people and the sea

CORAL REEF MONITORING REPORT 2018

Malapascua - Daanbantayan

Alicia Dalongeville (Lead Science Officer)
Axelle Jorcin (Co-Founder)
Ian Mills (Co-Founder)

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

This report summarises the findings of data collected from January to December 2018, as well as historical data collected since 2016 through the reef monitoring activities carried out by People and the Sea in the Municipality of Daanbantayan, Province of Cebu, Philippines. The collected data include benthic cover, hard coral lifeforms, coral impacts and stressors, coral recruitment, density and diversity of reef associated and commercially important fish species, as well as abundance of invertebrate species that are indicators of reef health.

As most of coral reefs worldwide, reefs in the Philippines show declining coral cover due to a variety of stressors. Most significant among these are overexploitation, direct impact of human activities and climate change. The coral reefs of Malapascua are prone to natural threats (typhoon, predation) as well as anthropogenic impacts such as destructive fishing practices, damages by touristic activities and water pollution. The results presented in this report aim to describe the health of Malapascua reefs and better understand how they respond to the different stressors.

Percentage hard coral cover across all surveyed sites is found to have increased since previous years to a current value of 33.7 (± 3.7) %, which represents an increase of 6.3% compared to the survey period of 2016. The coral impacts survey results show high occurrence of physical damages (8.9 ± 1.5 occurrences per 100m^2), predation (6.0 ± 1.1 per 100m^2) and recently killed corals (6.1 ± 1.5 per 100m^2). The mean fish density is slightly higher than the previous year, with a current value of 0.36 (± 0.03) fish/m^2 representing an increase of 6.7% compared to 2017. However, commercial fish species and large fish occur at very low abundance (0.044 ± 0.013 commercial fish/m^2). The abundance of coral predators, calculated from 100m^2 transect belts, is higher in 2018 than in previous years, with +0.27 *Acanthaster planci*, +5.47 *Drupella spp.* and +5.01 *Coralliophylia violacea* per 100m^2 in the three-years period. This drastic increase is related to the increase of coral cover, but may negatively impact reef health if the density of predators raises above sustainable levels (*i.e.* when the rate of coral regeneration becomes lower than the feeding rate of their predators).

Overall, the results may indicate a positive trend of coral recovery from previous damages caused by typhoons and human activities, although the low density and small sizes of exploited fish and invertebrate species still indicate overharvesting. Thanks to its long-term monitoring programme, People and the Sea collects data that aims to support the sustainable use of marine and coastal resources. Our objective is to engage with Local Government Unit (LGU) and the community of Malapascua to work together toward a community-based marine resource management and conservation model.

CONTRIBUTORS

This report was produced thanks to the work of the previous Lead Scientists of People and the Sea: Kim Jaloustre, Glyn Barret, Lucy Harding and Lee Hankinson, and with contribution of current site staff: Katie Burkart (Dive Manager), Roberta Cozzolino (Field Scientist), Aleja Genisan (Project Manager) and Sean Ross (Site Manager).

AKNOWLEDGEMENT

The work completed by People and the Sea would not have been possible without the hard work of all our volunteers and staff members. Our mission of conserving the beautiful coral reefs of the Philippines can only be successful through integration with coastal communities who rely on them so much. We would like to express our heart-felt gratitude to all devoted staff members working alongside the local community of Malapascua towards a healthy and sustainable future. The people of Malapascua have been welcoming and supportive since the beginning and we will continue to do all we can to give something back to them in return.

We are also very grateful for all the amazing and dedicated volunteers who have spent time working with us to collect such a huge volume of data over the past four years. As an organisation, we could not continue to promote marine conservation and raise environmental awareness without your support.

We would like to express our gratitude to our collaborators who kindly reviewed this report: Lee Hankinson, Klaus Stiefel, Glyn Barrett & Simone Franceschini.

And finally we would like to thank Barangay Logon, the Municipality of Daanbantayan and all of the local associations and businesses that have also shown their support and appreciation for the work we have conducted. We look forward to continuing to strengthen and develop these partnerships in the future, for the benefit of all.

INTRODUCTION

Coral reefs are ecologically important ecosystems hosting more than 35% of all living marine organisms, and supporting the livelihood of about half a billion people worldwide (Knowlton et al. 2010). Often called the 'rainforest of the oceans' because of their high productivity, biodiversity and crucial role in carbon sequestration, coral reefs provide numerous ecosystem services to human populations from coastal protection against waves and erosion to economic and cultural resources via fisheries and tourism (Harris et al. 2018). The core of all reef ecosystems are Scleractinian (reef-building) corals which offer shelter, food, habitat and nursery areas to various fish and invertebrate species (Graham and Nash 2013).

Worldwide, the health and survival of corals is threatened by several stressors, both natural (typhoon, predation) and anthropogenic (damages induced by human activities). Anthropogenic threats can be direct – destructive fishing practices (dynamite fishing, bottom trawling), damages by touristic activities (anchors, divers) – and indirect – water pollution, ocean acidification and warming caused by climate change (Hughes et al. 2003). Furthermore, as a result of climate change and an increasing human population, the frequency and intensity of coral stressors are rising, thereby jeopardising the long-term persistence of coral reef ecosystems, with potentially disastrous consequences for marine biodiversity and the human populations that these ecosystems support (Halpern et al. 2015; T. P. Hughes et al. 2003). The social, cultural and economic risks and costs of deteriorating reef quality are severe, and in order to better understand this phenomenon and counteract it, long-term monitoring of coral reefs is necessary – to provide data that can support action in a meaningful capacity.

A. Coral Reef Monitoring

The Philippine archipelago consists of more than 7,000 islands, most of which are fringed with coral reefs. The Philippines Sea encompasses about 25,000 km^2 of coral reefs (Allen 2008) and is part of the Coral Triangle region. Recognised as a marine biodiversity hotspot, the Coral Triangle hosts 605 zooxanthellate corals including 15 endemic species (76% of the world's total known species; Veron et al., 2009) and concentrates 52% of the Indo-pacific reef fish species on only 3% of the surface area (Allen 2008). These reefs supply resources for over 370 million people, a third of which depend directly on marine resources for their livelihood (Hoegh-Guldberg et al. 2009). In 2010 about 1.5 million Filipinos depended directly on the fishing industry for livelihoods (FAO 2014). In addition, coral reefs offer important alternative sources of income for many coastal communities via the tourism industry.

The central Philippines islands hosts particularly high levels of marine biodiversity (Carpenter and Springer 2005), and their coral reefs support about 20% of the total fisheries production of the country (Alcala and Russ 2002). However, coral reef resources of the Philippines have been exploited beyond sustainable levels, leading to a drastic erosion of coral cover and biodiversity. The first national assessment of coral reefs in the

Philippines was conducted from 1976 to 1981, and showed that 70.1% of the reefs were in "poor" and "fair" condition (<50% of live coral cover; Gomez, Aliño, Yap, & Licuanan, 1994). Recently, Licuanan et al. (2017) found that the amount of coral reefs in poor and fair conditions increased to 90% in only 35 years. This rapid decline is attributed to the many stresses pressing on coral reefs in the Philippines, mainly due to overexploitation, direct impact of human activities and climate change (Licuanan et al. 2017).

The urgent need to protect coastal resources of the country through improved resource management and conservation measures has been recognized by many institutions and local communities (Beger et al. 2004; Gomez et al. 1994). Key elements for developing effective conservation strategies include community involvement, co-operation of institutions and stakeholders in the area and long-term monitoring of coral reef health and biodiversity (Beger et al. 2004; Flower et al. 2017). Monitoring provides information on the state of the reefs and how they vary spatially and temporally. Long-term monitoring allows studying the impacts of natural and anthropogenic stressors, assessing reef recovery after disturbances, and measuring the success of conservation strategies (Day 2008; English, Wilkinson, and Baker 1997).

B. People and the Sea Organisation

People and the Sea (PepSea) has been created to respond to the need to protect coastal resources. Founded in 2014, PepSea is a marine conservation NGO, based on the island of Malapascua, in the Central Visayas region of the Philippines. Its mission is to promote capacity building and community-based marine resource management and conservation as a way to alleviate poverty and increase the resilience of coastal communities.

PepSea is a volunteer operating organisation, using citizen science to conduct coral reef monitoring and biodiversity assessments. Our volunteer training program allows for collection of long-term data that are shared with the Municipal Environment and Natural Resource Office (MENRO). PepSea aims to implement collaborations with governmental institutions such as the Department of Environment and Natural Resources (DENR) and the Bureau of Fisheries and Aquatic Resources (BFAR) in an effort to inform sustainable marine resource management initiatives.

C. Program Aims

Malapascua is a 2km^2 island located in the province of Cebu in the Visayan Sea, a key area in the Philippines known for its abundance and diversity of marine resources. The island hosts approximately 6000 inhabitants and supports a rapidly developing tourism industry. Fishing and tourism are the main sources of income for the community, with dive tourism alone fuelling approximately 80% of the local economy (Oliver et al. 2019, 2011). Hence the island population strongly depends on healthy coral reefs for food intakes and revenue. Coral reefs are now severely degraded due to decades of unsustainable fishing practices, natural damage from storms, as well as boat and diver impacts, nutrient loading, coral diseases and predators outbreaks (Oliver et al. 2019, 2011).

As with most islands in the central Visayas, fishing is carried out using Bangkas, traditional Filipino boats. The main fishing techniques include long lines, gillnets, spearfishing and fish traps. Dynamite fishing was likely previously used around the island but has decreased with the development of tourist diving activities since 2001. However, this destructive technique is still in use in the wider Municipality.

Malapascua is also situated in a typhoon-prone area. The two most recent to have directly caused damage to the island (Super-Typhoons Yolanda and Ruby in 2013 and 2014 respectively) are known to have had considerable effects on the surrounding reef. However, as no known monitoring took place prior to these natural disturbances, their impacts cannot be quantified.

The main objective of the coral reef monitoring project implemented by People and the Sea is to draw a baseline of the coral reefs condition and biodiversity in the Daanbantayan area, and to provide data to inform the establishment of sustainable marine resource conservation and management plans. Specifically, the aims of PepSea's survey activities in the year 2018 were to:

- Assess benthic cover composition, in particular evaluate coral coverage and substrate composition
- Evaluate coral recruitment rates
- Assess diversity and abundance of indicator and commercially targeted fish species
- Assess density of indicator invertebrate species, coral predators and commercially targeted invertebrate species.
- Quantify natural and anthropogenic impacts on corals

This report presents the results of PepSea monitoring program after four years of data collection. A methodology section describes the survey area, the volunteer training process, the survey methods and the data analyses. Results and discussion sections present the findings, conclusion and considerations drawn from the data over the four-year period.

METHODOLOGY

A. Study Area and Survey Sites

The survey area is located around the island of Malapascua (Barangay Logon), part of the Municipality of Daanbantayan, located in the Province of Cebu, Philippines (Figure 1). Malapascua island is 1km wide and 2.5 km long, and its marine habitat is characterised by small shallow patch reefs (<1km^2). Its climate is characterised by two predominant winds: *Amihan*, a North-Eastern wind which occurs from October to May/June and *Habagat*, a South-Western wind blowing the rest of the year that is usually accompanied by typically heavier rainfalls.

Currently, there are Municipal Ordinances designating 11 protected areas within the Municipality of Daanbantayan. The name, status and ordinance numbers of these protected areas are given in Table 1, and their location within the municipality are shown in Figure 1.

Table 1: Protected areas designated by Municipal Ordinance within the Municipality of Daanbantayan.

Name	Barangay	Status	Ordinance #
Dakit Dakit	Logon	Snorkelling and No-fishing zone	07-2010
Silangga	Logon	Snorkelling and No-fishing zone	07-2010
Kang Katao	Logon	Snorkelling and No-fishing zone	07-2010
Coral Garden	Logon	Snorkelling and No-fishing zone	07-2010
Bantigue	Logon	Snorkelling and No-fishing zone	07-2010
Lapus Lapus	Logon	Marine Reserve	05-2010 as Amended
Monad Shoal		Marine Reserve	05-2010 as Amended
Gato Island		Marine Reserve	05-2010 as Amended
Awo	Agujo	Marine Reserve and Protected Area	06-2010
Koral	Agujo	Marine Reserve and Protected Area	06-2010
Malbago	Malbago	Marine Reserve and Protected Area	06-2010

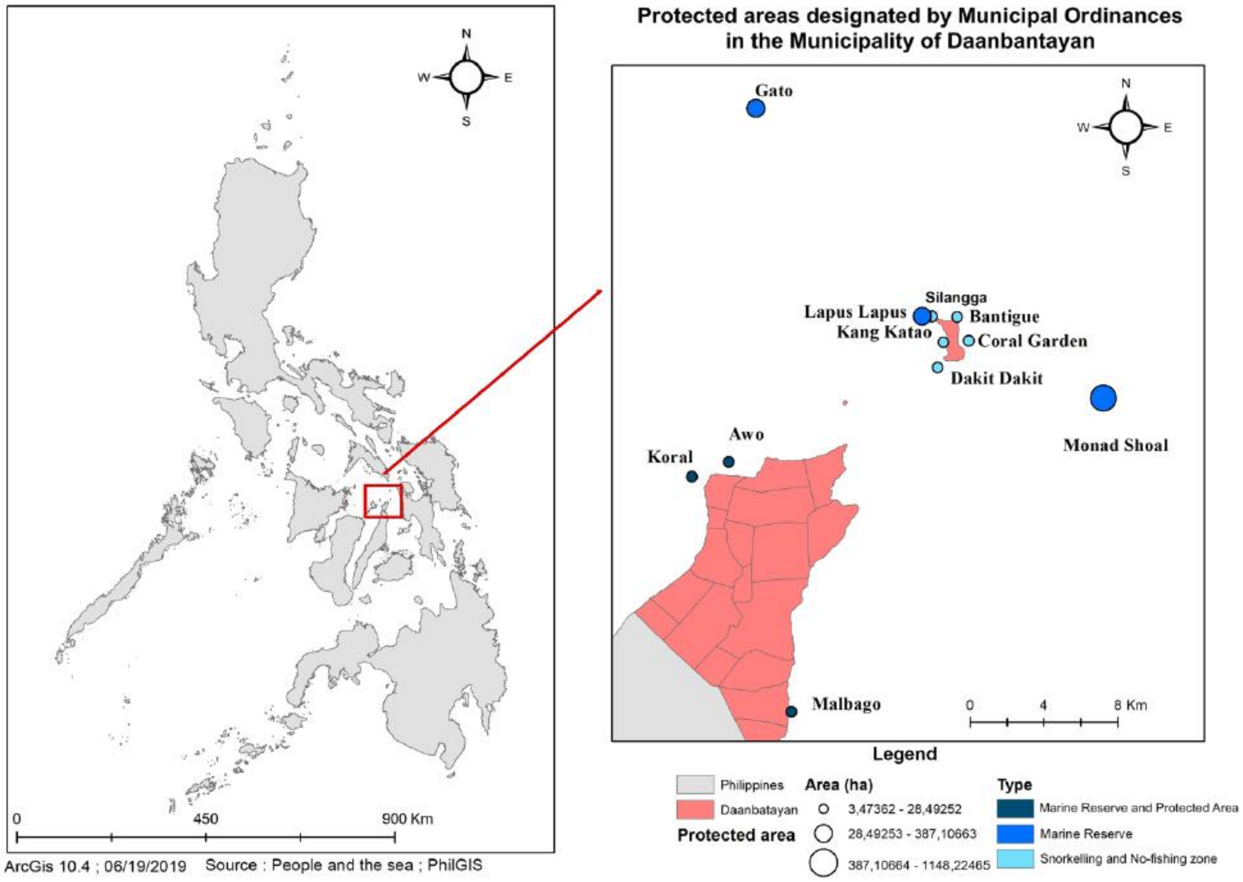

Figure 1. Situation map showing the location of the 11 protected areas within the Municipality of Daanbantayan. When the ordinance did not specify the GPS coordinates of the protected zone (all Marine Reserves and Snorkelling and No-fishing zones), the area covered by the protection status represents our interpretation of the text of the ordinance.

Only the Municipal Ordinance designating the three Marine Reserves and Protected Areas specifies the GPS coordinates of the protected zones. For the other areas, the boundaries and surface covered by the protection status represent our interpretation of the text of the ordinance. All ordinances describe some level of protective measures for the marine ecosystem including prohibitions of all kinds of fishing activities, marine life collection and habitat destruction, disposal of waste materials and restrictions on the use of diving and snorkelling gear that can encourage environmental disturbances. Yet physical markers delineating the protected sites are still lacking in the three Marine Reserves and the five Snorkelling and No-fishing zones surrounding Malapascua. In addition, enforcement of the ordinances is currently lacking in all of these designated areas, and illegal fishing is regularly observed.

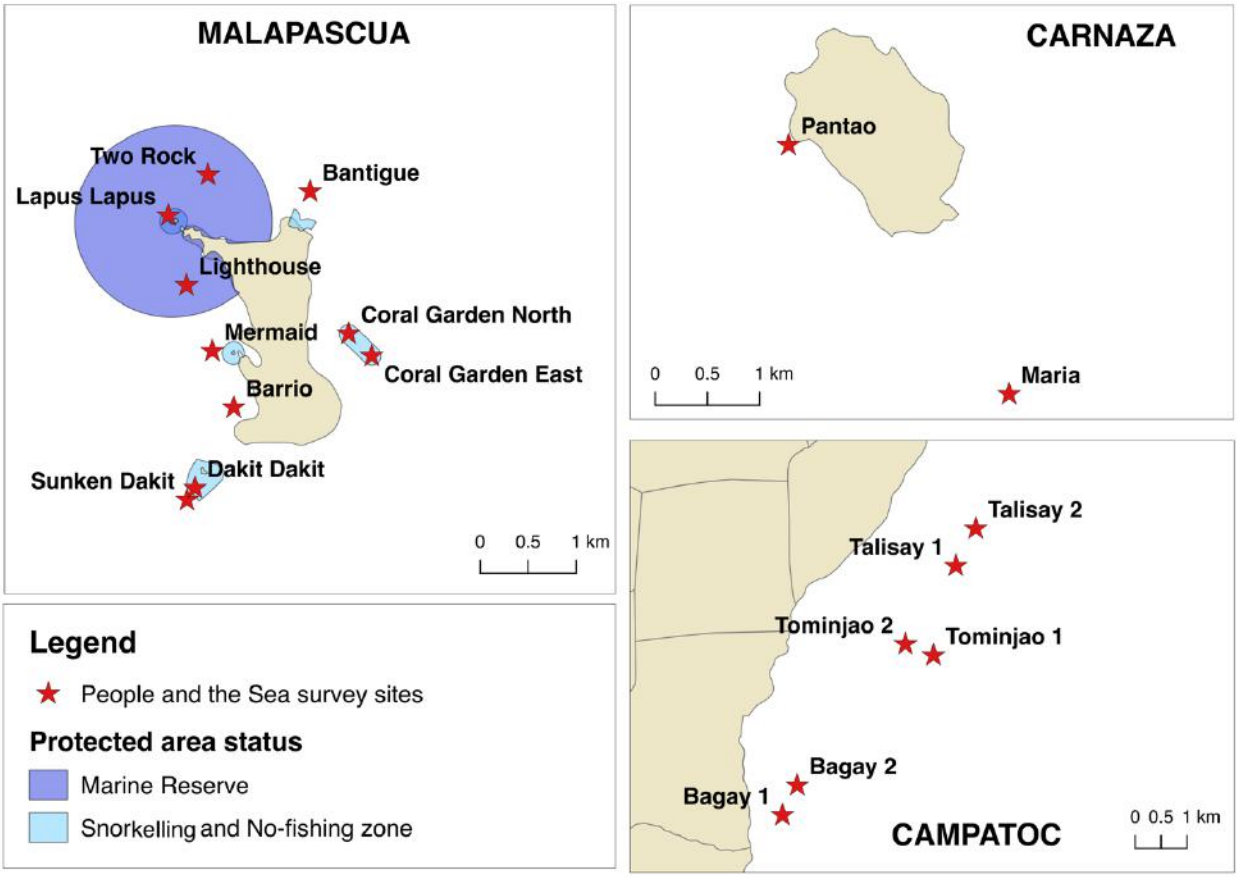

Figure 2. Location of the 18 survey sites within Daanbantayan Municipal waters.

PepSea currently have 18 permanent survey sites (Figure 2): 10 are located around the island of Malapascua, six in the Campatoc Shoal area (on the eastern coast of Daanbantayan mainland) and two are located around the island of Carnaza. Since our objective is a long-term monitoring of changes in coral reefs, we chose to use permanent sites rather than haphazard (random) transects. Indeed, permanent sites provide more precise information than random sites because there is no need to account for spatial variability, and interpreting their results is easier for the general public (Hill and Wilkinson 2004). The sites have been chosen to be representative of the coral reefs found in the area in terms of habitat, environmental conditions, degradation and protection level. Site selection also included practical considerations: easily accessible, waves and current exposure allowing diving under most conditions and depths allowing one-hour dive within no-decompression limits. Within each site, the transects are randomly placed to ensure that they are representative of the site.

At present, 14 of these sites are monitored annually and four biannually. There is a trade-off between the frequency of monitoring and the number of locations to monitor. The *Methods for Ecological Monitoring of Coral Reefs* (Hill and Wilkinson 2004) and the *Coral Reef Monitoring Manual* (Obura 2014) recommend monitoring surveys to be carried out every year, at the same season (within 1-2 months) to avoid bias due to seasonal variability. In addition, we randomly selected two sites in Campatoc and two sites in

Malapascua to be monitored twice a year in order to facilitate a more in-depth investigation into seasonal differences.

The coordinates, depth range and year of first monitoring of each site are summarized in Table 2. Each of the Malapascua and Carnaza sites comprises six permanent transects of 20m length, whereas the Campatoc sites are composed of three 30m long transects. The Campatoc sites have been established in coordination with the Municipal Environment and Natural Resource Office (MENRO). As a result, we kept their survey design (of three longer, 30m transects) to ensure compatibility with their adopted methodology. For all sites the transects are placed between 5 and 15 metres away from neighbouring transects. The beginning and the end of each transect is marked by an individually tagged metal rebar.

