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Similar coral cover but contrasting benthic and fish communities in a fish sanctuary and a reef next to a marble quarry in Romblon Island, Philippines

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Abstract

Marble quarrying on Romblon Island, Philippines, produces fine particulates and slurry near the shore, but to our knowledge its effects on nearby coral reefs have not been documented. In 2021, we compared a reef next to a marble quarry in Barangay Cajimos (Quarry reef) with a reef inside the Agtongo Fish Sanctuary (Sanctuary), about 1.2 km away. We photographed five benthic transects and counted reef fish on one belt transect per site. Hard coral cover was similar (20.6 ± 3.2% at the Quarry reef, 19.1 ± 2.9% at the Sanctuary), and both fell in hard coral cover Category D. The reefs differed in most other respects. The Quarry reef had four times more macroalgae (22.0 vs 5.2%), more dead coral with algae, and the only recently dead coral, while the Sanctuary had more rock and sponges. Benthic and coral species composition also differed (permutational multivariate analysis of variance, $p = 0.008$). The Sanctuary supported 31 fish taxa against 13, with 7.5 times the fish density and about four times as many roving herbivores. Coral cover alone would rank the reefs as equal, but the algae, dead coral and fish data show the Quarry reef in poorer condition in 2021. Quarry

sediment and reduced grazing are possible causes. Neither could be tested, because sedimentation was not measured and each condition had a single site, so the results are a two-site baseline. We recommend continued protection of the sanctuary, control of quarry runoff, and monitoring of sediment and turbidity.

Keywords: coral reef condition, macroalgae, marble quarrying, marine protected area, reef fish, sedimentation

Introduction

Coral reefs supply fisheries, shoreline protection and many other goods and services to coastal communities (Moberg & Folke, 1999). The Philippines lies at the center of marine shore fish diversity in the Indo-West Pacific (Carpenter & Springer, 2005), yet its reefs have been in decline for decades. National assessments since 1981 have placed most Philippine reefs in the fair or poor categories of live coral cover (Gomez et al., 1981, 1994), and the most recent nationwide survey found the same pattern (Licuanan et al., 2019). Licuanan (2020) has since proposed new categories for the Philippines that are based on hard coral cover alone and use letter grades in place of terms such as poor and fair. Across the Coral Triangle, more than 85% of reefs are threatened by local stressors, including pollution from land and sea (Burke et al., 2012).

Sediment is among the most damaging of these land-based stressors. Increased sedimentation and turbidity reduce coral growth, survival and recruitment and tend to favor a few stress-tolerant species (Erftemeijer et al., 2012; Fabricius, 2005; Rogers, 1990). Sediment settling on corals smothers their tissue, and the damage is greatest for fine sediment rich in organic matter, which fuels microbial activity at the coral surface (Weber et al., 2006, 2012). Suspended sediment also cuts the light that corals need, separately from its effects on tissue (Bessell-Browne et al., 2017; Jones et al., 2016). Dredging, coastal construction and other

activities that disturb sediment can raise these loads well above natural levels (Erftemeijer et al., 2012). Romblon Island has an established marble industry, and quarrying and processing of marble generate large volumes of fine particulates and slurry (Senoro et al., 2022). To our knowledge, the condition of reefs next to marble quarries on Romblon Island has not been documented.

Live coral cover is the indicator most often used to rank reef condition, but on its own it can miss important change. Reefs with similar coral cover can differ in the amount of macroalgae and dead coral they carry and in the fishes that graze them. Macroalgae compete with corals through shading, abrasion and chemical effects (Jompa & McCook, 2003; McCook et al., 2001; Rasher & Hay, 2010), and herbivorous fishes keep algae in check (Bellwood et al., 2004; Hughes et al., 2007). Where grazing declines or nutrient and sediment inputs rise, reefs can move toward algal dominance that is hard to reverse (Graham et al., 2015; McCook, 1999; Mumby & Steneck, 2008), although complete shifts are less common than often assumed (Bruno et al., 2009). Surveys that combine benthic cover, coral composition and reef fish give a fuller picture of reef condition than coral cover alone.

Marine protected areas (MPAs) are the main tool for managing reef fisheries in the Philippines. No-take reserves generally hold higher fish density and biomass than fished areas (Lester et al., 2009), and well-enforced Philippine reserves have produced lasting gains in fish biomass (Russ et al., 2004). Their effects on corals are weaker and less consistent (Selig & Bruno, 2010; Strain et al., 2019), although protection can improve coral recovery after disturbance (Mellin et al., 2016). Many Philippine reserves are also small or weakly enforced (Weeks et al., 2010), and it is unclear how far protection can offset land-based stress on nearby reefs.

This study compared the reef at the Agtongo Fish Sanctuary with the Cajimos coral reef next to a marble quarry, both in Romblon, Romblon, Philippines. We used photo transects to

measure benthic cover and hard coral composition, and a fish survey to describe reef fish species, abundance and trophic structure. We asked whether the two reefs differed in hard coral cover, and whether macroalgae, dead coral, coral composition and fish showed differences in reef condition that coral cover alone would not reveal. Because each condition is represented by a single site, the study is a descriptive baseline for the two reefs, not a test of the effects of quarrying or protection.

Methods

Study sites

The study was conducted on the coral reef next to the marble quarry in Barangay Cajimos (hereafter Quarry reef) and within the Agtongo Fish Sanctuary in Barangay Agtongo (hereafter Sanctuary), Romblon, Romblon, Philippines (Fig. 1). The marble quarry is about 3 km from the Romblon town center. The Quarry reef lies directly seaward of the quarry, with the nearest quarry workings roughly 200 m inland, and the Sanctuary is about 1.2 km to the northeast in a straight line (both distances measured from Fig. 1). Reefs at both sites are shallow crests that end in a drop-off or wall toward deeper water. Both sites are exposed to strong currents whose direction changes with the monsoon season (*habagat* and *amihan*). The sites were selected after consultation with the local community and a preliminary assessment by the survey team on 2 March 2021. Benthic and fish surveys were conducted on 27–29 March 2021, during the *amihan* (northeast monsoon) season.

The waters next to the marble quarry are a major fishing ground for residents of Barangays Logbon, Agtongo, Alad, and Cajimos, who depend on them for food, income, and livelihood. The area is also a shipping route between Romblon and Cajidiocan and between Romblon and Manila, and both sites are used by recreational divers.

The Agtongo Fish Sanctuary covers 12.83 ha, where the entire area is a no-take zone managed by the Municipal Agriculture Office of the local government unit of Romblon. At the time of the survey, the marble quarry in Cajimos was active, and runoff and processing water reached the sea through direct runoff.

