INSTITUTE FOR
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DAUIN · PHILIPPINES

OUTLOOK REPORT

2022

CONTENTS

DISCLAIMER

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This report, along with a range of information about IMR, is available online at www.institutemarineresearch.org. For information on our research methodologies and more detail on the key components of our Dauin reef ecosystem, please view our Annual Outlook Report 2020 at https://institutemarineresearch.org/our-research/our-results/.

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A MESSAGE FROM THE DIRECTORS

2022 was a pivotal year for IMR as we reopened our facilities to students and researchers from all over the world after an 11-month closure during the COVID-19 pandemic. During this closure, we remained dedicated to our mission and moved our facilities oceanfront in order to take scale-up our research and conservation capabilities. We are beyond excited about the possibilities this new chapter will provide!

Alongside the return of international travel, we welcomed Jen (Head of Science) back to the Philippines, and introduced Dan (Head of Operations) to the IMR team! This kickstarted a new year of research, which has been our best one yet due to the diversity of projects being conducted. However, this research has highlighted a number of conservation concerns that we have been battling, including a crown-of-thorns starfish outbreak, loss of Marine Protected Area boundaries, the continued spread of the Porites Ulcerative White Spot disease, and an increased prevalence of ghost-net fishing lines. With community power and government support, we have managed to drive down the COTS population, have our MPA boundaries reinstated, hold regular underwater clean-ups, and collaborate with researchers who are assisting in getting to the bottom of our disease outbreak.

At the end of 2022 we received a research grant from PADI Aware which has kick-started our first coral restoration program here in Dauin! In December of 2021, Dauin was hit by super typhoon Rai (Odette) which caused damage to high-exposure reef sites along the Dauin inshore reef. This has resulted in widespread coral mortality, generation of coral fragments, and unstable reef substrata. Our Functional Restoration and Growth Studies (FRAGS) project utilizes these susceptible corals (Corals of Opportunity; COPs) by reattaching their fragments to artificial structures of various composition and complexity.

Through a series of detailed monitoring and research efforts, we will determine the ability of previously coral-devoid artificial structures to become preliminary refuges to COPs, and later result in the sexual maturity of these COPs with the potential to reseed nearby and previously disturbed natural reefs. We are now 3 months into monitoring the growth of our first COPs, and we can't wait to see what we can achieve with this technique! Current findings can all be viewed in the contents of this report.

As we close another research year, we are so thankful for the support of an amazing team that keeps us inspired and focused on our research and conservation endeavors. Thank you to Jen (Head of Science) for making this report possible, your hard work and curiosity towards finding answers within our data to better preserve the health of Dauin's reef is outstanding. Thank you to our Research Fellows: Sarah and Fiona for your statistical eyes and contributions towards the findings in this report. Thank you to Dan (Head of Operations) for juggling the research projects underway at IMR and always making it look streamlined, as well as your commitment to EventMeasure and ensuring we are never backlogged with our fish data! And finally to our Research Assistants and Masters students: Jose, Andreas, Sarah, Niamh, Patricia, Kit, Payton, Kathryn, Kenyth, Talia, Emilia, Eliane, Casey, Georgie, John, and Luka – thank you for the underwater and data analysis hours you have all contributed towards, this project would not be achievable without you all!

IMR remains dedicated to evidence-based conservation and the future sustainability of Dauin's inshore reef. As we continue to scale our research scope, we look forward to the future with great expectations! Let's go science!

Rafael Manrique & Chelsea Waters

IMR IN NUMBERS

113 COMPLETED SURVEYS	169,500 CPCe POINTS ANALYSED	369 FISH SPECIES RECORDED
1,843 KG FISH BIOMASS RECORDED	118,095 INDIVIDUAL FISH RECORDED	11,300 M^2 CORAL REEF 3D MODELLED
30 VULNERABLE OR NEAR-THREATENED INDIVIDUALS RECORDED	2,773 IMPACTS RECORDED	53 DIFFERENT CORAL GENERA RECORDED

DAUIN LONG-TERM REEF MONITORING PROJECT

DAUIN LONG TERM REEF MONITORING PROJECT

Annual Trends: Benthic Composition

Overall benthic community composition has changed significantly throughout the years of the DLTRMP (multivariate generalised linear model (MVGLM) analysis of deviance, p<0.01, fig. 1-3). **Community composition is significantly different between all years** (pairwise comparisons p. adj<0.01, fig. 1) **except between 2021 and 2022** (p. adj=0.291, fig. 1 & 3). **Key intrinsic drivers of community composition change are algae, coral, abiotic substrate, sponges and octocorals** (fig. 2). **Percentage cover of algae, abiotic substrate and dead coral significantly change throughout the years of the DLTRMP** (MVGLM analysis of deviance univariate tests, p. adj<0.01, fig. 3, all other benthic components p. adj>0.05), although the percent cover of dead coral is very low in comparison to other benthic categories, hence it is not a key intrinsic driver of community composition (fig. 2). **Examining the individual effects of these composition changes, as well as interactions between different benthic components, is key in identifying potential areas of concern and effectively allocating resources for necessary management actions.**

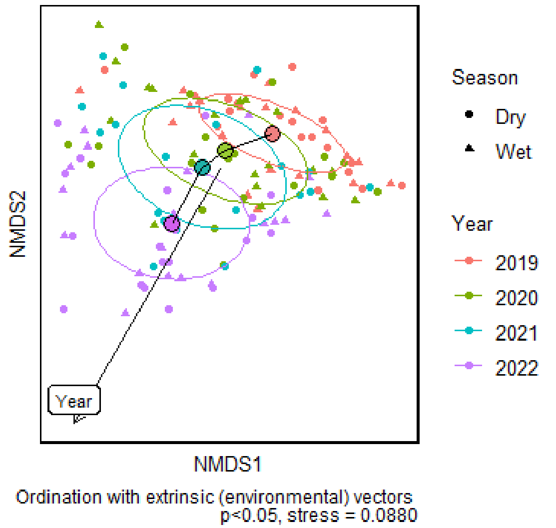


Fig. 1. Non-metric multidimensional scaling (NMDS) plot of benthic community in Dauin with fitted environmental variables (year, season) (k = 3, distance = bray, stress=0.0880). Arrows (length and direction) represent environmental variables significantly (p<0.05) explaining the ordination. Only two dimensions of the NMDS are illustrated for ease of representation. Larger circles represent NMDS centroids (means) for each year.

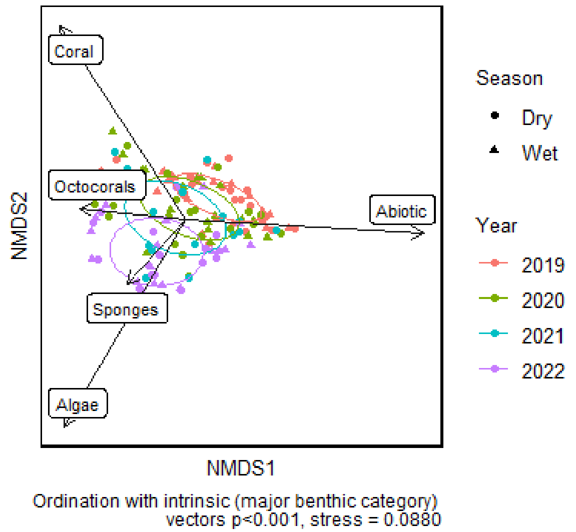


Fig. 2. NMDS plot of benthic community in Dauin with fitted intrinsic variables (major benthic category) (k = 3, distance = bray, stress=0.0880). Arrows (length and direction) represent categories significantly (p<0.05) explaining the ordination. Only two dimensions of the NMDS are illustrated for ease of representation.

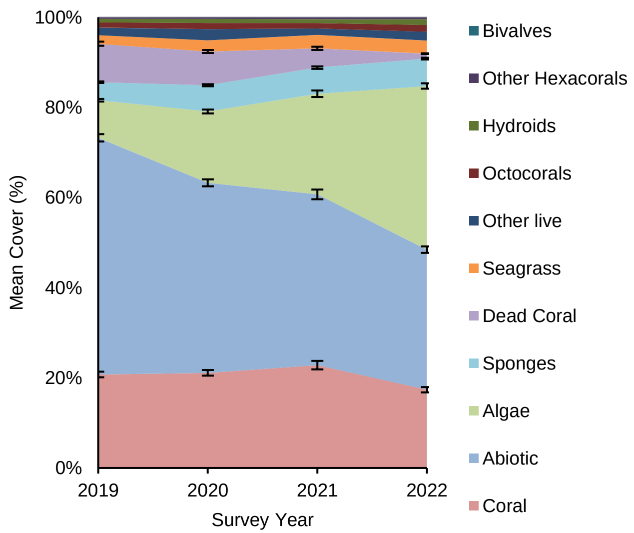


Fig. 3. Mean transect cover (% ± SE) of major benthic categories along Dauin Reef separated by year.

Coral cover has not changed significantly over the years of the DLTRMP (MVGLM analysis of deviance univariate tests, p. adj=n.s, fig 2-4). GAM revealed no strong relationship between coral cover and year, although a gentle decline since 2021 is visible (fig. 3 & 4). Net reef growth depends on the balance of calcification (and subsequent colony extension) and decalcification (erosion) processes[1]. These processes are determined by water quality parameters (e.g., temperature, salinity, pH, nutrient load, light availability, pCO2 and aragonite saturation state[2–5]), which fluctuate naturally[6,7], but are also affected by anthropogenic activity (e.g., climate change[1,8], nutrient runoff[9,10] and Crown-of-Thorns Starfish outbreaks (see Crown Of Thorns Sea Star: Outbreak and Recovery). Sufficient calcification for reef growth will become increasingly energetically costly under conditions projected for 2100 if CO_2 emissions continue unmitigated; and the synergistic impact of ocean warming and acidification with increased night-time dissolution will lead to an accelerated loss of carbonate frameworks[11]. **However, the trends in coral cover vary greatly between survey sites** (GAM, significant interaction between survey site and year, p. adj<0.01, see below, fig. 8). Increases in coral cover are likely as a result of net reef growth, however the observed rate of decreases in coral cover suggest localised disturbances are the cause (see below). IMR is investigating the ability for Dauin's reef ecosystem to recover after significant disturbances, which are yet to show signs of increasing coral cover (see Drivers of Natural Recovery).

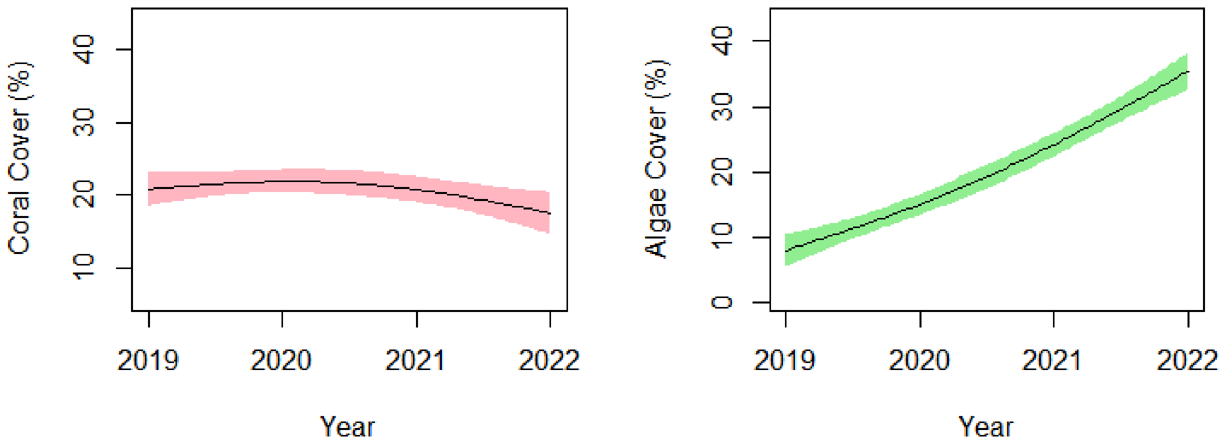


Fig. 4. Generalized additive model (GAM) plots showing the partial effects of year on the percent cover of (left) coral and (right) algae. *The shaded areas indicate the 95% confidence intervals. Coral R^2(adj) = 0.276, effective degrees of freedom (edf) = 1.85. Algae R^2(adj) = 0.377, edf = 1.78.*

Bare substrate, in the form of abiotic substrate and coral rubble, **decreases significantly every survey year throughout the DLTRMP** (MVGLM analysis of deviance univariate tests on abiotic substrate and dead coral, p. adj<0.01, fig. 3 & 6)**. This bare substrate is colonised by predominantly algae;** algae significantly increases throughout the DLTRMP (MVGLM analysis of deviance univariate tests, p. adj<0.01, fig 2-3). GAM revealed a strong relationship between algae cover and year (p<0.01, fig. 3 & 4), but also a significant interaction term between survey site and year (p. adj<0.01, fig. 5). **Significant predictors of changing algae cover were survey season and barangay** (GLMM, Wald Chi-Squared Test, survey season p<0.001 and barangay p<0.001, sponge p<0.05 and coral*sponge p<0.05, fig. 5). Seasonality (mean monthly air temperature and precipitation) had no significant effect (see Seasonal Fluctuations). High autocorrelation was also observed; the amount of algae cover at any one survey season is highly correlated with the amount of algae cover recorded the previous season. This confirms that trajectories of increasing algae cover vary between locations. T**he more southerly sites of Maayong Tubig (sites 18 and 19) and Masaplod Sur (sites 13-16) show the steepest increases, whereas Bulak II (site 7) and Lipayo II (site 8) show relatively much slower increases in algae cover (fig. 5). This information is be key in continuing to examine coral-algae dynamics in Dauin, as well as in determining any essential barangay-specific management actions**.

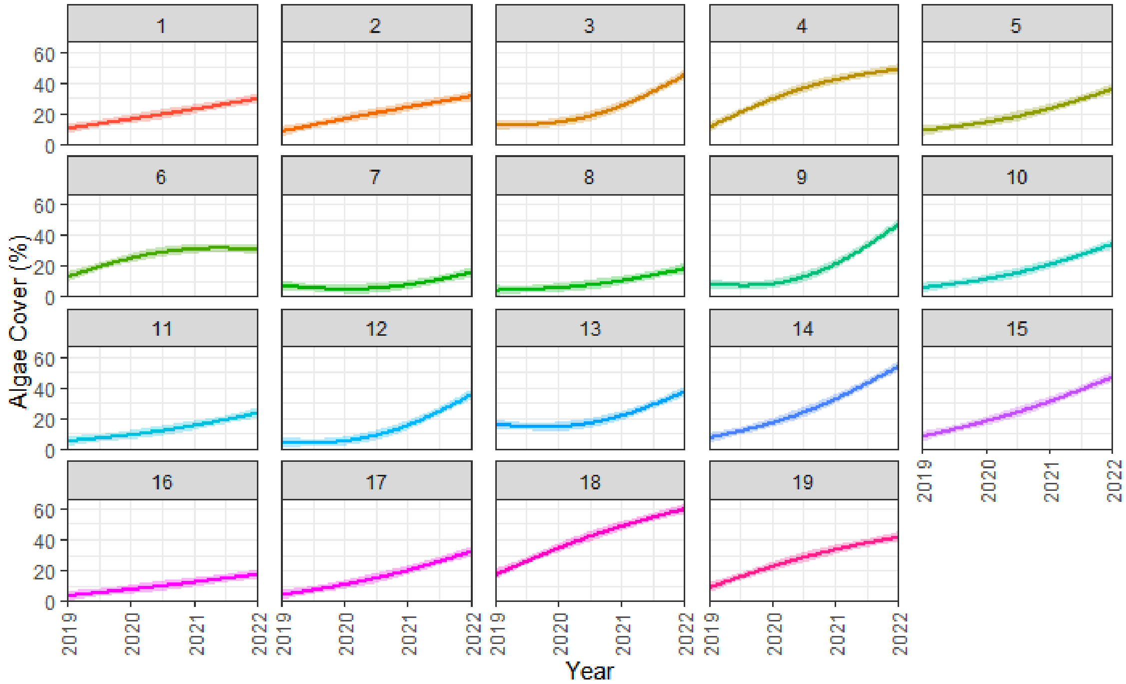


Fig. 5. Generalized additive model (GAM) plots showing the change in percent algae cover throughout the duration of the DLTRMP *separated by survey site. The shaded areas indicate the 95% confidence intervals.*

Turf algae cover is increasingly rapidly year on year (fig. 6). **Turf algae occupy available space quicker, grow faster and are less vulnerable to grazing and water turbulence compared to macroalgae and coralline algae**[12,13]. Additionally, colonisation of bare substrate is often dependent on pre-existing conditions; turf algae establishes faster in previously and/or currently algal-dominated habitats[14,15], whereas healthy coral-dominated habitats are more often colonised by coralline algae and other calcifiers[15]. **The dominance of turf algae over coralline algae (which can promote juvenile coral settlement**[16]**) may inhibit coral settlement in the long term, potentially contributing to a phase shift to an algal-dominated system**[17].

Other algae (macroalgae) declined slightly each year from 2019-2021, but increased from 2021 to 2022 to levels higher than those in 2019 (fig. 6). Increasing macroalgae abundance with limited resources (light and space) can lead to decreases in coral growth and survival[18] as macroalgae shades and smothers corals, thereby hindering its photosynthetic capabilities[19,20]. However, macroalgae can also beneficially shade corals, reducing the extent of coral bleaching under environmentally stressful conditions[21]. Globally, **increasing macroalgae cover has led to a phase shift in many reefs** from a coral-dominated system to assemblages with higher proportions of macroalgae[22–24]. The **lack of herbivorous fishes in the Dauin reef ecosystem** will allow for these increases in turf and macroalgae cover; herbivorous fish are crucial in limiting algal growth on coral reefs and preventing phase shifts to algae-dominated systems[23] (see Fish Functional Groups). **The rates of algal growth (particularly turf algae) in the Dauin ecosystem are concerning; if we lack the natural biological control provided by herbivorous fishes, we must deepen our understanding of other factors that may promote algal growth here in Dauin, such as runoff/nutrient loading. Water quality assessments will be key in this.**

Coralline algae increased steadily from 2019-2021, but has plateaued from 2021 to 2022 (fig. 6). Coralline algae has two main functional roles on coral reefs, 1) as a reef builder by contributing to **rubble consolidation and reef calcification**[25–27], and 2) **inducing larval settlement** of benthic organisms[28,29]. Growth of coralline algae is slower than that of turf algae, so whilst calcification of coralline algae results in rigid binding and recovery of Dauin's inshore reefs, it is a gradual process.

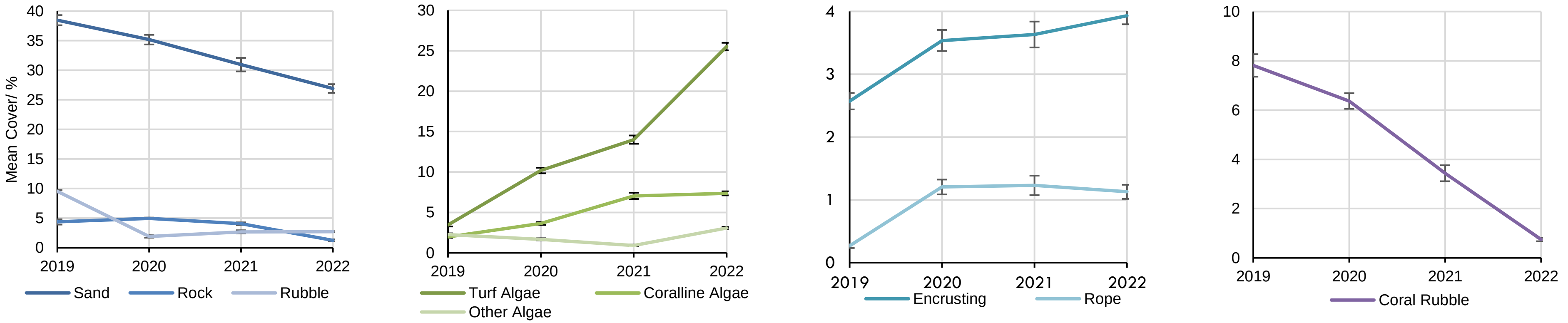


Fig. 6. Mean transect cover (% ± SE) along Dauin Reef, separated by survey year from left to right: abiotic substrate, algae categories, sponge types and dead coral categories*. N.B. only one season of data available for 2021.*

Sponge cover has not changed significantly over the years of the DLTRMP (MVGLM analysis of deviance univariate tests, p. adj=n.s, fig 3). However, **slight changes are seen in percent cover of encrusting and rope sponge** over time, both showing slight increases (fig. 6). Branching sponge cover shows no change. Sponges have a variety of functional roles in a coral reef ecosystem, including **binding live corals to the reef frame, stabilising reef rubble, recycling dissolved nutrients via the sponge loop and improving water clarity**[30–34]. Their temporary stabilisation allows for further encrustations and rigid binding by coralline algae[33]. Encrusting sponges "glue together" rubble pile interiors to 2m below the rubble surface, while erect sponges (such as branching and rope sponge) bind adjacent rubble pieces through superficial overgrowth[33]. Due to their resilience under environmental stress and disturbance, their role on coral reefs may become increasingly pronounced[35]. This temporary binding of loose rubble is occurring in Dauin. However, **it is important to monitor the relative benthic coverage of sponges and Scleractinian coral to identify any direct competition**; many sponges have been found to outcompete Scleractinian corals in space acquisition, although this depends on the presence of 'aggressive' sponge species, and sponges found on coral reefs vary greatly in their competitive abilities[36] (see below).

