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Effectiveness of village-based marine reserves on reef invertebrates in Emau, Vanuatu

THEMATIC SECTION
Community-based natural resource management (CBNRM): designing the next generation (Part 2)

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SUMMARY

Despite the current expansion of community-based marine conservation initiatives in the Pacific, few studies have specifically addressed their ecological efficiency to restore or enhance reef invertebrate resources. This paper investigated the effects of two very small (< 0.05 km^2) recent village-based marine reserves (*tabu* areas) located along the shallow fringing reef of Emau island, Vanuatu. Surveys focused on heavily harvested species (namely trochus, giant clams and green snails) and involved both experienced scientists and local villagers. Abundance, density and individual size data were collected by snorkelling along random transect belts located inside and outside the tabu areas, using simple PVC measuring tools specifically developed for participative monitoring. Habitat was assessed using a photographic method to quantitatively describe varied reef substrata. Resource recovery varied between the areas as a result of species-specific responses to contrasted reserve characteristics and local management practices. Fast-growing mobile *Trochus niloticus* exhibited strong positive abundance and size responses only within the older larger tabu area through the combined effects of protection from harvesting and translocation actions by local fishers. Similar trends were observed to a lesser extent for sessile slow-growing giant clams (*Tridacna* spp.), but these were not significant after four years of closure. Despite historical evidence of their presence in the area, surveys emphasized the severe population collapse of the heavily targeted green snail (*Turbo marmoratus*). Under certain conditions, very small-scale reserves, such as those implemented by village-based conservation initiatives, can rapidly and efficiently enhance local reef invertebrate resources. It is still unclear whether the changes are sufficient to restore critical levels of spawning biomass at larger scale and reverse the severe depletion of invertebrate resources occurring in Vanuatu.

Keywords: coral reefs, invertebrates, community-based management, Pacific

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INTRODUCTION

Concerns about overfishing in coral reef ecosystems have increased over the last decades; most Pacific insular countries are at risk of complete depletion of some vulnerable traditionally-harvested subsistence or commercial marine species (Ruddle 1998; Hunt 2003). Governance of marine tenure systems across the region, including issues of leadership, customary legitimacy and territory ownership, has a major influence on the complex relationships between communities and their environment, and more specifically on the management of fishing practices (Aswani 2005). Acknowledging that success or failure of management efforts in such systems largely depends on the attitude of the community owners and users, government fisheries managers have increasingly interacted with traditional authorities that control access rights and fishing rules over near shore areas and associated resources (Adams 1998; Zann 1999; Cooke *et al.* 2000). This situation catalysed the rise of cooperative management approaches across the whole Pacific region, where management options were decided by, and for, local communities with support from government agencies (Cinner & Aswani 2007). Community-based marine resource management may thus now be more widespread in Oceania than in any other tropical region in the world (Johannes 2002), with increasing support at national and international levels mainly owing to the worldwide failure of top-down centralized fishing regulations (Mora *et al.* 2009) and the increasing emphasis on the establishment of marine protected areas that mimic traditional fishing organizations (Cinner 2007).

In Vanuatu, fishing for sale and/or subsistence has severely affected the live stocks of reef molluscs, with populations now considered close to collapse in many locations despite the presence of suitable habitats for juveniles and adults (Amos 1995). In this context, since the early 1990s, Vanuatu has been experiencing a striking upsurge in small-scale initiatives to protect marine invertebrate resources, in particular trochus (*Trochus niloticus*), giant clams (*Tridacna* spp.), green snail (*Turbo marmoratus*) and sea cucumbers (Amos 1991, 1995; Johannes 1998; Jimmy 1995; Jimmy & Amos 2004). Between 1993 and 2001, the total number of marine resource management measures more than doubled (Johannes & Hickey 2004). One of the most common actions was the creation of very small village-based marine reserves (*tabu* areas) with permanent or temporary fishing bans for invertebrate species.