Table 2: Details of the 18 survey sites monitored in the PepSea program

Site Name	Area	GPS Coordinates (°)	Depth range (m)	First survey	Monitoring frequency
Coral Garden East	Malapascua	N11.33467 / E124.12467	3-4	2015	Annual
Dakit Dakit	Malapascua	N11.32292 / E124.10658	2-3	2015	Biannual
Lapus Lapus	Malapascua	N11.34809 / E124.10524	6-8	2015	Biannual
Lighthouse	Malapascua	N11.3414 / E124.10696	11-13	2015	Annual
Mermaid	Malapascua	N11.33512 / E124.10943	9-10	2015	Annual
Two Rocks	Malapascua	N11.35195 / E124.10902	4-7	2016	Annual
Coral Garden North	Malapascua	N11.33679 / E124.12247	2-3	2016	Annual
Barrio	Malapascua	N11.32999 / E124.11153	1.5-2.5	2016	Annual
Sunken Dakit	Malapascua	N11.3209 / E124.10701	2.5-3	2016	Annual
Bantigue	Malapascua	N11.35035 / E124.11879	9-11	2017	Annual
Bagay 1	Campatoc	N11.18901 / E124.04469	4-6	2016	Biannual
Bagay 2	Campatoc	N11.19438 / E124.04716	2.5-4.5	2016	Biannual
Tominjao 1	Campatoc	N11.21747 / E124.0714	4-6	2016	Annual
Tominjao 2	Campatoc	N11.21946 / E124.0664	5-6	2016	Annual
Talisay 1	Campatoc	N11.23339 / E124.07536	5.5-6.5	2016	Annual
Talisay 2	Campatoc	N11.24002 / E124.07891	10	2016	Annual
Maria	Carnaza	N11.49116 / E124.10944	8-10	2018	Annual
Pantao	Carnaza	N11.51299 / E124.09012	6-7	2018	Annual

B. Expeditions and Volunteer Training

PepSea expeditions consist of four-week volunteering programmes running continuously throughout the year typically involving three to seven volunteer divers. Within a year, each survey site is surveyed once (or twice for the biannual sites). The survey comprises four specific components: Benthic, Invertebrates & Impacts, Fish and Coral Recruitment.

The safety of all volunteers is the first priority of the program. Upon arrival, all volunteers are given a safety and emergency procedures briefing, and conservative diving guidelines are applied at all times during the expedition. All volunteers have to pass a 400m swim-test without mask or fins prior to enter any diving or snorkelling activities. In addition, all staff members are qualified Emergency First Responder or higher, and volunteers are trained to administer oxygen in the event of a diving related incident.

Non-certified diver volunteers undertake the PADI Open Water and Advanced Open Water (covering Boat, Peak Performance Buoyancy, Navigation, Fish ID and Deep Dive) courses the first week of the expedition. Already certified divers are evaluated by a check-dive, and all volunteers are trained in the use of compass, delayed surface marker buoys, and all survey specific equipment (tape reels, slates, plumb line, etc.). The training program allows all volunteers to gain sufficient diving experience in the local conditions, with a particular emphasis on good buoyancy and trim to avoid impacts on the ecosystem.

During the expedition, volunteers are trained to perform either benthic, invertebrates & impacts, coral recruits or fish survey. Only volunteers staying at least 8 weeks are trained for fish survey as the number of fish species/groups to learn (112) makes it challenging to achieve in the shorter training periods. The volunteers attend a series of lectures and presentations about specific terminology, biological and ecological concepts, and a comprehensive introduction to the marine life forms they will be surveying. Lectures are designed and given by marine biologists. Self-study materials are also available in the form of an electronic database of pictures, printed flashcards and ID books. During in-water training, volunteers undertake point-out dives with staff members, where they are shown the different marine organisms, substrates, coral impact and stressors they need to be able to identify as well as forms and species that could be misidentified. In a second phase, volunteers' abilities are tested through computer and in-water tests. Volunteers need to pass both exams with at least 90% before they can progress to survey training. Volunteers who do not pass all tests do not collect data, but can participate to surveys with alternative tasks (laying transects, videos or photography). To learn PepSea's survey methodology, volunteers conduct a land mock survey, and subsequent in-water practice surveys. During these practices, volunteers conduct the respective survey component they are trained on together with a staff member. Data recorded by volunteers and staff members are then compared, and discrepancies are debated using photographs taken by staff during the survey dive. This training continues until volunteers reach the level of competency required to conduct real surveys.

C. Survey Methods

PepSea's survey methodology has been designed in cognisance of a number of popular methodologies used by similar organizations (e.g. ReefCheck; Hodgson et al., 2004) and expanded upon (i.e. adding coral forms, additional invertebrate and impact categories and largely increase the target fish species list) to provide additional resolution to the data. For each transect, all four components of the survey are conducted on the same dive along the same transect tape.

1. Benthic Survey: Point Intercept Transects (PIT)

The Benthic survey aims to provide an estimation of benthic cover composition to inform about the reef topography, complexity and diversity. PepSea's benthic survey uses the Point Intercept Transect (PIT; Hill & Wilkinson, 2004) method (see Figure 3) and 30 benthic forms describing hard coral forms, algae, other sessile organisms (i.e. anemones, sponges, tunicates and soft corals) and substrates. The complete list and codes of the benthic forms are given in Appendix A.1.

Benthic forms are recorded every 25cm along a 20m (30m for Campatoc sites) transect, giving 80 sample points per transect (120 for Campatoc sites). The surveyor swims along the transect and drops a plumb line at each sampling point. The benthic form that the plumb line first lands on is recorded. This method is used to limit subjective bias that can be introduced in diver conducted surveys.

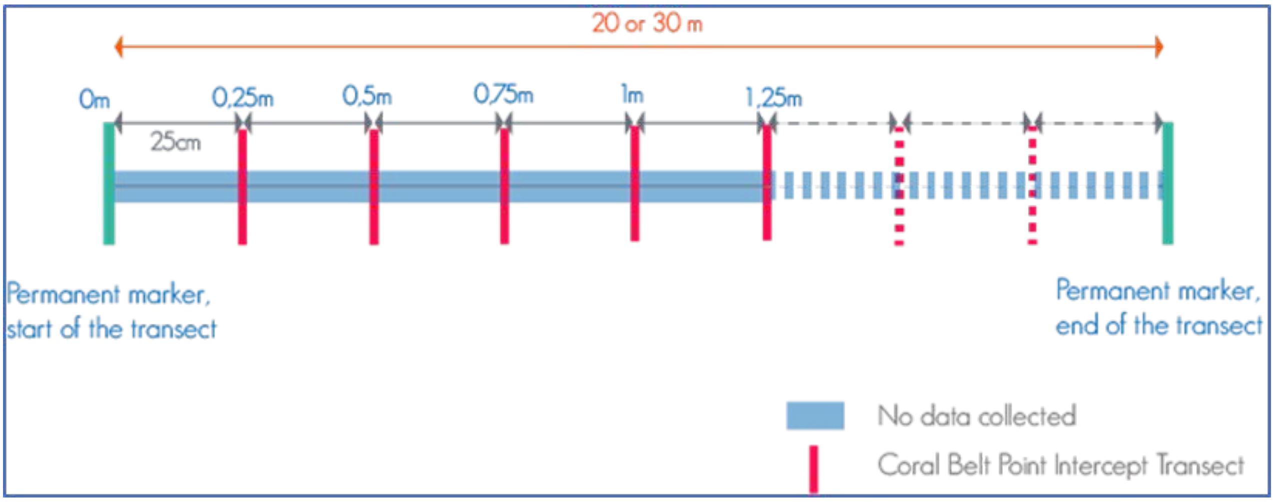

Figure 3. Point Intercept Transect (PIT) method used to conduct the benthic survey. The dark blue line represents the transect line. The pink lines mark the positions where data are collected (i.e. where the plumb line is dropped).

2. Invertebrates & Impacts Survey: Belt Transects (BT)

The Invertebrates and Impacts (I&I) survey aims to estimate: (*i*) the diversity and abundance of invertebrates with a special focus on reef heath indicator taxa and taxa targeted by local fisheries; and, (*ii*) the level of anthropogenic and natural impacts on corals, such as predation and physical damages. PepSea's I&I survey uses the Belt Transect (BT; Hill & Wilkinson, 2004) methods to record 21 invertebrate taxa and 10 types of reef impacts. The complete list of the targeted taxa and features is given in Appendix A.2.

The diver conducting the I&I survey dives as a buddy to the benthic PIT surveyor. Each BT is 5m wide (2.5 m on either side of the 20/30m transect line), hence a total surface area of 100m^2 (150m^2 for Campatoc sites) is surveyed. The diver swims in a U-shaped pattern and records all occurrence of targeted taxa and features within the BT (Figure 4).

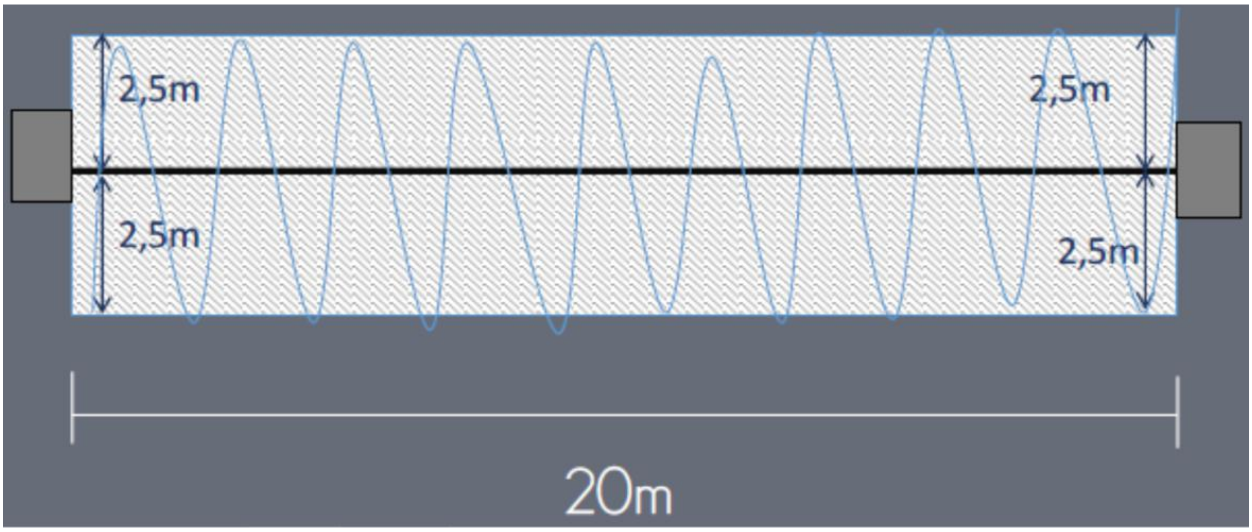

Figure 4. Belt Transect (BT) method used for the Invertebrates and Impacts survey. The black line represents the transect, and the blue line the trajectory of the diver swimming to record all occurrence of targeted taxa.

3. Fish Survey: Underwater Visual Census (UVC)

The fish survey is conducted first (before PIT, I&I and coral recruitment) to minimize the effect of behavioural avoidance of fish species towards divers. The fish survey aims to estimate the diversity and abundance of indicator and commercial fish species, in order to assess the reef fish assemblages and provide an insight into the state of local fisheries. Several practical and ecological criteria were applied to select the targeted fish species. First, they have to be easy to identify, hence: large enough, not too fearful of divers, and coloured or marked conspicuously enough to be easily distinguished. These criteria exclude cryptic fishes like many gobies and blennies, and favour diurnal mid-sized fishes like butterflyfish and Tetrodontidae (pufferfish, filefish and triggerfish). Then our fish list is tailored to the abundance of local fauna. This means excluding species which are so rare in the area that they are virtually never recorded, and species which are so common that they occur on every single survey dive and therefore provide little valuable information. Third, we target species which fulfill important ecological roles, such as grazers and corallivorous. We included commercial species targeted by local fisheries such as groupers, sweetlips, snappers and parrotfish. The full list of the 112 recorded fish species is given in Appendix A.3.

PepSea's fish survey uses the UVC method (Hill and Wilkinson 2004) to record fish targeted species. After the transect has been deployed all divers wait away from the transect for 10 minutes before starting the UWC. This waiting period allows fish to resume normal behaviour and return in the transect area (Hill and Wilkinson 2004). The surveyor swims along the transect at a constant, predetermined speed, one meter above the bottom, and records all occurrence of the targeted species. The survey area is 2.5m either sides of the transect tape and 2.5m above, hence a total volume of $250m^3$ is surveyed. The fish survey is conducted in eight or twelve minutes (depending on the length of the transect), allowing an accurate fish count while decreasing the impact of diver disturbance (Hodgson et al. 2004). To avoid double counting, we do not simultaneously survey two adjacent transects.

For commercial fish species, size estimation is used as a surrogate for the biomass and to assess the effect of fishing pressure on fish communities (Jennings and Polunin, 1996; Samoilys and Gribble, 1997). The fish groups that are sized are emperors (Lethrinidae), groupers (Serranidae), snappers (Lutjanidae) and parrotfish (Scaridae). Three size categories are recorded: Small (<15cm), Medium (15 to 30cm) and Large (>30cm). Volunteers are assessed on their sizing during training dives using plastic tubes of given length as a reference.

4. Coral Recruitment Survey

Coral recruitment survey is used to estimate reef regeneration. We define coral recruits as colonies visible to the naked eye whose dimension is ≥ 1cm and ≤ 5cm. The survey is conducted using $25cm^2$ quadrats placed along the belt, immediately adjacent to the transect line every two meters (Figure 5). Ten quadrats are completed per transect, alternatively on the left and the right side of the transect, with the first quadrat always starting on the left side for consistency. Individual coral recruits located within the quadrats were recorded and assigned to one of four size classes (1-1.9cm, 2-2.9cm, 3-3.9cm or 4-4.9cm size class).

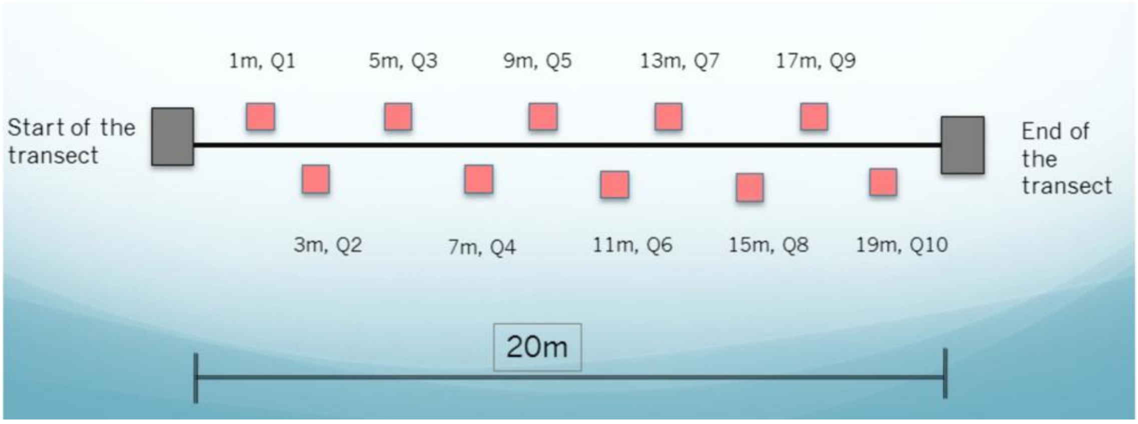

Figure 5. Coral recruitment survey. The black line represents the transect, and the red squares the 25cm^2 quadrats where coral recruits are counted.

5. Environmental Parameters

The following environmental parameters are recorded each day three times a day (at 7:30am, 12:30pm and 5:30pm):

- Air temperature - using an outdoor thermometer
- Overall weather (sunny, overcast, fair, cloudy, rainy or stormy) - estimated visually
- Cloud cover (per 20% increment) - estimated visually
- Wind speed - recorded from the Windfinder App
- Wind direction - recorded from the Windfinder App

During each survey dive, the following environmental parameters are recorded either on the boat or underwater:

- Overall weather (sunny, overcast, fair, cloudy, rainy or stormy) - estimated visually
- Cloud cover (in 20% increments) - estimated visually
- Incoming or outgoing tide – taken from tide tables
- Sea state, evaluated via the Beaufort scale - estimated visually
- Survey time
- Water salinity - measured from a water sample using a refractometer
- Water pH - measured from a water sample using a pH-meter
- Surface and bottom sea temperatures - read on surveyors' dive computer
- Depth at the beginning of each transect - read on surveyors' dive computer
- Horizontal visibility - estimated by divers using the transect tape
- Current strength (none, low, medium or strong) - estimated by divers

D. Data Analyses

For each survey site we calculated benthic cover and density of fish, invertebrate and coral impacts as an average of the six transects (three transects for the Campatoc sites). For the four sites that are monitored biannually, we took the average of the two annual surveys. To assess the temporal changes, we calculated the average benthic cover and density of fish, invertebrate and coral impacts per year from 2016 to 2018 for the 15 sites that have been surveyed over the whole period (nine sites in Malapascua and six in Campatoc; see Table 2). All analyses and graphs presented in the 'Results' section were done using the R software version 3.5.1 (R Core Team 2019).

Normality of the data was tested using a Shapiro-Wilk test (Shapiro and Wilk 1965) with a threshold p.value of 0.1, and verified by looking at their distribution on a histogram. For normally distributed variables (seven pairs of variables; see Appendix B.1), the correlation coefficient and its significance were calculated using the function *cor.test* in R with Pearson's method (Pearson 1948). For non-normally distributed data (12 pairs of variables), the Kendall method (Kendall 1948) was used with the same R function. The coefficients and p.values of all correlation tests, as well as the bivariate plots, are given in Appendix B.

RESULTS

A. Benthic Cover

Percentage benthic cover was determined from PIT surveys completed during the period January to December 2018 over 18 sites, among which 14 were surveyed once and four were surveyed twice. For the four sites that are monitored biannually, we took the average benthic percentage of the two surveys. In 2018, the mean reef builders (hard corals, fire coral *Millepora spp.* and blue coral *Heliopora spp.*) cover was 36.9 (± 3.8) %, and the mean soft coral cover 14.0 (± 6.0) % (Figure 6). Substrates suitable for corals to settle (rock and coralline algae) represent 19.6 (± 2.0) % of the benthic cover, whereas unstable substrates (sand, silt and rubble) cover 19.7 (± 3.6) % of the sea floor. Algae other than coralline (nutrient indicator algae, Halimeda and crustose) and other organisms (sponges, tunicates, hydroid, zoanthids, anemone and corallimorphs) represent respectively 6.7 (± 2.0) % and 1.5 (± 0.4) % of the mean 2018 benthic cover. Campatoc is the area with the highest reef builders cover (41.4 ± 6.5 %), and Malapascua has the largest proportion of soft corals (23.8 ± 10.1 %).

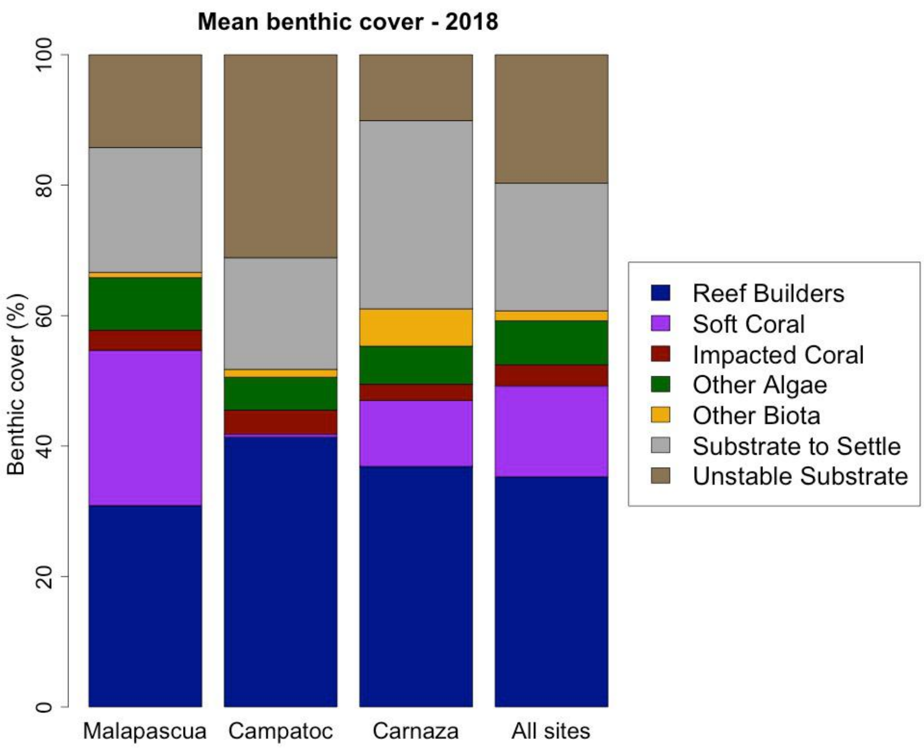

Figure 6. Benthic cover averaged for 2018 over the 10 sites surveyed in Malapascua, the six sites in Campatoc, the two sites in Carnaza, and overall 18 sites.

The site with the highest reef builders cover is Tominjao 1 (Campatoc) with 59.4%, and the site with the highest soft coral cover is Two Rocks (Malapascua) with 72.9% (Figure 7). The largest proportion of unstable substrates is found in Talisay 2 (Campatoc) with 58.3%, and Barrio (Malapascua) has the largest algae cover with 36.0%. In Malapascua, three sites in the North and South of the island (Two Rocks, Lapus Lapus and Sunken Dakit) are largely dominated by soft corals (Figure 7a), and four sites in the West and East are dominated by reef builders (Mermaid, Lighthouse, Coral Garden North and East; Figure 7a). Bantigue and Dakit Dakit show a mix of reef builders and soft corals, whereas Barrio's benthic cover is dominated by algae. Soft corals are almost absent from all Campatoc sites (Figure 7b). Four of these sites have a very high reef builders cover (Bagay 1 & 2 and Tominjao 1 & 2), whereas Talisay 1 & 2 are dominated by unstable substrates. In Carnaza, Maria shows a high cover of reef builders and soft corals, whereas Pantao is dominated by substrate to settle and reef builders (Figure 7c).