Cyanobacteria cover is very low along the Dauin reef but shows fluctuations throughout the DLTRMP (fig. 7). Cyanobacteria are a significant food source for grazing reef organisms, and provide nitrogen to coral reef ecosystems through fixation[119,120]. However, **cyanobacteria are becoming increasingly abundant on declining reefs as a result of changing land use and runoff**[121]. On reefs experiencing short-term algal blooms or phase shifts, cyanobacteria may inhibit coral recruitment, in turn reducing coral cover and limiting community recovery. Cyanobacteria are also able to directly kill live coral tissue[122], and are closely linked with coral disease[123,124]. Fluctuating cyanobacteria cover suggest the reef is responding to anthropogenic activity (i.e. eutrophication). Although cyanobacteria cover is low, it is essential to continue monitoring to recognise any long-term upward trends in percent cover, quantifying potential threats to coral recovery and assessing required management actions. **A deeper understanding of water quality along the Dauin coast, including identifying runoff "hotspots" will assist in this.**

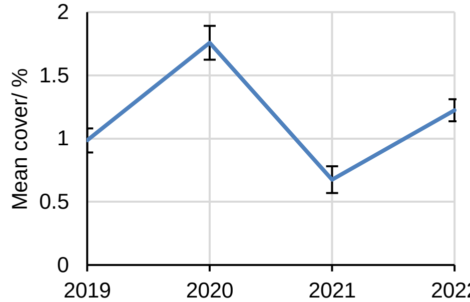


Fig. 7. Mean cyanobacteria transect cover (% ± SE) *along Dauin Reef separated by survey year.*

Scleractinia composition of reef

Scleractinian community composition has not changed significantly throughout the years of the DLTRMP (ANOSIM, p=n.s.). *Acropora, Echinopora, Porites, Anacropora* and *Pocillopora* are the dominant coral genera across the Dauin reefscape, contributing to 75% of total recorded coral cover. Of these five most dominant corals, two show clear changes in percent cover during the DLTRMP; *Acropora* and *Anacropora*. *Acropora* showed a gentle increase from dry season of 2019 to dry season of 2021, but **when monitoring began again in 2022, there has been a significant decline in *Acropora* cover compared to 2021 levels** (fig. 8)). *Anacropora* is found in Dauin at notable quantities only at Masaplod Sur (average throughout DLTRMP 9.8% percent cover, compared to all other sites which have <0.01%); it has been steadily declining since the DLTRMP began, from 2019 dry season to 2020 wet season, but seems to have plateaued from 2020 wet season to now at <1% percent cover (fig. 8). **The preservation of coral cover, particularly *Anacropora* at Masaplod Sur, is crucial**.

Diversity indices increased gently from 2019 to 2021 (2021 has highest scores across most indices) but have declined slightly from 2021 to 2022 (Table 1). A plethora of research, sometimes conflicting, exists on the role of disturbances on biodiversity[37–41]. Nonetheless, it is widely accepted that disturbances can maintain diversity by changing species composition, whereas reef regeneration after disturbances is dependent on various abiotic and biotic factors[9]. **The capacity for this reef ecosystem to absorb recurrent disturbances and adapt to change whilst maintaining ecosystem functions and structure is the core research focus of the DLTRMP** (see Drivers of Natural Recovery).

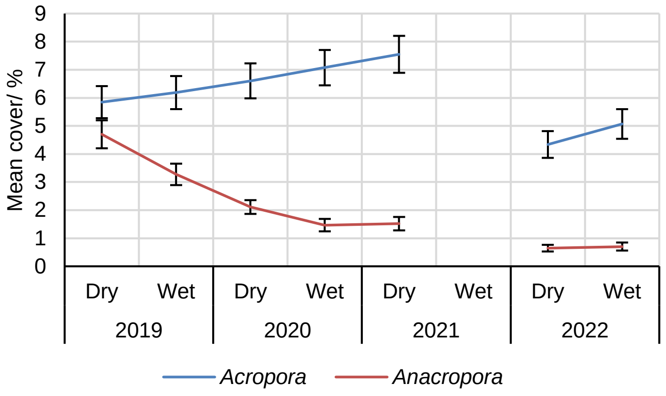


Fig. 8. Mean transect cover (% ± SE) of coral genera that change significantly throughout the DLTRMP, separated by survey season.

Table 1. Scleractinian diversity indices separated by survey season. *Mean genus richness refers to per transect, whereas total richness refers to the whole Dauin study area. Data bars are relative to minimum and maximum for Shannon (H), Inverse Simpson's (1/D), mean genus richness (G) and total genus richness. For Simpson's (SDI) and Pielou's evenness (J'), data bars are between 0 and 1 (the minimum and maximum for these metrics). Total genus richness for the duration of the DLTRMP is 53.*

	2019		2020		2021		2022	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Shannon (H)	1.29	1.45	1.56	1.60	1.62		1.62	1.55
Simpson's (SDI)	0.54	0.60	0.65	0.65	0.65		0.66	0.64
Inverse Simpson's (1/D)	2.97	3.39	3.89	3.84	4.06		3.64	3.66
Pielou's evenness (J')	0.52	0.58	0.61	0.61	0.61		0.62	0.62
Mean genus richness (G)	12.68	13.32	13.95	15.00	15.79		14.53	13.53
Total genus richness	41	41	46	43	48		44	40

Coral cover remains stable at most of our 19 survey sites, with only seven showing noteable changes between survey years of the DLTRMP (fig. 9). The only site with consistent positive change in coral cover (although small in magnitude) is the 5m site at Poblacion II (site 6, change from 2019 to 2022 <10%, fig. 9). Coral cover at Poblacion I and II at 10m (sites 1 and 5 respectively) increased notably from 2019 to 2020, before plateauing (fig. 9). Lipayo I Sur at 10m (site 9) had increases in coral cover from 2019-2021, but has since declined back to 2019 levels.

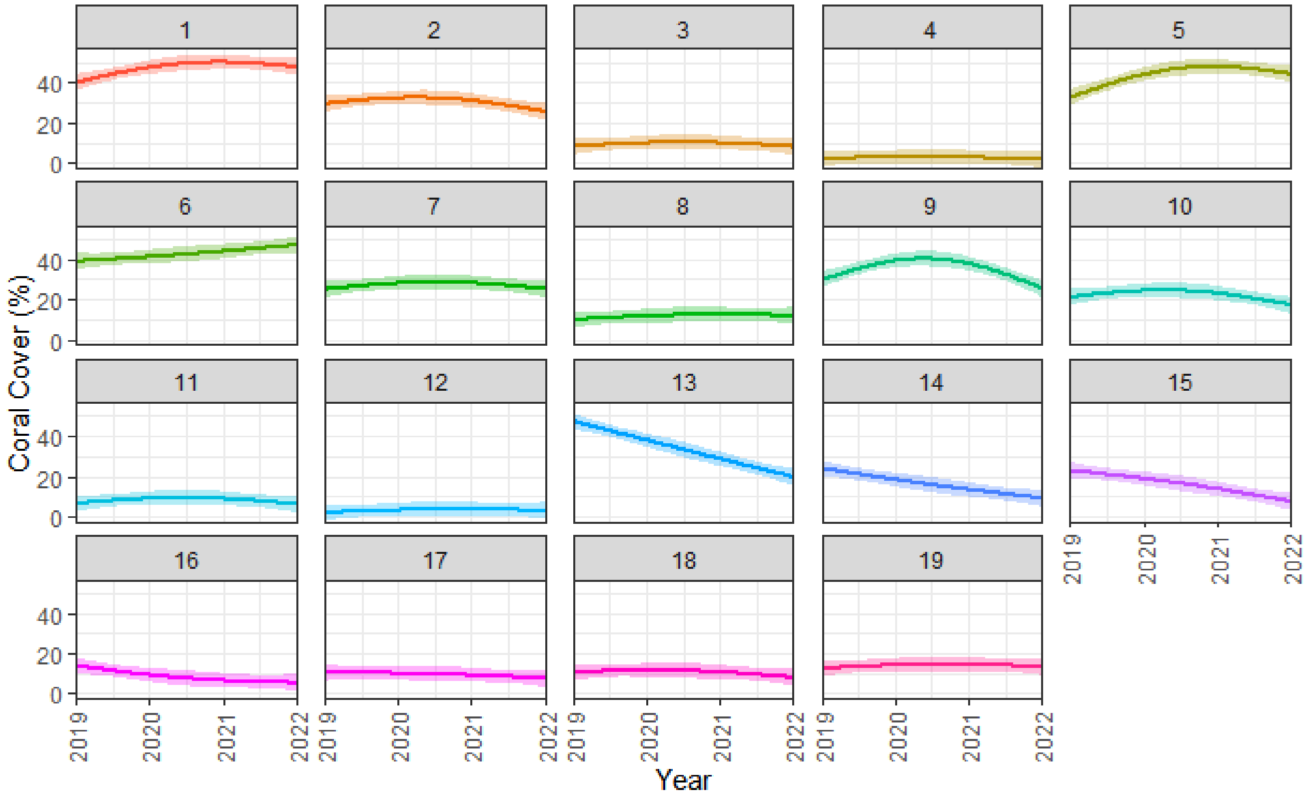


Fig. 9. Generalized additive model (GAM) plots showing the change in percent coral cover throughout the duration of the DLTRMP *separated by survey site. The shaded areas indicate the 95% confidence intervals.*

Most notably is the **severe loss in coral cover at Masaplod Sur (sites 13-16), which can be attributed to Crown-of-thorns (COTS) outbreaks** (see Crown Of Thorns Sea Star: Outbreak and Recovery), as well as possible inter-specific competition with rope sponge. Marine sponges can produce allelopathic compounds (biochemicals that influence the germination, growth, survival, and reproduction of other organisms in the same community) with specific roles in the competition for benthic space[42]. Rope sponge has much higher percent cover at Masaplod Sur than any other survey location – 85.4% of all rope sponge records of the DLTRMP are at the four Masaplod Sur survey sites. The rope sponge at Masaplod Sur is *Callyspongia samarensis* ("blue spaghetti sponge"). The *Callyspongia* genus is diverse, with 182 different species[43]. Extracts from *C. samarensis* have accelerated bleaching in *Porites* colonies[42], indicating their competitive advantage over Scleractinia. It is therefore possible that the loss in coral cover at Masaplod Sur is at least partially as a result of interspecific competition between *Anacropora spp.* and *C. samarensis*.

Drivers of Natural Recovery

The Dauin coastline has a history of typhoon disturbance; particularly Typhoon Pablo (November 2012) and Super Typhoon Odette (December 2021), both of which were category 5 and have caused partial destruction of coral skeletons and reef rock. As such, **some parts of the Dauin fringing reef are dominated by unconsolidated substrate**. Post-disturbance recovery of coral reefs is complex and varies temporospatially[150], as seen within the Dauin fringing reef where **temporal changes in benthic composition are site-specific**[151]. Depending on the extent of damage and the history of the reef, recovery can take anywhere from a few years to centuries, and shifts to algal-dominated systems may occur if the reef cannot recover[150].

Stable coral rubble is an attractive settlement substrate for coral larvae due to the presence of favourable biofilms[152–161], hence its ability to facilitate coral recruitment and reef recovery[162–165]. However, physically unstable reef rubble can cause abrasion and burial of juvenile coral[166]; **rubble consolidation is therefore essential in establishing a solid framework for coral settlement and growth**. Rubble can be bound by many different marine taxa, including turf algae[167], macroalgae[168–170], sponges[168,170], coralline algae[168,169,171], and corals[172]. These bindings can be flexible (by soft organisms) or rigid (calcifying organisms)[173–175].

Three DLTRMP survey sites have been highlighted to examine post-disturbance natural recovery, based on their exposure to wave action (shape of the coastline) and the percent cover of rubble and coral rubble; Site 6 (Poblacion District I at 5m), Site 14 (Masaplod Sur within the MPA boundary at 5m) and Site 18 (Maayong Tubig at 5m). **Benthic composition has changed significantly between every year at each of the three sites** (ANOSIM p<0.01, MVGLM pairwise comparisons, p.adj<0.05, fig. 27). Key drivers of this community change are algae, abiotic substrate and dead coral (bare substrate), and to a lesser extent sponge (fig. 28). **All three sites show significant decreases in percent cover of bare substrate** (MVGLM analysis of deviance univariate tests p. adj<0.05, fig. 29), **confirming that succession is occurring**.

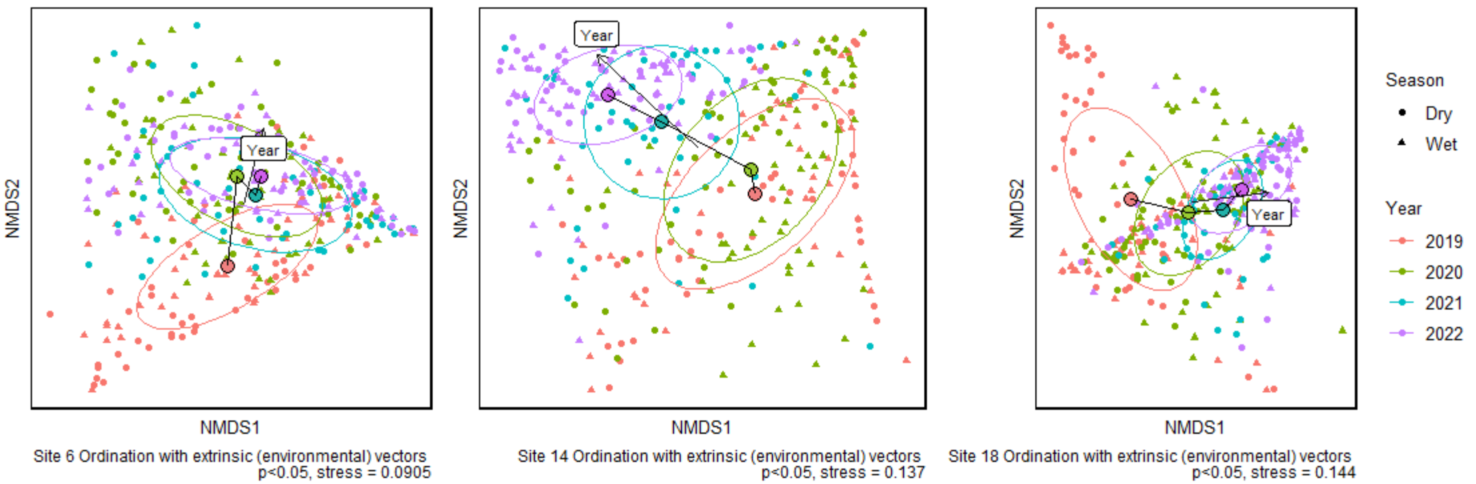


***Fig. 27. NMDS plot of benthic community at sites 6, 14 and 18 with fitted environmental variables**. Arrows (length and direction) represent environmental variables significantly (p<0.05) explaining the ordination. Larger circles represent NMDS centroids (means) for each year.*

All three sites show significant increases in total algae cover (MVGLM analysis of deviance univariate tests p. adj<0.05, fig. 29). **Following storm damage, benthic algal blooms generally develop first on bare substrate**[150]. Algal turfs can rapidly colonize and create bridges between rubble pieces, binding primarily the upper rubble surfaces[167]. However, **turf and macroalgae algae may inhibit juvenile coral settlement and survival**, as well as prevent the colonization of coralline algae. Autotrophic binders (such as turf, macroalgae and coralline algae) are most prevalent on these uppermost surfaces with high irradiance and high energy[167,176–178], which we are seeing at these sites in Dauin (fig. 29). However, **micro-environments (spaces within the rubble beds) that our current research methods are unable to quantify can house other, more cryptic binders such as sponges**, which are sheltered from high levels of sedimentation, light, and flow, as well as from competition with autotrophic binders.

Sponge cover increases significantly yet marginally at all sites, as percentage cover is much less than the other key benthic components (MVGLM analysis of deviance univariate tests p. adj<0.05, fig. 29). Sponges also provide flexible bindings, both within and above rubble piles; cryptic sponges with "void-filling" body forms can bind rubble piles from beneath and within, whereas encrusting and erect sponges can bind the upper rubble surfaces. **Disturbances that generate asexual sponge fragments can be followed by relatively rapid rubble binding**, where successional stages are skipped as sponge fragments rapidly reattach[168,179].

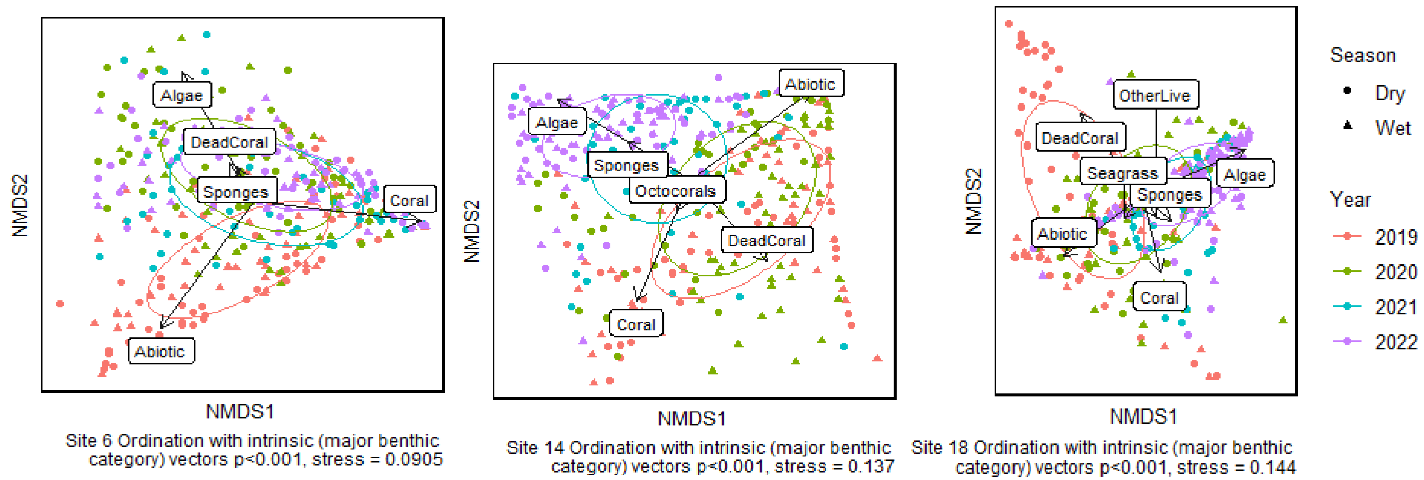


***Fig. 28. NMDS plot of benthic community at sites 6, 14 and 18 with fitted intrinsic variables**. Arrows (length and direction) represent environmental variables significantly (p<0.05) explaining the ordination.*

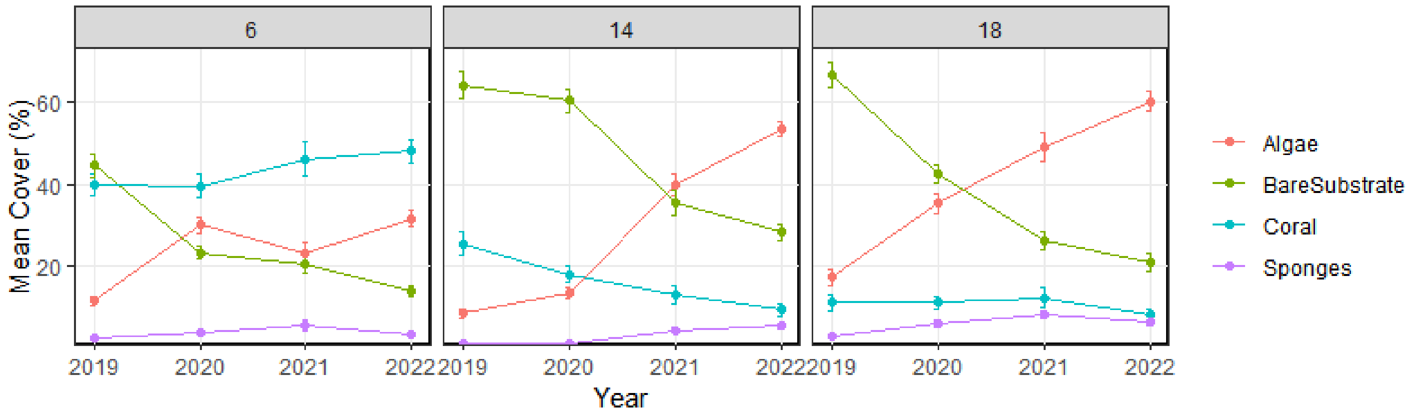


***Fig. 29. Mean transect cover of major benthic categories (% ± SE) at sites 6, 14 and 18 (left to right), separated by survey year**. Bare substrate is a grouping of abiotic substrate (rock, rubble, sand) and coral rubble.*

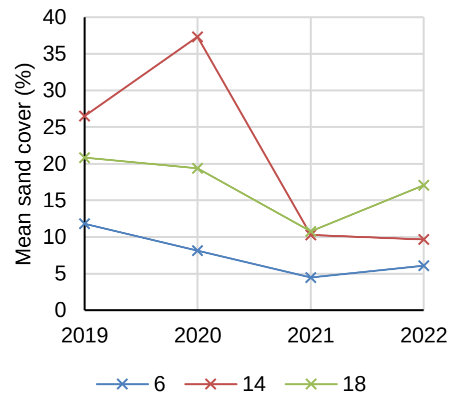


***Fig. 30. Mean transect cover sand (%) at sites 6, 14 and 18, separated by survey year**.*

Succession of organisms from turf algae to coralline algae can take at least six months (depending on microhabitat)[160], whereas rubble seeded by cryptic sponges could undergo stabilisation and colonisation by corals within 10 months[168]. **At these study sites, sponge cover is perhaps too low for this** (fig. 29).