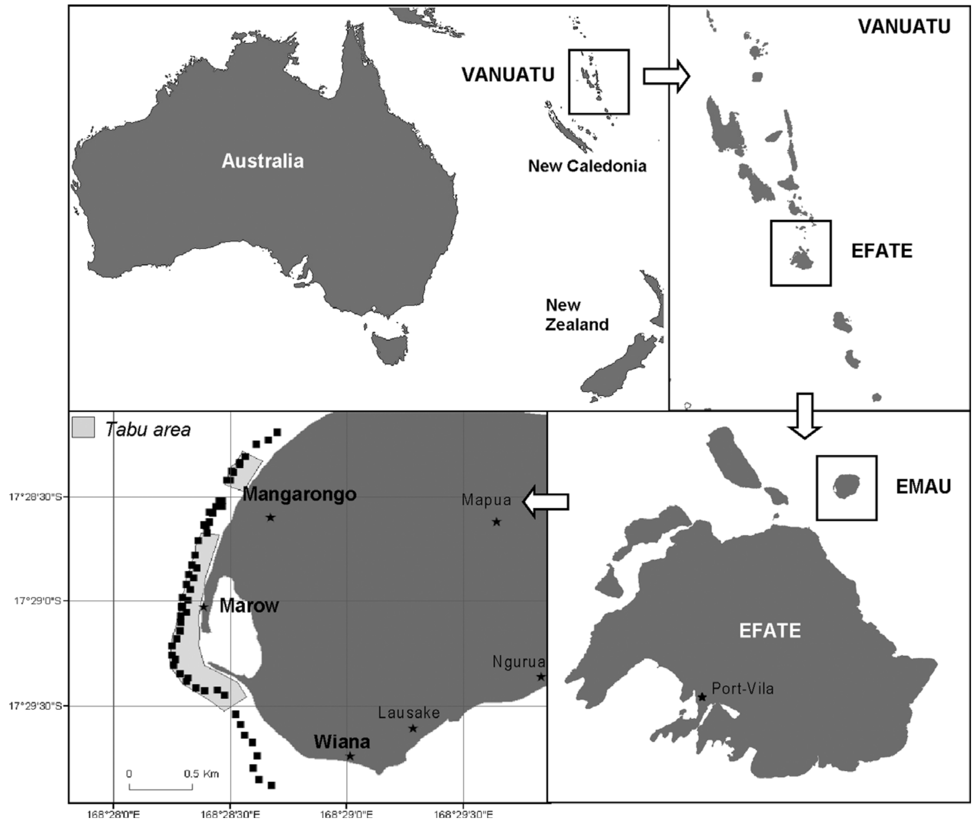

Figure 1 Location of the study area in west Emau island, North Efate, Vanuatu (south Pacific). Tabu area reef sampling stations are indicated by black squares.

About 40 partial or total fishing ground closures were reported in 21 villages across the period, usually corresponding to very restricted parts of the reefs (Johannes & Hickey 2004). These management actions generally receive strong support from local communities, suggesting that 'the marine reserve phenomenon in Pacific will continue' (Bartlett *et al.* 2009).

Despite the objectives of such locally-based conservation initiatives, biological and ecological considerations may be of secondary importance compared to their expected social and cultural outputs (Horowitz 2008; Charles & Wilson 2009; Léopold *et al.* 2010). Few papers have specifically addressed the efficiency of such small-scale reserves to restore or enhance resources (for example see Cinner *et al.* 2005; McClanahan *et al.* 2006): documented effects often concern government-led marine protected areas (MPAs) (for example Pelletier *et al.* 2005). Pacific island residents generally perceive reserves to be ecologically effective, but the scientific validation of these perceptions remains scarce and controversial (Bartlett *et al.* 2009). Expected ecological benefits may include structural and functional enhancement of fish/invertebrate communities inside no-take zones, including increases in density, spawning biomass, body size, species or genetic diversity and ecosystem resilience with, in certain cases, fishery effects through adult/larval dispersal to the adjacent fishing grounds (see reviews in Gell & Roberts 2003; Halpern 2003; Willis *et al.* 2003; Garcia-Charton *et al.* 2008; Perez-Ruzafa *et al.* 2008*a*, *b*).

However, while some empirical studies show that response to protection was reserve size-independent (for example Halpern 2003; Guidetti & Sala 2007), others highlight spatial thresholds affecting reserve benefits for harvested species (Claudet *et al.* 2008; Perez-Ruzafa *et al.* 2008*b*). This raises the question of the ecological and fisheries benefits of small-scale reserves, such as those being implemented in the Pacific owing to village-based initiatives (Berkes 2006).

In this study, we investigated the effects of two very small (<0.05 km^2) locally-managed reserves on the invertebrate resource at Emau island (Vanuatu). The specific objectives of this study were to: (1) investigate ecological effects of the reserves on heavily harvested invertebrate populations, (2) elucidate potential effects of protection from reef-top gathering on reef habitats, and (3) evaluate the results of village-based management from a conservation perspective, in the local context. Main commercial and subsistence species (trochus shell *Trochus niloticus*, giant clams *Tridacna* spp. and green snail *Turbo marmoratus*) were surveyed inside and outside the customary reserves of Marow and Mangarongo villages. Habitat features, invertebrate abundance, density and size structure were measured underwater with the support of local villagers.