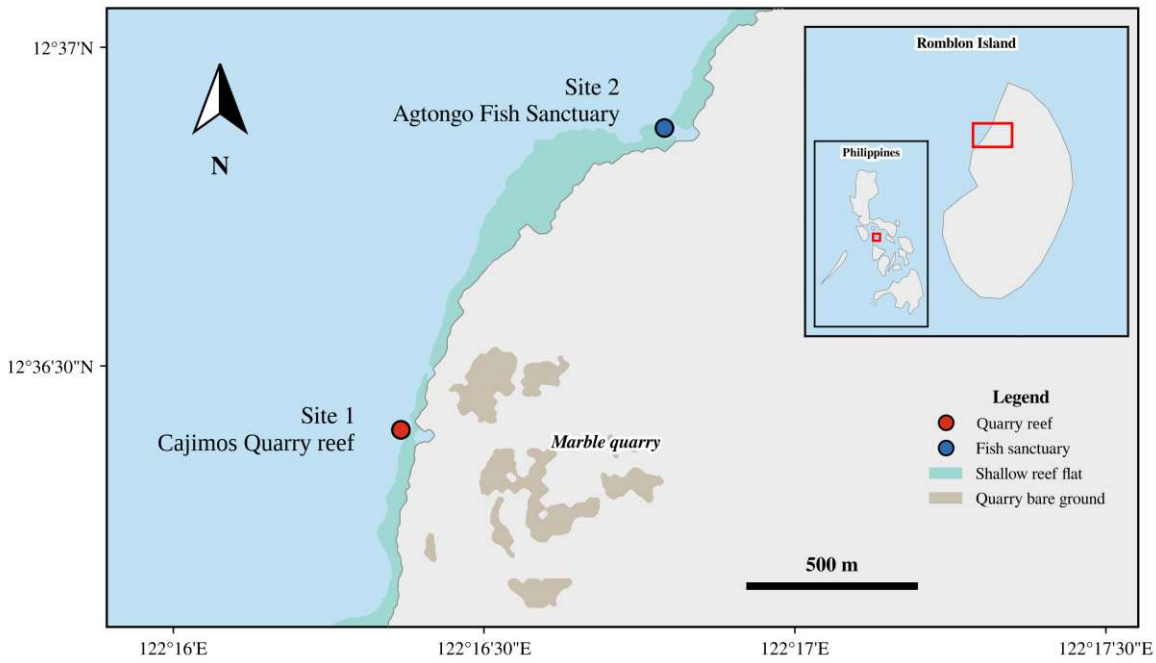


Fig. 1 The study sites at the Cajimos coral reef next to the marble quarry (Site 1) and the Agtongo Fish Sanctuary (Site 2), Romblon Island, Philippines. Coastline and quarry extent were traced from Maxar imagery (2021) via Google Earth. Coordinates are geographic (WGS 84)

Benthic assessment

Benthic communities were surveyed with the photo-transect protocol of Luzon et al. (2019). At each site, a 100 m main transect was laid parallel to the shore, and four 50 m replicate transects were placed at random vertical and horizontal distances from it, with the distances generated in spreadsheet software. The benthos was photographed with a camera mounted on a tetrapod. Fifty photographs from the main transect and 25 from each replicate transect were analyzed, giving about 150 photographs per site. The 100 m main transect is T1 at each site, and the replicates are T2 to T5. Transect depths ranged from 5–11 m at the Quarry reef and

115 3–8 m at the Sanctuary. Because T1 carried twice as many photographs, its cover is estimated
116 more precisely, but all transects estimate the same proportion, so they were treated as equal
117 replicates. Binomial mixed models fitted to the point counts, which weight each transect by
118 its number of points, gave the same conclusions for hard coral, macroalgae and abiotic
119 substrate (see Data analysis; Online Resource 2). The start and end coordinates of every
120 transect were recorded with a GPS unit. All dives followed the Professional Association of
121 Diving Instructors (PADI) safety standards cited in Luzon et al. (2019).

122 Photographs were analyzed in Coral Point Count with Excel extensions (CPCe) version 4.1
123 (Kohler & Gill, 2006), with 10 random points per photograph and a modified version of the
124 CPCe shallow coral code file. Each point was assigned to one of 12 major categories: coral,
125 gorgonians, sponges, zoanthids, macroalgae, other live organisms, non-living substrate,
126 coralline algae, dead coral with algae, diseased corals, unknowns, and tape, wand and shadow
127 (Online Resource 1). Points were also identified to subcategory where possible. Corals were
128 identified to genus or species and macroalgae to genus, non-living substrate was recorded as
129 pavement, rock, rubble, sand or silt, and dead coral with algae was split into dead coral with
130 algae, old dead coral, recently dead coral and dead gorgonian. Points on the tape, wand or
131 shadow were excluded from cover calculations. Hard coral cover was calculated from the
132 coral category after excluding hydroids, soft corals and sea anemones. Turf algae were scored
133 within the macroalgae category, and fleshy macroalgae (macroalgae excluding turf) were also
134 reported.

135 The two sites were annotated with slightly different versions of the code file (Online
136 Resource 1), and Sanctuary macroalgae were recorded only at the category level. Part of the
137 macroalgae at the Quarry reef was also left unidentified. The photographs were not re-scored
138 for this paper, so these differences are treated as a limitation in the Discussion. Corals were
139 identified using Coral Finder 2021: Indo-Pacific Coral Finder 4th edition (Kelley, 2021).

Because photograph-based identification of *Montipora* and *Acropora* to species is uncertain, coral composition was also analyzed at genus level.

Reef fish survey

Reef fish were surveyed by underwater visual census along a belt transect (English et al., 1997; Luzon et al., 2019). At each site, one observer (B. G. Mantes) swam slowly along a single 50 m transect, laid separately from the benthic photo transects, and recorded all fishes within 5 m on either side, giving a survey area of 500 m². The fish census was made on the same days as the benthic survey. Fish lengths were not available for this census, so fish biomass was not estimated. Each fish was identified to the lowest possible taxon, fishes that could not be confirmed to species were reported at genus or family level, and taxa were assigned to one of five trophic groups (herbivores, planktivores, benthic invertivores, piscivores and omnivores) from diet information in FishBase (Froese & Pauly, 2024). Piscivores included species that feed mainly on fishes or on fishes and large crustaceans. Taxa identified only to genus or family were given the group typical of that genus or family (Table 1). Densities are reported per 500 m² and per hectare.

Data analysis

Percent cover was calculated for each transect, and the transect was treated as the replicate (n = 5 per site), since photographs along the same line are not independent. Mean hard coral cover at each site and on each transect was classified with the hard coral cover (HCC) categories of Licuanan (2020): Category A (>44%), Category B (>33–44%), Category C (>22–33%), and Category D (0–22%). Differences between sites in each benthic category were tested with binomial generalized linear mixed models (GLMMs) fitted to the point counts, with site as a fixed effect and transect as a random intercept, using likelihood-ratio tests. GLMMs model proportions directly and weight each transect by its number of points

(Warton & Hui, 2011). They were fitted by maximum likelihood with 40-point Gauss–Hermite quadrature. As checks, we also ran Welch's t-tests on arcsine square-root transformed proportions and exact Mann–Whitney U tests. Holm correction was applied across the five main categories (hard coral, macroalgae, dead coral with algae, abiotic substrate and sponges); rock, sand, rubble and silt were treated as components of abiotic substrate and are reported unadjusted. The ratio of hard coral to macroalgae plus dead coral with algae was log-transformed before testing.

Community composition was compared with permutational multivariate analysis of variance (PERMANOVA; Anderson, 2001) on Bray–Curtis dissimilarities of square-root transformed cover, using all 252 possible permutations of the ten transects. Homogeneity of multivariate dispersion was tested with a permutational analysis of multivariate dispersions (PERMDISP; Anderson, 2006), and patterns were displayed with principal coordinates analysis (PCoA). The same procedure was applied to the relative abundance of hard coral species and repeated at genus level. Similarity percentages analysis (SIMPER; Clarke, 1993) was used to identify the benthic categories and coral species contributing most to the dissimilarity between sites. Hard coral diversity was described with taxon richness, the Shannon index (H′), Simpson's index (1−D) and Pielou's evenness (J′), and richness was compared at equal sampling effort by rarefaction (Gotelli & Colwell, 2001). Because each site had a single fish census, fish density and species counts were compared descriptively, and fish diversity was summarized with the Shannon index calculated from the counts. All analyses, including the GLMMs, PERMANOVA, PERMDISP, PCoA, SIMPER and rarefaction, were run with custom Python code built on the NumPy, SciPy, and pandas libraries.