Another factor to consider in the pace of natural coral reef recovery is the frequency of disturbance; **rubble must remain stable for enough time to be bound by these organisms and subsequently cemented**[180]. IMR is monitoring the recovery from Typhoon Pablo in 2012, which will have undoubtedly been hindered by Super Typhoon Odette in 2021. A recent storm (Paeng) in 2022 also damaged portions of the Dauin reef, particularly at shallower sites (fig. 31). **Increasing storm frequency and intensity in our changing climate will not only increase rubble mobilisation** (reducing the time available for binding and stabilisation), **but also generate more, often smaller and less complex rubble pieces**[180]. Additionally, rubble beds commonly experience greater hydrodynamic forcing than living reef (due to reduced drag and friction that structural complexity of living reef would provide[181], exacerbating their susceptibility to rubble mobilization[180]. High wave action at these shallow sites may also increase the fluctuations of sand depositions (particularly site 18, fig. 30), further inhibiting the growth of binding organisms. Lastly, future reef conditions (effects of warming and ocean acidification) may also impede the growth of calcifying binders and their precipitation of cements[180].

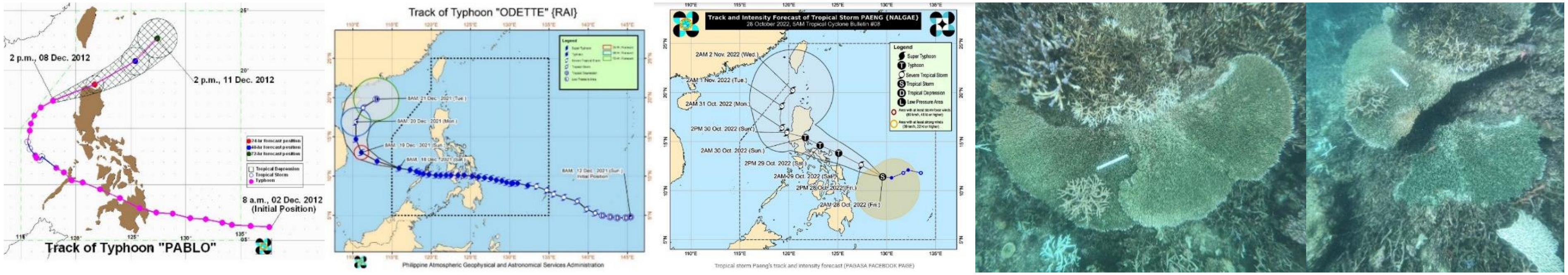


Fig. 31. (left to right) storm tracks of Typhoon Pablo, Super Typhoon Odette and Storm Paeng, same coral colony before and after Storm Paeng. *Left: 26th Oct 2022, right: 3rd Nov 2022.*

Unfortunately, and **most importantly, coral cover is not significantly increasing at any of these sites**, showing either no significant change (site 6 and site 18 MVGLM analysis of deviance univariate tests p. adj=ns, fig. 29), or significant decline (site 14 MVGLM analysis of deviance univariate tests p. adj<0.05, fig. 29. **Whilst algae and to a lesser extent sponge are beginning the process of rubble consolidation, we are not yet seeing the benefits of this in terms of coral cover**. It is possible larval settlement is occurring but not yet at great enough quantities (either in frequency of recruits or growth of juvenile colonies) to be detected by our current research methods. To deepen our understanding of natural recovery at these damaged sites in Dauin, **IMR will continue to monitor substrate consolidation (algae and sponge cover) relative to disturbance frequency, complimenting this with specific research methodologies to monitor larval settlement, survivorship, and growth of new coral recruits at these sites**. Management actions (artificial substrate stabilisation) at damaged reef sites in other parts of the world have exhibited marked increases in hard coral cover[182–185], so if Dauin's reefs are not able to recover naturally, this could be a viable option here. However, the risks associated with intervention methods are understudied[186], so would only be considered in Dauin if no evidence suggests natural recovery is occurring.

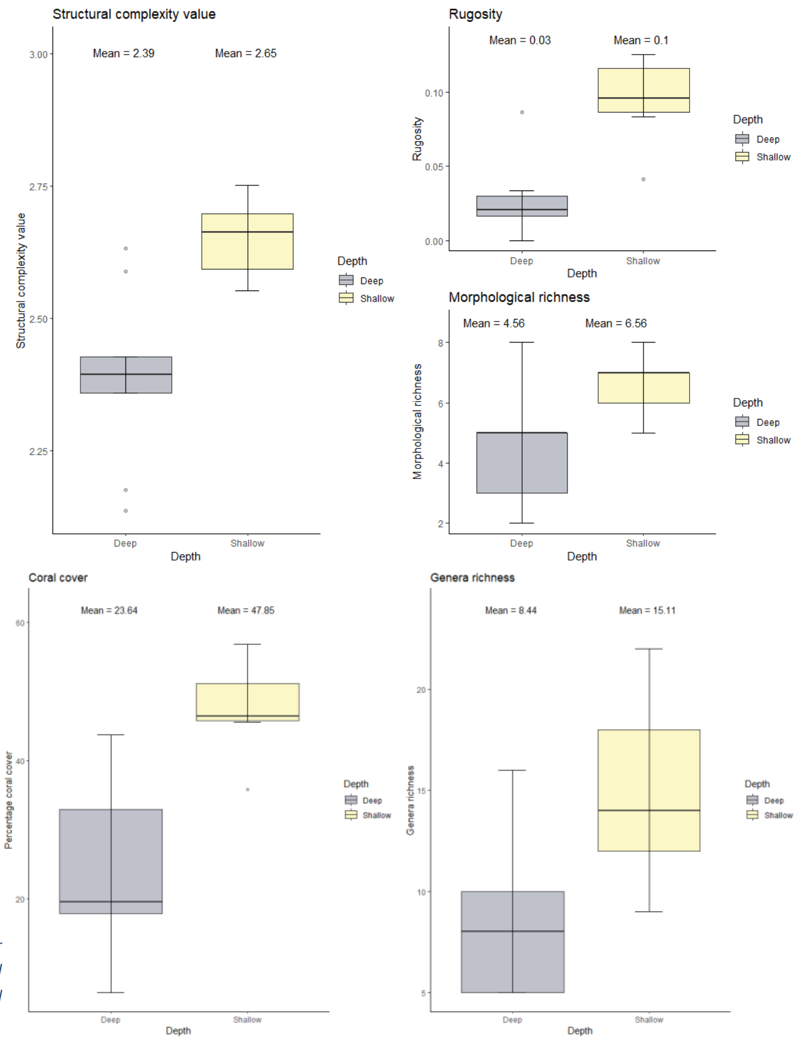
Masters Project: Approaching the "Deep reef refugia hypothesis" using coral reef structural complexity

José Ekstedt, Stockholm University

The deep reef refugia hypothesis (DRRH) suggests that mesophotic coral ecosystems might function as a refugium for shallow-water species threatened by natural and anthropogenic disturbances. Existing studies assessing the DRRH have reported varying results while at the same time having a regional bias. The morphological diversity of hard coral species creates complex structures usually referred to as the structural complexity of a coral reef, which directly influences habitat preferences and has been suggested to increase species richness, abundance, and diversity.

Structural complexity has frequently been used to compare shallow coral reefs but has gotten little attention when comparing mesophotic coral reefs to shallow coral reefs. Here, the aim was to evaluate the DRRH in Dauin, Philippines, a part of the understudied coral triangle, using structural complexity combined with genera and temperature comparisons as tools, by employing photo transects followed by digital analysis. This could give indications as to whether mesophotic coral reefs can host similar species and species compositions as shallow coral reefs.

The results show that mesophotic coral reefs have a different and lower structural complexity compared to shallow coral reefs. **Dissimilarities in structural complexity indicate that mesophotic coral ecosystems are unable to preserve shallow coral reef communities and have a limited potential to preserve shallow coral-associated species**. However, significant coral genera overlap suggests that specific coral genera and species could use the mesophotic coral ecosystems as a refugium. Lastly, water temperature decreased with depth, suggesting that a buffer exists towards future increases in sea surface water temperature. The conclusion is that, at least in Dauin, Philippines, the DRRH cannot be applied on a community level. It is likely limited to specific overlapping shallow coral and coral-associated species that are not affected by the differences in structural complexity.



Top: Differences in coral reef structural complexity proxies between deep and shallow coral reefs. *Box and whisker plots showing the difference in structural complexity value, rugosity, and morphological richness between MCE (deep) and the SCE (shallow). The top and bottom whiskers represent the lower and upper quartiles while the median is represented as a solid line. Above each box is the mean value of each dependent parameter.*

Bottom: The difference in total coral cover and coral genera richness between depths*. Box and whiskers plots of the mean total coral cover and coral genera richness between MCE (deep) and the SCE (shallow).*

Seasonal Fluctuations

Seasonal fluctuations have dramatic effects on coral reef benthic ecosystems, particularly coral-algal interactions[136,137]. Key environmental factors that vary seasonally and affect benthic ecosystems include **temperature, rainfall, and photosynthetically active radiation** (PAR). Seasonal temperature fluctuations can increase thermal stress and trigger coral bleaching[48], and alter the timing and intensity of algal blooms[138–140]. Seasonal increases in rainfall can increase nutrient availability and sediment deposition, which can lead to the proliferation of algae and loss in coral cover[141–144]. PAR availability varies seasonally due to changes in day length, cloud cover and turbidity, amongst other factors. PAR availability affects the photosynthetic rates of both algae and corals symbionts (Symbiodinium)[137,145]. **Understanding seasonal variability in Dauin allows us to extract and therefore examine long-term trends (removing the influence of seasonality)** within the Dauin benthos, to highlight any areas of concern, for example increasing algae cover irrespective of seasonality could suggest early stages of a phase-shift to an algal-dominated benthos. Understanding seasonal variability in Dauin is also critical for **predicting how benthic communities may respond/acclimate to future changes, such as those associated with climate change**[146]. However, seasonality also goes beyond the benthos; seasonality has been shown to have a profound influence on coral reef fish community structure[147], and to influence the number of Drupella larvae, with decreases in spring and winter when the water temperature was low and increased numbers in summer when the water temperature was high[148].

During the DLTRMP, **seasonal fluctuations have been heavily influenced by El Niño and La Niña events**. These events are characterized by changes in sea surface temperature and atmospheric circulation patterns in the tropical Pacific and have wide-ranging impacts on weather and climate patterns around the globe. **The most recent El Niño event occurred from November 2018 to July 2019** and was classified as a weak to moderate event[149]. During El Niño, the "Habagat" or southwest monsoon is weakened, leading to below-normal rainfall and above-normal temperatures in the western regions of the country, including the western Visayas. **The most recent La Niña event occurred from July 2021 to January 2023** and was classified as a moderate to strong event[149]. During La Niña, the so-called "Amihan" or northeast monsoon is strengthened, associated with above-normal rainfall and below-normal temperatures in many parts of the country in the eastern regions of the country, including the eastern Visayas. Dauin is in the central Visayas, but is still affected by these climate patterns, causing changes in air temperature and rainfall (fig. 25). As such, it can become difficult to isolate the influence of seasonality here.

Results from two-way ANOVAs with interaction terms of year and season show significant interactions between year and season for cyanobacteria, algae and sponge cover (ANOVA, p<0.001, fig. 26). However, results from GLMMs on algae cover and

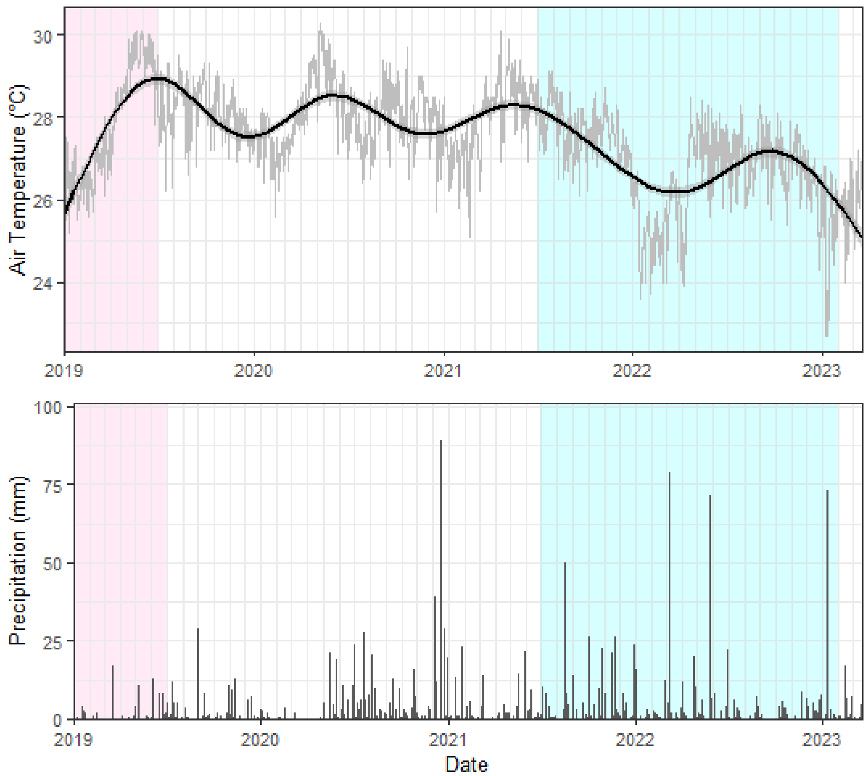


Fig. 25. Top: Dumaguete daily air temperature (°C) (grey) with a smoothed trendline (black). Bottom: daily precipitation (mm). Pink box represents El Niño conditions, blue box represents La Niña.

on bleaching frequently show no significance in seasonality (in the form of mean monthly air temperature and precipitation) relative to the influence of other variables. Air temperatures fluctuate in both frequency and magnitude far more than water temperature, so **water temperature** (SST or at relevant depth) **will provide much greater insight into seasonal patterns on the reef ecosystem in Dauin**. IMR will be investing in this equipment in 2023. Once we have robust information on the seasonal forces occurring in Dauin, we can better subtract these from long-term trends, to better identify and manage necessary areas of concern.

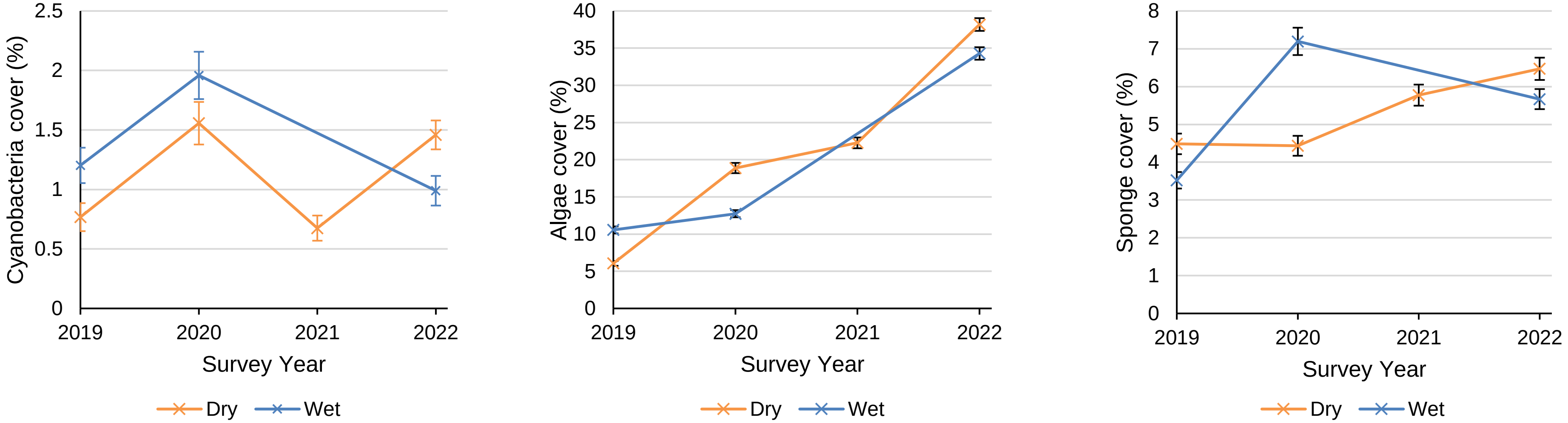


Fig. 26. Mean cyanobacteria, algae and sponge transect cover (% ± SE) along Dauin Reef separated by survey year and season, *highlighting interactions between annual and seasonal averages.*

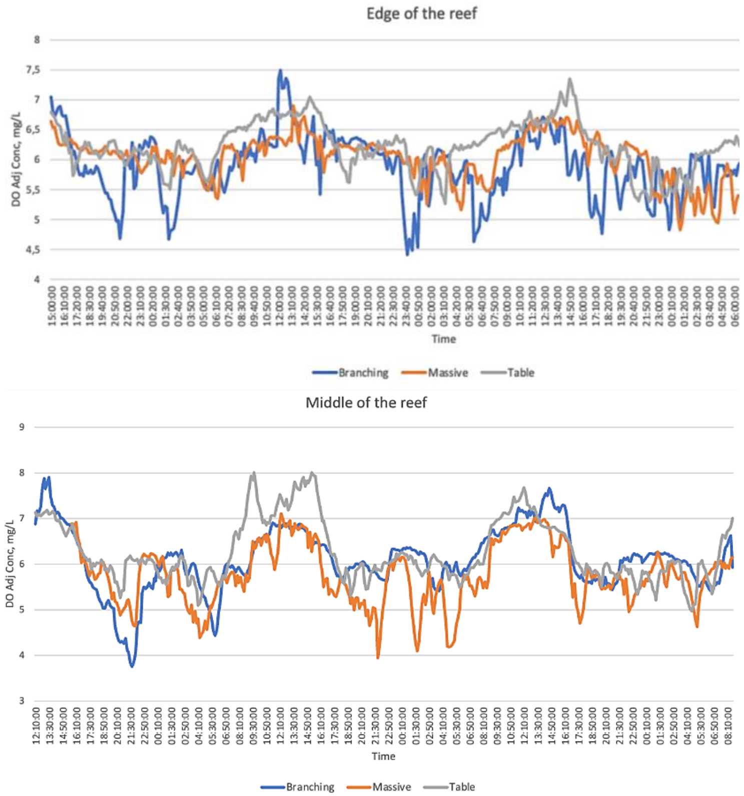
Masters Project: Oxygen fluctuations in coral reefs –coral morphology and reef location in the Philippines

Emilia Andersson, Stockholm University

Oxygen has an essential role in coral reef ecosystem's function and health; it is produced by corals' zooxanthellae and other primary producers and consumed by all reef organisms. Tropical coral reefs experience large natural oxygen fluctuations; high oxygen levels during the day when oxygen is produced via photosynthesis and low levels during the night when only respiration (oxygen consumption) is active. Marine organisms living in coral reefs are adapted to oxygen fluctuations, but climate change and other anthropogenic factors might expose corals to more prolonged and extreme oxygen levels, causing stress and potentially bleaching. Oxygen deficiency (hypoxia) refers to dissolved oxygen (DO) concentrations from <4 mgO_2l^{-1}, while excess oxygen (hyperoxia) are levels above 100% saturation. Oxygen tolerances varies among taxa, and hypoxia thresholds are almost entirely unknown for reef-building corals. Although oxygen has such a fundamental role in the coral reef ecosystem, the knowledge about its potential effects is low.

The relationship between oxygen concentrations, coral physiology, and oxygen thresholds has only been studied for a few species. The purpose of the study is therefore to investigate which corals and what parts of a reef are most likely affected by the potential threat of nocturnal hypoxia and hyperoxia. The study aims to answer two research questions; 1) How do DO concentrations vary between different coral morphologies; branching, tabulate and massive? and 2) Does DO concentration vary between the middle and the edge of the reef? To answer these questions, DO concentrations (mgO_2l^{-1}) and temperature (°C) were measured *in situ* using a HOBO U26-001 oxygen logger. Massive corals studied were *Porites spp.* and branching and tabular corals were *Acropora spp.*.

Initial results suggest corals in the middle of the reef experience larger DO fluctuations than at the edge, and that branching and tabulating corals experience larger DO fluctuations (longer and more intense periods of hyperoxia) and generally lower DO levels than massive colonies. Branching and tabulate corals have complex structures that create small, enclosed spaces with limited water flow, potentially leading to daytime hyperoxia and night-time hypoxia. In contrast, massive corals with increased water flow are less susceptible to extreme DO fluctuations. Potential hypoxia (<4 mgO_2l^{-1}) was recorded in both branching and massive coral colonies in the middle of the reef, but since hypoxia thresholds are almost entirely unknown for reef-building corals it is difficult to know whether this level was enough to cause hypoxic stress to the corals. Dissolved oxygen concentrations vary between coral morphologies and reef locations, indicating that both hypoxic and hyperoxic stress could be an influencing factor in corals' susceptibility to bleaching. Understanding reef oxygen concentration variations and its possible role in coral bleaching is essential for predicting how corals will respond to environmental changes and for developing strategies to conserve and manage coral reef ecosystems.



***Dissolved Oxygen concentrations** (mg/L) at massive, branching and tabulate corals at the edge (top) and middle (bottom) of the reef.*

Annual Trends: Impacts and Coral Mortality

Records of coral impacts have increased steadily and significantly throughout the DLTRMP (fig. 10, Kruskal-Wallis, p<0.001). Loss of this ecosystem foundation (coral mortality) could have severe consequences; phase shifts to algal-dominated systems and reef flattening are only a few of the widely documented effects of coral loss[23,44–49]. **Coral bleaching is the most prevalent impact, followed by unknown scarring, *Drupella spp.* feeding activity and fishing trash; all of these have increased significantly during the DLTRMP**, although Drupella has since declined (Kruskal-Wallis, Bleaching, p<0.001, Scar Unknown, p<0.001, Drupella, p<0.001, Fishing trash, p<0.05, Disease, p<0.001). Disease prevalence was low and stable throughout 2019-2021 but increased 6-fold in 2022 (fig.11).

Coral reef health is often influenced by **multiple stressors**, natural and anthropogenic[50]. When a coral is damaged or weakened, it is more susceptible to secondary stressors such as disease or bleaching increases, which can have synergistic or antagonistic effects[50–52]. Some stressors in Dauin will act synergistically e.g., temperature stress, predation, and nutrient enrichment (which is exacerbated due to the proximity of Dauin's reef to shore[53]). **Further research is required to determine the relationship between stressors and to quantify their interactions, to subsequently reduce their impact on the reef**.