MATERIALS AND METHODS

Study area

We studied a 3.7 km linear shallow fringing reef on the Western coast of Emau island, North Efate, Republic of Vanuatu (Fig. 1). Fishing activities were controlled by the villagers from Mangarongo and Marow over their traditional exclusive fishing grounds, though territory conflicts occurred at the boundaries between both villages. With support from local non-governmental organizations, village-based management has resulted in the implementation of two small customary reserves (tabu areas hereafter) with total fishing ban on all fish and invertebrates species (Fig. 1). The Mangarongo tabu area covers a 0.6 ha reef area and was established in 2005, three years before the present study. The Marow tabu area (2.3 ha) is located *c.* 350 m further along the same reef and its closure was effected in 2004, four years before the present study.

Invertebrate sampling

In March 2008, we surveyed 50 shallow reef stations randomly located along the reef (29 inside and 21 outside tabu areas). Stations were at 1–3 m depth and *c.*50 m apart. We laid one randomly selected (50 × 4 m) transect belt on each station using a 50 m colour-marked survey tape attached to the substratum. Two snorkellers swimming simultaneously along the two sides of the transect line collected data, each surveying a 2-m wide corridor. We focused our study on the harvested invertebrates trochus (*Trochus niloticus*), giant clam (*Tridacna* spp.) and green snail (*Turbo marmoratus*). All individuals belonging to the target species that were detectable without disturbing the substratum were counted and measured. Individual sizes were recorded using simple easy-to-use field tools developed for this study and suitable for participative monitoring (for example Tawake *et al.* 2001). They consisted of two specific underwater PVC measuring devices: (1) a 35-cm calliper used for giant clams, graduated from 0 to 30 cm in 2-cm size intervals and (2) a 40 × 15 cm plate with four calibrated holes (6–8–10–12 cm in diameter) used to measure trochus and green snail diameters. Invertebrate sizes were recorded by ticking individual marks directly on the PVC devices. Abundance data per species were derived by simply counting the individual size marks written on the devices.

Participative monitoring

The invertebrate surveys involved both experienced scientists and trained local villagers; six different snorkellers (three scientists and three villagers) were selected for the study needs. Before starting, local people were trained for half a day in the sampling protocol and use of the PVC measuring tools. Each of the 50 stations was then randomly assigned to a unique team composed of two scientists or two villagers, so as to investigate individual and expertise-related effects on resource monitoring.

Habitat

For each station, sediment type and substratum coverage variables were estimated using a photographic method developed to quickly and quantitatively describe contrasting reef habitats (Dumas *et al.* 2009). Pictures were taken from the surface along transects using a standard digital 8 megapixels Canon S80 camera in underwater housing, oriented perpendicular to the substratum; 25 pictures were taken per transect (namely one shot every two metres) and subsequently imported into an image analysis software including efficient user-friendly features for the estimation of sediment/substratum cover (CPCe [Coral Point Count with Excel extensions] software; Kohler & Gill 2006). Surface estimates expressed in per cent cover were derived from random stratified point count techniques using a nine points per m^{-2} ratio ensuring reliable habitat profiles with low bias and high precision. Eighteen local habitat variables were considered, related to sediment type and substratum coverage by large sessile organisms (Table 1). Percentage cover was then aggregated at the transect level (Dumas *et al.* 2009).

Table 1 Habitat variables referring to sediment type and substratum coverage used for habitat characterization in the selected sites (west Emau, North Efate, Vanuatu).

Sediment type	*Substrate coverage*
Mud	Branching corals
Sand	Digitate corals
Rubble (1–5 cm)	Tabular corals
Boulders (< 100 cm)	Massive corals
Bedrock	Submassive corals
Dead coral substrate	Foliose corals
	Encrusting corals
	Soft corals (Alcyonarians)
	Fire corals (Milleporidae)
	Seagrass
	Encrusting algae
	Macroalgae

Data analysis

We assessed the influence of expertise level on field observations using non-parametric Mann-Whitney U tests on abundance estimates from scientists versus those recorded by the trained villagers. Individual (between-diver) effects were also tested using non-parametric analyses of variance (Kruskall-Wallis ANOVAs).