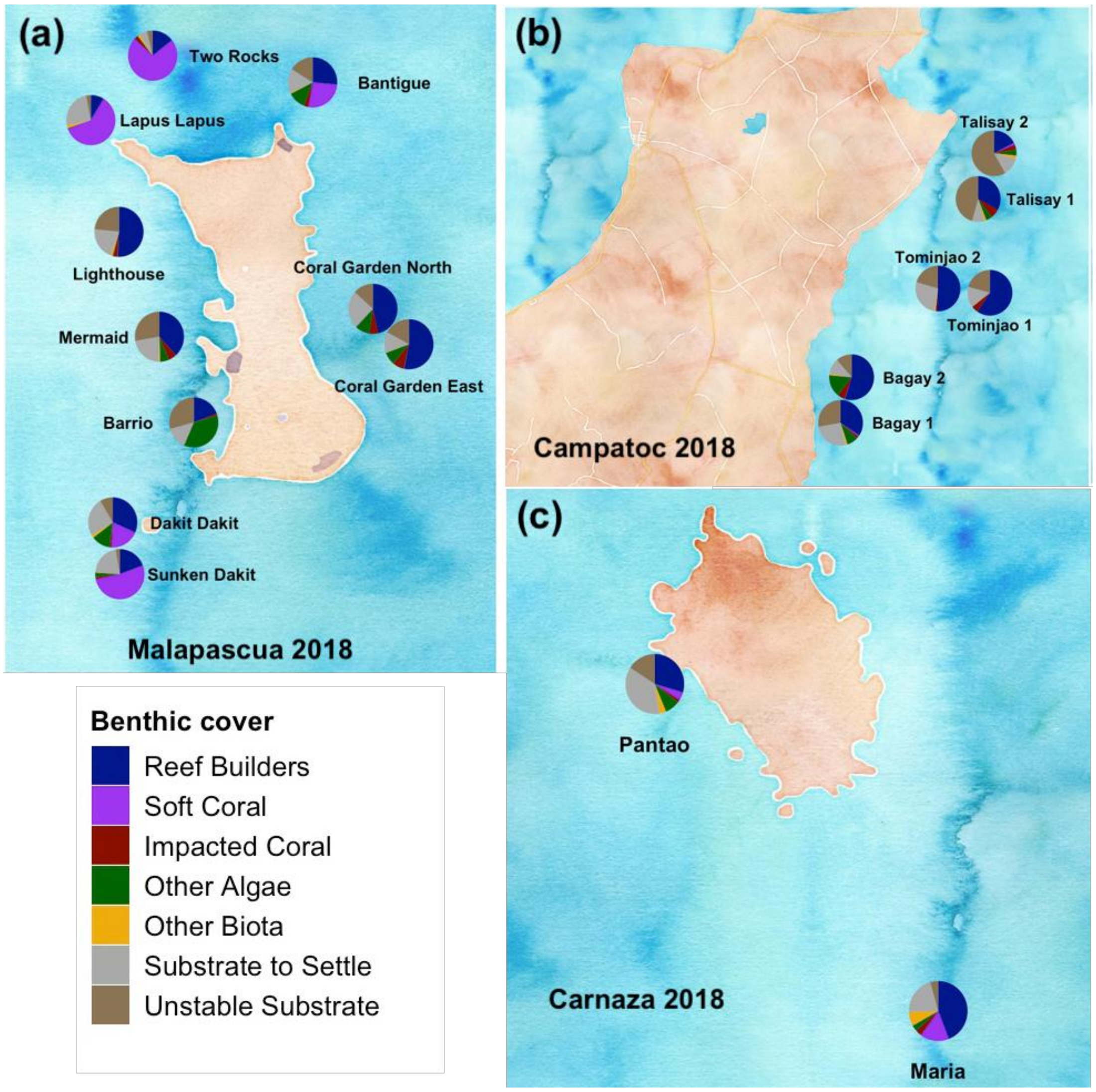

Figure 7. Maps of Malapascua (a), Campatoc (b) and Carnaza (c) showing the 2018 benthic cover percentage of each survey site.

To assess the temporal evolution of benthic cover, we calculated the mean cover per year from 2016 to 2018 for the 15 sites that have been surveyed over the whole period (nine sites in Malapascua and six in Campatoc; see Table 2). Over all sites, the reef builders cover increased 6.7% from 2016 to 2018, and the soft coral cover increased 4.2% (Figure 8). During the three-year period, the suitable substrates decreased by 4.7%, and the unstable substrates by 2.7%. Algae cover slightly decreased (-0.9%).

Malapascua shows an increase of soft coral (+6.9%), whereas Campatoc has a stronger increase in reef builders (+9.5%). Both areas show a decrease of impacted (dead and bleached) corals (-1.4% in Malapascua and -2.7% in Campatoc), and of suitable substrate to settle (-7.1% in Malapascua and -1.2% in Campatoc). Campatoc also displays a strong decrease of unstable substrate (-4.6%).

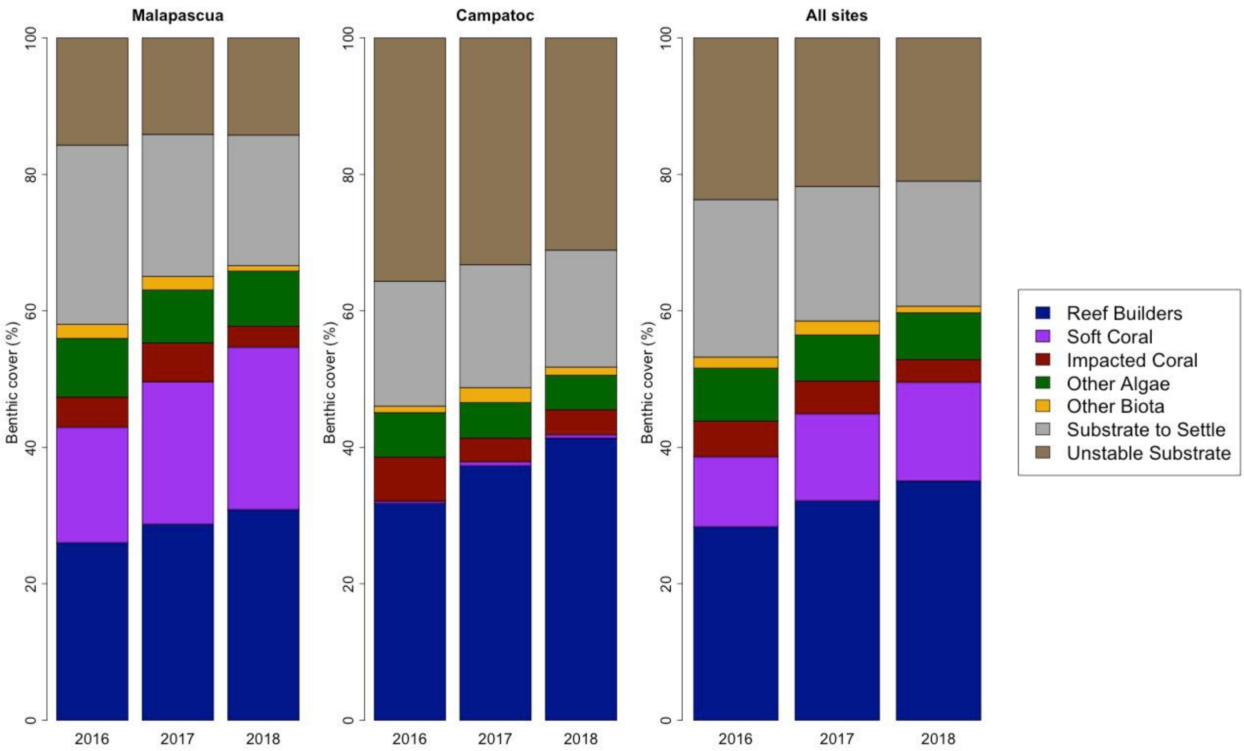

Figure 8. Benthic cover averaged per year from 2016 to 2018 for the nine Malapascua sites that have been surveyed over the three years - excluding Bantigue (left), the six Campatoc sites (middle) and the 15 sites together (right).

B. Coral cover

Percentage coral cover was determined from PIT survey data. The mean hard coral cover in 2018 was 28.7 (± 5.1) % in Malapascua, 41.3 (± 6.4) % in Campatoc, 36.8 (± 7.2) % in Carnaza and 33.7 (± 3.7) % over all sites. The mean total coral cover (soft and hard corals) in 2018 was 52.6 (± 6.0) % in Malapascua, 41.7 (± 6.3) % in Campatoc, 46.8 (± 12.9) % in Carnaza and 48.4 (± 4.1) % over all sites. As for benthic cover, we calculated the mean coral cover per year from 2016 to 2018 for the 15 sites that have been surveyed over the whole period (Table 2). From 2016 to 2018, mean hard and total coral covers increased in both Malapascua and Campatoc (Figure 9). During the three-year period, the mean cover of hard coral over the 15 sites increased 6.3%, and the mean total coral cover increased 10.5%. The cover of hard coral is higher and increased faster in Campatoc (+9.6% in three years) than in Malapascua (+4.0% in three years; Figure 9). Rather, total coral cover is higher and progressed slightly faster in Malapascua (+10.9%) than in Campatoc (+9.8%), due to an important increase of soft corals.

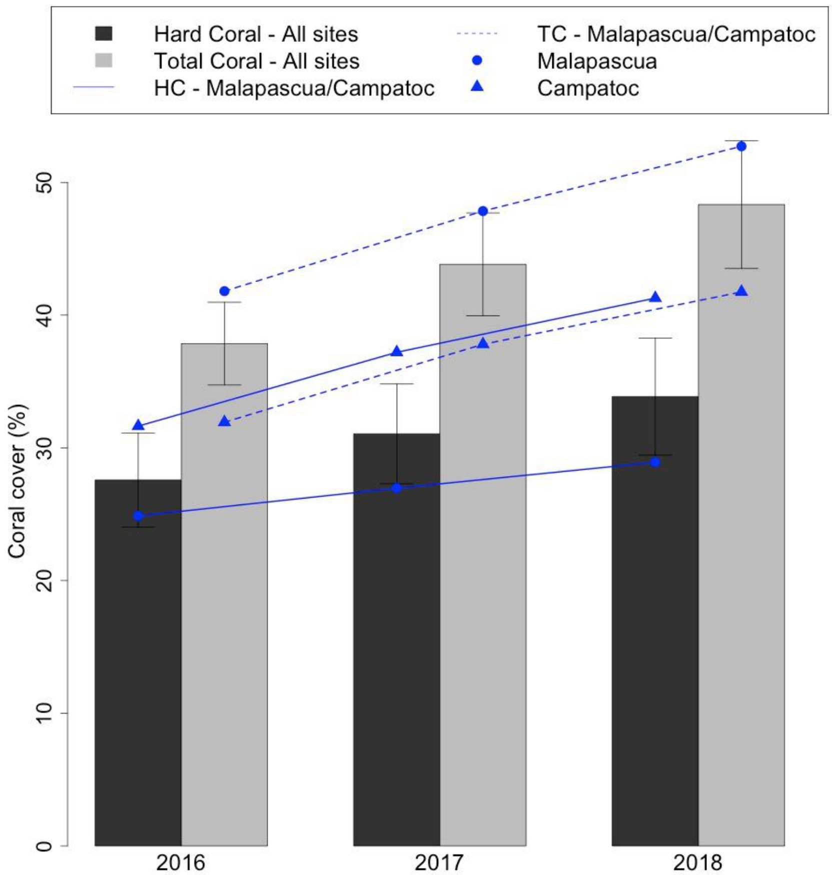

Figure 9. Hard coral (black bars/solid lines) and total coral (grey bars/dashed lines) cover averaged per year from 2016 to 2018 for the nine Malapascua sites that have been surveyed over the three years - excluding Bantigue (circles), the six Campatoc sites (triangles) and the 15 sites together (bars).

The percentage covers of hard coral (HC) and total coral (TC) of each site in 2018 are shown in Figure 10. Five survey sites have a hard coral cover considered excellent (>44%, Licuanan et al. 2017). Two of them are located in Malapascua: Lighthouse (50.7%) and Coral Garden East (50.0%); and, three are in Campatoc: Tominjao 1 (59.4%), Tominjao 2 (50.3%) and Bagay 2 (53.3%). Two survey sites have a total coral cover considered excellent (>75%, Licuanan et al. 2017; Figure 11b). Both are located in Malapascua and are dominated by soft corals: Two Rocks (83.5%) and Lapus Lapus (76.7%). Five sites have a hard coral cover considered poor (<22%, Licuanan et al. 2017; Figure 11a), and two of them also have a poor total coral cover (<25%, Licuanan et al. 2017): Barrio in Malapascua (19.2% of both hard coral and total coral cover) and Talisay 2 in Campatoc (17.5% of hard coral and a 18.9% of total coral cover). The three sites dominated by soft coral in Malapascua have poor hard coral cover but good total coral cover due to the high proportion of soft corals: Lapus Lapus (6.7% HC and 76.7% TC cover), Two Rocks (10.6% HC and 83.5% TC cover) and Sunken Dakit (15.6% HC and 67.9% TC cover; Figure 11).

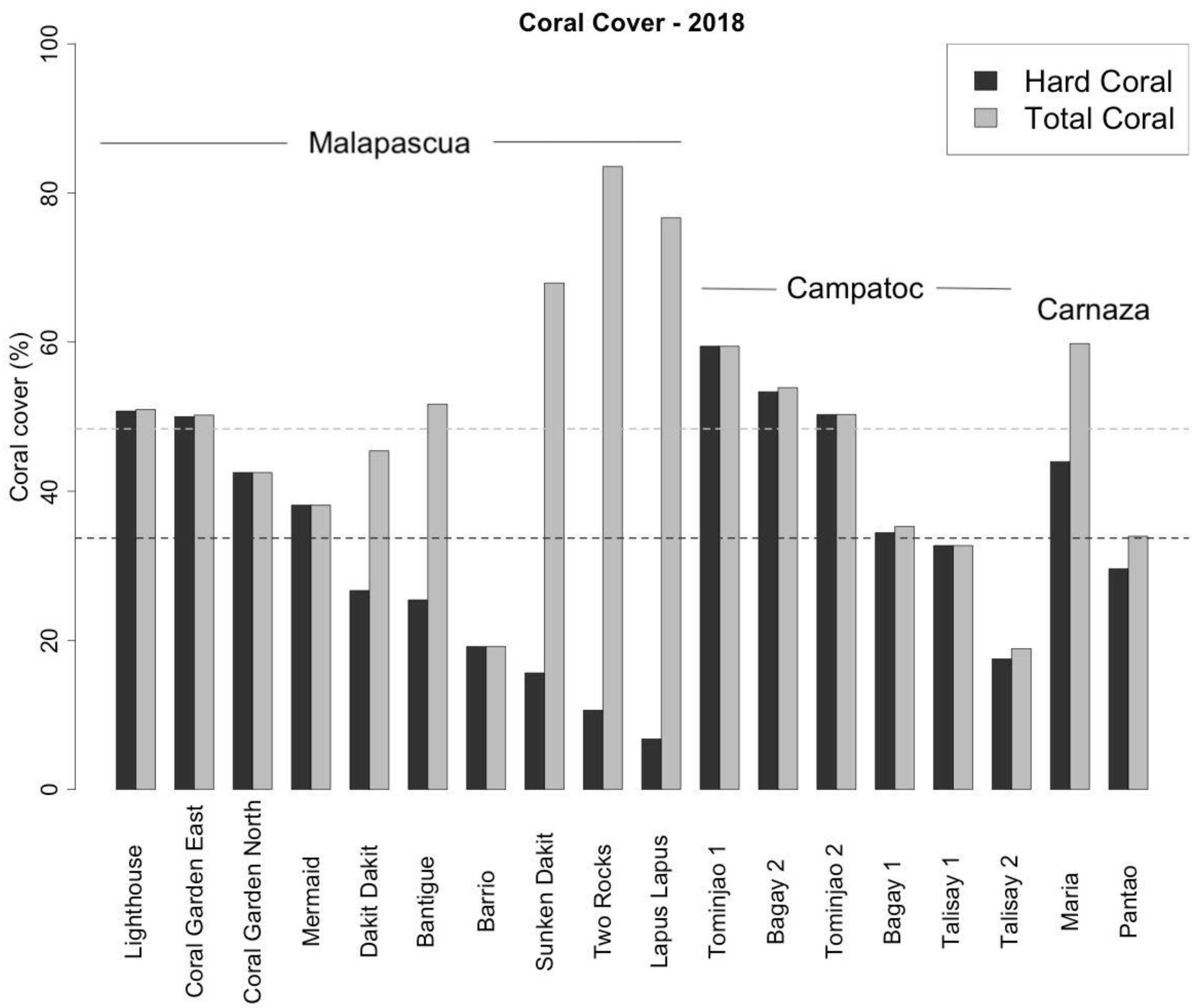

Figure 10. Hard coral (dark grey) and total coral (light grey) cover percentage of the 18 sites calculated from the PIT surveys conducted in 2018. The dashed lines represent the average hard coral (33.7% in dark grey) and total coral (48.4% in light grey) cover over all sites for 2018.

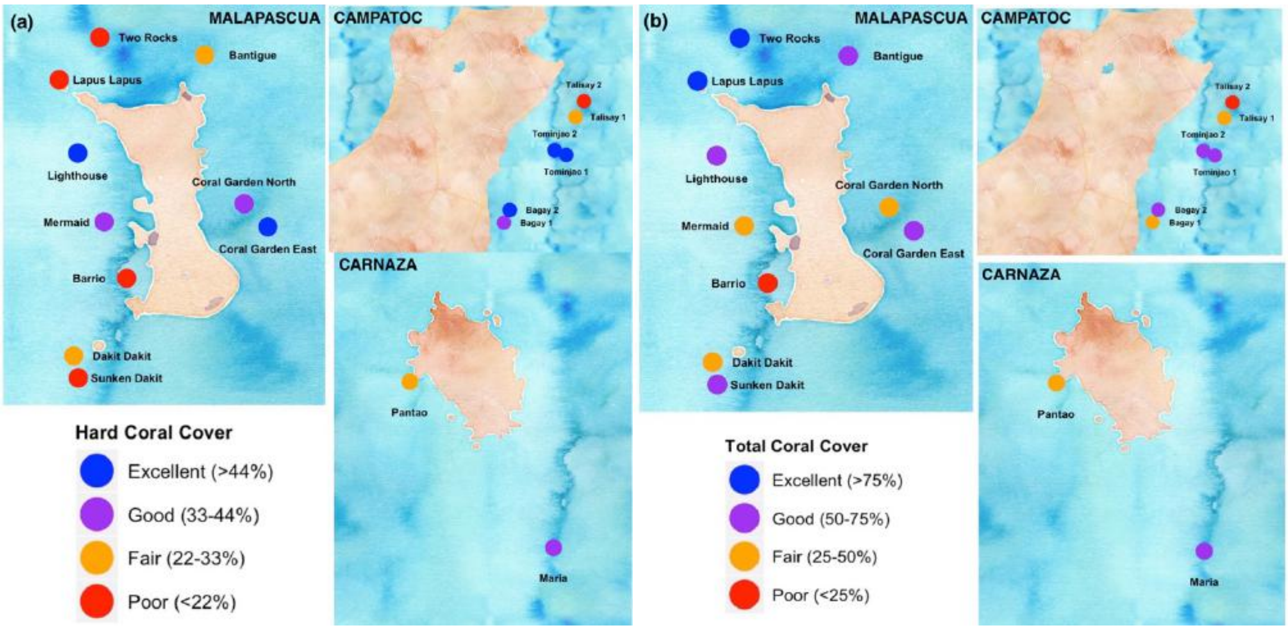

Figure 11: Map showing the health categories of each survey site based on their hard coral cover (a) and total coral cover (b), according to the scale of Licuanan et al. (2017).

In 2018, the most abundant coral forms are Massive/Sub-massive (25.8 ± 2.3 % of the total coral cover) and Branching (23.2 ± 5.4 % of the total coral cover). Soft corals represent 20.6 (± 9.1) %, Encrusting corals 14.3 (± 3.8) %, Corymbose 10.0 (± 3.9) % and Other forms (Table, Foliose, Columnar, Digitate and Solitary corals) constitute 6.1 (± 0.9) % of the total coral cover (Figure 12). Branching corals increased 3.9% between 2016 and 2018, whereas Massive/Sub-massive corals decreased 5.8%. The proportion of the other forms appears stable.

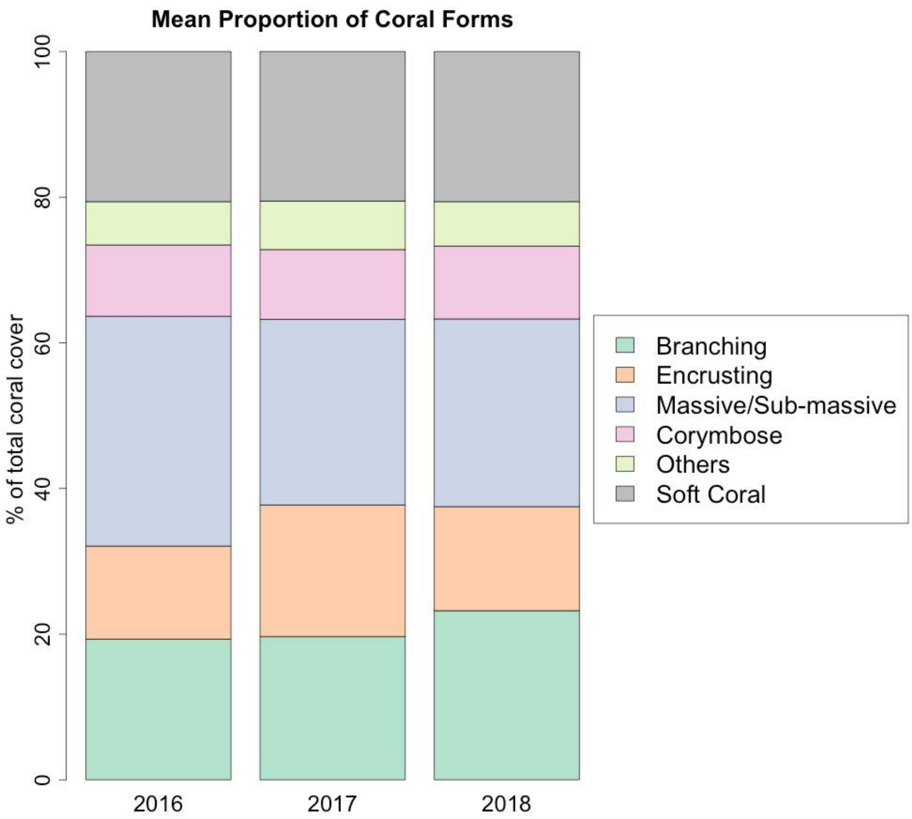

Figure 12. Proportion of the total coral cover represented by the different growth forms.For each year, the percentages are calculated on average over the 15 survey sites that have been surveyed over the three years.

C. Coral Health and Impacts

Abundance of coral impacts and stressors was determined from the belt transect surveys completed during the period January to December 2018 over 18 sites, among which 14 were surveyed once and four were surveyed twice. For the four sites that are monitored biannually, we took the average abundance of the two surveys. In 2018, the most abundant impact on corals are physical damages (broken colonies), with an average of 8.9 (± 1.5) occurrences per transect (100m^2) over the 18 sites (Figure 13). Damages due to predation are the second most abundant impact, with an average of 6.0 (± 1.1) impacted colonies per 100m^2. Recently killed corals (< 6 months) are found at an average density of 6.1 (± 1.5) per 100m^2. Coral diseases and bleached corals occur with densities of respectively 2.2 (± 0.4) and 2.0 (± 0.5) per 100m^2. Fishing trash (lines, nets or traps) and general trash are relatively uncommon, with an average of only 0.7 (± 0.2) and 1.0 (± 0.2) occurrence per 100m^2 (Figure 13).

