline of Dauin in order to investigates their effectiveness in future studies. Here, only the effect on local biodiversity was assessed. We did not include the socio-economic dimension (effects on the tourism or the fishing revenues) or governance, that are the two other dimensions to investigate when assessing MPA effectiveness (Gallacher et al, 2016).

# 2. MATERIALS AND METHODS

## 2.1. Experimental conditions

### 2.1.1 Survey Sites

The coast of Dauin was split into three research zones: North, Central, and South; each zone 3 km of coastline long (*Figure. 2.1.1*). Seven MPAs and two non-MPAs were explored. In the North Zone, two MPAs (Bulak and Lipayo) and an unprotected site (Black Diamond) were surveyed. In the Central Zone, two MPAs (Poblacion District 1 and Poblacion District 2) were surveyed. In the South Zone, two MPAs (Masapold North, Masapold South) and an unprotected site (Masapold) were surveyed. The subdivision in three zones was done to investigate whether there could be a local effect on the parameters studied.

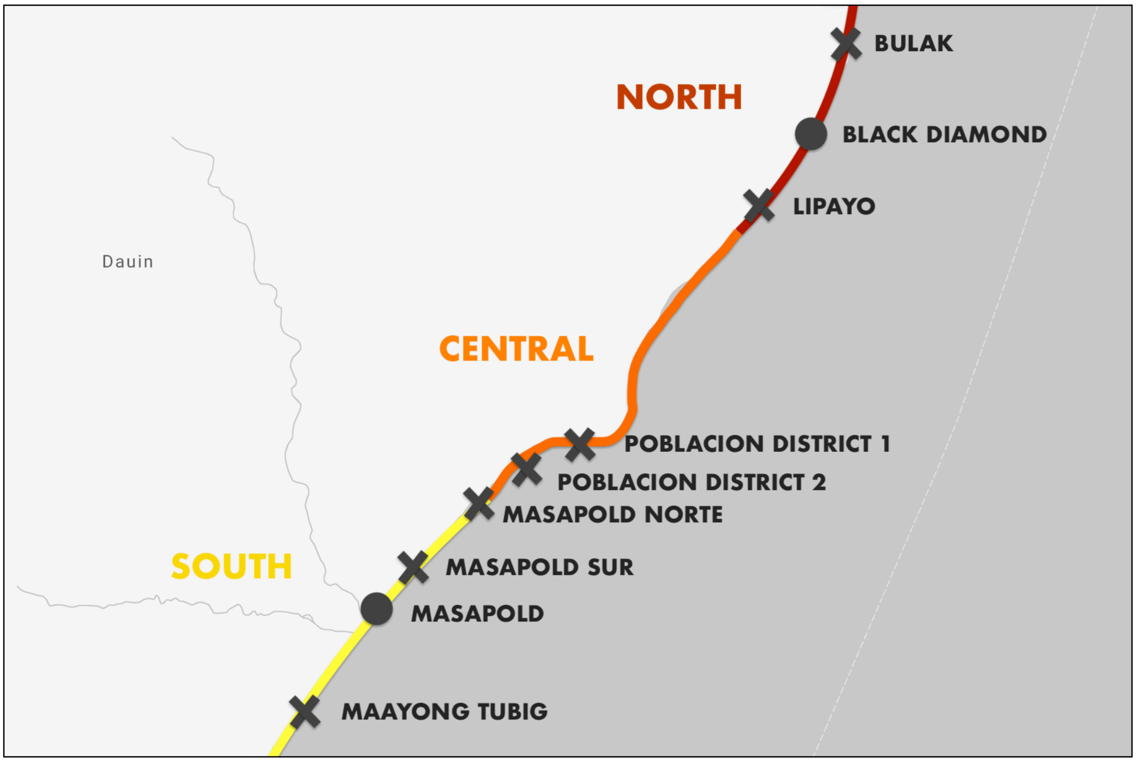



***Figure. 2.1.1.*** Map of Dauin showing the study sites and the research zones. The red region represents the North zone, the orange is the Central zone, and the yellow shows the South zone. Crosses represent MPAs, circles represent unprotected sites.

The **table. 2.1.1** presents the location, size, and date of the formal establishment of the MPAs located in Dauin as well as their name and Managing Fisheries Associations (FAs).

| LOCATION | AREA (ha) | DATE ESTABLISHED | NAME OF MPA | MANAGING FISHERIES ASSOCIATION (FA) |
|---|---|---|---|---|
| MASAPOLD NORTE | 6 | Feb. 10, 1997 | Sting Ray MPA | Masapold Norte Fishermen Association (MANFA) |
| POBLACION DISTRICT 1 | 9.2 | Sept. 1, 2000 | Sea Turtle Reef MPA | United Fishermen Association (UFA) |
| BULAK | 7.42 | Jan. 3, 2002 | Barracuda MPA | Bulak Bangus Fry Catchers Association (BBFCA) |
| MASAPOLD SUR | 6 | Jan. 3, 2002 | Yellow Snapper MPA | Kapunungan sa gagmayng mananagat sa Masapold Sur (KAGAMMAS) |
| LIPAYO | 8.209 | Jan. 3, 2002 | Frog Fish MPA | Lipayo Fishermen Association (LIFA) |
| MAAYONG TUBIG | 7.129 | Jan. 3, 2002 | Mandarin MPA | Panabulon-Alo Municipal Fishermen Association (PAMFA) |
| POBLACION DISTRICT 2 | 2.854 | May. 7, 2005 | Ghost Pipe MPA | Punta Fishermen Association (PUNTAFA) |
| **TOTAL** | **46,812** | | | |

***Table. 2.1.1*** Location, size and date of formal establishment of marine protected areas in Dauin. Also included the name of the MPA and Managing Fisheries Associations (FAs).
*Data from Dauin MPA draft management plan 2008-2012*.

These zones were established several years before our investigation (**Table 2.1.1**). This is the first study of the Dauin's coastline done by the Institute for Marine Research, therefore the IMR and the municipality decided to include all sites to have a global picture. Hence unprotected sites are underrepresented. However, we performed some additional analyses comparing some non-MPA only with their closest MPA knowing that the location of the non-MPAs studied are adjacent to the borders of the MPAs.

### 2.1.2 Transects set up

Each zone was first explored by a pair of divers and a snorkeler to find suitable sites to install permanent transects that will be used throughout the study. The divers set up the transect and did the benthic measures while the snorkeler took GPS data. The sites that had the greatest coral cover were chosen to set up the transects, as they are more interesting for the study that sand zones. The 50m long transects were set up at depths of 0-6 m and 6-12 m relative to chart datum (actual depth – tidal height). Temporary markers were used to mark the beginning and endpoints of each transect before being replaced with permanent transect stakes. Site numbers were assigned to each diving site studied, to facilitate interpretation (**Table 2.1.2**).

| | | | |
|---|---|---|---|
| Site 1 | MPA | Poblacion District 2 | 10 m |
| Site 2 | | | 5 m |
| Site 3 | MPA | Masapold North | 10 m |
| Site 4 | | | 5 m |
| Site 5 | MPA | Poblacion District 1 | 10 m |
| Site 6 | | | 5 m |
| Site 7 | Non-MPA | Black Diamond | 10 m |
| Site 8 | MPA | Lipayo | 10 m |
| Site 9 | | | 5 m |
| Site 10 | MPA | Bulak | 10 m |
| Site 11 | | | 5 m |
| Site 12 | MPA | Masapold South | 10 m |
| Site 13 | | | 5 m |
| Site 14 | Non-MPA | Masapold | 10 m |
| Site 15 | | | 5 m |
| Site 16 | MPA | Maayond Tubig | 5 m |
| Site 17 | | | 10 m |

***Table. 2.1.2*** Sites numbers accordind to dive sites studied.

### 2.1.3 Data collection timing

In total, one dry season (February to July 2019) and one wet season (August 2019 to January 2020) of data were analyzed. The data collection was carried out by researchers from the Institute for Marine Research (IMR) and by me. The measures' timing for each site is indicated in the appendix table. 7.1. For the majority of the sites, two replicates were taken for each season. Only the most representative has been kept, based on the quality of the footages.

## 2.2. Research Techniques

### 2.2.1 Benthic Assays

This technique was used to characterize the benthic organism coverage. Sessile benthic organisms survey was conducted using the LTMP methodology of the Australian Institute of Marine Science (AIMS) (Miller *et al*., 2018, Jonker *et al*. 2008). A GoPro camera held at 0.5m above the substrate took images along the transect line, perpendicular to the sea surface. Fifty images were taken per transect, i.e. one image per meter. Every meter, the operator placed the camera on top of the transect that was removed to take the photo (***Figure. 2.2.1***).

***Figure. 2.2.1***. Picture showing the benthic assays methodology in action.

### 2.2.2 SCUBA Search: Reef Impacts & Coral Mortality

This technique was used to characterize reef impacts and coral mortality in MPAs and non-MPAs. To obtain a more detailed picture of the causes and scope of coral mortality, a SCUBA search was conducted. A modified version of the AIMS LTMP methodology was used for this study (Miller *et al*., 2018). SCUBA surveys were conducted along the 50m transect, one meter on each side of the transect line, forming a 2m belt. The camera was oriented downwards, perpendicular to the sea surface and held at 0.5m above the substrate. The operator moved along the transect and took photos with a GoPro camera when an impact was found. Additionnal pictures were taken around the impact site to characterize the colony impacted. These photos allow identification of the coral species impacted, the size of the affected area and the entire colony (measurement of length, width, and height of the affected area).

### 2.2.3 Diver Operated Stereo Video System (DO-SVS) to identify fish community structure

This technique was used to describe the fish biomass along the transects: identify fish families, trophic structures, commercially important fish and reef fish and structural complexity. Transects are conducted using a diver-operated Stereo-Video System (DO-SVS; SeaGIS, Melbourne, Australia), comprised of two *GoPro Hero 5 Black* video cameras (***Figure. 2.2.2***).

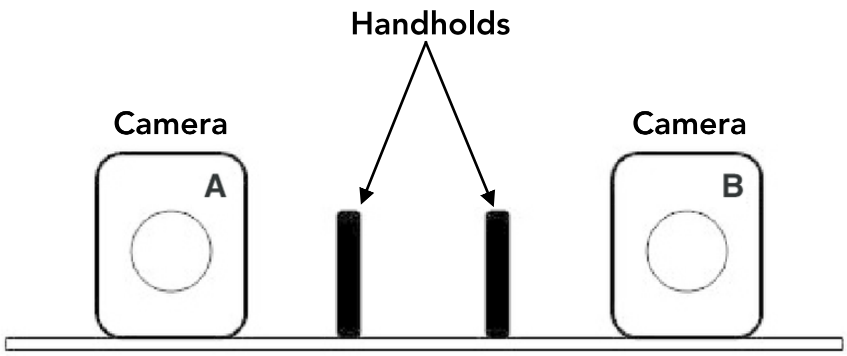



***Figure. 2.2.2*** Diagram of the Stereo-Video System. Comprised of 2 camera mounts containing a GoPro Hero 5 each, and 2 handholds.

To reduce potential disturbance to the fish community, cameras were set to record and synchronized before the entry. The SVS operator was in front of the investigation team. At the beginning of the 50m transects, cameras are held at 0.5m from the substrate, oriented parallel to it, tilted about 20° downwards. The operator placed the SVS centered above the transect and moved adjusting himself to the current while maintaining the SVS parallel to the transect. The operator filmed the reef along the 50m of the transect, moving at a regular rhythm. Transects take approximately 5-6 minutes to be registered (***Figure. 2.2.3***).

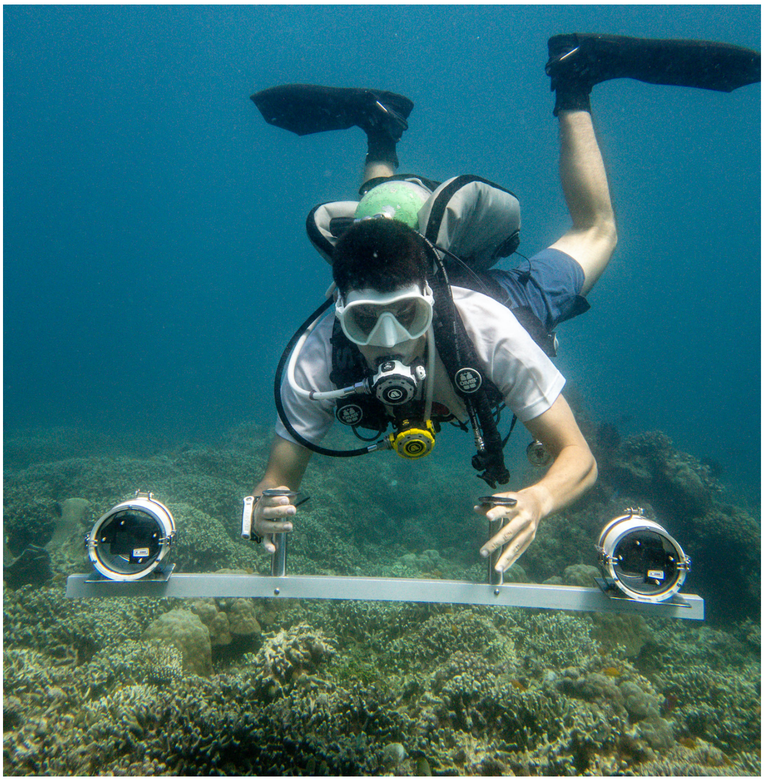


***Figure. 2.2.3***. Picture showing the Diver Operated Stereo Video System in action.

### 2.2.4 3-Dimensional Reef Modelling

This technique was used to assess the relationship between the fish community and the substrate roughness. Two GoPro Hero 5 cameras attached to a one-meter-long aluminum pole form a 3D camera system (Figueira *et al*. 2015). These cameras film at a wide-angle, with a resolution of 1080 pixels and 60 frames per second. The stereo-video measurement system is used to collect video images of the transect; the principle was described in Harvey and Shortis (1995). The cameras are fixed about 2m above the substrate and oriented downwards, perpendicular to the sea surface (Young *et al*. 2018) at the beginning of the 50m transects (***Figure. 2.2.4***). A lawnmower pattern is followed at a regular rhythm; the pattern covers the transect, overlapping it by one meter on each side. Each new step overlaps the previous one for at least 60% of the path so that the images can then be aligned correctly. Preliminary tests have demonstrated the effectiveness of this method in limiting alignment errors on single passes or even longer image intervals (Raoult *et al*. 2016).

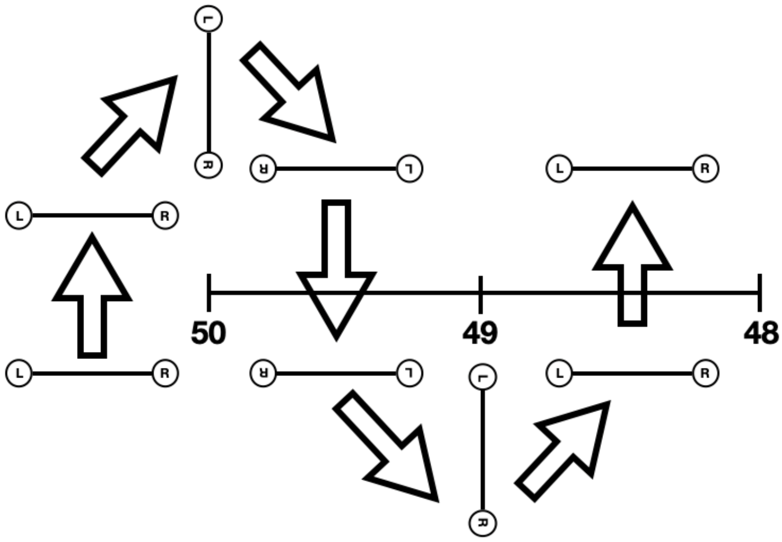



***Figure. 2.2.4***. Diagram showing the 3D modellers U pattern. The modeller keeps 2 m from the substrate and makes a turn between every metre mark. The Line with L and R on each side represents the DO-SVS with the L representing the Left camera and the R representing the right.

## 2.3. Data Analysis

### 2.3.1 Benthic Assays

The CPCe software was used for the analysis of the benthic assays (Kohler *et al*. 2006). The underwater images were placed on a matrix containing 30 randomly spaced points used for the species identification. The software generates a different matrix for each image.

To characterize the benthos and determine the coverage percentage of each organism and substrate type, a point overlay was used (Stopnitzky, 2014). The species code data for each image are stored in a .cpc file containing the image filename, point coordinates, and identified data codes (***Figure. 2.3.1***).

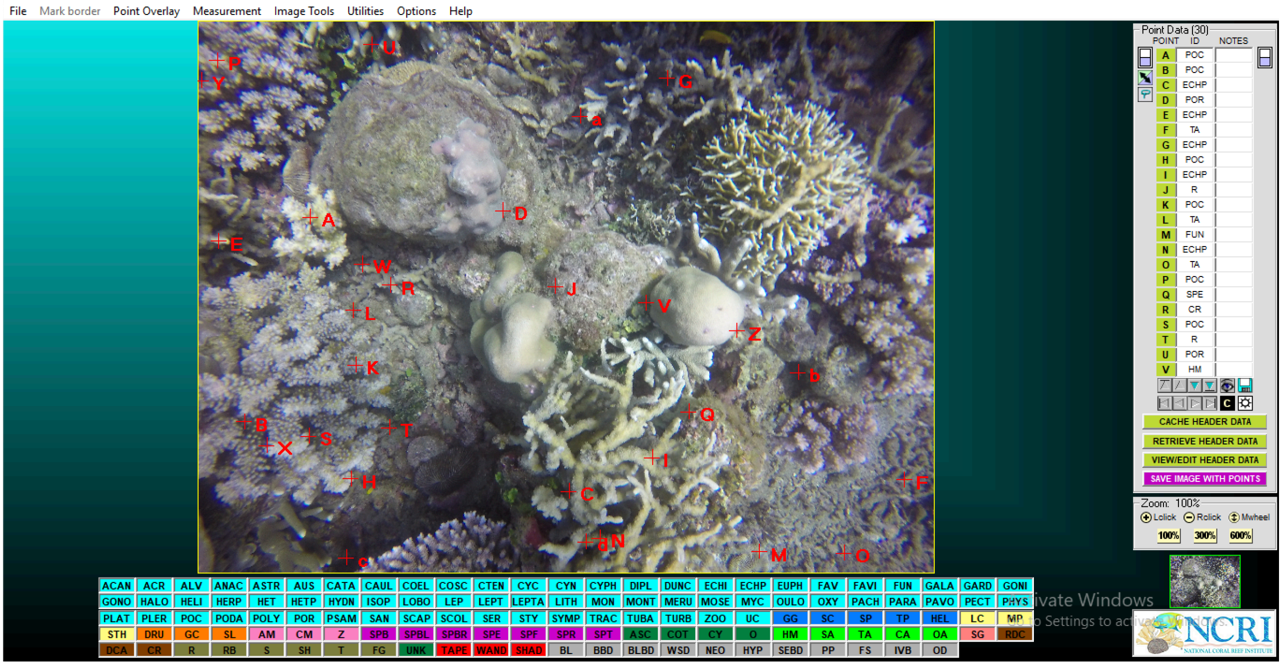



***Figure. 2.3.1***. Screenshot of the CPCe program showing the 30 random points on an image.

A predetermined codec containing all Indo-Pacific Scleractinian corals general, octocorals, hydroids, bivalves, other hexacorals (anemone, corallimorph, zoanthid), sponge growth forms, other living organisms (ascidian, a crown of thorns starfish, cyanobacteria, others e.g. fish), algae, seagrass, dead coral and abiotic (*see* ***Appendix 7.2 for full codec***) have been used to identify the different points.

Inter- and intra-transect and inter-and intra-site comparisons can be produced by combining the different data obtained in automatically generated Excel spreadsheets. Benthic organism coverage at each site and area, as well as in the whole community, were analyzed using the average values of the percentage coverage at each locality, and for each category of benthic animals. Since the distributions of mean proportions did not follow a normal distribution, the Student and Welch tests could not be used. Benthic coverage between sites was then compared using the non-parametric test Mann-Whitney-Wilcoxon (only the images containing 30 treated points were taken into account). Cluster Dendrograms enabled visualisation of the similarities between sites in terms of benthic type.

### 2.3.2 SCUBA Search: Reef Impacts & Coral Mortality

For the SCUBA Search, many impacts were recorded, such as Acanthaster plancii (crown-of-thorns starfish; COTS), COTS feeding scars, *Drupella spp*., *Drupella spp*. feeding scars, unknown scars, coral bleaching, and coral disease: black band disease (BBD), white syndrome (WS), brown band disease (BrBD), Porites pinking (PP), skeletal eroding band disease (SEB), hyperplasia (HYP), and neoplasia (NEO) (***Figure. 2.3.2***). This part is only descriptive, no further analysis was done.

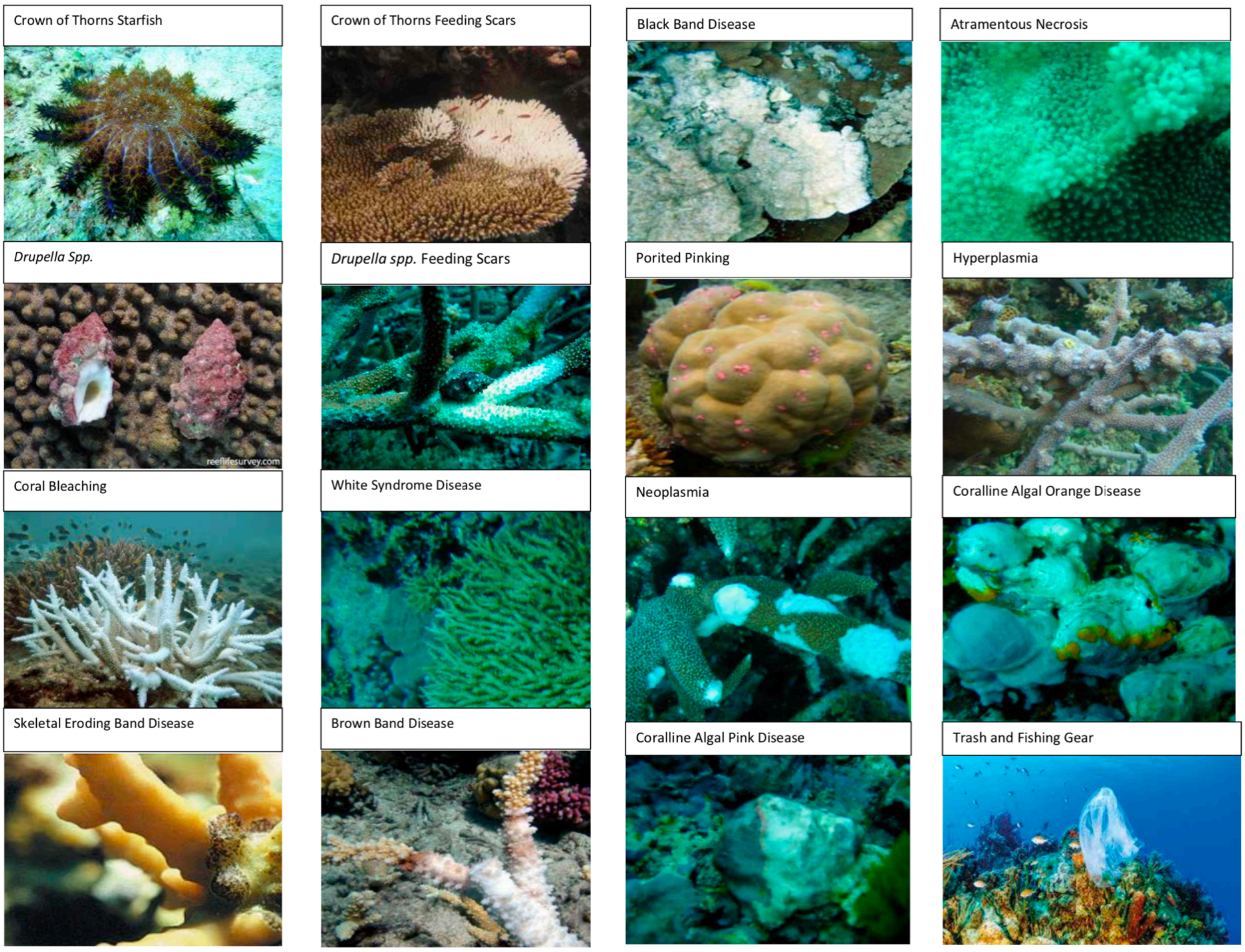



***Figure. 2.3.2***. Reef impact recorded using SCUBA Search.

### 2.3.3 Diver Operated Stereo Video System (DO-SVS)

SVS image synchronization, camera calibration, and measurements of fish found along the transect were performed using EventMeasure V5.25 software (SeaGIS, Melbourne, Australia). This software converts the central points of each fish encountered in a three-dimensional system (Holmes et al., 2013). It allowed eliminating fish that were too far from the area of interest (outside 2.5m on either side of and 5m in front of the camera system). Thus, only the fish in the contiguous lateral examination belt are along the transect (one meter around the line). Limitations in the front distance prevent fluctuations in visibility (cloudy light intensity) from affecting the data. Fish are identified at the species level. Measurements (length) are taken when the fish is visible on the two cameras. When a fish is only visible on the left video, a point identifying the fish at the species level is recorded (***Figure. 2.3.3***).

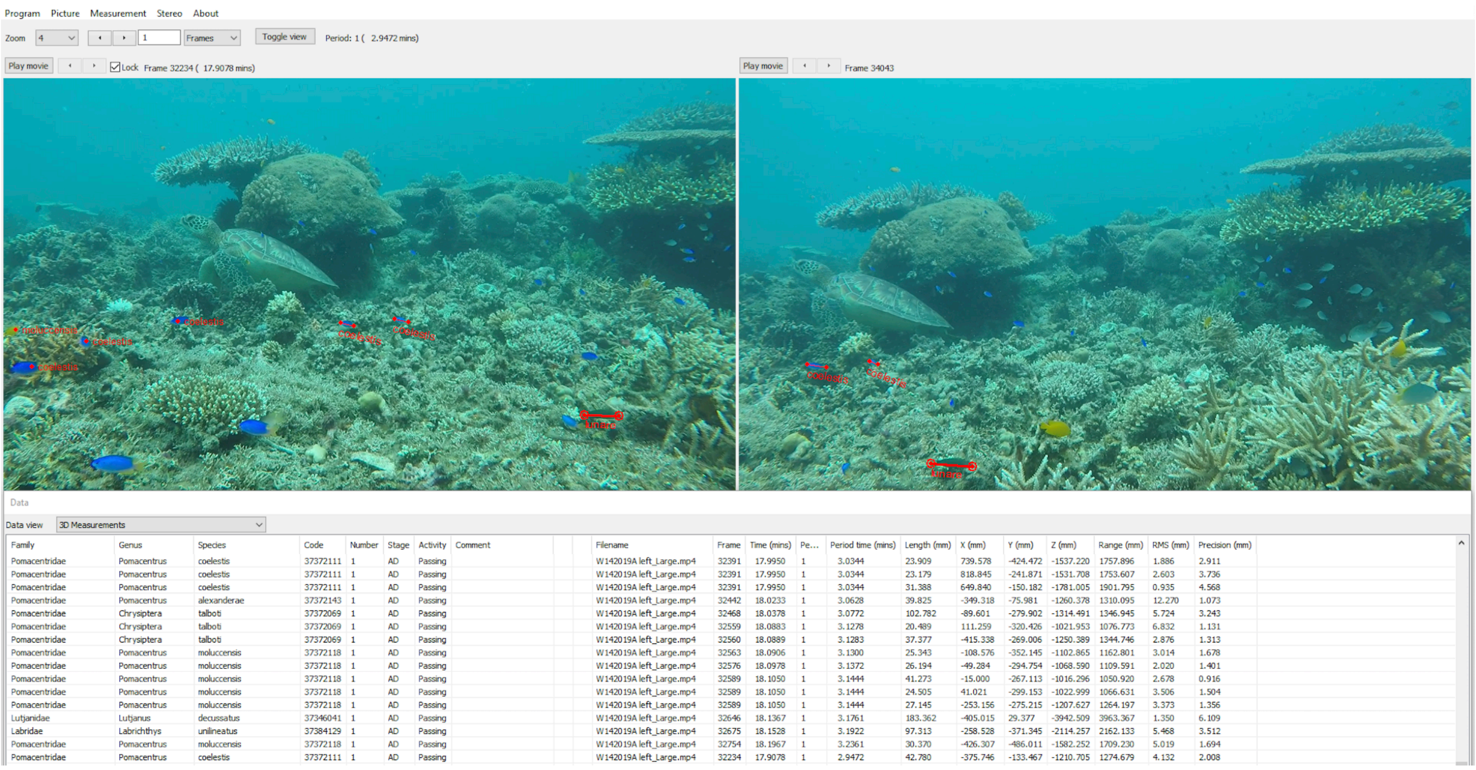



***Figure. 2.3.3***. Screenshot of the EventMeasure analysis. The left screen displays the video from the left camera and the right screen shows that from the right. Lengths of fish can be measured for fish that are sideways to the camera, while points can be recorded for fish at an awkward angle, or for those that can only be seen in the left screen.

Fish biomass was estimated using the equation: $W = aL^{b}$ where W is the weight (g), L is fish length (cm), and a and b are species-specific allometric constants obtained from FishBase.

When allometric constants were not available for specific species, the genus means were used. For points where length measures were not possible, the mean length for the species recorded across all depths and survey sites was used. If fish species were not identifiable (blurred image, too small...), family/sex data were not included in diversity or biomass data, but only in frequency data, as no appropriate allometric constants were available. The size of fish at first maturity was obtained from FishBase (Froese, 2019).

Fish species were classified into functional groups: grazers/detritivores, scrapers/small excavators, browsers, detritivores, obligate corallivores, planktivores, invertivores (invertivores/sessile group was included in this group), and piscivores/scavengers. In the FishBase « Food Items » table, trophic groups may be assigned according to the Food I-III hierarchical classification of food consumed by a species. This categorization is based on the nutritional composition of more than 20% of the registered articles available in FishBase (Boettiger *et al*., 2012, Froese, 2019).

Fish species were also categorized into IUCN Red List Categories (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 FishBase (Froese, 2019). At each site, the proportional biomass of each functional group was calculated.

Statistical analysis was limited to descriptive statistics and trend identification due to the limited number of replicates. Similarity analysis (ANOSIM) and the non-metric multidimensional scale (NMDS) were used to investigate the differences of fish species abundance and biomass in communities. The "vegan" package (Oksanen *et al*. 2019) in R (R Core Team, 2013) was used to explore the relationship between fish communities and seasons through the construction of NMDS plots. The continuous variable "coral cover" is transformed into a categorical variable (low or high depending on whether the value is below or above the average). Based on the biomass of fish species transformed by the fourth root for NMDS, a Bray-Curtis dissimilarity matrix was also built. The « interspecies » package was used to explore potential indicator species between seasons, MPAs / non-MPAs and depths.

### 2.3.4 3-Dimensional Reef Modelling

A 3D model (Agisoft Metashape Standard 9) was created using Structure from Motion (SfM) software and photogrammetry principles (***Figure. 2.3.4***). Photos extracted from video sequences were used, at a rate of one image per 30 taken by the two cameras.

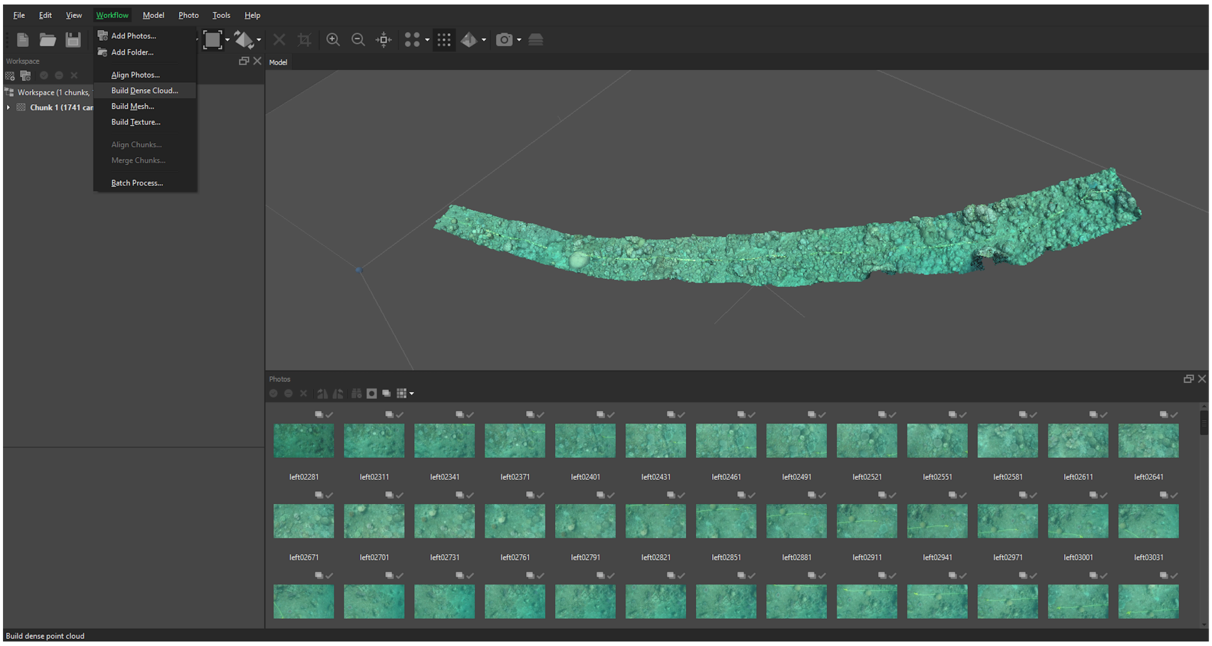



***Figure. 2.3.4***. Screenshot showing how to build a dense cloud on Agisoft Metashape Standard.

Images were aligned considering a generic preselection, key point limit of 40 000, tide point limit of 1 000, and an adaptative camera model adjustment. The alignment has been optimized for k4. A dense cloud was created with shallow and medium quality filtering, point colors calculated and set to 1m on each side of the transect. The XYZ cloud was rasterized. The mask that was previously on the transect has been removed and replaced with a mask that folds up the continuous blank areas.

Row statistical functions were calculated by excluding the masked area; thus, surface line length (length), range, Rq (RMS), slope, and variation (Gwyddion) were measured (Klapetek *et al*., 2012). The correlation between the 3D measurements on the fish biomass composition was studied using the Student test and Fisher test. Using the Mantel tests in the R (R Core Team, 2013) "vegan" package (Oksanen *et al*., 2019), NMDS plots were created to examine the relationship between fish communities and substrate roughness. Continuous numerical variables such as rugosity were converted into categorical variables (low or high depending on whether the value is below or above average).

# 3. RESULTS

## 3.1 Benthic composition

In order to characterize Dauin's benthic composition, we compiled measures of all collection sites obtained by the benthic assay. Dauin's benthic composition reveals that abiotic substrate types widely dominate the reef by 49.19%, mainly consisting of 69.97% sand and 20.67% rubble. This is followed by 21.86 % of hard coral, 9.42 % of dead coral <, 8.87 % of algae, 4.00 % of sponges and 2.11% of seagrass. The remaining 4.55% were composed of other alive forms, detailed in the ***Figure. 3.1.1***.

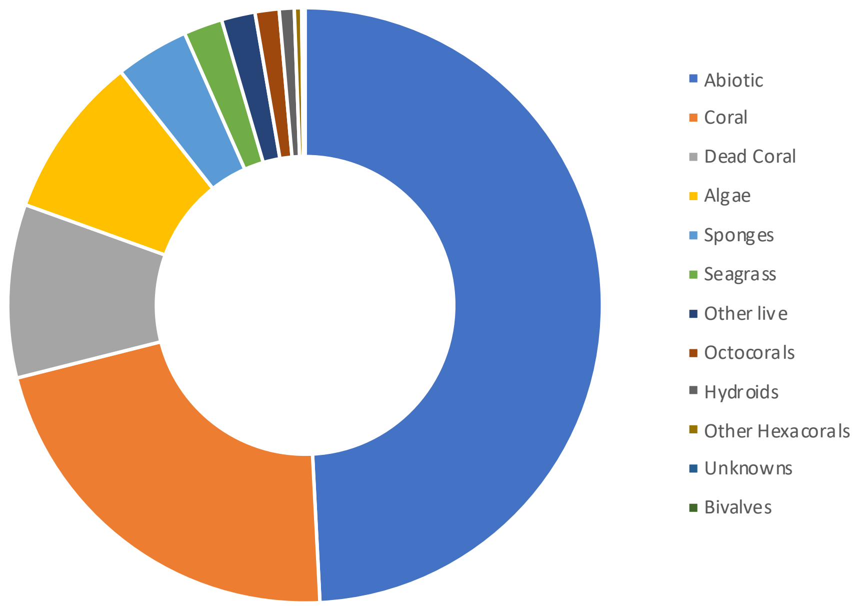



***Figure. 3.1.1***. Relative mean transect cover (%) of major benthic categories along Dauin Reef.

Regarding the comparison of the benthic populations between MPAs and non-MPAs, seagrass, dead coral and algae populations differed between the two zones. In MPAs, dead coral and algae were more present (10.49% vs 4.49% and 9.42. vs 6.32%, respectively; ***Figure. 3.1.2 and Figure 3.1.3***) while seagrass was less frequent (0.29% vs 10.47%) than in non-MPA areas. No significant difference was found for the other benthic categories in the two zones.

