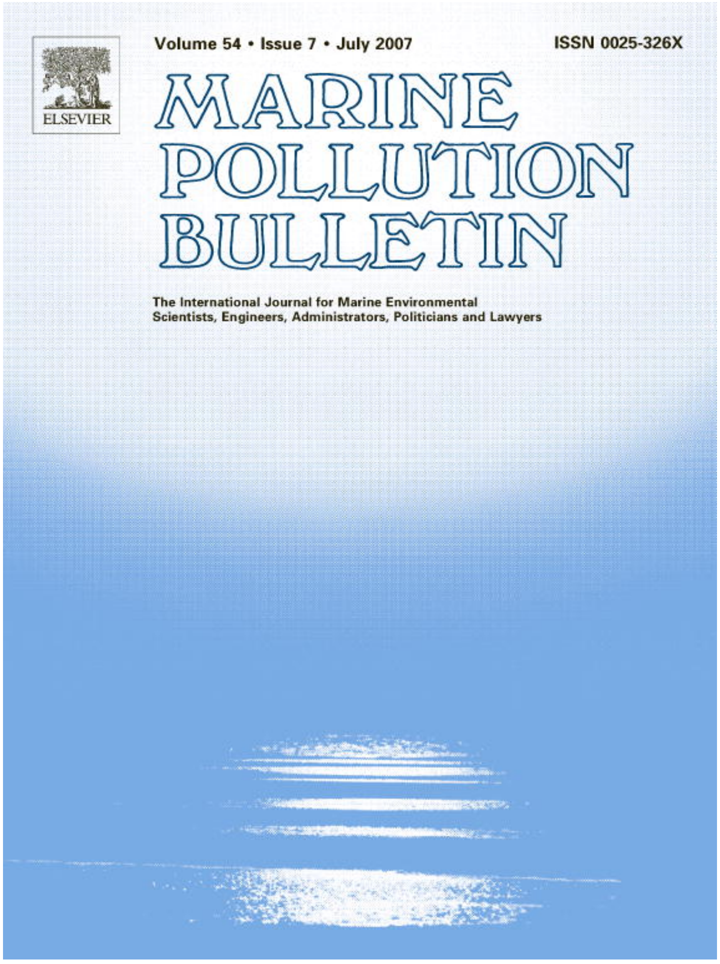
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Can dynamite-blasted reefs recover? A novel, low-tech approach to stimulating natural recovery in fish and coral populations

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Abstract

Throughout Southeast Asia, blast fishing creates persistent rubble fields with low coral cover and depauperate fish communities. We stabilized a 20-year-old rubble field in a Marine Protected Area in the Philippines, using plastic mesh and rock piles in replicated 17.5 m^2 plots, thereby increasing topographic complexity, fish habitat, and recruitment substrate surface area. Multivariate analysis revealed fish community shifts within the rehabilitated area from that characteristic of rubble fields to one similar to the adjacent healthy reef within three years, as measured by changes in fish abundance and body size. Coral recruitment and percent cover increased over time, with 63.5% recruit survivorship within plots, compared with 6% on rubble. Our low-cost approach created a stable substrate favoring natural recovery processes. Both rehabilitation and the elimination of poaching were integral to success, emphasizing the synergism between the two and the need to incorporate both when considering mitigation.

Keywords: Rubble stabilization; Reef rehabilitation; Dynamite fishing; Coral recruitment; Fish community shift; Philippines

1. Introduction

The practice of dynamite ("blast") fishing is a major cause of reef degradation in the Indo-Pacific. The resulting fragmented coral does not survive and creates unstable rubble fields unsuitable for recruitment (Alino et al., 1985; Gomez, 1988; Pet-Soede and Erdmann, 1998; Fox, 2004). Thus, unconsolidated rubble persists, topographic complexity is lost, and recruitment, fish habitat and reef function are greatly reduced (Christie and White, 1994; Fox et al., 2003). Although data are limited, they suggest that recovery is minimal in ecologically relevant time spans: 25 years ago, Alcala and Gomez (1979) predicted that reestablishing 50% of pre-blast coral cover would take 40 years. A more recent estimate by Riegl and Luke (1998) judged recovery would take several hundred years. In the Philippines, many rubble fields show virtually no hard coral cover 20–30 year post-blasting (L. Raymundo, pers. obs. and fisher interviews).

Short-term economic gain from blast fishing varies and mortality of non-target species can be high (Fox and Erdmann, 2000). The impacts of blast fishing on reef productivity and structure are fairly straightforward (Riegl and Luke, 1998; Alcala, 2000; Fox et al., 2003), and a growing body of evidence is showing that coral habitat destruction leads to immediate declines in fish species richness and abundance (Lewis, 1997; Halford et al., 2004). Recovery of fish assemblages may be strongly influenced by coral recovery; a failure of the coral community to recover can result in the loss of coral-associated fish communities (Syms and Jones, 2000). In the Philippines, fishery

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management is promoted by banning destructive fishing methods and establishing Marine Protected Areas (MPAs). No-take MPAs provide fish refugia, which are predicted to enhance adjacent fishing grounds via the ‘‘spillover effect’’ (Russ et al., 2003). MPAs are usually former fishing grounds, and many were destructively fished prior to protection. Most are small (averaging 15 ha; White et al., 2003) and managed by fishing communities. However, the effectiveness of MPAs blasted prior to protection is not usually considered by managers. Pre-existing rubble fields may result in a semi-permanent loss of productivity within an MPA, due to a lack of recruitment substrate (i.e., substrate limitation; Clark and Edwards, 1995) and fish habitat. Persistent low fish diversity and biomass has direct management implications. Without perceptible improvement in the reef community, enforcement can break down (Bernardo, 2001) and the MPA fails to meet its management objectives.