Coral physical damages are on average more abundant in Carnaza (14.9 ± 7.8 per 100m^2) than in Campatoc (3.6 ± 0.9 per 100m^2) or Malapascua (8.2 ± 1.8 per 100m^2). On the other hand, predation and diseases are more abundant in Malapascua (5.6 ± 1.3 predated colonies and 2.2 ± 0.5 diseases per 100m^2) and Campatoc (7.8 ± 2.3 predated colonies and 2.6 ± 1.0 diseases per 100m^2) than in Carnaza (2.2 ± 0.8 predated colonies and 0.9 ± 0.1 diseases per 100m^2).

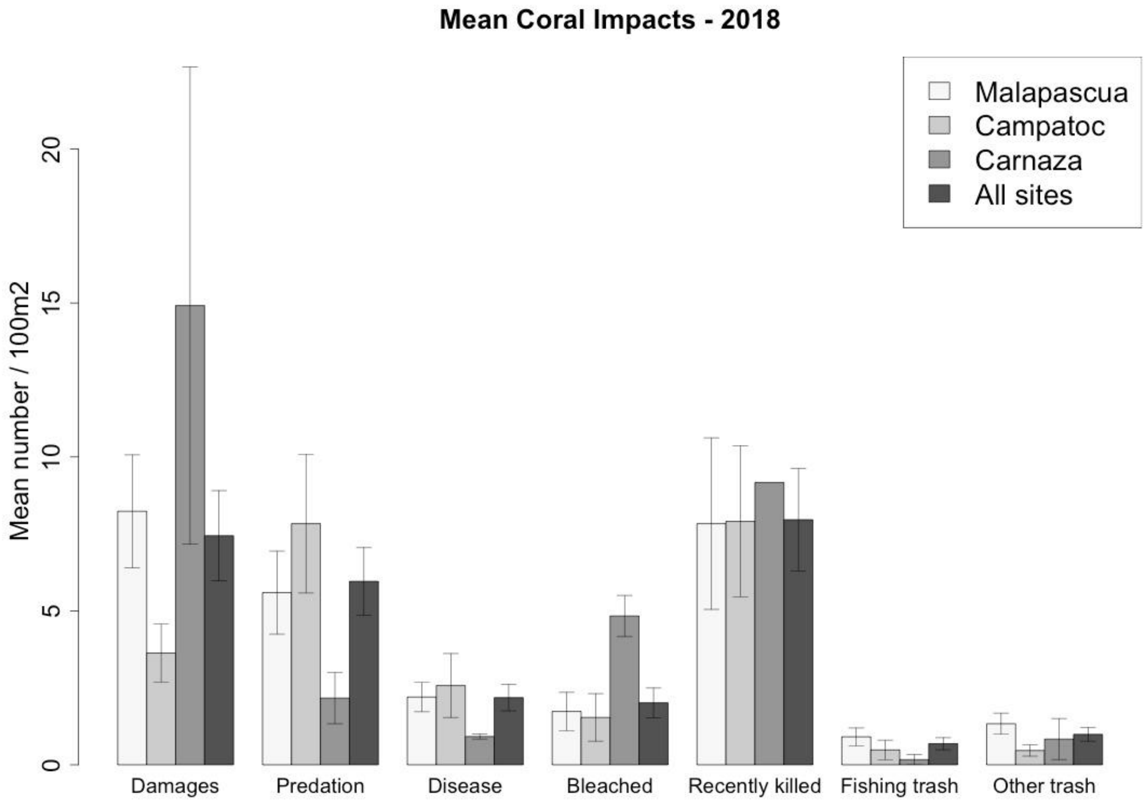

Figure 13. Abundance of coral impacts and stressors on average for Malapascua, Campatoc, Carnaza and over all sites in 2018.

For the year 2018, the highest numbers of recently killed corals are found in Coral Garden North in Malapascua (27.3 recently killed colonies per 100m^2; Figure 14), and in Tominjao 1 and 2 in Campatoc (12.2 and 16.0 recently killed colonies per 100m^2). The sites the most impacted by coral predation are Tominjao 1 and 2 in Campatoc (16.0 and 12.7 predated colonies per 100m^2), and Coral Garden East in Malapascua (12.3 predated colonies per 100m^2). Pantao in Carnaza and Dakit Dakit in Malapascua are the most affected by coral physical damages (22.7 impacted colonies per 100m^2 in Pantao and 21.4 in Dakit Dakit). Coral diseases occur the most at Bagay 1 and 2 in Campatoc (4.0 and 7.0 observations of diseased coral per 100m^2), and at Barrio in Malapascua (4.8 diseases per 100m^2). The sites most impacted by coral bleaching are Dakit Dakit in Malapascua (6.3 bleached colonies per 100m^2), Pantao in Carnaza (5.5 bleached colonies per 100m^2) and Bagay 2 in Campatoc (5.2 bleached colonies per 100m^2). Fishing trash are found more abundant at

Two Rocks and Bantigue in Malapascua (2.7 and 2.3 pieces per 100m^2) and at Bagay 1 in Campatoc (2.0 pieces per 100m^2). General trashes are more abundant at Barrio, Coral Garden East and Bantigue in Malapascua, with respectively 3.0, 2.8 and 2.7 pieces in average per 100m^2 (Figure 14).

In 2018, the density of recently killed corals seems to positively correlate with the abundance of the coral predator *A. planci* starfish (see bivariate plot in Appendix B.2), but the correlation is not significant. We also tested the correlation of coral damages with the percentage of branching coral forms, as they tend to break more easily than other forms, but the correlation appears weak and is not significant (see Appendix B).

Due to changes in the methodology (redefinition of coral damages, addition of recently killed corals), we do not have historical data to analyse the temporal variation of coral health and impacts.

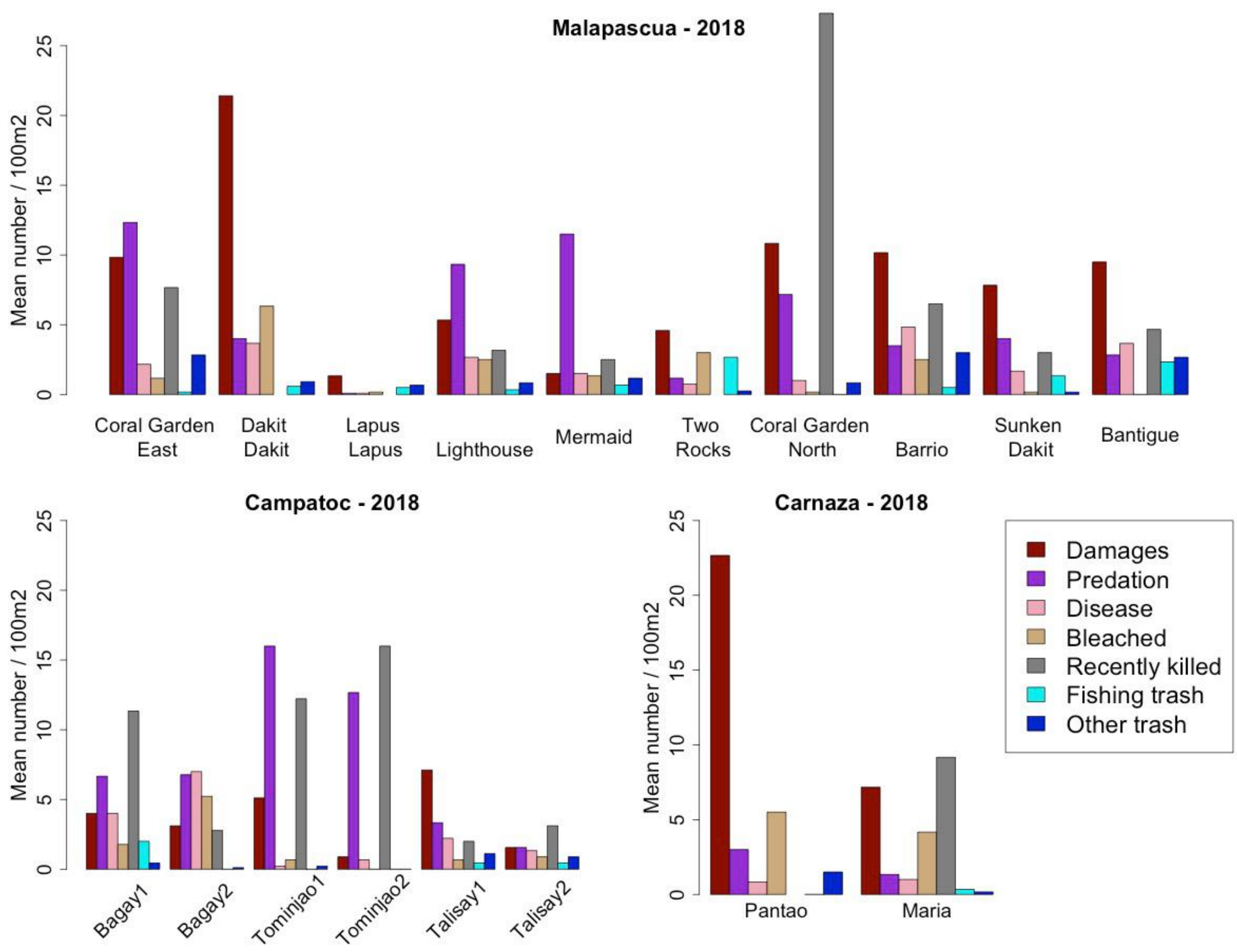

Figure 14. Abundance of coral impacts and stressors in average per 100m^2 transect for each of the 18 survey sites in 2018.

D. Coral Recruitment

Coral recruitment was assessed using the coral recruits survey data, and averaged over the 10 quadrats of 25cm^2 per transect. The overall mean density of coral recruits in 2018 in Malapascua is 23.55 (± 4.37) recruits per m^2, the mean density in Campatoc is 36.92 (± 4.10) recruits per m^2, and in Carnaza 32.13 (± 8.93) recruits per m^2 (Figure 15). Across all 18 survey sites, the mean density of coral recruits is 28.95 (± 3.17) recruits per m^2. The highest density is found at Bagay 1 in Campatoc with 49.78 coral recruits per m^2, and the lowest at Coral Garden North in Malapascua with 3.20 coral recruits per m^2. Results from 2018 show higher densities of the 1–1.9cm and 2-2.9cm size class, with mean density over all sites of 9.23 (± 1.22) and 9.62 (± 1.19) coral recruits per m^2 respectively. Coral recruits of size 3-3.9cm and 4-4.9cm have mean densities of 6.28 (± 0.73) and 3.82 (± 0.53) respectively (Figure 15). Densities of small size classes in comparison to larger ones are high for all three survey areas.

The density of coral recruits in 2018 appears negatively, but not significantly, correlated with algae cover (see Appendix B.2). The correlation with the cover of substrate to settle is not significant (Appendix B.1). Coral recruits density assessment was added to the reef monitoring program during Spring 2017, hence we do not have historical data to look at the temporal variation of coral recruitment yet.

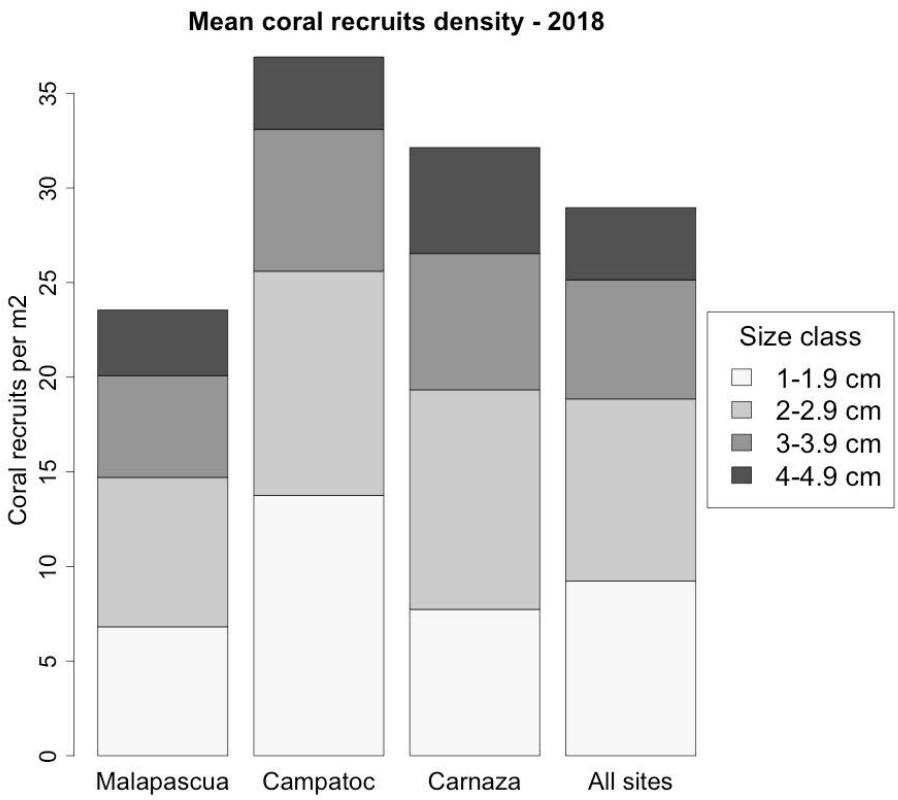

Figure 15.Mean number of coral recruits per size class recorded per square meter for 2018 over the 10 sites surveyed in Malapascua, the six sites in Campatoc, the two sites in Carnaza, and overall 18 sites.

E. Fish

Abundance of fish species was determined from the UVC surveys completed during the period January to December 2018 over 18 sites, among which 14 were surveyed once and four were surveyed twice. For the four sites that are monitored biannually, we took the average abundance of the two surveys. Fish densities given here account only for the 112 targeted species/groups, hence a subset of all present fish (excluding for instance all damselfish, gobies and blennies). The overall mean fish density in 2018 in Malapascua is 0.32 (± 0.04) sampled fish/m^2, in Campatoc 0.39 (± 0.06) sampled fish/m^2, in Carnaza 0.45 (± 0.08) sampled fish/m^2, and over all sites 0.36 (± 0.03) fish/m^2. For the year 2018, Tominjao 2 (Campatoc) shows the highest fish density with 0.61 sampled fish/m^2. Maria (Carnaza) and Lighthouse (Malapascua) also display high densities with respectively 0.53 and 0.51 sampled fish/m^2 (Figure 16). On the other hand, Coral Garden North and Coral Garden East (Malapascua) have very low fish densities with respectively 0.14 and 0.09 sampled fish m^{-2} (Figure 16).

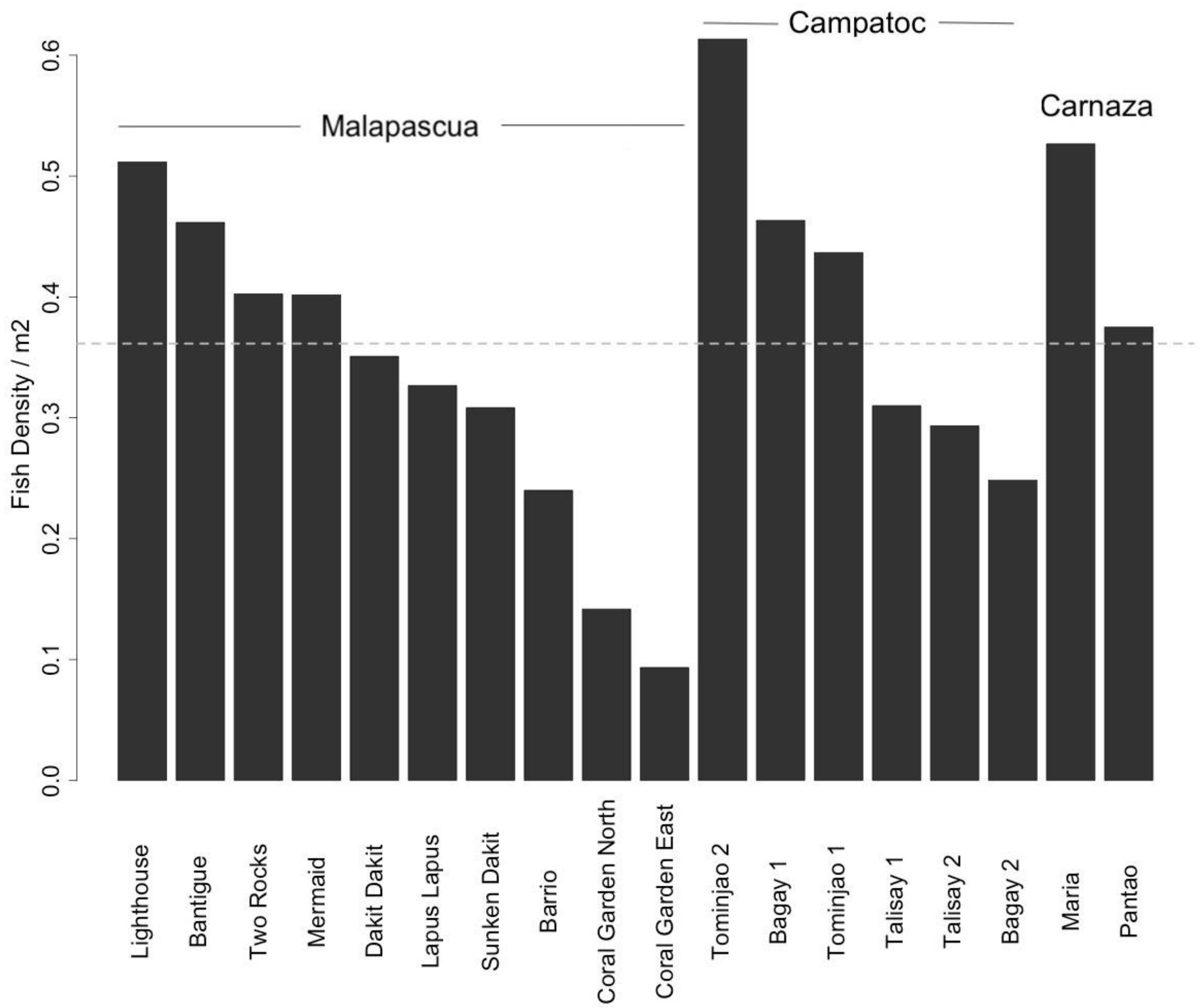

Figure 16. Fish density in average per m^2 for each of the 18 survey sites in 2018. The grey dashed line indicates the average density over all sites.

The list of fish species targeted in our UVC surveys was updated at the beginning of year 2017 (56 species were added), hence we can only look at the temporal trend of fish density for the year 2017 and 2018. To calculate the average fish densities, we excluded the sites that were surveyed before the change of the fish list (both Carnaza sites, Tominjao 1 & 2 in Campatoc and Two Rocks in Malapascua). Hence the average fish density for 2017 and 2018 was calculated from 13 sites (nine in Malapascua and four in Campatoc). Over all sites, the average fish density slightly increased from 2017 (0.30 sampled fish/m^2) to 2018 (0.32 sampled fish/m^2; Figure 17). In Malapascua, the density increased of 0.05 sampled fish/m^2 from 2017 to 2018 (Figure 17), but the opposite trend was found in Campatoc (-0.03 sampled fish/m^2 from 2017 to 2018).

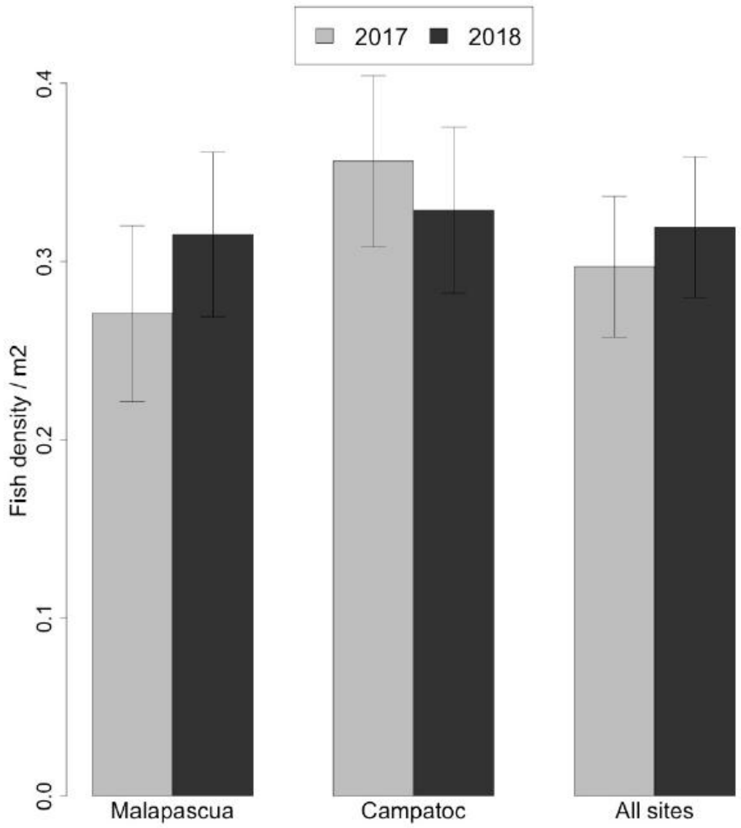

Figure 17. Density of sampled fish species per m^2 in average over the nine sites of Malapascua, the four sites of Campatoc and overall 13 sites surveyed in 2017 and 2018.

Fish biodiversity was assessed according to the total number of targeted fish species (species richness) or families (family richness) recorded per site. In 2018 over all sites, 61 different fish species from 23 different families have been observed - out of the 112 targeted species/groups from 30 families. The highest number of species recorded was in Malapascua with 54 species from 21 different families observed in the 10 survey sites. In Campatoc, 38 fish species from 21 families are observed in the six sites; and in Carnaza, 27 species from 14 different families are recorded in the two sites. The highest fish species richness are found in Lighthouse (33 species from 17 families), Lapus Lapus (31 species from 13 families), and Dakit Dakit (27 species from 16 families) in Malapascua (Figure 18). The lowest species and family richness are found in Pantao in Carnaza (nine species from five families), and in Coral Garden North and East in Malapascua (11 species from seven families in both sites; Figure 18).