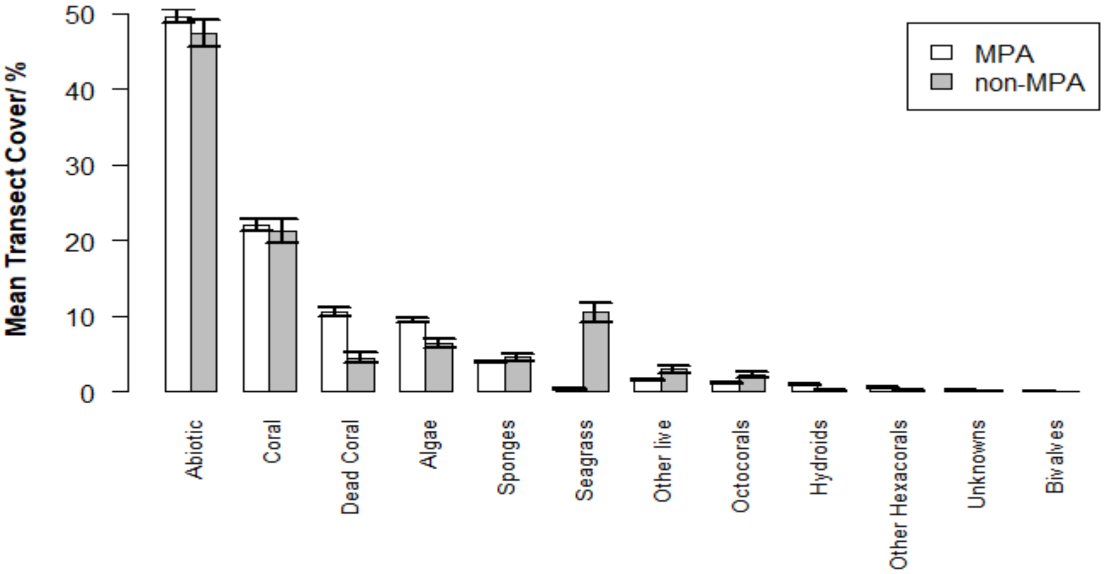



***Figure. 3.1.2***. Mean transect cover (% ± SE) of major benthic categories along Dauin Reef separated by MPA sites (White) and non MPA sites (Grey).

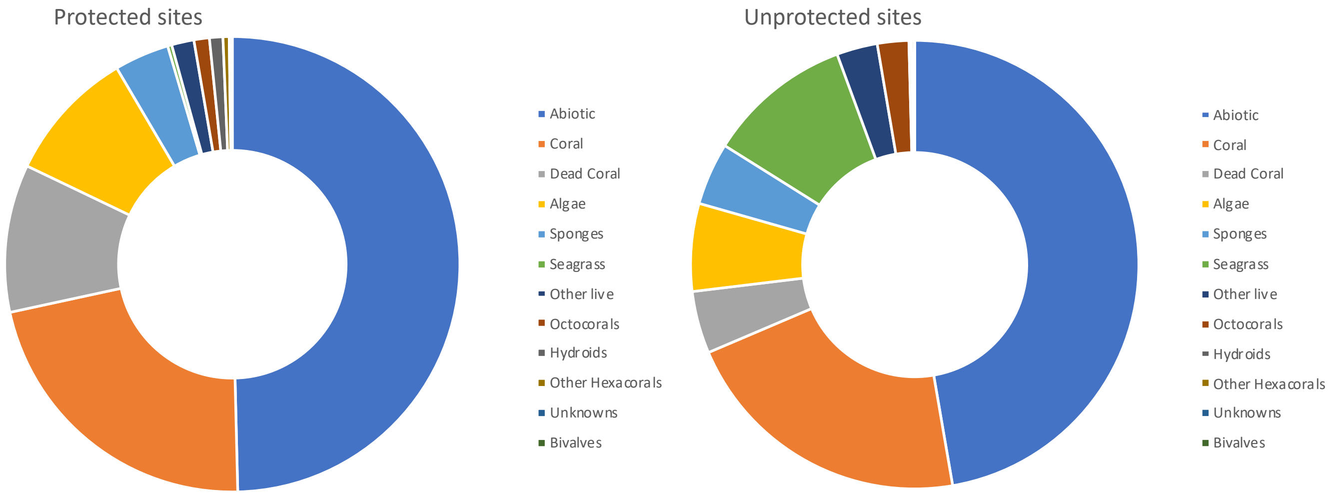



***Figure. 3.1.3***. Comparison between protected sites and unprotected sites for the relative mean transect cover (%) of major benthic categories along Dauin Reef.

When analyzing the categories per site (see additional figure **Table. 7.3.1**), seagrass is highly abundant in Masapold at 5m (Site 15, non-MPA) with 22.17%. Most of the other sites contain less than 3% of seagrass, excepted in Black Diamond at 10m (7.43%, site 7, non-MPA). Therefore, - higher weight is given to the specifics of a single site. These results include only three unprotected sites compared to the 14 protected sites along Dauin. These three unprotected sites are among the four sites with the most seagrass present along Dauin's reefs.

In order to assess whether there could be a local effect on the benthic population, we compared the three unprotected sites with the closest protected site at the same depth:

- Black Diamond at 10m (Site 7) with Bulak at 10m (Site 10),
- Masapold at 10m (Site 14) with Masapold South at 10m (Site 12),
- Masapold at 5m (Site 15) with Masapold South at 5m (Site 13).

Along with **Figures 3.1.2 and 3.1.3**, this sub-analysis confirmed that the seagrass category is under-represented in protected sites (***Table. 3.1.1***). Higher presence of algae was confirmed in two MPAs (Masapold South, at 5m and 10m, sites 12 and 13) and higher presence of dead coral only in one MPA (Masapold South at 5m, site 13). Analyzing the coral population at the local level highlights an information that was not obvious in the overall analysis: coral was overrepresented in two MPA zones (Masapold South, at 5m and 10m, sites 12 and 13) while underrepresented in Bulak at 10m (site 10). This table clearly highlights local effects for all benthic populations, excepted for seagrass that is consistently more present in all non-MPA zones.

| MPA vs non-MPA | Coral | Other Hexacorals | Octocorals | Bivalves | Hydroids | Sponges |
|---|---|---|---|---|---|---|
| 10 vs 7 | - | = | + | NaN | + | = |
| 12 vs 14 | + | NaN | = | NaN | = | - |
| 13 vs 15 | + | = | = | NaN | = | = |

| MPA vs non-MPA | Algae | Seagrass | Other live | Abiotic | Dead Coral | Unknowns |
|---|---|---|---|---|---|---|
| 10 vs 7 | = | - | + | + | = | = |
| 12 vs 14 | + | - | = | - | = | = |
| 13 vs 15 | + | - | = | = | + | NaN |

***Table. 3.1.1***. Results of the Mann-Whitney-Wilcoxon tests by site (closest MPA / non-MPA at the same depth) for the benthic categories present along Dauin Reef. "+" : more in the MPA than in the non-MPA; "-" : less in the MPA than in the non-MPA; "NaN": not a number (no element recorded at one site).

The local effect seems to influence benthic composition more than an MPA vs non-MPAs effect. The ***figure 3.1.4*** illustrates the variability of the benthic composition between the different sites.

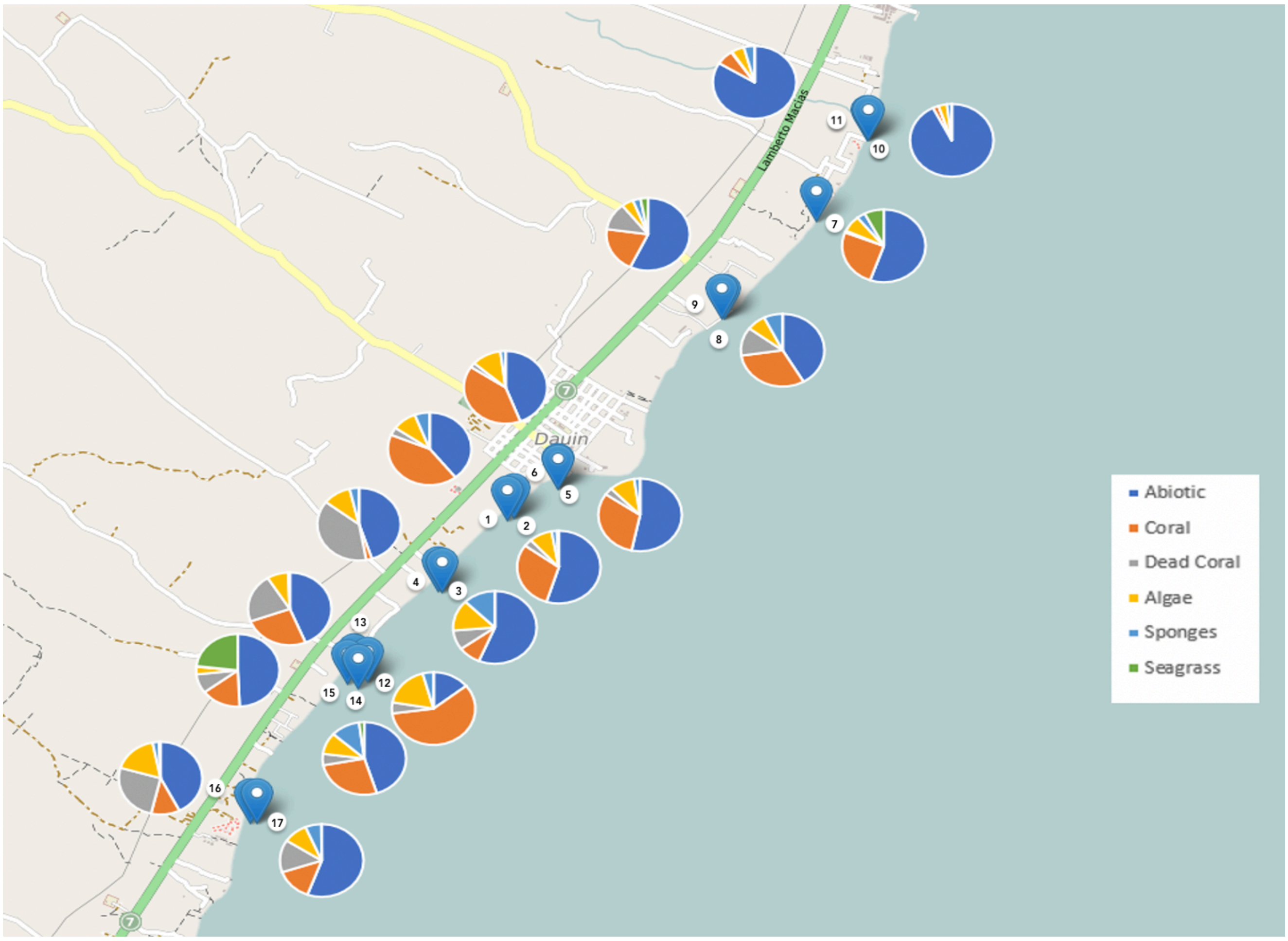



***Figure. 3.1.4***. Satellite map of survey sites with major benthic category proportions for the survey year. Graphs on shore side refer to 5m survey sites and thosepositioned in the water refer to 10m sites.

### 3.1.1 Corals

We then detailed the coral population at the genera level and compared them between MPAs and non-MPAs. A total of 44 Scleractinian coral genera were identified during the survey. The coral genera Acropora, Anacropora, Porites, Echinopora and Pocillopora dominate the Dauin reef system, contributing to 79.5% of all coral cover between them: 28%, 20.7%, 17.8%, 6.9% and 6.1% respectively (***Figure. 3.1.5***), with the remaining coral genera contributing less than 3% each.

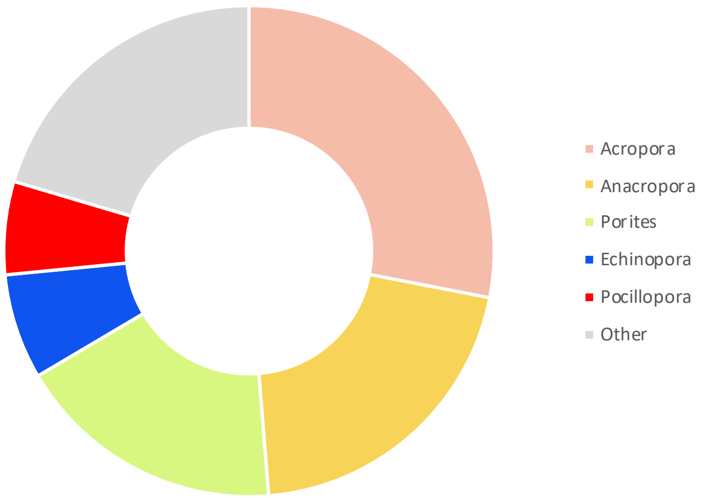



***Figure. 3.1.5***. Relative mean transect cover (%) of most common coral genera along Dauin Reef.

We compared the five most abundant coral genera in both study zones. When comparing MPAs vs non-MPAs, the following genera were more frequent: Porites (20.6% vs 4.6%, **Figure 3.1.6**), Echinopora (8.3% vs 0.3%), Pocillopora (6.7% vs 3.2%) and other genera (22.3% vs 11.3%). The two remaining genera studied were less frequent in MPAs than in non-MPAs: Acropora (24.7% vs 43.8%) and Anacropora (17.3% vs 36.8).

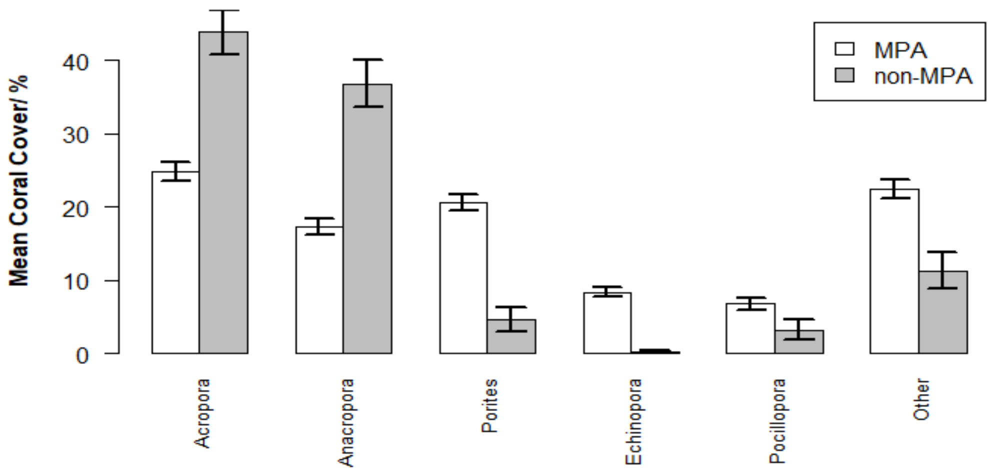



***Figure. 3.1.6***. Mean coral cover (% ± SE) of the five most coral genera along Dauin Reef separated by MPA sites (White) and non MPA sites (Grey).

We then restricted the analysis between non-MPAs and its closest MPAs, for the three more abundant corals: Acropora, Anacropora and Porites. The Mann-Whitney-Wilcoxon test reveals local differences: Bulak at 10m (Site 10) and Masapold South at 10m (Site 12) count more Porites corals than their neighbors Black Diamond at 10m (Site 7) and Masapold at 10m (Site 14; ***Table. 3.1.2***). Conversely, Acropora and Anacropora populations were less present in one MPA over the three sites: respectively at Bulak vs Black Diamond, 10m (Sites 10 and 7) and Masapold South vs Masapold, 5m (Sites 13 and 15). All other populations studied are similar between both zones. Once again, a geographic effect rather than an MPA / non-MPA effect is emphasized by the ***figure 3.1.7***.

| MPA vs non-MPA | Acropora | Anacropora | Porites |
|---|---|---|---|
| 10 vs 7 | 0,0000 | NaN | 0,0026 |
| 12 vs 14 | 0,8625 | 0,4644 | 0,0011 |
| 13 vs 15 | 0,5952 | 0,0075 | 0,2928 |

| MPA vs non-MPA | Acropora | Anacropora | Porites |
|---|---|---|---|
| 10 vs 7 | - | NaN | + |
| 12 vs 14 | = | = | + |
| 13 vs 15 | = | - | = |

***Table. 3.1.2***. Results of the Mann-Whitney-Wilcoxon tests by site (closest MPA / non-MPA) with p-values (on the top) and interpretation (on the bottom).

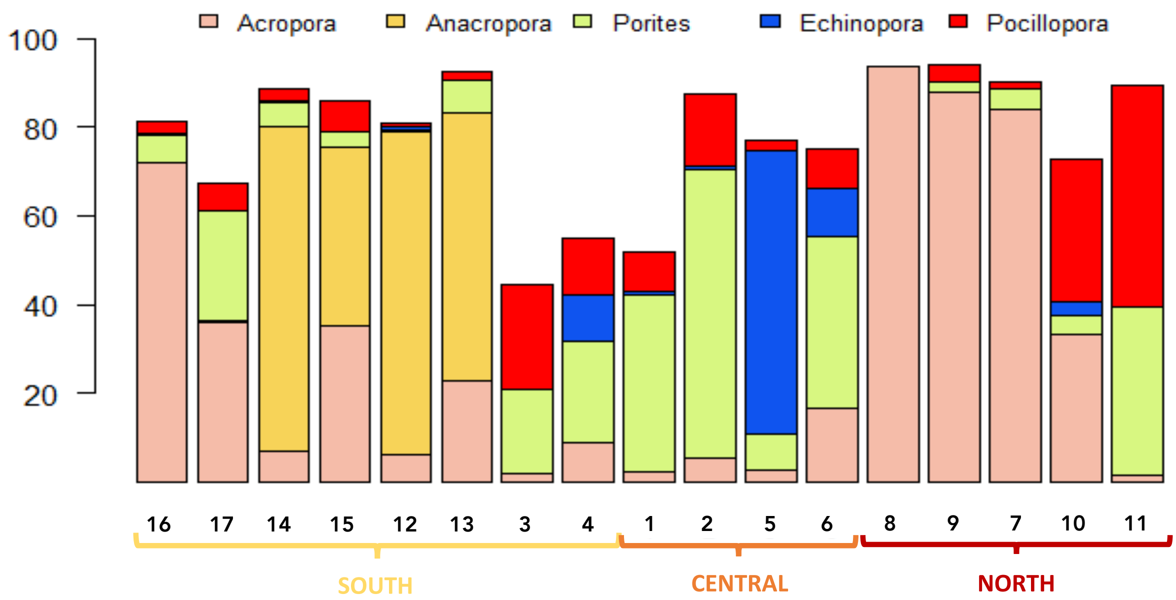



***Figure. 3.1.7***. Mean coral cover (%) of five most common coral genera along Dauin Reef survey sites.

Looking at the five most dominant coral genera across sites, most sites with higher coral cover tend to be dominated by one, or a few, coral genera (***Figure. 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). Pocillopora dominates Bulak at 5 (Site 11) and 10m (Site 10). Anacropora dominates Masapold and Masapold Sur MPA, both at 5 and 10m (Sites 12-15). Many sites are dominated by Acropora, such as Black Diamond at 10m (Site 7), Lipayo at 10 (Site 8) and 5m (Site 9), and Maayong Tubig at 5m (Site 16). Concretely, the genus Acropora is particularly abundant in the northern zone of Dauin whereas Anacropora type corals is exclusively present in the southern part of Dauin. The great majority of Porites and Echinopora have been recorded in the center of Dauin (***Figure. 3.1.7***).

Masapold Sur at 10m (Site 12) showed significantly greater coral cover (51.66%) than all other survey sites (***Figure. 3.1.8***, ***Table 7.3.1***). The sites with the next highest coral cover are Poblacion District II at 10m (Site 1) and Poblacion District I at 5m (Site 6), both with 39.65%. Survey sites with the lowest coral cover (<5%) are Masapold North at 5m (Site 4) and Bulak at 5m (Site 11). This dendrogram further documents the high variety between sites along the coastline: sites that have a similar coral composition are not necessarily close (for example, Masapold North (sites 3 and 4) and Bulak (sites 10 and 11).

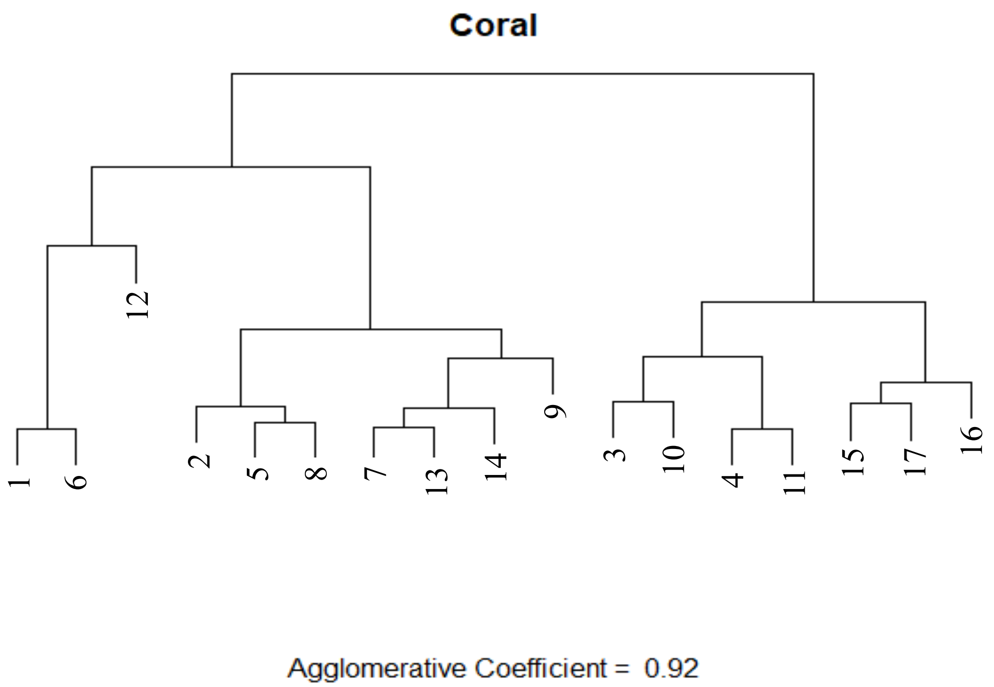



***Figure. 3.1.8***. Cluster dendrogram showing similarities between coral cover of different sites.

Acropora coral is proportionately more important on Lipayo at 10m (Site 8) with 28.57%, follow by Black Diamond at 10m (Site 7) and Lipayo at 5m (Site 9) with 21.20% and 17.72% respectively. Sites with less than 1% cover are Bulak at 5m (Site 11), Masapold North at 5 (Site 4) and 10m (Site 3), and Poblacion District 2 at 5 (Site 2) and 10m (Site 1) with 0.03%, 0.19%, 0.13%, 0.80% and 0.87% respectively (***Figure. 3.1.7***, ***Figure. 3.1.9***).

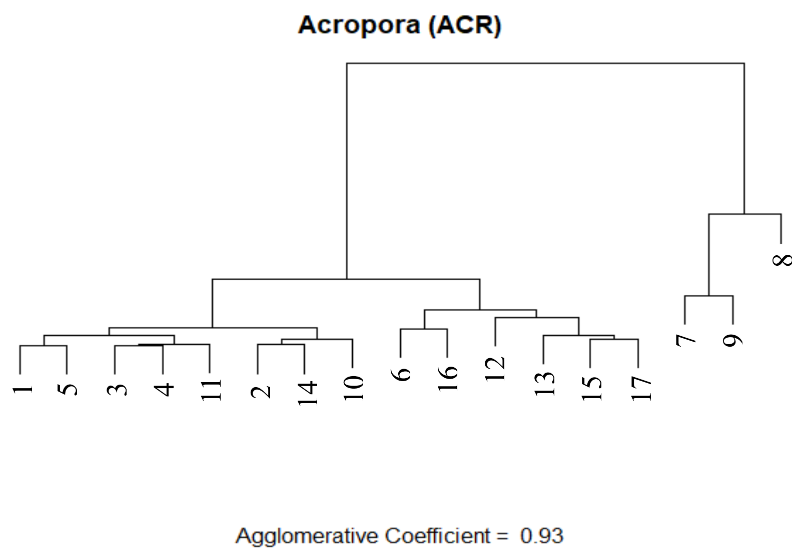



***Figure. 3.1.9***. Cluster dendrogram showing similarities between Acropora cover of different sites.

Anacropora coral is recorded at the higher percentage cover on Masapold South at 10m (Site 12) with 37.53%, follow by Masapold at 10m (Site 14) and Masapold South at 5m (Site 13) with 17.54% and 15.26% respectively. Sites with the lowest percentage cover are Masapold at 5m (Site 15) with 5.97%, Maayong Tubig at 10m (Site 17) and Poblacion District I at 10m with less than 1% cover (0.03%). All other sites do not have Anacropora on their reef (***Figure. 3.1.7***, ***Figure. 3.1.10***).

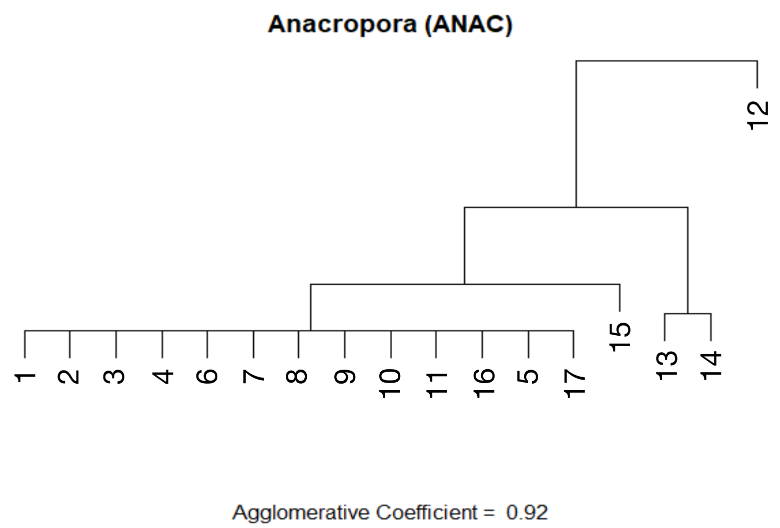



***Figure. 3.1.10***. Cluster dendrogram showing similarities between Anacropora cover of different sites.

Porites coral represent the greatest percent coverage on Poblacion District II at 5 (Site 2) and 10m (Site 1) with 19.09% and 15.78% respectively, follow by Poblacion District I at 5m (Site 6) with 15.35%. All other sites have less than 5% of Porites (***Figure. 3.1.7***, ***Figure. 3.1.11***).

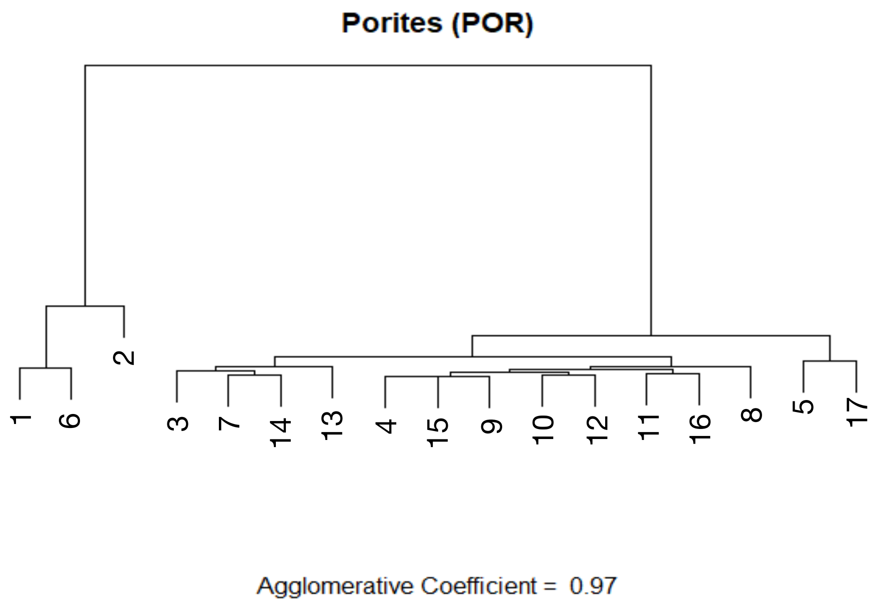



***Figure. 3.1.11***. Cluster dendrogram showing similarities between Porites cover of different sites.

Echinopora coral have the highest average percent coverage on the site Poblacion District I at 10 (Site 5) and 5m (Site 6) with 19.79% and 4.19% respectively. All other sites have less than 1% or no Echinopora (***Figure. 3.1.7***).

Pocillopora is present on Poblacion District II at 5 (Site 2) and 10m (Site 1) by 4.71% and 3.55% respectively and on Poblacion District I at 5m (Site 6) by 3.60. All other sites have less than 2% of Pocillopora (***Figure. 3.1.7***).

We then compared the three non-MPA sites (10, 12 and 13) to their closest MPA site (7, 14 and 15). According to the ***table 3.1.3***, diversity indices show minimal changes to genera diversity, richness, and evenness from protected to unprotected sites. The total genera richness (S) is almost the same in MPAs (n=26) and non-MPAs (n=28), same as the Pielou's Eveness with 0.40 in MPAs and 0.46 in non-MPAs and the Simpson Index with 0.63 in MPAs and 0.66 in non-MPAs. The Shannon (SW) Index seems to be more important in non-MPAs (n=2.21) than MPAs (n=1.89), but again, only 6 sites out of 17 were used to determine these diversity indexes. This further confirms that the coral cover varies according to the site, with no significant changes from MPAs to non-MPAs.

| *Diversity Index* | *All sites* | *Sites (8,12,13,7,14,15)* | *MPA (8,12,13)* | *non MPA (7,14,15)* |
|---|---|---|---|---|
| Shannon (SW) | 3,29 | 2,08 | 1,89 | 2,21 |
| Pielou's Evenness | 0,60 | 0,41 | 0,40 | 0,46 |
| Simpson (1-D) | 0,83 | 0,65 | 0,63 | 0,66 |
| Total Genera richness (S) | 44 | 35 | 26 | 28 |

***Table. 3.1.3***. Diversity indices for all the survey sites, and separated by MPAs and non-MPAs.

### 3.1.2 Abiotic Cover

The abiotic coverage is mainly composed of sand (69.97%), rubble (20.67%) and rock (9.33%). The remaining 0.03% is shell. No trash nor fishing gear were found (***Figure. 3.1.12***).

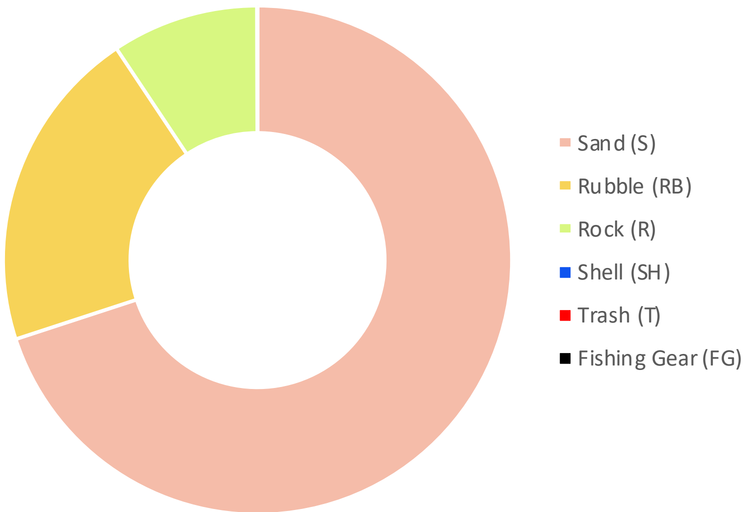



***Figure. 3.1.12***. Relative mean transect cover (%) of abiotic categories along Dauin Reef survey sites.

Sites with the highest abiotic percent cover include Bulak at 5 (Site 11) and 10m (Site 10), with 90.10% and 76.13% respectively, Lipayo at 5m (Site 9), with 56.77% and Black Diamond at 10m (Site 7), with 54.40%. Sites with the lowest abiotic cover include Masapold Sur at 10m (Site 12), Poblacion District II at 10m (Site 1), Masapold at 10m (Site 14) and Lipayo at 10m (Site 8), with 12.55%, 37.27%, 40.15% and 40.99% respectively (***Table 7.3.1, Figure. 3.1.13***). Once again, this shows a variability between sites with no clear local effect: for example, the Northern site Bulak (sites 10 and 11) is close for its abiotic composition to the Southern site Masapold South at 10m (site 12).

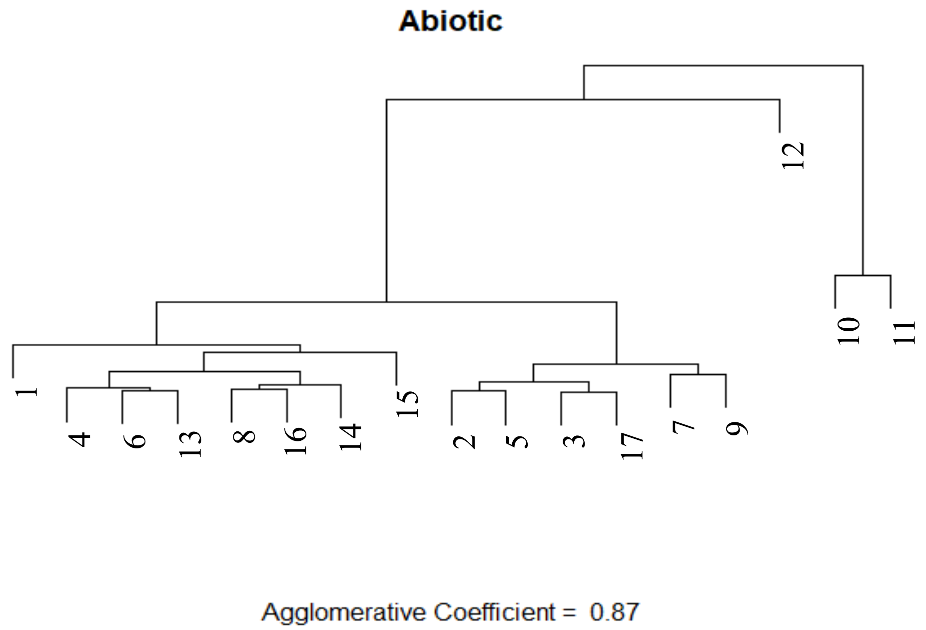



***Figure. 3.1.13***. Cluster dendrogram showing similarities between abiotic cover of different sites.

The comparison of abiotic covers between the 3 MPAs and the 14 non-MPAs is shown in ***Figure. 3.1.14.*** Sand, the major abiotic category is less represented in MPAs than in non-MPAs (66.10% vs 88.65%, respectively). On the contrary, Rubble and Rock are more important in abiotic cover proportion in protected areas, as they represent 23.82% and 10.04% respectively against 5.45% and 5.88% in unprotected areas. However, this trend is probably due to local differences rather than MPA/non-MPA as the ***figure. 3.1.15*** highlights important variety between sites and depths.

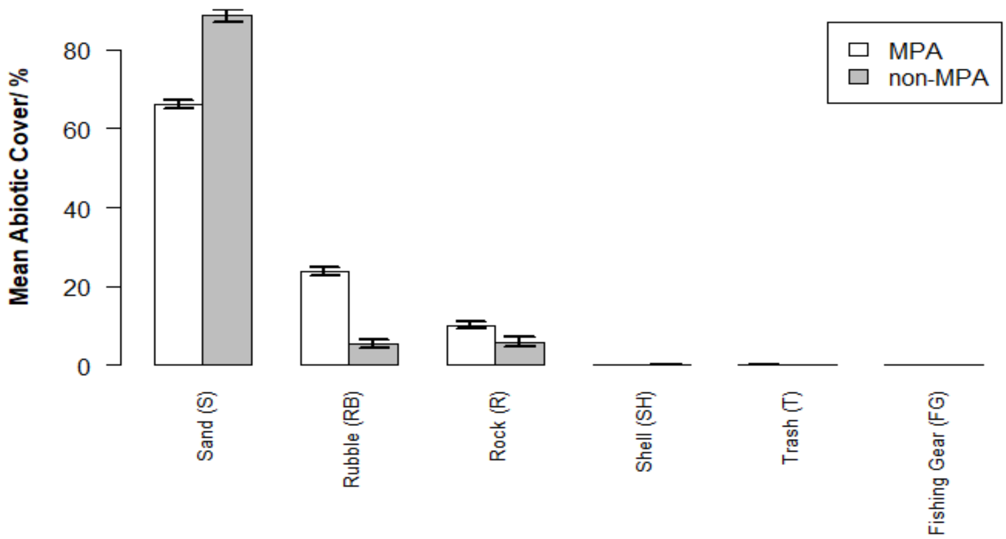



***Figure. 3.1.14***. Mean abiotic transect cover (% ± SE) along Dauin Reef survey sites separated by MPA sites (White) and non MPA sites (Grey).

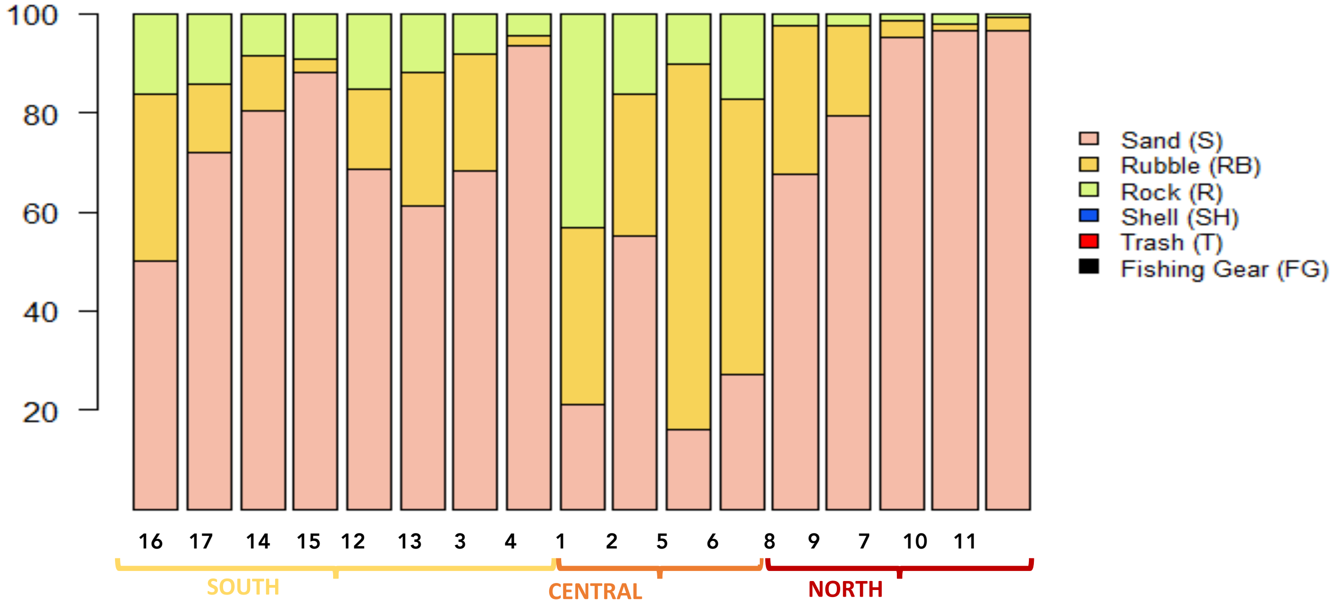



***Figure. 3.1.15***. Mean abiotic categories cover (%) along Dauin Reef survey sites.

Sand cover changes significantly with site (***Figure. 3.1.16***); Bulak at 5 (Site 11) and 10m (Site 10) have the highest average percent sand cover at 86.97% and 73.42% respectively, followed by Black Diamond (Site 7) with 51.80%. Sites with the lowest average percent sand cover are Poblacion District II at 10m (Site 1), Poblacion District I at 10m (Site 5) and Masapold South at 10m (Site 12), with 7.88%, 8.37%, and 8.63% respectively. These are the northernmost sites of Dauin that are the most covered with sand (***Figure. 3.1.15***).