The goal of this pilot study was to develop and test a low-cost, low-technology method of stabilizing rubble to create substrates suitable for coral and fish recruitment. Rehabilitation often relies heavily on coral transplantation or deployment of artificial structures, both of which are labor-intensive, costly, and often only marginally successful (Harriot and Fisk, 1988; Gittings et al., 1993; Polovina, 1989; Lam, 2000; Jokiel and Naughton, 2001; Svane and Petersen, 2001; Edwards and Clark, 1998). Coral rubble provides a suitable settlement substrate for many marine invertebrates, providing rugosity and an appropriate biofilm (Pawlik, 1992; Mundy, 2000; Harrington et al., 2004). The issue, therefore, is instability; settled invertebrates become abraded, fouled and buried before they can grow large enough to establish themselves in space (Alino et al., 1985; Nzali et al., 1998; Fox, 2004). We hypothesized that if rubble movement could be minimized, settled coral recruits would survive long enough to grow over the rubble and consolidate it, thereby initiating recovery of the reef community. An MPA was targeted as the treatment site, for the management concerns discussed above, to protect our study plots from anchor damage, and to allow accurate assessment of the effect of rehabilitation on fish recovery in the absence of fishing pressure. An additional goal was to involve the community management organization in our work and use this project to build management capacity.

2. Methods

2.1. Site description

The study took place within the Calagcalag Marine Protected Area, in Negros Oriental, central Philippines; established in 1988 by local government resolution, and managed by the Calagcalag *Bakhawan* Fisher's Association (CABAFA). The MPA covers 10.4 ha and encompasses a 3.3-ha platform reef 1 km offshore (Fig. 1). The reef flat rises to 8 m depth and is dominated by a 2.400 m^2 rubble field, created by repeated dynamite fishing until the mid-1980s (Raymundo et al., 2005). While rubble covers approximately 8% of the total reef area, it is located in the reef zone which would normally support the greatest coral cover and fish diversity. Fishers have reported little improvement in their catch, a breakdown of management efforts, and regular poaching within the reserve.

Replicate line intercept transects on the platform reef within the MPA in February 2003 bisected both healthy reef and the rubble field, and revealed similar amounts of live coral cover (40.9%) and rubble (39.6%). The fish community was characterized by low biomass and small body sizes, particularly of commercially-important species (*Lutjanus decussatus, Naso* spp., *Acanthurus* spp. *Ctenochaetus* spp., *Caesio* spp, *Chlororus* spp., *Scarus* spp., and *Cephalopholis argus*). We subdivided the reef flat into three zones for periodic monitoring (Fig. 1): (1) the central *rubble field* (R); (2) the *rehabilitation treatment area* (RHB), the southern corner of the rubble field where we established our stabilization plots; and (3) adjacent *healthy reef* (HR). The unmodified rubble field and healthy reef areas provided contrasting existing conditions against which to compare changes in the fish community and coral cover in response to our treatment in the rehabilitation plots.

2.2. Rehabilitation treatment

Within the rehabilitation treatment area, we deployed five 17.5 sqm plots (Fig. 2) at two time intervals (three in June 2003, the coral spawning season, and two in October 2003, prior to the storm season). The total rehabilitated area, which included the spaces between these plots, covered approximately 20% of the rubble field. Establishing small individual plots allowed for statistical replication to examine rates of coral recruitment and recruit survival, and was cost-effective.

Treatment plots consisted of locally-available plastic mesh screen, with a 2-cm diameter mesh size (Fig. 2). These mesh ‘‘carpets’’ were laid directly on rubble and anchored in place with rebar stakes. Holes were cut into the mesh to accommodate existing coral heads, which were used as additional anchorage. Rock piles were constructed on land using reef rock and cement, to create hollow, pyramid-shaped structures that were positioned on the mesh (1 pile/0.5 m^2, 1 m in height). Previous studies suggested that coral recruit survival is higher on surfaces elevated from the substrate (Clark and Edwards, 1995), and spatially complex structures are strongly linked with more diverse fish assemblages (Holbrook et al., 2002). Therefore, our rock piles added weight and stability, while increasing microhabitat availability and recruitment surface area.

2.3. Fish community analysis

All plots were censused for fish and coral recruitment, three to four times per year for four years (Table 1). The fish community was monitored using the underwater visual