Results

Benthic cover

Hard coral cover was similar at the two sites. It averaged 20.6 ± 3.2% (mean ± standard error [SE], n = 5 transects) at the Quarry reef and 19.1 ± 2.9% at the Sanctuary (GLMM, $\chi^2 = 0.13$, p = 0.72; Welch's t = 0.32, p = 0.76; Online Resource 2, Fig. 2). Transect values overlapped almost completely, ranging from 10.8 to 29.6% at the Quarry reef and from 12.9 to 29.8% at the Sanctuary. With soft corals and hydroids included, live coral averaged 21.4 ± 3.3% at the Quarry reef and 19.3 ± 3.0% at the Sanctuary. Both site means fall in HCC Category D (0–22%) of Licuanan (2020), although three transects (T1 and T2 at the Quarry reef, T1 at the Sanctuary) reached Category C (>22–33%).

The sites differed in what covered the rest of the reef. Macroalgae covered 22.0 ± 6.0% of the Quarry reef and 5.2 ± 0.4% of the Sanctuary (GLMM, $\chi^2 = 8.01$, Holm-adjusted p = 0.019), and every transect at the Quarry reef had more macroalgae than every Sanctuary transect (exact Mann–Whitney U = 25, p = 0.008; Holm-adjusted p = 0.040). The Welch test gave weaker support after Holm correction (adjusted p = 0.147; Online Resource 2) because cover varied widely among transects at the Quarry reef. Excluding turf, fleshy macroalgae averaged 18.8 ± 4.8% at the Quarry reef; turf was not separated at the Sanctuary. *Sargassum* (7.4 ± 3.1%), turf algae (3.2 ± 1.9%), *Turbinaria* (1.9 ± 0.8%) and *Padina* (1.8 ± 0.6%) were recorded only at the Quarry reef (Fig. 3). The remaining macroalgal cover there (about 8%) was scored as unidentified macroalgae. Dead coral with algae averaged 12.3 ± 5.7% at the Quarry reef and 1.8 ± 0.4% at the Sanctuary. The GLMM supported this difference ($\chi^2 = 5.45$, Holm-adjusted p = 0.039), but the rank and t tests did not (Mann–Whitney p = 0.22; Welch p = 0.11), because the difference came almost entirely from T1 (22.4%) and T2 (29.2%) at the Quarry reef. Its transects T3 to T5 instead had the highest macroalgal cover (29.6–35.8%), and these three transects held all of the *Sargassum* recorded in the survey

(10.0–15.0% per transect; Fig. 4). Recently dead coral was found only at the Quarry reef (0.7 ± 0.5%).

Abiotic substrate made up 69.5 ± 3.8% of the Sanctuary and 43.7 ± 3.3% of the Quarry reef (GLMM, χ^2 = 12.98, Holm-adjusted p = 0.002; Welch Holm-adjusted p = 0.005; Mann–Whitney p = 0.008), and all three tests agreed. Rock accounted for most of this gap, with 28.9 ± 2.2% cover at the Sanctuary against 5.9 ± 1.1% at the Quarry reef (GLMM p < 0.001; Mann–Whitney p = 0.008). Sand was higher at the Sanctuary (29.5 vs 21.1%) and rubble was higher at the Quarry reef (16.7 vs 10.4%); both differences were marginal in the GLMMs (p = 0.047 and 0.048, unadjusted) and not supported by the rank tests (p = 0.10 and 0.15). Sponges covered 3.9 ± 1.2% of the Sanctuary and 0.2 ± 0.1% of the Quarry reef (GLMM Holm-adjusted p = 0.025; Mann–Whitney p = 0.095). The ratio of hard coral to macroalgae plus dead coral with algae was 2.84 ± 0.44 at the Sanctuary and 0.61 ± 0.10 at the Quarry reef (p < 0.001).

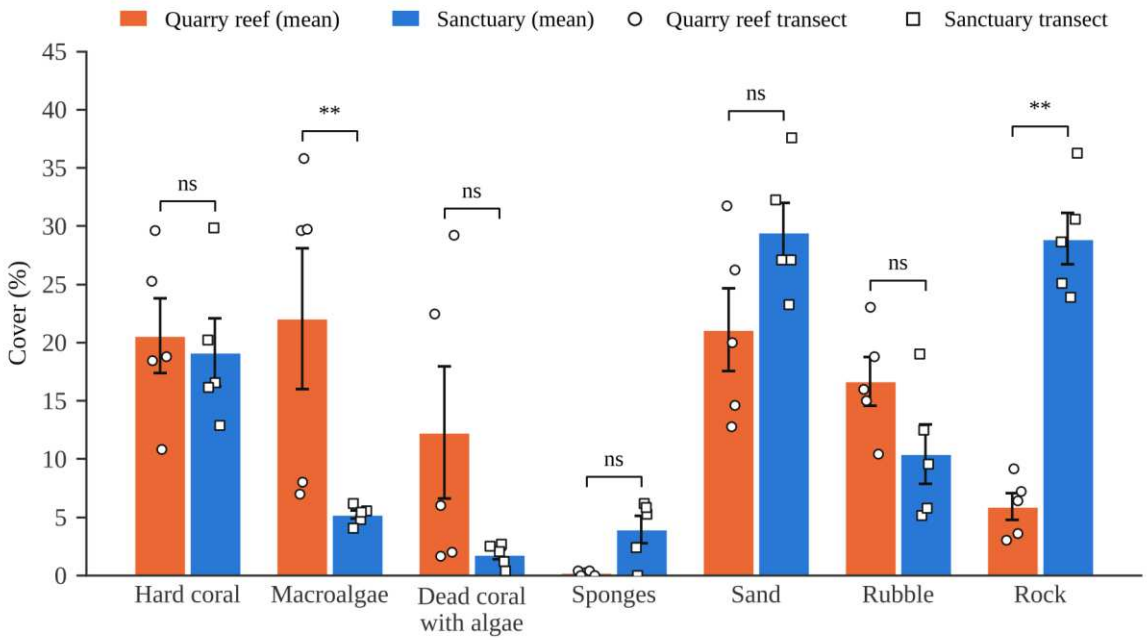


Fig. 2 Mean (± SE) percent cover of the main benthic categories at the Quarry reef and the Sanctuary (n = 5 transects per site). Bars are site means; open circles are individual transects

at the Quarry reef and open squares are individual Sanctuary transects. Symbols show exact Mann–Whitney U tests (unadjusted): ** $p < 0.01$; ns, $p \geq 0.05$. GLMM and Holm-adjusted results are given in Online Resource 2