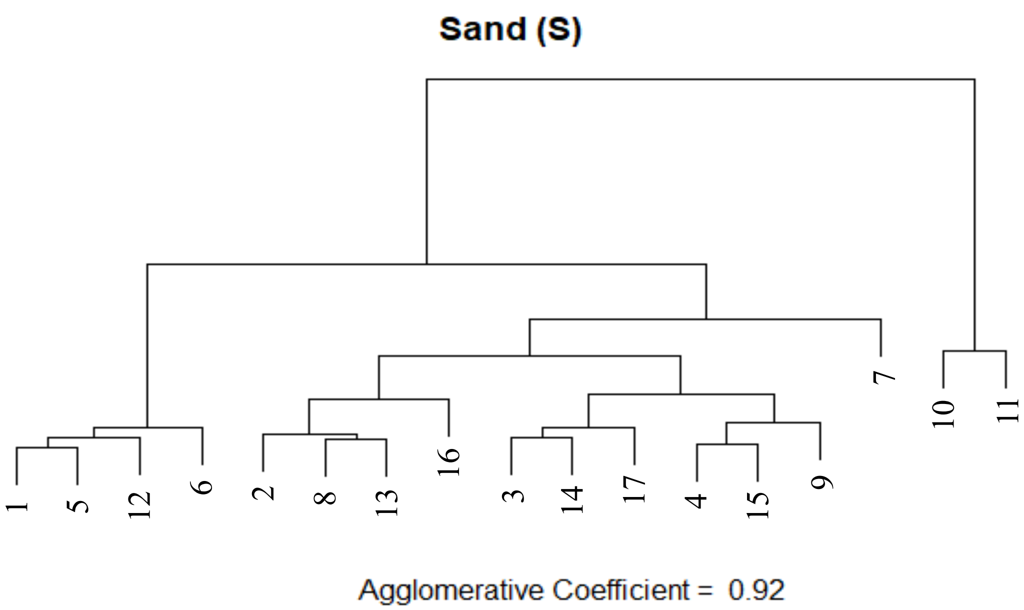



***Figure. 3.1.16***. Cluster dendrogram showing similarities between sand cover of different sites.

Rubble coverage also varies with site more than MPA/non-MPAs (***Figure. 3.1.17***). Poblacion District I at 5 (Site 6) and 10m (Site 5) show significantly higher rubble percent cover than all other sites, with 24.23% and 38.80% respectively. All other sites have rubble cover below 16%. Sites with the lowest rubble cover are Masapold North at 5m (Site 4) and Bulak at 10m (Site 10) with only 1% coverage, followed by Masapold South at 5m (Site 15) and Black Diamond at 10m (Site 7) with 1.30% and 1.87% respectively. The sites with the most rubble on the reefs are located in the center of Dauin (***Figure. 3.1.15***).

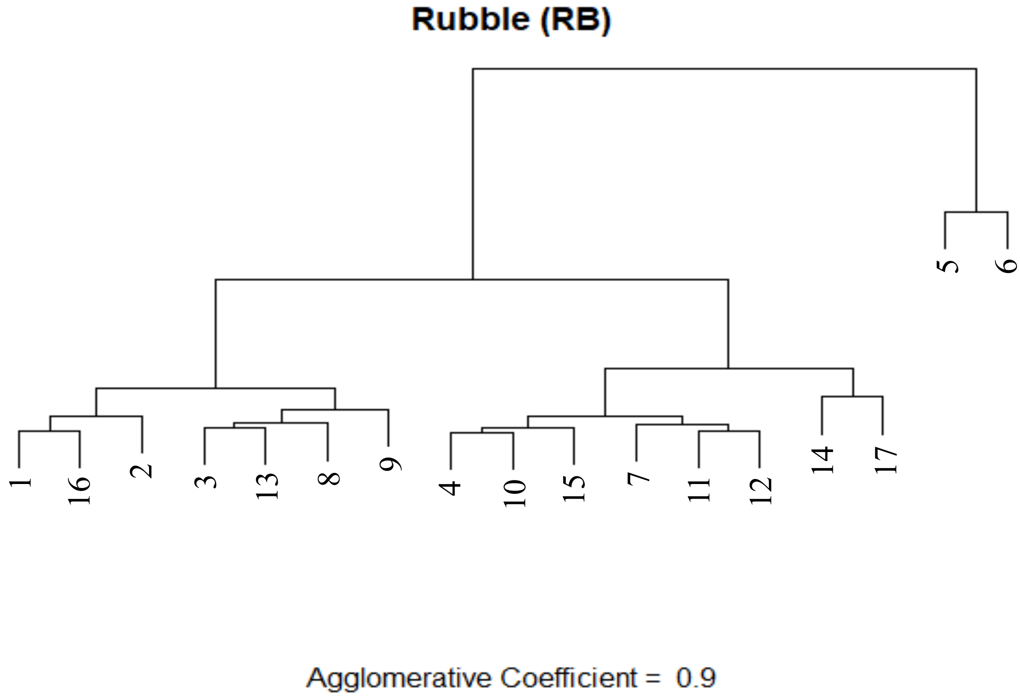



***Figure. 3.1.17***. Cluster dendrogram showing similarities between Rubble cover of different sites.

Rock coverage changes only with site (***Figure. 3.1.15***). Poblacion District II at 10m (Site 1) has significantly higher percent rock cover than all other sites, with an average of 16.09%. This is followed by Poblacion District II at 5m (Site 2), Poblacion District I at 5m (Site 6), and Maayong Tubig at 10m (Site 17) and 5m ( Site 16), with 8.53%, 7.59%, 7.30% and 6.73% respectively. Sites with lowest percent rock cover are Bulak at 5m (Site 11), Black Diamond at 10m (Site 7), and Lipayo at 10 (Site 8) and 5m (Site 9), with 0.53%, 0.70%, 0.93% and 1.27% respectively. Geographically, rocks are most present in the central and southern part of Dauin (***Figure. 3.1.15***).

### 3.1.3 Dead Coral

Coral rubble (CR) contributes to on average 92.06% of dead coral category, whereas dead coral with algae (DCA) and recently dead coral (RDC) contribute to 7.29% and 0.65% respectively (***Figure. 3.1.18***).

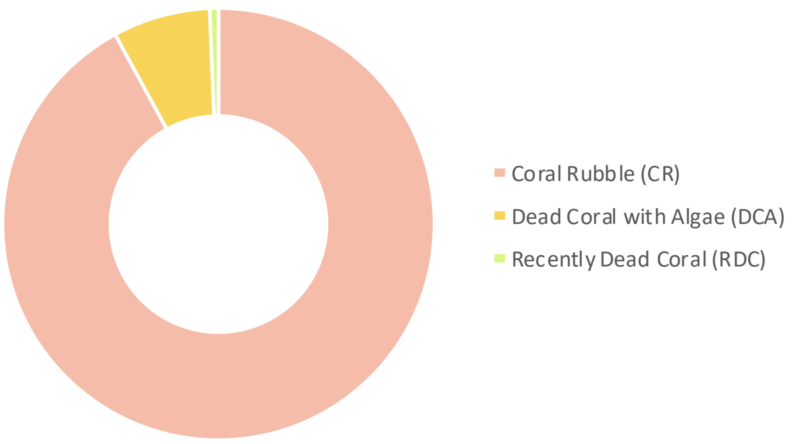



***Figure. 3.1.18***. Relative mean transect cover (%) of dead coral categories (CR: coral rubble, DCA: dead coral with algae, RDC: recently dead coral) along Dauin Reef survey sites.

Sites with highest dead coral percent cover are Masapold North at 5m (Site 4), Maayong Tubig at 5m (Site 16) and Masapold South at 5m (Site 13), with 37.44%, 25.40% and 21.43% respectively ***(Table 7.3.1)***. These sites are located exclusively on the southern part of Dauin. All other sites have average dead coral percent cover below 15%. Sites with the lowest percent dead coral cover include Bulak at 5 (Site 11) and 10m (Site 10) and Black Diamond at 10m (Site 7) with 0.03%, 0.30% and 0.88% respectively ***Figure. 3.1.19***).

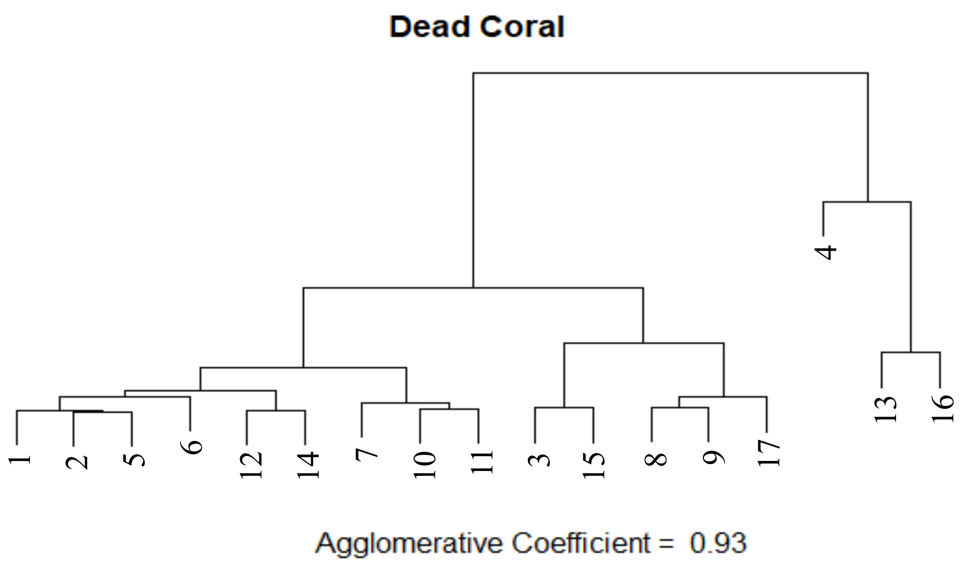



***Figure. 3.1.19***. Cluster dendrogram showing similarities between Dead Coral cover of different sites.

Dead coral cover as a category seems to remained approximatively the same in both protected and unprotected sites (***Figure. 3.1.20***), but vary between sites, as shown in the **figure. 3.1.21**.

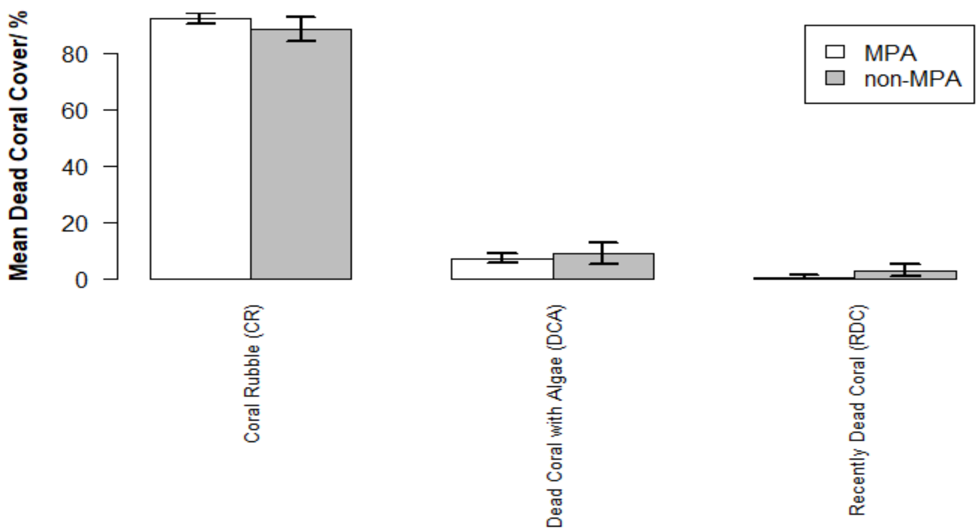



***Figure. 3.1.20***. Mean dead coral transect cover (% ± SE) along Dauin Reef survey sites separated by sites (MPAs in white and non-MPAs in grey) and type; CR: coral rubble, DCA: dead coral with algae, RDC: recently dead coral.

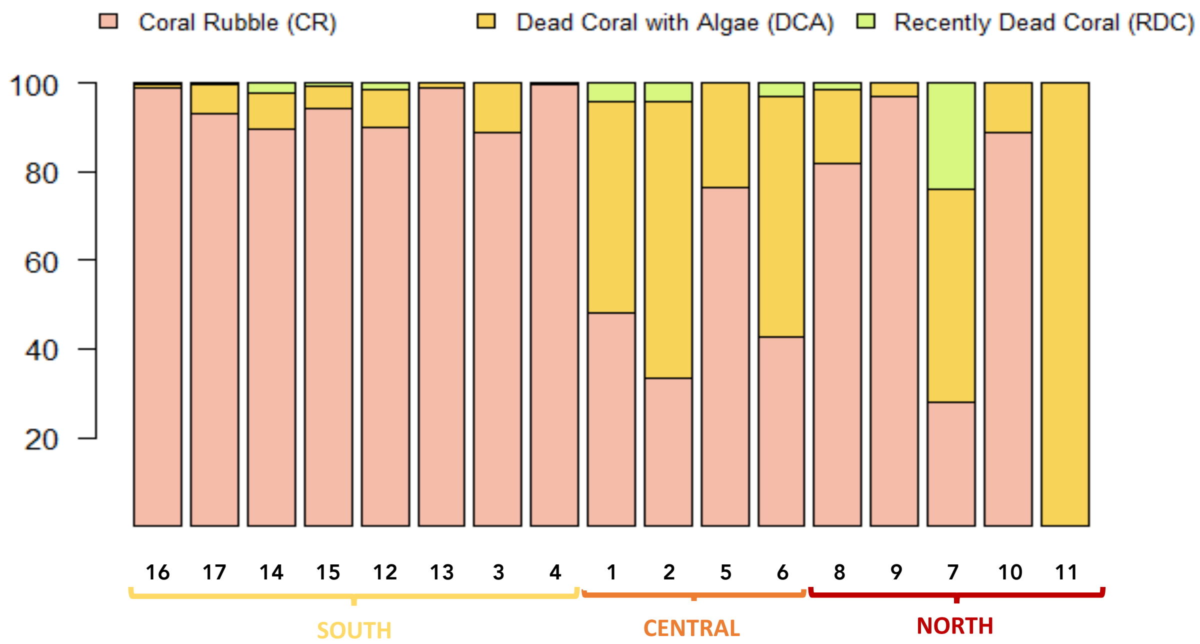



***Figure. 3.1.21***. Mean dead coral categories cover (%) along Dauin Reef survey sites.

Coral Rubble (CR) shows significantly higher percentage cover on Masapold North at 5m (Site 4) than all other sites, with 37.32%. Other sites with high percent CR cover include Maayong Tubig at 5m (Site 16) and Masapold South at 5m (Site 13), with 25.13% and 21.16% respectively. All other sites have CR percent cover below 15%. Sites with lowest CR cover are Black Diamond at 10m (Site 7), Bulak at 10m (Site 10) and Poblacion District I at 5m (Site 6), all of which have less than 1% CR cover (0.23%, 0.27% and 0.89% respectively). Bulak at 5m (Site 11) is the only site that has no CR recorded along the reef (***Figure. 3.1.21***) Coral rubble representing 92.06% of the dead coral, it is therefore logical to read similar sites groupings according to the results of the dendrogram cluster (***Figure. 3.1.22***).

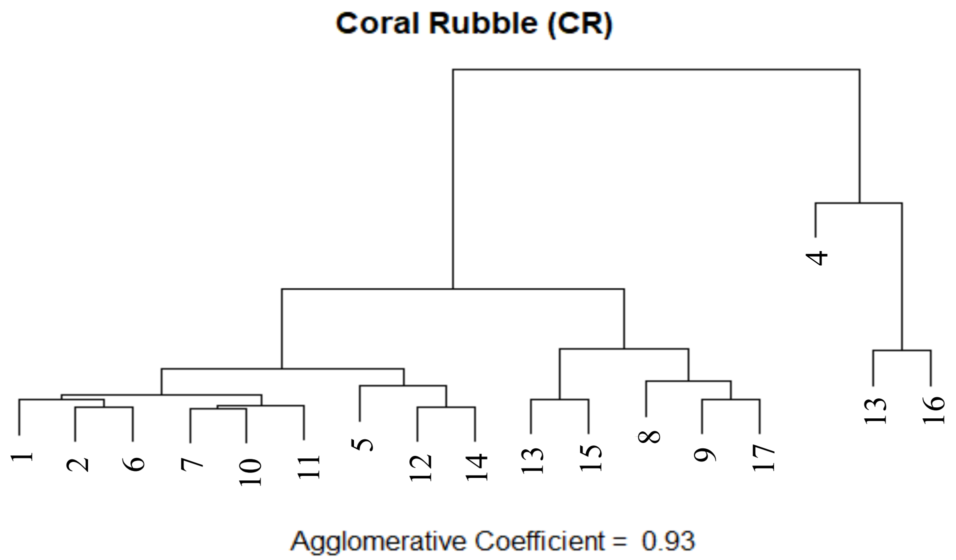



***Figure. 3.1.22***. Cluster dendrogram showing similarities between Coral Rubble cover of different sites.

Dead Coral with Algae (DCA) average percent cover for sites is much lower, ranging from 0-2.1%, with Lipayo at 10m (Site 8), Poblacion District II at 5 (Site 2) and 10m (Site 1), and Poblacion District I at 5m (Site 6) having average DCA coverage above 1% (***Figure. 3.1.21***). All other sites have negligible coverage of DCA.

Recently Dead Coral (RDC) represent a small percent cover along Dauin reefs. The site with the most RDC recorded is Black Diamond at 10m (Site 7) with 0.20% and Lipayo at 10m (Site 9) with 0.19%. All other sites have negligible or no DRC coverage on their reefs (***Figure. 3.1.21***). More generally, it is observed that the four sites where the highest dead coral cover has been reported are on protected sites: Sites 17, 13, 16 and 4, all located in the south of Dauin. Also, three of the four least affected sites are protected: Sites 11, 10 and 6 (***Table. 3.1.1***).

### 3.1.4 Algae

Turf algae, coralline algae and other algae combined contribute to 91.8% of algae recorded, with Halimeda contributing 8.17% and sargassum contributing <0.02% (***Figure. 3.1.23***).

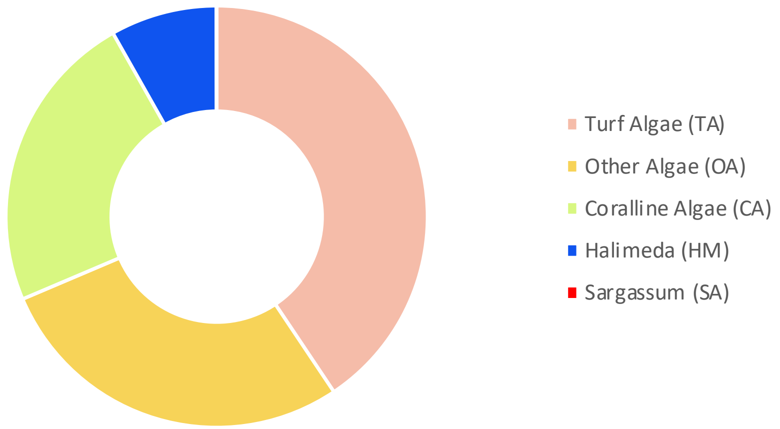



***Figure. 3.1.23***. Relative mean transect cover (%) of algae categories along Dauin Reef survey sites.

Sites with the highest algae percent cover are Maayong Tubig at 5m (Site 16), Masapold South at 10m (Site 12), Masapold North at 10m (Site 3) and Poblacion District I at 5m (Site 6), with 16.97%, 15.84%, 12.59% and 11,29% respectively. Sites with the lowest algae percent cover are Bulak at 5 (Site 11) and 10m (Site 10) and Masapold at 5m (Site 15), with 3.17%, 4.5% and 3.27% respectively (***Table 7.3.1, Figure. 3.1.24***).

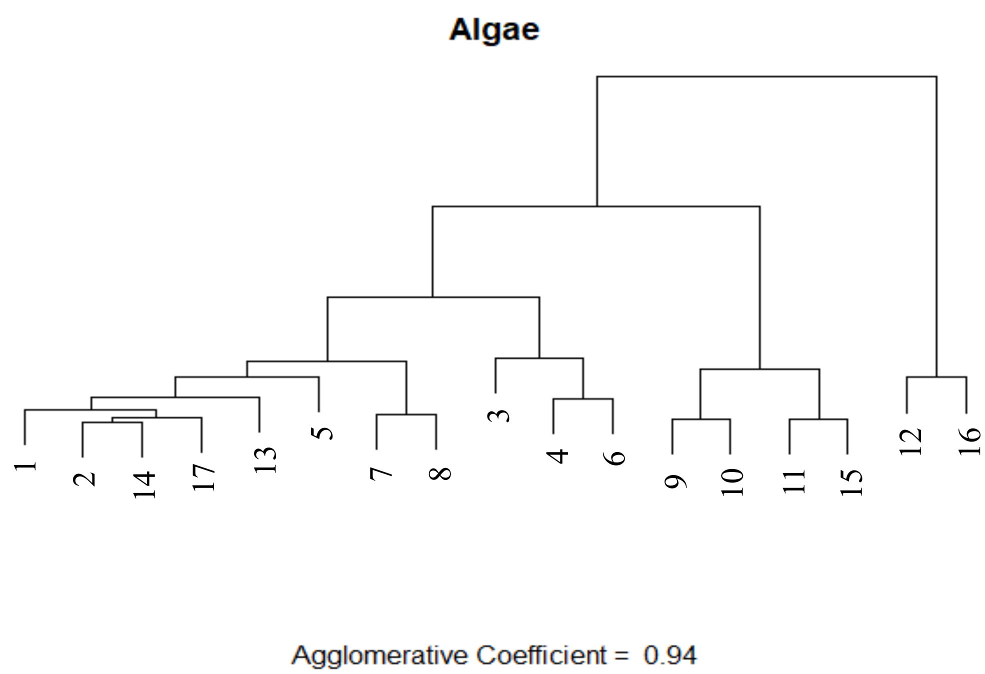



***Figure. 3.1.24***. Cluster dendrogram showing similarities between Algae cover of different sites.

Graphically, algae cover seems to change in protected areas or unprotected areas (***Figure. 3.1.25***). Turf algae (TA), Coralline Algae (CA) and Halimeda (HM) are less represented in non-MPAs with 23.6%, 9.7% and 2.6% respectively against 43.1%, 25.2% and 9.0% respectively in MPAs. Conversely, the Other Algae (OA) category is much more represented in non-MPAs with 64.0% than MPAs with 22.7%. No differences were observed between MPAs and non-MPAs for sargassum (0.0% vs 0.2%, respectively).

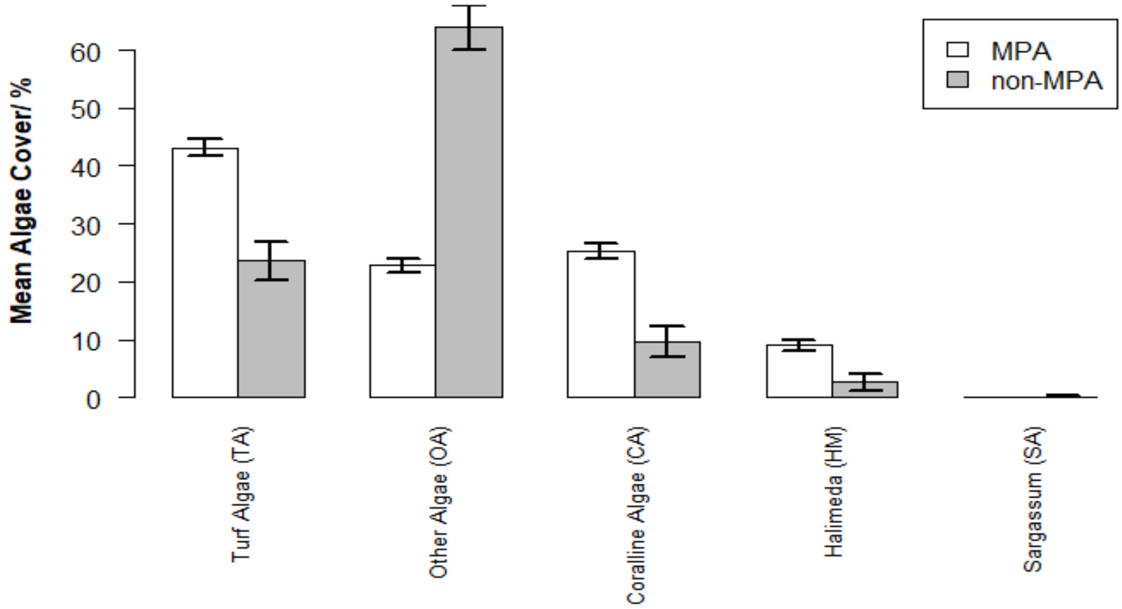



***Figure. 3.1.25***. Mean algae transect cover (% ± SE) along Dauin Reef survey sites separated by MPAs / non-MPAs and type.

The ***figure. 3.1.26*** highlights the differences between the sites for the algae categories.

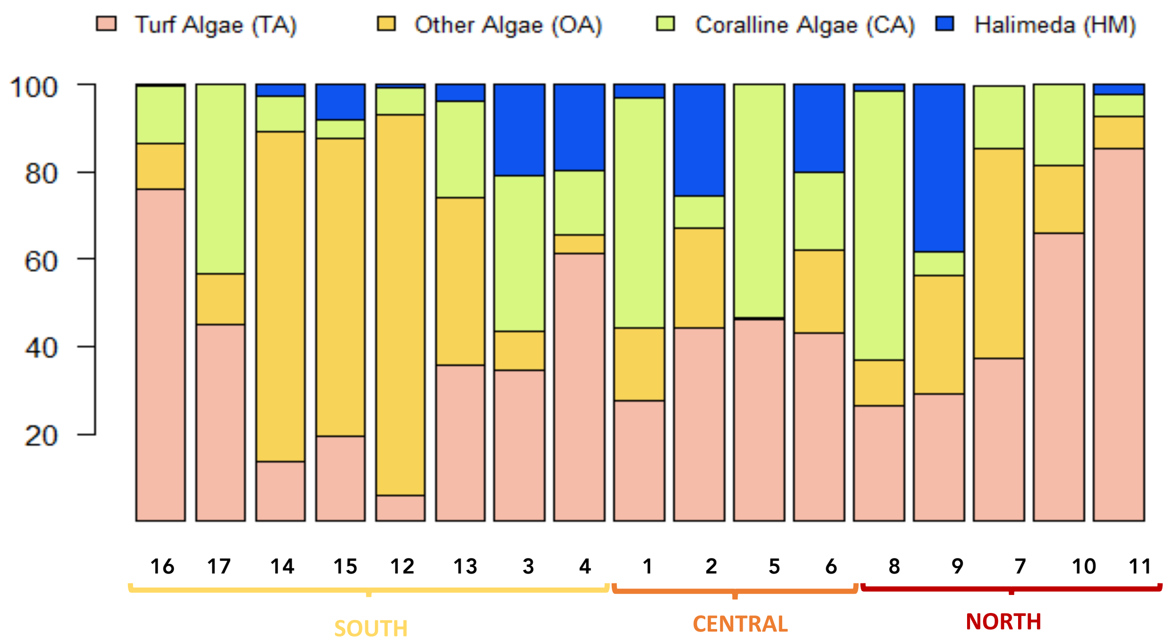



***Figure. 3.1.26***. Mean algae categories cover (%) along Dauin Reef survey sites.

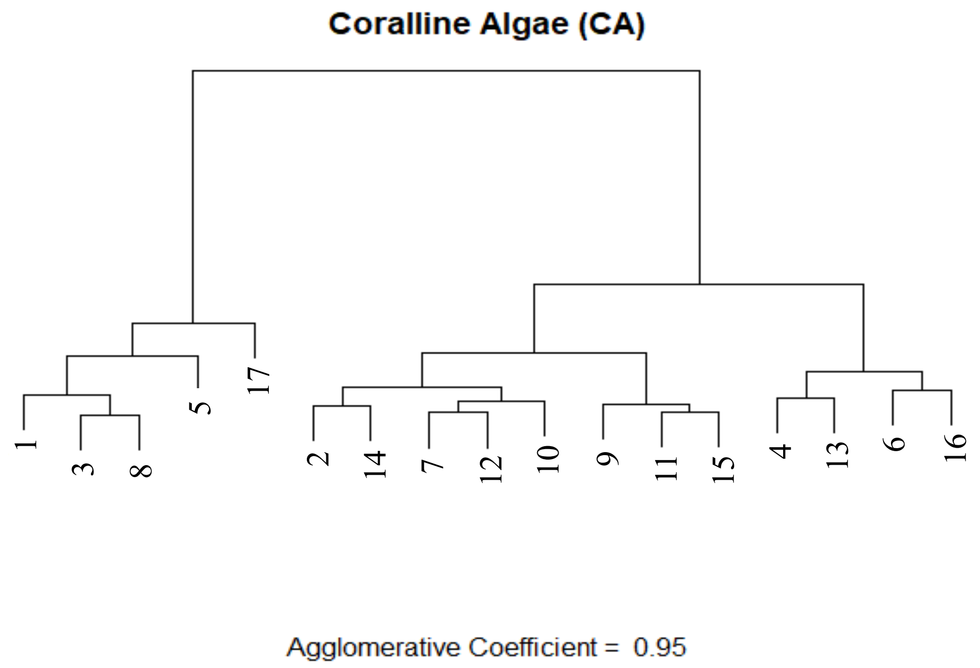



*Figure. 3.1.25*. Cluster dendrogram showing similarities between Coralline Algae cover of different sites.

Turf algae cover is more site specific, with Maayong Tubig at 5m (Site 16) and Masapold North at 5m (Site 4) showing greatest percentage: 12.90% and 6.55% respectively. All other sites have turf algae percent cover below 5%. Sites with lowest turf algae cover are Masapold at 5m (Site 15) and Masapold South at 10m (Site 12) with 0.63% and 0.94% respectively (***Figure. 3.1.26***, ***Figure. 3.1.27***).

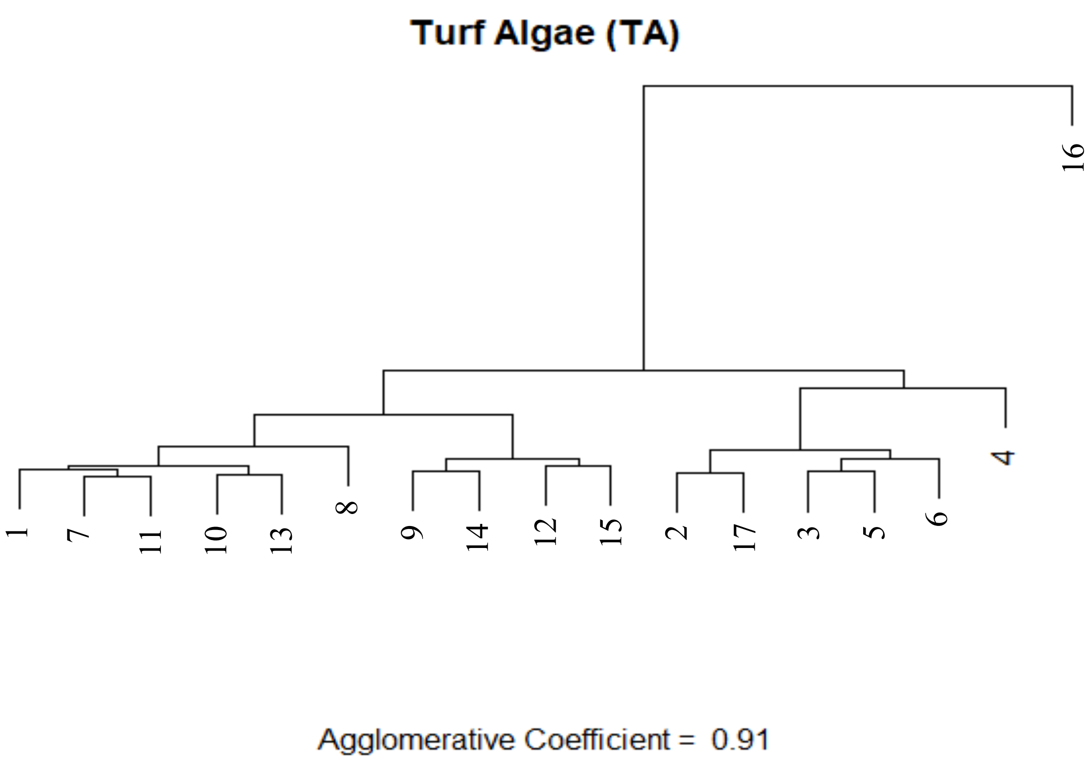



***Figure. 3.1.27***. Cluster dendrogram showing similarities between Turf Algae cover of different sites.

Coralline algae cover also varies with site more than MPAs / non-MPAs. Looking at site, Poblacion District I at 10m (Site 5), Poblacion District II at 10m (Site 1), Masaplod North at 10m (Site 3), Lipayo at 10m (Site 8) and Maayong Tubig at 10m (Site 17) show significantly higher coralline algae percent cover than all other sites, with 5.19%, 4.73%, 4.51%, 4.51% and 3.80% respectively. All other sites have coralline algae cover below 2.5%. Sites with the lowest coralline algae cover are Masaplod at 5m (Site 15), Bulak at 5m (Site 11) and Lipayo at 5m (Site 9) with 0.13%, 0.17%, and 0.26% respectively (***Figure. 3.1.26***, ***Figure. 3.1.28***).

Other algae, which includes macroalgae such as *Turbiniaria spp*., *Dictyota spp*. and *Udotea spp*., also varies with site even if unprotected sites seem to record much more percentage cover than protected sites. Masapold South at 10m (Site 12), Masapold at 10m (Site 14), Black Diamond at 10m (Site 7) and Masapold South at 5m (Site 13) have higher « other algae » percent cover than other sites, with 13.83%, 6.47%, 3.43% and 3.10% respectively. All other sites have less than 3% « other algae » cover. Poblacion District I at 10m (Site 5), Bulak at 5 (Site 11) and 10m (Site 10), Masapold North at 5 (Site 4) and 10m (Site 5) and Lipayo at 10m (Site 8) all had « other algae » percent cover less than 1% (***Figure. 3.1.26***, ***Figure. 3.1.28***).

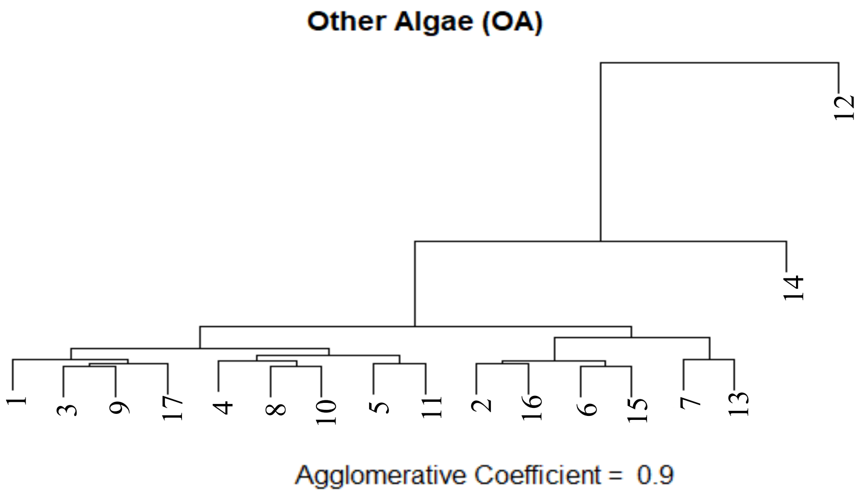



***Figure. 3.1.29***. Cluster dendrogram showing similarities between Other Algae cover of different sites.

Halimeda cover varies with site although the MPAs / non MPAs differs in percentage cover, same as coralline algae. Looking at site, Masaplod North at 10m (Site 3), Poblacion District I at 5m (Site 6), Poblacion District II at 5m (Site 2), Masaplod North at 5m (Site 4) and Lipayo at 5m (Site 9) have significantly higher Halimeda percent cover than all other sites, with 2.61%, 2.24%, 2.21%, 2.09% and 1.75% respectively. All other sites have less than 1% Halimeda cover. Poblacion District I at 10m (Site 5), Black Diamond at 10m (Site 7), Bulak at 10m (Site 10) and Maayong Tubig at 10m (Site 17) all had no records of Halimeda along the transects (***Figure. 3.1.26***).

More generally, looking at the other benthic categories, it is observed that the four sites with the most algae are protected: Sites 6, 3, 12, and 16 (distributed in the south and the center of Dauin). Conversely, three of the four sites with the least algae are also protected: Sites 11, 10 and 9, which are more in the northern part of Dauin (***Table. 3.1.1***).

### 3.1.5 Sponge

Encrusting, branching and tube sponge combined contribute to 89.97% of sponge recorded, with rope sponge contributing 6.6% and ball, barrel and fan sponges contributing 3.42% combined together (***Figure. 3.1.30***).