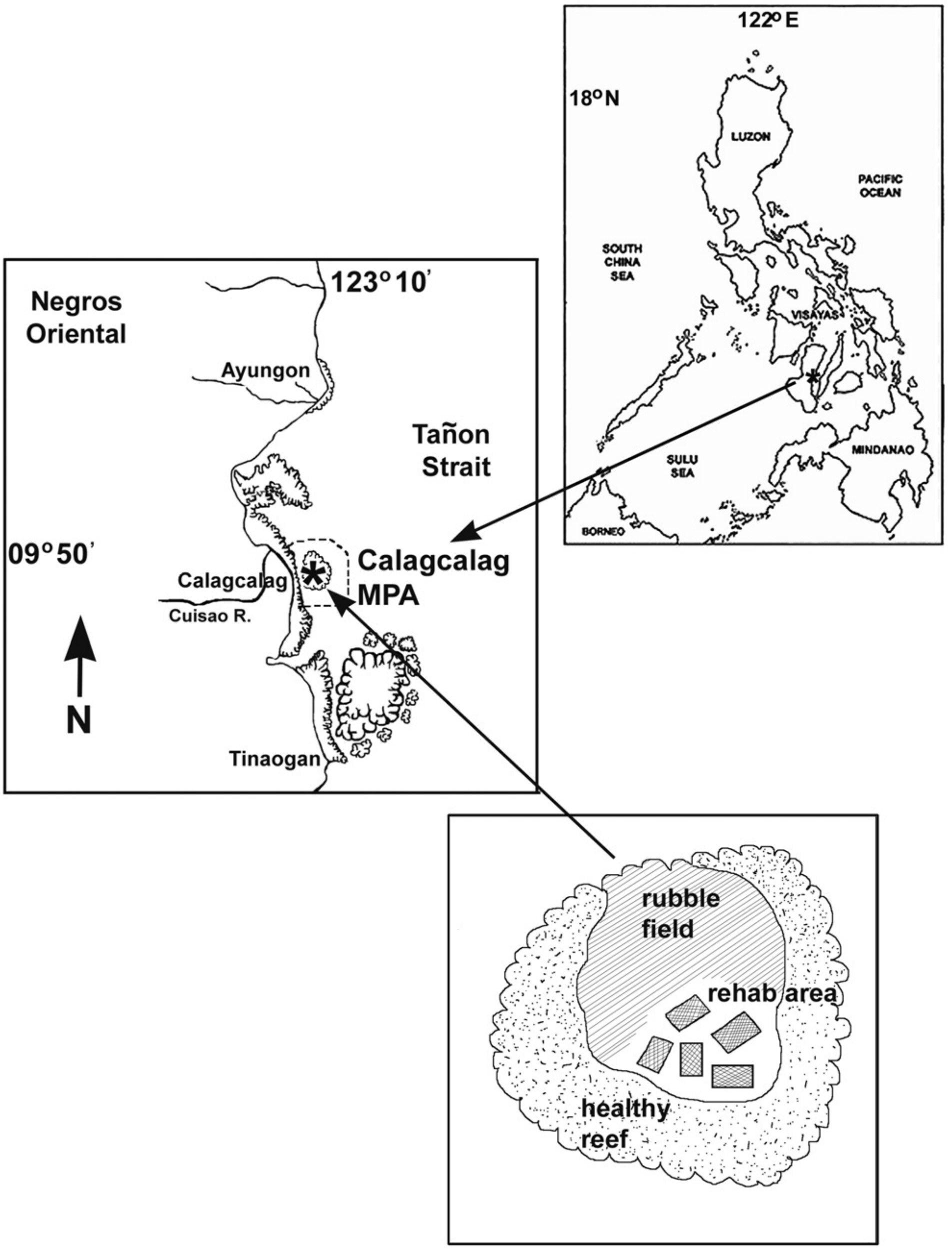

Fig. 1. A map of the study area, showing its location within the Philippines (inset) and a schematic, showing the relative positions of the rubble field, rehabilitation treatment area, and surrounding healthy reef.

census technique (English et al., 1997), evaluating a 50 m × 10 m area in each zone. Within each belt, all individuals were identified to species and counted by a single observer (A.P. Maypa). The length of each fish was estimated in centimeters (±2 cm). An estimate of biomass was calculated from density and length data, converted to mass using published length-mass relationships for specific species (Fishbase, 2004). Due to the small size of the coral rehabilitation area, transects could not be replicated. Therefore, changes in the fish community were evaluated by grouping censuses into discrete time periods and testing for shifts in fish community composition, density, biomass and body size between these periods and between the three identified zones. A total of 33 500 m^2 belt transects were completed between February 2003 and July 2006. Fish community groupings were based on reef fish abundance by family and size per transect. Arbitrary size classes were defined based on the dominance of recorded sizes of fish per family, especially for target fishes (e.g., for Scarids: small = <10 cm; large = >10 cm; see Table 2). Groupings were then generated by hierarchical agglomerative cluster analysis. A dendogram plot was produced using Bray-Curtis Similarity and average linkage to generate cluster groups of similar community composition and abundance. The contributing factors for each group, similarities within groups and dissimilarities between groups were identified by SIMPER analysis. All tests were conducted using the statistical software PRIMER (Clarke and Warwick,

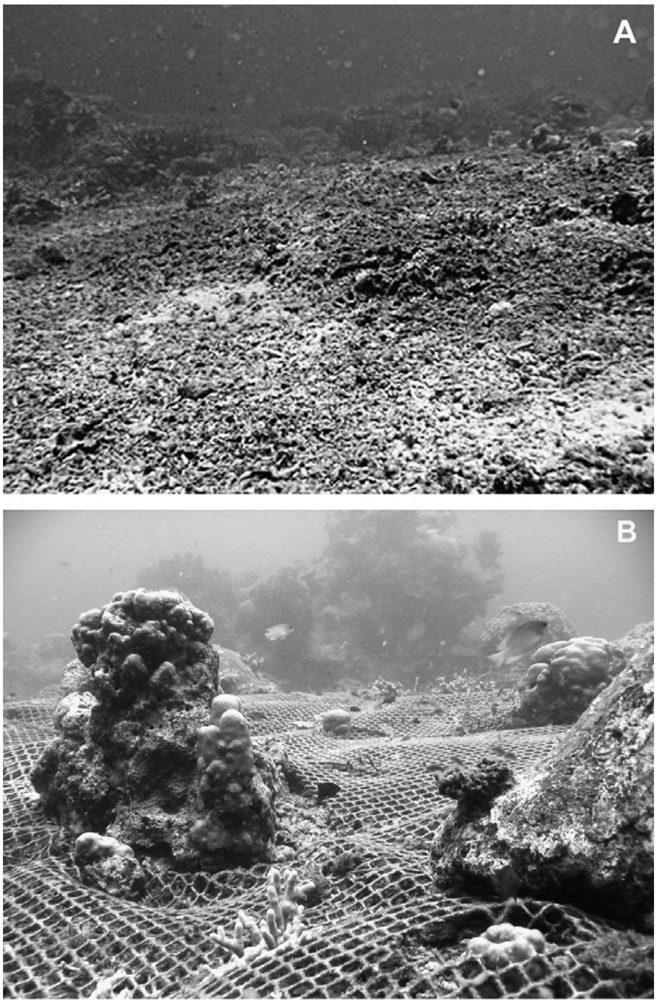

Fig. 2. Calagcalag MPA rehabilitation site. (A) Rubble field in 2003, created by blast fishing which stopped in the mid-1980s. (B) Side-view of a stabilization plot, showing the plastic mesh net, existing coral heads, and rock piles used to prevent rubble shifting.

2001). Preliminary hierarchical clustering was used to investigate the ecological integrity of the perceived groupings and revealed that a number of transect groupings did not continue to match the pre-determined zones (i.e., R, RHB, HR) over time. Transects were, therefore, grouped by fish community type and pooled across time for multivariate analyses of the three zones.