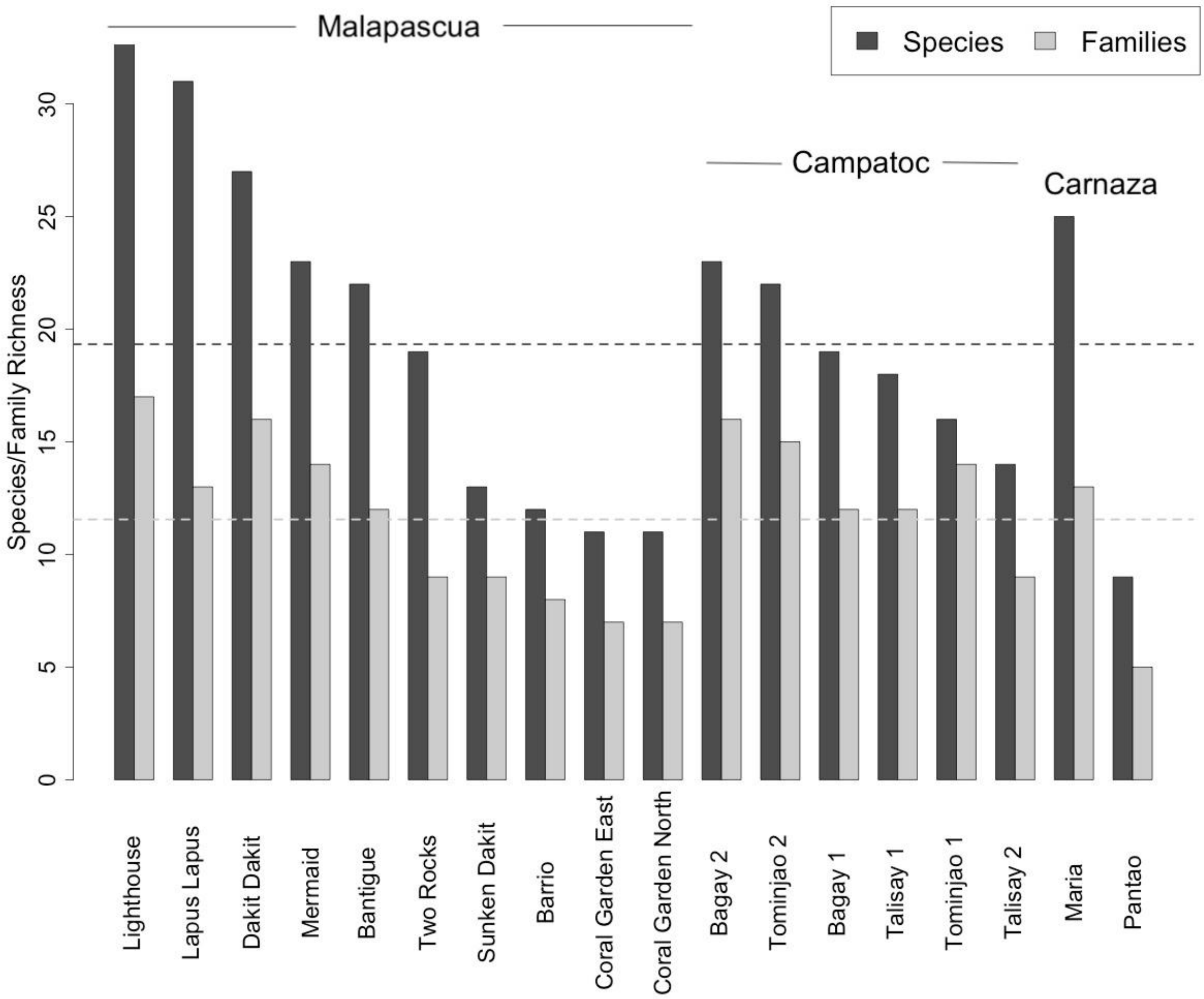

Figure 18. Fish species and family richness in each of the 18 survey sites in 2018. The dashed lines indicate the average species (dark grey) and family (light grey) richness over all sites.

We looked specifically at the densities of fish species targeted by commercial and artisanal fisheries: parrotfish (*Scaridae*), snappers (*Lutjanidae*), groupers (*Serranidae*), rabbitfish (*Siganidae*), sweetlips (*Haemulidae*), emperors (*Lethrinidae*) and other rarely observed commercial species (including tuna, jacks, trevallies and rays) labelled as 'Other'. In 2018, the mean density of commercial fish species is 0.044 (± 0.013) fish/m^2 over all sites. Commercial species is found more abundant in Campatoc, with an average density of 0.065 (± 0.024) commercial fish/m^2. In Malapascua, the average density is 0.020 (± 0.005) commercial fish/m^2, and in Carnaza 0.016 (± 0.004) commercial fish/m^2 (Figure 19). Parrotfish are the most abundant group with an average density of 0.011 (± 0.005) fish/m^2 over all sites, followed by snappers ($9.5x10^{-3}$ ± 0.007 fish/m^2), groupers ($8.9x10^{-3}$ ±

0.002 fish/m^2), rabbitfish (3.7x10^{-3} ± 0.001 fish/m^2), sweetlips (9.7x10^{-4} ± 4x10^{-4} fish/m^2), other commercial species (5.5x10^{-4} ± 3x10^{-4} fish/m^2) and emperors with no individual observed in 2018. The sites showing the highest densities of commercial fishes are Tominjao 2 (0.167 fish/m^2), Bagay 1 (0.100 fish/m^2) and Lighthouse (0.055 fish/m^2; Figure 19). In Tominjao 2, the most common group is snappers (0.130 fish/m^2), Bagay 1 has a higher density of parrotfish (0.083 fish/m^2) and Lighthouse shows similar densities of parrotfish, snappers and groupers (respectively 0.021, 0.017 and 0.012 fish/m^2; Figure 19). None of the commercial species are recorded in two of the sites: Sunken Dakit in Malapascua and Pantao in Carnaza. Groupers is the most commonly observed group (recorded in 13 out of 18 sites), and the rarest is sweetlips (observed in five sites).

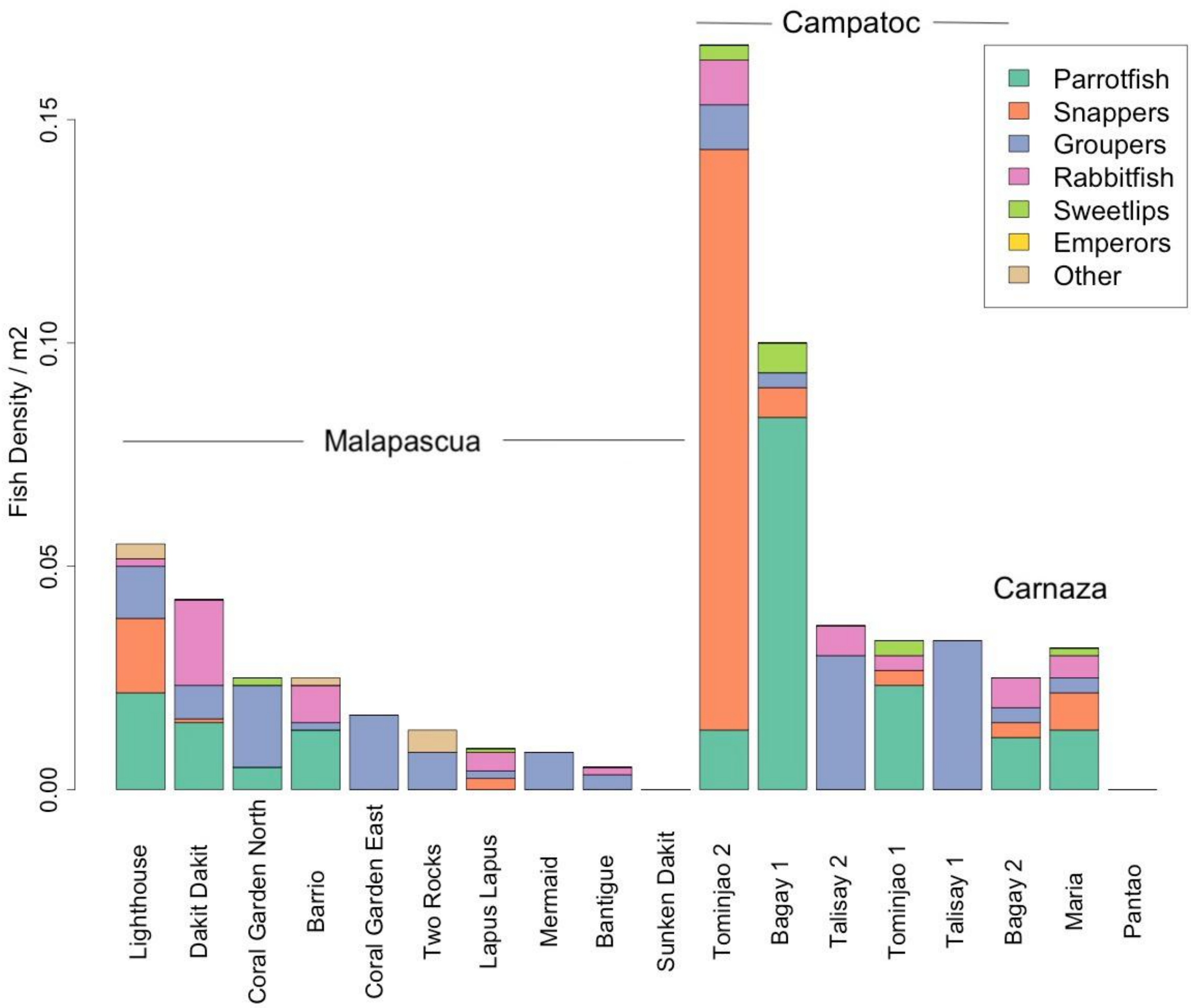

Figure 19. Density of commercial fish speciesparrotfish (Scaridae), snappers (Lutjanidae), groupers (Serranidae), rabbitfish (Siganidae), sweetlips (Haemulidae), emperors (Lethrinidae) and other rarely observed commercial species (including tuna, jacks, trevallies and rays) labelled as 'Other', in average per m^2 for each of the 18 survey sites in 2018.

We looked at the density of fish species according to two functional traits: diet and maximal body size. Traits data were gathered from Mouillot et al. (2014) for the targeted species. For the fish recorded as a group (for example Anemone fish or Emperors), we took the average of the most commonly observed species. Diet includes six categories: Planktivorous, Coralivorous, Herbivorous, Invertivorous, Omnivorous and Piscivorous. Maximal body size of the species was divided in six categories: 0-7cm, 7.1-15cm, 15.1-30cm, 30.1-50cm, 50.1-80cm and >80cm (Appendix A.3).

In 2018 over all survey sites, the size category most commonly observed is fish between 30.1 and 50cm (density of 0.130 fish/m^2). Large fish species are very rarely recorded, with a mean density of 8.80×10^{-4} fish/m^2 for the 50.1 to 80cm category, and 2.82×10^{-3} fish/m^2 for species larger than 80cm (Figure 20).

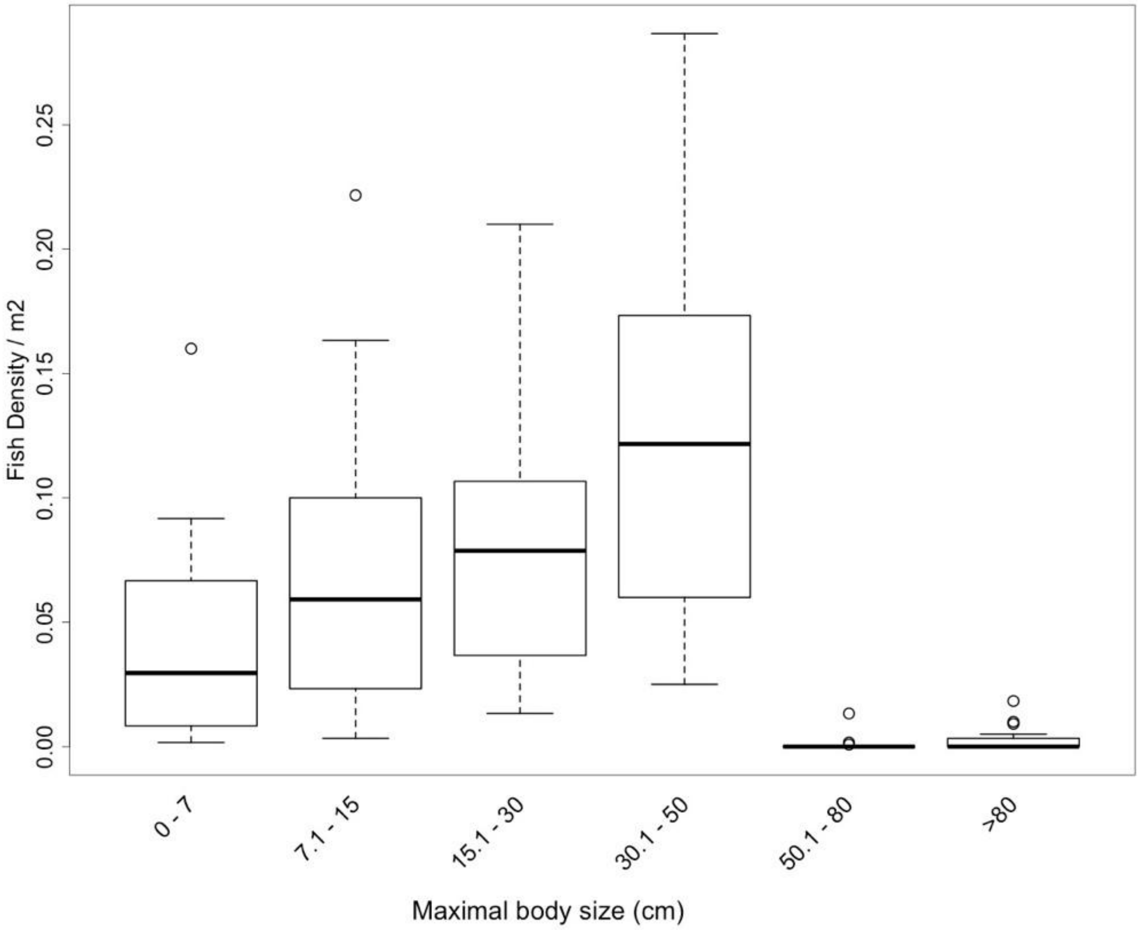

Figure 20. Boxplot of fish density per size category observed in 2018 in average over the 18 survey sites. Maximal body size of the species/group were split into six categories.

Over all survey sites in 2018, Planktivorous species are the most commonly observed, with a mean density of 0.119 fish/m^2. Corallivorous species are found at a density of 0.067 fish/m^2, and Herbivorous species at a density of 0.063 fish/m^2. Piscivorous species are the rarest, with a mean density of 0.011 fish/m^2 (Figure 21).

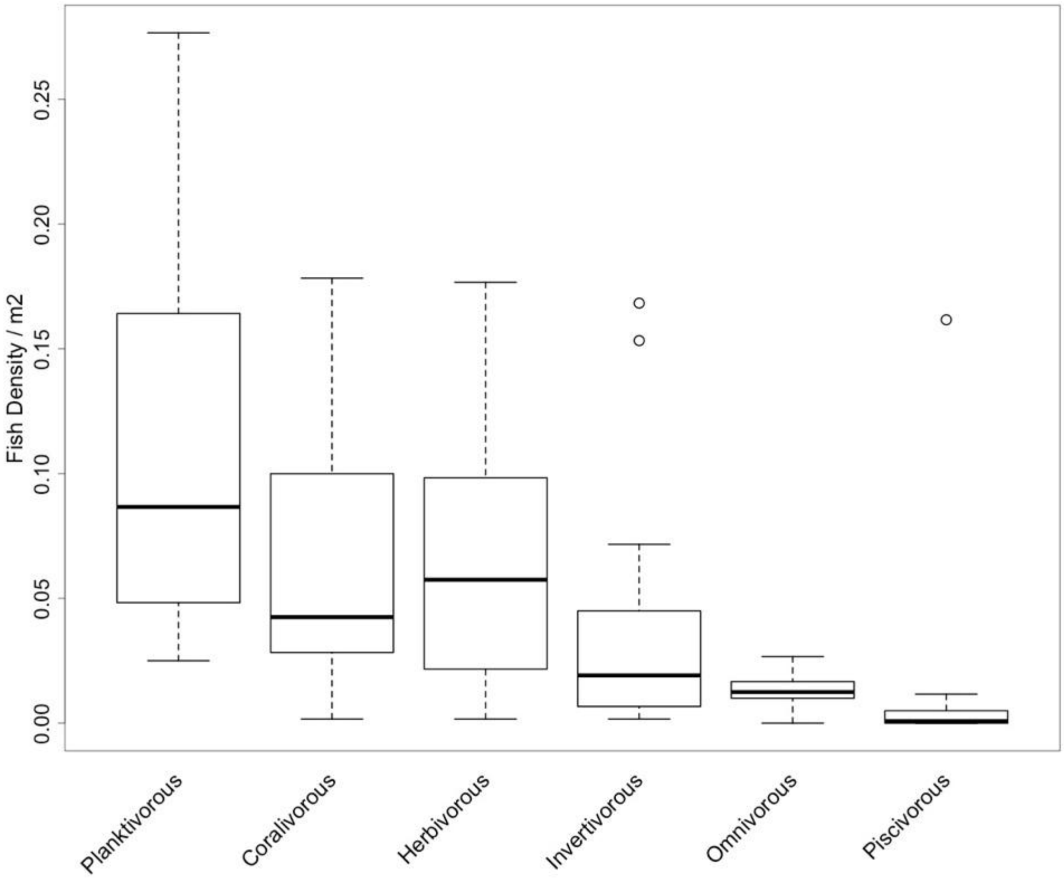

Figure 21. Fish density per diet type observed in 2018 in average over the 18 survey sites.

Out of the 30 targeted fish families, 22 have been observed in 2018 over the 18 survey sites. Labridae (wrasses) are the most commonly observed with an average density of 0.119 (±0.020) fish/m^2 (Figure 21). This abundance of Labridae reflects a high density of crescent wrasse (*Thalassoma lunare*). Chaetodontidae (butterflyfish) are also commonly observed (mean density of 0.077 ± 0.015 fish/m^2), as well as Pomacanthidae (angelfish; mean density of 0.036 ± 0.006 fish/m^2), Pomacentridae (from which we only record the subfamily Amphiprioninae or anemone fish; mean density of 0.026 ± 0.005 fish/m^2) and Acanthuridae (surgeon and unicorn fish; mean density of 0.025 ± 0.007 fish/m^2). The rarest families, with densities lower than $5x10^{-5}$ fish/m^2, are Haemulidae (sweetlips), Zanclidae (Moorish idol), Carangidae (jacks and trevally), Scorpaenidae (lionfish), Lethrinidae (emperors) and Muraenidae (moray eels; Figure 22).

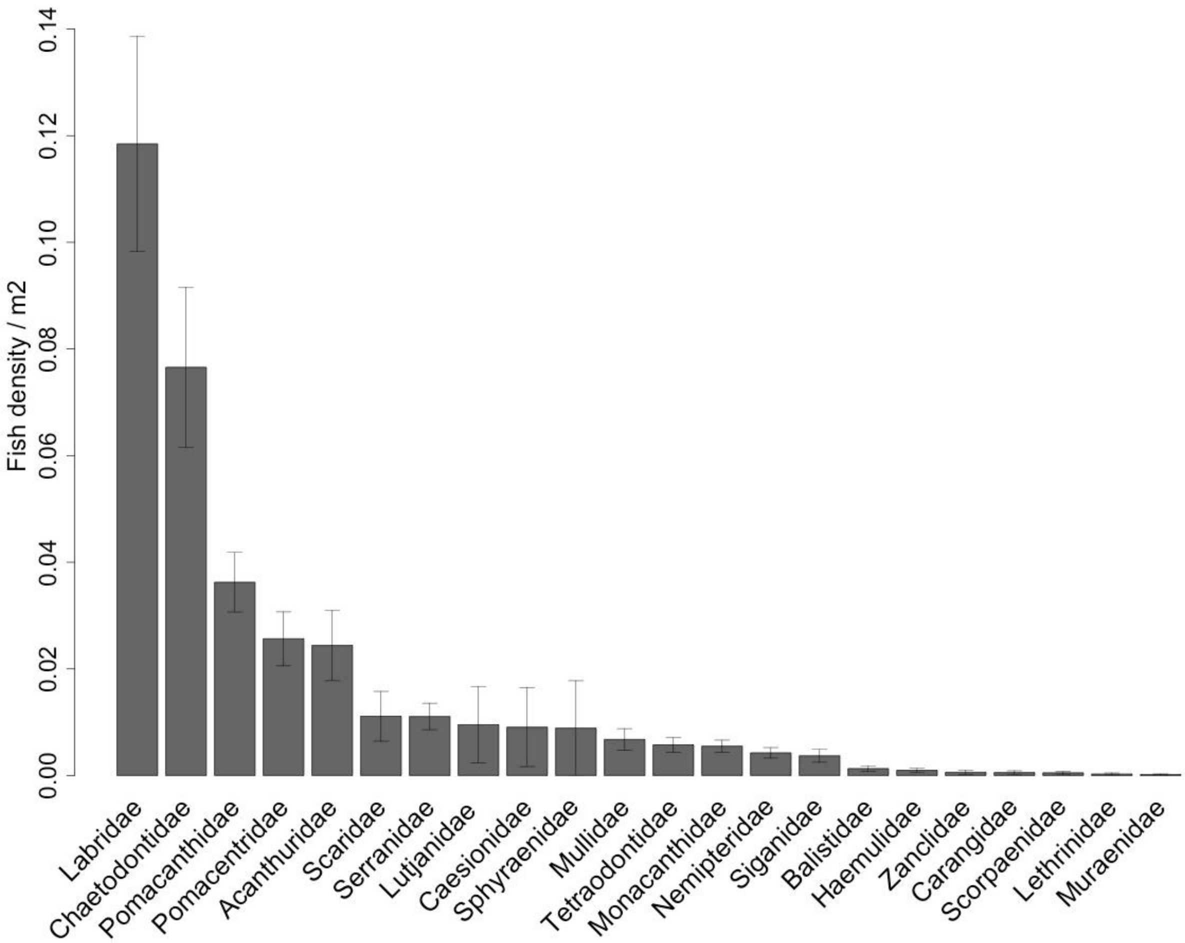

Figure 22. Fish density per family for 2018 in average over the 18 survey sites.

The total fish diversity of 2018 is significantly positively correlated to total coral cover (Kendall's tau = 0.298; p.value = 0.087; see Appendix B), but not hard coral cover. Fish density is not correlated to either total or hard coral cover. The density of grazers (herbivorous fish species) is not significantly correlated to algae cover (Appendix B).