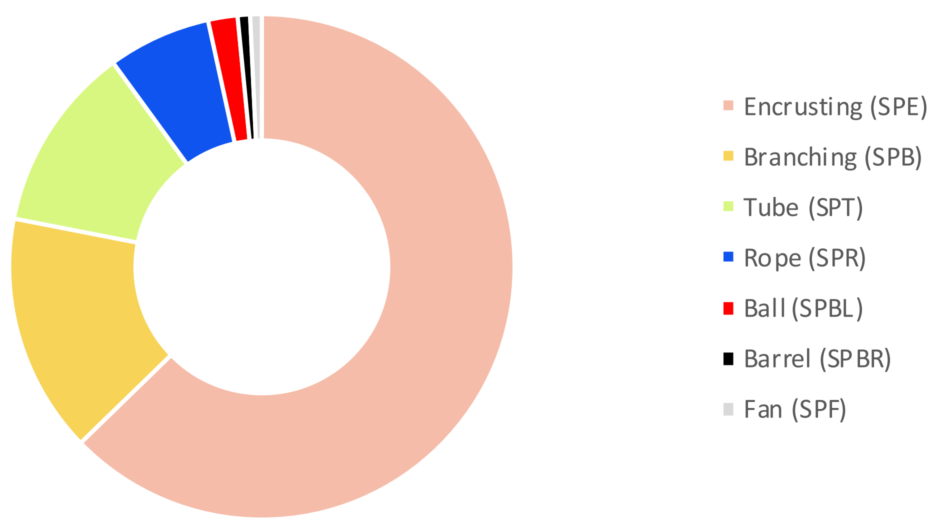



***Figure. 3.1.30***. Relative mean transect cover (%) of sponge categories along Dauin Reef survey sites.

Masapold North at 10m (Site 3) and Masapold at 10m (Site 14) show the greatest mean percent sponge cover, significantly higher than all other sites, with 11.32% and 10.0% respectively. Sites with the lowest sponge percent cover are Masapold at 5m (Site 15) and Masapold South at 5m (Site 13) which have less than 1% sponge cover (0.27% and 0.61% respectively) (***Table 7.3.1, Figure. 3.1.31***).

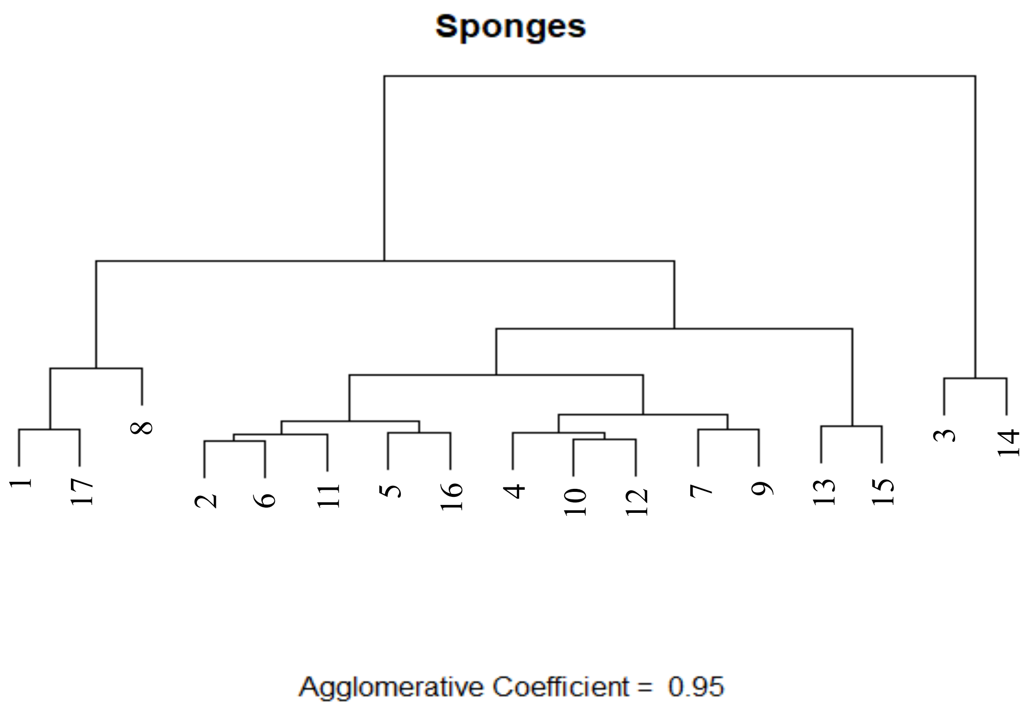



***Figure. 3.1.31***. Cluster dendrogram showing similarities between Sponge cover of different sites.

The percent cover of sponge along Dauin's reefs seems to vary from MPAs and non-MPAs (***Figure. 3.1.32***) especially for the following categories: Encrusting Sponge cover (MPAs: 72.98% and non-MPAs: 21.98%), Branching Sponge cover (MPAs: 12.98% and non-MPAs: 24.69%) and Tube Sponge cover (MPAs: 2.55% and non-MPAs: 49.14%). The other sponges' categories do not appear to show differences between MPAs and non-MPAs.

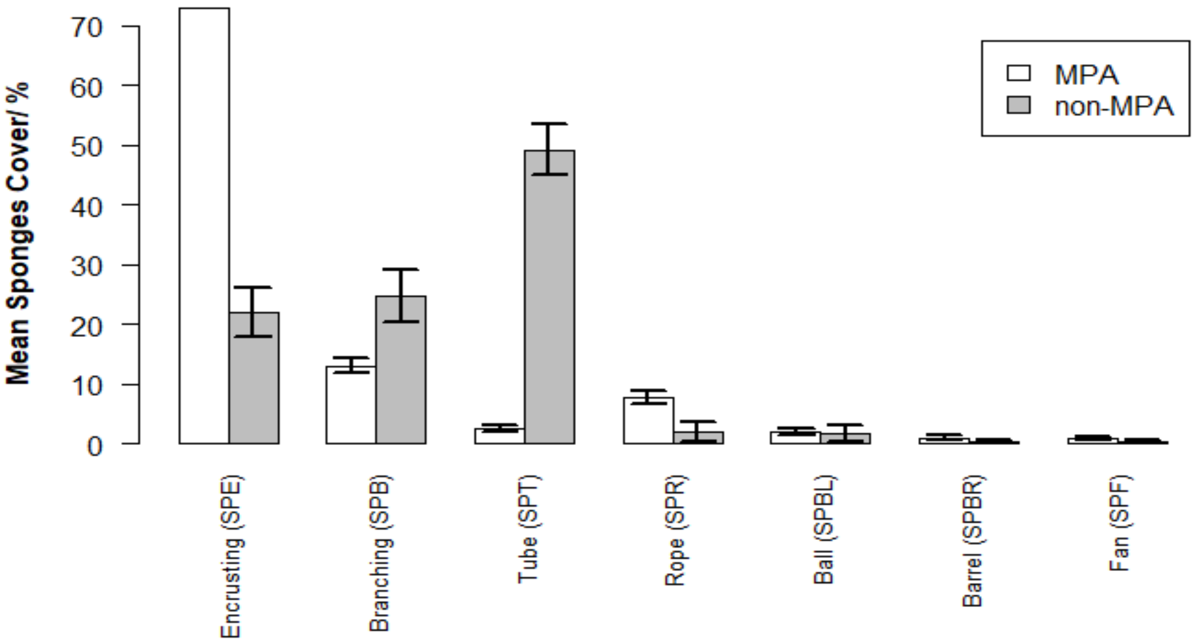



***Figure. 3.1.32***. Mean sponge transect cover (% ± SE) along Dauin Reef survey sites separated by MPAs / non-MPAs and type.

Within the sponge category, all seven growth forms studied show differences between sites (***Figure. 3.1.33***). Ball, barrel and fan sponges all have average percent covers of less than 0.1% each, hence differences are minor.

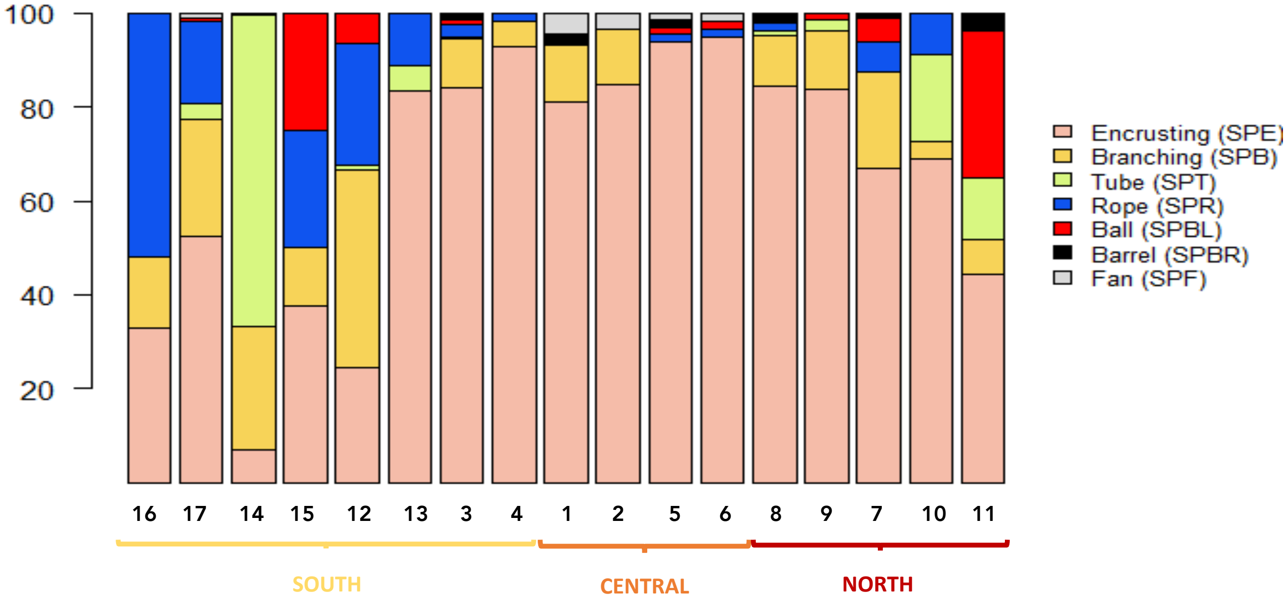



***Figure. 3.1.33***. Mean sponge categories cover (%) along Dauin Reef survey sites.

Encrusting Sponge (SPE) varies with site more than MPAs / non-MPAs. Masapold North at 10m (Site 3) and Lipayo at 10m (Site 8) has significantly greater encrusting sponge cover than all other sites, with an average of 9.52% and 6.01% respectively, followed by Poblacion District II at 10m (Site 1) and Masapold North at 5m (Site 4), with 4.42% and 3.31% respectively. Sites with the lowest encrusting sponge cover are Bulak at 10m (Site 11), Masapold South at 10 (Site 12) and 5m (Site 13), Masapold at 10 (Site 14) and 5m (Site 15) and Maayong Tubig at 10m (Site 16), which have percent covers of less than 1% (***Figure 3.1.33, Figure. 3.1.34***).

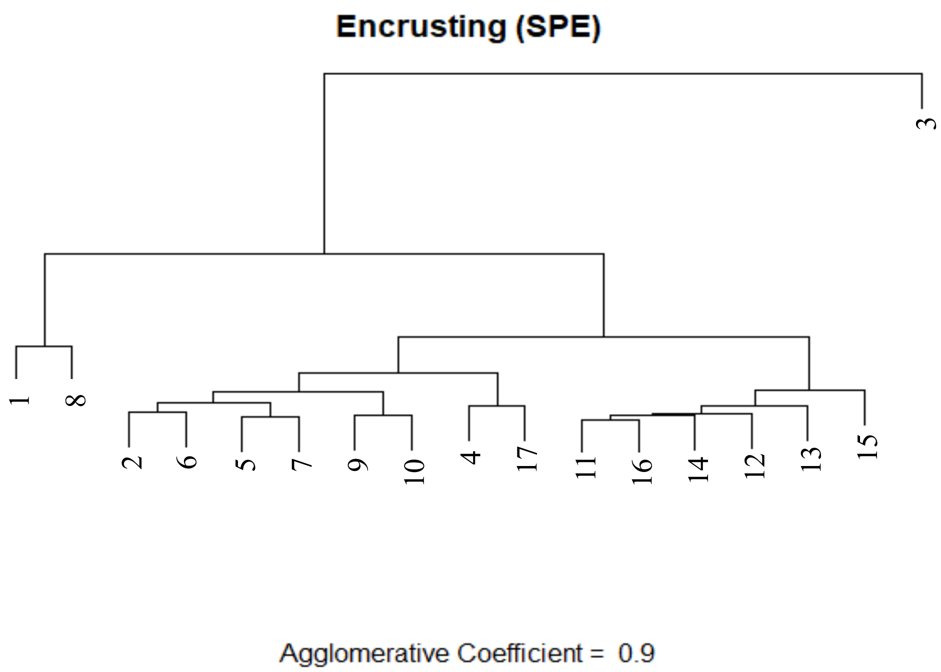



***Figure. 3.1.34***. Cluster dendrogram showing similarities between Encrusting Sponge cover of different sites.

Branching Sponge (SPB) is the second most represented sponge category along Dauin. Masapold at 10m (Site 14), Masapold South at 10m (Site 12), Maayong Tubig at 10m (Site 17) and Masapold North at 10m (Site 3) have significantly greater branching sponge cover than all other sites with 2.63%, 1.58%, 1.43% and 1.20% respectively. All other sites have less than 1% branching sponge cover with the exception of Masapold South at 5m (Site 13), Poblacion District I at 5 (Site 6) and 10m (Site 5) that have no records of branching sponge along the transects (***Figure 3.1.33, Figure. 3.1.35***).

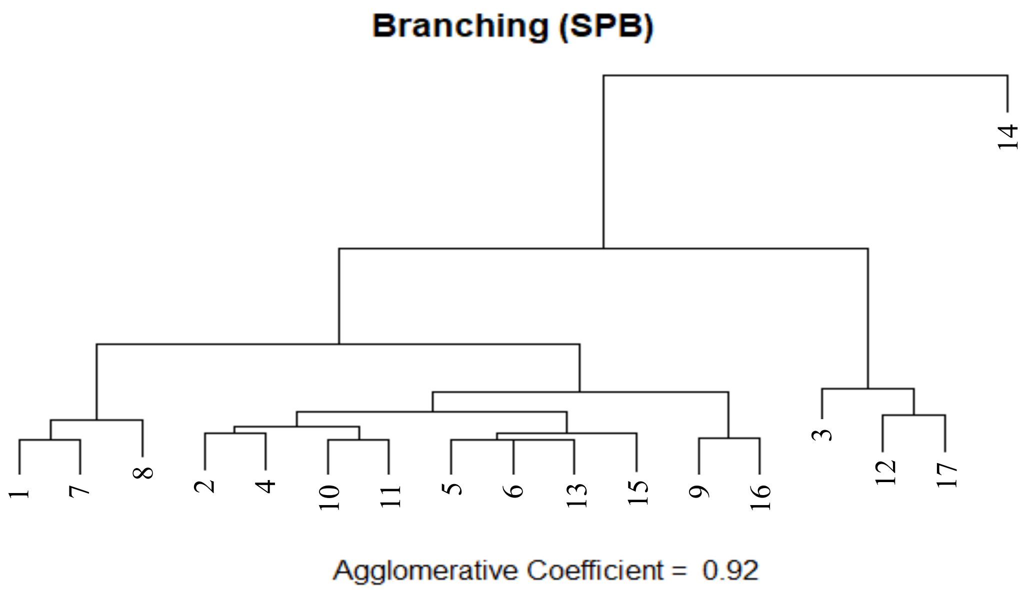



***Figure. 3.1.35***. Cluster dendrogram showing similarities between Branching Sponge cover of different sites.

Tube sponge (SPT) cover also varies with site. Masaplod at 10m (Site 14) is the site that has significantly higher tube sponge cover with 6.64%. All other sites have less than 1% cover, and only 9 out of 17 sites had records of tube sponge along the transect (***Figure 3.1.33, Figure. 3.1.36***).

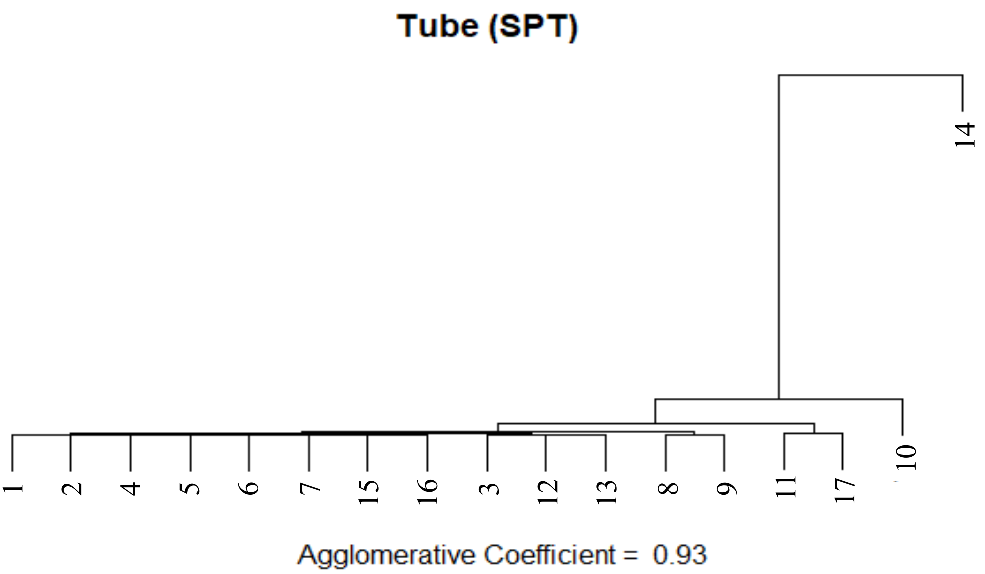



***Figure. 3.1.36***. Cluster dendrogram showing similarities between Tube Sponge cover of different sites.

Regarding Rope Sponge (SPR), Maayong Tubig at 5 (Site 16) and 10m (17) have significantly higher percent cover than all other sites, with 1.27% and 1.0% respectively. These sites are located on the south part of Dauin. All other sites have less than 1% rope sponge cover. Poblacion District II at 5 (Site 1) and 10m (Site 2), Lipayo at 5m (Site 9), Bulak at 5m (Site 11), and Masapold at 10m (Site 14) all had no records of rope sponge along the transect (***Figure 3.1.33***).

Ball sponge (SPBL) cover is not very widespread along the Dauin coast. However, a few sites have a small percentage of ball sponge on their reefs: Bulak at 5m (Site 11), Masapold South at 10m (Site 12) and Black Diamond at 10m (Site 7) with 0.57%, 0.23% and 0.17% respectively. Only 9 out of 17 sites had records of tube sponge along the transect (***Figure 3.1.33***).

Barrel sponge (SPBR) change cover is again site specific; for all sites along Dauin this sponge type is recorded only with less than 0.15%. Lipayo at 10m (Site 8) is the site that have recorded the higher barrel sponge percent cover (***Figure 3.1.33***).

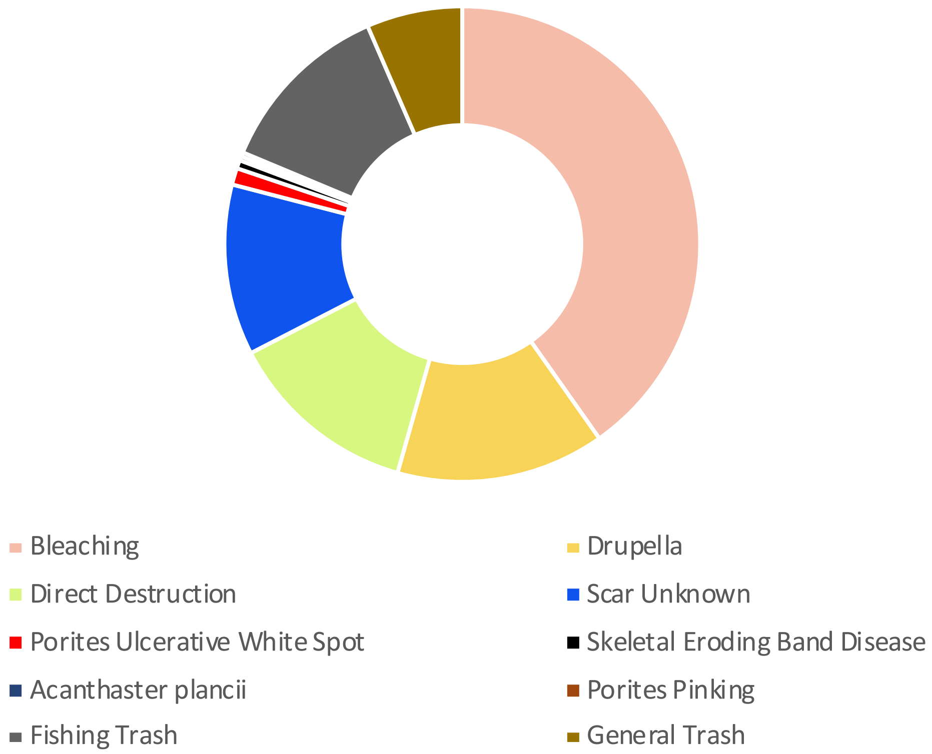
Fan sponge (SPF) cover is only recorded in the central part of Dauin. Looking at site, only 7 out of the 17 survey sites had recorded presence of fan sponge. Of those that did, mean percent cover was no more than 0.25%. Poblacion District II at 10m (Site 1) has significantly higher fan sponge percent cover than all other sites, with 0.23%. All other sites have less than 0.1% fan sponge cover (***Figure 3.1.33***).

### 3.1.6 Seagrass

Seagrass was recorded along the transects of 6 survey sites, although it accounts for on average only 2.11% of the benthic composition of Dauin's reefs, as 13 of 17 sites show negligible percent seagrass cover (<1%). The highest seagrass percentage cover was recorded at Masapold at 5m (Site 15), at 22.17%, significantly higher than all other sites (***Table 7.3.1***). Other sites with significantly greater average percent cover of seagrass include Black Diamond at 10m (Site 7) with 7.43%, Lipayo at 5m (Site 9) with 2.91% and Masapold at 10m (Site 14), with 1.80%.

### 3.1.7 Hydroids

Hydroids represent a minor component of the benthic composition of Dauin's reefs, averaging a coverage of 0.81%. Most sites showed negligible hydroid coverage (<1%), although the sites with highest percentage cover, Bulak at 10m (Site 10) and Poblacion District II at 10m (Site 1),




difference between protected and unprotected zones (*Figure. 3.1.3*, *Figure 3.1.4*, **Table 3.1.1**).

***Figure. 3.2.1***. Relative occurrence of recorded impacts along Dauin Reef for 2019 survey year, where the colour gradient from dark to light represents descending percentiles.

## 3.2 Reef Impacts & Coral Mortality

A total of 353 impacts were recorded throughout the survey year (wet and dry season) across Dauin's reefs: 301 impacts in MPAs and 52 in non-MPAs, an average of 21.5 and 17.3. The ***figure 3.2.1*** represents these impacts per the causing agent.

When examining counts per replicate, an average of 10.40 impacts was seen across the entire survey year. Coral bleaching has been the most prevalent impact during the research year with an average of 8.35 impacts per transect, follow by trash (general and fishing reunited) with 3.88, *Drupella spp*. feeding activity with 2.94, direct destruction with 2.71 and unknown scarring with 2.41 (data not shown).

When comparing reef impacts between protected and unprotected zones, bleaching incidences seems to be higher in MPAs (mean incidence of 9.21/100m2) than non-MPAs (mean incidence of 4.33/100m2; ***figure. 3.2.2)***. No differences were observed for the other categories. Diseases such as Porites Ulcerative White Spot, Skeletal Eroding Band Disease or Porites Pinking as well as *Acanthaster plancii* were all found only in MPAs with a negligeable incidence.

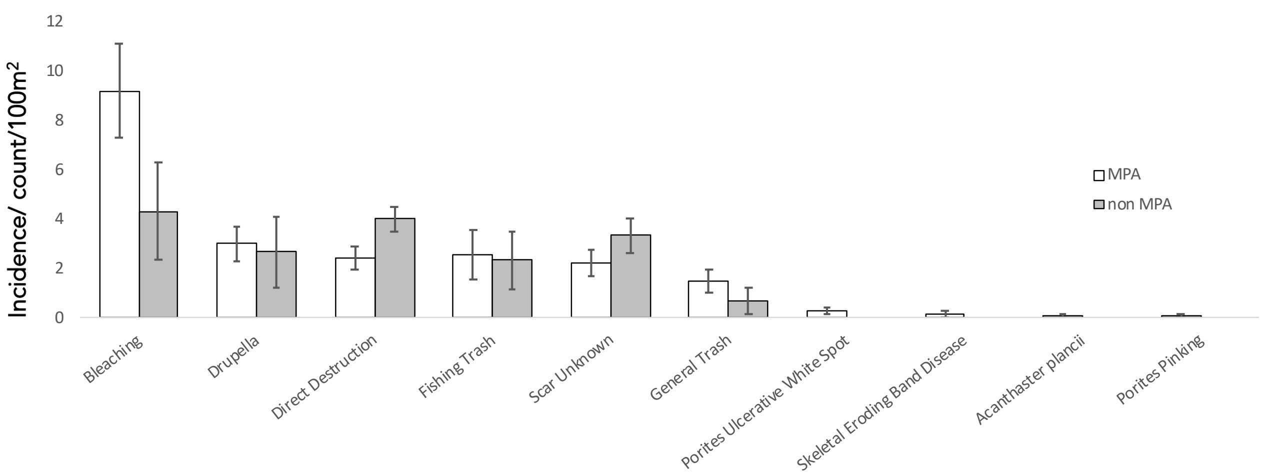



***Figure. 3.2.2***. Mean incidence (count/100m$^2$ ± SE) of recorded impacts along Dauin Reef separated by MPAs and non-MPAs.

### 3.2.1 Impacts nature per site

Most sites show consistent counts of impacts, averaging 21.5 per 100m2 transect, although a few sites have notably higher or lower impact counts; Lipayo at 10m (Site 8) and Maayong Tubig at 5m (Site 16) have both 38 per 100m2 and 100% of affected area, whereas Poblacion District II at 10m (Site 1) and Bulak at 5m (Site 11) have 8 and 10 per 100m2 respectively with an average of 73% and 96% of corals affected (**Figure. 3.2.3**).

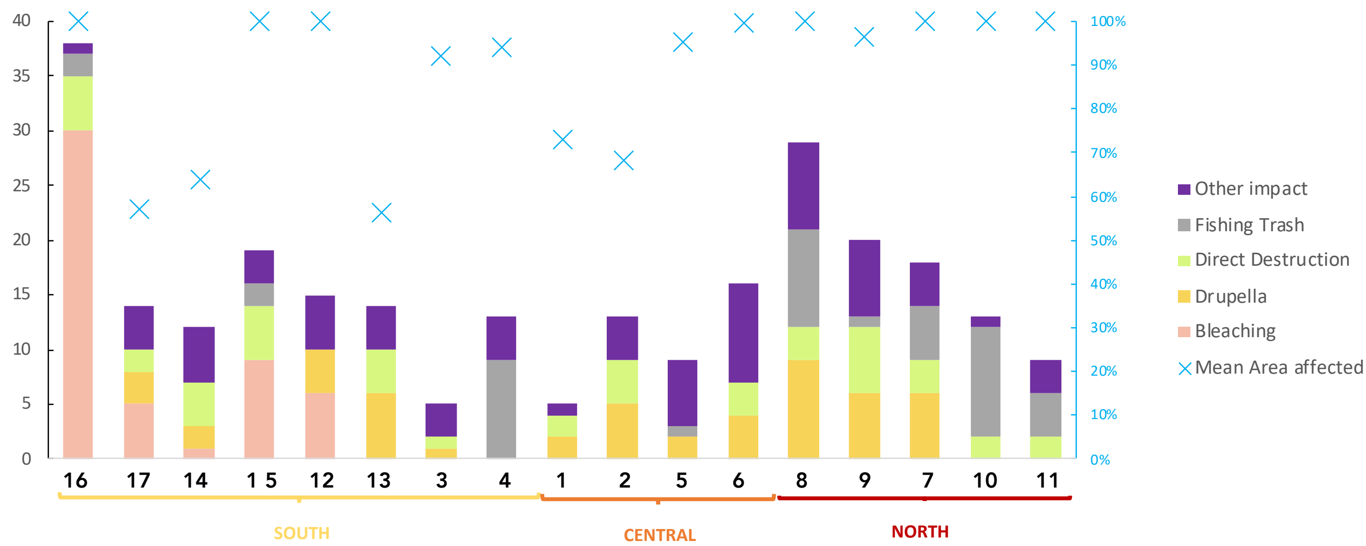



***Figure. 3.2.3*** Mean incidence (count/100m$^2$) and mean affected area (Colony Size Affected) along Dauin Reef survey sites.

Bleaching remained consistent throughout the year across Dauin's reefs; the season had no significant effect on this incidence during the survey year (data not shown).  A total of 51 mean incidences of bleaching were reported. Geographically, all bleaching impacts recorded are located on the southernmost part of Dauin: the highest frequency was reported in Maayong Tubig at 5m (Site 16) with 30 counts/100m2 (***Figure 3.2.3***).. Lower frequencies are reported in Masapold at 5m (9 counts/100m2, site 15), Masapold South at 10m (6 counts/100m2, site 12), Maayong Tubig at 10m (5 counts/100m2, site 17) and Masapold at 10m (1 counts/100m2, site 14).

Drupella spp. feeding activity was recorded 50 times during the study. This impact has significantly higher incidences in Lipayo at 10m (Site 8) with 9 recorded, follow by Masapold South at 5m (Site 13), Lipayo at 5m (Site 9), and Black Diamond at 10m (Site 7); all with 6 counts recorded for each site (Figure 3.2.3). All other sites have five or less than five impacts recorded. Maayong Tubig at 10m (Site 17), Masapold at 5m (Site 15), Masapold North at 10m (Site 4) and Bulak at 10 (Site 10) and 5m (Site 11) have no Drupella spp. Feeding activities on their reef.

Direct destruction affects all sites with an average of 46 incidences per site, excepted for Masapold South at 10m (Site 12), Masapold North at 5m (Site 4) and Poblacion District I at 10m (Site 5) where this impact was not observed (***Figure 3.2.3***). Sites with higher impacts recorded are Lipayo at 5m (Site 9) with 6 counts/100m2, follow by Masapold at 5m (Site 15) and Maayong Tubig at 5m (Site 16) with 5 counts per transect recorded for both sites. All other sites have less than 5 direct destructions incidences.

All sites in the Northern part of Dauin coast had fishing trash (***Figure 3.2.3***). In the Southern part, we reported fishing trash in 3 sites, with an average of 9 impact /100m$^2$ in Masapold North at 5m (site 4). In central Dauin, fishing trash is only reported at Poblacion District at 10m with a mean incidence of 1 impact /100m$^2$.

Other impacts include unknown scarring and diseases that are more genera specific. We reported 72 incidences (***Figure 3.2.3***). They were found distributed all along the Dauin coast with Poblacion at 5 (Site 6) and 10m (Site 5), Lipayo at 5 (Site 9) and 10m (Site 8) as the majors sites with 9, 5, 7 and 8 incidences recorded, respectively. All other sites count five or less than five unknown scarring and/or diseases..

For most of the sites (12 out of 17), when we observed an impact on a coral located on the transect, the impact affected the whole colony (90-100%, ***Figure 3.2.3***, blue crosses). For the remaining five sites (17, 14, 13, 1 and 2), the impact affected more than half of the colony.

All impacts cannot be measurable; thus the percentage of affected area is not available for all impacts. For the impact that could be measured, an average of 88% of the corals are affected.

The **figure 3.2.3** also show that the area affected by the impact is not correlated to the number of different impacts found on the colony. For example, four different impacts were found in Maayong Tubig at 10m (site 17) where 60% of the colony is affected; while 95% of the colony was affected by only two different impacts in Masapold North at 10m (site 4).

### 3.2.2 Genera Affected by the impacts

We then detailed the nature of the impacts found in the five most impacted coral observed. Acropora is the most impacted genera recorded with 82 impacts listed, followed by Fungia, Pocillopora, Porites and Cyphastrea with 60, 39, 15 and 12 impacts respectively (**Figure. 3.2.4**). The coral genera were not subject to all of the impacts and there is a different pattern for each genera, excepted for Fungia and Cyphastrea that are mainly affected by bleaching.

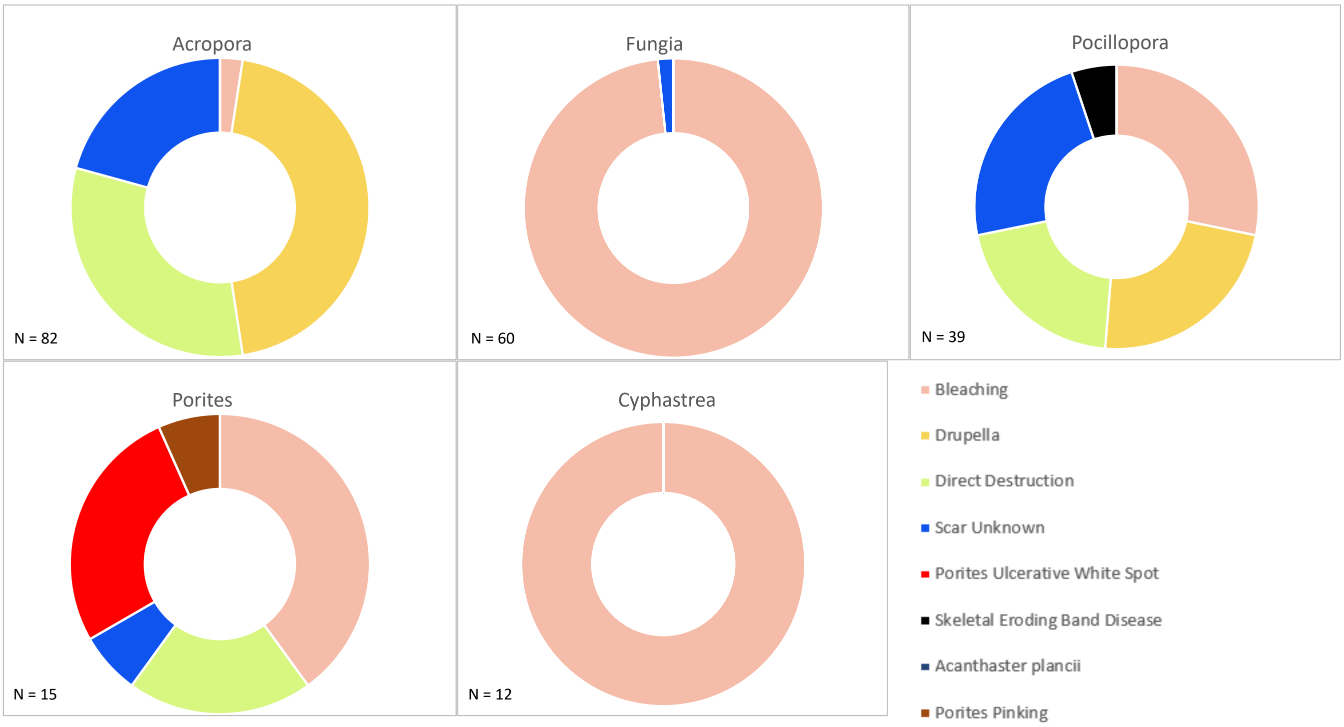



***Figure. 3.2.4*** Relative incidence of different impacts recorded on five most frequently impacted coral genera along Dauin Reef. n refers to the total number of impacts recorded for the genus for the survey year.

Acropora is affected mostly by *Drupella spp*. feeding activity with 37 impacts registered, followed by direct destruction, unknown scarring and bleaching with 26, 17 and 2 impacts respectively ***(Figure 3.2.4***).. Fungia is impacted almost exclusively by bleaching with 59 impacts recorded, and only one unknown scarring. Pocillopora is mostly impacted by bleaching (11 impacts recorded), unknown scarring and *Drupella spp*. feeding activity with 9 impacts each, direct destruction with 8 impacts and disease (predominantly Skeletal Eroding Band Disease) with 2 impacts. Porites is mostly recorded impacted by bleaching with 6 impacts recorded and diseases (Porites Pinking and White Syndrome Disease) with 3 impacts recorded, and a few counts of direct destruction and unknown scarring. Cyphastrea is exclusively impacted by bleaching with 12 recorded.

-Regarding the other coral genera affected, Anacropora and Echinopora are mostly impacted by unknown scarring. Galaxea is impacted by bleaching, *Drupella spp*. feeding activity and unknown scarring. Stylophora is mostly impacted by bleaching, *Drupella spp*. feeding activity and unknown scarring. Goniastrea, Goniopora, Pavona, Favia, Seriatopora and Hydnophora are impacted almost exclusively by bleaching, with a few counts of disease, *Drupella spp*. feeding activity, unknown scarring and direct destruction. Platygyra is exclusively impacted by bleaching as well as Cyphastrea, Favites, Montastrea, Ctenactis, Leptastrea, and Asteropora (data not shown). For the five most common corals, we then investigated the incidence of the impacts and area covered in MPA and non-MPAs.

Acropora appears to be the only genera more affected by impacts in non-MPAs than in MPAs with 6.33 mean incidence per site against 4.50 in MPAs (***Figure 3.2.5***). However this must be confirmed statistically, and additional facts have to be taken into account. Indeed, the area affected in MPAs is higher than in non-MPAs with 48% of Acropora corals impacted vs 28%. The affected percentage is not available for all the impacts listed, and Acropora corals are much more abundant on unprotected sites than protected sites even if its distribution is site specific (***Figure. 3.1.6***, ***Figure 3.1.7***).