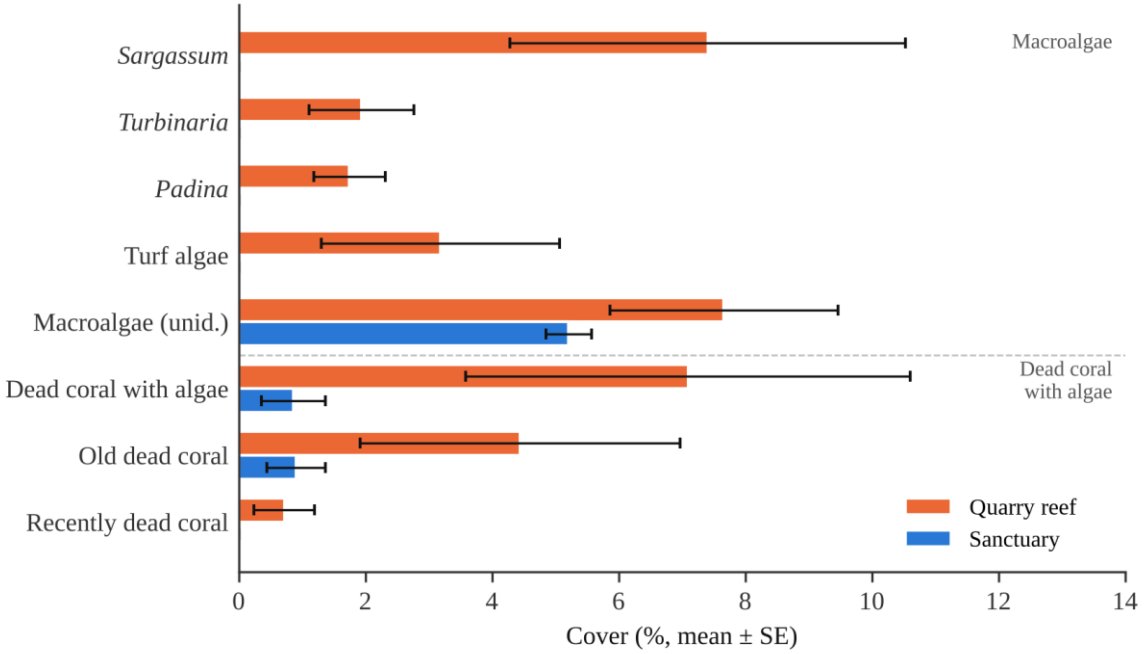


Fig. 3 Mean (± SE) percent cover of macroalgal taxa and dead coral subcategories. Sanctuary macroalgae were scored only at the category level (Macroalgae, unidentified), so the absence of genus-level bars for the Sanctuary reflects annotation and not necessarily absence of those taxa. At the Quarry reef, about 8% macroalgal cover was also scored as unidentified

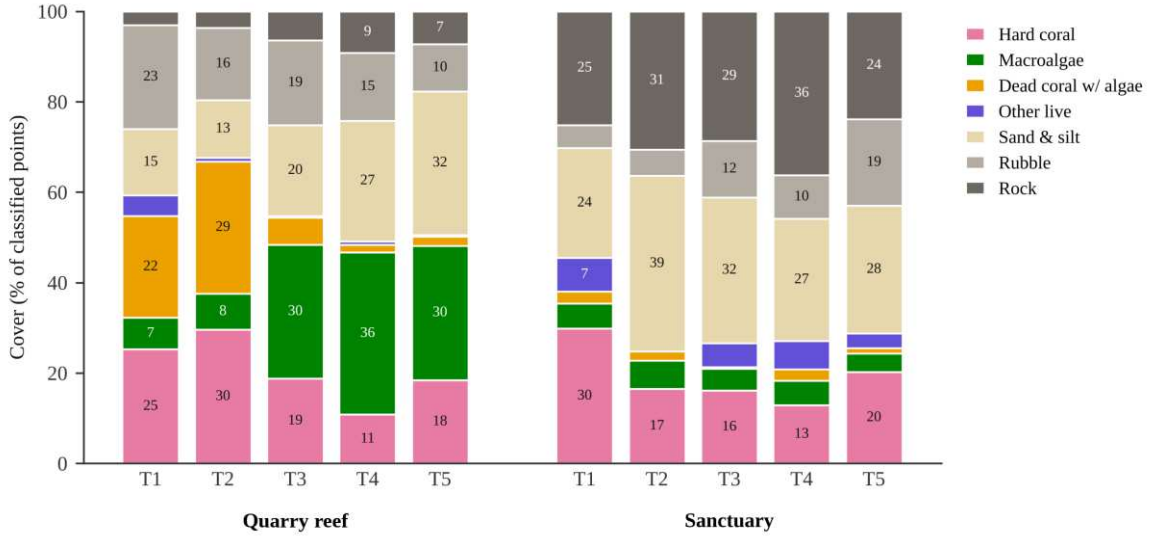


Fig. 4 Benthic composition of each transect, as percent of classified points. Numbers inside the bars are values of 7% or more

Benthic community composition

The overall make-up of the benthos differed between sites (PERMANOVA pseudo-F = 7.34, R^2 = 0.48, p = 0.008, 252 unique permutations; Online Resource 3). Site accounted for about half of the variation among transects. Multivariate dispersion did not differ (PERMDISP, mean distance to centroid 0.13 at the Quarry reef and 0.09 at the Sanctuary, p = 0.15), so the PERMANOVA result reflects a shift in composition rather than a difference in spread. In the PCoA ordination the two sites separated along the first axis, which explained 53.7% of the variation (Fig. 5a). The Sanctuary transects formed a tight cluster. Transects T1 and T2 at the Quarry reef sat apart from T3 to T5 along the second axis (29.2%), matching the split between dead coral with algae and macroalgae described above.

Average Bray–Curtis dissimilarity between sites was 27.2%. Rock contributed the most (22.2%), followed by macroalgae (16.5%), dead coral with algae (13.9%) and sponges (11.4%). Rubble and sand added another 15.9%, bringing the cumulative contribution to 79.9%. Hard coral contributed only 6.0% (Online Resource 4).

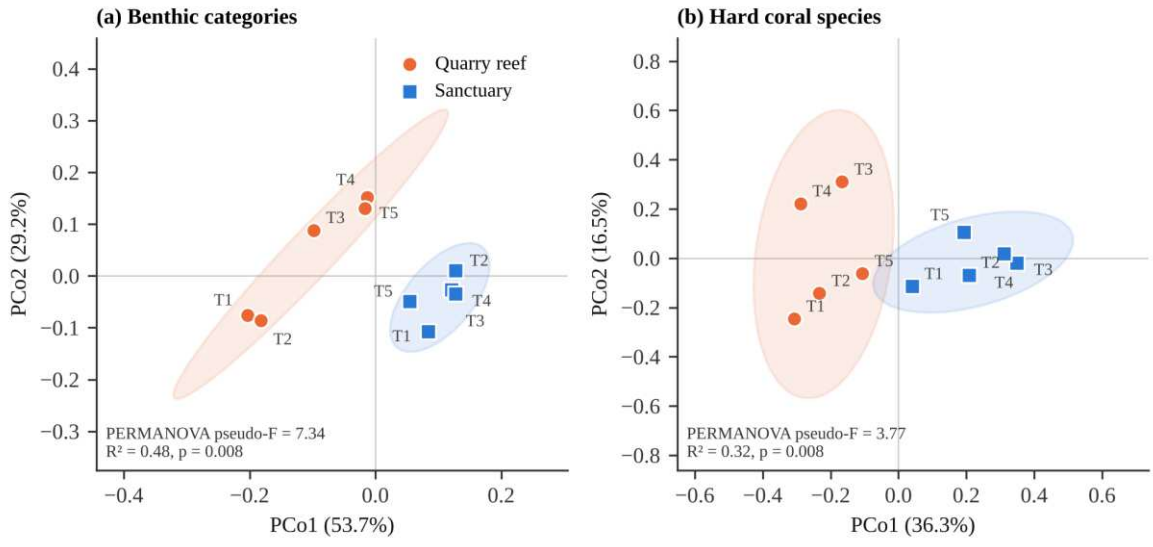


Fig. 5 Principal coordinates analysis (PCoA) of transects based on Bray–Curtis dissimilarity of square-root transformed data: (a) benthic categories, (b) hard coral species composition. Shaded ellipses are 95% confidence ellipses for each site

Hard coral assemblage

A total of 44 hard coral taxa from 24 genera were recorded. The Quarry reef had 36 taxa in 20 genera from 319 hard coral points, and the Sanctuary had 28 taxa in 16 genera from 306 points. Twenty taxa occurred at both sites, 16 only at the Quarry reef and 8 only at the Sanctuary. Rarefied to 306 points, richness at the Quarry reef was 35.5 taxa (95% CI 34.3–36.8), still above the 28 taxa at the Sanctuary (Fig. 6a), but richness per transect did not differ ($p = 0.84$), so the difference appears only in the pooled sample. The Sanctuary assemblage was more even (pooled Pielou $J' = 0.82$ vs 0.73; Simpson $1-D = 0.91$ vs 0.86), which gave it a slightly higher Shannon index ($H' = 2.75$ vs 2.62) despite fewer taxa. At the transect level none of the diversity measures differed between sites, although evenness came close (J' 0.75 ± 0.04 vs 0.85 ± 0.03, $p = 0.056$; Online Resource 5, Fig. 6b–d).