F. Invertebrates

Density of invertebrate indicator species was determined from the belt transect surveys completed during the period January to December 2018 over 18 sites, among which 14 were surveyed once and four were surveyed twice. To assess the temporal evolution, we calculated the mean density per year from 2016 to 2018 for the 15 sites that have been surveyed over the whole period (nine sites in Malapascua and six in Campatoc; see Table 2). Figure 23 shows the mean number of invertebrates per transect of 100m^2 in 2016, 2017 and 2018. Target species have been grouped per types of taxa: sea urchins include Pencil (*Eucidaris spp.*), Flower (*Toxopneuste spp.*), and Collector (*Tripneuste spp.*) urchins. Long-spined urchins, *Diadema spp.,* are analysed separately. Sea stars include all sea stars but

A. planci (brittle stars and feather stars are not recorded), sea cucumbers include the Greenfish (*Stichopus chloronotus*), the Pinkfish (*Holothuria edulis)*, the Prickly redfish (*Thelenota ananas)* and all other sea cucumbers. Octopus, cuttlefish and squids are grouped as Cephalopods, and the Triton trumpet snail, all nudibranchs and cowries are grouped as Gastropods (coral predators – *C. violacea* and *Drupella spp.* snails - are analysed separately). See Appendix A2 for the complete list of targeted species per taxa group.

The density of sea urchins, sea cucumbers, sea stars and gastropods increased slightly from 2016 to 2018 (+0.73 sea urchin individuals, +0.42 sea cucumber individuals, +1.33 sea star individuals and +0.87 gastropod individuals per 100m^2). Conversely, anemones and giant clams (*Tridacna spp.*) are less abundant in 2018 than 2016 (-1.17 anemone and -0.45 clam per 100m^2). Cephalopods and coral banded shrimps have been very rarely observed over the three years (Figure 23).

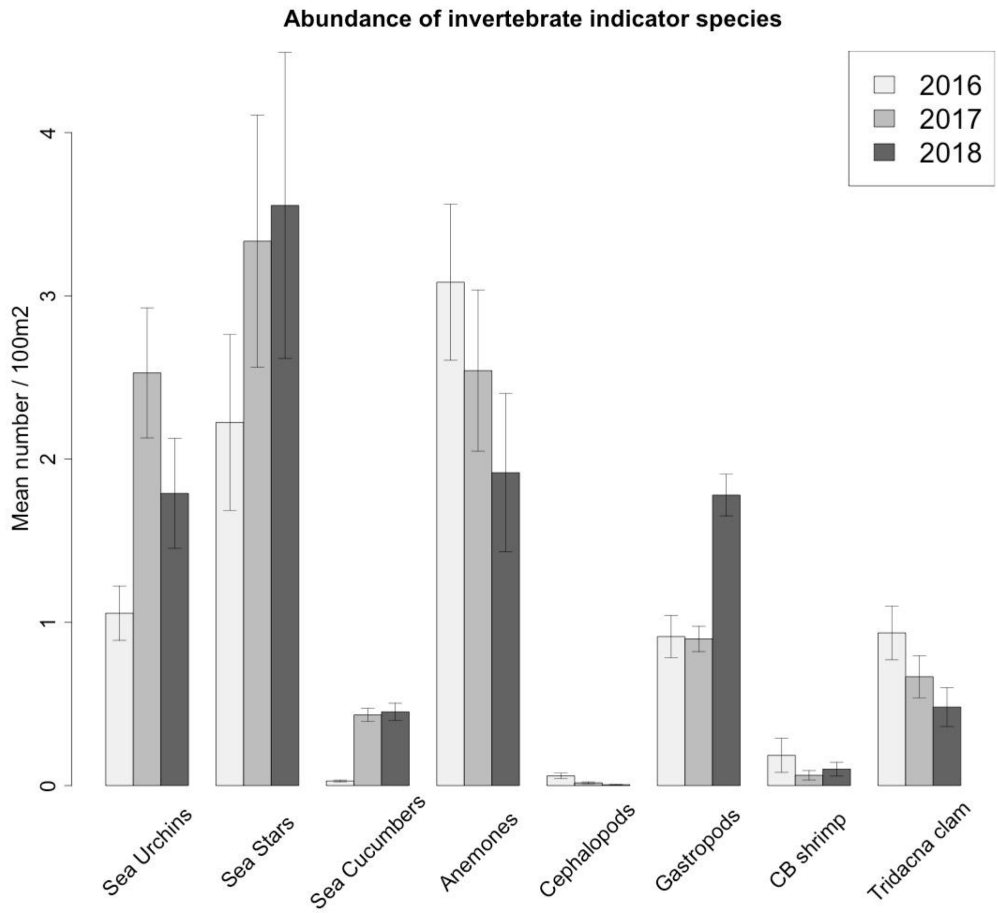

Figure 23. Density of invertebrate indicator taxa calculated on average over the 15 sites surveyed in 2016, 2017 and 2018. The list of targeted species per taxa group is given in Appendix A2.

We calculated the density of the same taxa groups separately for three types of sites (soft coral dominated, hard coral dominated and mixed sites) for the year 2018. Soft coral dominated sites are defined by a soft coral cover > 20% and a hard coral cover <20% (3 sites): Two Rocks, Lapus Lapus and Sunken Dakit in Malapascua. Hard coral dominated sites are characterized by a soft coral cover lower than 2% (11 sites): Coral Garden East and North, Lighthouse, Mermaid and Barrio in Malapascua, and all Campatoc sites. Mixed sites are defined by a soft coral cover >2% and a hard coral cover >20% (four sites): Dakit Dakit and Bantigue in Malapascua, and the two Carnaza sites.

Sea urchins are more abundant in hard coral dominated sites: on average 2.25 (± 0.46) individuals per 100m^2 in hard coral dominated sites, and 0.28 (± 0.06) in soft coral dominated sites. On the other hand, sea stars and gastropods are more abundant in soft coral dominated sites: in average 6.61 (± 2.35) sea stars and 2.36 (± 0.27) gastropods per 100m^2 in soft coral dominated sites, and 2.17 (± 0.69) sea stars and 1.43 (± 0.14) gastropods in hard coral dominated sites (Figure 24).

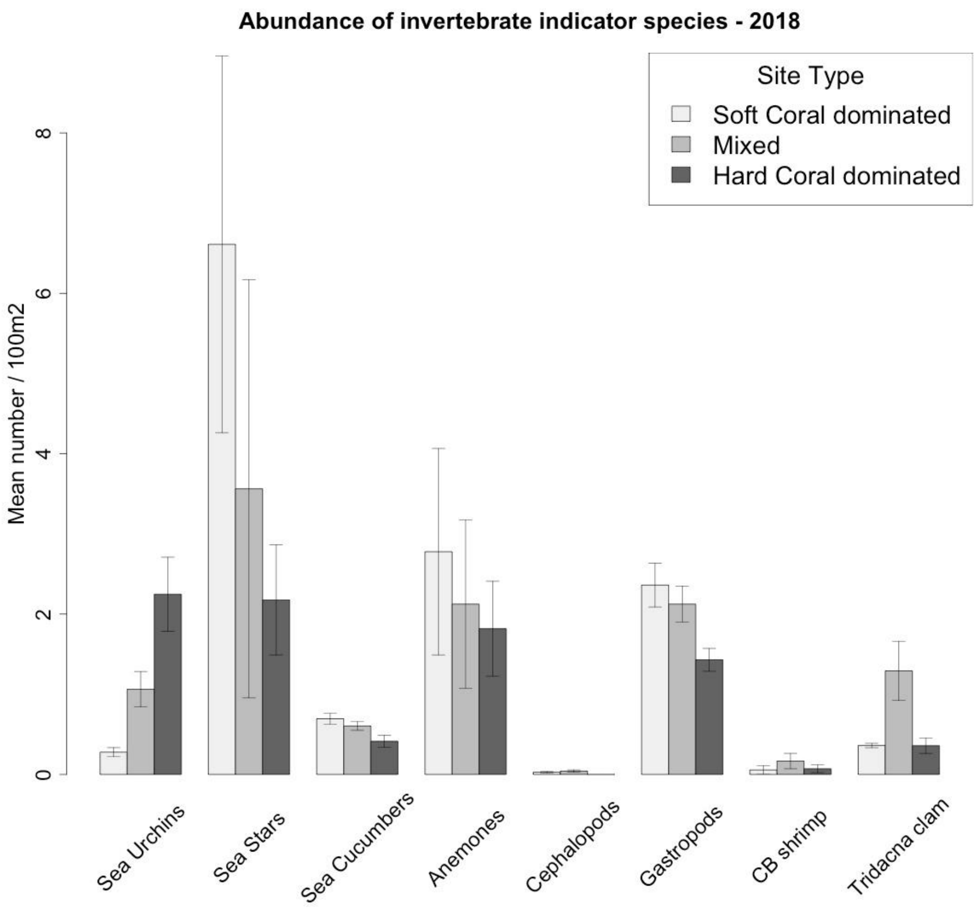

Figure 24. Mean density of invertebrate indicator taxa per site type for 2018.

Figure 25 shows the density of three major coral predators - *A. planci* Crown-of-Thorns sea star, *Drupella spp*. and *Coralliophila violacea* snails, calculated in average over our 15 survey sites in 2016, 2017 and 2018. In 2018, an average of 0.76 (± 0.35) *A. planci*, 9.48 (± 3.17) *Drupella spp.* and 16.82 (± 5.36) *C. violacea* have been counted per 100m^2 transect. The abundance of all three predators has increased from 2016 to 2018 (Figure 24), with +0.27 *A. planci*, +5.47 *Drupella spp.* and +5.01 *C. violacea* per 100m^2 in the three-years period.

The density of *Drupella spp.* in 2018 is significantly positively correlated to the hard coral cover (Kendall's tau = 0.455; p.value = 0.045; Appendix B). Hard coral cover also seems to be positively (although not significantly) correlated to the density of the two other predators (see bivariate plot in Appendix B.2).

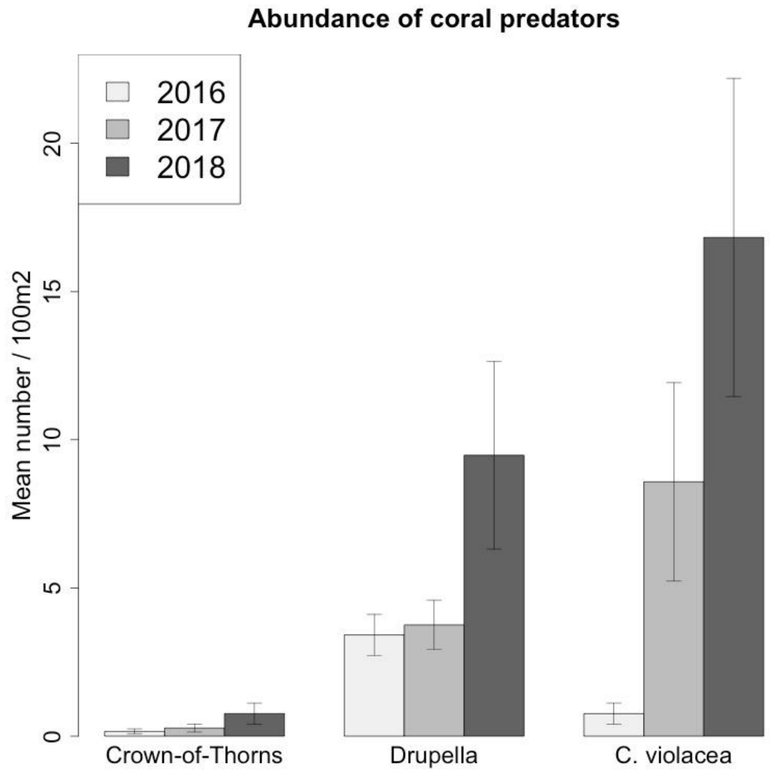

Figure 25. Density of coral predators calculated on average over the 15 sites surveyed in 2016, 2017 and 2018.

The density of long-spined urchins (LSU; *Diadema spp.*) on average over the 18 survey sites in 2018 is 78.3 (± 12.9) individuals per 100m^2 transect. In Malapascua, the mean density in 2018 is 82.7 (± 17.8) LSU per 100m^2 transect, in Campatoc 78.3 (± 25.6) LSU per 100m^2 and in Carnaza 53.2 (± 25.3) LSU per 100m^2. The abundance of LSU showed a small increase from 2016 to 2018 in Malapascua (+ 46 LSU per 100m^2), while staying stable in Campatoc (Figure 26). In 2018 the highest densities of LSU were recorded in Dakit Dakit (183.6 individuals per 100m^2) and Sunken Dakit (166.0 individuals per 100m^2)

in Malapascua; and in Tomijao 1 & 2 (respectively 122.9 and 176.2 individuals per 100m^2) in Campatoc (Figure 26). The density of LSU in 2018 appears to be negatively (although not significantly) correlated to the algae cover (see bivariate plot in Appendix B.2).

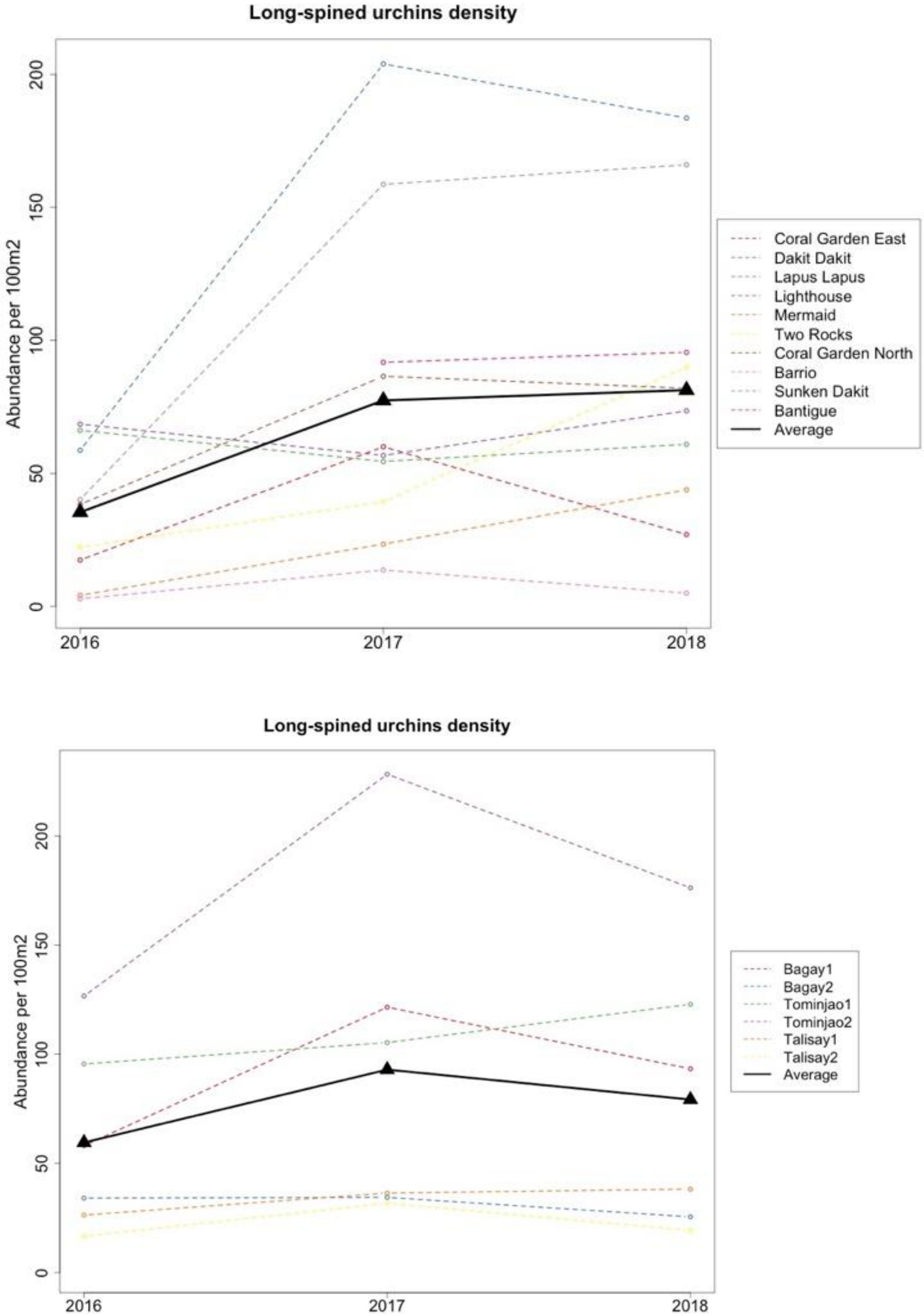

Figure 26. Density of long-spined urchin in Malapascua (top) and Campatoc (bottom) from 2016 to 2018 per site and in average. Pyramids represent the average of all Malapascua/Campatoc sites.

DISCUSSION

A. Benthic Cover

The reefs surveyed by People and the Sea around Malapascua can be placed into three categories according to their benthic cover: hard coral (HC) reefs (where reef builders are the dominant benthic cover), soft coral (SC) reefs (where soft corals are the dominant benthic cover) and mixed reefs (MR). SC reefs are mostly located on the north-eastern part of Malapascua island, whereas HC reefs dominate in the Campatoc area and both the western and eastern sides of Malapascua (Figure 7). A high cover of reef builders (i.e. HC reefs) is typically an indicator of healthy reefs as they provide valuable habitat areas for other marine organisms by virtue of the three-dimensional structure created by their calcified skeletons (Hennige, Suggett, Hepburn, Pugsley, & Smith, 2010). Species richness and abundance of reef fish are, for example, directly related to the habitat complexity of coral forms (Gratwicke & Speight, 2005). Health and diversity of reef builders is therefore directly linked to ecosystem functioning and subsequently ecosystem services provided to human populations (Graham & Nash, 2013).

Benthic communities dominated by a group other than hard corals (i.e. SC reefs) are often a sign of degraded reefs. Indeed, degradation of coral reefs is often associated with a shift in the composition of the benthic community, usually from reef builder dominated to macroalgae dominated communities (Hughes et al., 2007; Inoue, Kayanne, Yamamoto, & Kurihara, 2013). Even though they are less common, shifts toward other types of benthic organisms, such as sponges, corallimorphs and soft corals, have been documented (Fox, Pet, Dahuri, & Caldwell, 2003; Norström, Nyström, Lokrantz, & Folke, 2009; Ward-Paige, Risk, Sherwood, & Jaap, 2005) and found to be related to bottom-up control (primary producers and nutrient availability) and reduction in water quality (Baum, Januar, Ferse, Wild, & Kunzmann, 2016; Norström et al., 2009). Heavily disturbed and overfished reefs may undergo a shift toward soft coral dominance, as most soft coral species are successful colonizers thanks to their high fecundity and diverse dispersal modes (Hughes, 1994; Roberts, 1995). Hence, the dominance of soft corals on some of our survey sites is likely related to the history of blast fishing, *A. planci* starfish outbreaks and damages caused by typhoons on the reefs around Malapascua. In addition, HC reefs are located in areas that are more sheltered from the stronger currents occurring in Malapascua (pers. obs.). The relatively calm conditions and clear water are beneficial for coral growth, especially for branching corals (Veron, 2000). Rather, abundance of soft corals is usually higher in current exposed reefs (Fabricius 1997). As macroalgae shifts, soft coral shifts are difficult to reverse as the scleractinian recruitment is inhibited by the soft corals (Fox et al., 2003). Even though soft corals (Octocorallia) do not provide a 3D hard structure, their skeletons made of spiculite and carbonate calcium can provide habitat for other reef organisms and especially fish (Ferrari, 2017; Jeng, Huang, Dai, Hsiao, & Benayahu, 2011). And indeed, we have found that the diversity of fish species is significantly correlated to total coral cover but not hard coral cover, which strengthen the idea that soft corals also support the biodiversity of reefs.

A low coverage of other organisms such as anemones, sponges, zooanthids and corallimorphs has been observed on all sites. Only one site (Barrio in Malapascua) is dominated by algae (turf and macroalgae) associated with a low coral cover. This may indicate an insufficient herbivory (Graham et al., 2008) and/or high nutrient loadings that favour macroalgae growth and negatively impact coral cover (Stimson, Larned, & Conklin, 2001). Located at the entrance of the main port of the island and close to the densely inhabited 'Barrio's beach', the high abundance of algae at the Barrio site could be explained by nutrient enrichment due to waste water run-off and boat pollution. Water quality assessment and a future monitoring program would facilitate a more in-depth analysis.

B. Coral Health and Impacts

Mean percentage of coral cover is the highest observed since the beginning of People and the Sea monitoring in 2015. This result suggests a trend of coral reef recovery around Malapascua island and the surrounding areas of Campatoc and Carnaza island. These reefs were heavily impacted by Typhoon Yolanda in 2013. The observed increase in coral cover shows the potential of natural recovery after such natural disturbances. Licuanan et al. (2017) described four health categories (Poor, Fair, Good and Excellent) for coral reefs in the Philippines based on their coral cover. With a mean hard coral cover of 28.7 (± 5.1) % in 2018, the reefs around Malapascua are in a 'Fair' condition according to that scale, and above the national average of 22.8% (Licuanan, Robles, and Reyes 2019). In addition, the results of the recent assessment of Licuanan et al. (2017, 2019) show that Filipino reefs have deteriorated since the initial surveys of Gomez & Alcala (1981) in the country. Thus, our results indicate that the conditions of coral reefs in Malapascua are more positive compared to the national trend in the Philippines (Licuanan et al. 2017; Licuanan, Robles, and Reyes 2019). This positive pattern could be explained by the recent rapid development of touristic activities, mainly diving related, which have provided alternative livelihoods and decreased the use of destructive fishing practices.

All of the HC dominated survey sites show a relatively large amount of physical coral damages, predation and recently killed corals. All of our survey sites are located in fishing zones and touristic areas; therefore, the coral impacts are likely related to touristic activities (snorkelling, diving, anchoring and littering) or fishing activities (nets, fish traps, fishing lines and overexploitation). Dakit Dakit and Coral Garden East and North in Malapascua are the most impacted by coral damages. Those are shallow sites within delineated 'Snorkelling and No-Fishing zones', where most of the snorkelling activities of the island take place. Hence, the high occurrence of coral damages in those sites is likely related to snorkelers' damages and boat anchoring. Despite the presence of mooring lines, anchoring on the reef remains common around the island (pers. obs). Collecting data on the strength of currents on these sites in the future could help to determine the relative impact of diver/snorkeler damage vs natural breakage.