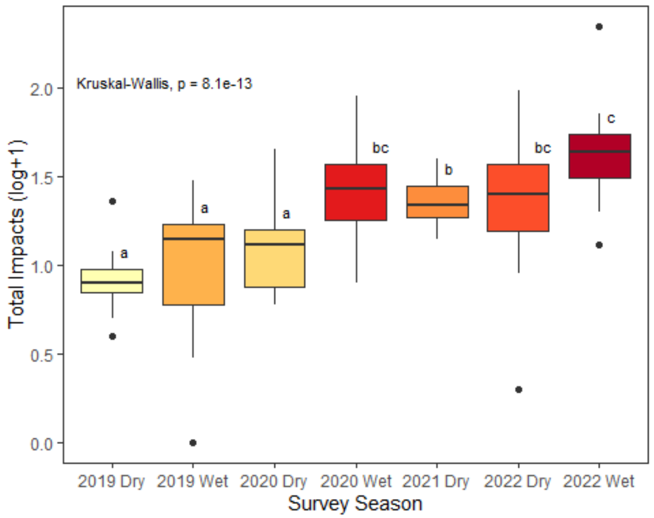


***Fig. 10. Boxplot of total impact frequency (count/100m^{-2}) per survey season**. Letters represents significant differences within a category between years; years with different letters are significantly different from each other (p<0.05).*

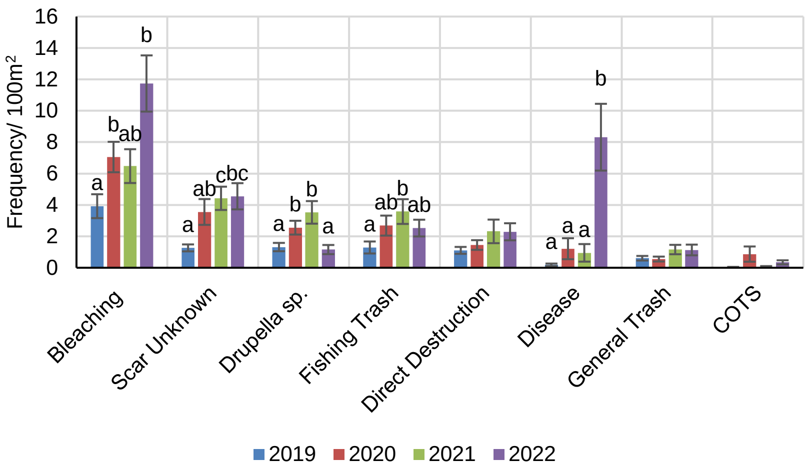


***Fig. 11. Mean frequency (count100m-2 ± SE) of recorded impacts along Dauin Reef separated by year**. Letters represents significant differences within a category between years; years with different letters are significantly different from each other (p<0.05).*

Management actions should be prescriptive, as different areas along the coastline have different primary concerns. Coral bleaching, the most prevalent impact across Dauin's reef, cannot be solved locally, but other impacts can be effectively managed at a local scale, either by the municipality of Dauin or by individual barangays. **Abating some of these localised threats will aid in curbing the synergistic effects of multiple stressors, enabling Dauin's reefs to become more resilient and recover from other, more widespread threats such as bleaching**. **Local efforts could be concentrated on the following threats at these locations:**

- Fishing trash: Bulak, Lipayo and Masaplod Norte (stone fishing: Lipayo and Masaplod Sur)
- Direct destruction: Lipayo, Poblacion, Maayong Tubig and Masaplod Sur
- Disease: Poblacion
- Crown-of-thorns starfish (COTS): Masaplod Sur

***Porites* is the most frequently impacted Scleractinian genera**, followed by *Acropora, Pocillopora* and *Fungia*. *Porites* is mostly affected by disease (see PUWS below), accounting for 72.9% of recorded impacts. **Ten of the 15 most frequently impacted coral genera are predominantly affected by bleaching** (*Fungia, Goniastrea, Favites, Favia, Montipora, Seriatopora, Pavona, Galaxea, Cyphastrea* and *Hydnophora*). *Acropora, Pocillopora* and *Anacropora* are mostly affected by a combination of unknown scarring and Drupella feeding activity. Stylophora is the only genus of the 15 to be mostly affected by direct destruction, accounting for 40.4% of impact records.

Coral bleaching, the most common impact recorded in Dauin, occurs when Symbiodinium are expelled from the coral host; the coral host may survive and regain Symbiodinium, or it may die. Triggers of coral bleaching include extreme temperatures, high irradiance, prolonged darkness, heavy-metal exposure and pathogens[54]. However, **most large-scale bleaching events are attributed to increased water temperature combined with increased solar radiation**[54]. Global climate change is widely accepted as the driving force behind these mass bleaching events[55]. Some studies have proposed that corals will adapt to new climatic conditions in ways that cannot be captured by short-term experiments, but others conclude that life cycles and generation times may be too long to facilitate this change[56] or that rapid adaptation is only plausible under reduced emission scenarios[57]. Bleaching susceptibility is often tied to mortality; however recent observations of reefs impacted by significant underwater heatwave events showed mortality was not correlated to bleaching susceptibility[58].

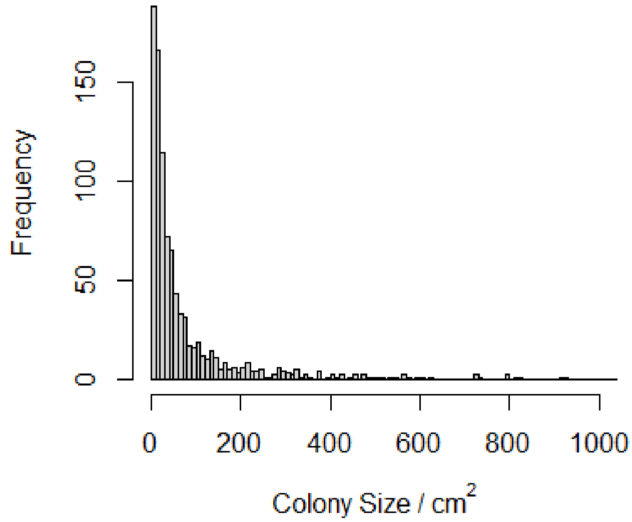


*Fig. 12. **Total frequency of bleaching records on size groupings**, for the entire duration of the DLTRMP.*

In Dauin, there is no significant difference in total bleaching frequency at 5m vs 10m sites (GLMM, depth not included in MAM, ANOVA, p=n.s (see below)). Other research findings on the influence of depth on bleaching vary. One study in the Red Sea found that the most extensive bleaching was at 5m, although this was not significantly different to 10m[59], consistent with our result above. However, another study in the Red Sea found that bleaching prevalence at 5m was significantly higher than at 10 and 15m (10 and 15m were not significantly different from each other)[60]. Other studies have also found that bleaching mortality can vary considerably over small depth ranges[61], and some have found the impact of heat stress events could actually be higher in deeper reefs[62–64]. This indicates that many deeper coral reefs are at least as vulnerable to climate variability and change as shallower reefs[65], hence depth may not be able to act as refuge from coral bleaching. These findings should be considered when examining the susceptibility of Dauin's reefs to ocean warming and heat stress events. Additionally, a study in the Coral Sea (Australia) found taxon-specific patterns in bleaching; some taxa bleached less at depth, some bleached most at intermediate depths, and others exhibiting no difference among depths, although they did also report that mortality of the more abundant taxa was lower at greater depths[66]. This highlights the importance of understanding species-specific responses to heat-stress, as well as potential differences in the rates of adaptation. In Dauin, *Fungia* is the most frequently bleached coral genus (total bleaching records: 250), followed by *Goniastrea* (102) and *Pocillopora* (102). Coral bleaching is also more frequent here in smaller colonies (fig. 12.), and in solitary colonies (total bleaching records: 253), followed by encrusting (226) and branching (199) morphologies.

Coral bleaching is becoming more frequent in Dauin (fig. 13). **Understanding the factors that determine coral bleaching sensitivity and severity** (e.g., depth, microhabitat, genus, colony size/maturity, growth rates and morphology[67–74]) **is important in predicting future events, as well as understanding the reef's resilience to bleaching events**. For example, the prevalence of bleaching is driven by heat stress, but the severity of bleaching is associated with both heat and nitrogen stress; locally generated nitrogen pollution can exacerbate the extent of coral bleaching events[75]. It has also been suggested that the source of nitrogen, natural or anthropogenic, can have different effects of bleaching and mortality; corals exposed to nitrate exhibited more frequent and longer-lasting bleaching, as well as increased probability of mortality[76]. Significant predictors of bleaching frequency were time (categorised by the survey period "LTC") and mean monthly temperature (GLMM, Wald Chi-Squared Test, LTC p<0.001, mean monthly temperature p<0.05, fig. 14c). Mean monthly precipitation, depth and coral cover were not significant predictors of bleaching frequency. Although we do not see severe/mass bleaching events in Dauin yet, adaptive management actions should be prepared. In Indonesia, spatial bleaching projections were used to determine that only approximately 45% of coral reef areas currently within MPAs will likely act as thermal refugia[77]. This combination of climate projections with spatial analysis can and should be used to support the development of MPA and conservation strategies, to achieve the best possible long-term local management actions for global threats such as climate change.

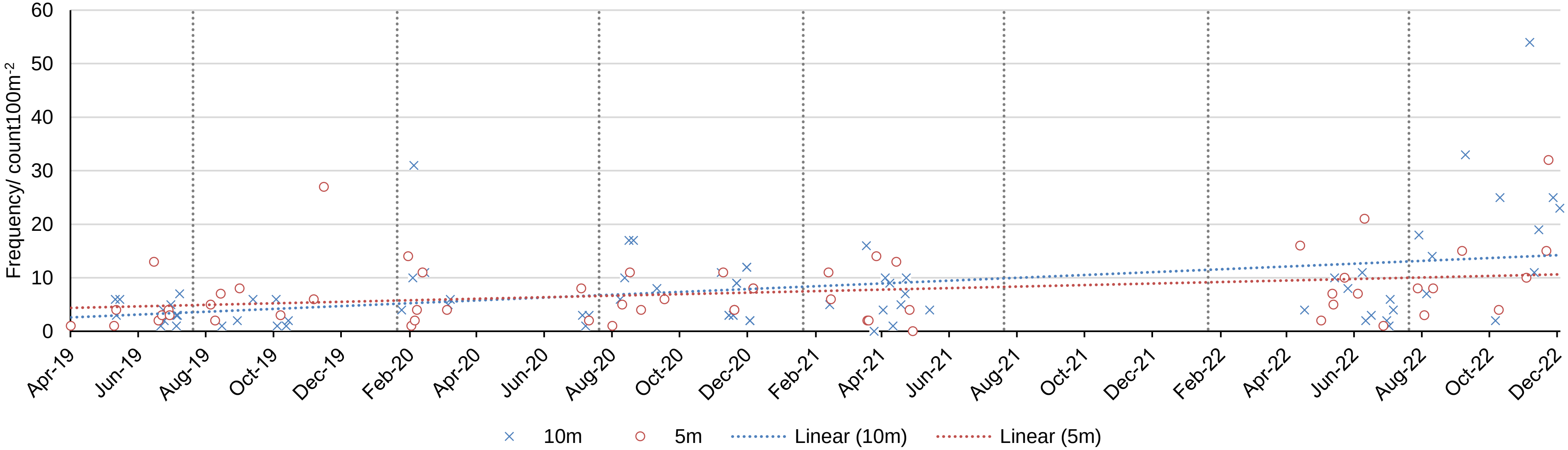


__Fig. 13. Frequency of recorded bleaching impacts along Dauin Reef for every survey conducted, separated by depth of site and survey season__ (represented by the dotted vertical lines). 10m trendline: y = 0.0087x - 375.28, R^2 = 0.1726. 5m trendline: y = 0.0047x - 199.11, R^2 = 0.1003

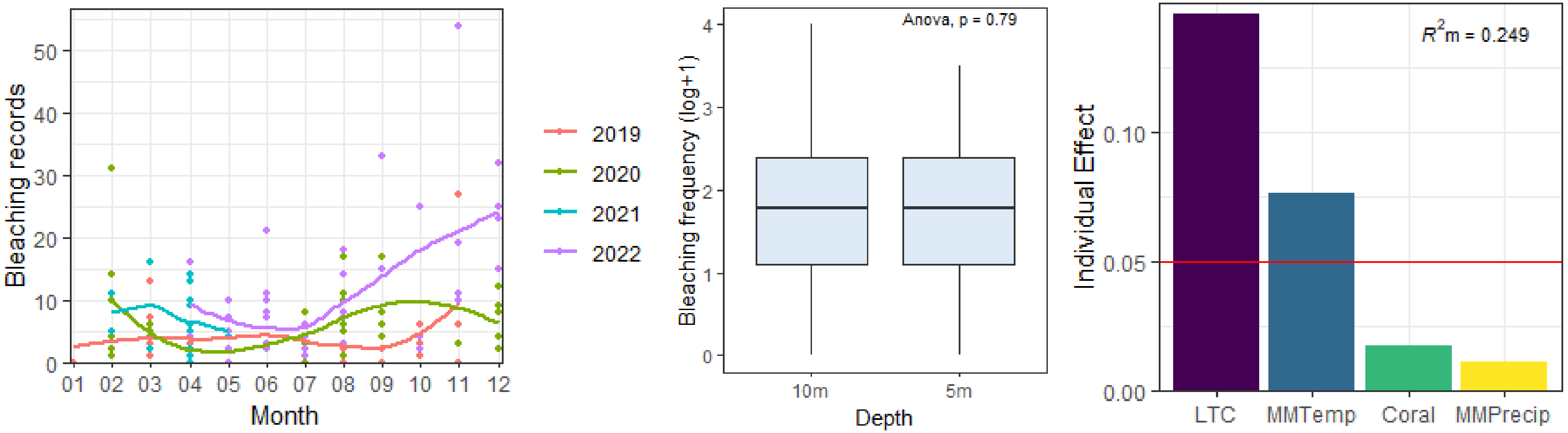


Fig. 14. left) ***Frequency of recorded bleaching impacts along Dauin Reef for every survey conducted, separated by survey year*** *to observe annual trends. Lines represent non-linear trendlines for each year. middle)* ***Boxplot of bleaching frequency per depth category*** *surveyed, with quoted ANOVA p- value. c)* ***Individual effect of GLMM fixed effects on bleaching frequency****, with quoted marginal R^2 value for whole model.*

Fishing trash has significantly increased throughout the DLTRMP (Kruskal-Wallis, $p<0.05$). The abundance of fishing trash varies along the Dauin coastline; hotspots are Bulak, Lipayo, Masaplod Norte and Masaplod Sur. The effects of marine litter on a variety of marine taxa and ecosystems (including coral reefs) are well documented, such as **entanglement, ingestion, substrate damage, transportation of invasive species, as well as the range of impacts associated with microplastics**[78–83]. Prevailing currents and the proximity to shore may contribute to the influx and retention of trash in the Dauin reef[84]. Substrate composition will also influence trash retention, as structurally complex corals such as *Acropora spp.* and *Montipora spp.* are more often in contact with marine debris[83]. Identifying hotspots of fishing trash disposal and retention is essential in determining best management actions to reduce this trash. Now we have an understanding of these hotspots, **we can try to reduce fishing trash through community engagement, education on the importance of proper waste disposal practices and improving waste management infrastructure**. By promoting awareness and providing resources for

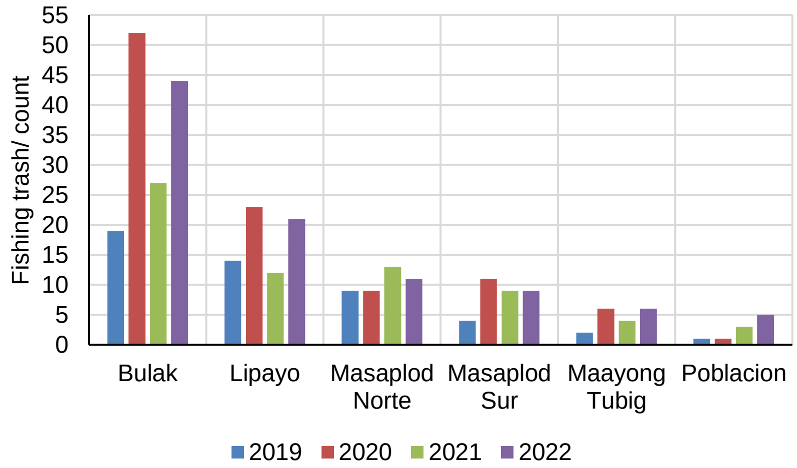


Fig. 15. Total number of fishing trash items per location *(count), separated by survey year and barangay.*

responsible trash disposal, we can work towards reducing the amount of fishing trash along our coastlines and ultimately, improve the overall health of our oceans and communities.

Evidence of stone fishing has been found in 2019, 2020 and 2022 within a few MPAs along the coastline; Lipayo, Masaplod Norte and Masaplod Sur. *Kayakas* is the local version of the *muro-ami* fishing practice[85,86], both of which are destructive and have been prohibited in the Philippines since 1986[86]. A non-destructive alternative, *pa-aling*, was introduced[87], although its use is still spatially restricted[88]. The records of stone fishing in Dauin's MPAs, whether from *muro-ami* or *kayakas*, is concerning; **these illegal practices are still being used** instead of the less destructive *pa-aling*. This suggests **some of the marine reserves in Dauin are lacking sufficient enforcement**.

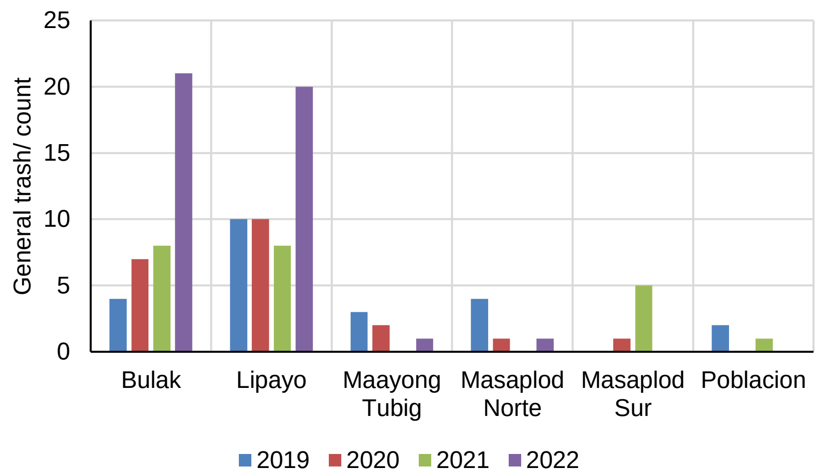


Fig. 16. Total number of general trash items per location *(count), separated by survey year and barangay.*

Although **general trash remains relatively low** in the data from the DLTRMP, we consider any litter entering our seas to be too much litter. It Is a goal of IMR to improve the management of the sources of trash (both general and fishing) and work towards the provisioning of infrastructure to reduce littering. As a first step towards this, **IMR will soon install bins at some of the most heavily used beaches in Dauin**; Poblacion and Dauin South (Poblacion II). With cooperation from the Dauin municipality, these bins will be emptied as part of the regular trash collection service. It is our hope that people will also use these bins after beach clean-ups, preventing as much litter as possible from entering our water. We hope to continue to install these bins across Dauin to reduce litter, as well as engaging with the local community to foster a culture of responsible waste management. Whilst installing bins is a step towards reducing litter, **it is also important to address the root causes of the problem. This should include promoting sustainable consumption practices, reducing single-use plastics, and encouraging proper disposal of waste in all areas of our community**.

The area of coral mortality as a result of corallivorous ***Drupella spp.*** (marine snails, fig. 17) spiked in wet season of 2020, but otherwise **has remained consistent throughout the DLTRMP**. The frequency of *Drupella spp.* feeding records also spiked in wet season of 2020 but remained high into dry season of 2021, before returning to baseline levels (fig. 18). *Drupella spp.* outbreaks are associated with high coral mortality[89–95] and reduced reef resilience and recovery[96] leading to phase shifts. **Links have been observed between *Drupella spp.* outbreaks and physical damage (direct destruction)**[97]**, disease**[89]**, mass bleaching**[98]**, mechanical and salinity stress**[99]**, chronic overfishing of predators**[100]**, eutrophication**[92] **and seasonality (particularly water temperature and runoff)**[92,101]. Many of these stressors are recorded along the Dauin coastline, potentially exacerbating the effects of *Drupella spp.* predation. Causes for *Drupella spp.* outbreaks are mainly climatic and biological, such as storm damage (direct destruction), climate change and the reduction of natural predators and/or competitors[102].