Montipora was the most common genus at both sites, making up 36.7% of hard coral points at the Quarry reef and 41.5% at the Sanctuary (Fig. 7). *Porites* (26.3 vs 12.7%), *Acropora* (10.7 vs 5.6%) and *Seriatopora* (4.7 vs 0.7%) were proportionally more common at the Quarry reef. *Echinopora* (0.3 vs 9.5%), *Heliopora* (3.4 vs 8.2%), *Pavona* (0 vs 7.5%) and *Turbinaria* (0.3 vs 4.6%) were more common at the Sanctuary (all values Quarry reef vs Sanctuary). Most *Porites* points at both sites were massive *P. lutea* (65% of *Porites* at the Quarry reef and 74% at the Sanctuary). At the Quarry reef, branching *P. cylindrica* and *P. nigrescens* made up a further 21% and 10% of *Porites* points. As a share of all hard coral points, massive *P. lutea* was almost twice as common at the Quarry reef (17.2 vs 9.5%).

Species composition differed between sites (PERMANOVA pseudo-$F = 3.77$, $R^2 = 0.32$, $p = 0.008$), with no difference in dispersion (PERMDISP $p = 0.69$; Online Resource 3, Fig. 5b). Average dissimilarity was 64.2%, and eight species accounted for 45.8% of it. *Pavona venosa* (8.0% of the dissimilarity), *Montipora confusa* (6.9%), *Echinopora horrida* (5.4%), *Heliopora coerulea* (5.0%) and *Turbinaria mesenterina* (4.2%) were more abundant at the

Sanctuary. *Montipora delicatula* (7.4%), *Porites cylindrica* (4.5%) and *Acropora divaricata* (4.4%) were more abundant at the Quarry reef. At genus level, composition also differed between sites (PERMANOVA pseudo-F = 3.14, R^2 = 0.28, p = 0.008; PERMDISP p = 0.69; Online Resource 3).

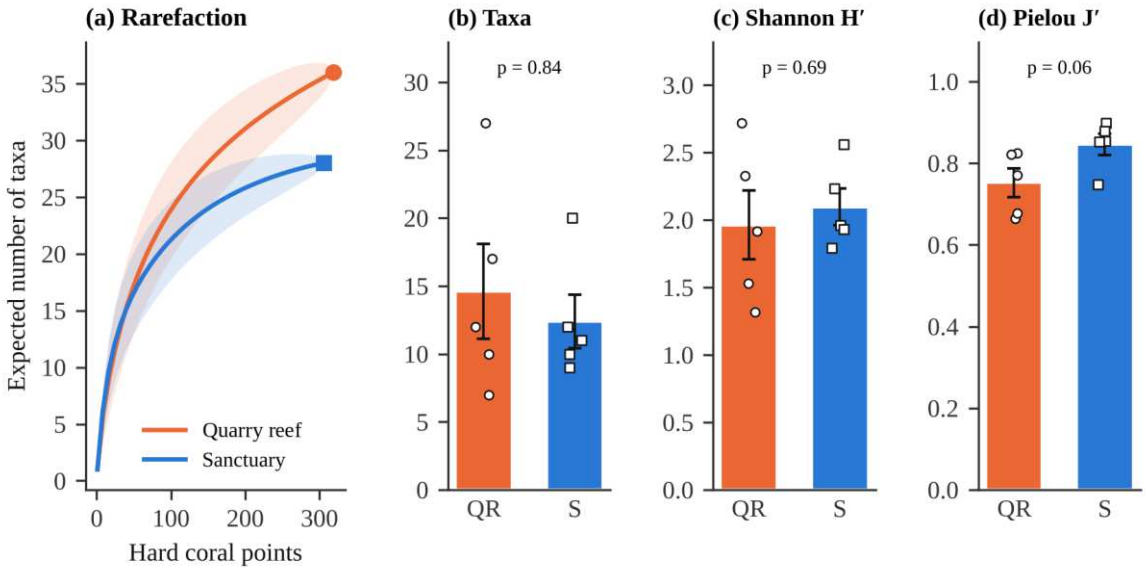


Fig. 6 Hard coral diversity: (a) rarefaction curves with 95% confidence bands; (b–d) number of taxa, Shannon H′ and Pielou J′ per transect (mean ± SE, open symbols are transects), with exact Mann–Whitney p values. QR, Quarry reef; S, Sanctuary

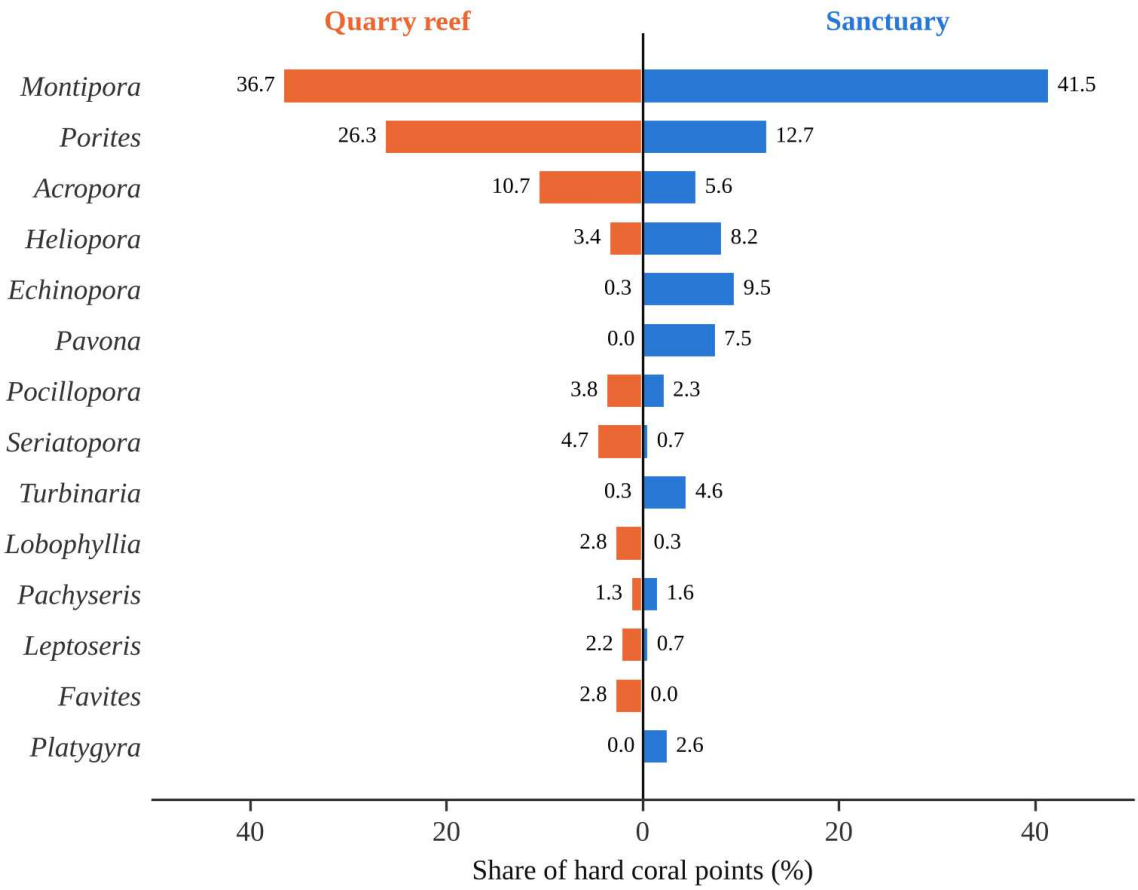


Fig. 7 Share of hard coral points by genus at the Quarry reef and the Sanctuary (14 most common genera)

Reef fish assemblage

A total of 1,191 fish belonging to 31 taxa and 24 families were counted at the two sites (Table 1). Lutjanidae and Pomacentridae had the most taxa, with three each. Pomacentridae was also the most abundant family, with 534 individuals (44.8% of all fish; Fig. 8b). The most abundant taxa were *Pomacentrus* sp1 (383 individuals), *Caranx* sp. (251) and *Plotosus lineatus* (100), all recorded only at the Sanctuary.