We investigated the habitat-related effects of protection using a combination of univariate and multivariate techniques. The similarity of the habitat in tabu and non-tabu stations was assessed in each village using multivariate ANOSIM procedures on the 18 substratum variables (Clarke & Warwick 2001). From the 18 sunstratum variables, we retained six variables with a potential protection-related effect (total live coral, branching coral, encrusting coral, rubble, bedrock and sand; see Leujak & Ormond 2007, 2008) for non-parametric Mann Whitney U tests, in order to check for differences between tabu and non-tabu areas.

We assessed the relationships between species spatial patterns and habitat using multivariate techniques; the 18 substratum variables (Table 1) were ordinated using

Table 2 Influence of training and individual effects on the invertebrate surveys in west Emau (North Efate, Vanuatu). Total transects surveyed (%) and mean abundances per transect (± SD) for *Trochus niloticus* and *Tridacna* spp. Associated tests for team- and diver-effects. NS = not significant.

Team	*Transects (%)*	*Mean abundance (n ± SD)*	
		T. niloticus	*T. maxima*
Team 1			
All divers	57.1	0.6 (1.1)	0.7 (1.1)
Diver 1	9.8	0.6 (1.2)	1.3 (2.1)
Diver 2	17.9	0.8 (1.2)	0.5 (0.6)
Diver 3	29.5	0.6 (1.0)	0.5 (0.7)
Team 2			
All divers	42.9	0.8 (1.8)	0.7 (1.2)
Diver 4	8.9	1.8 (3.4)	1.0 (1.6)
Diver 5	26.8	0.6 (1.0)	0.8 (1.1)
Diver 6	7.1	0.5 (1.1)	0.0
Team effect		NS	NS
Diver effect		NS	NS

non-metric multidimensional scaling (MDS), in order to establish a multifactorial typology of the habitat. We then plotted species abundances on the resulting diagrams.

We assessed the ecological effects of the Mangarongo and Marow tabu areas on invertebrate population structure by comparing total abundance and size variations both inside and outside tabu areas, using non-parametric Mann-Whitney U tests. Species spatial distribution patterns were addressed by plotting abundance data per species relative to distances from village centre; data were fitted using non-linear least square regressions.

RESULTS

Diver effects

We were unable to identify expertise-related bias when comparing species abundance data between scientists and local fishers (Table 2). Both teams recorded extremely similar abundances regardless of the species considered (Mann-Whitney U tests, $n = 100$, $p = 0.95$ and 0.55 for *T. niloticus* and *Tridacna* spp., respectively). Similarly, we detected no individual effect when comparing data from the six snorkellers (Kruskall-Wallis ANOVAs, $n = 100$, $p = 0.86$ and 0.08 for *T. niloticus* and *Tridacna* spp., respectively).

Invertebrate assemblages

Abundances of harvested species were generally low, ranging from 0 to 700 individuals ha^{-1} (i.e. 0–14 individuals per transect). Giant clams (*Tridacna* spp.) and trochus (*Trochus niloticus*) exhibited similar mean densities of 74 and 81 individuals ha^{-1} (1.5 and 1.6 individuals per transect), respectively, while *Turbo marmoratus* was not observed in the survey transects.

Habitat

The 18 substratum variables did not reveal marked differences related to reserve status in the Marow or Mangarongo areas (Fig. 2). Only a few stations in Marow reserve indicated some habitat differences in terms of higher dead coral cover (Fig. 2*a*, lower right corner). Multifactorial analyses of similarity (ANOSIM) did not show any habitat differences between tabu and non-tabu areas (Marow, R = 0.09, $p = 0.11$; Mangarongo, R = 0.112, $p = 0.13$). Only encrusting coral cover and sand showed significant differences in the Marow tabu area, while other variables were similar both inside and outside the tabu area (Table 3). Protection status was not a major structuring factor for the studied reef habitats.

Influence of tabu areas on invertebrate structure

The surveyed reef species exhibited very patchy distributions. On the whole, the Marow tabu area exhibited larger invertebrate populations (mean 2.7 individuals transect^{-1} for *T. niloticus* and 2.1 individuals transect^{-1} for *Tridacna* spp.) than the Mangarongo tabu area (mean 1.0 individuals transect^{-1} for *T. niloticus* and 1.1 individuals transect^{-1} for *Tridacna* spp.) (Fig. 3).