Fig. 17. D. Rugosa, Feeding Aggregation, *KohTao, Thailand, 30 Aug. 2010. Author: ConserveMarine*

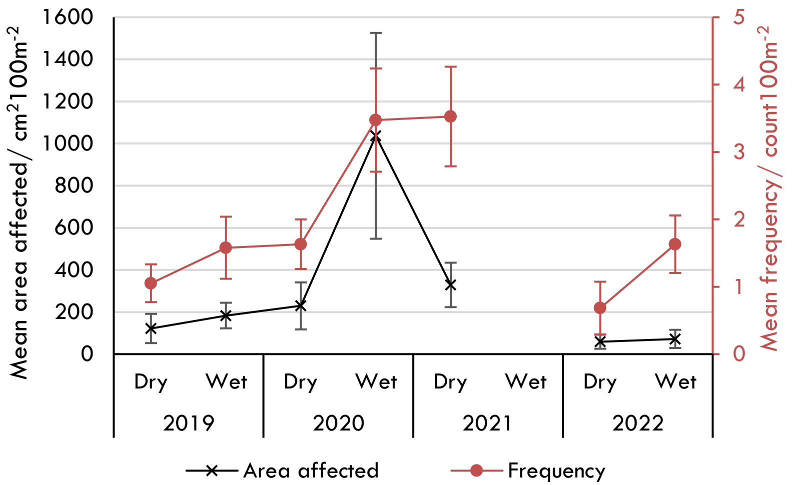


Fig. 18. Mean total coral area affected per 100m² transect (cm²100m⁻² ± SE) by Drupella spp. feeding activity and frequency of Drupella feeding records *per 100m² transect (count100m⁻² ± SE) separated by survey season.*

Drupella spp. primarily feed on fast-growing corals with high recruitment rates, such as *Acropora spp.*, *Pocillopora spp.* and *Montipora spp.*[103], although feeding preferences may change according to abundance[101] as they exhibit high plasticity in adapting feeding preferences[104]. **If there is a loss of a preferred food item (such as *Acropora spp.*), other species are likely to experience greater predation pressure from *Drupella spp***[104]. Most *Drupella spp.* feeding activity records from the DLTRMP are on *Acropora spp.* (64.6% of records), followed by *Pocillopora spp.* (22.3% of records), which are two of the most common coral genera in the area. However, with the reduction in *Acropora* cover since 2019 (fig. 8), **it is possible predation pressure on other coral genera such as *Pocillopora* will increase**.

Whilst *Drupella* spp. are most frequently observed at low densities, the damage caused by outbreaks can be similar to that of *Acanthaster planci* (COTS)[90,91]. To understand the threat of observed *Drupella spp.* abundances to coral cover in Dauin, it is essential to determine the density of *Drupella spp.* that can be sustained based on coral cover and growth[105]; quantifying *Drupella spp.* feeding rates as well as coral growth rates is key in this. Bessey *et al.* (2018) defined outbreak densities of *Drupella cornus* as a function of coral cover and growth and *Drupella* consumption rates[106]. Using this model, with Dauin's mean coral cover of 20.1%, *Drupella spp.* densities of 1.1 individual m^{-2} would be considered an outbreak. However, this model is based on *Acropora spicifera* and on conditions such as growth rates found in Western Australia, so the applicability of this model to Dauin's reef ecosystem will need validating, ideally with *in situ* measurements of *Drupella spp.* consumption rates and coral growth rates. To understand the dynamics of coral predation related to the co-occurrence of anthropogenic and natural impacts, monitoring programs should **collect temporal and spatial data on non-outbreaking/non-aggregating populations**[104], in order to **quantify synergistic or antagonistic effects of other impacts**. Little is known about the non-outbreaking/non-aggregating *Drupella* spp. populations in Dauin, so insight on this will help us to assess the influence of *Drupella* spp. on the overall health and resilience of this reef ecosystem.

The frequency of **direct destruction** (fig. 19) increases slightly (Kruskal-Wallis, p=n.s, fig. 11) throughout the DLTRMP. Causes of direct destruction can be natural (storms, wave action) or anthropogenic (boat anchors, recreational use from snorkelling/diving[107–109], destructive fishing practices). Resistance of corals to physical forces depends on several factors; the shape, size, and skeletal density of the coral, as well as the nature of the physical force being exerted[110–112]. **In Dauin, branching corals are the most frequently impacted by direct destruction**. *Acropora* is the genus most frequently damaged, followed by *Pocillopora*. Direct destruction is acutely detrimental to coral health, through fragmentation (particularly detrimental for slower growing species) and reduced fitness and susceptibility to secondary stressors[52,113,114] e.g., corallivores, disease[99,115–120]. During the DLTRMP, secondary impacts have been recorded in 43% of direct destruction cases; most commonly predation, followed by bleaching and disease. Additionally, under harsh environmental conditions, the corals' ability to recover from physical injuries becomes compromised[121].

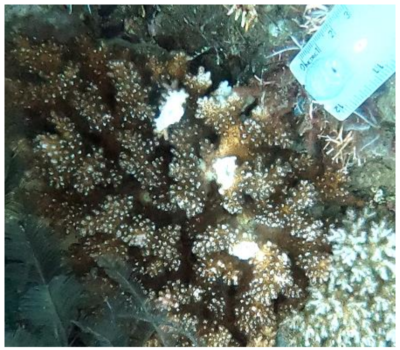


Fig. 19. Damaged Pocillopora sp. *(white parts show exposed skeleton at break points)*

Crown-of-thorns starfish (COTS, *Acanthaster planci*) are on average found at low abundances across the Dauin reef ecosystem. The exception to this is Masaplod Sur, where outbreaks have occurred for many years; 64.6% of COTS recorded during the DLTRMP were at Masaplod Sur (see Crown Of Thorns Sea Star: Outbreak and Recovery). *Acropora spp.* is the most commonly impacted genus by COTS on the Dauin fringing reef. ***Acropora spp.* is one of the preferred coral genera for COTS** [122,123]. Tabulate growth forms are favoured over branching, submassive, foliose and massive[123]. Larval survivorship is also greater when maternal diets include *Acropora spp.*[124], indicating that COTS outbreaks may be more likely on reefs with high *Acropora spp.* cover. **The high proportion of *Acropora spp.* across Dauin's reef ecosystem is therefore conducive to COTS outbreaks, highlighting the need for effective management of potential causes for COTS population outbreaks**.

Coral disease prevalence was consistently low for the first years of the DLTRMP, before significantly increasing in 2022 (Kruskal-Wallis, p<0.001, for all years compared to 2022 p.adj <0.01)**, because of a spike in Porites Ulcerative White Spot disease**. *Porites* trematodiasis (also known as *Porites* pinking), Skeletal Eroding Band Disease, White Syndromes, Neoplasia and Brown Band Disease have been recorded during the DLTRMP at very low frequencies (fig. 20). Factors previously found to increase disease outbreaks include temperature stress[125,126], lesions[89,99,115], corallivores as disease vectors [117–120], nutrient enrichment/runoff[127–129], high coastal human population[130], fish assemblage alterations[131] and proximity to algae[128].

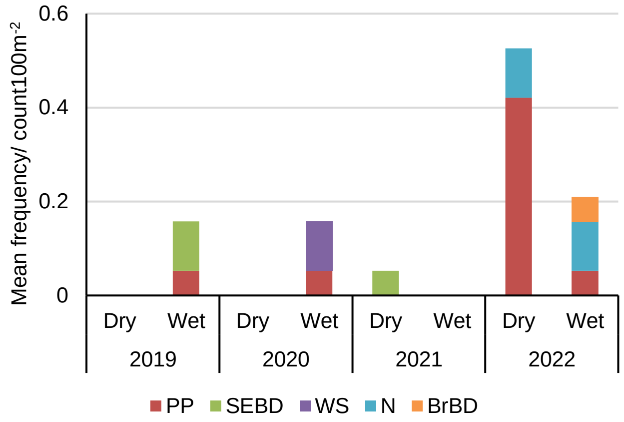


***Fig. 20. Mean frequency of disease incidences (count100m⁻²) along Dauin Reef separated by disease type and survey season, excluding Porites Ulcerative White Spot**. PP = Porites Pinking, SEBD = Skeletal Eroding Band Disease, WS = White Syndrome, N = neoplasia, BrBD = Brown Band Disease.*

In Dauin, *Porites* is the genus most affected by disease, by *Porites* Ulcerative White Spot (PUWS) and *Porites* trematodiasis (PP). *Porites* is a dominant disease host within the Philippines, particularly in the Central Visayas[132]. **PUWS is prevalent throughout the Philippines, however mortality is generally low**[132]. It affects both branching and massive *Porites spp.*; prevalence per species is correlated with species density (host availability), not morphology[133]. Although the rate of tissue loss for PUWS is slower than other white syndromes, recovery from PUWS is rare, limited only to colonies with low-intensity infections[133]. **PUWS prevalence is positively correlated with human population density, and outbreaks of PUWS are driven by elevated nutrient levels and organic carbon**[134]. Warmer sea temperatures also increase incidence of PUWS[134]. Links also exist between sewage-derived nitrogen pollution and white syndrome severity in *Porites* spp.[135]. It is possible that the Dauin fringing reef is exposed to these diseases as a result of sewage outfall and nutrient enrichment from increased runoff; IMR will confirm this with water quality testing along the Dauin coastline.

Although the mean frequency of PUWS records increases significantly over the years in Dauin (Kruskal-Wallis, p<0.001), the percent cover of *Porites* across the coastline has no significant changes (one-way analysis of variance no significant effect of survey season, p=n.s). This suggests that perhaps this disease is rarely fatal (consistent with other research[132]), or there is a substantial delay between onset of disease and mortality. **Continued monitoring of the prevalence of this disease is needed, as well as examining its severity and subsequent mortality** of Porites spp.; as one of the dominant coral genera on the Dauin reef, **widespread loss of this genus could have significant ecological impacts**.

The prevalence of PUWS along the Dauin coastline varies greatly; it was only recorded in two locations in 2019, four 2020 in, six in 2021 and at all 11 survey locations along the coast in 2022 (fig. 22). Prevalence is lowest at Bulak I (the most northerly of survey sites), and highest at Poblacion II. **The best area to examine the causative agent(s) and trajectory of this disease in Dauin and its potential impact on the ecosystem is Poblacion II, where PUWS prevalence is highest**. **Neither the 5m nor 10m site at Poblacion II shows significant changes in Porites cover** (ANOVA 10m: p=n.s, 5m: p=n.s)**, despite increases of an order of magnitude in PUWS records** (fig. 24). However, there is a gentle decline in the trendline for the 5m *Porites* percent cover, so further monitoring is required in order to confirm any significant changes to the *Porites* cover at this patch reef. **It is possible there is a time lag between colony infection and subsequent mortality;** as 2022 shows a large increase in PUWS prevalence, it is possible we are not yet seeing mortality as a result of these new infections.

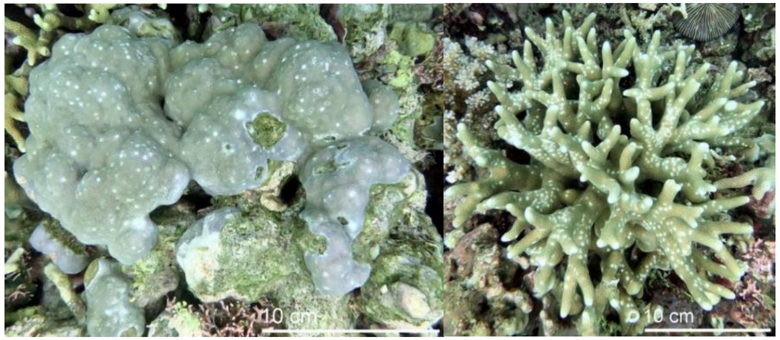


***Fig. 21. Examples of severely PUWS-infected colonies**, massive and branching.*

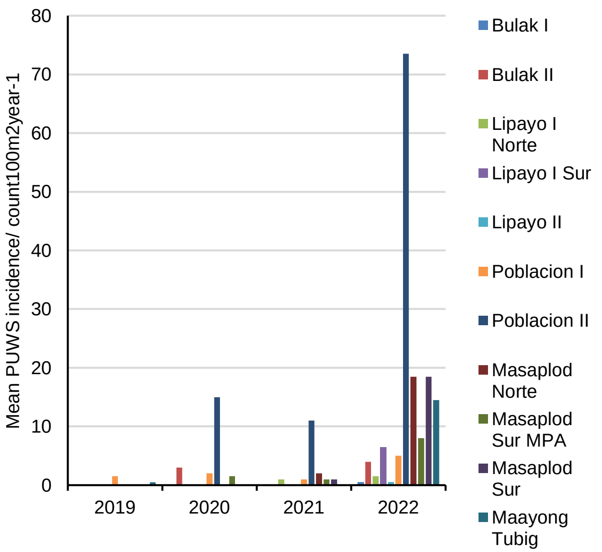


***Fig. 22. PUWS incidence per year (mean of two survey seasons) at different survey locations**, ordered from north to south. N.B. 2021 only one season so mean for year is the total for dry season.*

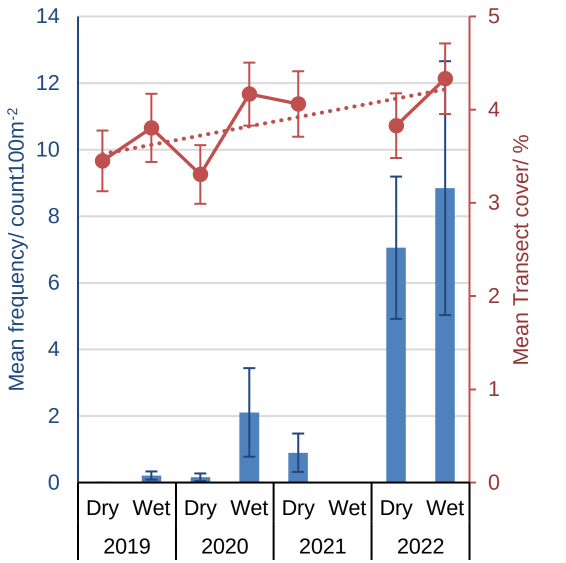


***Fig. 23.** Bars: **mean frequency of PUWS across Dauin per survey season** (count100m^{-2} ± SE). Line with markers: **mean transect cover of Porites** (% ± SE) along Dauin Reef per survey season. Dotted line: linear trendline of* Porites *percent cover.*

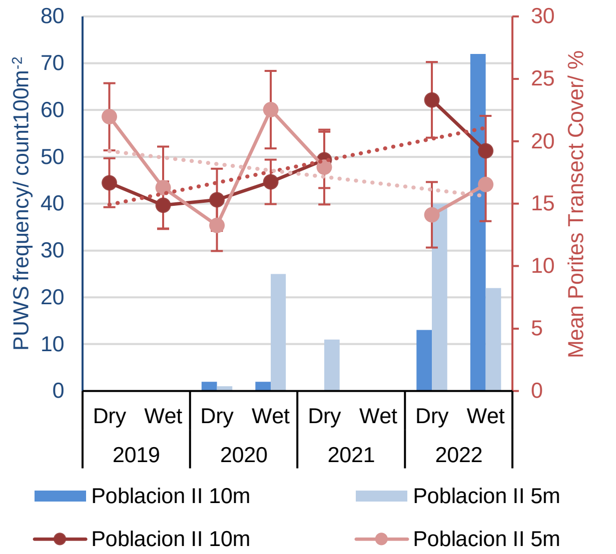
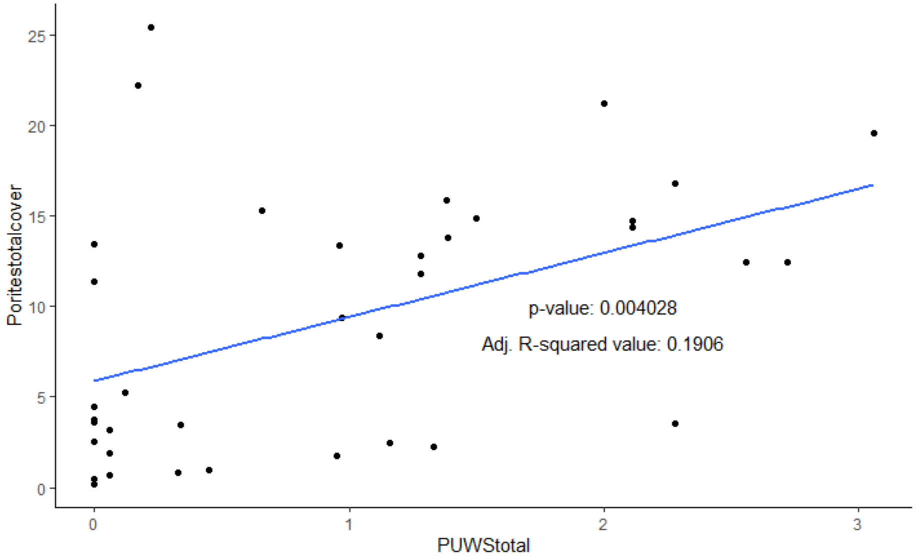


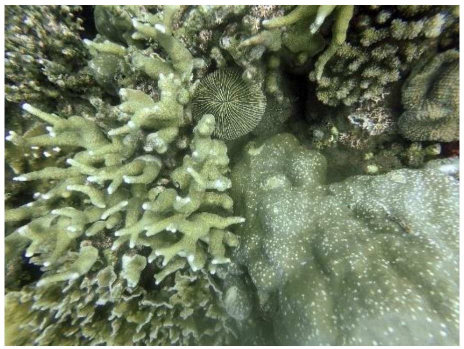
***Fig. 24.** Bars represent **total frequency of PUWS at Poblacion II 10m and 5m survey sites per survey season** (count100m^{-2}). Lines with markers represent **mean transect cover of Porites** (% ± SE) at Poblacion II 10m and 5m survey sites per survey season. Dotted lines: linear trendline of* Porites *percent cover.*

Masters Project: New records of Porites Ulcerative White Spot Disease in the Philippines; Implications for the Future of MPA Management

Niamh Meyler, Stockholm University



Regression line for PUWS total cover against the total percent cover of Porites spp. in all transects



Disease is an underestimated and understudied threat to coral reefs. A recent increase in incidents of Porites Ulcerative White Spot (PUWS) disease on the Dauin shores inspired me to take action and review the potential causes and effects on the coral community. My study set out to analyse PUWS in existing long-term monitoring data to gain more knowledge about its transmission and prevalence in Philippine waters. The Institute for Marine Research has been monitoring the Dauin reefs since 2019. Using data already available, I determined that PUWS has been consistently present in Dauin, Philippines since IMR's monitoring began in 2019. I also had the opportunity to visit Apo Island with IMR and found new records of PUWS within the Marine Sanctuary where previous studies found it to be free of PUWS as of 2005[132]. Mucus samples were collected from infected and healthy Porites corals will be analysed in a genetics lab to find more information about the pathogen causing PUWS and how it is transmitted within the ecosystem.

The rates of infection in Dauin reefs lead us to consider an important question; what does this mean for the recovery of Dauin reefs? Raymundo et al. 2003[133] found that only 2 infected Porites spp. colonies died over their 17-month-long study. They also found that PUWS has a low rate of tissue loss and the disease may be present in the colony for quite a long period of time without displaying any more than minor tissue loss. Raymundo's report is consistent with this current study as **very little tissue loss was observed in the Dauin reefs despite some observations of highly advanced levels of PUWS lesions on some coral colonies.** Unfortunately, the low rates of tissue loss may not be enough to predict any positive trends for the future of the Dauin reefs.

Though we have very little information available regarding the source and transmission of PUWS in Dauin, we have succeeded in the first multi-year observation of PUWS on a single reef. This report also recommends a greater emphasis on coral disease mitigation efforts be incorporated into MPA management plans. **There is more work to be done with PUWS on Dauin shores**.

Annual Trends: Fish Community Dynamics

A total of 369 fish species within 39 different families have been recorded since the beginning of the DLTRMP (118,095 individuals, equating to an estimated biomass of 1842.96kg). Mean total abundance has changed significantly throughout the DLTRMP (ANOVA, p<0.001, fig. 32), increasing significantly from 2019 to 2020, before gently declining, with **2022 abundance and biomass significantly lower than 2020, but still significantly higher than 2019**. Abundance also varies significantly by location (ANOVA, p<0.001, fig. 32); **fish abundance and biomass are lowest at Masaplod Sur (both inside and outside the MPA) and Lipayo I Norte**. Biomass (calculated as a function of length, see METHODS) follows the same trends; significantly changing throughout the years of the DLTRMP (ANOVA, p<0.001) and between locations (ANOVA, p<0.001). **Reversing these significant declines in fish populations is crucial, whilst ensuring the reef provisioning needs of the local community continue to be met**.

Of the 369 fish species recorded, **three are listed as Near Threatened** by the IUCN; *Taeniura lymma* (Bluespotted ribbontail ray), *Chlorurus bowersi* (Bower's Parrotfish) and *Scarus hypselopterus* (Yellow-tail Parrotfish), and **two are listed as Vulnerable**; *Oxymonacanthus longirostris* (Orange spotted filefish), and *Epinephelus fuscoguttatus* (Brown-marbled grouper). *O. longirostris* has been recorded at Poblacion District I and II and Lipayo I Sur. *E. fuscoguttatus* has been recorded at Masaplod Norte and Lipayo II. Coral reef ecosystems are increasingly subjected to disturbances, natural and anthropogenic, which can reduce habitat quality, quantity and connectivity[187,188]. **Subsequent management actions at these sites should consider the rarity of these Vulnerable species, as well as those potentially affected by reduced habitat quantity, quality and connectivity**.