Fish community data were analyzed for the effects of rehabilitation and management initiatives (see below) on fish communities. Biomass of target species was pooled by trophic level (i.e., herbivores, planktivores, invertebrate feeders, piscivores). Data were grouped by census period and reef zone, as defined by Bray-Curtis Similarity and Cluster Analyses, and compared to the timeline of management initiatives. Total target species biomass data were tested for normality using Kolmogorov's test for normality and Levene's test for homoscedasticity and analyzed using a Two-Way Analysis of Variance without replication, testing for differences in total biomass between censuses and reef zones. Bonferroni post hoc tests determined where the significance lay between tested factors; this test is considered the most conservative in its estimation of differences (Velleman, 1988).

2.4. Coral recruitment

All recruits observed on plots were counted during each census, to establish a rate of recruitment and a cumulative count of recruits per plot over three years of monitoring. In May 2004, 10–12 recruits from each plot deployed in June 2003 ($n = 30$, total), and 25 from the adjacent rubble field were haphazardly tagged for survival monitoring. Colony diameter of each recruit was measured using a caliper; all were 1.5–2 cm in diameter when tagged. These were monitored for survival for 10 months. In 2005, two years post-treatment, benthic composition (live hard coral, rubble, rock/turf algae, macroalgae, dead coral) was assessed within each of the three zones along five 20 m transects per zone. Within rehabilitation plots, we classified rubble underlying mesh plots as rubble unless live coral was growing over it, and rock piles without recruits were classified as rock with turf algae. Differences in dominant substrate types between the three zones were tested using One-way Analysis of Variance, after establishing assumptions of normality and homoscedasticity. Bonferroni's post-hoc tests were used to determine which of the comparisons between zones were significant.

Table 1
Schedule of fish and coral censuses

Date	Census no.	Activity
February 2003	0	Baseline assessment of benthic cover and fish
August 2003	1	1-months post-treatment monitoring census of coral and fish recruits
September 2003	2	2-months monitoring census of coral and fish recruits
October 2003	3	3-months monitoring census of coral and fish recruits
February 2004	4	6-months monitoring census of coral and fish recruits
July 2004	5	1-year monitoring census of coral and fish recruits
October 2004	6	18-months monitoring census of coral and fish recruits
March 2005	7	Monitoring census of coral and fish recruits
May 2005	8	2-year monitoring census of fish recruits
August 2005	9	Monitoring census of fish recruits
December 2005	10	2.5-year monitoring census of fish recruits
July 2006	11	3-year monitoring census of coral and fish recruits

Table 2
Results of SIMPER analysis showing abundance of reef fish (per 500 m^2) according to family and size that contribute to similarities within community types in Calagcalag MPA, central Philippines

Fish family groupings	Dominant species	*A*1: Rubble field	*B*1: Rehab plots and healthy reef	*B*2: Rehab plots and healthy reef
Pomacentridae	*Pomacentrus* spp.	91.1 ± 11.8	654.9 ± 59.6	244.60 ± 11.65
Small labridae	*Cirrhilabrus cyanopluera* *Thalassoma* spp.	308.3 ± 17.3	158.8 ± 4	60.7 ± 18.89
Grazing Acanthuridae	*Ctenochaetus* spp. *Zebrasoma scopas* *Acanthurus pyroferus*	18.9 ± 4.8	65.4 ± 7.9	36.20 ± 7.2
Small Scaridae (<10 cm)	*Chlororus* spp. *Scarus* spp.		17.1 ± 3.7	
Larger Scaridae (>10 cm)	*Chlororus* spp. *Scarus* spp.	8.0 ± 1.2	32.1 ± 5.5	9.4 ± 2.4
Caesionidae	*Caesio caerulaurea* *C. cunning*	6.4 ± 3.9	33.0 ± 8.3	5.1 ± 3.4
Chaetodontidae	*Chaetodon* spp. *Heniochus varius*	0.1 ± 0.1	3.5 ± 0.6	5.6 ± 1.6

2.5. MPA management initiatives

Since MPA establishment, little institutional support had been available to CABAFA. No financial support was provided for basic equipment and CABAFA members were no longer deputized to police their reserve, as this required periodic training and renewal. Monitoring of benthos and fish was not undertaken, so there was no means of assessing the impact of MPA establishment on reef health. Hence, poaching was frequent. During the project's second year, we allocated funds for the purchase of a patrol boat, search lights and sign boards identifying the MPA. A community officer (CO) was hired during the third year of the project (2005), to strengthen management capacity, facilitate communication between CABAFA, the mayor, and the local Department of Environment and Natural Resources (DENR). This communication link was vital to long-term management, as both the mayor's office and the DENR were responsible for allocating funds for equipment maintenance. The CO also organized law enforcement and monitoring workshops for fishers during the third year, allowing CABAFA to reduce poaching and assess improvements in their MPA.

3. Results

3.1. Fish community shifts

Three fish communities were identified based on reef fish abundance by family and size, as recorded from censuses conducted over four years within the three zones (rubble field, rehabilitated area and healthy reef). Each grouping was described as a community type with a temporal component which became apparent during monitoring: Three major cluster groups (*A*, *B*1, *B*2) were identified using multivariate analysis. Clustering delineated three groupings, at a distance of 20; groupings were supported by MDS analysis (Fig. 3). All rubble area and initial rehabilitation area (i.e., 2003) censuses were characterized by high labrid densities and low target fish species densities, and segregated into group *A*. Group *B*1 comprised four intermediate rehabilitation area censuses (2004–2005), characterized by high labrid and pomacentrid densities, moderate densities of scarids, and low densities of other target fish species. The third group, *B*2, comprised all healthy reef and later rehabilitation area (2005–2006) censuses. The *B*2 group is characterized by high pomacentrid densities, low labrid densities, moderate densities of small scarids, and higher densities of all other target species than either *A* or *B*1 groups (Table 2). Groups *B*1 and *B*2 were the most similar; A1 was dissimilar to both (Similarity between groups: $A1{:}B1 = .33$; $A1{:}B2 = .31$; $B1{:}B2 = .62$).