Our results show a high abundance of coral colonies impacted by predators (Crown-of-Thorns *A. planci*, *Drupella spp.* or *C. violacea* snails), and a drastic increase in the density of these three predators within the last three years. This pattern is likely due to a lack of predators of these species, caused by overharvesting, and could also be related to water quality or temperature (Great Barrier Reef Marine Park Authority 2017; Rotjan and Lewis 2008). Even though coral predators are natural inhabitant of the reefs, the direct consumption of live coral represents a biotic stressor that can affect coral survival and cause rapid coral decline when the predators outbreak (Rotjan and Lewis 2008). Hence our results show that the density of recently killed corals is positively (despite not significantly) correlated to the density of *A. planci* starfish, suggesting that coral mortality is likely caused by predation of the starfish. Crown-of-Thorns have been particularly problematic for the reefs in Malapascua, as regular outbreaks have been reported in diverse dive sites around the island. Population assessments are currently conducted in order to get an estimation of the population and possibly plan a control program in collaboration with the local government.

C. Coral Recruitment

As coral recruitment has been added to our survey in 2017, we currently lack data to assess the temporal trend; several years of information on patterns of coral recruitment being crucial to understand population dynamics and estimate resilience to natural disturbances such as crown-of-thorns outbreaks, typhoons or bleaching events (Hughes et al. 1999). High coral recruit density is found in soft coral dominated sites, as expected considering the high colonization rates of these organisms (Hughes 1994; Roberts 1995). Heavily impacted sites such as Barrio, Dakit Dakit and Coral Garden show low densities of coral recruits, which raises concern regarding their resilience capacity. The density of recruits is not correlated to the percentage of available substrate to settle, which indicates that coral recruitment is not limited by space, but possibly by other factors such as low coral reproduction rates, low larvae survival or a low settlement rate.

Recruit size class analysis shows a dominance of small size recruits (1-2.9cm). This may indicate an increase in the spawning of adult colonies or in the settlement of recruits. But it could also be a sign of increased rates of mortality of the largest recruits (Moulding 2005). It will be interesting to look at the evolution of recruit size class density in the following years to better understand the pattern.

D. Fish

People and the Sea's list of fish species recorded during the survey was modified in early Spring 2017. Hence, we can only analyse the temporal variation of fish density and diversity over two years. A slight increase in fish density is found in Malapascua between 2017 and 2018, whereas the opposite pattern is observed in Campatoc. Survey sites in Campatoc have been selected by local stakeholder groups as part of a Marine Protected

Area (MPA) creation process led by the Municipal Environment and Natural Resource Office (MENRO). During the aforementioned process, they were identified as areas where high levels of fishing pressure existed. This high fishing pressure could explain the decrease we found in fish abundance. Rather, Malapascua sites might be subjected to decreasing fishing pressure because of the development of tourism bringing alternative sources of income for the local community. Reef monitoring data over a longer time period will allow confirmation or otherwise of this assumption.

Our results for the year 2018 do not show a significant correlation between coral cover and fish density. Some sites with high coral cover also display high fish densities (Lighthouse, Mermaid, Tominjao 1 & 2, Maria), but other sites show high coral covers and poor fish densities (Coral Garden East and North, Bagay 2). Relationships between coral cover and fish abundance is highly complex, and often related to food, depending on the families or groups considered (Öhman and Rajasuriya 1998). Fish populations are affected by many factors, such as juvenile recruitment, inter and intraspecific competition, predation and fishing, and the relative importance of these factors varies between species and years (Chabanet et al. 1997). Coral cover and habitat complexity (mainly related to the diversity of coral forms) are likely to be important drivers of fish abundance as they provide food and shelter for many species (Chabanet, Dufour, and Galzin 1995). However, heavily degraded reefs are found to host lower abundance and diversity of fish (Chabanet, Dufour, and Galzin 1995). Hence the low fish density found in Coral Garden sites despite their high coral cover may be explained by the high abundance of coral impacts (predation, damages, killed coral) in these sites.

On average in 2018, we observed 19 different fish species out of the 112 targeted. The correlation between fish species richness and total coral cover is significant, which demonstrates the importance of corals to support the biodiversity of other taxa. In addition, coral diversity (e.g. the diversity of coral forms and species) has been shown to correlate with fish diversity more than coral cover (Galzin et al. 1994). We cannot test that hypothesis as we do not record coral at the genus level. Fish species richness is strongly correlated to fish density for all sites except Bagay 2, which displayed a low fish density but high species richness. Hence, the low fish abundance in this site is likely caused by a high level of fishing pressure (see first paragraph).

The most abundant fish families in 2018 are small sized reef fish with relatively small home range (Mouillot et al. 2014): Labridae (wrasses), Chaetodontidae (butterflyfish) and Pomacanthidae (Angelfish). Our analyses of fish density per diet type show a dominance of planktonic and coralivorous species. High density of coralivorous species is positive for reef health as it indicates an abundance and diversity of corals sufficient to sustain species feeding exclusively on corals (Cole, Pratchett, and Jones 2008). Coralivorous species also play a critical role in regulating distribution and abundance of certain prey corals (Cole, Pratchett, and Jones 2008). The relatively high abundance of herbivorous species, such as parrotfish, rabbitfish and surgeonfish, also has a positive impact on reef health as grazers are crucial to limit algae growth and prevent ecosystem shift from coral dominated to macroalgae dominated reefs (Hoey and Bellwood 2008; Hughes et al. 2007; Rasher et al. 2012).

Most large reef fish species have commercial interest in the Philippines. Parrotfish, snappers, groupers, emperors, sweetlips and rabbitfish are commonly sold on fish markets. In 2018, we only recorded two occurrences of the large size category (> 30cm) for all of the sized species (parrotfish, snappers, emperors and groupers) in all of the sites, which represent 0.25% of all observations of sized species. In addition, most observations of sweetlips are juveniles. Some sites, such as Mermaid and Bantigue, have high overall fish densities but show low abundances of commercial fish species. Similarly, Sunken Dakit and Pantao show medium overall fish densities, but none of the commercial groups are observed. This pattern likely indicates high fishing pressure occurring on these sites. On the other hand, sites such as Coral Garden North and East have the lowest overall fish densities but medium densities of commercial species (i.e. a higher than average proportion of the fish in these sites are commercial species). This result seems to confirm the hypothesis of a low fish density being more related to coral degradation than to excessive fishing pressure on these sites. Groupers were the most commonly recorded group, but the majority (93%) of observed individuals are small sized (<15cm). Similarly, parrotfish are the most abundant group, but 90% of observed individuals measures less than 15cm. Snappers show a higher occurrence of larger individuals, with 56% of observed fish belonging to the medium size category (15 to 30cm). Our analyses of fish density per ecological trait show a dominance of medium size fish species (15 to 50cm of maximum body length). Large size species (>50cm of maximum body length) are very rarely observed, which reinforces the previous results. Very low abundance of large fishes indicates high fishing pressure that probably exceed sustainable levels and may threaten long term population persistence. Continuous monitoring of fish abundance and diversity in the following years will provide more information regarding the evolution of fish populations.

Several of People and the Sea's survey sites are located within areas protected by municipal ordinance (Lapus Lapus, Dakit Dakit, Coral Garden North & East, Two Rocks and Lighthouse). However, none of these areas benefit from an enforcement of these ordinances. Therefore, we cannot assess the influence of the protection measures. However, since the beginning of 2019, efforts have been made to enforce the protection of the Dakit Dakit designated area. This has been accompanied by the installation of buoys that clearly delineate its extent. Future monitoring of this site will allow us to quantify the effectiveness of these efforts.

Efforts have previously been made to enforce regulation of the Monad Shoal Marine Reserve, a sea mount located about 10km South-East of the island and popular diving spot for the sighting of Pelagic Thresher Shark (*Alopias pelagicus*). Fish abundance, size and species diversity are clearly higher in Monad Shoal than in any of the survey sites, and top predators such as sharks and rays are regularly observed (pers. obs.). That could be partially due to the protection effort. People and the Sea has recently started to collect data on fish abundance and diversity in Monad Shoal, as well as in Malapascua dive sites, using the Roving Diver Technique (Bohnsack 1996) in collaboration with local dive centres. These data will provide interesting insight regarding the effect of enforced protection measures on fish populations. At present, the amount of data collected is not sufficient to include a full analysis in the present report. In addition, monitoring permanent sites on Monad Shoal will provide additional information regarding benthic cover, coral health and potential impacts due to the high level of diving tourism.

E. Invertebrates

Invertebrates are largely used as biological indicators of coral reef ecosystems, as their density may reflect changes in reef composition and structure (Jones and Kaly 1996). Our results show a slight increase in the density of sea stars, sea cucumbers and gastropods (Cowries, triton trumpet and nudibranchs) between 2016 and 2018. The triton trumpet and 12 cowrie species are nationally protected and their collection forbidden. Hence, the increase in their densities may indicate a recovery of their populations. However, they have been historically heavily exploited for their shell and may still be collected around Malapascua. Similarly, Triton trumpets have likely suffered from over-exploitation, with no observations recorded in 2018 in any of the survey areas. Similarly, the very low abundance of commercially important cephalopods (squids, cuttlefish and octopus) might also be related to their exploitation. Although since they are highly mobile and cryptic (especially octopus), the little number of observations of cephalopod species might also be due to avoidance behaviour.

There are over one hundred sea cucumber species in the Philippines, 25 of which are harvested commercially. After years of overexploitation, harvesting of all sea cucumber species has been regulated since 2013 in the Philippines, but they remain largely exploited as the effectiveness or enforcement of this regulation is often not sufficient (Jontila et al. 2018). The three commercial sea cucumber species that are targeted in our surveys (the Greenfish - *Stichopus chloronotus*, the Pinkfish - *Holothuria edulis*, and the Prickly redfish - *Thelenota ananas*) have never been observed in any of the sites since the beginning of People and the Sea monitoring in 2015. This clearly indicates that populations of these species have collapsed due to overharvesting.

The mean density of giant clam species (*Tridacna spp.*) has slightly decreased from 2016 to 2018. Giant clams are important reef filter feeders that also contribute to the reef structure and rigidity (Jones and Kaly 1996). They have long been exploited across the tropical Pacific and Indian Oceans as source of high-value food and for their shell (Tisdell, Shang, and Leung 1994), and their numbers declined drastically during the twentieth century (Moorhead 2018). All giant clam species are nationally protected and their collection, sale and consumption is strictly prohibited in the Philippines. However, they are commonly illegally harvested in Malapascua (pers. obs) and throughout the Philippines as they have extremely high economic value (Sobradil 2019). The giant clams recorded in 2018 are small sized, as no individual exceeds 30cm length. Sixty percent of all observed individuals measures between 10 and 20cm length, and only 17% between 20 and 30cm length. Giant clams can grow to over 120cm length for the largest species *Tridacna gigas*, and have a lifespan between 100-200 years (Neo et al. 2017). Low abundance and small size of the clams we observe likely result from a history of severe overharvesting. Enforcement of the protection of giant clam may allow for population recovery. Future monitoring of *Tridacna* species will provide more insight regarding that matter.

We calculated the density of invertebrate taxa separately for three types of sites (soft coral dominated, hard coral dominated and mixed sites) for the year 2018. Soft coral dominated sites show higher densities of all types of invertebrates but urchins and giant clams. Soft coral themselves provide little food for other reef taxa, as most of soft coral species produce high concentrations of toxic or feeding-deterrent metabolites (Sammarco, Coll, and La Barre 1985). Soft coral dominated reefs are located on platforms of outer-shelf reefs exposed to relatively strong currents, since many soft coral species are relatively inefficient in photosynthesis and thus require high levels additional food intake (Fabricius 1997). Hence, the higher abundance of invertebrate taxa on soft coral dominated reefs may be explained by the high level of nutrients available in such reefs, generating a high abundance of primary producers which support the whole food web.

The higher abundance of urchins on hard coral dominated sites is likely related to higher algae cover on these reefs, as most urchin species are grazers and feed on algae (McClanahan and Shafir 1990). Our results also show a very high density of long-spined urchins (LSU) *Diadema spp.,* which has increased between 2016 and 2018. LSU are important grazing species that help controlling algae growth and thus help preventing shifts from coral domination to macroalgae domination in impacted reefs (Hughes et al. 2007). The density of LSU seems correlated to the algae cover, although not significantly. Possible explanations for the increasing abundance of LSU is an increase of algae abundance, a lack of their natural predators, such as triggerfish and some pufferfish species, or a lack of competitor grazing fish species such as parrotfish, surgeonfish or rabbitfish (McClanahan and Shafir 1990).

The mean density of the three recorded coral predators (*A. planci* sea star, *Drupella spp.* and *Coralliophila violacea*) has drastically increased from 2016 to 2018. Among these predators, *A. planci* is the most influential due to its very high rate of coral consumption. Indeed, one *A. planci* individual can consume 5 to 6 m^2 of live coral per year (Rotjan and Lewis 2008), and they periodically reach population outbreaks with densities of 5 to 6 individuals per square meter (Great Barrier Reef Marine Park Authority 2017; Rotjan and Lewis 2008). Such outbreaks often cause nearly 100% coral mortality in the affected area (Carpenter 1997). *Drupella spp.* are obligate corallivore that specialize on fast-growing acroporid corals, especially *Acropora* and *Montipora spp.* (Morton, Blackmore, and Kwok 2002). At high densities, *Drupella* snails can also cause significant coral damage. For example, a *Drupella spp.* outbreak on Ningaloo Reef (Western Australia) caused a decrease of live coral cover by up to 86% in some reefs (Rotjan and Lewis 2008). The *C. violacea* snail feeds preferentially on the slow growing corals *Porites spp.* (Clements and Hay 2018). Even though they have a low consumption rate and leave little visible damages, feeding by *C. violacea* can reduced coral growth by up to 43% depending on snail size

(Clements and Hay 2018). The increased abundance of coral predators we are observing around Malapascua is likely related to the increase of hard coral cover, as predator density is correlated to hard coral cover. Continued monitoring will indicate whether populations are increasing to levels that causes significant damage to the reefs.

CONCLUSION

Long term monitoring of coral reefs is a fundamental part of resource management, which can be used to detect the impacts of natural and human activities, assess the potential resilience of the ecosystem, and measure the efficiency of conservation strategies (Flower et al. 2017). Overall, our results indicate that the coral reefs around Malapascua are relatively healthy compared to the national average in the Philippines, and given that they are recovering from recent major typhoon events. This positive pattern is a sign of resilience from these events, and likely a benefit of the development of touristic activities on the island. Conversely, an excessive increase in tourism has negative impacts on coral reefs including water quality issues, diver and snorkeler damages, anchor damage, and sedimentation from coastal erosion and over-development (Harriott and Harriott 2002). Whether or not these issues are overcome by the benefits brought by diving related tourism (alternative livelihood for fisher-folks, installation of mooring lines, increase of environmental awareness within the local community) on Malapascua remains unsure. Future monitoring of the reefs as well as further environmental assessments (e.g. water quality, waste management, carrying capacity and monitoring of other habitats such as seagrass and mangrove) will provide the information necessary to investiagte that question. Crown-of-Thorns starfish have been particularly problematic for the reefs in Malapascua, as regular outbreaks have been reported in diverse sites around the island. Population assessments are being conducted by PepSea in order to get an estimation of their densities and feeding habits; and possibly plan a control program in agreement with the local government.

Malapascua island is surrounded by five ‘Snorkelling and No-Fishing Zones’ and one ‘Marine Reserve’ designated by Municipal Ordinances. These ordinances proscribe any kind of fishing or extraction of marine life, but so far only one of the Snorkelling and No-Fishing Zones (Dakit Dakit) has buoys delineating the protected area. These buoys have been installed in February 2019 even though the ordinance was passed in 2010. In addition, Gato Island, Monad Shoal and Lapus Lapus have all been designated as Marine Reserves since 2002 (Ordinance No. 07-2002, amendment Ordinance No. 05-2010). However, all of these protected areas are still lacking numerous elements that would contribute to their effectiveness in protecting marine biodiversity and resources, including (but not limited to) in-depth stakeholder consultation, management board, monitoring, and enforcement of regulations (Edgar et al. 2014; Fox et al. 2012). Both ecological (e.g. habitat representativity, size, spacing) and social factors (e.g. participatory decision making, bounded resource use, monitoring and enforcement systems) foster effective Marine Protected Areas - MPAs (Fox et al. 2012). Thanks to its long-term monitoring programme, People and the Sea collects data that aim to support the creation and management of evidence-based MPAs. The main objective of our organisation is to engage with Local Government Units (LGU) and the community of Malapascua to work together toward a community-based marine resource management and conservation, as we believe it is the only way to achieve meaningful protection of marine ecosystems in the long run.

REFERENCES

Alcala, A. C., and G. R. Russ. 2002. "Status of Philippine Coral Reef Fisheries." *Asian Fisheries Science* 15: 177–92.

Allen, Gerald R. 2008. "Conservation Hotspots of Biodiversity and Endemism for Indo-Pacific Coral Reef Fishes." *Aquatic Conservation: Marine and Freshwater Ecosystems* 18 (5): 541–56. https://doi.org/10.1002/aqc.880.

Barut, Noel C, Mudjekeewis D Santos, Leony L Mijares, Rodelio Subade, Nygiel B Armada, and Len R Garces. 2003. "Philippine Coastal Fisheries Situation." In *Worldfish Center Conference Proceedings*, 885–914. Penang, Malaysia: Silvestre G, Garces L, Stobutzki I, editors.

Beger, Maria, Alastair R. Harborne, Terence P. Dacles, Jean-Luc Solandt, and Gerardo L. Ledesma. 2004. "A Framework of Lessons Learned from Community-Based Marine Reserves and Its Effectiveness in Guiding a New Coastal Management Initiative in the Philippines." *Environmental Management* 34 (6):786–801. https://doi.org/10.1007/s00267-004-0149-z.

Bohnsack, J. A. 1996. "Two Visually Based Methods for Monitoring Coral Reef Fishes." In *A Coral Reef Symposium on Practical, Reliable, Low Cost Monitoring Methods for Assessing the Biota and Habitat Conditions of Coral Reefs*. Office of Ocean and Coastal Resource Management: M.P. Crosby, G.R. Gibson, and K.W. Potts (eds.).

Carpenter, Kent E., and Victor G. Springer. 2005. "The Center of the Center of Marine Shore Fish Biodiversity: The Philippine Islands." *Environmental Biology of Fishes* 72 (4): 467–80. https://doi.org/10.1007/s10641-004-3154-4.

Carpenter, ROBERT C. 1997. "Invertebrate Predators and Grazers." In *Life and Death of Coral Reefs*, 198–229. New York: Chapman and Hall.

Chabanet, P., V. Dufour, and R. Galzin. 1995. "Disturbance Impact on Reef Fish Communities in Reunion Island (Indian Ocean)." *Journal of Experimental Marine Biology and Ecology* 188 (1): 29–48. https://doi.org/10.1016/0022-0981(94)00184-F.

Chabanet, P., H. Ralambondrainy, M. Amanieu, G. Faure, and R. Galzin. 1997. "Relationships between Coral Reef Substrata and Fish." *Coral Reefs* 16 (2): 93–102.

Clements, Cody S., and Mark E. Hay. 2018. "Overlooked Coral Predators Suppress Foundation Species as Reefs Degrade." *Ecological Applications: A Publication of the Ecological Society of America* 28 (7): 1673–82. https://doi.org/10.1002/eap.1765.

Cole, Andrew J., Morgan S. Pratchett, and Geoffrey P. Jones. 2008. "Diversity and Functional Importance of Coral-Feeding Fishes on Tropical Coral Reefs." *Fish and Fisheries* 9 (3): 286–307. https://doi.org/10.1111/j.1467-2979.2008.00290.x.

Day, Jon. 2008. "The Need and Practice of Monitoring, Evaluating and Adapting Marine Planning and Management—Lessons from the Great Barrier Reef." *Marine Policy*, The Role of Marine Spatial Planning in Implementing Ecosystem-based, Sea Use Management, 32 (5): 823–31. https://doi.org/10.1016/j.marpol.2008.03.023.

Edgar, Graham J., Rick D. Stuart-Smith, Trevor J. Willis, Stuart Kininmonth, Susan C. Baker, Stuart Banks, Neville S. Barrett, et al. 2014. "Global Conservation Outcomes Depend on Marine Protected Areas with Five Key Features." *Nature* 506 (7487): 216–20. https://doi.org/10.1038/nature13022.

English, Susan (S), Clive (CR) Wilkinson, and Valonna (V) Baker. 1997. *Survey Manual for Tropical Marine Resources (2nd Edition)*. Australian Institute of Marine Science. http://epubs.aims.gov.au//handle/11068/13062.

Fabricius, K. E. 1997. "Soft Coral Abundance on the Central Great Barrier Reef: Effects of Acanthaster Planci, Space Availability, and Aspects of the Physical Environment." *Coral Reefs* 16 (3): 159–67. https://doi.org/10.1007/s003380050070.

Fishery and Aquaculture Country Profiles. Philippines (2014). Country Profile Fact Sheets. In: FAO Fisheries and Aquaculture Department [online]. Rome. Updated 2014. [Cited 7 August 2019]. http://www.fao.org/fishery/

Flower, Jason, Juan Carlos Ortiz, Iliana Chollett, Sabah Abdullah, Carolina Castro-Sanguino, Karlo Hock, Vivian Lam, and Peter J. Mumby. 2017. "Interpreting Coral Reef Monitoring Data: A Guide for Improved Management Decisions." *Ecological Indicators* 72: 848–869.

Fox, Helen E., Michael B. Mascia, Xavier Basurto, Alice Costa, Louise Glew, Dennis Heinemann, Leah B. Karrer, et al. 2012. "Reexamining the Science of Marine Protected Areas: Linking Knowledge to Action." *Conservation Letters* 5 (1): 1–10. https://doi.org/10.1111/j.1755-263X.2011.00207.x.

Galzin, R., S. Planes, V. Dufour, and B. Salvat. 1994. "Variation in Diversity of Coral Reef Fish between French Polynesian Atolls." *Coral Reefs* 13 (3): 175–80. https://doi.org/10.1007/BF00301196.

Gomez, E. D., and A. C. Alcala. 1981. "Status of Philippine Coral Reefs." In *Proceedings of the Fourth International Coral Reef Symposium, Manila*, 1:275–282.

Gomez, E. D., P. M. Aliño, H. T. Yap, and W. Y. Licuanan. 1994. "A Review of the Status of Philippine Reefs." *Marine Pollution Bulletin* 29 (1): 62–68. https://doi.org/10.1016/0025-326X(94)90427-8.

Graham, N. A. J., and K. L. Nash. 2013. "The Importance of Structural Complexity in Coral Reef Ecosystems." *Coral Reefs* 32 (2): 315–26. https://doi.org/10.1007/s00338-012-0984-y.