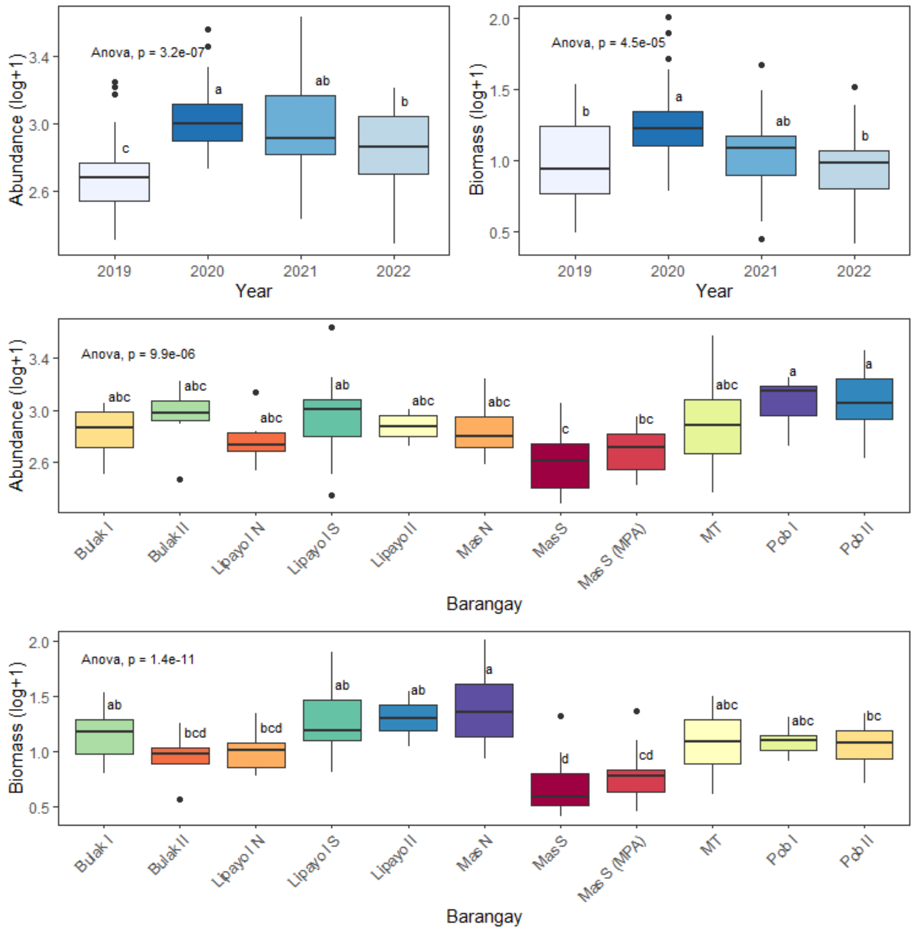


*Fig. 32. **Boxplot of mean abundance (count/250m⁻²) and biomass (kg/250m²) (log+1 transformed) separated by year (top), and barangay (middle and bottom)**. Letters represent significant differences between catetgories; years/barangays with different letters are significantly different from each other (p<0.05).*

There are no significant differences in the fish community compositions between years (ANOSIM, p=n.s). *Pomacentridae* accounts for 73% of fish by abundance, followed by *Labridae*, *Serranidae*, *Caesonidae* and *Acanthuridae*, accounting for 6%, 4%, 3% and 3% respectively. The relatively high abundance of the *Serranidae* family is due to two species; *Pseudanthias huchtii* (Threadfin anthias) and *Pseudanthias tuka* (Yellow striped fairly basslet), which comprise 95% of the Serranidae family by abundance. By biomass, *Pomacentridae* accounts for 28%, followed by *Lutjanidae*, *Caesionidae*, *Acanthuridae* and *Scaridae*, accounting for 12%, 11%, 8% and 5% respectively. Globally, damselfish and wrasse are ubiquitous

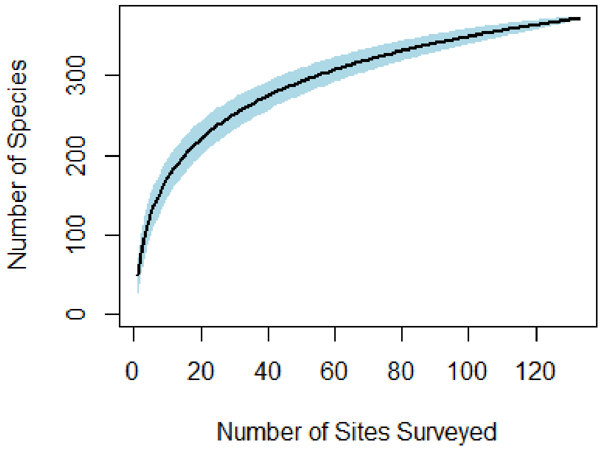


***Fig. 33. Species accumulation curve** for the current 133 samples of the DLTRMP, obtained with the function specaccum of the 'vegan' R package. Confidence intervals (from standard deviation) are represented by shaded area around curve. Calculated using "exact" method, which finds the expected (mean) species richness.*

and abundant components of reef fish assemblages, and often the most speciose families[189,190]. Damselfish are able to occupy a vast array of niches within the reef ecosystem due to their high degree of variation and specialisation, in terms of feeding, habitat and shelter selection[191]. They are also able to withstand environmental change by adapting these strategies[191], explaining their high prevalence on coral reefs globally amidst severe environmental changes as a result of frequent and intense disturbances. Wrasses are the second-most speciose reef fish family (second to *Gobiidae)*[192], with huge variety in body shape, size, feeding strategies and mating systems[193]. The species accumulation curve is gently moving towards a plateau, but we are still recording many new species each year (fig. 33), suggesting that the fish community of Dauin's reefs have not yet been surveyed representatively after the 133 replicates of the DLTRMP thus far.

A large-scale study across 18 oceanic islands found **species richness and fish density were mainly influenced by biogeographical and energetic factors, whereas functional dispersion and biomass were strongly influenced by anthropogenic factors**[194]**.** Reef fish community structure is strongly shaped by responses to a vast number of biotic and abiotic factors, such as temperature, depth, current direction and intensity, benthic composition, topographic complexity, food availability, competition, recruitment patterns[189,195–197]. Temporal fluctuations can also affect fish community structure, such as variation in physical conditions (temperature, currents etc.), biological traits (mortality, growth etc.) and behavioural patterns (migration, spawning etc.)[198]. Ecological processes such as ontogenetic migration[199] (where fish occupy different sites at different life stages based on habitat features such as complexity or food availability), and niche partitioning[200] (where different species occupy different habitats as a result of natural selection and resource competition) can also shape the fish assemblage. For example, damselfish exhibit low levels of habitat specialisation, but this specialisation in higher in juveniles than in adults[201]. This highlights the necessity of diverse and complex refuge sites for juvenile damselfish, which we observe in Dauin in their close associations with branching coral colonies. These associations are important to understand when we consider future scenarios with potentially reduced coral cover, as coral loss may not uniformly impact all life stages[201]. **The lack of change in fish community composition in Dauin suggests that these factors are stable enough to maintain current community compositions**.

Significant predictors of total fish abundance were time of day of survey, coral cover and sponge cover, as well as a significant coral*sponge interaction term (GLMM, Wald Chi-Squared Test, hour $p<0.001$, coral $p<0.001$, sponge $p<0.05$ and coral*sponge $p<0.05$, fig. 34b-f). Tidal height and state were not significant predictors of total fish abundance (tidal height $p=0.06$ and tidal state $p=0.07$), but are included in the model as they improved overall model fit (AIC). Survey season, depth, seasonality (mean monthly air temperature and precipitation), algae cover and sea state had no effect. The lack of significance of algae cover is expected, due to the low proportional abundance of herbivorous fishes in Dauin (see Functional Groups). The significant effect of time of day our surveys are completed suggests we may need to a) deepen our understanding of diurnal fish behavioural patterns, and b) perhaps adjust our survey methodologies to account for these natural fluctuations.

The lack of change in community composition (ANOSIM, p=n.s) **suggests that fishing pressures are not selectively targeting specific fish and causing substantial declines in particular families/species**. From this we can conclude that current fishing practices in terms of species harvested will sustain the current fish population structure in Dauin. However, if trying to change the fish community structure, for example to increase the abundance of herbivores and piscivores (see below), changing the species harvested in fishing practices would promote this. Additionally, anthropogenic factors such as fishing pressures and other disturbances may also play a significant role in the size structure of the Dauin fish assemblage[202]; investigating the size structure of the fish populations and the external forces affecting size structure along the Dauin fringing reef will shed more light on the driving forces behind these differences in reef fish communities along the coast (see Fish Stocks – Commercially Important Fish).

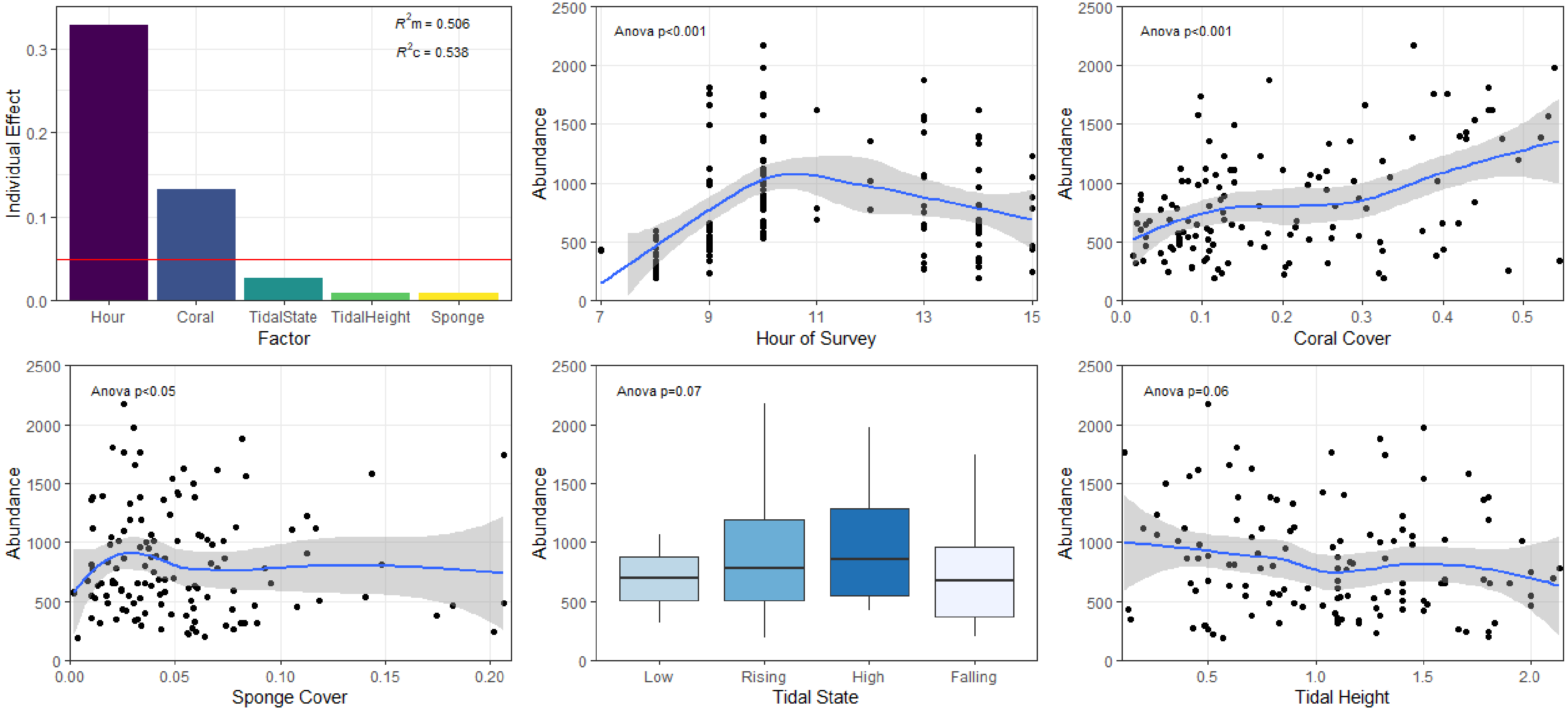


__Fig. 34. a) Individual effect of GLMM fixed effects on bleaching frequency__, with quoted marginal R^2m and R^2c (which includes random effect) values for whole model. __b-f) relationship of time of survey (hour), coral cover, sponge cover, tidal state and tidal height on fish abundance__, with p-values denoting significance of variable on total fish abundance, and smoothers for continuous variables with standard error, showing overall trends.

Functional Groups

Community composition in terms of fish functional groups does not change significantly between surveys years of the DLTRMP (ANOSIM, p=n.s, fig. 35 & 36). The functional groups that comprise the largest proportions (by abundance) of the fish community as of 2022 are omnivores (31.9%), planktivores (28.0%) and herbivore & planktivores (26.4%); all other functional groups contribute 4% or less individually. By biomass, omnivores represent 22.5% of the fish community in 2022, followed by herbivore & planktivores (19.5%) and invertivore & piscivores (19.2%). **Although the community composition of functional groups remains unchanged from 2019-2022, there are concerns regarding the lack of herbivores and piscivores**. We do not have data on how long these groups have been missing, but the effect of this on the health of Dauin's reef ecosystems could be severe.

The Dauin reef ecosystem supports an **even distribution of trophic generalists (omnivores) over specialists**, **which has not significantly changed over the course of the DLTRMP** (ANOSIM, p=n.s). Loss of specialists and replacement by generalists (biotic homogenisation) is an emerging global phenomenon[203], which can have severe impacts on ecosystem functioning and community structure[204]. Ecological theory predicts generalists (trophic or habitat) are less susceptible to disturbances than specialists[205], which several studies have demonstrated[205–207]. **The foundation of trophic generalists in Dauin's fish assemblages suggests resilience to future disturbances**. Frequent and/or intense disturbances may cause biotic homogenisation as specialists are lost, but this has not occurred during the DLTRMP, suggesting that either there have been no major disturbances, or there is a lag time effect and we are yet to see impacts of any disturbances on the reef fish communities.

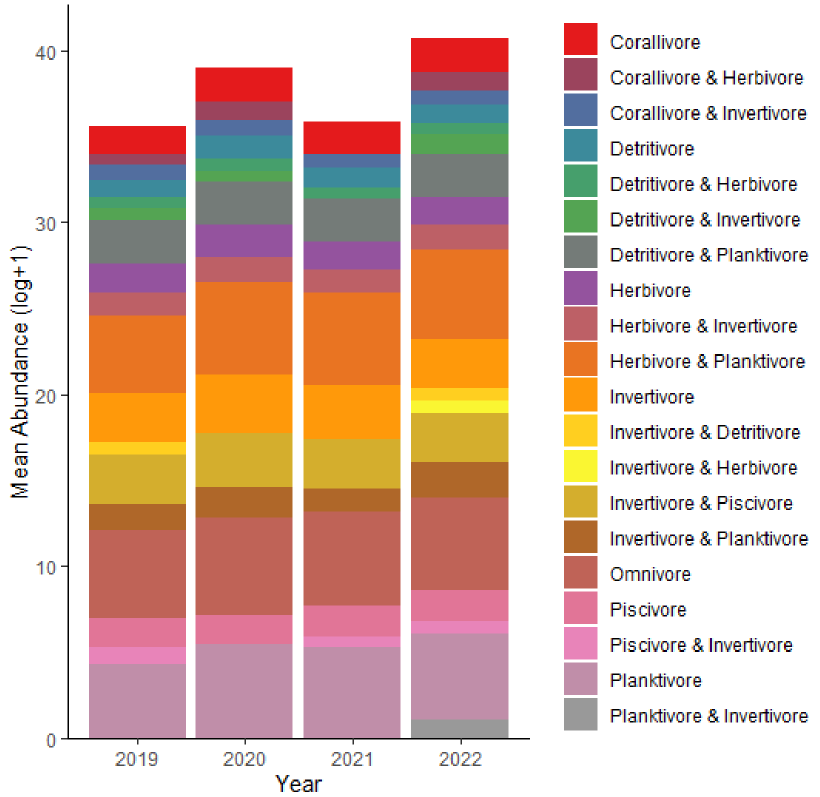


***Fig. 35. Mean abundance (log+1) of fish functional groups** per transect recorded along Dauin Reef separated by survey year.*

Due to the increasing algal cover across Dauin's reefs, the health of the herbivorous reef fish population is of concern; herbivorous fish are crucial in limiting algal growth on coral reefs and preventing phase shifts to algae-dominated systems[23]. **Obligate herbivores have very low abundance (0.6%, fig. 35) and species richness (27) along the Dauin reef ecosystem,** although their contribution to biomass is relatively high (4.1%), as exclusive herbivores are comprised of mostly large-bodied fishes (e.g. *Scaridae*, *Acanthuridae* and *Siganidae).* An average of only approximately 6 obligate herbivore individuals are recorded per survey. Although we have data on the niche partitioning (browsers, grazers, scrapers and croppers) of these obligate herbivores[208], we do not have enough records of these fish to statistically examine their influence on the benthic composition (algae cover). ***Siganidae* are one of the main fish families responsible for removing macroalgal biomass on coral reefs[209]; over the course of the 133 surveys of the DLTRMP we have recorded only 169 individuals in the *Siganidae* family**.

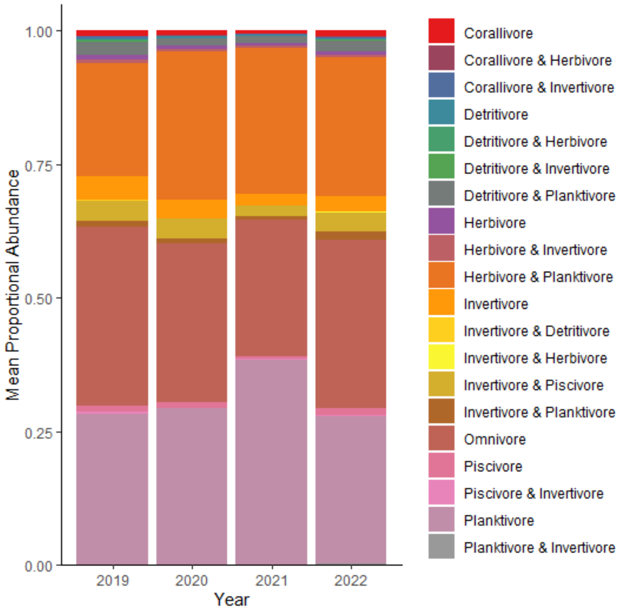


Fig. 36. Mean proportional abundance of fish functional groups *per transect recorded along Dauin Reef separated by survey year.*

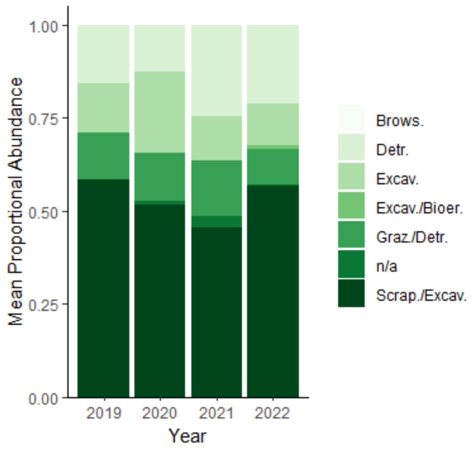


Fig. 37. Mean proportional abundance of herbivorous fish functional groups *per transect recorded along Dauin Reef separated by survey year. Brows.= browsers, Detr.= detritivores, Excav.= excavators, Excav./Bioer.= large excavators and bioeroders, Graz./Detr.= grazers and detrititvores, n/a= information not available, Scrap./Excav.= small scrapers and excavators.*

Survey season, seasonality (mean monthly air temperature and precipitation), depth, tidal height and state, sea state, time of day the survey was completed, coral, algae and sponge cover had no significant effect on the abundance of herbivorous fish (GLMM). Most of the variation in the abundance of herbivores resulted from the random effect of survey (R^2c= 0.570, R^2m= 0.141, high adjusted intra-class coefficient of 0.499) **The strong influence of survey site on herbivore abundance suggests a) we may need to create spatially-specific management actions for the conservation of the small herbivorous reef fish population in Dauin** (such as Bulak and Lipayo), and b) the lack of influence of algae cover on herbivore abundance shows there is an ample food availability for all herbivores, suggesting that they are not exhibiting strong grazing pressures on algae and therefore may not be able to prevent a phase-shift to algal dominated system if we reach this point.

A variety of herbivore species and functional groups is essential to preserve coral reef health. Herbivore functional group diversity and co-occurrence benefits the coral reef benthic state, for example co-occurrence of cropping and scraping herbivores can promote coral accretion[210]. A global synthesis on macroalgal removal by herbivores on coral reefs found that in all regions studied (Atlantic, Indian and Pacific Ocean), a small subset of the herbivore assemblage accounted for the majority of browsing[211]; this is consistent with our fish assemblage in Dauin (fig. 37). **This review recommended the implementation of broader scale conservation efforts for high-performing browser species, rather than localised conservation tools such as MPAs**[211].

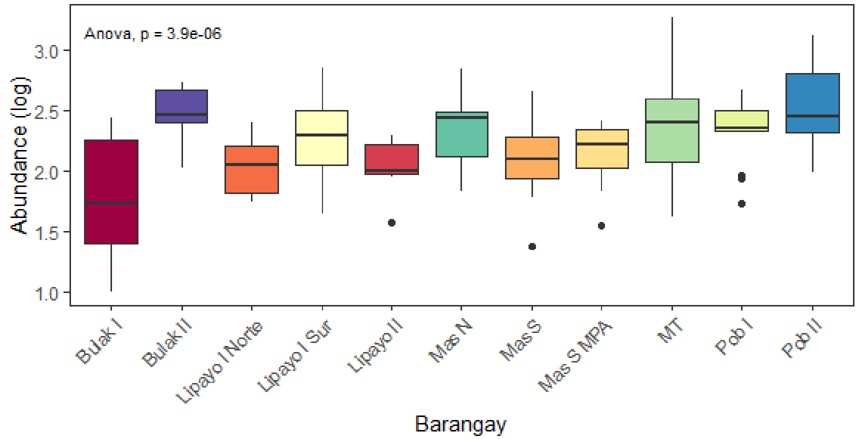


Fig. 38. Boxplot of mean herbivore abundance *(count/250m^{-2}) (log+1 transformed)* ***separated by barangay***

Due to the rarity of obligate herbivores as a whole in Dauin, it is likely that they are not substantially influencing the benthic composition, which may explain (at least in part) the rapidly increasing algal cover across Dauin's reefscapes (fig. 26). This begs the questions – **why are Dauin's reefs functionally lacking obligate herbivorous reef fishes**, and **how can we change this**? Interestingly, a literature review from 2019 suggests that marine protected areas and the specific protection of herbivorous fish (including parrotfish) have had little effect on coral reef resilience, potentially because local stressors such as fishing and pollution are often swamped by the more global threats of climate change[212]. Conversely, a study in Kenya in 2022 found that fishing restrictions (a combination of no-take zones and areas restricted to traditional fishing methods (artisanal fishermen using traps, nets, spearguns, hook and line)) support reef resilience by increasing herbivorous fish biomass of key species and thereby promote macroalgae removal[213]. Macroalgae removal rates were higher in protected areas, associated with more large-bodied browsers which were rarely observed in fished areas[213]. As a local grassroots organisation, **IMR is committed to identifying the most suitable management options locally based on our data of the health of the reef, whilst continually assessing the impact of these management actions on both the reef ecosystem and the local fishing population, to ensure efforts are effective and suitable for all key stakeholders**.