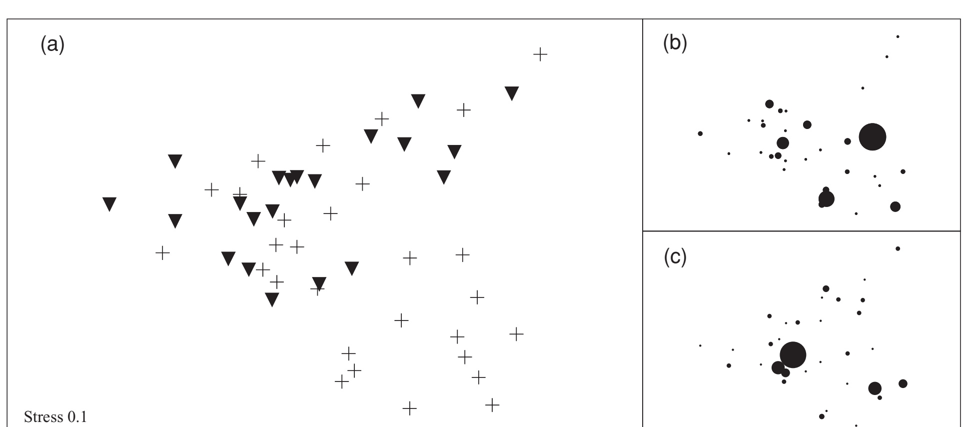

Figure 2 Two-dimensional MDS of the reef stations in west Emau (North Efate, Vanuatu) based upon habitat variables. (*a*) Station plot showing tabu (+) versus non-tabu (▼) stations. Same plots with black circles proportional to the abundance of (*b*) trochus shells (*Trochus niloticus*) and (*c*) giant clams (*Tridacna* spp.), respectively.

Table 3 Comparisons of reef habitat variables between tabu (inside) and non-tabu (outside) areas in west Emau (North Efate, Vanuatu). Mann Whitney's U tests: $^{*}p < 0.05$, NS = not significant.

Habitat variable	*Mangarongo tabu area*			*Marow tabu area*		
	inside	*outside*	*p*	*inside*	*outside*	*p*
Live coral (total)	28.5	32.7	NS	18.9	25.1	NS
Branching coral	1.9	2.5	NS	2.9	1.9	NS
Encrusting coral	7.7	6.1	NS	2.4	4.6	*
Rubble	0.7	2.4	NS	3.2	2.9	NS
Bedrock	35.2	28.8	NS	21.1	23.2	NS
Sand	2.6	2.8	NS	0.7	2.2	*

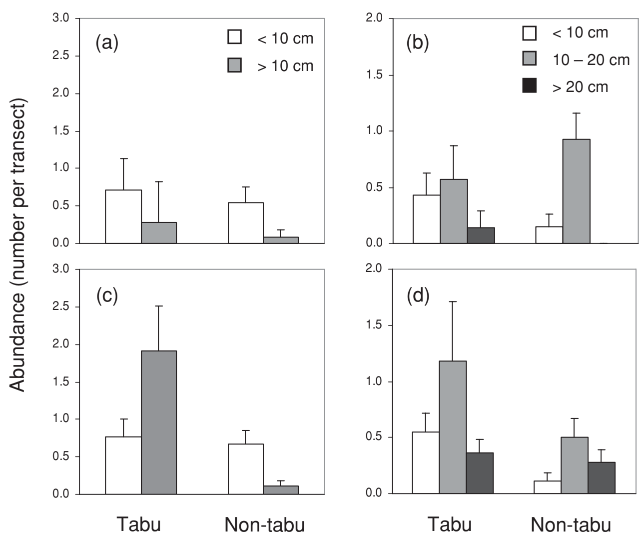

Figure 3 Abundances (mean ± SE) of different size classes of target species in tabu versus non-tabu reef stations in Mangarongo (*a*, *b*) and Marow (*c*, *d*) villages (west Emau, Vanuatu). (*a*, *c*) Trochus shells (*Trochus niloticus*) and (*b*, *d*) giant clams (*Tridacna* spp.)