Great Barrier Reef Marine Park Authority. 2017. "Crown-of-Thorns Starfish Control Guidelines: Second Edition." Report. Great Barrier Reef Marine Park Authority. http://elibrary.gbrmpa.gov.au/jspui/handle/11017/3162.

Halpern, Benjamin S., Melanie Frazier, John Potapenko, Kenneth S. Casey, Kellee Koenig, Catherine Longo, Julia Stewart Lowndes, et al. 2015. "Spatial and Temporal Changes in Cumulative Human Impacts on the World's Ocean." *Nature Communications* 6 (July): 7615. https://doi.org/10.1038/ncomms8615.

Harriott, Vj, and Vicki J. Harriott. 2002. "Marine Tourism Impacts and Their Management on the Great Barrier Reef." CRC Reef Research Centre.

Harris, Daniel L., Alessio Rovere, Elisa Casella, Hannah Power, Remy Canavesio, Antoine Collin, Andrew Pomeroy, Jody M. Webster, and Valeriano Parravicini. 2018. "Coral Reef Structural Complexity Provides Important Coastal Protection from Waves under Rising Sea Levels." *Science Advances* 4 (2): eaao4350. https://doi.org/10.1126/sciadv.aao4350.

Hill, Jos, and Clive Wilkinson. 2004. *Methods for Ecological Monitoring of Coral Reefs: Version 1*. Townsville: Australian Institute of Marine Science.

Hodgson, G., J Hill, W Kiene, L Maun, J Mihaly, J Liebeler, C Shuman, and R Torres. 2004. *Reef Check Intruction Manual: A Guide to Reef Check Coral Reef Monitoring*. Pacific Palicades. California, USA: Reef Check, Inst. of the Environment.

Hoegh-Guldberg, Ove, Hans Hoegh-Guldberg, J. E. N. Veron, Alison Green, Edgardo D. Gomez, A. Ambariyanto, and L. Hansen. 2009. "The Coral Triangle and Climate Change: Ecosystems, People and Societies at Risk."

Hoey, A. S., and D. R. Bellwood. 2008. "Cross-Shelf Variation in the Role of Parrotfishes on the Great Barrier Reef." *Coral Reefs* 27 (1): 37–47. https://doi.org/10.1007/s00338-007-0287-x.

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, et al. 2003. "Climate Change, Human Impacts, and the Resilience of Coral Reefs." *Science* 301 (5635): 929–33. https://doi.org/10.1126/science.1085046.

Hughes, T. P., A. H. Baird, E. A. Dinsdale, N. A. Moltschaniwskyj, M. S. Pratchett, J. E. Tanner, and B. L. Willis. 1999. "Patterns of Recruitment and Abundance of Corals along the Great Barrier Reef." *Nature* 397 (6714): 59. https://doi.org/10.1038/16237.

Hughes, Terence P. 1994. "Catastrophes, Phase Shifts, and Large-Scale Degradation of a Caribbean Coral Reef." *Science* 265 (5178): 1547–51. https://doi.org/10.1126/science.265.5178.1547.

Hughes, Terence P., Maria J. Rodrigues, David R. Bellwood, Daniela Ceccarelli, Ove Hoegh-Guldberg, Laurence McCook, Natalie Moltschaniwskyj, Morgan S. Pratchett, Robert S. Steneck, and Bette Willis. 2007. "Phase Shifts, Herbivory, and the Resilience of Coral Reefs to Climate Change." *Current Biology* 17 (4): 360–65. https://doi.org/10.1016/j.cub.2006.12.049.

Jones, Geoffrey P., and Ursula L. Kaly. 1996. "Chapter 3 - Criteria for Selecting Marine Organisms in Biomonitoring Studies." In *Detecting Ecological Impacts*, edited by Russell J. Schmitt and Craig W. Osenberg, 29–48. San Diego: Academic Press. https://doi.org/10.1016/B978-012627255-0/50005-7.

Jontila, Jean Beth S., Harold M. Monteclaro, Gerald F. Quinitio, Sheila Mae Santander-de Leon, and Jon P. Altamirano. 2018. "Status of Sea Cucumber Fishery and Populations across Sites with Different Levels of Management in Palawan, Philippines." *Ocean & Coastal Management* 165 (November): 225–34. https://doi.org/10.1016/j.ocecoaman.2018.08.025.

Kendall, M.G. 1948. *Rank Correlation Methods*. Rank Correlation Methods. Oxford, England: Griffin.

Knowlton, Nancy, Russell E. Brainard, Rebecca Fisher, Megan Moews, Laetitia Plaisance, and M. Julian Caley. 2010. "Coral Reef Biodiversity." In *Life in the World's Oceans*, 65–78. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781444325508.ch4.

Licuanan, Ardea M., Michelle Z. Reyes, Katrina S. Luzon, Marie Angelica A. Chan, and Wilfredo Y. Licuanan. 2017. "Initial Findings of the Nationwide Assessment of Philippine Coral Reefs." *Philippine Journal of Science* 146 (2): 177–185.

Licuanan, W.Y., R. Robles, and M. Reyes. 2019. "Status and Recent Trends in Coral Reefs of the Philippines." *Marine Pollution Bulletin* 142 (May): 544–50. https://doi.org/10.1016/j.marpolbul.2019.04.013.

McClanahan, T. R., and S. H. Shafir. 1990. "Causes and Consequences of Sea Urchin Abundance and Diversity in Kenyan Coral Reef Lagoons." *Oecologia* 83 (3): 362–70. https://doi.org/10.1007/BF00317561.

Moorhead, Anne. 2018. "Giant Clam Aquaculture in the Pacific Region: Perceptions of Value and Impact." *Development in Practice* 28 (5): 624–35. https://doi.org/10.1080/09614524.2018.1467378.

Morton, Brian, Graham Blackmore, and C. T. Kwok. 2002. "Corallivory and Prey Choice by Drupella Rugosa (Gastropoda: Muricidae) in Hong Kong." *Journal of Molluscan Studies* 68 (3): 217–23. https://doi.org/10.1093/mollus/68.3.217.

Mouillot, David, Sébastien Villéger, Valeriano Parravicini, Michel Kulbicki, Jesus Ernesto Arias-González, Mariana Bender, Pascale Chabanet, et al. 2014. "Functional Over-Redundancy and High Functional Vulnerability in Global Fish Faunas on Tropical Reefs." *Proceedings of the National Academy of Sciences* 111 (38): 13757–62. https://doi.org/10.1073/pnas.1317625111.

Moulding, Alison L. 2005. "Coral Recruitment Patterns in the Florida Keys." *Revista de Biología Tropical* 53 (May): 75–82.

Neo, Mei Lin, Colette C.C. Wabnitz, Richard D. Braley, Gerald A. Heslinga, Cécile Fauvelot, Simon Van Wynsberge, Ser.G.E. Andréfouët, et al. 2017. "Giant Clams (Bivalvia: Cardiidae: Tridacninae): A Comprehensive Update of Species and Their Distribution, Current Threats and Conservation Status." In *Oceanography and Marine Biology*, edited by S. J. Hawkins, A. J. Evans, A. C. Dale, L. B. Firth, D. J. Hughes, and I. P. Smith, 1st ed., 87–387. CRC Press. https://doi.org/10.1201/b21944-5.

Obura, David. 2014. "Coral Reef Monitoring Manual South-West Indian Ocean Islands." Indian Ocean Commission.

Öhman, Marcus C., and Arjan Rajasuriya. 1998. "Relationships between Habitat Structure and Fish Communities on Coral." *Environmental Biology of Fishes* 53 (1): 19–31. https://doi.org/10.1023/A:1007445226928.

Oliver, Simon P., Thomas M. Grothues, Amie L. Williams, Voltaire Cerna, Medel Silvosa, Gary Cases, Matthew Reed, and Simon Christopher. 2019. "Risk and Resilience: High Stakes for Sharks Making Transjurisdictional Movements to Use a Conservation Area." *Biological Conservation* 230 (February): 58–66. https://doi.org/10.1016/j.biocon.2018.11.013.

Oliver, Simon P., Nigel E. Hussey, John R. Turner, and Alison J. Beckett. 2011. "Oceanic Sharks Clean at Coastal Seamount." Edited by Steven J. Bograd. *PLoS ONE* 6 (3): e14755. https://doi.org/10.1371/journal.pone.0014755.

Pearson, Karl. 1948. *Early Statistical Papers*. Cambridge, England: University Press.

R Core Team. 2019. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing.

Rasher, Douglas B., Sebastian Engel, Victor Bonito, Gareth J. Fraser, Joseph P. Montoya, and Mark E. Hay. 2012. "Effects of Herbivory, Nutrients, and Reef Protection on Algal Proliferation and Coral Growth on a Tropical Reef." *Oecologia* 169 (1): 187–98. https://doi.org/10.1007/s00442-011-2174-y.

Roberts, Callum M. 1995. "Effects of Fishing on the Ecosystem Structure of Coral Reefs." *Conservation Biology* 9 (5): 988–95. https://doi.org/10.1046/j.1523-1739.1995.9051332.x-i1.

Rotjan, Rd, and Sm Lewis. 2008. "Impact of Coral Predators on Tropical Reefs." *Marine Ecology Progress Series* 367 (September): 73–91. https://doi.org/10.3354/meps07531.

Sammarco, Paul W., John C. Coll, and Stephane La Barre. 1985. "Competitive Strategies of Soft Corals (Coelenterata: Octocorallia). II. Variable Defensive Responses and Susceptibility to Scleractinian Corals." *Journal of Experimental Marine Biology and Ecology* 91 (3): 199–215. https://doi.org/10.1016/0022-0981(85)90176-5.

Shapiro, S. S., and M. B. Wilk. 1965. "An Analysis of Variance Test for Normality (Complete Samples)." *Biometrika* 52 (3–4): 591–611. https://doi.org/10.1093/biomet/52.3-4.591.

Sobradil, R. 2019. "Current Status Of Giant Clams: An Implication For Conservation Management In The Island Garden City Of Samal." Oral communication presented at the 15th National Symposium in Marine Science, Aklan, Philippines, July 5.

Tisdell, C., Y. C. Shang, and P. Leung. 1994. "Economics of Commercial Giant Clam Mariculture." *Economics of Commercial Giant Clam Mariculture.* https://www.cabdirect.org/cabdirect/abstract/19936792945.

Veron, J.E.N., Lyndon M. Devantier, Emre Turak, Alison L. Green, Stuart Kininmonth, Mary Stafford-Smith, and Nate Peterson. 2009. "Delineating the Coral Triangle." *Galaxea, Journal of Coral Reef Studies* 11 (2): 91–100. https://doi.org/10.3755/galaxea.11.91.

APPENDIX A

A.1 Benthic organisms and substrate types recorded in the PIT surveys

Type	Form recorded	Benthic category
Hard corals	Branching	Reef builders
	Columnar	Reef builders
	Corymbose	Reef builders
	Digitate coral	Reef builders
	Encrusting	Reef builders
	Foliose	Reef builders
	Massive	Reef builders
	Solitary	Reef builders
	Sub-massive	Reef builders
	Table	Reef builders
Impacted corals	Recently Killed Coral	Impacted corals
	Dead Coral with Algae	Impacted corals
	Bleached hard coral	Impacted corals
Octo-corals	Soft coral	Soft corals
	Blue coral	Reef builders
Algae	Halimeda	Other algae
	Crustose	Other algae
	Nutrient Indicator Algae	Other algae
	Coralline Algae	Substrate to settle
Substrates	Rock	Substrate to settle
	Rubble	Unstable substrate
	Sand	Unstable substrate
	Silt	Unstable substrate
Other organisms	Anemone	Other biota
	Corallimorph	Other biota
	Fire coral	Reef builders
	Hydroid	Other biota
	Sponge	Other biota
	Tunicate	Other biota
	Zoanthid	Other biota

A.2 List of invertebrates and impacts surveyed on Belt Transects

	Sea urchins (Echinoidea)	Long spined urchin	*Diadema spp.*
		Collector urchin	*Tripneuste spp.*
		Flower urchin	*Toxopneuste spp.*
		Pencil urchin	*Eucidaris spp.*
	Sea stars (Asteroidea)	Crown of thorns	*Acanthaster planci*
		Other sea stars	
	Sea cucumbers (Holothuroidea)	Greenfish	*Stichopus chloronotus*
		Pinkfish	*Holothuria edulis*
		Prickly redfish	*Thelenota ananas*
		Other sea cucumbers	
	Cnidarians (Actiniaria)	Anemone	
Molluscs	Cephalopods (Cephalopoda)	Cuttlefish	
		Octopus	*Octopus spp.*
		Squid	
	Arthropods (Arthropoda)	Coral Banded Shrimp	*Stenopus spp.*
	Bivalves (Bivalvia)	Giant clam	*Tridacna spp.*
	Gastropods (Gastropoda)	Cowrie	*Cypraea spp.*
		Drupella	*Drupella spp.*
		Nudibranch	
		Triton trumpet	*Charonia tritonis*
		Violet coral snail	*Coralliophila violacea*
Impacts	Coral damages	Anchor	
		Dynamite	
		Unknown	
	Trash	Fishing	
		General	
	Impacted corals	Bleached hard corals	
		Disease	
		Predation	
		Recently Killed Coral	

A.3 List of fish species surveyed with Underwater Visual Census

Diet is coded as follows: HD = Herbivorous/Detrivorous, IM = Invertivorous targeting mobile invertebrates, CR = Coralivorous, OM = Omnivorous, PK = Planktivorous and PS = Piscivorous. Size is coded as follows: 1 = 0-7cm, 2 = 7.1-15cm, 3 = 15.1-30cm, 4 = 30.1-50cm, 5 = 50.1-80cm, and 6 = >80cm.

Family	Common name	Species	Diet	Size
Acanthuridae	Surgeonfish not in list	Acanthurus spp	HD	3
	Convict Surgeonfish	*Acanthurus triostegus*	IM	3
	Bignose Unicornfish	*Naso vlamingii*	OM	2
Balistidae	Black Triggerfish	*Melichthys niger*	IM	1
	Blackpatch Triggerfish	*Rhinecanthus verrucosus*	IM	1
	Bridled triggerfish	*Sufflamen fraenatum*	IM	4
	Clown Triggerfish	*Balistoides conspicillum*	PS	6
	Flagtail Triggerfish	*Rhinecanthus rectangulus*	PK	2
	Orange-lined Triggerfish	*Balistapus undulatus*	PS	2
	Picasso triggerfish	*Rhinecanthus aculeatus*	IM	1
	Pinktail Triggerfish	*Melichthys vidua*	IM	2
	Redtooth Triggerfish	*Odonus niger*	IM	2
	Scythe Triggerfish	*Sufflamen bursa*	IM	4
	Titan Triggerfish	*Balistoides viridescens*	PS	6
	Yellowmargin Triggerfish	*Pseudobalistes flavimarginatus*	IM	2
	Triggerfish not in list		OM	4
Caesionidae	Fusilier Group		IM	4
Carangidae	Rainbow Runner	*Elagatis bipinnulata*	IM	2
	Jack / Trevally general		PS	NA
Chaetodontidae	Black-backed Butterflyfish	*Chaetodon melannotus*	CR	3
	Chevroned Butterflyfish	*Chaetodon trifascialis*	CR	2
	Eastern Triangular Butterflyfish	Chaetodon baronessa	CR	3
	Eclipse Butterflyfish	*Chaetodon bennetti*	OM	2
	Eightband Butterflyfish	Chaetodon octofasciatus	CR	2

	Latticed Butterflyfish	*Chaetodon rafflesii*	IM	2
	Long-beaked Butterflyfish	*Chelmon rostratus*	IM	2
	Meyer's Butterflyfish	*Chaetodon meyeri*	CR	1
	Panda Butterflyfish	Chaetodon adiergastos	OM	2
	Raccon Butterflyfish	*Chaetodon lunula*	OM	1
	Redfin Butterflyfish	*Chaetodon lunulatus*	CR	1
	Spot Banded Butterfly	Chaetodon punctatofasciatus	IM	1
	Spot-tail Butterflyfish	Chaetodon ocellicaudus	CR	1
	Vagabond Butterflyfish	*Chaetodon vagabundus*	IM	1
	Butterflyfish not in list		NA	1
	Highfin Coralfish	Coradion altivelis	OM	1
	Orange-banded Coralfish	Coradion chrysozonus	OM	1
	Ocellate Coralfish	Parachaetodon ocellatus	OM	2
	Pennant Bannerfish	*Heniochus chrysostomus*	PK	2
	Longfin Bannerfish	Heniochus acuminatus	OM	1
	Singular Bannerfish	Heniochus singularius	HD	4
	Humphead Bannerfish	Heniochus varius	HD	4
Congridae	Garden Eel	Heteroconger spp	IM	4
Ephippidae	Spadefish Group	Platax spp	OM	3
Haemulidae	Diagonal-banded Sweetlips	Plectorhinchus lineatus	PS	3
	Goldstriped Sweetlips	Plectorhinchus chrysotaenia	IM	2
	Many-spotted Sweetlips	Plectorhinchus chaetodonoides	IM	1
	Oriental Sweetlips	Plectorhinchus vittatus	HD	1
	Ribbon Sweetlips	Plectorhinchus polytaenia	IM	1
	Striped Sweetlips	Plectorhinchus lessonii	IM	2
	Sweetlips unidentified		NA	3
Labridae	Bluestreak Cleaner Wrasse	Labroides dimidiatus	OM	1
	Crescent Wrasse	Thalassoma lunare	PK	4
	Humphead wrasse	Cheilinus undulatus	PS	6
	Red-breasted wrasse	Cheilinus fasciatus	IM	3
Lethrinidae	Emperor/Bream group	Lethrinus spp	NA	NA

Lutjanidae	Checkered Snapper	Lutjanus decussatus	PK	3
	Humpback Snapper	Lutjanus gibbus	IM	3
	Midnight Snapper	Macolor macularis	PK	4
	Onespot Snapper	Lutjanus monostigma	IM	3
	Red Snapper	Lutjanus bohar	HM	5
	Two-spot Snapper	Lutjanus biguttatus	IM	1
	Snapper not in list	Lutjanus sp	NA	3
Monacanthidae	Barred Filefish	Cantherhines dumerilii	PS	5
	Blackheaded Filefish	Blackhead Filefish	OM	2
	Longnose filefish	Oxymonacanthus longirostris	PK	1
	Scawled filefish	Aluterus scriptus	HD	3
	Filefish not in list		OM	3
Mullidae	Goatfish Group		IM	3
Muraenidae	Moray (various)		IM	3
Nemipteridae	Coral Bream Group		NA	2
Pomacanthidae	Lamack's Angelfish	Genicanthus lamarck	IM	2
	Three-Spot Angelfish	Apolemichthys trimaculatus	HD	4
	Vermiculated Angelfish	Chaetodontoplus mesoleucus	HD	1
	Angelfish not in list		NA	3
Pomacentridae	Anemonefish Group		NA	2
Scaridae	Bumphead Parrotfish	Bolbometopon muricatum	HD	5
	Bicolor Parrotfish	Cetoscarus ocellatus	OM	2
	Parrotfish general		HD	NA
Scombridae	Long-jawed Mackerel	Rastrelliger kanagurta	IM	4
	Tuna (various)		PS	NA
Scorpaenidae	Lionfish Group	Pterois sp	NA	NA
Serranidae	Barramundi Cod	Cromileptes altivelis	PS	6
	Chocolate Grouper	Cephalopholis boenak	IM	3
	Coral Grouper	Cephalopholis miniata	IM	4
	Flagtail Grouper	Cephalopholis urodeta	IM	5
	Honeycomb Grouper	Epinephelus merra	PK	2

	Leopard Coral Grouper	Plectropomus leopardus	PK	2
	Peacock Grouper	Cephalopholis argus	PK	3
	Grouper not in list		NA	NA
	Doublebanded Soapfish	Diploprion bifasciatum	IM	3
	Six-lined Soapfish	Grammistes sexlineatus	IM	4
Siganidae	Rabbitfish Group	Siganus sp.	HD	NA
Sphyraenidae	Barracuda general		PS	NA
Tetraodontidae	Blackspotted Puffer	Arothron nigropunctatus	IM	3
	Blue-spotted Puffer	Arothron caeruleopunctatus	PS	3
	Map Puffer	Arothron mappa	OM	3
	Reticulated puffer	Arothron reticularis	PK	3
	Star Puffer	Arothron stellatus	IM	6
	Striped puffer	Arothron manilensis	PS	3
	Whitespotted Puffer	Arothron hispidus	IM	3
	Black-saddled Toby	Canthigaster valentini	IM	1
	Crown Toby	Canthigaster coronata	IM	1
	Papuan Toby	Canthigaster papua	PS	1
	Porcupinefish	Diodon hystrix	IM	3
Zanclidae	Moorish Idol	*Zanclus cornutus*	IM	4
Echeneidae	Sharksucker	Echeneis naucrates	IM	6
Alopiidae	Pelagic Thresher	Alopias pelagicus	PS	6
Carcharhinidae	Blacktip Reef Shark	Carcharhinus melanopterus	PS	6
	Whitetip Reef Shark	Triaenodon obesus	PS	6
Dasyatidae	Blue-spotted Stingray	Neotrygon kuhlii	PS	6
	Blue-spotted Ribbontail Ray	Taeniura lymma	NA	NA

APPENDIX B

B.1 Results of the correlation tests

Correlation tests were performed using the *cor.test* function of R. When both variables were normally distributed (in grey), the Pearson's correlation was calculated. When at least one of the variables was not normally distributed (in black), the Kendall's method was used. Significant correlations (p.value <0.1) are in bold.

Variables		Correlation coeff.	p.value
HC cover	Fish diversity	0.051	0.84
HC cover	Fish density	0.15	0.41
HC cover	Algae cover	-0.136	0.592
HC cover	*A. planci*	0.335	0.152
HC cover	***Drupella spp***	**0.455**	**0.045**
HC cover	*C. violacea*	0.426	0.167
TC cover	**Fish diversity**	**0.298**	**0.087**
TC cover	Fish density	0.19	0.293
TC cover	Algae cover	-0.283	0.103
Algae cover	*Diadema spp*	-0.229	0.303
Algae cover	Fish grazers	-0.164	0.343
Algae cover	RKC	0.073	0.864
RKC	*A. planci*	0.038	0.899
RKC	*Drupella spp*	-0.143	0.72
RKC	*C. violacea*	-0.056	0.896
Coral recruits	Available substrate	-0.063	0.805
Coral recruits	Algae cover	-0.358	0.144
Coral damages	Branching corals	0.364	0.116
Coral damages	HC cover	0.182	0.459

B.2 Bivariate plots of all tested correlations

The lines show the linear regression between the two variables. Significant correlations (p.value <0.1) are shown by wider lines and an * in the plot title.