The Sanctuary supported a larger and richer fish assemblage than the Quarry reef (Table 1). It had 31 taxa from 24 families against 13 taxa from 13 families, and every taxon seen at the Quarry reef was also recorded at the Sanctuary. Fish density was 1,051 individuals per 500 m^2 at the Sanctuary and 140 at the Quarry reef, a 7.5-fold difference (about 21,000 vs 2,800

individuals per hectare). Without the two schooling species *Caranx* sp. and *P. lineatus*, the Sanctuary still held five times as many fish (700 vs 140). Shannon diversity calculated from the counts in Table 1 was 2.12 at the Sanctuary and 1.67 at the Quarry reef. At the Quarry reef, two planktivores, *Pomacentrus* sp2 (51 individuals) and *Caesio* sp. (45), made up 69% of all fish.

Roving herbivores (Acanthuridae, Scaridae and Siganidae) numbered 55 individuals at the Sanctuary and 14 at the Quarry reef. The same three herbivore taxa occurred at both sites, so herbivores made up a larger share of species at the Quarry reef (23%, 3 of 13 taxa) than at the Sanctuary (10%, 3 of 31; Fig. 8a). Benthic invertivores had the most species at both sites (38% at the Quarry reef and 35% at the Sanctuary). Piscivores made up 26% of species at the Sanctuary and 15% at the Quarry reef, and they showed the largest contrast in numbers, with 278 individuals at the Sanctuary, most of them *Caranx* sp., against 2 at the Quarry reef. Planktivores made up 16% of species at the Sanctuary and 15% at the Quarry reef, and omnivores 13% and 8%. Trophic groups for each taxon are given in Table 1.

Table 1 Reef fish taxa, number of individuals and assemblage summary at the Agtongo Fish Sanctuary and the Quarry reef at Cajimos, Romblon, Romblon. Counts are individuals per 500 m². Trophic groups: H, herbivore; P, planktivore; BI, benthic invertivore; Pi, piscivore; O, omnivore.

Family	Taxon	Trophic group	Sanctuary	Quarry reef
Acanthuridae	*Acanthurus* sp.	H	19	6
Apogonidae	*Apogon* sp.	P	30	–
Balistidae	Balistidae (unidentified)	BI	5	1
Caesionidae	*Caesio* sp.	P	30	45
Carangidae	*Caranx* sp.	Pi	251	–
Chaetodontidae	Chaetodontidae (unidentified)	BI	9	2
Cirrhitidae	*Cirrhitus* sp.	BI	5	–
Ephippidae	*Platax pinnatus*	O	1	–
Haemulidae	Haemulidae (unidentified)	BI	5	–
Holocentridae	*Myripristis berndti*	P	5	–

Family	Taxon	Trophic group	Sanctuary	Quarry reef
Labridae	*Thalassoma lunare*	BI	13	19
	Thalassoma sp.	BI	11	–
Lutjanidae	*Lutjanus decussatus*	Pi	7	–
	Lutjanus ehrenbergii	Pi	2	–
	Lutjanus sp.	Pi	7	–
Mullidae	*Parupeneus multifasciatus*	BI	1	4
	Parupeneus sp.	BI	8	–
Nemipteridae	*Scolopsis* sp.	BI	8	1
Ostraciidae	*Ostracion* sp.	O	1	–
Plotosidae	*Plotosus lineatus*	BI	100	–
Pomacanthidae	*Pygoplites diacanthus*	BI	1	–
Pomacentridae	*Pomacentrus* sp1	P	383	–
	Abudefduf sp.	O	42	–
	Pomacentrus sp2	P	58	51
Scaridae	*Scarus* sp.	H	30	6
Scorpaenidae	*Pterois lunulata*	Pi	5	1
Serranidae	*Epinephelus* sp.	Pi	1	–
Siganidae	*Siganus* sp.	H	6	2
Synanceiidae	*Synanceia verrucosa*	Pi	1	1
	Synanceia sp.	Pi	4	–
Tetraodontidae	*Arothron* sp.	O	2	1
Total individuals			1,051	140
Assemblage summary				
Families			24	13
Taxa			31	13
Density (ind. 500 m^{-2})			1,051	140

320

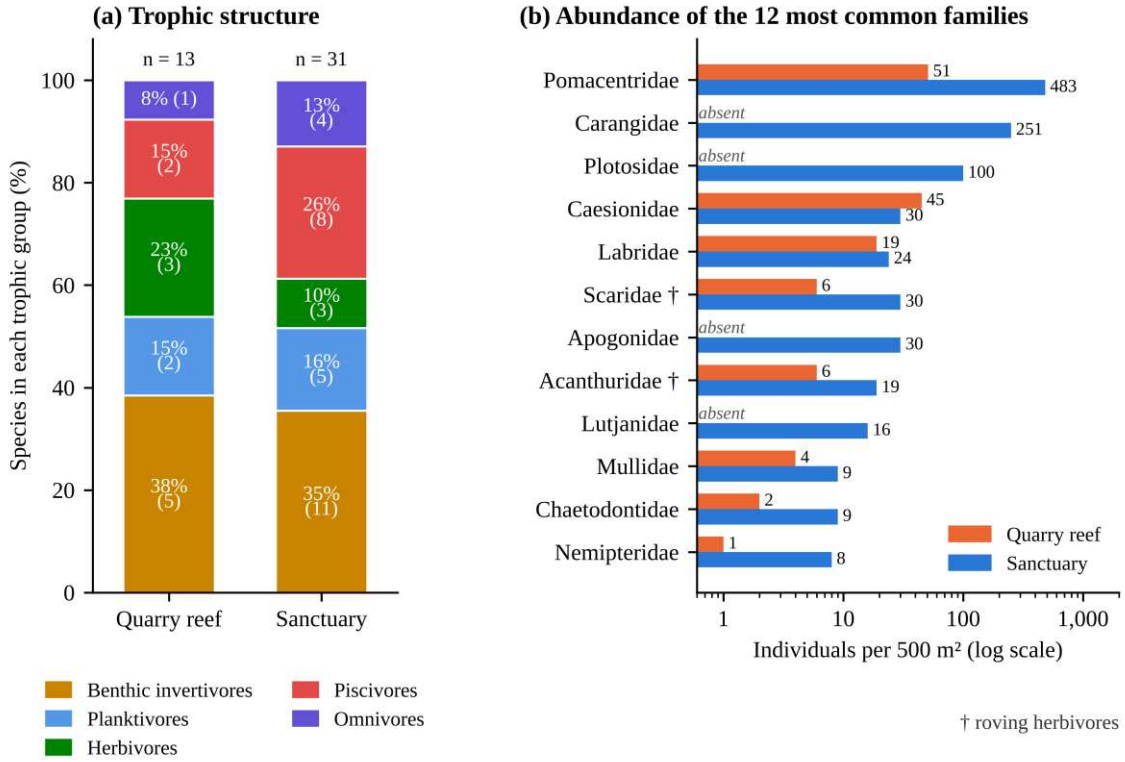


Fig. 8 Reef fish assemblages at the Sanctuary and the Quarry reef. (a) Trophic structure as the percentage of species in each trophic group, with the number of species in parentheses; n is the number of taxa at each site, and trophic groups follow Table 1. (b) Number of individuals per 500 m² in the 12 most abundant families (log scale); † marks roving herbivores. Families not recorded at a site are marked "absent"