For Marow, *T. niloticus* total abundance was three times greater inside the tabu area than outside (2.7 and 0.8 individuals transect^{-1} for stations inside and outside the reserve, respectively; Mann-Whitney U test, $p < 0.05$, $n = 40$). Stations inside the tabu area harboured more large (> 10 cm) individuals of trochus (1.9 individuals transect^{-1} inside as opposed to 0.1 individuals transect^{-1} outside Marow reserve; Mann-Whitney U test, $p < 0.01$). However small to medium size trochus abundances did not differ inside and outside the reserve (Table 4). We observed a marked longitudinal structure for *T. niloticus* in the Marow area; abundances were at their greatest in reef stations located in front of the village, then decreased towards both edges of the tabu area (Fig. 4*a*). We found that non-linear least square regressions of abundance data against distance from the village centre (Fig. 4*b*, *c*) indicated a significant exponential decrease in trochus abundances northward and southward from the village centre (fitted simple exponential model accounting for 51% and 45% of total variance respectively, $p < 0.01$). We did not observe such spatial gradients for giant clams, although higher abundances were consistently found close to the north edge of the reserve (*c*. 500 m distance from the village centre). Giant clams of all sizes were generally more abundant inside the tabu area (Fig. 3 ; mean 2.1 and 0.9 individuals transect^{-1} inside and outside tabu area, respectively), but results were only significant for individuals in the 8–10 cm size class (Mann-Whitney U test, $p < 0.05$).

Table 4 Comparisons of tabu (inside) and non-tabu (outside) areas on trochus shell (*Trochus niloticus*) and giant clam (*Tridacna* spp.) densities and sizes in west Emau (North Efate, Vanuatu). Means per transect and results of Mann Whitney's U tests. Levels of significance: $^{*}p < 0.05$; $^{**}p < 0.01$, NS = not significant.

Variable	*Mangarongo tabu area*			*Marow tabu area*		
	inside	*outside*	*p*	*inside*	*outside*	*p*
Trochus niloticus						
Total abundance	1.00	0.62	NS	2.68	0.78	*
Size ≤ 6 cm	0.00	0.31	NS	0.32	0.27	NS
Size 6–8 cm	0.00	0.15	NS	0.18	0.33	NS
Size 8–10 cm	0.71	0.08	NS	0.27	0.06	NS
Size 10–12 cm	0.29	0.08	NS	1.00	0.11	**
Size ≥ 12 cm	0.00	0.00	NS	0.91	0.00	**
Tridacna maxima						
Total abundance	1.14	1.08	NS	2.09	0.88	NS
Size ≤ 4 cm	0.00	0.00	NS	0.09	0.00	NS
Size 4–6 cm	0.00	0.00	NS	0.05	0.00	NS
Size 6–8 cm	0.29	0.15	NS	0.05	0.11	NS
Size 8–10 cm	0.14	0.00	NS	0.36	0.00	*
Size 10–12 cm	0.00	0.15	NS	0.32	0.11	NS
Size 12–14 cm	0.14	0.23	NS	0.18	0.06	NS
Size 26–28 cm	0.00	0.00	NS	0.05	0.00	NS

Total abundance or abundance per size class for *T. niloticus* did not differ significantly between tabu and non-tabu reef stations at Mangarongo (0.6 and 1.0 individuals transect^{-1} inside and outside tabu area, respectively; Mann-Whitney U tests, $n = 20$). *Tridacna* spp. also exhibited similar abundance values both inside and outside the Mangarongo tabu area (mean 1.1 individuals transect^{-1} in both). While large clams (namely those > 20 cm) were only found inside this area, no differences in abundance were detected for any of the 13 size classes (Table 4).

DISCUSSION

Effectiveness of small tabu areas on invertebrate resources

Our results suggest that, under certain conditions, even very small-scale tabu areas such as those implemented by village-based conservation initiatives can efficiently enhance reef invertebrate populations, at least at local scale. Yet, despite similar location and status, the benefits of the two tabu areas