Total target fish biomass increased significantly over time (ANOVA $F = 5.56$; $p = 0.0003$; post-hoc test: census periods 7, 9, 10, 11>0–6, 8) and between reef zones ($F = 7.57$; $p = 0.0031$; post-hoc test: rehab area = healthy reef > rubble field). The biomass for the period August 2005 to March 2006 within both rehabilitation and healthy reef zones was significantly higher than all other zones and times (Fig. 4). This corresponded to the time when management initiatives within the fishing community were begun (i.e., enforcement and monitoring training). Thus, the fish community appeared to be responding to both rehabilitation treatment and improved management. When we further characterized the fish community by trophic groups, these trends were consistent, particularly for herbivores and planktivores (Fig. 5). Herbivores responded rapidly to both rehabilitation and improved enforcement, more than doubling in biomass by 2006 in all three community types. Planktivores showed a large increase but high variability within the rehabilitated area, a seven-fold increase by 2006 within the healthy reef, and a slight increase within

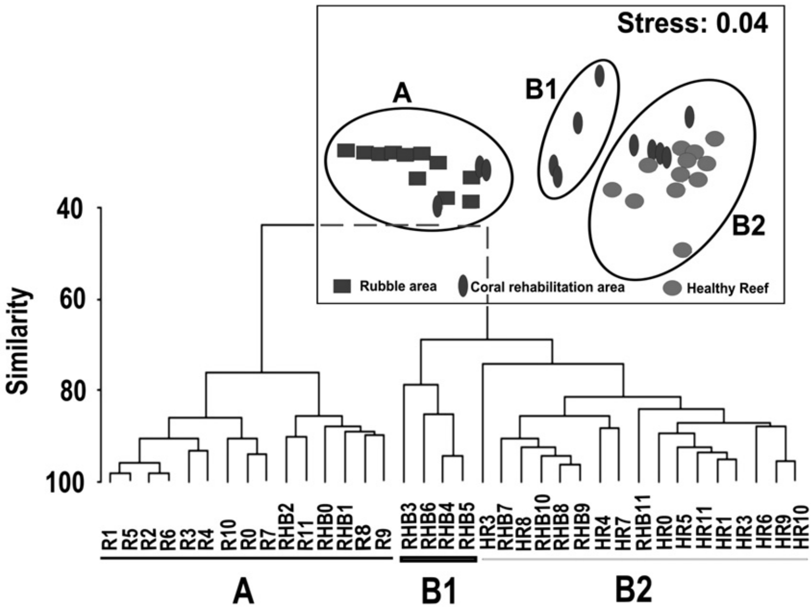

Fig. 3. Dendogram of hierarchical clustering (group-average linking) of reef fish abundance by family and size from three habitat types (rubble field, rehabilitation area and healthy reef), using the Bray-Curtis Similarity Matrix. Symbol: R = rubble, RHB = rehabilitation area, HR = healthy reef. Numbers after each symbol represent monitoring censuses from 2003 to 2006 (refer to Table 1 for dates). Inset: Cluster diagram of fish census groupings corresponding to the dendrogram.

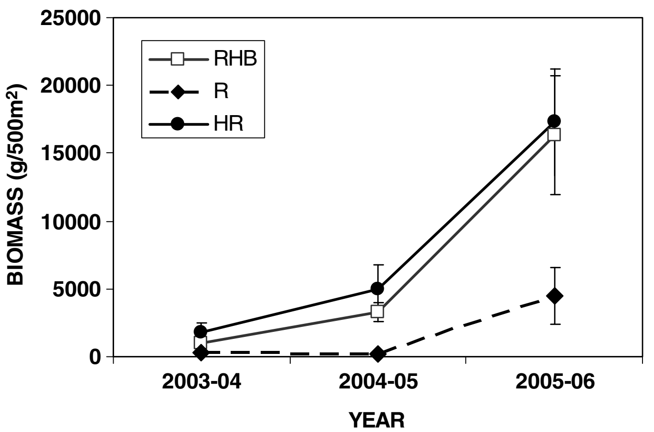

Fig. 4. Changes in total target fish biomass over time for three reef zones within the Calagcalag MPA. Mean ± SE for $n = 12$ census periods, using groups defined by hierarchical cluster analysis: 2003–04: census periods 0–4; 2004–2005: census periods 5–7; 2005–2006: census periods 8–11.

the rubble field. Large piscivores showed slight increases in biomass within the healthy reef community and rehabilitation plots, but were virtually absent from the rubble field throughout the study.

3.2. Coral recruitment

Deployment of the first three plots was timed to occur during the spawning season (May–July; L. Raymundo and others, pers. obs.), so that settlement surfaces would be available after a conditioning period. An encrusting community composed of turf algae, diatoms and crustose coralline algae developed on the mesh within three weeks after deployment, and 1-cm diameter recruits began appearing on the plots by September 2003. The number of recruits observed during our census visits continued to increase on these plots over time from a mean of 0.5 ind/m^2 in September 2003 to 4.5 ind/m^2 by March 2005 (Fig. 6). In contrast, recruits did not appear on the October-deployed plots until one year later and the number of recruits on these plots did not significantly increase over the next five months. The recruiting community was dominated by *Faviidae*, *Poritidae* and *Acroporidae* (Fig. 7); *Millepora* and *Agariciidae* were also common. The generic composition generally reflected that of the surrounding healthy coral community.