The abundance of facultative herbivores (classified as having two trophic guilds e.g. herbivore & planktivores, one of which is herbivory), **is much greater than that of obligate herbivores, at 31,934 individuals (27%).** However, information on the food items of most of these (25,409 individuals) is limited to “benthic algae/weeds” [214], which gives us no more information on niche partitioning of Dauin’s herbivorous fishes. Herbivory, in particular grazing activity by parrotfishes, can be a crucial component in natural recovery of coral reefs, as grazers free space for coral settlement[215]. **Further research is needed to quantify the influence of these facultative herbivores, both in terms of greater detail in their food items as well as the proportion of their diet that is plant-based**. Current research seems to be exploring this; within the Surgeonfish family, 85 species have been recently categorised as “browsers, brushers, croppers, concealed croppers, sediment-suckers and/or water-column feeders”, using morphological and behavioural traits[216]. With more resources such as these, potentially combined with empirical data collected in Dauin, we can better quantify the ability of obligate and facultative herbivores to aid natural reef recovery in Dauin.

Obligate piscivores have very low abundance (0.6%, fig. 35) biomass (1.6%) and species richness (10) along the Dauin reef ecosystem. When including facultative piscivores (classified as having two trophic guilds e.g. piscivore & planktivores, one of which is piscivory), abundance (4.2%), biomass (20.8%) and species richness (78) all contribute much more to the overall Dauin reef fish community (fig. 35). Piscivores are apex predators in coral reef ecosystems and play a **vital role in top-down community structuring**[217,218]. Exclusion studies on small patch reefs (similar to the Dauin fringing reef ecosystem structure) have consistent findings; the removal or exclusion of predators leads to changes in abundance, species richness and mortality of prey species[219,220]. However, predator-prey interactions are more in-depth than just predators eating prey; **fear of predators has been shown to alter the behaviour, physiology and morphology of prey as they aim to reduce predation risk. These are known as ‘non-consumptive effects’ (NCEs)**, which is an emerging research topic in coral reef ecology. A review in reef-fish assemblages finds that NCEs significantly alter reef function, however there is currently lacking evidence of demographic changes and knowledge gaps in the specific mechanistic pathways and how these concepts apply in multi-predator multi-prey environments[221]. Interestingly, the lack of predators (obligate piscivores) in Dauin will also influence the reef fish assemblages, due to the lack of these NCEs. Predator risk has been observed to limit herbivorous grazing to areas close to shelter, with higher risk areas subsequently having higher macroalgae cover[222]. **The lack of NCEs in Dauin may therefore promote wider grazing areas of herbivores and reduce algae cover; although this would require a large enough population of herbivores to do so**. As with obligate herbivores, the proportion of piscivores in the Dauin fish assemblage has not changed significantly since 2019, but the fact **they contribute so little to the overall community structure is concerning** nonetheless. Many ecological factors may influence the relative abundance of piscivores, such as daily foraging movements, seasonal migrations and ontogenetic shifts[198223], so it is possible that our survey methods (e.g. time of day) are affecting how often we record piscivores. However, the absence of piscivores may also be due to long-term fishing pressures[7,224,225].

Fish Stocks – Commercially Important Fish

There is no significant change in the proportional abundance or biomass of commercially important fish species between the survey years of the DLTRMP (ANOSIM, abundance p=n.s, biomass p=n.s, fig. 39). Unsurprisingly, commercially important fish have low abundance but relatively high biomass in Dauin, as larger-bodied fish are heavily favoured, which are naturally less abundant in reef ecosystems. 100 commercially important fish species (CIS) have been recorded in Dauin, accounting for 27.1% of total species richness. Although the difference is not significant, **there is slightly less** (in abundance and biomass, fig. 39) **commercially important fish in 2021 compared with all other years, which could be as a result of locals leaning more on fishing as a result of reduced income from tourism** (see Coronavirus-19, Tourism and Marine Protected Areas).

Determining the sustainability of fishing practices in Dauin is challenging, as catch information is often required which can be hard to quantify in small-scale and local fishing communities. NOAA defines the maximum sustainable yield (MSY) as "the largest long-term average catch that can be taken from a stock under prevailing environmental and fishery conditions" and overfishing as "a stock having a harvest rate higher than the rate that produces its MSY"[226]. Another definition provides more insight based on the data we have available to us in Dauin; "**abundance is considered to be adequate if there is a large enough proportion of the original adult stock remaining that production of juveniles (recruitment) is not significantly reduced**"[227]. Through examining the size distribution of commercially important fish species (proportions of adults and juveniles), we can monitor determining the reproductive capacity and therefore the health/sustainability of Dauin's commercially important fisk stocks. **Exploited fish communities shift toward smaller individuals**, truncating their size structure as a result of size-selective fishing[228] (where larger-bodied animals are

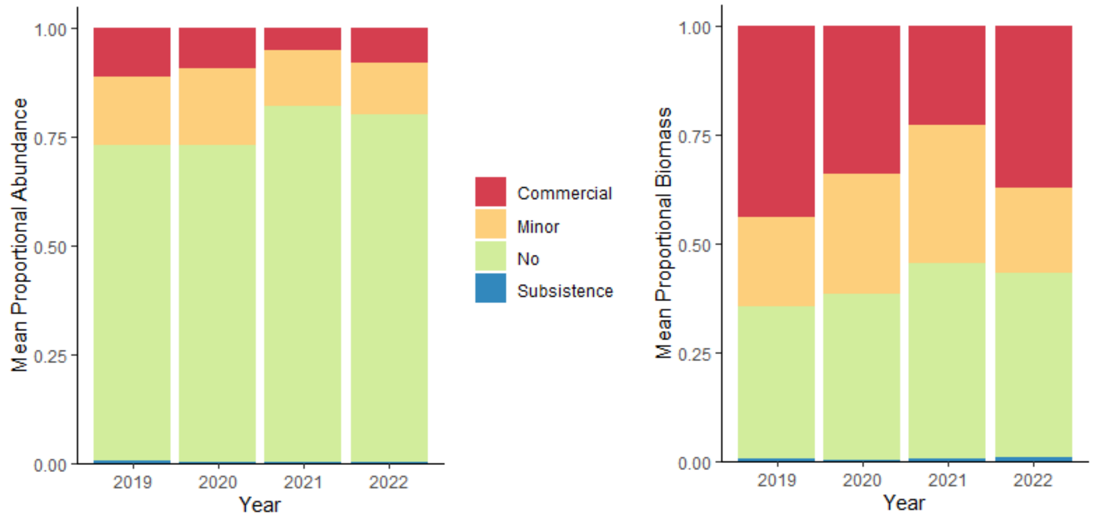


***Fig. 39. Relative mean abundance (left) and biomass (right) of commercial importance types** per transect of fish recorded along Dauin Reef separated by survey year.*

Case study: Fishing Community in Dauin

A study on the local fishing community in Dauin found that over half (54%) of the study participants (10) fished only in Dauin, and fishing pressure appears to be consistent along the coast. The most commercially valuable (per kg) fish in Dauin are trevally, tuna, mackerel and snapper. Fifty percent of fishing activity occurs in the first 100m from shore (10% of fishing activity travels over 10km, to the Mindanao border). The most common methods for fishing are hook and line, gillnets and fishing nets over seagrass. Although not recorded in this study, fishing cages are often seen along the Dauin reef ecosystem, and have been recorded during the DLTRMP. 20% of fishers said MPAs were beneficial to them, whereas 80% said it was problematic to their livelihood. No information is yet available on their catch/fishing efforts. See[274] for more information.

preferentially harvested as they are more valuable and more obvious and easier to catch[229]). **Size-selective fishing hinders the reproductive potential of the fish community by removing sexually mature individuals**[230], potentially causing recruitment failure[231] and altering the stability of the community, increasing its sensitivity to other disturbances and stressors such as ocean warming[228]. If coral reef fish communities continue to be heavily fished, fishermen target smaller individuals, as the largest have already been exploited to local extinction[232]. **MPA design can significantly influence their efficacy and the sustainability of fishing practices**[233]**; re-evaluation of Dauin's MPA network may be needed in order to combat reducing fish populations.**

The commercially important fish population in Dauin is skewed towards smaller individuals, with few records of commercially important species (CIS) individuals above 25cm in length (fig. 40). Although it appears minimal, there has been a **significant reduction in the body length of all CIS fish during the DLTRMP** (ANOVA, p<0.001, all years significantly different from each other, p.adj<0.05) except 2021-2022, fig. 40). However, it is important to note **that the scarcity of these large-bodied CIS during DLTRMP surveys does not guarantee that these fish are functionally extinct in the Dauin reef community**; the abundance of a species decreases as body size increases[234,235], hence these large-bodied CIS are naturally rarer in the ecosystem. Additionally, larger-bodied fish such as *Lutjanidae* (snapper), *Haemulidae* (sweetlips) and *Serranidae* (grouper) tend to have larger home ranges[236], hence recording them in a survey is less likely. Nonetheless, **avoiding the shift to a size-truncated fish assemblage is crucial in maintaining healthy and effective ecosystem functioning;** continued monitoring and management action is key in this.

Examining size distributions of specific species allows us to determine the proportion of juveniles to adults, and if this has changed throughout the DLTRMP. Information on the length at first sexual maturity (obtained from FishBase or peer-reviewed sources) is crucial in this, which is readily available for our most commonly encountered CIS (except *Ostorhinchus aureus*). Eight commercially important fish species have more than 100 length measurements from the DLTRMP. However, no information on length at sexual maturity is available for *O.*

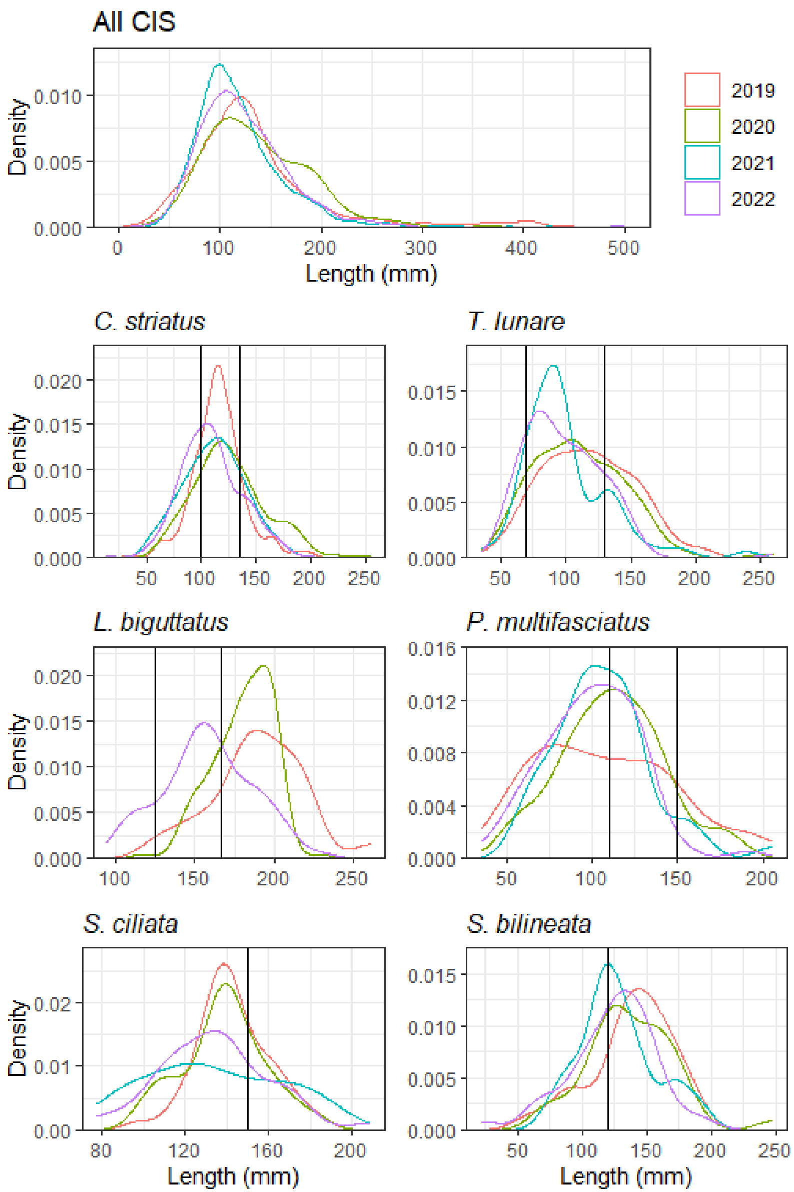


Fig. 40. Density plots of recorded lengths of commercially important fish *during the DLTRMP, separated by survey year. All CIS = all commercially important fishes with recorded lengths. Species specific graphs vertical lines represent length (or upper and lower limit of range of lengths) at which that species reaches sexual maturity. Species with over 100 measurements over the course of the DLTRMP were selected. n measurements: C. striatus = 901, T. lunare = 720, L. biguttatus = 310, P. multifasciatus = 268, S. ciliata = 167, S. bilineata = 128.*

aureus and *Plotosus lineatus* only has measurements from two out of the four survey years, so these are excluded from this analysis. For species: *C. striatus, P. multifasciatus,* information on length at sexual maturity is available on FishBase[214], whereas for *T. Lunare, L. biguttatus, S. ciliata, S. bilineata* other sources were required[237–239]. **Species with size-truncated (mostly juvenile) populations are *Parupeneus multifasciatus* and *Scolopsis ciliata*** (fig. xx). Populations of *Ctenochaetus striatus* and *Thalassoma lunare* have an even distribution of juveniles and adults, whereas populations of *Lutjanus biguttatus* and *Scolopsis bilineata* are more skewed towards mature adults (fig. xx). Of these frequently recorded CIS, **significant changes are seen in the lengths of *L. biguttatus*** (ANOVA, p<0.001, sig diffs between 2019-2022 (p.adj<0.05) and 2020-2022 (p.adj<0.05). no other sig diffs), *C. striatus* (p<0.001, all sig diffs (p.adj<0.05) except 2019-2021 and 2021-2022) **and *T. lunare*** (p<0.001, all sig diffs (p.adj<0.05) except 2019-2020, 2020-2021 and 2021-2022), all of which show reductions in mean length (fig. 40). No significant changes are seen in the size structure of the populations of *P. multifasciatus* (p=n.s), *S. ciliata* (p=n.s) and *S. bilineata* (p=n.s). **Continued removal of *L. biguttatus, C. striatus* and *T. lunare* at the current pace, as well as continued removal of *S. ciliata* at any pace could lead to recruitment failure in these commercially important fish species.** As some of the most common CIS found in Dauin, this could have implications for the entire commercial fish assemblage, ecosystem functioning and reef resilience, as well as the fishing community of Dauin that rely on these stocks for their livelihood.

Left to right, top to bottom: Orange spotted filefish (O. longirostris), Brown-marbled grouper (E. fuscoguttatus), Two-spot banded snapper (L. biguttatus), 2) Moon wrasse (T. lunare) and 3) Saw-jawed monocle bream (S. ciliata). Image credit: François Libert

Coronavirus-19, Tourism and Marine Protected Areas

The effects of COVID-19 on wildlife (or more specifically the lack of humans on wildlife) has been a prominent topic of research since 2020[240–243]**, including in marine environments**[244–248]. Of particular interest is the studies that focus on the effects of COVID-19 on fishing activities, fishers' livelihoods, food security and fish stocks/overfishing. In coastal communities in Kenya, fish trade and fisheries livelihoods were greatly disrupted; a loss of income and livelihoods, reduced cash flow, declining food security, and impacts on wellbeing[249]. In Bangladesh, illness, reduced income, labour crisis, complexity in food supply and low consumer demand were identified as some of the primary affecting drivers[250], although an increase in fish stock occurred due to less disturbance from fishing activities [251]. Four different studies [252–255] reported widespread and general decrease in fishing activities, with great economic but also psychological consequences for the communities[256]. In Davao, the impacts of COVID-19 restrictions on fishers and their families were high due to the lockdown policy imposed in the fishing villages during the earlier phases of restrictions by the government. The study also highlighted a **lack of mobility, food inadequacy, travel restrictions and their children's education for the fishers and their families**. **Fishing activity in Davao was greatly reduced during the initial lockdown, but resumed shortly after restrictions were lifted in approximately June 2020**[252].

"...A lack of monitoring and enforcement of shared stocks [during the pandemic] may encourage some states to revert to a less responsible level of management, monitoring and control of fishing operations..." - FAO[275]

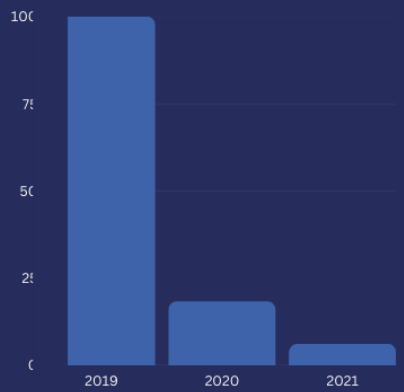
Coronavirus has also hugely affected Marine Protected Areas. International travel restrictions leading to **reduced visitor revenues in MPAs** in some areas lead to **budget shortfalls** for MPAs, causing the suspension of essential management activities and staff redundancies[257]. Benefits of reduced visitation were also recorded, with reports of **reduced pollution and a boost in fish numbers**, but perhaps less dramatic than expected[258]. Increased fishing pressures have been recorded in many areas[257], including where **people return to subsistence livelihoods;** people who lost livelihoods from tourism had to rely on fishing[259] (see below for how COVID-19 affected tourism in the Philippines). **Public compliance to restriction measures** also changed over time[258] and location (**increased illegal fishing in more rural areas** but regulations nearer urban areas continuing to be respected)[259]. Increases in illegal fishing have been observed[258], including within MPAs (e.g., Kenya, Indonesia, Seychelles and Australia[260]) but also in terms of destructive fishing practices[259]. Increased coastal populations as people return from urban areas may have also confounded impacts to nearshore fisheries and MPAs[259].

Fig. 41. *Face mask found on reef edge in Dauin.*

The impacts of the above on the Dauin inshore reef ecosystem are difficult to quantify, mostly due to a lack of information/reporting. It is possible the lack of COTS culling activities at Masaplod Sur during the pandemic allowed for the severe outbreak of COTS seen in 2022 (see below). The reef fish community composition has not changed significantly since 2019, suggesting the global pandemic had no detrimental impact on specific fish species in Dauin, but the total abundance of reef fish has declined since 2020, potentially as a result of increased fishing pressure or reduced enforcement of MPA regulations due to COVID-19. Nonetheless, the COVID-19 pandemic has clearly highlighted the importance of sustainable and rigorous management of Marine Protected Areas. This includes supporting the *effective* management of MPAs, reducing illegal and destructive fishing practices, and investing in sustainable tourism and alternative livelihoods for communities.

TOURISM IN THE PHILIPPINES

Before the global pandemic, the tourism industry was one of the key contributors to the sustained growth of the Philippine economy.



Income from "travel services" declined by 81.7% from 2019 to 2020, and a further 66.5% from 2020 to 2021.

TOURISTS

2019: 8.3 million tourists
2020: 1.5 million tourists
2021: 163,879 tourists

TOURISM EMPLOYMENT

2019: 5.7 million people
2020: 4.7 million people

After 11 years of consecutive growth, the tourism direct value added (TDGVA) declined by 61.2% to P973.3 billion in 2020 from P2.5 trillion in 2019. TDGVA as a percentage of gross domestic product (GDP) at 5.4% in 2020 is the lowest in 20 years.

Source: https://cpbrd.congress.gov.ph/images/PDF%20Attachments/Facts%20in%20Figures/FF2021-81_Impact_of_Covid-19_Crisis_on_the_Tourism_Sector.pdf

Asia and the Pacific suffered the largest drop in international arrivals at -84% (followed by Middle East and Africa (-75%), Europe (-70%) and the Americas (-69%))

Source: https://www.bsp.gov.ph/Media_And_Research/Publications/EN22-02.pdf

The Philippines was among the first countries to go on a lockdown in March 2020 and resorted to stricter restrictions, known as "Enhanced Community Quarantine" (ECQ).

The Philippines reopened its borders to vaccinated foreigners in February of 2022. Foreign tourists in Negros Oriental rose from 532 in 2021 to 1,954 in just the first half of 2022 (Jan - Jun). Dauin had the highest number of tourists out of all local government units in Negros Oriental, with 1,352 foreign tourists.

Source: https://www.pna.gov.ph/articles/1183874

COTS OUTBREAK AND RECOVERY

Crown Of Thorns Sea Star: Outbreak and Recovery

Masters Project: Coral loss caused by an outbreak of Crown-of-thorns sea star (*Acanthaster planci*) at a shallow reef in Dauin, Philippines

Leo Andreas Viktor Arleborg, Stockholm University

Coral reefs face many threats as human-induced global changes compile and one of those is the increased frequency of local population surges of the coral-eating crown-of-thorns sea star (COTS). Management of COTS outbreaks are usually done by culls through vinegar injection, reducing local population numbers quickly. How do feeding rates, coral loss rates and COTS behaviour change in an outbreak where culls are ongoing? This project studies this by tracking COTS numbers, position, live coral and changes over time on 40 coral colonies in a reef with an active outbreak in Masaplod Sur MPA in Dauin, Philippines.