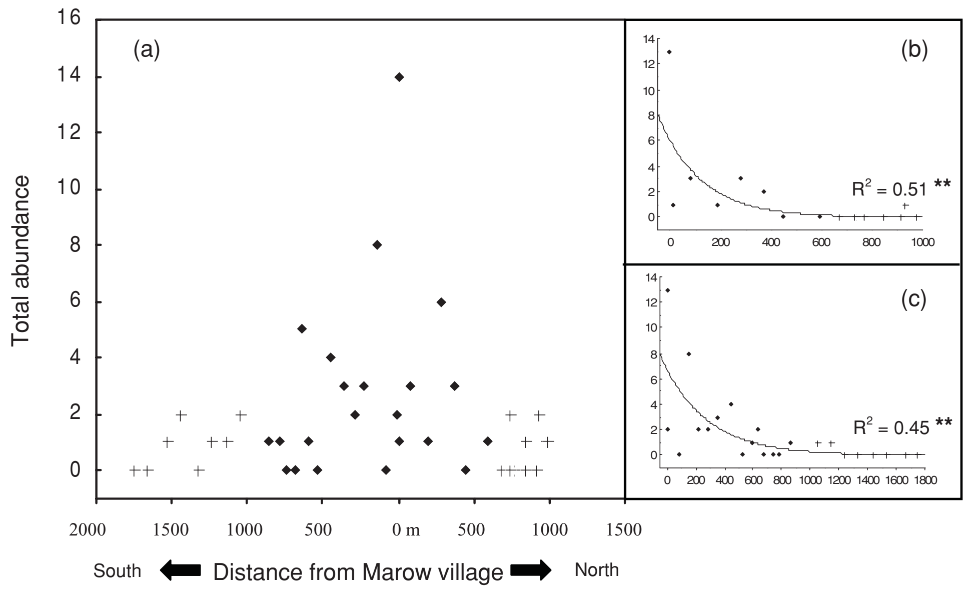

Figure 4 Longitudinal distribution pattern of *Trochus niloticus* along the reef stations of Marow (west Emau, Vanuatu). Abundance per transect plotted against distance (m) from the centre of Marow village for tabu (♦) and non-tabu (+) sites for (*a*) all transects, (*b*) north transects and (*c*) south transects. Exponential curve with associated coefficient and probability ($^{*}p < 0.05$; $^{**}p < 0.01$).

studied were strongly site-specific. Density and size estimates provide clear evidence of population enhancement in the Marow tabu area, in particular for the mother-of-pearl *Trochus niloticus*. The Marow tabu area also harboured large adult individuals, in contrast with the surrounding reef stations where they were virtually absent. We observed similar trends for giant clams *Tridacna* spp. (almost all individuals observed by scientist team belonging to *Tridacna maxima*), although tabu effects were less significant. The lack of a clear positive response for *Tridacna* spp. in Marow may also partially result from statistical issues related to generally low abundances in the study area (only 74 individuals were recorded across the 50 transects). On the contrary, the Mangarongo tabu area did not significantly affect trochus or giant clam populations. Despite historical evidence of the presence of green snails (*Turbo marmoratus*) in the area, we did not observe any specimens at the studied stations, regardless of their protection status; this supports the likely accuracy of reports by local fishers of a severe population collapse.

These results highlight different efficiencies in restoring harvested invertebrate populations occurring along the same reef at small spatial scales. Effects of reserves on assemblages can be modified or obscured by confounding habitat effects (Garcia-Charton *et al.* 2008), yet habitat may only partially account for the observed difference between Marow and Mangarongo tabu areas. Despite slightly higher dead coral cover inside the Marow tabu area, the habitat typology derived from the 18 sediment/substratum coverage variables emphasized strong similarity between the Marow and Mangarongo stations. Hydrological parameters (for example water current, temperature, salinity and nutrient loads) were not recorded in this study, but are unlikely to strongly differ at the scales involved, in particular given the closeness of the two tabu areas (only 350 m apart along one continuous reef). More likely, different stages of population recovery may be hypothesized as a result of species-specific responses to contrasted age or size characteristics of the studied areas and/or local management practices.

Ecological responses to protection

While our data support the conclusions of Halpern (2003) that marine reserves can induce rapid increases in population densities over short periods of time, they also suggest that effect magnitude may be species size and time-dependent. Thus, population recovery was currently observed only within the older and larger Marow tabu area (2.3 ha, closed four years before our study), in contrast with the smaller more recent Mangarongo tabu area (0.6 ha, closed three years before our study). Under a certain threshold, reserve size may become a critical factor, by limiting the availability of suitable reef habitats for species reproduction/growth, in particular for species exhibiting ontogenic changes in their habitat preference such as in *T. niloticus*. Moreover, very small reserves may not enable a significant proportion of mobile trochus to remain protected from fishing if their displacement range exceeds the no-take zone (Chapman & Kramer 2000). Purcell (2004) recommended that MPAs should include a band of reef at least 0.5 km wide, including reef slope, crest and flats used by juvenile and adults trochus. Secondly, the rapidity of response to protection is also mediated by species life-history strategies, with quicker effects expected for fast-growing and early-mature species. Large benthic invertebrates do not usually fall into the latter category, therefore requiring more time before significant effects on population structure can be reached. This is more likely the case for slow-growing bivalve species, especially if they also experience highly variable temporal recruitment such as giant clams (Lucas 1994). These results therefore support the conclusions of Sale *et al.* (2005), highlighting the importance of framing any ecological assessment of reserve efficiency in a spatial (for example reserve size) and temporal (for example duration of protection) context.