Recruit survival was significantly higher in tagged colonies settled on the mesh plots vs. unconsolidated rubble (ANOVA $F = 8.64$; $p < 0.05$). Mesh recruits showed a mean survival of 63.4% ± 32% to 10 months, while recruits settled on rubble adjacent to mesh plots showed a survival of 6% ± 10% for the same time period. Mean diameter of plot recruits at 10 months (assuming settlement in early July 2003) was 6.35 cm ± 2.7 cm, and all displayed extensive upward branching growth. In contrast, recruits settled onto unconsolidated rubble were generally abraded and displaying partial mortality; most died or disappeared within the monitoring period and none developed any upward growth, remaining 2–4 cm in diameter. Most mortality of tagged recruits on the plots occurred on two plots (1 and 5) that had become partially buried from shifting rubble during a storm in October 2004. These plots continued to show low recruitment relative to other plots (Fig. 6), though recruitment had increased in plot 5 by 2006. In general, recruits settling on mesh grew both downward,

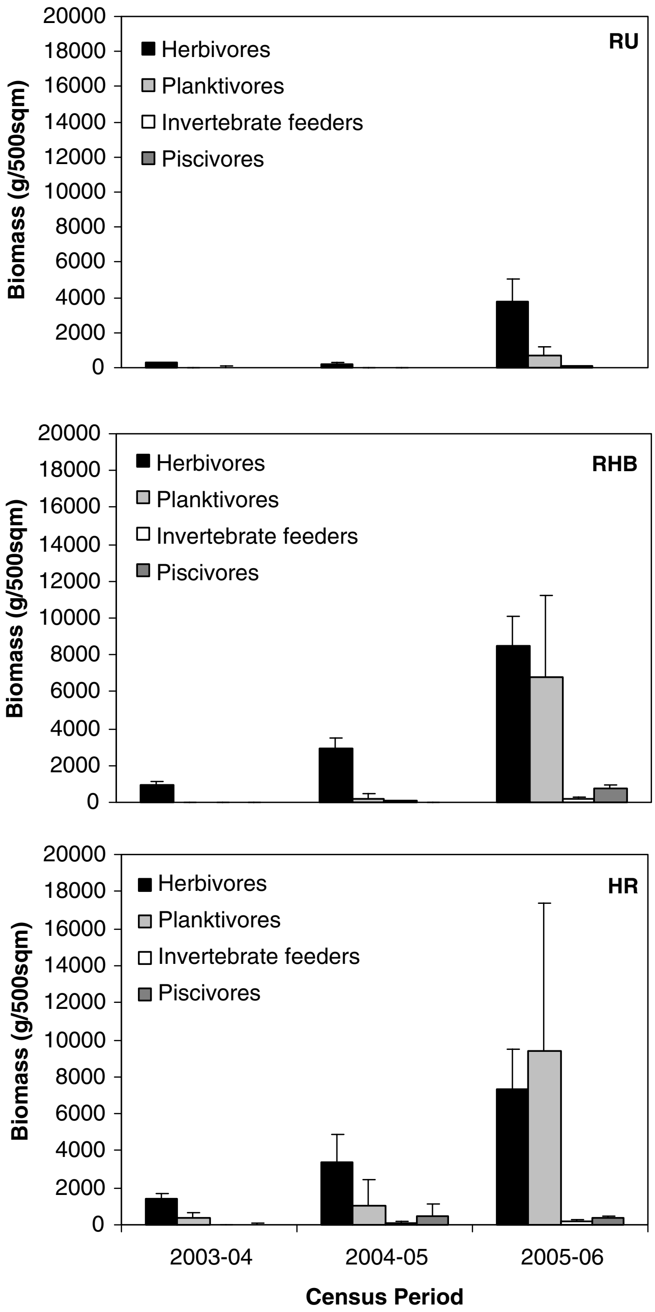

Fig. 5. Changes in fish biomass per trophic group over time, in (a) healthy reef (HR), (b) rehabiliated area (RHB), and (c) rubble field (RU). 2003: $n = 3$ monitoring censuses 0–3, 2004–2005: $n = 4$ (monitoring censuses 4–7) and 2005–2006: $n = 4$ (monitoring censuses 8–11) (Mean ± SE).

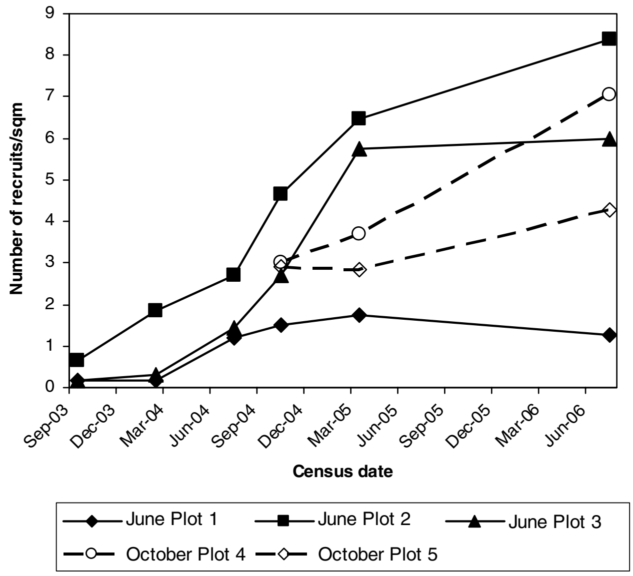

Fig. 6. Cumulative mean number of coral recruits per square meter of plot area of early-established plots (June 2003) and late-established plots (October 2003) (Mean ± SE).

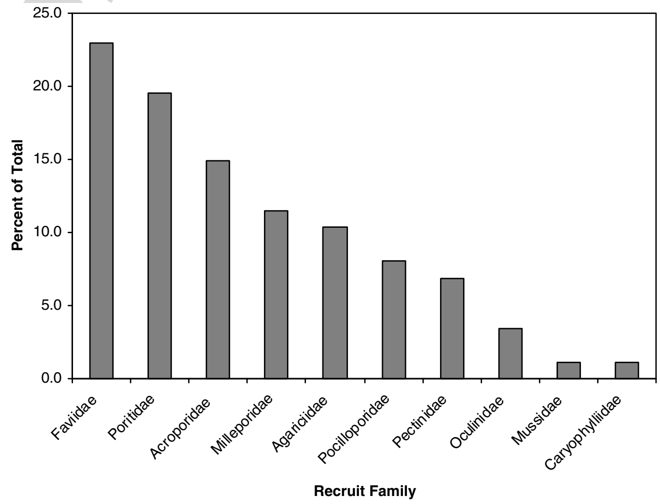

Fig. 7. Composition of recruited coral community on six plots in July 2006, three year after plot establishment.

cementing onto underlying rubble and developing extensive basal growth, and upward and through the mesh, developing the characteristic juvenile colony morphology (Fig. 8). This effectively cemented the underlying rubble to the mesh, which was rapidly covered by growing coral tissue.