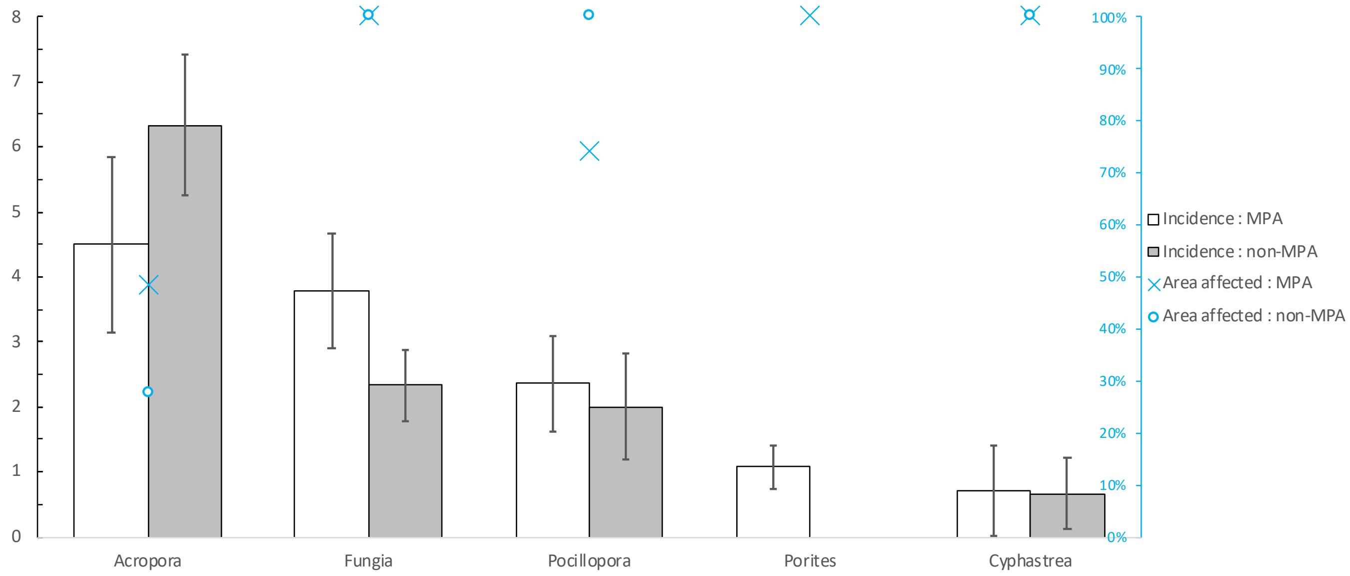



***Figure. 3.2.5***. Mean incidence (count/100m² +/- SE) of the impacts and size of the affected area for the five most commonly affected coral genera separated by MPA / non-MPA.

Impacts on Porites were only recorded in MPAs with an affected percentage of coral of 100%. However, the presence of Porites in non-MPAs was low, thus these results are to be further confirmed. The incidence of impacts also appears to be higher in MPAs for Fungia (mean incidence of 3.79 vs 2.33; **Figure 3.2.5**).

Two genera appear to be equally impacted in MPAs and non-MPAs: Pocillopora (mean incidence per site in MPAs: 2.36 vs 2.00 in non-MPAs; area affected 74% vs 100%) and Cyphastrea (mean incidence of 0.71 in MPAs vs 0.67 in non-MPAs; 100% of the area affected).

## 3.3 Reef Fish Community Structure

### 3.3.1 Fish Families

A total of 19684 fish were recorded during the survey year, with a total biomass of 401kg of fish and a species richness of 244 within 36 fish families. This equates to an average of 579 fish per 250m$^2$ transect, weighing 11,76kg, and with an average species richness of 40 (***Figure. 7.3.3***).

Species richness for MPAs came in at 219, whereas for non-MPAs, 95 species were recorded. Equating this to an average across one 250m$^2$ transect, MPAs had an average fish abundance of 581, with an average biomass of 13kg, and a species richness of 31. Conversely, in non-MPAs, an average of 568 fish were recorded per 250m$^2$ transect, weighing 5kg, with a species richness of 31.

Species diversity is fairly consistent across sites, ranging from 46 to 85 species per site. Poblacion District II at 10m (Site 1) shows the greatest species diversity with 85 species recorded, follow by Maayong Tubig at 10m (Site 17) with 80 species, Poblacion District I at 10m (Site 5) with 72 species and Masapold North at 5m (Site 4) with 70 species. Maayong Tubig at 5m (Site 16), Masapold at 5m (Site 15) and Bulak at 5m (Site 11) are the sites with less species diversity recorded; 46, 47 and 48 respectively.

Pomacentridae accounts for 70.23% of fish by abundance (***Figure. 3.3.1***), and 21.29% of fish biomass (**Figure 3.3.2**). The next most abundant families are Labridae, Acanthuridae, Serranidae, and Caesonidae, accounting for 9.17%, 3.50%, 3.43% and 1.97% of the fishes respectively (***Figure. 3.3.1***). 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 comprise 93% of the Serranidae family by abundance. In terms of biomass, Pomacentridae is followed by Lutjanidae, Serranidae, Labridae, Acanthuridae and Caesionidae accounting for 21.29%, 9.67%, 9.16%, 7.63%, 7.20% and 6.76% respectively (***Figure. 3.3.2***).

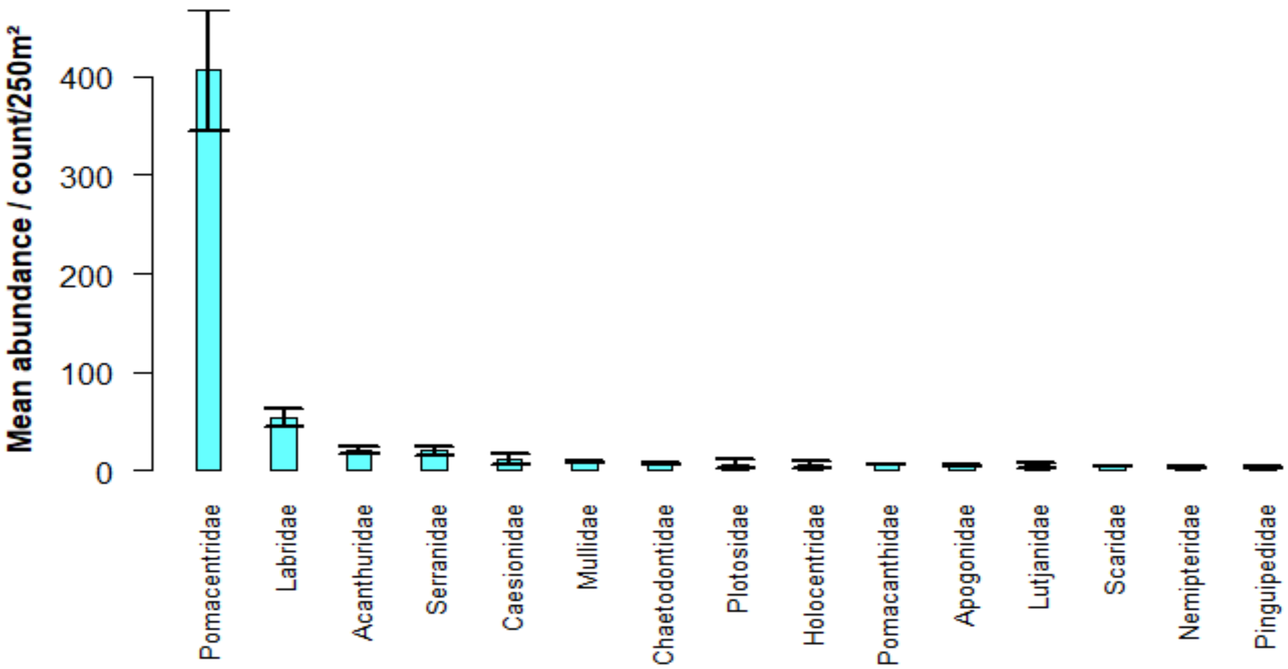



***Figure. 3.3.1***. Mean abundance per transect (count/250m$^2$ ± SE) of the 15 most abundant fish families recorded along Dauin Reef for the survey year.

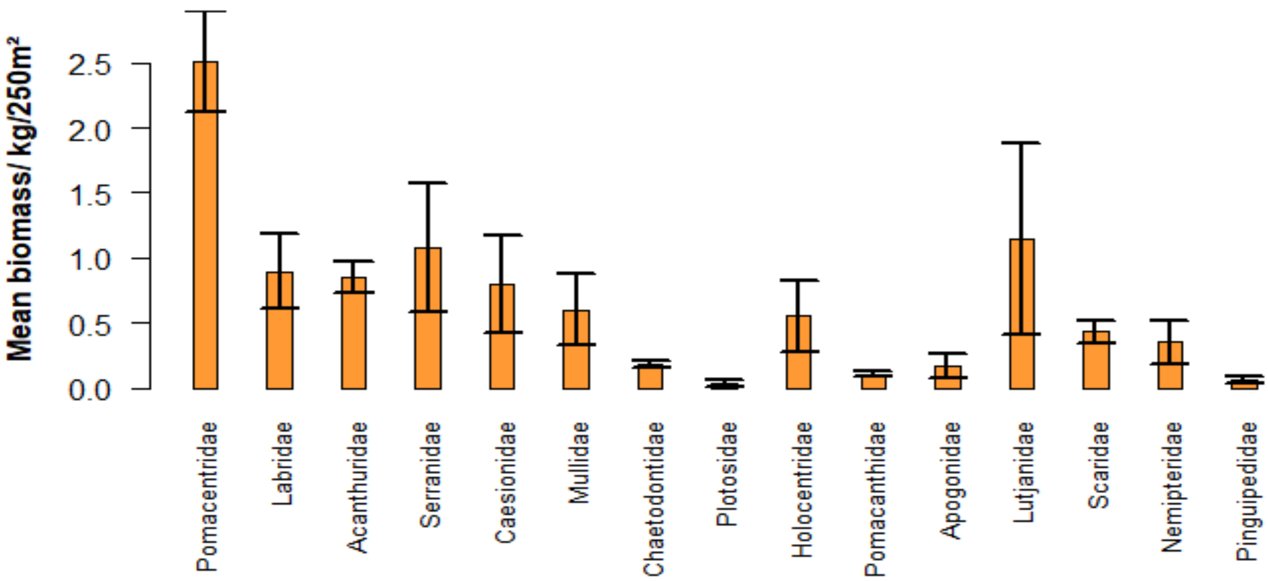



***Figure. 3.3.2***. Mean biomass per transect (kg/250m$^2$ ± SE) of the 15 fish families that contribute the most to biomass, recorded along Dauin Reef for the survey year.

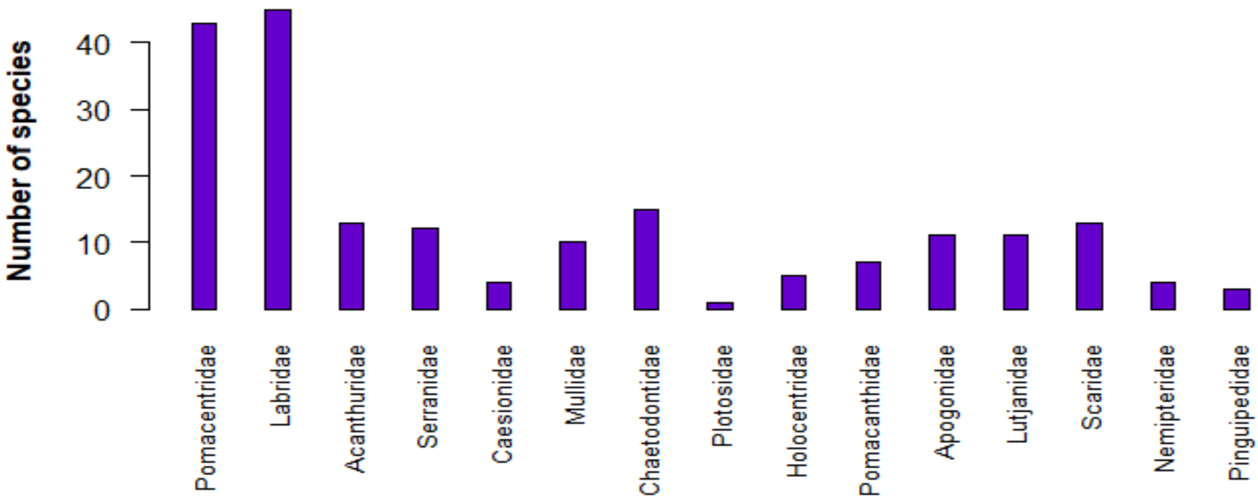



***Figure. 3.3.3***. Total species richness of all fish families recorded along Dauin Reef for the survey year.

The species accumulation curve has not yet begun to a plateau (***Figure. 3.3.4***), suggesting that the fish communities among Dauin's reefs have not yet been surveyed representatively after the 34 replicates of the survey year.

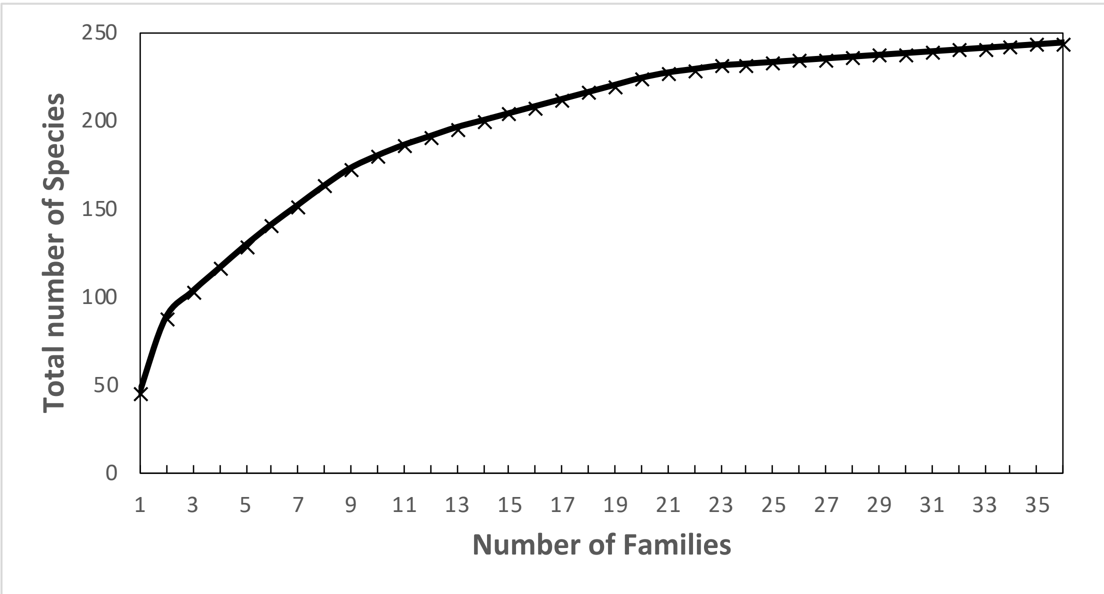



***Figure. 3.3.4***. Species Accumulation Curve for the cumulative total number of species recorded across Dauin reef survey sites.

Some families listed along Dauin present many species. Graphically, out of three families, 103 species are counted and this number doubles very quickly: 204 species out of 15 families (***Figure. 3.3.4***). For the most abundant family, Labridae, a total of 45 species is counted out of the 504 existing (Parenti & Randall, 2000). Pomacentridae accounts for 43 species out of the 360 that exist and finally, 15 species of Chaetodontidae are found out of the 129 listed in the world.

Examining trends as averages per transect, analysis of similarities (ANOSIM) revealed a weak difference (p=0.034, R=0.08) between the abundance of fish species between MPAs and non-MPAs. However, when analyzing biomass, no significant difference was seen between protected and unprotected areas (p=0.868, R=-0.045). No significant differences were observed in community composition between the two survey depths (5 and 10m), when examining abundance (p=0.281, R=0.021) or biomass (p= 0.8681, R =-0.04584). These results are shown clearly in the NMDS plot showing MPAs / non-MPAs and Depth for fish biomass (***Figure. 3.3.5***).

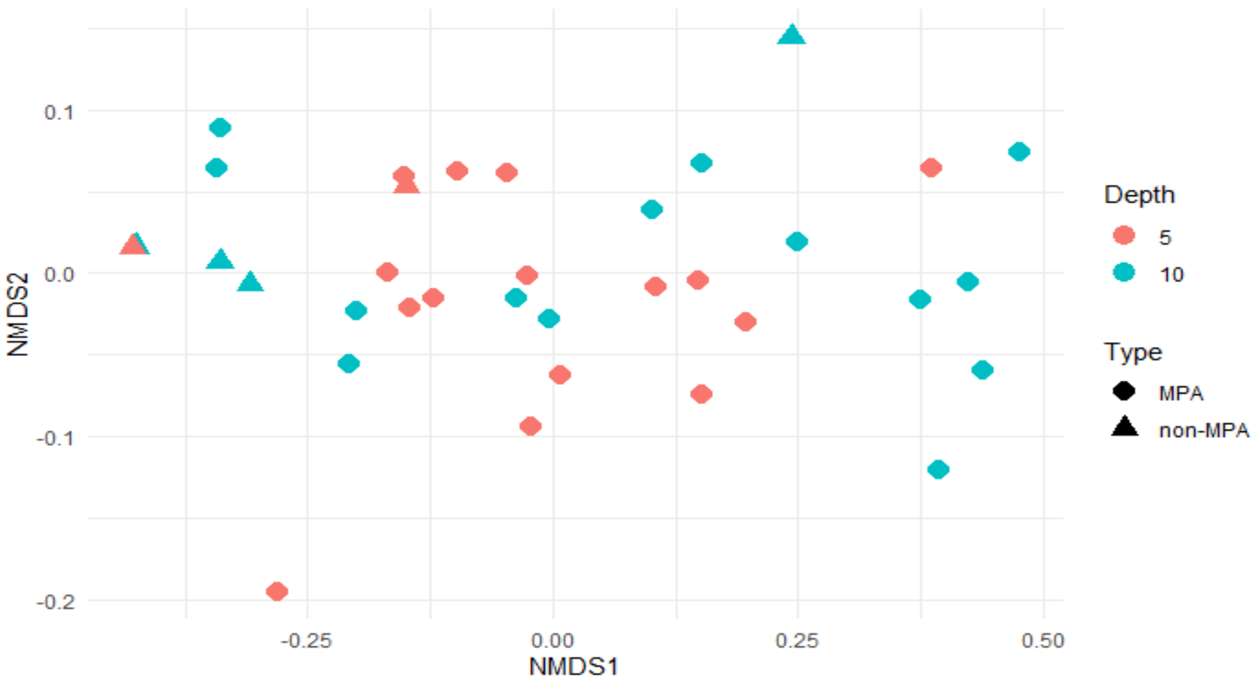



***Figure. 3.3.5***. Non-metric multidimensional scaling (NMDS) plot of fish biomass weighted communities for each depth in MPAs and non-MPAs.

Looking at the IUCN Red List Categories of the recorded species from the survey year, the majority of species recorded are considered species of Least Concern (170 species), followed by species that are Not Evaluated (59 species) (***Figures 3.3.6 and 3.3.7***).

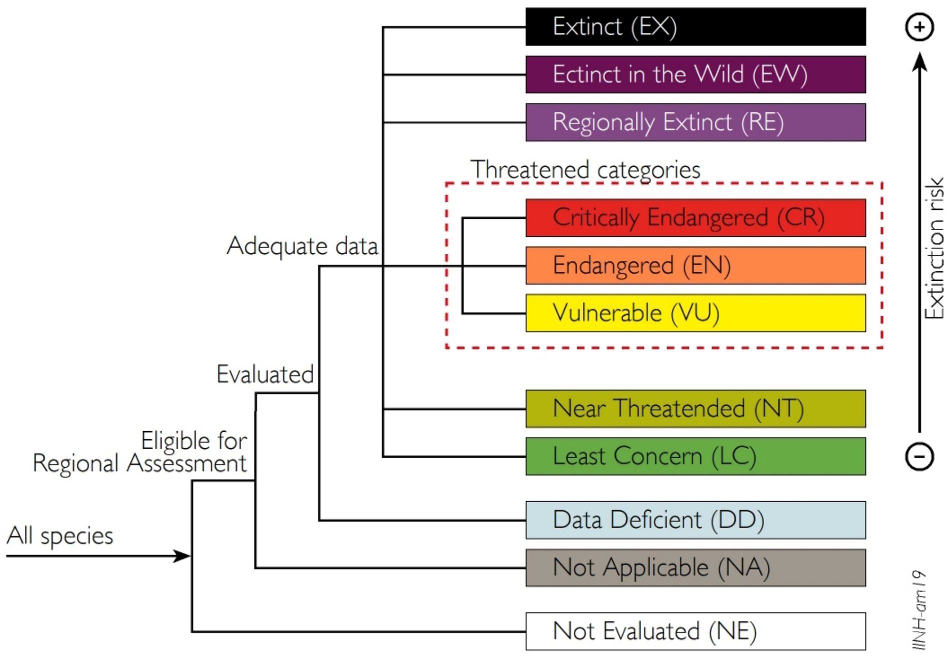



***Figure. 3.3.6***. Structure of IUCN Red List categories.

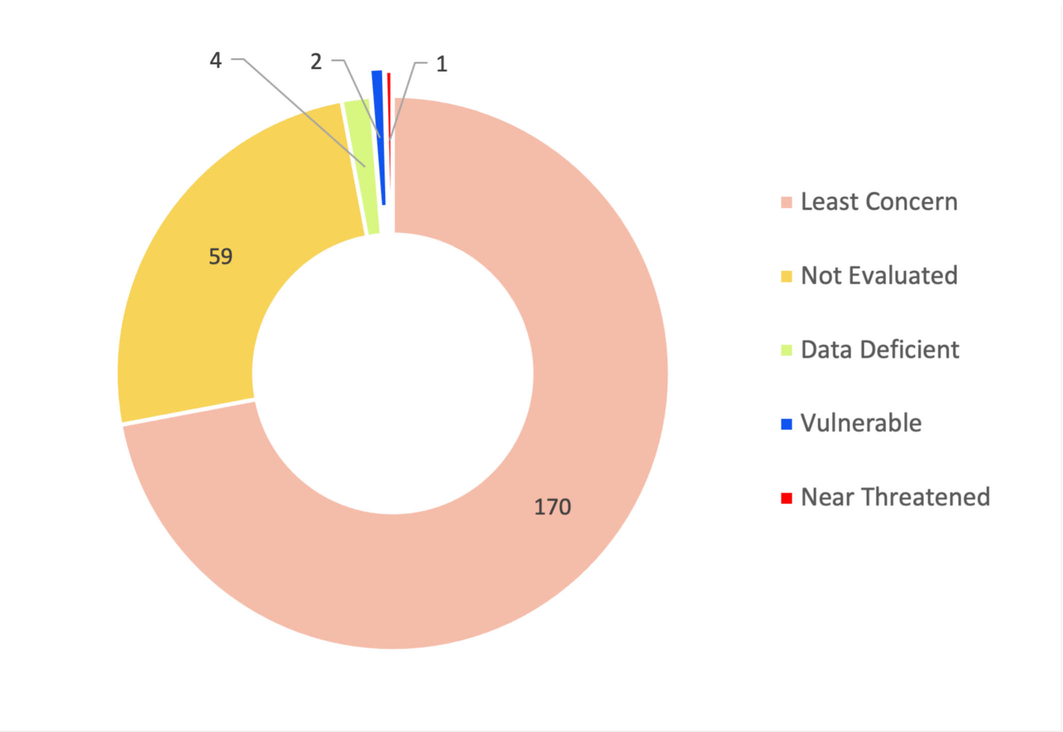



***Figure. 3.3.7***. Relative number of species within each IUCN Red List Category for the survey year. Highlighted outside of pie are Vulnerable and Near Threatened species

Four of the species recorded during the study are currently considered Data Deficient: *Aeoliscus strigatus* (Razorfish), *Chaetodon ocellicaudus* (Spot-tailed Butterflyfish), *Lutjanus xanthopinnis* (Yellowfin Snapper), *Siganus unimaculatus* (Blotched foxface). Only one species recorded during the survey year is listed as a Near Threatened species: *Scarus hypselopterus* (Yellow- tail Parrotfish), which was recorded four times during the wet season (no records during the dry season), twice at Poblacion District I at 5m (Site 6), once at Poblacion District II at 5m (Site 2) and once at Masaplod South at 10m (Site 12), all MPAs. Two of the species recorded during the year are categorized as Vulnerable: *Oxymonacanthus longirostris* (Orange spotted filefish), and *Epinephelus fuscoguttatus* (Brown-marbled grouper). *O. longirostris* was recorded twice during the survey year, both at Poblacion District I at 5m (Site 6) during the dry season. *E. fuscoguttatus* was also recorded one during the survey year: during wet season at Masaplod North at 10m (Site 3), both MPAs.

The ***Figure. 3.3.8*** indicates which fish categories were found by sites. Species categorized as « Near Threatened » and « Vulnerable »were all found in protected sites. A non-transect appearance of the species *E. fuscoguttatus* (classified as Vulnerable) was noted on the unprotected site of Black Diamond at 10m (Site 7).

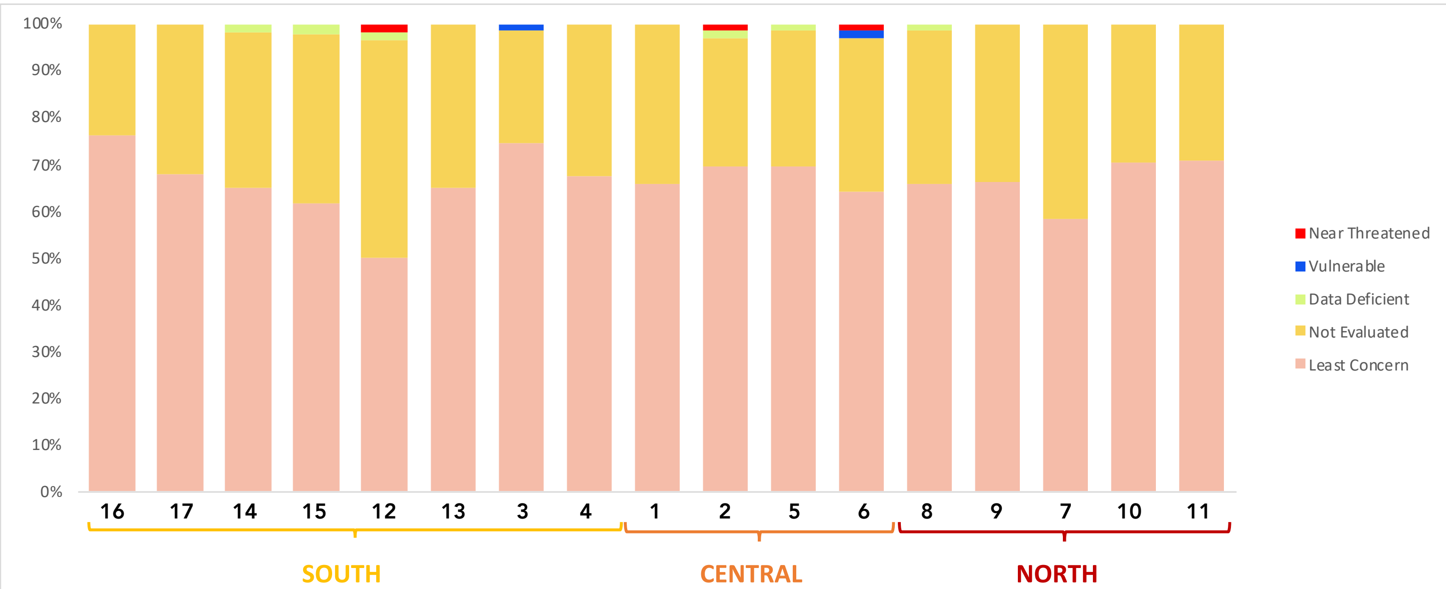
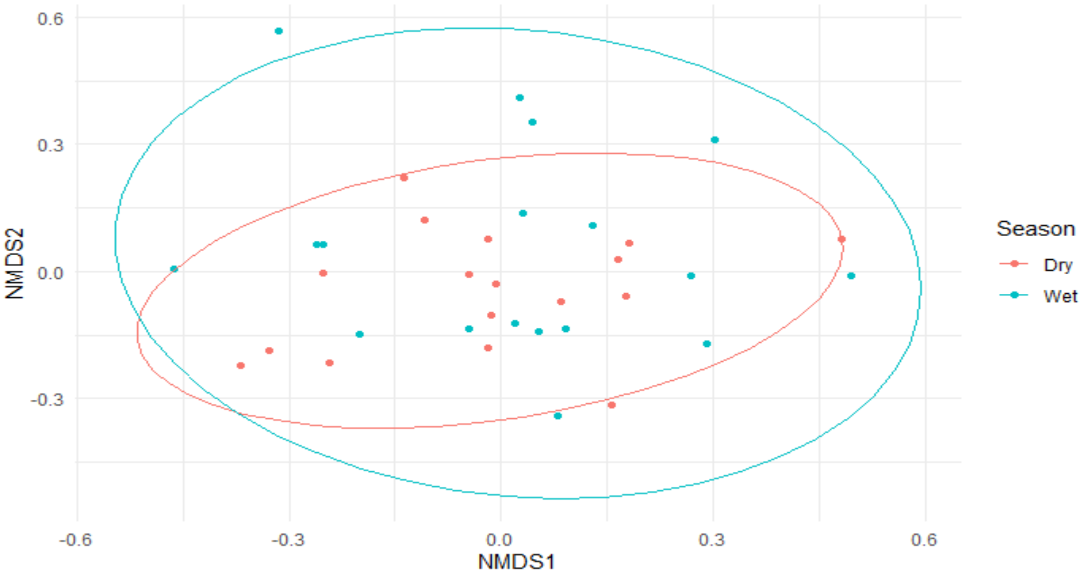


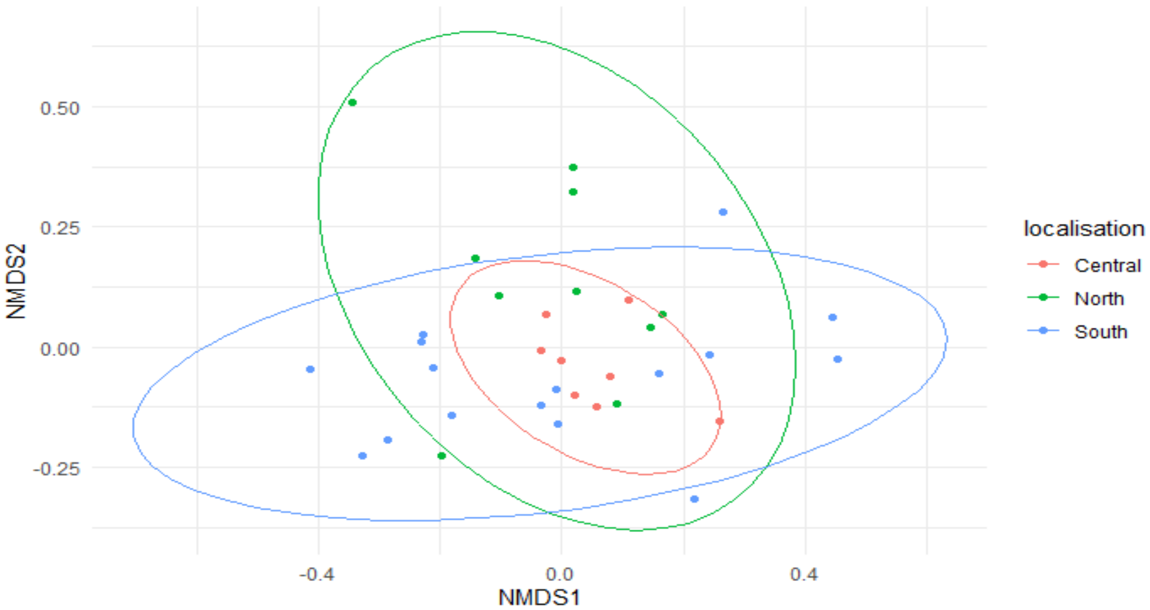

***Figure. 3.3.8***. Relative number of species (%) within each IUCN Red List Category along Dauin Reef survey sites.

Non-metric multidimensional scaling (NMDS) indicates that the fish communities are quite similar between the seasons (***Figure. 3.3.9a***), location along the coastline (***Figure. 3.3.9b***), depth of the measure (***Figure. 3.3.9c***) and amount of coral cover (***Figure. 3.3.8d***). However, when comparing the fish communities in MPAs vs. non-MPAs, the ellipses do less overlap (***Figure. 3.3.9e***). This suggests differences in the fish communities between the two study zones. However, as obvious in this figure, non-MPAs are underrepresented and further measures are necessary to conclude.

a)




b)



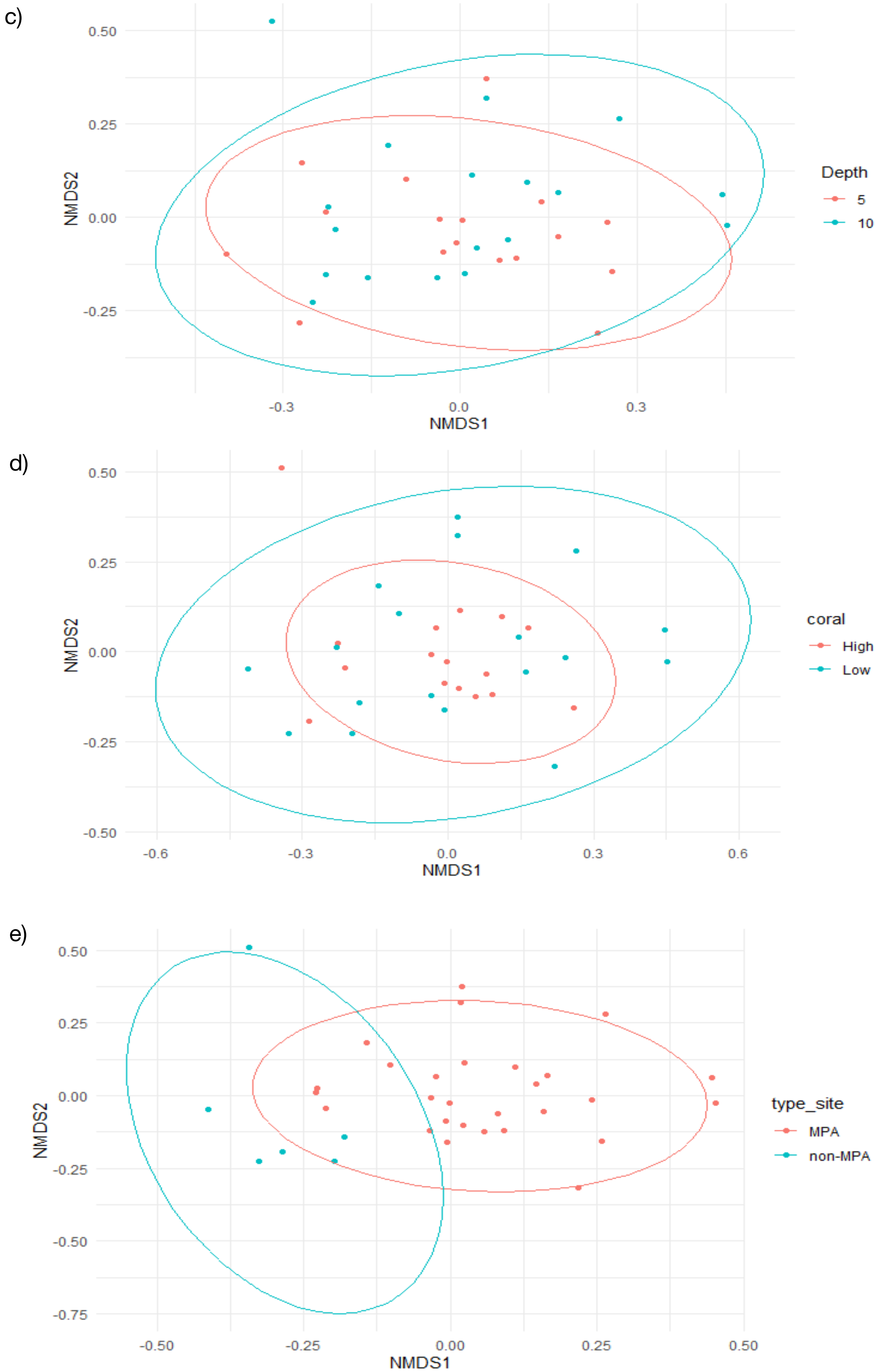



***Figure. 3.3.9***. Non-metric multidimensional scaling (NMDS) of fish biomass weighted communities according to a) season, b) location along the Dauin coastline, c) depth, d) coral cover, and e) protected and unprotected sites.

### 3.3.2 Trophic Structure

Examining relative fish abundance and biomass by trophic groups, the Herbivore & Planktivore group is the most abundant across Dauin's reefs, followed by exclusive Planktivores and Omnivores, with average abundances of 182, 170 and 136 per 250m$^2$ transect (***Figure. 3.3.10***). All other trophic groups showed average abundances of less than 30 per transect.

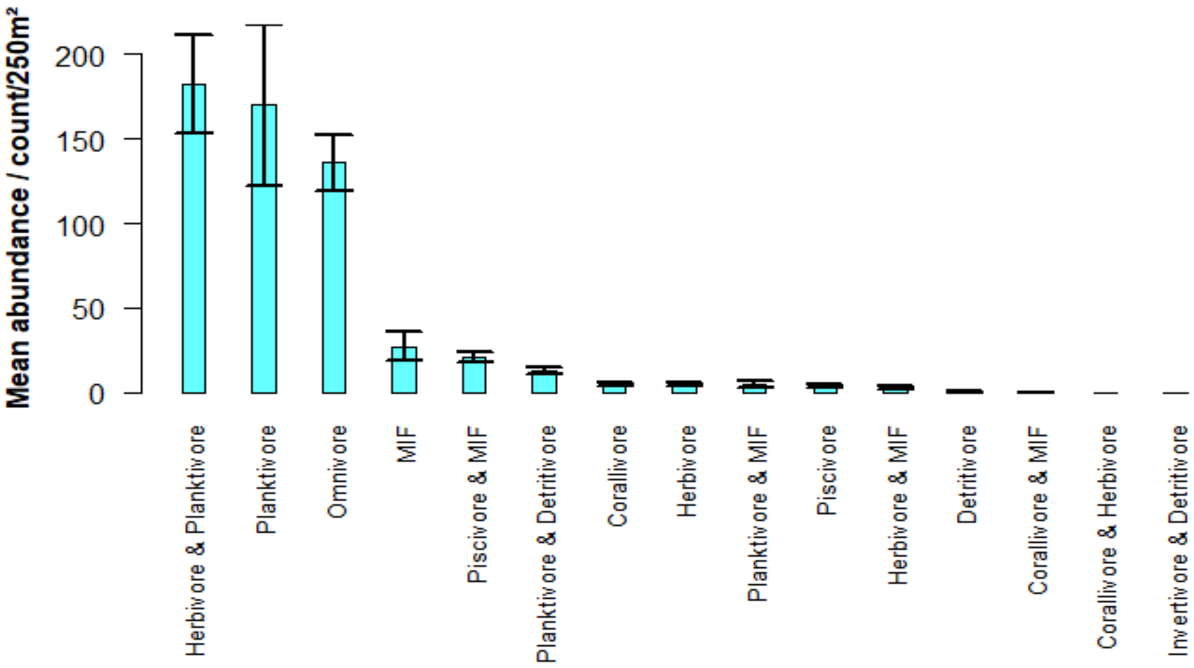



***Figure. 3.3.10***. Mean abundance per transect (count/250m$^2$ ± SE) of fish functional groups recorded along Dauin Reef for the survey year. MIF: Mobile Invertebrate Feeder.