Yet, the population increase observed in Marow tabu area for trochus (especially for large adult individuals >10 cm) may have different causes. Local (intra-reef) adult migrations may be discounted: our results clearly emphasize the absence of large individuals in adjacent non-tabu stations. Similarly, migration from remote reefs is unlikely, given the restricted displacement ability of adult trochus (Clarke *et al.* 2003). If recruitment occurs across the area, natural population growth followed by the exclusion of large individuals outside Marow tabu area through fishing could occur. Tagging experiments partly support this hypothesis, as growth rates at this island make it theoretically possible for newly settled trochus to reach 10 cm inside the tabu area in less than four years (Bour 1985). However, because the quality of trochus shell generally decreases with size owing to sun bleaching and deterioration by boring organisms, middle-sized trochus are also actively targeted by fishers throughout the Pacific (Nash 1993) and, in Vanuatu in particular, regardless of the 9 cm minimum size limit set in 1983. Protection from fishing inside the Marow tabu area should therefore not only benefit large individuals; densities of 6–8 and 8–10 cm size-classes should also increase, and we did not observe such an increase.

Village-based management practices

So where do the large trochus come from? That observed size patterns may result from a combination of direct human intervention and natural biological processes, through the translocation of individuals from non-protected stations by the fishers themselves. Interviews with local fishers from Marow village indicated that they usually move middle and large trochus occasionally found outside the tabu area towards the centre of the protected zone. This is consistent with the trochus abundance peaking in front of the village and decreasing towards the edges of the tabu area. Similar translocation actions were reported by Marow fishers for adult individuals of *Hippopus hippopus* giant clams. According to the fishers, rationales for this primarily included the desire to avoid poaching at the boundaries of their village tabu area and to increase the stock of harvestable individuals with a view to future reopening of the tabu area. In contrast with conventional MPAs, definitive (with no time limit) fishing bans rarely occur in Vanuatu, and village-based reserves commonly experience partial or total openings, for example for customary-related events or when resource levels are considered sufficient by the community. While these translocation actions do not appear to be custom driven, they may have profound ecological consequences, in particular from the perspective of population recruitment. Indeed, fishers tend to associate breeding stock aggregation with fishery closure, in a similar way to government-supported restocking actions enforced throughout the country (Jimmy 1995). The importance of gregarious behaviour for optimal reproduction and/or larval settlement is increasingly recognized for marine invertebrates including trochus, green snails and clams (Ettinger-Epstein *et al.* 2008; Hadfield & Paul 2001). Since recruitment appears to be strongly density-dependent for these species, increasing their density inside the tabu areas through translocation/aggregation by the fishers themselves may indirectly enhance reserve effects. Even with the support of these informal village-based management practices, self-replenishment of such severely depleted populations remains uncertain. Given the low abundances of target mollusc species recorded across the area, threshold densities of adult conspecifics ensuring natural recovery may not be reached because of Allee effects (for example Stephens *et al.* 1999), at least in the present phase. In the case of fast-growing trochus, short-term stock rebuilding could still be expected inside the tabu area if juvenile growth counterbalances natural mortality. For slow-growing sessile giant clams that cannot actively aggregate for sexual reproduction, there is a risk that reduced reproductive success may cause the progressive decline and eventually the extinction of populations in the area, unless they are replenished by recruits from other populations and/or additional measures are taken by the community to protect and aggregate breeding stocks.

Resource surveys and monitoring

Beyond this brief study, periodic assessments are required to investigate whether and how rapidly invertebrate resources recover. For optimal results, monitoring should meet two particular criteria. Firstly, it should provide robust relevant ecological indicators of population size structure. The size data in this case helped to identify size-specific effects such as translocation. Secondly, monitoring should involve the local communities. Participatory monitoring is crucial to strong local support for conservation, therefore monitoring methods must be adapted to community education and equipment levels. In this study, we developed cheap, simple and easy-to-use devices that allowed local snorkellers to efficiently record and measure the size of trochus and giant clams, as accurately as trained scientists. A sampling design (including the location and the dimensions of transect stations) was also provided to the communities to improve their locally-based monitoring programme, with the support of both governmental and non-governmental agencies.

Restoring critical densities of spawning biomass is a challenge in coral reefs, where invertebrate populations may not easily recover from overfishing (Nash 1993). In Vanuatu, as in other Pacific countries, further scientific work will be required to validate the ecological effectiveness of highly diverse community-led resource management initiatives, at relevant temporal and spatial scales. Keeping in mind that results tend to be site- and species-specific and therefore will require further testing before they can be generalized, small-scale village-based marine reserves show promising results for the management of reef invertebrates in the Melanesian context.

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