3.3. Changes in benthic composition

Fig. 9 summarizes benthic composition for the three zones two years post-treatment. Hard coral cover was higher within rehabilitation plots than on untreated rubble. This increase was not yet significant, and healthy reef areas predictably contained much higher coral cover (Fig. 9; ANOVA $F = 18.946$; $p < 0.01$). Rehabilitation plots showed rubble cover intermediate between that of the untreated rubble field and healthy reef (ANOVA $F = 45.071$; $p < 0.0001$; post-hoc test: rubble > rehab area > healthy reef). However, the presence of the seasonal macroalga *Padina australis* (considered a separate benthic cover category, and absent during the 2003 pre-treatment surveys) masked the percent cover of rubble in our 2005 surveys. When we removed macroalgae as a substrate category and considered only the underlying rubble, highly significant differences between the three communities were

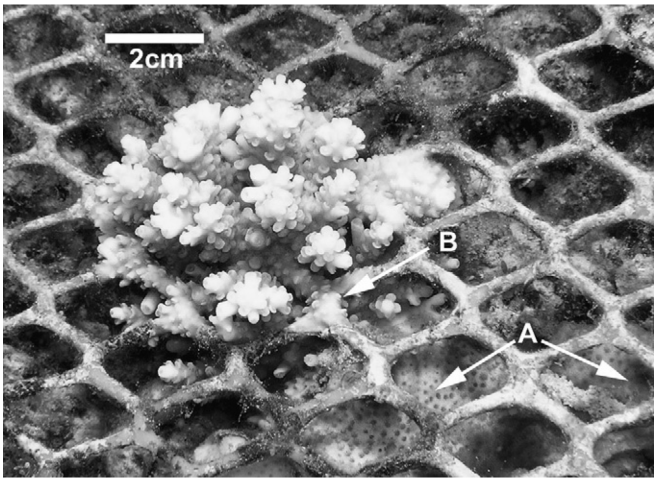

Fig. 8. A close-up view of the mesh net used to cover and stabilize rubble, showing a coral recruited to the underlying rubble, growing up through the mesh. A = extensive basal growth on rubble; B = upward growth attaching the mesh to underlying rubble.

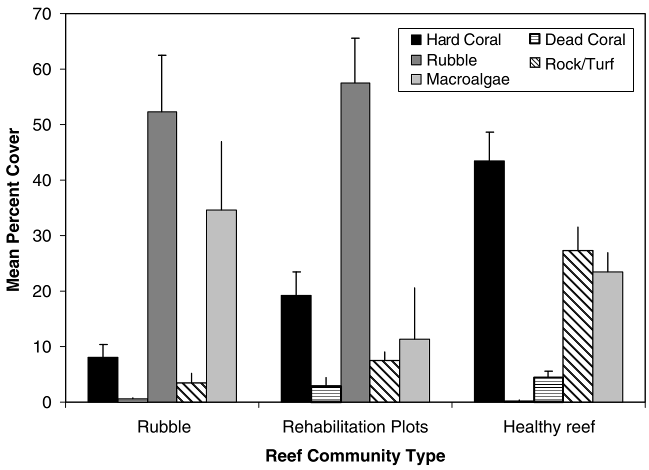

Fig. 9. Substrate composition of three community types (rubble, rehabilitated rubble plots, healthy reef) two years after plot establishment (Mean ± SE, $n = 5$ transects per community). Macroalgal cover was dominated by the brown alga *Padina australensis*.

revealed (ANOVA $F = 45.07$; $p < 0.0001$; post-hoc test: healthy reef < rehab area < rubble). Interestingly, little *Padina* grew on the rehabilitation plots; cover by the macroalga was higher, though not significantly, within both rubble and healthy reef zones.

4. Discussion

This pilot study tested an approach to stabilizing coral rubble resulting from dynamite fishing using low-cost local technology. This approach did not require costly coral transplantation, as it created conditions which favored successful recruitment and subsequent rubble consolidation. Both fish community abundance and coral cover visibly improved within two years of plot establishment. The early increase in live coral cover on our rehabilitation plots represents a trend we believe will continue over time, due to significantly higher recruit survival and growth on the mesh plots. However, as a pilot project, our approach requires testing at additional sites, to determine the replicability of our results.

We initially identified three reef zones which we monitored over time: the rubble field, our arbitrarily-selected rehabilitation area, and healthy reef. Over four years of monitoring, three distinct fish communities had developed, though one, $B1$, was transient and appeared to represent a transition between A and $B2$. The results of multivariate analyses of the fish community must be interpreted with caution; our density categories are arbitrary groupings which describe relative differences between zones within the study site over the course of this study. It is significant, however, that all rubble censuses segregated only into 1 group (A) throughout the four years, characterized by low densities, or complete absence, of target species. Similarly, all healthy reef censuses consistently grouped into $B2$, characterized by the highest overall fish density and highest abundance of target fish species. The rehabilitation area, in contrast, showed a gradual temporal shift from A to $B2$ over the course of our study. Further, there was a five-fold increase in biomass from 2003 to 2005/6 in the healthy reef zone. This was a direct result of both rehabilitation and improved management. Our involvement in the community appeared to positively influence enforcement, which we sought to further strengthen by providing a Coastal Law Enforcement Training Workshop in October 2005 for CABAFA members. Thus, we cannot tease out the effects of our rehabilitation and better management on the shifts we see in the fish community. Improved enforcement is clearly reflected in the rapid increase in target fish biomass for all three monitored zones soon after the training, and for the remainder of our study. However, our results also indicate that improved enforcement may have its greatest impact on fish biomass in healthy reef and rehabilitated areas, but much less so in rubble fields. Biomass increased significantly within the rubble field, to almost 6000 g/500 m^2 after three year, but was still approximately half that of the healthy reef and rehabilitation plots. Efforts to protect reefs with extensive untreated rubble that show no improvement in coral cover may, therefore, waste limited resources.