Discussion

Similar coral cover, different reef condition

The two sites have similar hard coral cover but differ in most other components of the benthos. Hard coral cover of about 20% places both in HCC Category D, the lowest of the four categories of Licuanan (2020). National assessments have long placed most Philippine reefs in the lower coral cover classes (Gomez et al., 1994; Licuanan et al., 2019). Judged by coral cover alone, the Quarry reef and the Sanctuary would be ranked as equivalent. Table 2 compares the two sites across all benthic and fish indicators measured in this study.

Table 2 Comparison of reef condition indicators at the Quarry reef and the Sanctuary. Benthic values are mean ± SE of five transects; fish values are site totals per 500 m². Tests are from Online Resources 2, 3 and 5.

Indicator	Quarry reef	Sanctuary	Difference
Benthic cover			
Hard coral (%)	20.6 ± 3.2	19.1 ± 2.9	No clear difference (GLMM p = 0.72)
HCC category (Licuanan, 2020)	D	D	Same category
Transects in HCC Category C (>22–33%)	2 of 5	1 of 5	–
Macroalgae (%)	22.0 ± 6.0	5.2 ± 0.4	Higher at Quarry reef (GLMM Holm p = 0.019)
Dead coral with algae (%)	12.3 ± 5.7	1.8 ± 0.4	Higher at Quarry reef (GLMM only)
Recently dead coral (%)	0.7 ± 0.5	0	Quarry reef only
Hard coral : (macroalgae + DCA)	0.61 ± 0.10	2.84 ± 0.44	Higher at Sanctuary ($p < 0.001$)
Rock (%)	5.9 ± 1.1	28.9 ± 2.2	Higher at Sanctuary ($p < 0.001$)
Rubble (%)	16.7 ± 2.1	10.4 ± 2.5	Marginal (GLMM p = 0.048)
Sponges (%)	0.2 ± 0.1	3.9 ± 1.2	Higher at Sanctuary (GLMM only)
Hard coral assemblage			
Taxa (pooled / rarefied to 306 points)	36 / 35.5	28 / 28.0	More at Quarry reef (pooled only)
Evenness, Pielou J′ (pooled)	0.73	0.82	More even at Sanctuary
Dominant genera	*Montipora*, *Porites*, *Acropora*	*Montipora*, *Porites*, *Echinopora*	Composition differs (species and genus, p = 0.008)
Reef fish			
Taxa / families	13 / 13	31 / 24	2.4 times more taxa at Sanctuary
Density (individuals)	140	1,051	7.5 times higher at Sanctuary
Roving herbivores (individuals)	14	55	About 4 times higher at Sanctuary

DCA, dead coral with algae; GLMM, generalized linear mixed model; HCC, hard coral cover; Holm p, Holm-adjusted p value

The rest of the benthos shows that the two reefs are not equivalent. At the Quarry reef, macroalgae and dead coral with algae together cover more of the reef than live hard coral does, while at the Sanctuary hard coral outnumbers them almost three to one. The balance between corals and fleshy algae is widely used to judge reef state, because a shift toward algal dominance can persist once established (Graham et al., 2015; Mumby & Steneck, 2008). Bruno et al. (2009) showed that complete phase shifts to macroalgae are less common than often assumed, and the Quarry reef as a whole is not macroalgae-dominated. On three of its five transects, however, macroalgae covered about 30% of the reef, more than the hard coral on the same lines (10.8 to 18.8%).

Macroalgae and dead coral at the Quarry reef

Algae at the Quarry reef took two forms. On T1 and T2, dead coral with algae covered 22 to 29% of the substrate, and these were the only transects with recently dead coral. Dead coral skeletons are colonized by algal turfs soon after the coral dies (Diaz-Pulido & McCook, 2002), so these lines probably record coral mortality that has not yet broken down into rubble. On T3 to T5, fleshy macroalgae, mainly *Sargassum*, covered about 30% of the reef. Macroalgae harm corals through shading, abrasion and chemical effects, and the strength of these effects differs among algal groups (Jompa & McCook, 2003; McCook et al., 2001; Rasher & Hay, 2010). Dense *Sargassum* stands also reduce browsing by herbivorous fishes, which helps them persist (Hoey & Bellwood, 2011).

The two usual explanations for algal growth of this kind are reduced grazing by herbivores and higher input of nutrients or sediment (Bellwood et al., 2004; Hughes et al., 2007; McCook, 1999). The fish survey is consistent with the first, although it rests on a single census per site. Roving herbivores (surgeonfishes, parrotfishes and rabbitfishes) were about four times more numerous at the Sanctuary (55 vs 14 individuals), and fish density there was 7.5 times higher. Terrestrial runoff delivers nutrients and fine particles that favor macroalgae

366 over corals (Fabricius, 2005), and corals in contact with algae suffer higher mortality where
367 sedimentation is high (Nugues & Roberts, 2003). Marble quarrying and processing in
368 Romblon involve cutting rock and boulders with heavy equipment, which generates large
369 volumes of fine particulates and slurry (Senoro et al., 2022). Where this material reaches the
370 sea it adds fine suspended sediment, so the marble quarry is a plausible local source. Without
371 measurements of sedimentation and turbidity, however, the roles of grazing and sediment
372 cannot be separated, and the two may act together, since dense macroalgae themselves
373 suppress herbivore feeding (Hoey & Bellwood, 2011). Reefs that lose coral to algal
374 overgrowth can also recover when grazing and water quality allow (Diaz-Pulido et al., 2009),
375 so the present condition of the Quarry reef need not be permanent.

376 ***Abiotic substrate and sponges at the Sanctuary***

377 At the Sanctuary, space not occupied by coral was mostly rock and sand, with little algae.
378 Hard substrate kept free of fleshy algae is what one would expect under strong grazing, and
379 open substrate of this kind is available for coral settlement (Bellwood et al., 2004; Mumby &
380 Steneck, 2008). The higher herbivore numbers at the Sanctuary fit this explanation, although
381 exposure, depth or substrate type could also contribute. Rock was also the category that
382 contributed most to the multivariate difference between sites, so how it was scored matters.
383 Neither site recorded more than trace amounts of crustose coralline algae, which is unusual
384 for hard reef substrate and suggests that some "rock" points may have been encrusted
385 pavement. Point-count classifications vary considerably among observers (Beijbom et al.,
386 2015; Leujak & Ormond, 2007), and a check of rock, pavement and old dead coral points at
387 both sites would strengthen this result.

388 Sponges covered 3.9% of the Sanctuary against 0.2% of the Quarry reef. Sponges are a large
389 and functionally important part of reef communities, interacting with corals, algae and other
390 organisms in many ways (Wulff, 2006). On some reefs they increase as corals decline (Bell et

al., 2013), and reefs can move toward states dominated by organisms other than macroalgae (Norström et al., 2008). Sponge cover at the Sanctuary is too low to suggest such a shift, but it is a useful baseline for monitoring.