Fig. 42. Example of COTS exhibiting outbreak behaviour, with 9 individuals per colony

In 45 days, COTS were responsible for a 33.9% loss in coral cover, 24.0% of which was in the first 17 days before the first cull. Coral loss rates averaged 333.8 cm^2 day^{-1} colony^{-1} before the first cull took place, then 76.76 cm^2 day^{-1} colony^{-1} when culls were done weekly. A total of 712 COTS were found, mostly underneath corals. Culling was proven effective in decreasing numbers found up to a week after culls, and COTS were more likely to hide after first cull. Coral loss due to COTS does not differ after first cull and COTS aggregating does not lead to higher predation rates but COTS predation rates were found to increase slightly after first cull. Feeding rates are similar to previously recorded in earlier studies. The COTS population in this outbreak has likely been feeding on corals for 3 years.

Methods deployed in this project are easy to deploy in lesser funded marine conservation projects as little specialised material is needed. Culls by vinegar injection are effective in decreasing but do not stop coral loss entirely, it is likely the most suitable action when an outbreak is ongoing as it decreases coral loss and prevents COTS aggregation and subsequent reproduction, protecting neighbouring reefs from new outbreaks.

Fig. 43. *One of the tagged colonies at days 3, 14, 21, 39 (left to right) and graph of same colony area affected vs time (culling began on day 17 on vertical dotted black line)*

IMR Continuation of COTS research

Outbreaks of COTS are one of the most destructive disturbances on coral reefs[5], causing mass coral mortality, long-term changes to community structure[197,198], reef structural complexity collapse and declining biodiversity and productivity[199,200]. A corallivore 'outbreak' is commonly described as "brief episodes of unsustainably high densities"[201], or "increases (often rapid) in their abundance above threshold densities that can be sustained by local coral assemblages, which in turn depends on the abundance and turnover of coral prey"[202]. Pratchett *et al.* summarised the variability and subsequent difficulty in defining COTS outbreak thresholds, as well as the importance in defining thresholds for management actions[203]. As such, a threshold for an 'outbreak' must be defined according to local conditions. COTS are highly fecund with enormous reproductive potential[205], small changes in recruitment may be enough to initiate outbreaks[201]. Additionally, post-settlement survival of COTS is highest in relatively shallow waters, obliquely exposed fore reef habitats and areas with high coral rubble cover[206]; parts of the Dauin coastline closely match this description.

Causes of rapid increases in COTS population densities have been debated for over 50 years[261], including as a response to 1) natural disturbances[204], 2) nutrient enrichment[203] and 3) predator removal[203]. This lack of knowledge will have severely hampered the implementation of effective management approaches[261]. Recent research from the Great Barrier Reef has found that fish biomass removal through commercial and recreational fisheries may be a major driver of COTS population outbreaks[261], systematic increases were recorded in COTS densities with increasing fish biomass removal, including for known COTS predators. Furthermore, the biomass of fish species and families that influence COTS densities were 1.4 to 2.1-fold higher in no-take marine reserves, while COTS densities were 2.8-fold higher on reefs open to fishing. This research also finds coral reefs with intact predatory fish assemblages can contribute to restricting COTS densities and outbreak size and frequency. The above all clearly demonstrate the applicability of targeted fisheries-based management to prevent COTS outbreaks[261] and effectively reduce their detrimental impacts. In Dauin, COTS outbreaks are only seen at Masaplod Sur, which is the area with the lowest total fish abundance and biomass along the Dauin coastline (fig. 32).

Research into the efficacy of mitigation techniques for COTS outbreaks examined; water quality improvements, MPA zoning and manual control, finding that manual control was the most direct (and only effective) means of reducing COTS densities and improving hard coral cover [262]. Repeat visits improved these results[262]. Manual control also skewed the population size structure towards smaller, less damaging individuals, in doing so also allowing recovery of hard coral cover, thereby directly achieving the ultimate goal of COTS control[262]. IMR effectively managed the severe COTS outbreak seen in the shallow reef at Masaplod Sur (outside of our DLTRMP survey area) in 2022 using manual control in the form of injections of household vinegar (which has proven to be an effective culling method without damaging the reef[263]) (fig. 44). During the height of the outbreak, many COTS were seen on the top of large tabulate *Acropora* colonies (fig. 42), whereas now the remaining COTS population are highly cryptic deep within branching corals, also with a much higher proportion of juveniles.

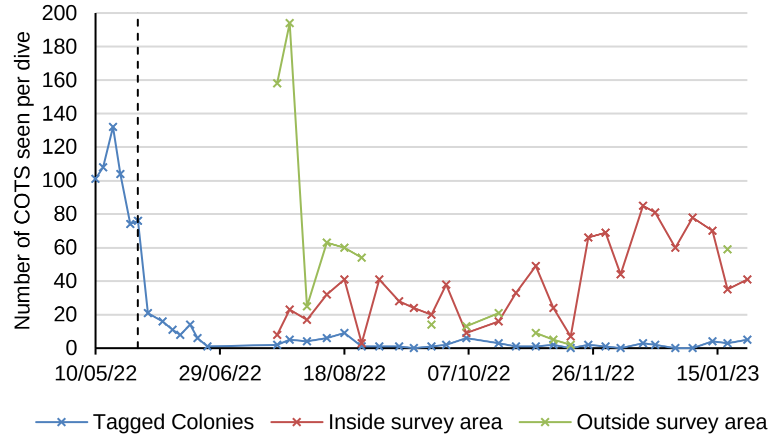


Fig. 44. Number of COTS seen per dive on tagged colonies for the above research project, within the survey area of which those tagged colonies exist, and outside of this survey area. Culling began on 27/05/22 (vertical dashed line). *NB: numbers fluctuate as a result of number of divers per dive.*

Juvenile COTS are herbivorous[264], undergoing ontogenetic shifts to a coralline diet after approximately 13-15 months[265]. Unfortunately, juveniles are highly plastic and resilient to food scarcity, with the ability to 'pause' their growth in the absence of coral and remain physiologically viable on an algal diet for years, in doing so delaying the herbivory–corallivory ontogenetic transition[266]. This may allow cohorts of herbivorous juveniles to accumulate in the reef infrastructure for at least 6 years and likely longer, although with high juvenile mortality (99% between ages 8 and 23 months) other factors such as predation, disease and rough seas can reduce this[266]. In Dauin, including Masaplod Sur, conditions are mostly calm (reference abiotic data sheet on sea state although surveys are maybe skewing this). This coupled with the reduced fish population at Masaplod Sur could promote the survival of these cryptic juvenile COTS, which we are unable to manually control. IMR therefore suggests reducing the fishing pressure at Masaplod Sur, along with continued culling efforts, to manage the particularly high COTS populations at this one location along the coast.

IMR is also researching the post-outbreak recovery of the reef at Masaplod Sur, at both the individual colony and reefscape level. For individual colony recovery, we hope to track the regeneration and skeletal linear extension of COTS feeding scars. At the reefscape level, we are looking at the successional process on dead coral colonies, as well as recruitment success on this newly available substrate (number of recruits settling, diversity, survival and growth).

FUNCTIONAL RESTORATION AND GROWTH STUDIES (FRAGS)

FRAGS (Functional Restoration And Growth Studies)

Dauin presents the optimal case study to determine the reseeding potential of artificial reefs in recruitment poor locations. Three artificial reef sites can be found along the Dauin coastline, comprised of varying structure types, materials and complexities. Due to the recent super typhoon, whole colonies have been uprooted from their base and are undergoing breakage, scouring and burial due to their inability to reattach to the unstable reef substrata. This project will utilize these susceptible corals (Corals of Opportunity; COPs) by reattaching their fragments to various artificial structures. Using artificial structures to transplant COPs (rather than suitable natural substrate) ensures space availability for incoming larvae, which is essential for maintaining site resilience.

In 2022, IMR began work into our FRAGS project. Key research questions of this project are:

1. What factors promote the post-settlement survival of fragments onto artificial structures?
2. How do corals life history traits affect fragment survivorship and growth rates?
3. How do ecological variables affect fragment survivorship and growth rates?
4. How does the planting of fragments onto artificial reef structures affect the reef fish community and over what period do these changes to occur?
5. Can the outplanting of COPs facilitate larval settlement due to changing chemical cues and 3-dimensional structure?
6. How long after out-planting fragments is sexual maturity reached, and do any of the above variables affect this?

The Lipayo artificial reef site in Dauin has been selected for this study. The various artificial structures were deployed between 2007 and 2016, most of which have low to no coral cover (including the large cages and bar pyramids. However, there are a few structures that have relatively high coral cover (cement pyramids and tyre clusters). For more information on our FRAGS project, view our Project Proposal on our website.

Fig. 45.: top) artificial reef structure (cage), and bottom) planted fragments 12 weeks after planting*, showing signs of linear extension over the cable tie used to secure them to the structure.*

Our first step in this project including planting 73 fragments on two different structure types at the Lipayo artificial reef site. Reported here are preliminary findings on survivorship, 12 weeks after planting. Total survivorship after 12 weeks is down to 40% (fig. 47). Notable causes of death are detachment of fragments from the structure and aggressive sponge competition (*Clathria spp.*). **Detachment will be reduced by continuing trials with the epoxy mix.** The *Clathria* genus contains approximately 350 species and has been observed growing over and subsequently killing living coral colonies[267–270]. Interestingly, *Clathria venosa* has been identified as an indicator of urban pollution[271]. To reduce mortality as a result of this sponge competition, we will **increase the distance between this sponge and where the fragments are planted** (for smaller structures like cement bells, none of the bell will be used if there is any *Clathria spp.* present). Two fragments close to each other on the deep cage were overgrown by an ascidian identified as *Diplosoma listerianum*[272], which is found globally from temperate to tropical waters[273]. Whether this encrusting compound ascidian killed the fragments or just colonised already dead bare skeleton is unknown.

Initial survivorship is higher in *Pocillopora* fragments than *Acropora* and *Stylophora* (fig. 48, although much fewer *Stylophora* fragments were planted overall, so a loss of 1 individual has a much greater effect on survivorship percentage). Both planting locations show a similar overall trend of decline in survivorship (no significant difference, Kaplan-Meier, p=n.s, fig. 49), but by week 12 survivorship at the cages is 44%, whereas the bells is at 32%. Sponge competition is the primary cause of death on the bells (although it is also present on the cages), and detachment is primary cause of death on cages.

IMR hopes that this research initiative will provide a best practices handbook on coral "fragging" to replenish damaged reefs, including empirical results on both operational and biological variables that improve survivorship and growth. We also hope to create donor larval sites by increasing coral cover on these artificial structures, in turn increasing larval availability and recruitment throughout Dauin's reef system.

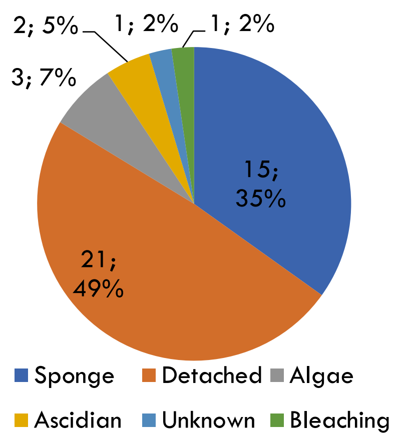


Fig. 46. *Cause of death for fragments of all genera and planting location at week 12. Data labels show total number and percentage.*

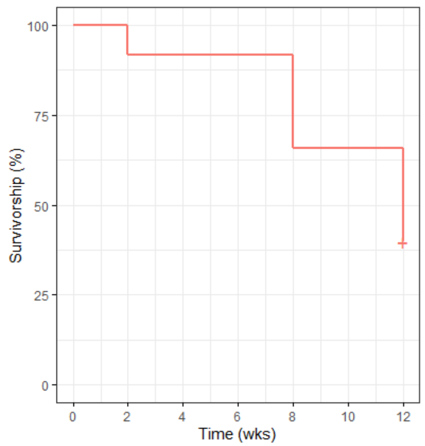


Fig. 47. *Kaplan-Meier survival curves of all fragments planted (n = 73) from week 0 (planting) to week 12 (latest assessment), with all genera and planting location.*

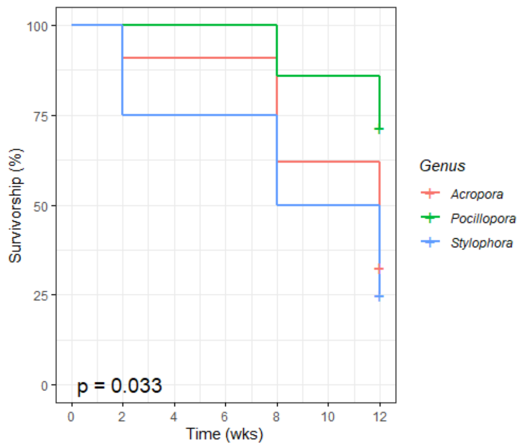


Fig. 48. *Kaplan-Meier survival curves of fragments from week 0 (planting) to week 12 (latest assessment), separated by genus. Genera do not have the same survival probability (p<0.05). Acropora n = 55, Pocillopora n = 14, Stylophora n = 4.*

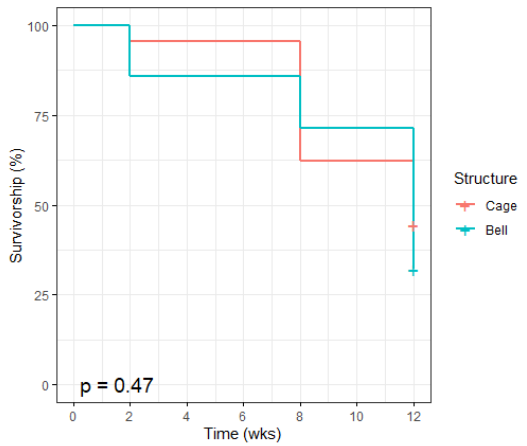


Fig. 49. *Kaplan-Meier survival curves of fragments from week 0 (planting) to week 12 (latest assessment), separated by planting location. Groups have the same survival probability (p>0.05). Cage n = 45, Bell n = 28*

MANAGEMENT ACTIONS

1. Readdress the conservation goals of the Lipayo, Masaplod Norte and Masaplod Sur marine reserves as a result of the continued recordings of fishing line and the destructive muro-ami fishing technique.
2. Tighten enforcement on Poblacion District I, Lipayo, Maayong Tubig, Masaplod Sur and Masaplod Norte marine reserves due to the presence of "Vulnerable" and "Near Threatened" IUCN Red Listed species.
3. Encourage the Dauin-wide protection of the vulnerable Orange spotted filefish and Brown-marbled grouper, as well as the near threatened Bluespotted ribbontail ray, Bower's Parrotfish and Yellow-tail Parrotfish.
4. Improve management of the sources of trash (both general and fishing) through community engagement and education, and work towards the provisioning of infrastructure to reduce littering (bins and regular trash collection), particularly in Lipayo, Bulak, Maayong Tubig and Masaplod Norte.
5. Continue COTS culling efforts at Masaplod Sur, as well as reduce fishing pressure in the area to promote post-outbreak recovery and reduce the likelihood and severity of future COTS outbreaks.
6. Use spatial water quality data (particularly nutrient loads) to manage wastewater outfalls at necessary locations along the Dauin coastline, particularly with regards to coral disease prevalence.
7. Reduce fishing pressure on herbivores, particularly a) large-bodied browsers (rabbitfishes, unicornfishes) and scrapers (parrotfishes), and b) particularly at Bulak and Lipayo.
8. Reduce fishing pressure on the commercially important 1) two-spot banded snapper (L. biguttatus), 2) moon wrasse (T. lunare) and 3) saw-jawed monocle bream (S. ciliata), to encourage the return to size distributions with even proportions of adults to juveniles.

FUTURE RESEARCH

1. Deepen the understanding of the capacity for this reef ecosystem to absorb recurrent disturbances and adapt to change whilst maintaining ecosystem functions.
    a. Quantify coral larval supply, settlement and survival to determine limiting factors on reef recovery, as well as the factors influencing these e.g., prevailing currents, availability of suitable substrate, predation pressure and benthic competition,
    b. Explore research techniques to examine subsurface, cryptic rubble stabilisation,
    c. Monitor the influence of repeated disturbances and rubble mobilisation on rubble stabilisation,
    d. If required, assess environmental impact of artificial substrate stabilisation techniques.
2. Determine the causes of fish population decline in Dauin; is this a response to increased pressure from coronavirus and will the populations begin to recover, or is this a long-term trend of overfishing/ecosystem collapse?
    a. Does the size of Dauin's MPAs influence this; should MPAs be redesignated to consider buffer zones, habitat and genetic connectivity and home ranges of fishes with the need for greater conservation efforts.
3. Monitor water quality to determine:
    a. suitability of conditions for coral growth,
    b. nutrient loading and/or seasonal changes as potential drivers of rapid algal growth,
    c. if sewage outfall/wastewater/runoff is responsible for the spatial distribution and severity of Porites Ulcerative White Spot,
    d. the impacts of seasonal changes on bleaching severity,
    e. the hydrodynamic forcing at sites with high rubble cover to determine potential limitations of natural reef recovery,
    f. its impact on cyanobacteria fluctuations.
4. Determine drivers of rapid algal growth (e.g., nutrients, lack of herbivores) and continue to monitor increase trajectory; are we observing natural

succession which will in turn make way for new coral settlement and growth, or are we witnessing phase shifts to algal-dominated systems?

5. Quantify possible interspecific benthic competition between *Anacropora spp.* and rope sponge at Masaplod Sur.
6. Determine the applicability/validity of AI software for benthic composition analysis.
7. Examine the causes of direct destruction along the Dauin reef (anthropogenic or natural), in order to develop effective management actions and advice for the community to reduce damage to the reef.
8. Continue to monitor the presence of Porites Ulcerative White Spot along the Dauin reef, to determine if high prevalence leads to high mortality.
9. Examine the niche partitioning and diet compositions of Dauin's facultative herbivores to identify any functional roles within herbivores that are lacking.
10. Quantify the impact (if any) of lacking herbivores in Dauin on algae cover; is there a way to determine historic populations of herbivores? Can we increase protection of herbivorous fishes, or will that have detrimental effects on fishing community livelihoods?
11. Monitor any changes in Drupella spp. feeding preferences and potential drivers of these changes. Gather information on their baseline populations in Dauin (non-outbreak/aggregating populations), in order to quantify synergistic effects of other impacts.
12. Monitor the size structure of more commercially important reef fish species within the Dauin inshore reef to determine their species-specific reproductive potential. Continue to monitor size distributions of those suggested above (Management Action 7) with regards to effective management.
13. Explore the relationships between different stressors (impacts) in Dauin, determine any synergistic/ antagonistic interactions, and the effects of these multiple stressors on the subsequent susceptibility of corals to further impacts and therefore the resilience of the reef to future disturbances.
14. Further our knowledge on bleaching susceptibility and severity/mortality, particularly in regard to local water temperature thresholds for different genera, as well as quantifying the effects of nutrients e.g. nitrogen on bleaching.

METHODS & STATISTICAL ANALYSIS

For details on data collection methodology please refer to our 2020 Outlook Report. Fish biomass calculated as $W=aL^b$, where W is weight (g), L is fish length (cm), and a and b are species-specific allometric constants obtained from FishBase[19]. The genus mean was used when allometric constants for a specific species were not available. For points (where length measurements were not possible), the mean length for the species recorded across all depths and survey sites was used. Where fish were unidentifiable to species level (small size, blurry etc.), entries of family/genus were included in abundance data, but not in diversity or biomass data, as no suitable allometric constants were available. Length at first maturity of all fish species (where available) were obtained from FishBase[19]. For testing changes in CIS lengths, all lengths were log transformed to achieve normal distributions.

For community composition analysis, distance matrices were calculated using the Bray-Curtis method (with function vegdist in the R package 'vegan'). Linearity and homogeneity of variance assumptions were checked using metaMDS stressplots and betadisper function in the R package 'vegan'. ANOSIMS were completed using relative species matrices (decostand function in the R package 'vegan', method=total, dissimilarity = Bray Curtis, 9999 permutations) to test for significant differences between environmental variables. Generalized additive models (GAM) were used to examine the changes in coral and algae percent cover over time (years) and different survey sites (included as random effects with random intercept and smooth function). Function gam.check function (in R package 'mgcv') was used to check model fit. Autocorrelation (AR1) was included in both models.

A Generalized Linear Mixed Model (GLMM) was used ('glmmTMB' package in R) to investigate the relationship between the environmental variables and algae cover; a negative binomial distribution with zero-inflation and a log link function was specified for the response variable due to overdispersion. Fixed effects included time (categorical in the form of chronological survey season codes), mean monthly air temperature, mean monthly precipitation, depth (categorical 5 or 10m) and barangay. The model included a nested random effect term for a) site nested within depth, and b) site nested within barangay, with random intercepts and random slopes at the site level, also with an autoregressive correlation structure (AR1). Hierarchal regression was used to achieve the minimum adequate model (MAM) using AIC ranks and ANOVAs to test for significant differences in the fit of the models.

A GLMM was used ('glmmTMB' package in R) to investigate the relationship between environmental variables and bleaching frequency; a negative binomial distribution was specified for the response variable due to overdispersion. Fixed effects included time (categorical in the form of chronological survey season codes "LTC"), mean monthly air temperature, mean monthly precipitation, depth (categorical 5 or 10m) and coral cover. Hierarchal regression was used to achieve the minimum adequate model (MAM) using AIC ranks and ANOVAs to test for significant differences in the fit of the models.

A GLMM was used ('glmmTMB' package in R) to investigate the relationship between environmental variables and total fish abundance; a negative binomial distribution was specified for the response variable due to overdispersion. For herbivore abundance, the same variables were used but with gaussian distribution on log transformed abundance data. Fixed effects included time (year and month), mean monthly air temperature, mean monthly precipitation, hour of survey, depth (categorical 5 or 10m), tidal state and height, sea state, and coral, algae and sponge cover. Random effects were included (survey site). Hierarchal regression was used to achieve the minimum adequate model (MAM) using AIC ranks and ANOVAs to test for significant differences in the fit of the models.

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