The rapid response of herbivores in all community types was consistent with what has been reported elsewhere. McClanahan et al. (2000) reported that common herbivores increased in biomass significantly faster than other trophic groups in reefs where macroalgae removal had been undertaken as a rehabilitation measure. The fish community in the Calagcalag MPA appeared to respond similarly to a different mitigation technique. In contrast, large, long-lived piscivores predictably showed a much slower response. This is to be expected; Russ and Alcala (2004) calculated that 15 years is necessary for full recovery of predatory fish species within MPAs, assuming full protection. Therefore, visible spillover effects of these species on the adjacent fishery can be predicted to take longer.

Since their establishment, rehabilitation plots have remained intact over three storm seasons. Although our original concern was that mesh sheets would become detached and foul surrounding coral heads, all sheets have remained firmly attached, and no rock piles have overturned or shifted (L.R., pers. obs). One particularly severe storm in October 2004 resulted in partial coverage by shifting rubble (1/3 of each plot) of two plots. We elected to leave the rubble in place to observe its effect over time. Initially, tagged coral recruits showed higher mortality on these plots; Plot 1, in particular, has continued to show low recruit numbers. Both of these plots were located on a slight slope, which was undoubtedly a major factor in the movement of rubble and subsequent recruit mortality. Interviews with local fishers regarding the severity of this storm indicated that it represented the most severe weather this coastal area generally receives. Therefore, we conclude that, barring a rare catastrophic storm event, the plots would be expected to remain stable and intact over the early years of deployment, while consolidation by recruits was taking place.

The timing of plot deployment appeared to have a major effect on the speed at which plots would become colonized by coral recruits. Recruits, 1–1.5 cm in diameter, were first observed on mesh within three months after the June deployment. The size of these recruits strongly suggested that these were products of the summer spawning season (May–June 2003), settling onto mesh or underlying rubble shortly after deployment. Recruitment continued to increase thereafter, even after the spawning season. This could be explained by the aseasonal settlement of brooded corals such as *Pocillopora damicornis* and the hydrozoan *Millepora dichotoma,* and by the eventual appearance of recruits that had cryptically settled among rubble fragments and were initially not visible. In contrast, no recruits were observed on the October-deployed plots for approximately one year after deployment, though when they did appear, their numbers were high and approximated those on the small plots. By July 2006, the number of recruits per square meter on June- vs. October-deployed plots was approximately the same. It is unclear why aseasonal species such as *P. damicornis,* common on the June plots, failed to appear on the October plots for almost one year post-deployment. Certain species of corals and other invertebrates settle aggregatively, and many require a substrate that is appropriately conditioned (Morse et al., 1996; Raymundo and Maypa, 2004). Regardless of reasons for the observed difference, our results suggest that it is important to deploy mesh to coincide with the broadcast-spawning season. In reef communities dominated by annually spawning corals (acroporids, faviids, etc.), plots could remain virtually uncolonized until months after the following spawning season if timing is not considered.

The cost of materials and labor to deploy the plots averaged \$75/17.5 m^2 plot. As materials were locally available, and CABAFA provided voluntary assistance, the cost was minimized. Additional costs were incurred for monitoring. The plots themselves needed no maintenance; once established they required no additional anchoring or cleaning over the three years they were monitored. If we had elected to completely cover the entire rubble field (a 0.24 ha area), the initial outlay is estimated at \$10,560. Conversely, establishing rehabilitation "islands" throughout the 0.24-ha area (at our current ratio of 5 plots/500 m^2) would cost approximately \$3300. This approach, combined with our reliance on local materials and volunteer assistance, made this relatively cost-effective. Spurgeon and Lindahl (2000) reviewed current reef restoration methods and reported costs ranging from US\$13,000 to >US\$100 mil/ha of damaged reef. Other cost-effective methods are available (Bowden-Kerby, 1997; Lindahl, 1998), though most rely on coral transplantation and are inappropriate for unstable rubble fields. Therefore, this method, at present, appears to be one of the most cost-effective techniques currently available, and one of the few (see Fox et al., 2005) that directly addresses the issue of shifting rubble.

Our approach did not necessitate coral transplantation, as recruits were abundant and survival was high on the mesh substrates. The site had the advantage of having natural mature colonies nearby which provided propagules. However, in areas with few reproductive colonies nearby, transplantation can "jump start" recovery by increasing habitat complexity in the early stages, if this is a perceived necessity, fragments are readily available, and larval supply is low. As other studies have shown (Birkeland et al., 1979; Harriot and Fisk, 1988; Clark and Edwards, 1995), survival and re-establishment of transplants varies between species, is dependent on attachment method and fragment size, and is labor-intensive and costly. With careful species selection and attachment protocol, efficacy of transplantation can be maximized (for a recent review of active restoration measures, see Rinkevich, 2005).

We strongly believe that the positive shifts in the target fish community (increased biomass, average size) were a product not only of our rehabilitation treatments, but also of improved management. The two factors worked synergistically to bring about change: facilitating natural recovery via the temporary creation of additional fish habitat and subsequent long-term increase in living coral cover may not have triggered an increase in fish biomass without reduced poaching. Conversely, improved management may not have occurred without our intervention and assistance. Numerous examples exist throughout Southeast Asia of the necessity of continuing support and involvement of outside organizations, largely from academia, NGOs or government institutions, to the continued success of community-based management (White and Vogt, 2000; Chou et al., 2002). The initial positive results of this project have clearly illustrated the importance of addressing management concerns when considering rehabilitation options, and basing the development of mitigation technologies in sound science.

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