Rubble was more common at the Quarry reef (16.7 vs 10.4%), although the difference was only marginal (GLMM p = 0.048, unadjusted). Loose rubble is a poor surface for coral recruits because it moves and abrades them, and rubble fields can stay unconsolidated for years (Fox et al., 2003; Kenyon et al., 2023). Where the rubble at the Quarry reef came from (storms, anchors, past blast fishing or natural breakdown of dead coral) cannot be determined from these data.

Coral assemblage differences

Species composition separated the sites more clearly than coral cover. The Quarry reef had more taxa in the pooled sample, including after rarefaction (Gotelli & Colwell, 2001), although richness per transect did not differ, and it had proportionally more branching *Acropora* and *Seriatopora*. In trait-based classifications the first falls in the competitive group, which grows fast but is sensitive to stress, and the second in the weedy group, which quickly colonizes recently disturbed space (Darling et al., 2012). Chronic sedimentation usually lowers coral diversity and favors stress-tolerant growth forms such as massive *Porites* (Dikou & van Woesik, 2006; Erftemeijer et al., 2012; Golbuu et al., 2011; Rogers, 1990). The assemblage at the Quarry reef gives a mixed signal. Massive *P. lutea* made up almost twice the share of hard coral there as at the Sanctuary (17.2 vs 9.5%), which fits sediment stress, but the stress-sensitive and opportunistic branching genera were also more common. If sediment from the marble quarry affects this reef, its effect on corals may be recent or intermittent, or may act mainly by favoring algae.

Corals also differ widely in how they handle sediment. Sediment rejection depends on colony shape and polyp size (Stafford-Smith & Ormond, 1992), tissue damage depends largely on the organic content of the sediment and the microbial activity it supports (Weber et al., 2012), and experimental responses vary with coral species and sediment type (Tuttle & Donahue, 2022). Marble is metamorphosed limestone, so quarry fines are mostly calcium carbonate with little organic matter. In experiments, fine silts rich in organic matter and nutrients stressed corals within short exposures, while sandy or nutrient-poor sediments had smaller effects (Weber et al., 2006). Fine marble dust may therefore harm corals less through the microbial processes that make organic-rich silt damaging, and more through smothering and turbidity. Very fine particles also stay in suspension longer than coarse sediment and settle on the surfaces that coral larvae need, so they may affect recruitment as well as adult colonies (Erftemeijer et al., 2012). Marble processing may also release metals. Senoro et al. (2022) cite studies elsewhere that found elevated Cu, Zn, Pb, As, Cr, Hg, Ni and Co in sediments receiving marble mine discharge, and they linked elevated zinc in soils of Romblon town partly to machinery used in marble quarrying. Metals are a separate stressor that should be measured alongside sediment load. Suspended sediment cuts the light available to corals, separately from the effects of particles settling on tissue (Bessell-Browne et al., 2017; Jones et al., 2016). Measuring both sedimentation and turbidity at the two sites would show whether the Quarry reef is exposed to levels known to stress corals.

The Sanctuary had relatively more *Pavona venosa*, *Echinopora horrida*, *Turbinaria mesenterina* and *Heliopora coerulea*, which are mostly foliose, plating or encrusting forms. This difference could reflect depth, exposure or substrate rather than protection. Part of it may also come from scoring, since the two sites were annotated with slightly different versions of the code file (for example, *Montipora* sp. and *Euphyllia* spp. appear only in the

Sanctuary version and hydroids only in the version used at the Quarry reef), and coral richness comparisons should be checked after re-scoring with a common list.

Protection status and limitations

The fish survey shows the pattern expected inside a no-take reserve. The Sanctuary held more fish in every trophic group, although most of its piscivores were a single school of *Caranx* sp. No-take reserves generally hold more and larger fishes, including herbivores (Lester et al., 2009), and well-enforced Philippine reserves have produced clear gains in fish biomass over time (Russ et al., 2004). Effects on corals are weaker and less consistent. Selig and Bruno (2010) found that coral cover generally held steady inside MPAs while it declined outside, with the benefit growing as MPAs aged, Strain et al. (2019) found stronger MPA effects on fishes than on benthic cover, and Mellin et al. (2016) found that protection mainly improved coral recovery after disturbance. Many Philippine MPAs are also small or weakly enforced (Weeks et al., 2010). A strong fish response with no difference in coral cover is therefore consistent with the wider literature. Higher grazing inside the Sanctuary is one route by which protection could be keeping macroalgae low there (Mumby & Steneck, 2008). The fish contrast cannot be credited to protection alone, however, because poorer habitat and sediment near the marble quarry could also reduce fish numbers at the Quarry reef.

The design limits how far these results can be taken. Each condition is represented by a single site, so transects replicate variation within a site but not between protected and unprotected reefs (Hurlbert, 1984). The differences reported here are between two places, and protection, marble quarrying, and any natural differences between the sites, such as depth, exposure or aspect, are confounded. With five transects per site, the smallest p-value an exact permutation test can return is 0.008, and power to detect moderate differences in coral diversity is low. Univariate differences were tested with binomial mixed models and checked with t and rank tests (Warton & Hui, 2011). With only five transects per site, likelihood-ratio tests in mixed

models can be somewhat liberal, so the differences supported by the GLMM alone (dead coral with algae and sponges) should be read with caution. Dispersion was tested alongside PERMANOVA so that location and spread effects were not confused (Anderson, 2001, 2006; Anderson & Walsh, 2013). SIMPER contributions (Clarke, 1993) describe which categories differ most but are not tests in themselves. The fish data are reported as single totals per site, so they could not be tested statistically, and counts of schooling species such as *Caranx* sp. and *P. lineatus* can vary widely between censuses. Finally, the surveys were made in 2021, before the fourth global coral bleaching event was confirmed in 2024 (Reimer et al., 2024). Both reefs may have changed since, so these results are best read as a 2021 baseline.

Scoring is the other main limitation. Points were classified in CPCe (Kohler & Gill, 2006) using slightly different versions of the same code file at the two sites. Genus codes for macroalgae were available at both sites, but all Sanctuary macroalgae were recorded as unidentified macroalgae, while most algae at the Quarry reef were identified to genus (about a third of its macroalgal cover was still scored as unidentified), so the genus-level algal contrasts in Fig. 3 partly reflect annotation. Re-scoring both sites with a single code file, ideally by the same analyst, would remove this source of bias. Adding at least two more sites per condition, measuring sedimentation and turbidity, repeating fish counts on replicate transects, and analyzing sediment at the Quarry reef for carbonate content and the metals reported near Romblon marble operations (Senoro et al., 2022) would allow the roles of protection and marble quarrying to be tested directly.

Conclusions and management implications

In 2021, the Agtongo Fish Sanctuary and the Cajimos reef next to the marble quarry had similar hard coral cover (about 20%, Category D), but the Quarry reef carried far more macroalgae and dead coral and far fewer fish. Coral cover alone would therefore have missed

the poorer condition of the Quarry reef, and monitoring of reefs near quarries should include algae, dead coral and fish.

The low algal cover and abundant herbivores at the Sanctuary are consistent with the effect of protection on grazing fishes. The algae and recent coral mortality at the Quarry reef may be linked to sediment from marble quarrying, to reduced grazing, or to both. Sedimentation and turbidity were not measured, however, and each condition was represented by a single site, so neither cause can be confirmed from these data. We recommend continued protection of the Agtongo Fish Sanctuary and, as a precaution, measures that keep quarry runoff and marble fines out of nearshore waters at Cajimos. Future monitoring should measure sediment and turbidity at both reefs, score all photographs with a single code file, add replicate sites for each condition and repeat fish counts on replicate transects.

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Project administration, Supervision, Writing – review and editing. All authors read and approved the final manuscript.

Data availability. The point-count data, fish counts, and analysis code are available from the corresponding author upon reasonable request.

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