Biomass trends are similar (***Figure. 3.3.11***), with the same top three trophic groups: exclusive Planktivores, Omnivores, Herbivores & Planktivores, with 2.56kg, 2.45kg and 2.08kg respectively. Piscivore & Mobile Invertebrate Feeders (MIF) contribute much more to community structure in terms of biomass than abundance, with biomass close to that of the Herbivore & Planktivore group, at 2.06kg. The lowest contributors to community structure in terms of both abundance and biomass are the Corallivore & Herbivores, the Corallivore & MIFs, and exclusive Detritivores (***Figure. 3.3.11***).

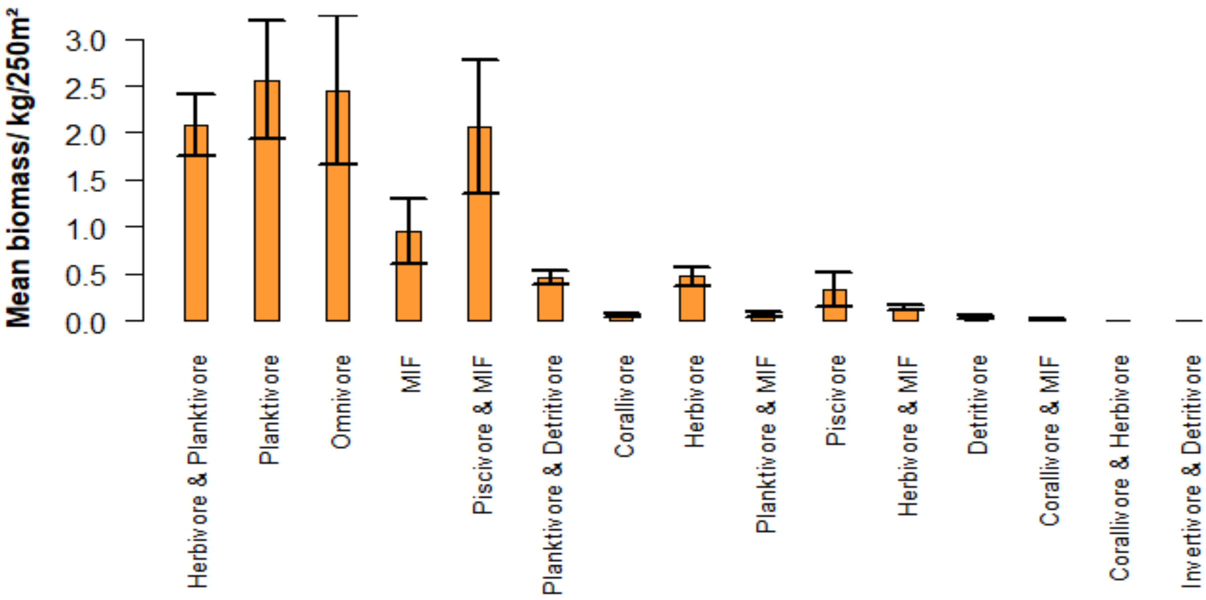



***Figure. 3.3.11***. Mean biomass per transect (kg/250m$^2$ ± SE) of fish functional groups, recorded along Dauin Reef for the survey year. MIF: Mobile Invertebrate Feeder.

The trends in most abundant fish and highest contributors to biomass varies between sites, regardless of their protected or unprotected status (***Figures 3.3.12 and 3.3.13***).. The three most abundant trophic groups are the same in MPAs and non-MPAs, although in a different order; 1st Herbivore & Planktivore, 2nd Omnivore and 3rd Planktivore in non-MPAs, and 1st Herbivore & Planktivore, 2nd Planktivore and 3rd Omnivore in MPAs.

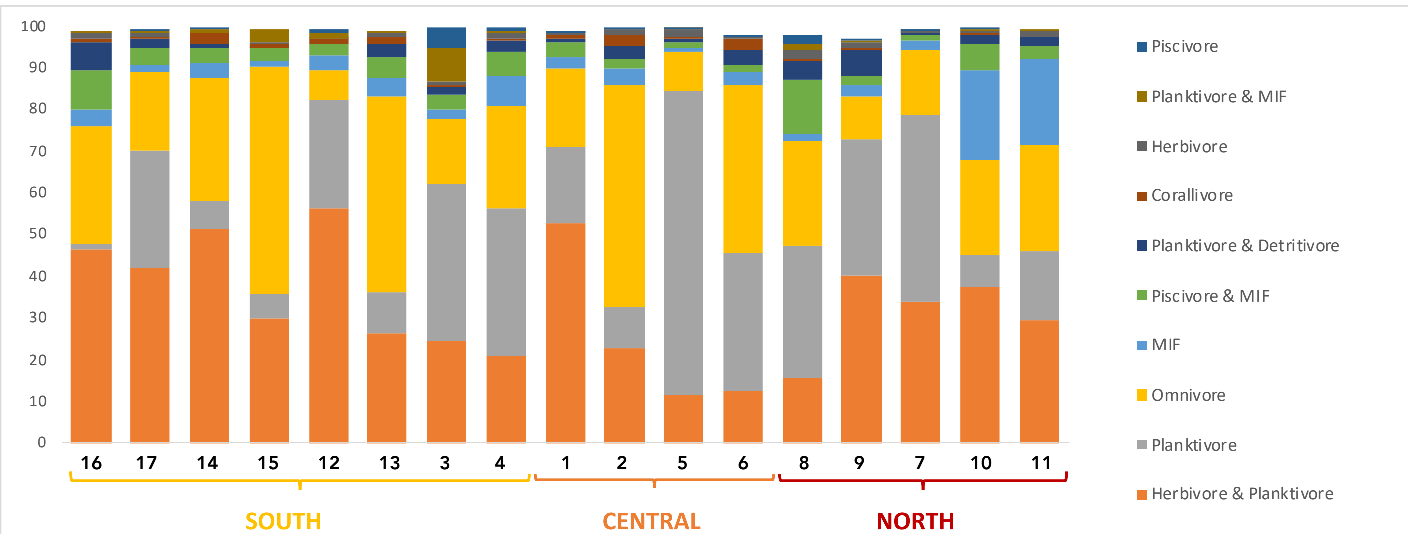



***Figure. 3.3.12***. Relative mean abundance (%) of fish functional groups per 250m$^2$ transect recorded along Dauin Reef.

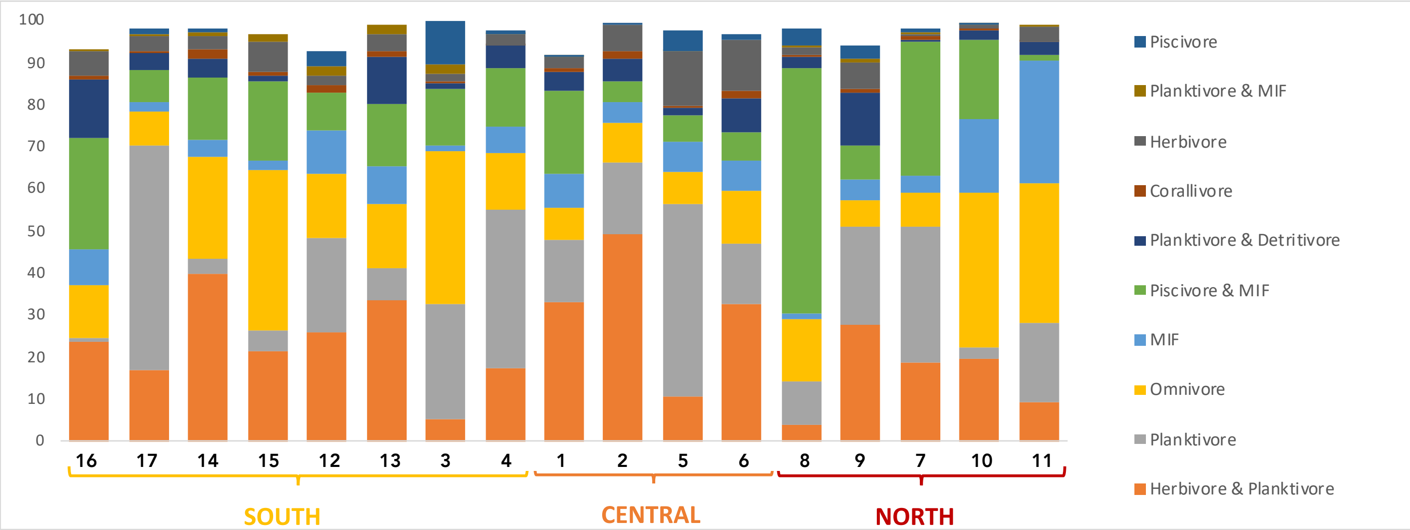



***Figure. 3.3.13***. Relative mean biomass (%) of fish functional groups per 250m$^2$ transect recorded along Dauin Reef.

Herbivore & Planktivore functional group is most widely represented on Masapold South at 10m (Site 12), Poblacion District II at 10m (Site 1), Masapold at 10m (Site 14, non-MPA), and Maayong Tubig at 5m (Site 16) with 56%, 52%, 51%, and 46% abundance respectively. Sites with less Herbivore & Plaktivore fish are Poblacion at 10 (Site 5) and 5m (Site 6), and Lipayo at 10m (Site 8) with 11%, 12%, and 16% respectively (***Figure. 3.3.12)***. Regarding the biomass, Poblacion District II at 5 (Site 2) and 10m (Site 1), Masapold at 10m (Site 14, non-MPA), and Masapold South at 5m (Site 13) are the most abundant in this trophic group with 49%, 33%, 40%, and 33% respectively. Lipayo at 10m (Site 8) and Masapold North at 10m (Site 3) are the less abundant with 4% and 5% ***(Figure 3.3.13***).

Planctivorous Fish are most abundant in Poblacion District I at 10m (Site 5), Black Diamond at 10m (Site 7, non-MPA), and Masapold North at 10m (Site 3) with 73%, 45% and 38% respectively and less abundant in Southern Dauin, at Maayong Tubig at 5m (Site 16), and Masapold at 5 (Site 15, non-MPA) and 10m (Site 14, non-MPA), with 1% and twice 6% respectively (***Figure. 3.3.12)***. Based on the biomass, Planctivorous fish are more represented at Maayong Tubig at 10m (Site 17), Poblacion District I at 10m (Site 5) and Masapold North at 5m (Site 4) have 53%, 46%, and 37% respectively whereas and less represented at Maayong Tubig at 5m (Site 16), Bulak at 10m (Site 10), and Masapold at 10 (Site 14, non-MPA) and 5m (Site 15, non-MPA) have 1%, 3%, 5%, and 6% respectively ***(Figure 3.3.13***).

Omnivores dominate the sites of Masapold at 5m (Site 15, non-MPA), Poblacion District II at 5m (Site 2), and Masapold South at 5m (Site 13), with 55%, 53%, and 47% respectively. Conversely, Masapold South at 10m (Site 12), and Poblacion District I at 10m (site 5) have less omnivores on their reefs with 7% and 9% (***Figure. 3.3.12)***. For the biomass, the site of Masapold at 5m (Site 15, non-MPA) dominate again with 38%, followed by Bulak at 10m (Site 10), and Masapold North at 10m (Site 3) with 37% and 36%. The sites Lipayo at 5m (Site 9) is the less important regarding the biomass of omnivores with 7%. Black Diamon at 10m (Site 7, non-MPA), Poblacion District I at 10m (Site 5), Poblacion District II at 10m (Site 1), and Maayong Tubig at 10m (Site 17) are just behind with 8% each***(Figure 3.3.13***).

Mobiles Invertebrates Feeders (MIF) are more abundant in the Northest part of Dauin , reaching 21% of the fish in Bulak at 10m (Site 10) and 5m (Site 11) and to 18% and 29% of fish biomass in the same sites respectively. All other sites have less than 10% of MIF both in abundance and biomass (***Figure. 3.3.12, Figure 3.3.13***).

Piscivores & MIF represent 13% of fish abundance in Lipayo at 10m (Site 8) and less than 10% in all the other sites (***Figure. 3.3.12)***. Their contribution to the total biomass is far more important, representing 58% in Lipayo at 10m (Site 8), 32% in Black Diamond at 10m (Site 7, non-MPA), and 27% in Maayong Tubig at 5m (Site 16). They represent less than 20% of the total biomass in the other sites ***(Figure 3.3.13***).

Planktivore & Detritivore functional group is mostly represented in Maayong Tubig at 5m (Site 16) and Lipayo at 5m (Site 9) with a fish abundance of 7% and 6% aligned to the fish biomass where this group is most represented in Maayong Tubig at 5m (Site 16) and Liapyo at 5m (Site 9), and also Masapold South at 5m (Site 13) with 14%, 13% and 12% of the total biomass, respectively (***Figure. 3.3.12, Figure 3.3.13***). All other sites have less than 5% of these fish both for abundance and biomass. Masapold at 5m (Site 15, non-MPA), Masapold South at 10m (Site 12), and Black Diamond at 10m (Site 7, non-MPA) have no record of Planktivore & Detritivore fish on their reefs (***Figure. 3.3.12, Figure 3.3.13***).

Corallivores are present on 11 out of the 17 sites studied along Dauin, with less than 5% of fish abundance and biomass. Same for the *Herbivore* functional group which is recorded on 11 out of the 17 sites studied along Dauin and with less than 3% of fish abundance. For the biomass, this group represent 13% and 12% in Poblacion District I at 10 (Site 5) and 5m (Site 6) respectively. All other sites have less than 10% of herbivores fish biomass (***Figure. 3.3.12**, **Figure 3.3.13***).

Planktivores & MIF fish are present on 9 out of the 17 sites with a maximum of 8% of fish abundance in Masapold North at 10m (Site 3) and less than 5% of fish biomass (***Figure. 3.3.12, Figure 3.3.13***).

Piscivores are recorded on 7 sites out of 17 with less than 5% of fish abundance and biomass (***Figure. 3.3.12, Figure 3.3.13***).

NMDS and beta-dispersion plotswere used to represent the community composition of the functional groups by the season, the measures' location, or by MPA/non-MPA (***Figure. 3.3.14***). When comparing the fish community measured during the wet vs the dry season,  no differences are graphically apparent as the two ellipses collapse (***Figure. 3.3.14a***). Same conclusion when comparing the communities by their location:,  all the points are located in the same area (***Figure. 3.3.14c***), suggesting  that the functional groups are similar at the north, central and south parts of Dauin coastline.  However, when comparing the fish communities located in protected vs unprotected areas, the non-MPAs points seem to be located in a different pattern than MPA points, resulting in two ellipses that suggest different composition. Yet additionnal measures are necessary to conclude  as the study only takes into account 3 unprotected sites.

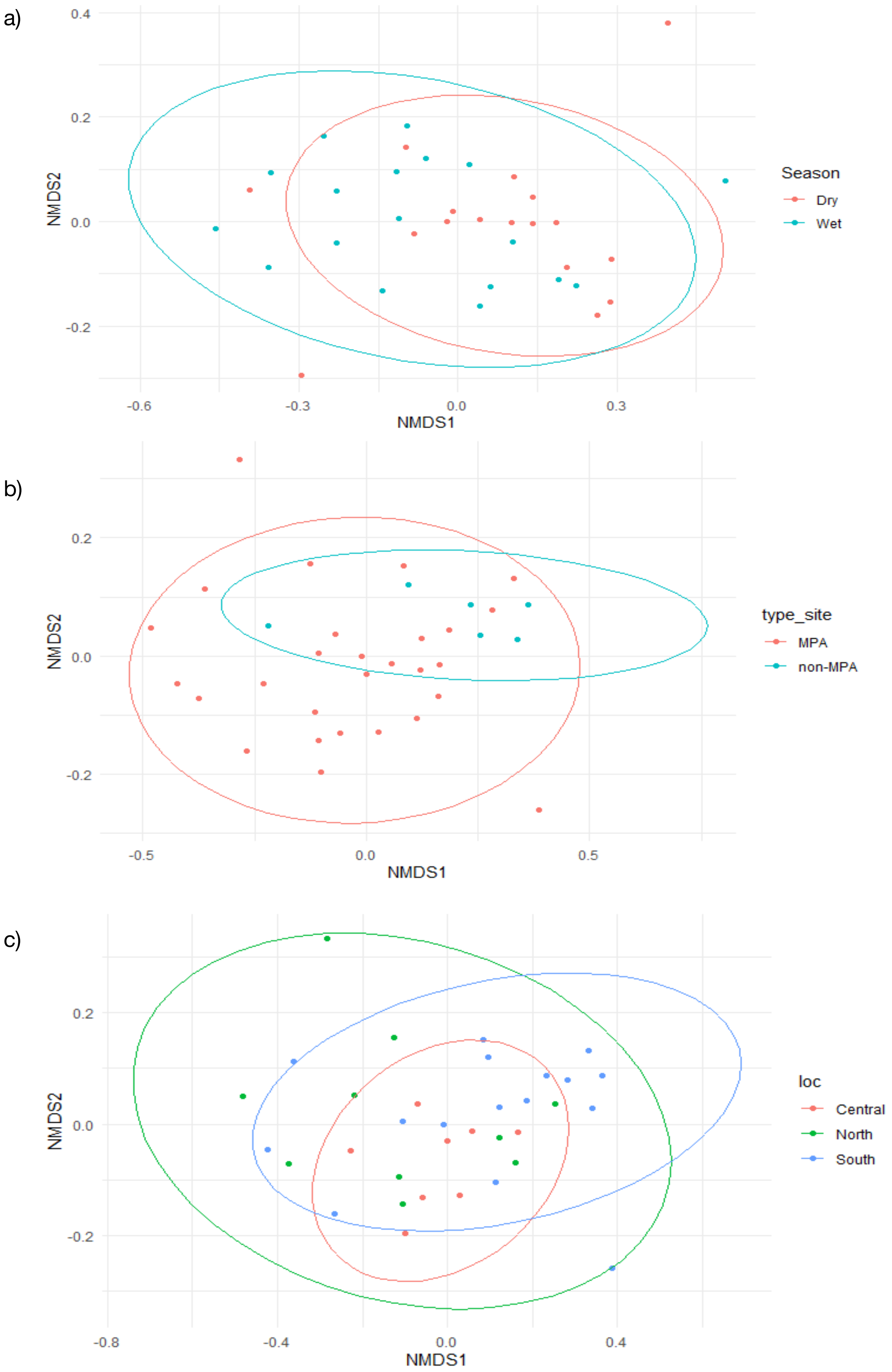



***Figure. 3.3.14***. Non-metric multidimensional scaling (NMDS)of fish functional group biomass weighted communities according to a) season, b) protected and unprotected sites, and c) location along the Dauin coastline.

### 3.3.3 Commercially Important Fish

Over the survey year, a total of 2444 commercially important fish individuals were recorded, equating to 12.4% of all recorded fish. 72 commercially important fish species were recorded (33% of total species richness), across 18 different fish families. Labridae has the most commercially important fish species recorded during the survey year (n=15), followed by Lutjanidae (n=9), Mullidae (n=9), Serranidae (n=8) and Acanthuridae (n=6) (***Figure. 3.3.15***, ***Table. 7.3.2***).

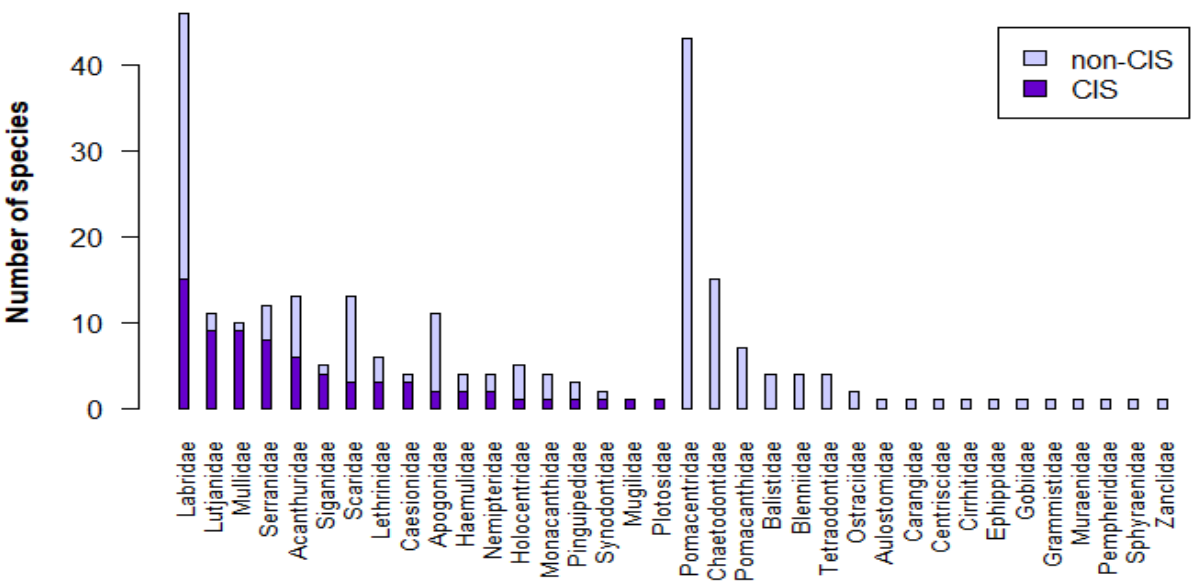



***Figure. 3.3.15***. Total number of species of all fish families recorded along Dauin reef for the survey year, separated into commercially-important species (CIS) and non commercially-important species (non-CIS).

An average of 9 commercially important fish species were recorded per 250m$^2$ transect (22.5%). The most abundant commercially important fish families are Labridae, Acanthuridae, Caesionidae and Mullidae with an average count per transect of 13.8, 13.7, 11.2 and 8.0 respectively. The less abundant are Lethrinidae, Monacanthidae, Pinguipedidae, and Synodontidae; all with 0.1/250m$^2$ (***Figure 3.3.16***).

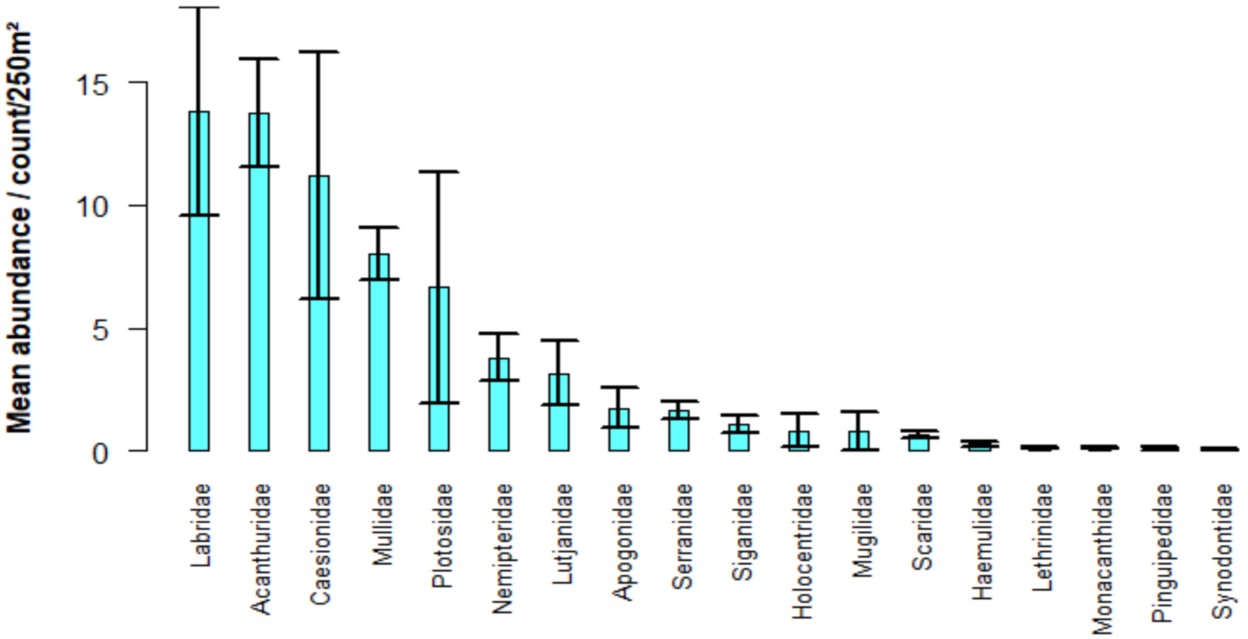



***Figure. 3.3.16***. Mean abundance per transect (count/250m$^2$ ± SE) of commercially important fish species, grouped into families, recorded along Dauin reef for the survey year.

The biggest contributors to biomass of commercially important fish are Lutjanidae, Caesionidae and Serranidae with an average per transect of 0.9kg, 0.8kg and 0.8kg respectively. Again, the families of fish that contribute the least are Lethrinidae, Monacanthidae, Pinguipedidae, and Synodontidae, plus Plotosidae, Holocentridae, and Haemulidae which all represent an average of 0kg/250m$^2$. (***Figure. 3.3.17***).

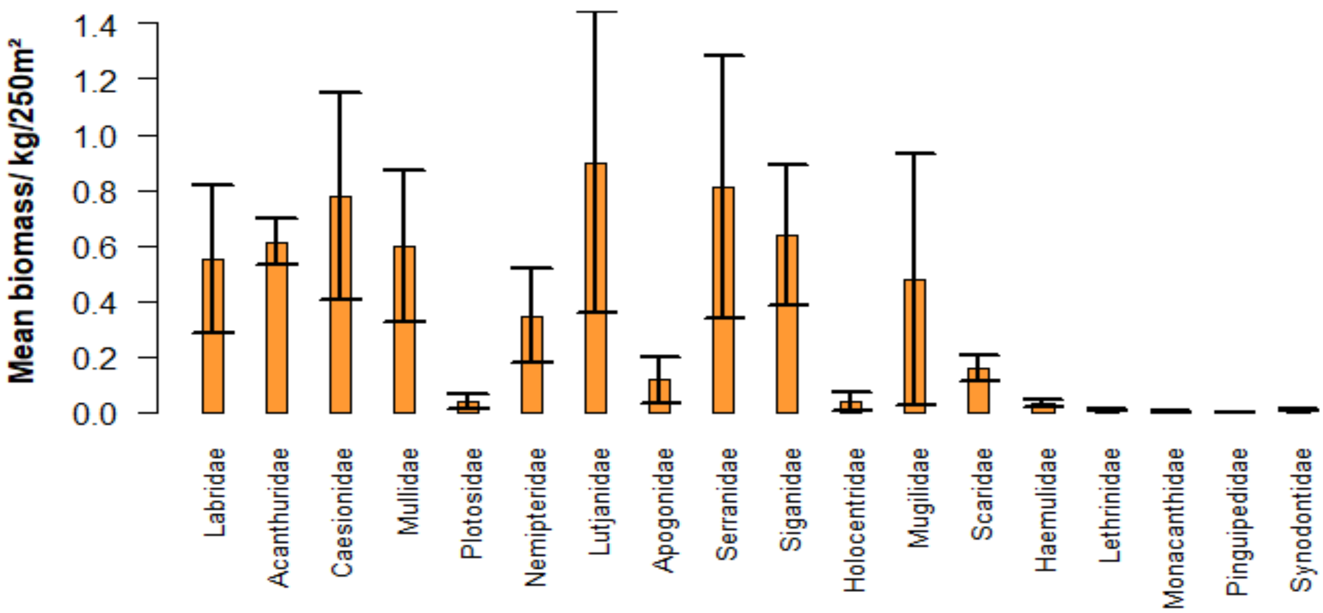



***Figure. 3.3.17***. Mean biomass per transect (kg/250m$^2$ ± SE) of commercially important fish species, grouped into families, recorded along Dauin Reef for the survey year.

The relative abundance and biomass contributions to the fish community of commercially important fish species varies greatly between sites (***Figure. 3.3.18***, ***Figure. 3.3.19***). To understand their distribution in more detail, fish were separated in four categories: commercial, minor, subsistence fisheries and none.

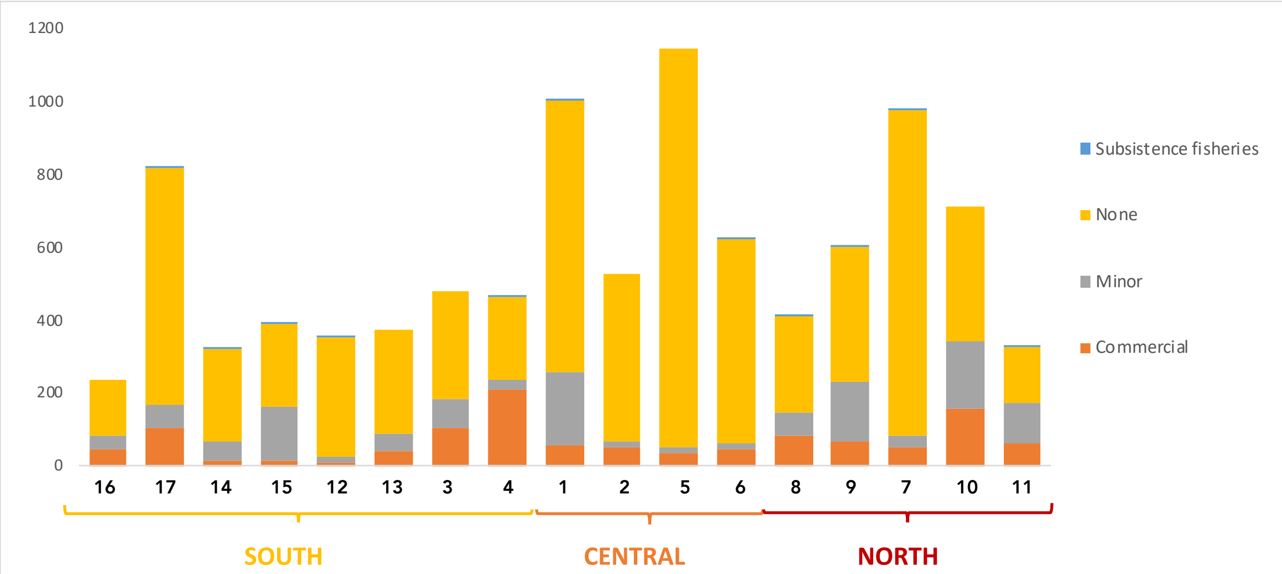



***Figure. 3.3.18***. Mean site abundance (%) of fish separated by commercial importance (orange: commercial; grey: minor; yellow: none; blue: subsistence fisheries) categories and site, recorded along Dauin Reef for thesurvey year.

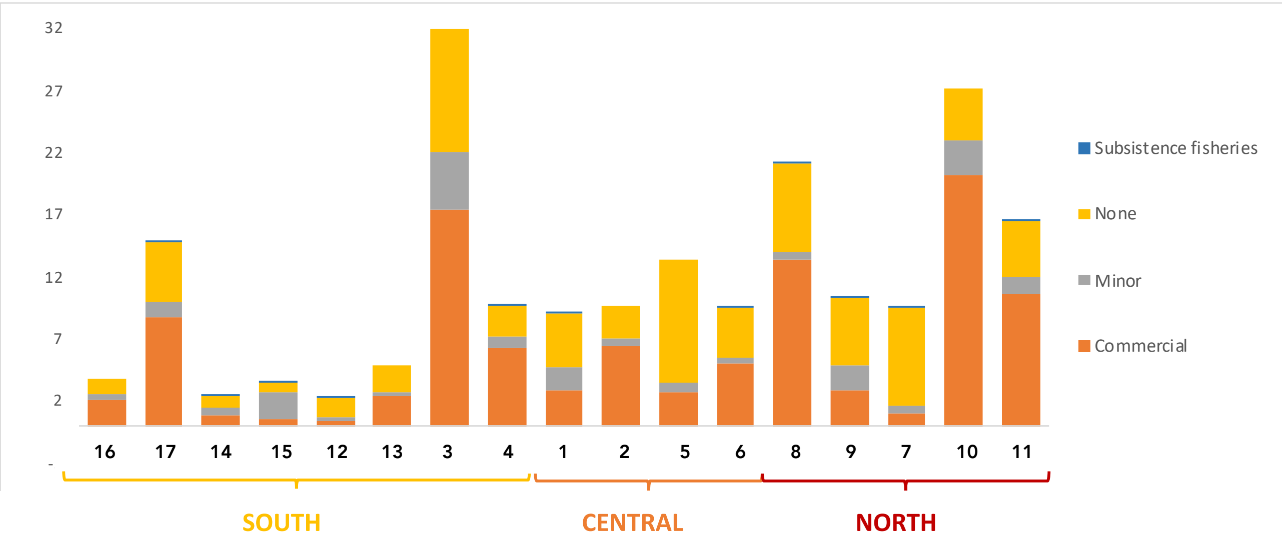



***Figure. 3.3.19***. Mean site biomass (%) of fish separated by commercial importance (orange: commercial; grey: minor; yellow: none; blue: subsistence fisheries) categories and site, recorded along Dauin Reef for thesurvey year.

Masaplod Norte at 5m (Site 4) have the greatest abundance of commercially important fish with 211 recorded, follow by Bulak at 10m (Site 10), Maayong Tubig at 10m (Site 17), and Masapold North at 10m (Site 3) with 155, 105 and 104 respectively (***Figure. 3.3.18***).
When considering their biomass, Lipayo at 10m (Site 8) and Bulak at 5m (Site 11) are also included in the sites with the highest amount (by weight) of commercially important fish species with 13.4kg and 10.6kg. Bulak at 10m (Site 10) and Masapold North at 10m (Site 3) are the ones with the greatest biomass of commercially important fish: 20.2kg and 17.4kg respectively (***Figure. 3.3.19***).

NMDS plots suggest there is no difference in community composition of commercially important species between seasons, location or MPAs and non-MPAs as the ellipses collapse for every parameter tested (***Figure. 3.3.20***).

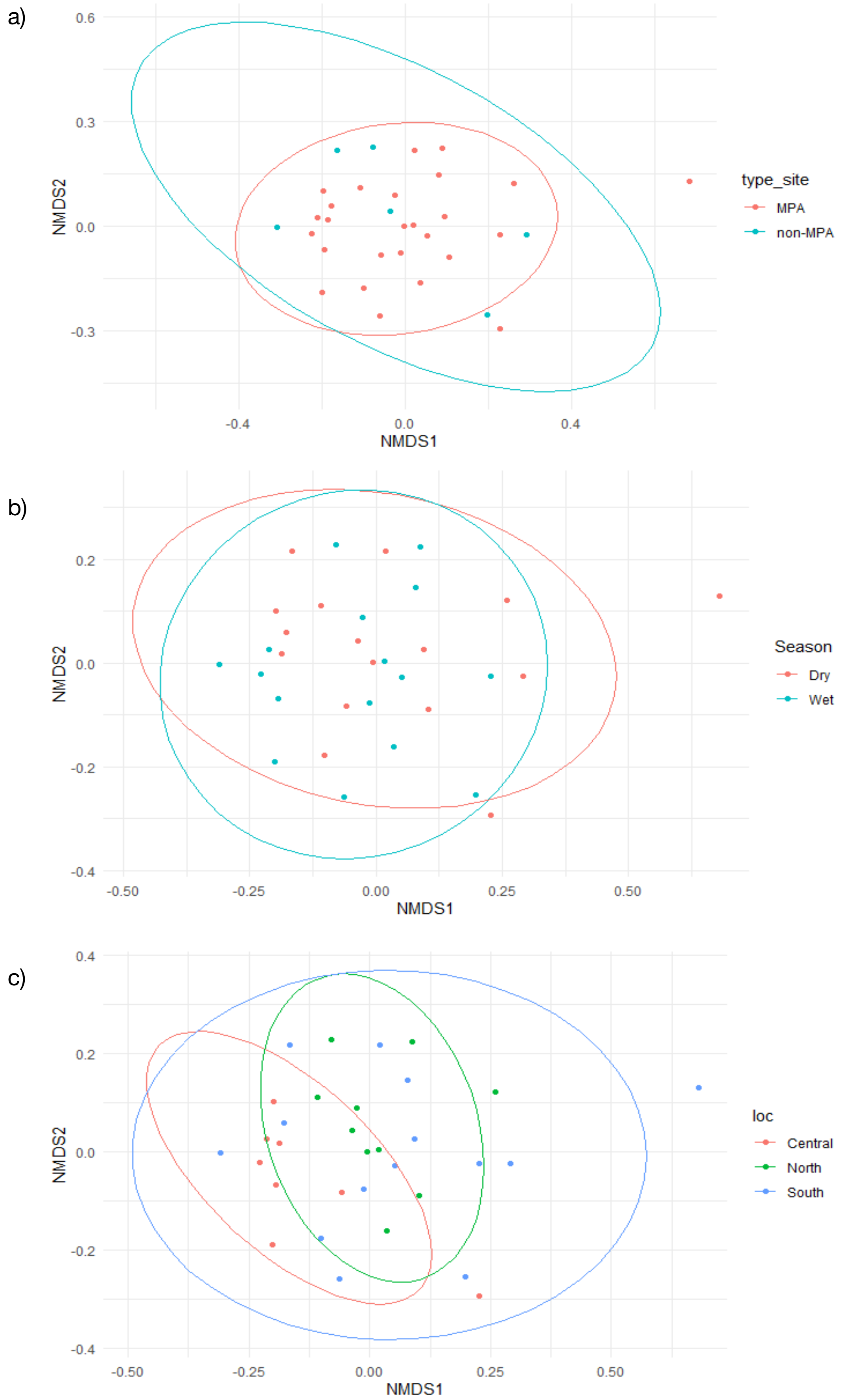



***Figure. 3.3.20***. Non-metric multidimensional scaling (NMDS) of biomass weighted commercially important fish species communities by a) MPAs and non-MPAs, b) season, and c) location along the Dauin coastline.

For the majority of commercially important fish species that were recorded and measured during the survey year (n=64), lengths at first maturity (obtained from FishBase) was unavailable. When this information was available, the size distribution of the population could be examined to determine the proportion of juveniles vs adults. Species with exclusively juvenile populations reported are *Myripristis murdjan* and *Lutjanus argentimaculatus* (***Figure. 3.3.21***). *Plotosus lineatus* and *Lutjanus fulvus* have largely juvenile populations, *Parupeneus multifasciatus* has a more balanced juvenile to adult proportion, whereas populations of *Epinephelus merra*, *Lutjanus vitta* and *Thalassoma hardwicke* are skewed towards mature adults (***Figure. 3.3.21***). For *Siganus guttatus*, the recorded population was exclusively adults. However, it is important to note the sample sizes of these populations – with five out of nine of these species having 10 or less measured observations, overall size distributions of these species cannot be easily described at this point in this study.

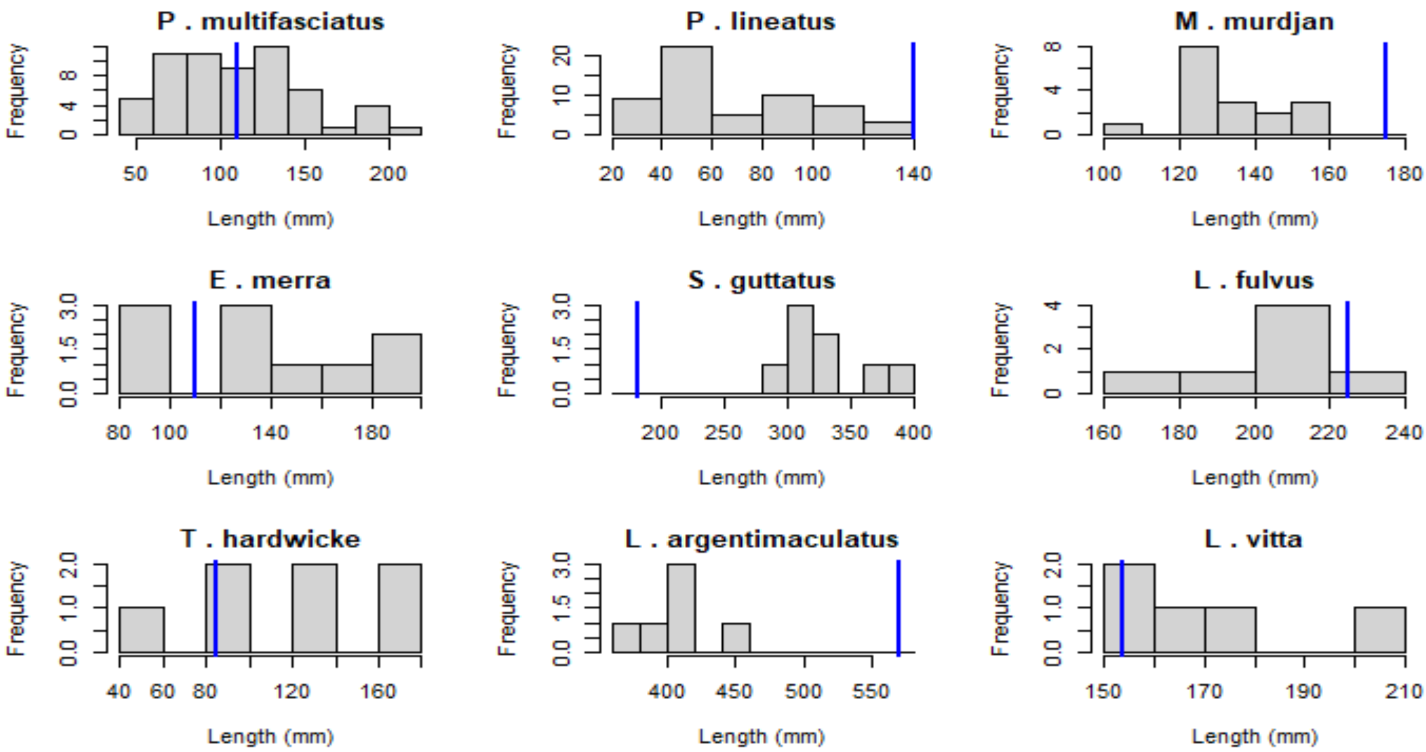



***Figure. 3.3.21***. Frequency distribution of recorded lengths for 9 commercially important fish species; *Parupeneus multifasciatus* (n=60), *Plotosus lineatus* (n=56), *Myripristis murdjan* (n=17), *Epinephelus merra* (n=10), *Siganus guttatus* (n=8), *Lutjanus fulvus* (n=7), *Thalassoma hardwicke* (n=7), *Lutjanus argentimaculatus* (n=6) and *Lutjanus vitta* (n=5). Blue vertical line represents length at first maturity, according to FishBase 2020.

### 3.3.3 Reef Fish and Structural Complexity

Dauin's patchy reefs show variation in structural complexity, from sand- dominated structures (e.g. Bulak), and coral fields (e.g. Masaplod South). Most sites (10 out of 17) show minimal changes to 3- Dimensional complexity (below ±5 RMS) between seasons. Sites that show higher changes to 3-D structure (Sites 6, 17, 4, 16, 10, 2, 13) are likely due to divergence in the survey path (***Table. 7.3.4***). Averaging 3D metrics (length, rugosity, slope, variation and range) across sites, all metrics show increases from dry to wet season, with the exception of slope which decreases from 0.101 in dry season to - 0.068 in wet (although variations of 0.204 in dry and 0.186 in wet suggest the decrease is not significant) (***Table. 7.3.4***).

The ***figure 3.3.22*** shows the difference of rugosity between sites along Dauin. The sites with higher rugosity on their reefs are Poblacion District II at 5m (18.28; Site 2), Maayong Tubig at 5m (16.73; Site 16), Masapold South at 5m (16.30; Site 13), Poblacion District I at 5m (14.31; Site 6) and Bulak at 10m (11.06; Site 10). , , A higher rugosity reflects coral reefs with relief, a complex habitat that favors a rich biodiversity.

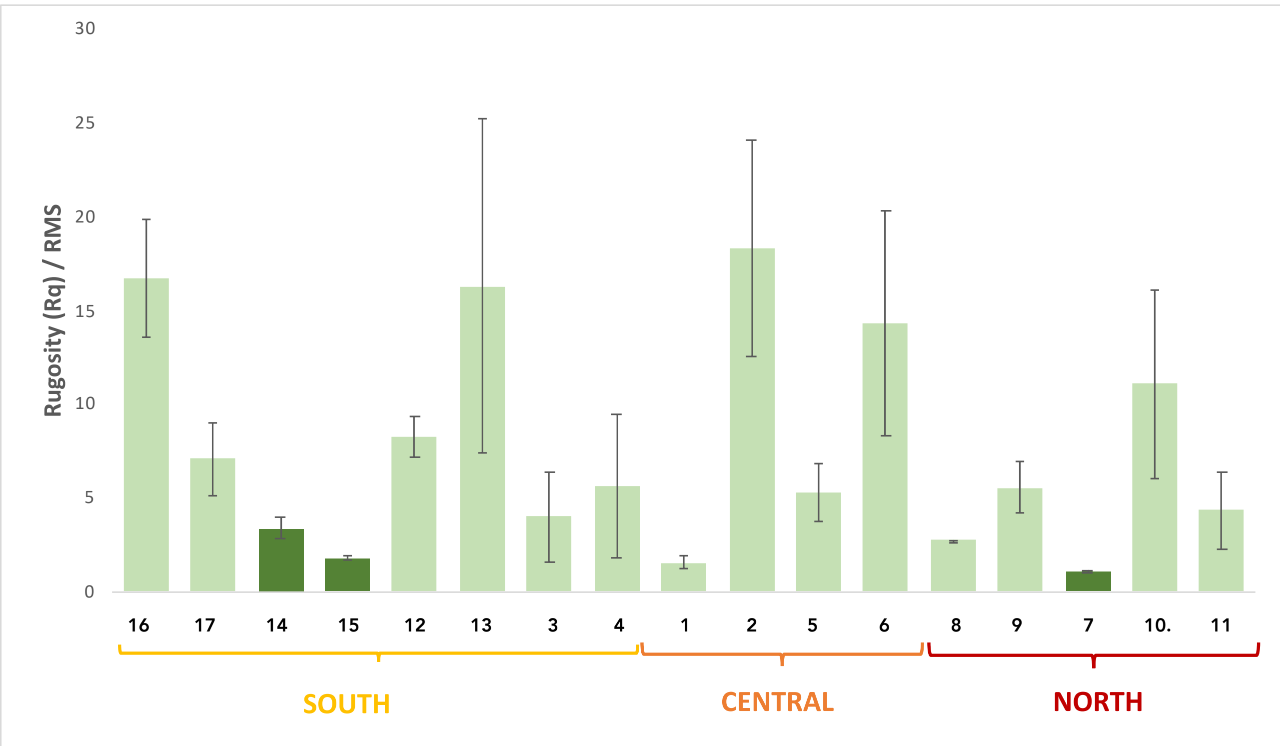



***Figure. 3.3.22***. Mean Rugosity (Rq, RMS ± SD) along Dauin Reef survey sites.

All other sites have a rugosity of less than 10. The unprotected sites studied are those with the lowest rugosity: Masapold at 10m (3.38; site14), at 5m (1.78; site 15) and Black Diamond at 10m (Site 7), with only 1.07 (***Figure. 3.3.22***). However some MPAs also show low rugosity. Two MPAs present a very low rugosity: Poblacion District II at 10m (site 1) with 1.56 and Lipayo at 10m (Site 8) with 2.72 (***Figure. 3.3.22***).

The ***figure 3.3.23*** compare the 3D model and the rugosity graph of one MPA (Black Diamond at 10m; Site 7) and a close non-MPA (Lipayo at 10m; Site 8) at the same depth, during the same season (dry). Roughness is higher on the MPA than the non-MPA. Along with the previous figure, this suggests a difference between MPAs and non-MPAs. However these results should be further confirmed, as we compared 14 MPAs with only 3 non-MPA sites.

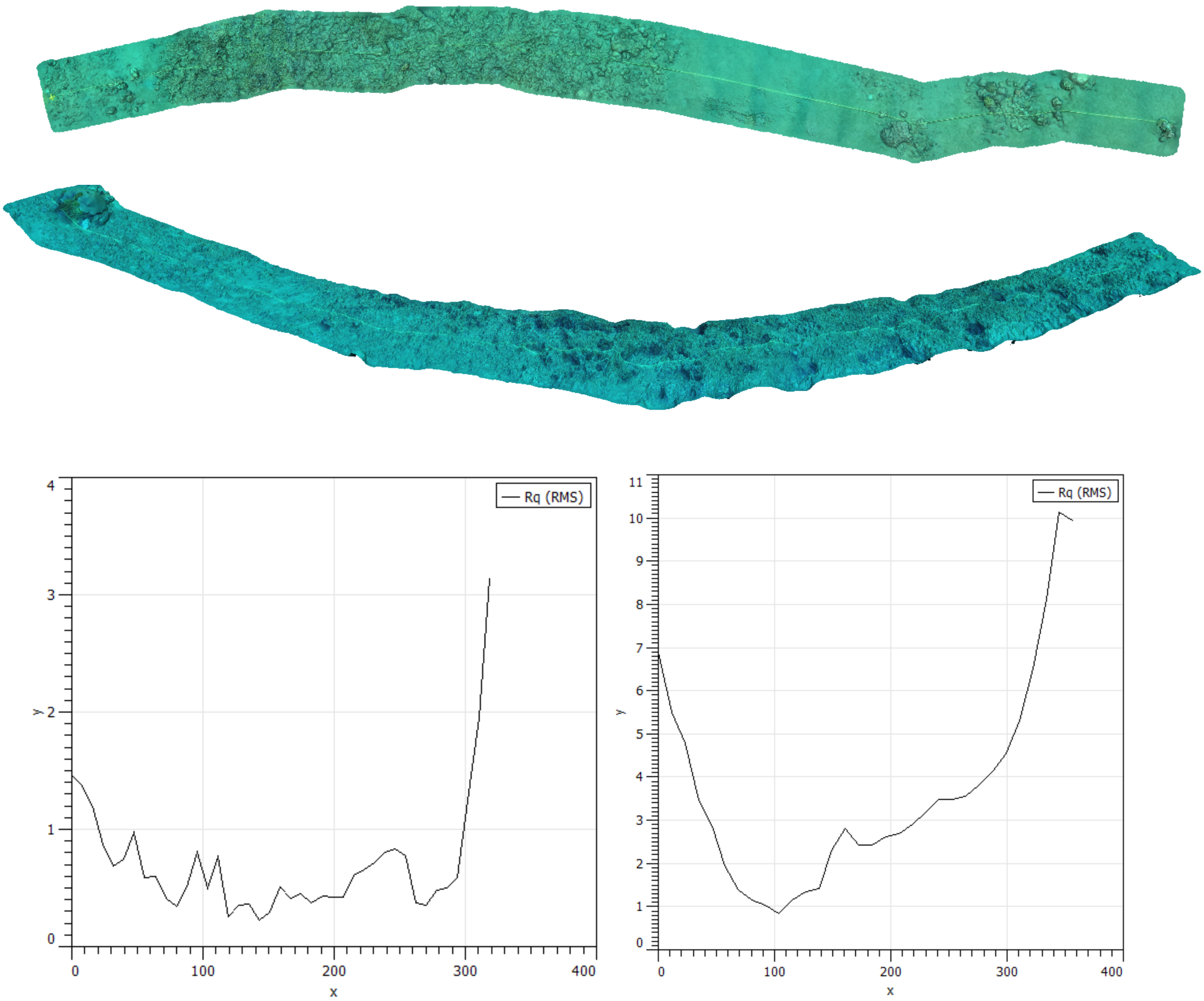



***Figure. 3.3.23.*** Above: Digital elevation models of Black Diamond (Site 7) on the left and Lipayo (Site 8) on the right, produced with SfM photogrammetry techniques at 10m. Below: Average rugosity (Rq) of Black Diamond (Site 7) on the left and Lipayo (Site 8) on the right (scale is in megapixels).

Linear regressions and Fisher tests on the effect of 3D metrics on fish community structure showed that all the environmental matrix of all 3D metrics combined had no significant effect on fish community structure ($p$= 0.88 for abundance,; $p$= 0.79 for biomass,; ***Figure. 3.3.24***). Individual metrics also showed no significance as the $p$-value is always >0.05 Correlations of rugosity vs fish abundance or biomass are very weak and therefore no significant, when looking at the entire fish population (R2= 0.0021 and 0.0008 respectively), as well as specifically at the Pomacentridae family (R2= 0.0057 and 0.0011 respectively) (***Figure. 3.3.24***).

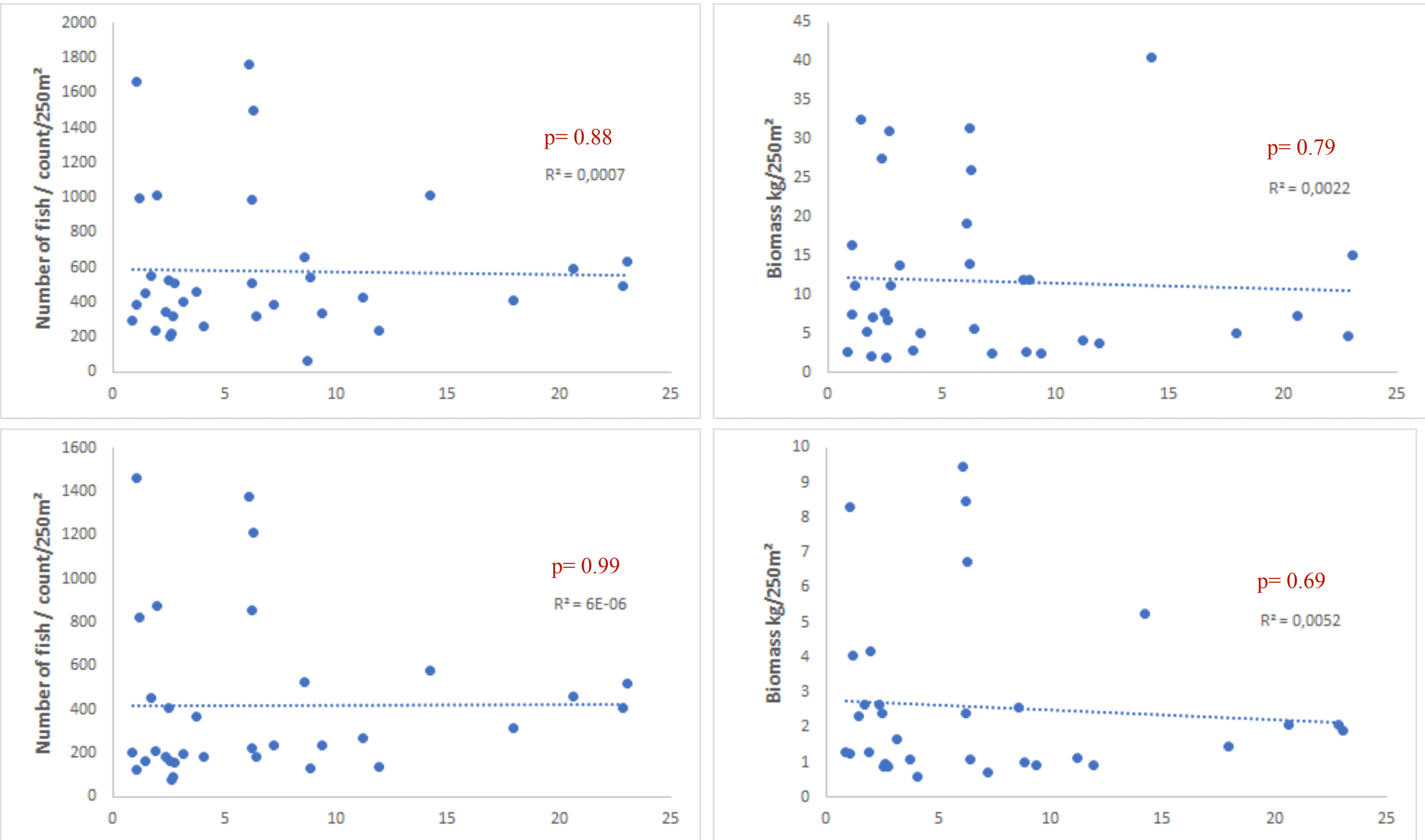



***Figure. 3.3.24***. Rugosity (Rq, RMS ± SD) vs total fish abundance (count/250m$^2$) (left panels) and biomass (kg/250m$^2$) (right panels) along Dauin Reef survey sites, with trendline and $r^2$ values. Above: all fish, bottom : exclusively Pomacentridae.

Finally, we investigated whether the fish communities measured from high and low rugosity sites were different. The two ellipses of the non- metric multidimensional scaling (NMDS) are quite similar and suggests that differences in the fish communities between high and low rugosity are negligible (***Figure. 3.3.25***).

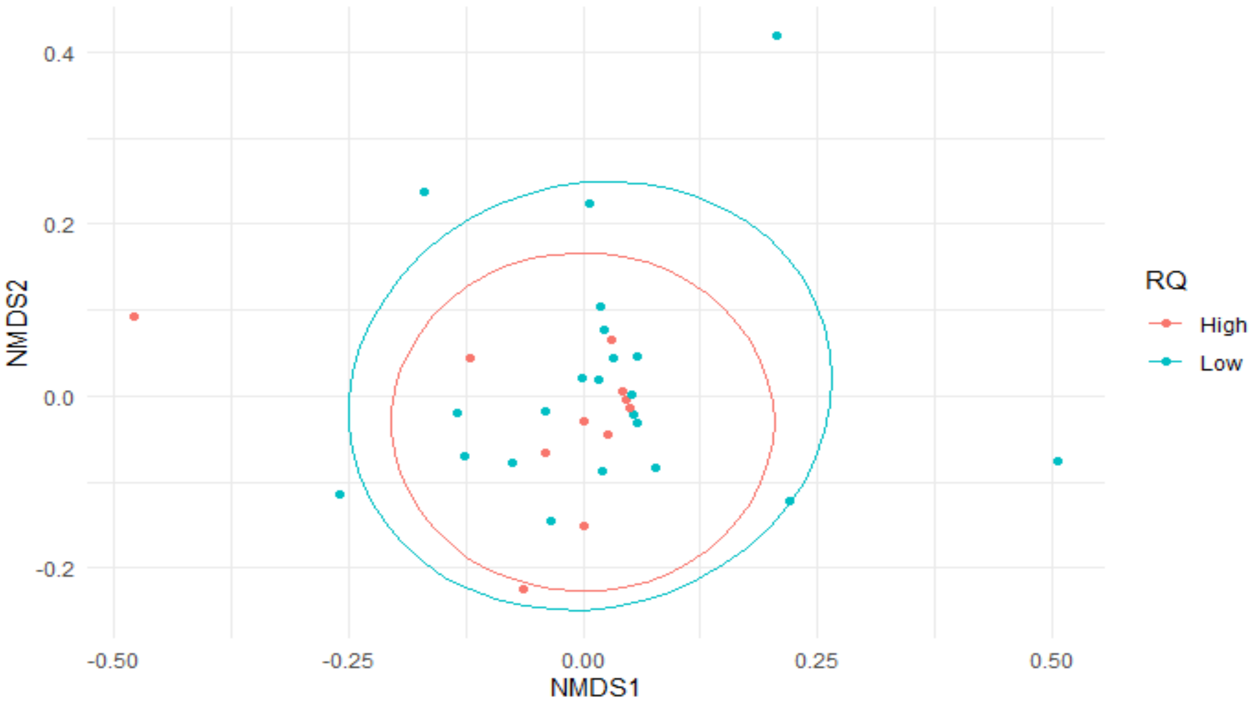



***Figure. 3.3.25***. Non-metric multidimensional scaling (NMDS) (Left) of fish biomass weighted communities according to rugosity.

# 4. DISCUSSION

The Philippines initiated their MPA programs in the 1970s and implemented more than 1,600 MPAs, covering about 240km2 (White *et al*., 2014). Some MPAs have been able to sustain small-scale fisheries when properly managed (Alcala and Russ, 2006, 2006, Indab and Suarez-Aspilla, 2004, Maliao *et al*., 2004), however, only 30% of all MPAs in the Philippines are well managed (White *et al*., 2014). Two decades ago, the municipality of Dauin implemented seven MPAs across the municipality to regulate fishing pressures, abolish destructive practices, and address important issues such as food security, economic growth, and ecosystem resilience.

In this report a baseline of Dauin's MPAs on the local biodiversity have been provided. This includes investigating the protection of critical habitats such as coral reefs as well as the composition and structure of the community (Gallacher et al., 2016). The reef ecosystem along Dauin's coastline was characterized in terms of benthic composition, coral reef impacts and the reef fish community structure. As a primary overview of Dauin's MPAs, we combined measures from the seven MPAs and two non-MPAs, one year-long to cover the dry and the wet seasons. As detailed hereafter, we noted a high variability between the study sites. Added to the underrepresentation of the unprotected sites (three vs fourteen MPAs), we report here a descriptive overview more than a proper significant comparison between Dauin's MPAs and non-MPAs.

## 4.1 Benthic composition

### 4.1.1 Abiotic Cover

Dauin's benthic cover is mainly composed of abiotic components, predominantly sand and rubble. This was considered for the selection of the transects' location: zones with the highest coral cover were chosen to increase the diversity of the measures. The same selection criteria were applied to both groups, MPAs and non-MPAs, reducing the selection bias at its minimum. The abiotic cover also included rock and shell. We reported a higher presence of rubble and rock in protected zones. Interestingly, no trash nor fishing gear were found, suggesting that the study sites were relatively spared from this type of human pollution. Coral, algae and sponge represent the majority of the biotic cover.

### 4.1.2 Coral

The overall coral population was similar in protected and unprotected zone. This reflects local discrepancies: corals were more abundant in the Southern MPA, but less abundant in the Northern MPA, when compared with the closest unprotected zone. Our result suggests that the Southern MPA Masapold South would be effective in protecting corals, but not Bulak. However, this should be confirmed by further studies focusing on smaller zones, as we clearly observed local effects.

*Acropora* spp., *Anacropora* spp., *Porites* spp., *Echinopora* spp. and *Pocillopora* spp. are the dominant coral genera found across the Dauin reefscape, contributing to 79% of the recorded coral cover. The three major coral genera all show a geographical predominance: Northern Dauin for *Acropora* spp., Southern Dauin for *Anacropora* spp. and Center zone for *Porites* spp.. *Echinopora* spp. and *Pocillopora* spp. are also found in some sites along the coastline, with an uneven distribution.

Along with such geographical distribution, we document a high variability between close sites and depths. Accordingly, we did not observe a consistent difference for the tree major coral populations across protected areas when compared to the closest unprotected site. The differences we report are local for *Acropora* spp. and *Anacropora* spp., which population is less abundant in one MPA site over three, respectively Bulak and Masapold South. We report more *Porites* spp. in two protected sites located on the North and on the South of Dauin. These results should however be confirmed by further studies, as the differences observed here should more reflect a local effect than an MPA one.

Dominance of a single coral genera and concomitant lack of diversity rises concerns regarding the resiliency of reef sites. Impact and coral mortality assays reveal that *Acropora* spp., *Porites* spp. and *Pocillopora* spp. to be most susceptible to impacts such as disease, bleaching, predation from corallivous invertebrates, and direct destruction. As detailed later, these genera were affected by several impacts, not only one type. Furthermore, the sites where the highest impacts were founds, in terms of number and percentage of area affected, are *Acropora* spp. dominant sites: Black Diamond, Lipayo and Maayong Tubig.

Changes in the structure and composition of coral communities have been observed following diverse natural and anthropogenic disturbances, such as hurricanes and storms, pollution, sedimentation, fishing, disease, and outbreaks of coral predators. In the Indo-Pacific region, the immediate effects of disturbances can generally shift coral communities from assemblages of stress-sensitive branching and plating corals, such as species of Acropora and Montipora, toward altered assemblages of stress-tolerant massive corals such as species of massive Porites, Cyphastrea and Favia species (reviewed in Darling et al., 2013).

### 4.1.3 Dead coral

Dead corals were present in all study sites, at a proportion averaging half that of hard coral. South Dauin presented the highest dead coral cover, its proportion exceeding that of live coral in two sites: Maayong Tubig and Masapold North. In both sites, as well as in Masapold South, the proportion of dead coral was higher at 5 than at 10 meters-depths, probably due to the corals sensibility to ultraviolet radiation (Lesser 1997).

Only 8% of the dead coral indicates a recent degeneration, the majority is coral rubble. We distinguished different coral death dynamics in Dauin. South Dauin presents the highest dead coral cover, mainly ancient. Conversely, North Dauin has the lowest dead coral cover, with a more recent coral death that is also observed in Central Dauin.

Dead coral cover was similar in protected and unprotected zones, excepted in South Dauin: we found more dead coral in the MPA Masapold South than in its close non-MPA Masapold. This was only significant at 5m depth and should be further confirmed.

Coral reef ecosystems are widely considered to be one of the most sensitive ecosystems to global change. They are challenged by many stressors; local and anthropogenic factors exacerbate the global effects of warming and acidification (Ban et al., 2014). Among those stressors (Rasher et al., 2012, Ban et al., 2014), we did find spatial variations for the ones that could explain local effects along Dauin's coastline: COT feeding scars, coral disease, algal cover, likely due to eutrophication, bleaching events, coral species diversity and direct damage due to human fishing or boats anchors. Local dead coral variation can also be explained by storm damage, the cascading effects of overfishing, coastal pollution, reduced salinity and terrestrial sedimentation, however we did not report them here. Interactions between those stressors are complex and can even be synergistic (Ban et al., 2014), which emphasizes the relevance of deeper monitoring of Dauin's reefscape at more local levels.

### 4.1.4 Algae

Algae distribution was variable between sites and depths, with a higher presence in Center and South Dauin. Degraded coral reefs show a decline in coral cover with a shift toward more algae (Pandolfi et al., 2005; Jackson et al., 2014). One anthropogenic mechanism involved is eutrophication, an excessive richness of nutrients. Eutrophication destabilizes coral reefs by causing excessive growth of algae, supported by the excessive rich nutrient source, and suffocation of coral reefs due to the decline of available oxygen (Good et al., 2021). Accordingly, the highest algae cover is in South Dauin, where we found the highest proportion of dead coral. Most sites were coral-dominated reefs, but we identified three algae-dominated sites: Masapold North, at both depths measured; Maayond Tubig and Bulak at 5 meters depth. Surprisingly, all are MPAs. Our results suggest that the implementation of protected zones could not restore a healthiest coral / algae balance, as Masapold South presents a higher proportion of algae than its closest non-MPA site Masapold. In North Dauin, the algae population was similar in both protected and unprotected zones.

Turf algae is the most important genera observed, followed by Coralline algae and Halimeda. We report a higher presence of these genera in protected zones than unprotected ones, compared with other algae genera. Turf algae are the main food for herbivores and the primary competitors with reef-building hard corals (Bruggemann et al., 1994; Ledlie et al., 2007; Hamilton et al., 2014). Filamentous turf algae are often first to colonize bare substrate, which is commonly observed after largescale coral mortality (McClanahan et al., 2001, Adjeroud et al., 2009, Mellin et al., 2016). They establish faster in previously algal dominated areas, indicating a higher supply of propagules from the direct surrounding environment (Diaz-Pulido and McCook, 2004).

Herbivorous fish strongly suppress macroalgal colonization and growth, lessen algal damage to corals, and promote coral recruitment and growth. By preventing algae domination, they strengthen reef resilience (Rasher et al., 2012). On another side, once established, algal-dominated communities limit coral and herbivores recruitment, thereby reinforcing their persistence (Rasher et al., 2012). In our study, algae dominance was at the expense of live coral,

but was not correlated to herbivores population or coral genera. Herbivorous fish contribute relatively little to total biomass of reef fish across the Dauin reefscape, posing preliminary concerns over the capacity for algal removal from previously disturbed sites.
The algae cover can be influenced by high levels of nutrients from the excretion of reef fishes, differences in macroalgal species and palatability or competition with sponges (Loh et al., 2015). Nevertheless in our study, algae dominance was not associated to higher fish biomass, algae genera, sponges presence or genera.

### 4.1.5 Seagrass

Seagrasses are a highly productive ecosystem, providing shelter and food to several animals. They provide physical structure, enhancing community diversity, biomass and primary and secondary production. They also recruit algae, sponge, coral and sessile invertebrates that are rare or absent in unvegetated bottoms (Duffy et al., 2006). Seagrasses are threatened by anthropogenic pollution, eutrophication, overfishing, and the destruction of physical and biogenic habitat (Duffy et al., 2006). They are also used by humans as packing material, children's toys, fertilizers, and animal feeds (ADB et al., 2014). We thus expect MPAs to increase their presence in the benthos.

Seagrass presence was negligible excepted in two sites: Black Diamond and Masapold, the two unprotected zones of this study. Hence, when comparing each non-MPA site with the closest one, matching depth, the seagrass population was significantly higher in non-protected zones than in protected ones. However, this result should be considered with caution as it could reflect local seagrass beds and not an MPA-effect.

Indeed, when considering other factors that could explain an under-representation of seagrass in protected zones, none is conclusive. Fishes and sea urchins can negatively impact seagrass growth and production, by feeding on them (Duffy et al., 2006). Here we did not monitor the urchins, but we found no significant differences in the herbivorous population inside or outside MPAs. On another hand, macroalgae that adapt better in polluted environments tend to substitute seagrass in continuous dystrophic conditions (Mocenni and Vicino, 2006). In addition, in Masapold, the lower presence of seagrass in non-MPAs is concomitant with a higher presence of algae, but this correlation is not observed in Black Diamond.

### 4.1.6 Sponge

Sponges represent 4% of the overall population reported, with a high variability between sites and depths. South Dauin has both the highest and the lowest proportion of sponges reported. The population is similar between protected and unprotected zones, excepted in Southern Dauin with less sponges reported in the MPA Masapold South than in the non-MPA Masapold, both at 10m. However, this is not observed at 5m. Encrusting sponge is the main genera reported over Dauin's coastline. Encrusting sponge and rope sponges appears more frequent in protected zones than unprotected ones. Inversely, our study suggests that branching sponges and tube sponge are more frequent in non-MPAs than in MPAs.

Sponges fulfill several functions in reef ecosystems: they provide an important physical habitat in seagrass systems, water clearance, and a shelter for many animals (Duffy et al., 2006). Interestingly, according to our measures, the sponge and seagrass populations does not appear to be correlated. Sponges also threaten reef-building corals expansion and health. This is likely due to a combination of shading, physical inhibition of water flow and gas exchange. They also produce allelopathic metabolites that may impact coral physiology, reproduction, and susceptibility to bleaching or pathogenesis (Porter and Targett, 1988, Pawlik et al., 2007, Loh et al., 2015). Spongivorous fish thus play a regulatory role in the sponges / coral competition. In the absence or low presence of sponge predators, such as in overfished areas, coral overgrowth by sponges can be increased by 3 folds (Loh et al., 2015). Following this hypothesis, the lower presence of sponges in the Masapold South MPA would support its efficiency. However, this should be further confirmed: we did report the presence of spongivorous fish (Pomacanthidae, Labridae, Monacanthidae, Ostraciidae and Tetraodontidae species), but we did not detail the sponges population according to their palatability, nor analyze the correlation between them, and finally, whether this would be influenced by the site protected status.

### 4.1.7 Hydroids

Hydroids are minor components of the benthos, averaging 0.81% of the overall categories.

We report a significantly higher hydroid population in the northern MPA site, Bulak, when compared to its adjacent unprotected site, Black Diamond. Benthic hydrozoans are considered as good indicators species of environmental conditions. Morphological changes in individual colonies may indicate turbulent conditions or heavy metal disturbance, while changes in abundance and distribution of hydrozoan species can indicate hydrodynamic condition or climate changes, as well as an anthropogenic impact. Human activities impact hydrozoan assemblages in their composition and species richness (Yilmaz et al., 2019). In this study, we did not detail the hydroid population at the species level, however our results highlight the relevancy of such further studies to assess Dauin's MPA effectiveness.

## 4.2 Reef impacts and mortality

Assessment of coral health indicate that local stressors are causing coral mortality within the Dauin reefscape. An average of 10 impacts were reported per transect, with a great heterogenicity along the coastline. Whilst most impacts such as direct destruction, disease and *Drupella* spp. feeding activity affect all or most survey sites, other impacts are more site specific. The highest impacts were found in Lipayo and Maayong Tubig, while the less impacted sites were also MPAs: Poblacion District II and Bulak. Acropora was the most impacted genera but was also the more frequent in our study. However, it was less exposed to bleaching, the first cause of impact on corals, than all other genera.

### 4.2.1 Trash and direct destruction

Trash and direct destruction were reported in most sites. They vary with location as some sites are more famous for diving activities and therefore attract many visitors every day who are susceptible to damage the reef. The highest destruction was observed in Lipayo, Masapold and Maayong Tubig. Snorkeling and SCUBA diving can contribute to direct and indirect reef degradation. The tourist activity generated by protected areas would be unfortunately counterproductive, as damages caused by fins and boat anchor contribute to the destruction of the coral skeleton. Accordingly, we reported more impacts in MPA than non-MPA sites, with an average of 21.5 vs 17.3 impacts per site. We also reported 2.8 times more diving boats in protected sites than in non-MPAs. In addition to destruction from tourism, we noticed the presence of *muro-ami* fishing in Lipayo, Masapold South and Masapold. In this Japanese method, nets are maintained by stones or rocks that are pounded into the reefs, causing skeletal coral damage. *Muro-ami* was banned in Philippines since 1986, due to the tremendous damage it causes to coral reefs. Our report suggests that enforcement measures of Dauin's MPAs can be straightened.

### 4.2.2 Coral Bleaching

Coral bleaching accounted for most of reef impacts but concerned exclusively the Southernmost part of Dauin: Masapold South, Masapold and Maayong Tubig, the latter harboring the highest bleaching impacts. Interestingly, South Dauin is where we reported most of ancient dead coral. Coral bleaching was more present in MPAs than in non-MPAs. This probably reflects an over-representation of MPA sites and should be confirmed by further studies, but is still noteworthy as is unexpected for protected zones. Coral bleaching presence only at South sites is not correlated to coral species. Indeed, Anacropora spp. were only reported in South Dauin, however bleaching was not systematic in those species; and we did not report these species in Maayond Tubig, where the highest coral bleaching was observed. Finally, bleaching-sensitive corals, such as species of Acropora and Pocillopora, are present all along Dauin's coastline, and not restricted to the South, where bleaching is observed. Coral bleaching presence only at South sites would more reflect a persistent local effect.

Corals are highly dependent on their symbiotic algae zooxanthellae for their growth, reproduction and maintenance. Environmental stressors can disrupt their symbiotic relationship and cause bleaching, the loose of zooxanthellae and their photosynthetic pigments. Bleaching can be caused by sedimentation, disease, variations in light and sea surface temperatures, freshwater flooding and pollution; the two latter being common direct anthropogenic stressors for localized bleaching events (West et al., 2003). Corals may recover but prolonged exposure can result in mortality, which favors algal overgrowth, as seen here in South Dauin. Finally, Maayond Tubig, where we report the highest impacts and coral bleaching, is also the barangay with the highest population density.

### 4.2.3 Diseases and corallivores

Physical damages to the coral skeleton make it more susceptible to secondary stressors. After injury, coral diverts its energy to the repair and regeneration of tissue (D'Angelo et al., 2012). The energetic cost of repair would increase disease susceptibility by lowering the immune responses of the corals (Mullen et al., 2004). Furthermore, the lesions caused by fragmentation could be sites for the introduction of pathogens, increasing vulnerability to disease (Bright et al., 2016). Lesions may also attract corallivores (Brawley et al., 1982, Morton et al., 2002, Chong-Seng et al., 2011), which are vectors for disease (Sussman et al., 2003, Williams et al., 2005, Gignoux-Wolfsohn et al., 2012).

COTs feeding scars have only been recorded at Poblacion District I at 10m, the site where we reported the highest *Echinopora* spp. presence. This is surprising as *Acanthaster* spp. are generally preferring fast growing, opportunistic corals such as branching Acropora and Pocillopora species. Even if predation on the genus Echinopora was observed, this coral is generally avoided by COTs as it defends itself from predation by juvenile Acanthaster planci and kills the predator (Johansson et al., 2016).  COTs have also been seen near survey sites of some other locations such as Masapold South, but outside of the transect area.

*Drupella* spp. feeding activity was reported in many sites, similarly between MPAs and non-MPAs. Its highest impact is reported in Lipayo and Masapold South, the two sites where Muro-ami fishing was reported. Both sites also harbor high records of other impacts, including unknown scarring and genera-specific diseases. Of note, we did not report *Drupella* spp. feeding activity in Fungia, Porites and Cyphastrea coral species.

The interactions between coral bleaching and disease are complex, as we still question whether bleaching would be the result of an infection, would facilitate disease outbreaks, or if both would have synergistic effects on coral mortality (Ban et al., 2014). In this study, we report some sites with disease impacts only, while corals affected by bleaching in South Dauin were all disease-affected. The corals vulnerability to bleaching and disease may be genera specific, as *Fungia* spp. and *Cyphastrea* spp. were only affected by bleaching, while the three other species were affected by both impacts, with a different impact pattern.

Unfortunately, we cannot conclude that MPAs have a benefic effect on coral impacts. This must be confirmed by further studies, restricted to more local sites as we highlight local discrepancies.

## 4.3 Reef fish community structure

### 4.3.1 Fish families

A total of 36 fish families were recorded along the Dauin inshore reef. The total species richness is 244; with almost half of it represented by three species: Labridae, Pomacentridae and Chaetodontidae. Species diversity ranged from 46 to 85 species per site, with a great heterogenicity between sites and depths, without clear local pattern. However, the fish communities are similar between the locations along the coastline, depth of the measure and amount of coral cover. Species diversity does not seem to be influenced by the coral health. Varying species diversities were found in South Dauin, where the dead coral, impacted coral and algae covers were the highest. For example, the highest species diversity was found in Poblacion District II at 10m and Maayond Tubig at 10m. In those sites, coral impacts were respectively the lowest and the highest.

Not surprisingly, Pomacentridae represents the major abundance (70.23%), biomass (21.29%) and species richness (45) of reef fish along Dauin's coastline. Pomacentridae is one of the most abundant and ecologically diverse families of coral reef fishes. This coral-dwelling specialist is highly dependent on living coral for shelter and food (Wilson *et al*., 2008).

Fish abundance and biomass are expected to be higher in protected areas, with lower fishing pressure allowing fish to multiply and grow to adult size. In our study, the fish communities do show slight differences between protected and unprotected zones. However, fish abundance was slightly higher in unprotected zones, statistically representing a weak difference between fish populations in MPAs and non-MPAs. However, this became not significant when analyzing the fish populations within the two depths. No differences were observed when comparing fish biomass. MPAs implementation increase abundance, biomass, size of organisms and species diversity within the MPA (Roberts *et al*., 2001). A review of 89 MPA studies reported that on average, creating a marine reserve doubles density, triples biomass, and raises organism size and diversity by 20-30% relative to the unprotected areas (Halpern *et al*., 2003). However, the fish density in 30% of these reserves did not differ from that of adjacent fished sites, and in 7% of these reserves, fish density was lower compared with fished sites (Halpern *et al*., 2003). A further review of 21 protected areas mitigates MPAs effects on reef fish: they showed an impact on density and a suggestive one for the organism size, but no significant impact on biomass or species richness (Lester *et al*., 2008). Here, fish diversity is not linked to the MPA size. We found similar high fish diversity in Poblacion District II and Poblacion District I, while these MPA are respectively the smallest and greatest.

Several variables can influence the impact of protected areas on biodiversity: species composition, adult mobility, home range size of fish within the reserve, and the types and quality of habitats both inside and outside the reserve (Halpern *et al*., 2003). Furthermore, the intensity of fishing occurring outside a reserve can have a large impact on the reserve protection (Halpern *et al*., 2003). In this study, we did not monitor the fishing activity nearby protected zones, but we did observe fishing boats around and inside the MPAs, with a similar frequency for both zones. Added to the *muro-ami* fishing reported in two MPAs, this suggests that compliance to the protected status is not total in Dauin MPAs.

Our result cannot conclude on Dauin MPAs' efficiency on fish abundance and biomass, however a positive impact on threated species should be considered. We report the presence of 2 vulnerable species, *Oxymonacanthus longirostris* and *Epinephelus fuscoguttatus*, and one near threated specie, *Scarus hypselopterus*, in four protected areas: Poblacion District I and II, Masapold North and Masapold South.

#### 4.3.2 Trophic structures

Coral reefs are amongst the more productive ecosystems. Over the last three decades, living coral cover has declined roughly 40% in the Indo-Pacific. The decline in live coral cover affects coral structural complexity, with severe consequences on trophic structure and biodiversity (Birkeland 2015, Alvarez-Filip et al., 2009, Good et al., 2021). Reef degradation impacts the abundance and diversity of associated fish. Functional group analyses are used to examine how reef fish assemblages respond to disturbances and habitat degradation, due to their classification based on trophic level, ecological role, body size, home range, habitat association, or a combination of these factors (Graham et al., 2006). Along Dauin's reefscape, the prevalence of trophic groups varies with study sites, with no clear spatial pattern. The trophic structure supports a high prevalence of habitat generalists, consisting largely of herbivore & planktivores, strictly planktivores and omnivores.

Piscivore & mobile invertebrate feeders also contribute to the community structure by their biomass. Frequent and intense coral loss result in a reef fish community dominated by habitat generalists at the expense of coral-dwelling specialists, as habitat generalists appear more resilient to changing resource and habitat availability (Bellwood et al., 2006, Wilson et al., 2008). Whether the trophic structure of the Dauin inshore reef is indicative of post-disturbance recovery will require continued monitoring of trophic structuring.

Our study suggests that the reef fish populations could be different in MPAs and non-MPAs, but this should be further confirmed. Herbivore & planktivores were the main category in both areas, however the planktivore group was more important in protected zones than unprotected ones, where omnivores exceeded them. Though a review showed that MPAs implementation are associated with higher fish density and biomass for all functional groups (Halpern et al., 2003), other studies challenges that. Effects of reserves vary for different taxonomic groups and not all species increase in response to reserve protection (Lester et al, 2009, Maliao et al., 2009).

### 4.3.3 Commercially important fish

The direct removal of reef fish from the ecosystem has also been explored; 72 commercially important fish species (33% of total species richness) across 18 different fish families were identified in Dauin. Labridae, Lutjanidae, Mullidae, Serranidae and Acanthuridae were the most abundant commercially important fish families, with Lutjanidae, Caesonidae and Serranidae being the biggest contributors to biomass. Top-trophic level species are preferentially fished, and thus expected to increase with protection because of the elimination of fishing mortality in the reserves (Roberts 1997, Jennings 2001, Russ 2006). Along with that, the increase in the overall density of fishes in Philippine marine reserves was largely accounted for by exploited fishes (Maliao *et al*., 2009). In our study, the piscivore density and abundance appears higher in MPAs, but should be further confirmed, considering the MPA over-representation in our study and low proportion of this trophic group. The relative abundance and biomass of these commercially important fish species varied greatly between sites, with a tendency towards higher values in North Dauin. We found no significant difference in community composition of commercially important species between protected and unprotected zones.

Reduction of live coral and increased algal cover can lower abundance of fish that associate with corals as juveniles and may therefore result in changes to adult communities (Wilson *et al*., 2008). Furthermore, human fishing is size-selective, preferentially removing the largest individuals. Intensive fishing induces fish phenotypes towards the predominance of smaller and earlier-maturing individuals, which produce smaller and less viable larvae. Both contribute to declining fish biomass (Fidler *et al*., 2018). MPAs implementation have demonstrated to increase the average of fish body-size and age within MPAs compared to fished reefs (Lester *et al*., 2009), due in part to a shift towards advantageous phenotypes that are known to confer higher fecundity (Fidler *et al*., 2018). Along with increased fish abundance, reserves can potentially produce more offspring than exploited populations. Reserves are thus predicted to supply fisheries by spillover of juveniles and adults into fishing grounds (Roberts *et al*., 2001). When the length at first maturity was available, the size distribution of the population could be examined to determine the proportion of juveniles vs adults. We only report exclusive or mainly juvenile populations of *Myripristis murdjan, Lutjanus argentimaculatus, Plotosus lineatus* and *Lutjanus fulvus*. Species with exclusive or main adult population were *Siganus guttatus, Epinephelus merra, Lutjanus vitta* and *Thalassoma hardwicke*. Only *Parupeneus multifasciatus* appeared to have more balanced juvenile and adult proportion. Considering the sample size of data available, those results should be confirmed, and we did not further analyze the fish populations between protected and unprotected zones.

### 4.3.4 Reef fish and structural complexity

Coral structural complexity is a key habitat feature 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 many species inhabiting coral reefs. As such, structural complexity of coral reefs drives numerous functions linked to the resilience of these ecosystems (Done et al., 1997, Fisher et al., 2007). Dauin's reefscape is uneven, with sand-dominated structures and coral fields.

The sites with the highest reef rugosity were all protected zones, while unprotected sites harbor the lowest rugosity. This suggests a favorable more complex habitat in MPAs than in non-MPAs. However, the correlation between rugosity and fish community structure, abundance or biomass was not significant in our study. Considering the over-representation of MPAs in the study design, our result should be further confirmed.

The species richness and abundance of reef fish communities have often been related to structural topographic complexity; a measure of variation in the vertical relief of the habitat (Risk 1972, Luckhurst et al., 1978, Friedlander et al., 2003). High topographic complexity may promote high abundance and diversity due to increased refuge availability, decreased encounter rates between competitors and their prey, consequently reducing the effects of predators and competition (Sano et al., 1987, Hixon et al., 1991, Beukers et al., 1997, Almany 2004). The species accumulation curve in Dauin has not yet begun to plateau, with results not yet supportive of habitat complexity dictating species richness. Settlement patterns and habitat preferences of coral reef fish within the Dauin inshore reef will become apparent with continued monitoring and will be important for targeted management and habitat enhancement.

## 4.4 Limits to MPA efficiency and further studies

Here we could not report significant increases in fish abundance, biomass diversity and fish size as commonly reported in MPAs (Roberts *et al.*, 2001). The recovery process of fish populations in reserves is complex and is influenced by a wide range of factors.

### 4.4.1 MPA size and age

Dauin's MPA are relatively small (<1km2). The effect on the reserve size on its efficiency is related to the magnitude of its impact. Some studies showed positive effects on fish parameters even in small MPAs (Halpern *et al.*, 2003, Lester *et al.*, 2009). Many reported no correlation between the MPA size or age and fish parameters, but a greater absolute difference for larger and older reserves (Halpern *et al.*, 2003, Maliao *et al.*, 2009). Otherwise, bigger reserves are more efficient because the number of fish that benefit from it is more important. Additionally, bigger reserves provide several habitats that can benefit to some fish, and thus protect adequately all their life stages (Halpern *et al.*, 2003). Added to the size, the spacing between MPAs is crucial to account for ecological connectivity, such as natural variation in larval dispersal distances (Weeks *et al.*, 2010, Green *et al.*, 2014). However, the current extent, distribution, and size of Philippines MPAs are inadequate to fulfill conservation objectives (Weeks *et al.*, 2010).

### 4.4.2 Enforcement level

Some studies demonstrated that the density of exploited fishes in less-enforced reserves decreased after years of protection, suggesting poaching. Forbidden fishing in marine reserves is among the major cause of their reduced efficiency in the Philippines (Christie et al., 2002, Walmsley and White 2003, Maliao et al., 2009). It is also suggested that the presence of MPA and initial improved fish abundances may attract fisher while coral reef conditions worsen throughout the Philippines (Christie et al., 2002). This emphasizes the importance of community-based management systems and enforcement level. The latter is critical for effectively protecting fish populations inside MPAs. Without adequate investment in human and financial capacity, marine reserves cannot reach optimal conservation outcomes (Maliao et al., 2009, Di Franco et al., 2016, Gill et al., 2017). Dauin has become a coastal and dive tourism hub in the province. A significant increase in the population is expected as more businesses and expatriates are established. Therefore, enforcement of local MPAs to regulate tourism and prevent fishing activities is of major importance for the reefscape (Oracion 2019).

### 4.4.3 Further studies

This study was the first encompassing the seven Dauin protected zones and had the objective to report an overview of the reefscape in terms of benthic characterization and fish communities. The subdivision in three zones, i.e. North, Central and South Dauin was used to investigate whether the coastline would be subjected to local effect. We clearly observed different dynamics in these three zones, suggesting local ecological processes and anthropogenic factors impacting the reefscape. Differences between MPAs can be considerable, even between close sites. Therefore, further studies should assess MPAs effectiveness one by one, as combining fish population parameters and benthic measures from heterogenous sites could be misleading. Furthermore, each MPA should be paired to a close non protected zone, to ensure good representativity of both study groups. Those parameters should increase representativity and significance of the measures, which were missing in this study. Finally, a monitoring for several years would enhance comprehension of Dauin’s protected zones functioning and dynamics. This would further serve as a feedback to enforcement measures efficiency or provide arguments to enhance them.

# 5. CONCLUSION

## 5.1 Benthic characterization

Half of Dauin's benthic cover is composed of abiotic components, mainly sand; while the biotic components are mainly coral, algae and sponge. Acropora, Anacropora, Porites, Echinopora and Pocillopora species are the dominant corals reported. Algae population was mainly composed of Turf, Coralline and Halimeda algae. Among sponges that remained minor in Dauin's reefscape, encrusting sponges are the major genera reported.

## 5.2 Coral impacts

Local stressors are causing coral mortality within the Dauin reefscape. The more frequent impacts were bleaching, *Drupella* spp. feeding and direct destruction. Acropora, the main coral present in Dauin, was the most impacted genera. We cannot conclude that MPAs have a benefic effect on coral impacts in Dauin. We reported more impacts in protected sites than in unprotected sites, concomitant to the presence of diving boats and fishing tracks in MPAs.

## 5.3 Reef fish community structure

We report 36 fish families with a species richness of 244; almost half of it represented by three species: Labridae, Pomacentridae and Chaetodontidae. The trophic structure supports a high prevalence of habitat generalists. We cannot conclude on Dauin MPAs' efficiency on increasing fish abundance and biomass and we found no difference in the commercially important species, however the MPAs may have a positive impact on threated species. Finally, the correlation between rugosity and fish community structure, abundance or biomass was not significant.

## 5.4 Local effects

Nevertheless, this study highlights clear local differences that can guide further studies.

South Dauin is characterized by dominance of Anacropora corals, high dead coral and algae covers and coral bleaching. When comparing the populations in the Masapold South MPA to the non-MPA Masapold, Porites spp., dead coral and algae populations were superior in the MPA; while Anacropora spp. and sponges populations were inferior in the protected zone. Central Dauin is characterized by dominance of Porites corals, a high algae cover, COT feeding scars presence in Poblacion District I, and the absence of *Drupella spp.* feeding. North Dauin is characterized by dominance of Acropora corals and the lowest dead coral cover. When comparing the populations in the Bulak MPA to the non-MPA Black Diamond, *Porites* spp. and hydroids were more present, while *Acropora* spp. were less present in the protected zone.

## 5.5 Limits to MPA efficiency and further studies

Our results underline the need for further studies across Dauin's coastline in order to assess MPAs efficiency and guide the different stakeholders towards better enforcement measures and compliance to the protected status of already implemented MPAs. The most suitable option to submit to the local government at this stage would be to make a case for the unification of MPAs to create a much larger area. Not only this would benefit to the marine biodiversity, but also to the local population that highly depend on the reef for subsistence.

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# 7. APPENDIX

## 7.1 Abiotic data table

| Site Name | Depth (m) | Replicate | Survey Date | Season | Fishing Boats | Dive Boats |
|---|---|---|---|---|---|---|
| Bulak | 5 | A | 30/01/2020 | WET | 0 | 0 |
| | 10 | A | 07/09/2019 | WET | 1 | 0 |
| | 5 | A | 13/04/2019 | DRY | 1 | 0 |
| | | B | 25/06/2019 | DRY | 0 | 1 |
| | 10 | A | 13/04/2019 | DRY | 0 | 9 |
| | | B | 12/07/2019 | DRY | 0 | 0 |
| Black Diamond | 10 | A | 24/10/2019 | WET | 1 | 0 |
| | | B | 22/11/2019 | WET | 0 | 0 |
| | 10 | A | 03/04/2019 | DRY | 0 | 0 |
| | | B | 06/07/2019 | DRY | 1 | 0 |
| Lipayo | 5 | A | 19/10/2019 | WET | 0 | 9 |
| | | B | 23/01/2020 | WET | 0 | 0 |
| | 10 | A | 24/09/2019 | WET | 0 | 0 |
| | | B | 23/11/2019 | WET | 0 | 2 |
| | 5 | A | 12/04/2019 | DRY | 0 | 0 |
| | | B | 24/05/2019 | DRY | 0 | 0 |
| | 10 | A | 12/04/2019 | DRY | 0 | 0 |
| | | B | 24/05/2019 | DRY | 1 | 0 |
| Poblacion disctrict 1 | 5 | A | 17/08/2019 | WET | 3 | 2 |
| | 10 | A | 19/09/2019 | WET | 0 | 1 |
| | | B | 15/10/2019 | WET | 0 | 0 |
| | 5 | A | 27/03/2019 | DRY | 0 | 2 |
| | | B | 27/06/2019 | DRY | 0 | 1 |
| | 10 | A | 27/03/2019 | DRY | 0 | 1 |
| | | B | 20/07/2019 | DRY | 0 | 2 |
| Poblacion disctrict 2 | 5 | A | 18/11/2019 | WET | 1 | 1 |
| | | B | 26/11/2019 | WET | 1 | 0 |
| | 10 | A | 21/11/2019 | WET | 3 | 1 |
| | 5 | A | 23/03/2019 | DRY | 0 | 2 |
| | | B | 22/05/2019 | DRY | 0 | 2 |
| | 10 | A | 25/03/2019 | DRY | 1 | 0 |
| | | B | 18/07/2019 | DRY | 0 | 1 |
| Masapold North | 5 | A | 12/09/2019 | WET | 1 | 0 |
| | | B | 25/11/2019 | WET | 2 | 1 |
| | 10 | A | 10/09/2019 | WET | 0 | 0 |
| | 5 | A | 26/03/2019 | DRY | 0 | 1 |
| | | B | 10/07/2019 | DRY | 0 | 1 |
| | 10 | A | 26/03/2019 | DRY | 0 | 0 |
| | | B | 23/05/2019 | DRY | 2 | 1 |
| Masapold South | 5 | A | 21/08/2019 | WET | 0 | 1 |
| | 10 | A | 22/08/2019 | WET | 0 | 0 |
| | | B | 14/11/2019 | WET | 0 | 0 |
| | 5 | A | 22/04/2019 | DRY | 0 | 0 |
| | | B | 04/07/2019 | DRY | 0 | 3 |
| | 10 | A | 22/04/2019 | DRY | 0 | 0 |
| | | B | 27/05/2019 | DRY | 0 | 2 |
| Masapold | 5 | A | 26/08/2019 | WET | 1 | 1 |
| | 10 | A | 26/08/2019 | WET | 1 | 1 |
| | | B | 15/11/2019 | WET | 0 | 0 |
| | 5 | A | 23/04/2019 | DRY | 0 | 0 |
| | | B | 01/07/2019 | DRY | 0 | 1 |
| | 10 | A | 23/04/2019 | DRY | 0 | 2 |
| Maayong Tubig | 5 | A | 27/11/2019 | WET | 1 | 1 |
| | | B | 24/01/2020 | WET | 0 | 1 |
| | 10 | A | 26/10/2019 | WET | 0 | 1 |
| | 5 | A | 29/04/2019 | DRY | 0 | 1 |
| | | B | 11/07/2019 | DRY | 1 | 1 |
| | 10 | A | 28/04/2019 | DRY | 0 | 0 |
| | | B | 17/07/2019 | DRY | 0 | 1 |

## 7.2 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 | OA | 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 | | |

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

## 7.3 Additional figures

| | SOUTH | | | | | | | | CENTRAL | | | | NORTH | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Site* | *16* | *17* | *14* | *15* | *12* | *13* | *3* | *4* | *1* | *2* | *5* | *6* | *8* | *9* | *7* | *10* | *11* | ***all sites*** |
| *Depth* | *5m* | *10m* | *10m* | *5m* | *10m* | *5m* | *10m* | *5m* | *10m* | *5m* | *10m* | *5m* | *10m* | *5m* | *10m* | *10m* | *5m* | |
| **Abiotic** | 41,70 | 51,37 | 40,15 | 47,30 | 12,55 | 43,19 | 51,07 | 44,12 | 37,27 | 52,86 | 52,49 | 43,61 | 40,99 | 56,77 | 54,40 | 76,13 | 90,10 | ***49,19*** |
| **Coral** | 10,90 | 13,17 | 23,84 | 14,80 | 51,66 | 25,20 | 7,92 | 2,22 | 39,64 | 29,22 | 30,90 | 39,65 | 30,51 | 20,14 | 25,27 | 6,10 | 2,20 | ***21,86*** |
| **Dead Coral** | 25,40 | 13,30 | 4,50 | 8,13 | 4,33 | 21,43 | 7,85 | 37,44 | 3,28 | 3,11 | 3,15 | 2,08 | 12,46 | 12,12 | 0,83 | 0,30 | 0,03 | ***9,42*** |
| **Algae** | 16,97 | 8,73 | 8,57 | 3,27 | 15,84 | 8,09 | 12,59 | 10,69 | 8,95 | 8,59 | 9,74 | 11,29 | 7,35 | 4,59 | 7,13 | 4,50 | 3,17 | ***8,87*** |
| **Sponges** | 2,43 | 5,73 | 10,00 | 0,27 | 3,73 | 0,61 | 11,32 | 3,56 | 5,46 | 1,97 | 2,24 | 1,95 | 7,12 | 2,98 | 3,23 | 3,77 | 1,80 | ***4,00*** |
| **Seagrass** | 0,57 | 0,13 | 1,80 | 22,17 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,70 | 0,00 | 0,00 | 0,00 | 2,91 | 7,43 | 0,00 | 0,00 | ***2,11*** |
| **Other live** | 1,07 | 5,13 | 6,30 | 2,23 | 3,96 | 0,64 | 3,07 | 0,10 | 0,87 | 1,30 | 0,70 | 0,30 | 0,97 | 0,15 | 0,30 | 2,87 | 0,97 | ***1,83*** |
| **Octocorals** | 0,87 | 1,17 | 4,67 | 1,70 | 5,40 | 0,57 | 2,67 | 0,61 | 0,60 | 0,90 | 0,17 | 0,17 | 0,19 | 0,04 | 0,43 | 1,80 | 0,03 | ***1,31*** |
| **Hydroids** | 0,10 | 0,17 | 0,10 | 0,07 | 0,13 | 0,07 | 2,40 | 0,51 | 3,52 | 0,77 | 0,00 | 0,17 | 0,07 | 0,04 | 0,37 | 3,97 | 1,23 | ***0,81*** |
| **Other Hexacorals** | 0,00 | 0,83 | 0,00 | 0,07 | 1,04 | 0,20 | 0,50 | 0,64 | 0,07 | 0,50 | 0,57 | 0,73 | 0,04 | 0,07 | 0,53 | 0,57 | 0,30 | ***0,40*** |
| **Unknowns** | 0,00 | 0,27 | 0,03 | 0,00 | 1,01 | 0,00 | 0,50 | 0,06 | 0,27 | 0,07 | 0,03 | 0,00 | 0,22 | 0,19 | 0,07 | 0,00 | 0,10 | ***0,16*** |
| **Bivalves** | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,10 | 0,03 | 0,07 | 0,00 | 0,00 | 0,07 | 0,07 | 0,00 | 0,00 | 0,00 | 0,00 | ***0,02*** |

4 lowest average values | 4 highest average values

***Table. 7.3.1***. Relative mean transect cover of major benthic categories along Dauin Reef survey sites. MPAs are in white and non-MPAs in grey.

| Family | Genus | Species | n= |
|---|---|---|---|
| *Acanthuridae* | *Acanthurus* | *auranticavus* | 10 |
| *Acanthuridae* | *Acanthurus* | *pyroferus* | 21 |
| *Acanthuridae* | *Ctenochaetus* | *striatus* | 462 |
| *Acanthuridae* | *Naso* | *hexacanthus* | 1 |
| *Acanthuridae* | *Naso* | *lituratus* | 7 |
| *Acanthuridae* | *Naso* | *unicornis* | 12 |
| *Apogonidae* | *Ostorhinchus* | *hartzfeldii* | 10 |
| *Lutjanidae* | *Lutjanus* | *monostigma* | 2 |
| *Lutjanidae* | *Lutjanus* | *rivulatus* | 4 |
| *Lutjanidae* | *Lutjanus* | *russellii* | 4 |
| *Lutjanidae* | *Lutjanus* | *vitta* | 8 |
| *Lutjanidae* | *Macolor* | *macularis* | 11 |
| *Lutjanidae* | *Lutjanus* | *argentimaculatus* | 16 |
| *Lutjanidae* | *Lutjanus* | *biguttatus* | 40 |
| *Lutjanidae* | *Lutjanus* | *decussatus* | 18 |
| *Lutjanidae* | *Lutjanus* | *fulvus* | 13 |
| *Monacanthidae* | *Amanses* | *scopas* | 198 |
| *Mugilidae* | *Crenimugil* | *seheli* | 27 |
| *Caesionidae* | *Pterocaesio* | *pisang* | 104 |
| *Caesionidae* | *Pterocaesio* | *tessellata* | 191 |
| *Caesionidae* | *Pterocaesio* | *tile* | 182 |
| *Haemulidae* | *Plectorhinchus* | *chaetodonoides* | 5 |
| *Haemulidae* | *Plectorhinchus* | *polytaenia* | 5 |
| *Holocentridae* | *Myripristis* | *murdjan* | 28 |
| *Labridae* | *Anampses* | *meleagrides* | 1 |
| *Labridae* | *Cheilinus* | *chlorourus* | 3 |
| *Labridae* | *Cheilinus* | *fasciatus* | 10 |
| *Labridae* | *Cheilinus* | *oxycephalus* | 3 |
| *Labridae* | *Cheilinus* | *trilobatus* | 5 |
| *Labridae* | *Cheilio* | *inermis* | 17 |
| *Labridae* | *Coris* | *batuensis* | 12 |
| *Labridae* | *Coris* | *gaimard* | 23 |
| *Labridae* | *Gomphosus* | *varius* | 37 |
| *Labridae* | *Halichoeres* | *scapularis* | 34 |
| *Labridae* | *Hemigymnus* | *melapterus* | 5 |

| Family | Genus | Species | n= |
|---|---|---|---|
| *Labridae* | *Novaculichthys* | *taeniourus* | 8 |
| *Labridae* | *Oxycheilinus* | *digramma* | 4 |
| *Labridae* | *Thalassoma* | *hardwicke* | 10 |
| *Labridae* | *Thalassoma* | *lunare* | 397 |
| *Lethrinidae* | *Lethrinus* | *atkinsoni* | 2 |
| *Lethrinidae* | *Lethrinus* | *erythracanthus* | 1 |
| *Lethrinidae* | *Monotaxis* | *grandoculis* | 1 |
| *Mullidae* | *Parupeneus* | *barberinus* | 47 |
| *Mullidae* | *Parupeneus* | *ciliatus* | 1 |
| *Mullidae* | *Parupeneus* | *crassilabris* | 13 |
| *Mullidae* | *Parupeneus* | *cyclostomus* | 12 |
| *Mullidae* | *Parupeneus* | *multifasciatus* | 193 |
| *Mullidae* | *Parupeneus* | *pleurostigma* | 6 |
| *Mullidae* | *Upeneus* | *tragula* | 7 |
| *Nemipteridae* | *Scolopsis* | *bilineata* | 70 |
| *Nemipteridae* | *Scolopsis* | *ciliata* | 89 |
| *Pinguipedidae* | *Parapercis* | *cylindrica* | 3 |
| *Plotosidae* | *Plotosus* | *lineatus* | 470 |
| *Scaridae* | *Chlorurus* | *bleekeri* | 19 |
| *Scaridae* | *Scarus* | *ghobban* | 1 |
| *Scaridae* | *Scarus* | *tricolor* | 3 |
| *Serranidae* | *Cephalopholis* | *argus* | 15 |
| *Serranidae* | *Cephalopholis* | *boenak* | 1 |
| *Serranidae* | *Cephalopholis* | *miniata* | 3 |
| *Serranidae* | *Cephalopholis* | *sonnerati* | 1 |
| *Serranidae* | *Cephalopholis* | *urodeta* | 15 |
| *Serranidae* | *Epinephelus* | *fuscoguttatus* | 2 |
| *Serranidae* | *Epinephelus* | *merra* | 20 |
| *Serranidae* | *Plectropomus* | *laevis* | 3 |
| *Serranidae* | *Pseudanthias* | *squamipinnis* | 2 |
| *Siganidae* | *Siganus* | *corallinus* | 2 |
| *Siganidae* | *Siganus* | *guttatus* | 28 |
| *Siganidae* | *Siganus* | *puellus* | 1 |
| *Siganidae* | *Siganus* | *virgatus* | 12 |
| *Synodontidae* | *Saurida* | *gracilis* | 2 |

***Table. 7.3.2***. Commercially Important Fish Species recorded during the survey year.

| Family | Total species richness |
| --- | --- |
| Labridae | 45 |
| Pomacentridae | 43 |
| Chaetodontidae | 15 |
| Acanthuridae | 13 |
| Scaridae | 13 |
| Serranidae | 12 |
| Apogonidae | 11 |
| Lutjanidae | 11 |
| Mullidae | 10 |
| Pomacanthidae | 7 |
| Lethrinidae | 6 |
| Holocentridae | 5 |
| Siganidae | 5 |
| Balistidae | 4 |
| Blenniidae | 4 |
| Caesionidae | 4 |
| Haemulidae | 4 |
| Monacanthidae | 4 |
| Nemipteridae | 4 |
| Tetraodontidae | 4 |
| Pinguipedidae | 3 |
| Ostraciidae | 2 |
| Synodontidae | 2 |
| Aulostomidae | 1 |
| Carangidae | 1 |
| Centriscidae | 1 |
| Cirrhitidae | 1 |
| Ephippidae | 1 |
| Gobiidae | 1 |
| Grammistidae | 1 |
| Mugilidae | 1 |
| Muraenidae | 1 |
| Pempherididae | 1 |
| Plotosidae | 1 |
| Sphyraenidae | 1 |
| Zanclidae | 1 |

***Table. 7.3.3***. Fish families recorded along Dauin reefs and their associated species richness.

| | 1 | | | 2 | | | 3 | | | 4 | | | 5 | | | 6 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ |
| Length | 25.2 | 43.7 | -18.6 | 61.2 | 229.0 | -167.8 | 34.8 | 126.3 | -91.5 | 22.7 | 257.8 | -235.2 | 70.2 | 148.4 | -78.2 | 174.5 | 111.9 | 62.6 |
| ± | 25.8 | 27.1 | | 25.9 | 66.8 | | 17.5 | 53.3 | | 13.0 | 5.0 | | 32.4 | 75.3 | | 61.7 | 62.2 | |
| Rq(RMS) | 1.2 | 1.9 | -0.8 | 11.2 | 23.0 | -11.8 | 1.4 | 6.3 | -4.8 | 1.0 | 8.8 | -7.8 | 2.5 | 6.1 | -3.6 | 20.7 | 8.6 | 12.1 |
| ± | 0.4 | 1.0 | | 7.8 | 8.4 | | 0.6 | 2.0 | | 0.2 | 0.3 | | 1.1 | 2.7 | | 4.8 | 2.7 | |
| Slope | 0.2 | 0.0 | 0.2 | 0.5 | -0.4 | 0.9 | -0.1 | 0.1 | -0.2 | -0.1 | 0.0 | -0.2 | 0.0 | 0.0 | 0.0 | 0.5 | -0.4 | 0.8 |
| ± | 0.1 | 0.1 | | 0.4 | 0.2 | | 0.1 | 0.1 | | 0.2 | 0.0 | | 0.1 | 0.1 | | 0.3 | 0.6 | |
| Variation | 9.7 | 17.7 | -8.1 | 33.6 | 86.7 | -53.1 | 7.4 | 38.5 | -31.1 | 5.9 | 77.3 | -71.5 | 19.4 | 40.3 | -20.9 | 90.2 | 45.5 | 44.7 |
| ± | 10.3 | 11.8 | | 23.3 | 27.7 | | 5.6 | 18.4 | | 2.8 | 11.0 | | 11.4 | 26.2 | | 29.1 | 24.4 | |
| Range | 3.6 | 6.0 | -2.4 | 28.1 | 70.7 | -42.5 | 4.0 | 17.6 | -13.6 | 3.3 | 29.8 | -26.5 | 7.9 | 19.4 | -11.5 | 63.7 | 25.2 | 38.5 |
| ± | 1.6 | 3.0 | | 23.7 | 31.6 | | 2.0 | 8.4 | | 0.8 | 0.9 | | 2.9 | 9.1 | | 18.3 | 11.5 | |

| | 7 | | | 8 | | | 9 | | | 10 | | | 11 | | | 12 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ |
| Length | 26.2 | 45.5 | -19.3 | 39.1 | 39.9 | -0.8 | 95.6 | 102.5 | -7.0 | 59.2 | 165.4 | -106.2 | 103.8 | 55.5 | 48.4 | 164.9 | 156.0 | 8.9 |
| ± | 21.8 | 13.0 | | 7.7 | 25.5 | | 22.6 | 55.7 | | 15.2 | 67.7 | | 41.8 | 25.5 | | 88.9 | 55.3 | |
| Rq(RMS) | 0.9 | 1.1 | -0.2 | 2.7 | 2.7 | 0.0 | 2.6 | 6.2 | -3.6 | 3.2 | 14.2 | -11.0 | 6.4 | 2.3 | 4.1 | 9.4 | 7.2 | 2.2 |
| ± | 0.8 | 0.8 | | 1.3 | 1.4 | | 1.8 | 1.7 | | 1.2 | 3.9 | | 1.8 | 0.3 | | 3.5 | 2.8 | |
| Slope | 0.0 | 0.1 | -0.1 | 0.2 | 0.0 | 0.2 | 0.0 | -0.1 | 0.1 | 0.2 | -0.4 | 0.5 | -0.1 | 0.1 | -0.1 | -0.2 | -0.2 | -0.1 |
| ± | 0.1 | 0.1 | | 0.2 | 0.2 | | 0.1 | 0.3 | | 0.1 | 0.2 | | 0.3 | 0.2 | | 0.1 | 0.2 | |
| Variation | 6.1 | 9.8 | -3.7 | 12.6 | 11.8 | 0.7 | 21.0 | 23.9 | -2.9 | 14.5 | 60.3 | -45.8 | 24.7 | 14.2 | 10.6 | 41.4 | 40.2 | 1.3 |
| ± | 6.3 | 4.5 | | 3.9 | 8.9 | | 10.8 | 6.5 | | 3.7 | 13.3 | | 6.3 | 6.0 | | 21.0 | 14.3 | |
| Range | 2.3 | 5.4 | -3.1 | 7.3 | 7.7 | -0.3 | 8.2 | 19.3 | -11.0 | 9.1 | 46.5 | -37.4 | 19.6 | 8.1 | 11.5 | 29.1 | 23.4 | 5.7 |
| ± | 2.1 | 2.2 | | 3.0 | 5.6 | | 4.4 | 5.7 | | 3.8 | 15.4 | | 5.9 | 1.7 | | 13.8 | 10.9 | |

| | 13 | | | 14 | | | 15 | | | 16 | | | 17 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ | Dry | Wet | Δ |
| Length | 34.4 | 247.2 | -212.8 | 32.6 | 65.0 | -32.4 | 75.4 | 33.1 | 42.3 | 93.6 | 123.4 | -29.8 | 95.2 | 150.8 | -55.6 |
| ± | 12.4 | 72.9 | | 25.6 | 38.1 | | 29.1 | 16.7 | | 32.9 | 74.1 | | 29.8 | 86.9 | |
| Rq(RMS) | 4.1 | 22.8 | -18.7 | 2.5 | 3.8 | -1.2 | 1.9 | 1.7 | 0.2 | 8.7 | 18.0 | -9.3 | 12.0 | 6.3 | 5.6 |
| ± | 1.2 | 6.9 | | 1.5 | 2.3 | | 0.9 | 1.3 | | 2.4 | 8.2 | | 3.3 | 1.4 | |
| Slope | 0.4 | 0.4 | 0.0 | -0.2 | -0.1 | -0.1 | 0.0 | 0.0 | 0.0 | 0.4 | -0.6 | 1.0 | 0.7 | 0.1 | 0.6 |
| ± | 0.1 | 0.3 | | 0.3 | 0.1 | | 0.1 | 0.1 | | 0.3 | 0.2 | | 0.7 | 0.2 | |
| Variation | 13.6 | 85.9 | -72.4 | 11.0 | 15.0 | -4.0 | 14.1 | 6.7 | 7.4 | 31.1 | 54.0 | -22.9 | 51.4 | 41.7 | 9.8 |
| ± | 6.3 | 25.2 | | 7.3 | 9.7 | | 5.3 | 4.4 | | 9.1 | 28.4 | | 8.8 | 22.5 | |
| Range | 12.3 | 65.5 | -53.2 | 7.1 | 10.0 | -2.9 | 6.5 | 4.1 | 2.4 | 26.2 | 52.0 | -25.8 | 40.1 | 21.5 | 18.7 |
| ± | 5.9 | 18.1 | | 4.7 | 7.3 | | 3.5 | 3.7 | | 7.6 | 27.8 | | 9.2 | 6.4 | |

***Table. 7.3.4***. 3D metrics (length, rugosity, slope, variation, range with ± (arb. units)) along Dauin Reef survey sites separated by season.