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Multivariate responses of the coral reef fish community to artificial structures and coral transplants

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Abstract. The effects of artificial structures and coral transplants on fish abundance, number of species, and community composition were examined during a two-year study at three locations in North Sulawesi, Indonesia. Three experimental treatments (10 x 10 m rubble plots (a.) left untreated, (b.) covered with concrete structures, and (c.) covered with a combination of structures and coral fragments) were monitored using monthly underwater visual censuses. An additional census of adjacent plots in the ambient reef served as comparison with the natural reef fish community. The effect of treatments differed between experimental sites. At the site with the lowest coral cover and structural complexity in the ambient reef, fish community responses were most marked, with an 8-fold increase in fish abundance in the Structures + Corals treatment compared to the untreated rubble plot. At the other two sites, abundance and number of species in the experimental treatments did not surpass that of the natural plots. At all locations, multivariate dispersion of the fish community samples decreased with increasing complexity of the experimental plots. The results underline the importance of reef context in the selection of appropriate restoration measures and show that results may differ depending on condition of the ambient reef.

Key words: coral transplantation, artificial reefs, Indonesia, fish community, restoration

Introduction

Coral reefs are complex, heterogeneous marine habitats mainly composed of biogenic carbonate structures that are deposited by hermatypic scleractinian corals and host numerous associated species of animals and plants (Vaughan 1919, Wells 1957). Fishes are among the most conspicuous reef dwellers. A wide range of fish species depend on live corals, e.g. for food or shelter (Patton 1976, Choat and Bellwood 1991, Cole et al. 2008). Fish abundance and species diversity are positively correlated with habitat complexity and amount of live coral cover (Risk 1972, Carpenter et al. 1982, Bell and Galzin 1984, Sano et al. 1984, Gratwicke and Speight 2005).

In response to the ongoing degradation of coral reefs world wide, the discipline of coral reef restoration has become increasingly established over the past two decades, although it remains largely in its infancy compared to the restoration of other ecosystems (Precht 2006, Edwards and Gomez 2007). Clark (2002) has cautioned that ‘reef restoration is largely limited by incomplete knowledge on the ecosystem processes.’

Techniques frequently employed in coral reef restoration include the use of artificial reefs and transplantation of live corals (Jaap 2000, Clark 2002, Zimmer 2006), the latter currently being the most frequently used tool in active coral reef restoration (Edwards and Gomez 2007). However, despite the numerous studies on the link between live coral substrate and reef fishes, few workers have addressed the effects of coral transplantation on the reef fish community (Pamintuan et al. 1994, Cabaitan et al. 2008).

In this study, the effects of artificial structures alone and in combination with coral transplants on fish abundance and community composition were examined to gain a better understanding of the ecosystem processes pertaining to reef restoration.

Material and Methods

The present study was conducted at three locations in North Sulawesi, Indonesia (Fig. 1), between May 2005 and July 2007. The Gangga site was in the shallow upper reef slope in front of a dive resort, with low fishing pressure in the immediate vicinity of the experimental treatments, while the other two sites were at deeper sections of the reef slope (Table 1) and lay within the borders of Bunaken National Marine Park. At each site, three 10 x 10 m rubble plots were marked and cleared of remaining coral colonies and rocks, so that a flat rubble area remained. Plots lay at similar depths and were located between 5 and 20 m apart. At each site, the plots were randomly assigned to three treatments. Control plots (**C**) remained as empty rubble fields. In the other two treatments, the substrate was covered with 100 bamboo boards.

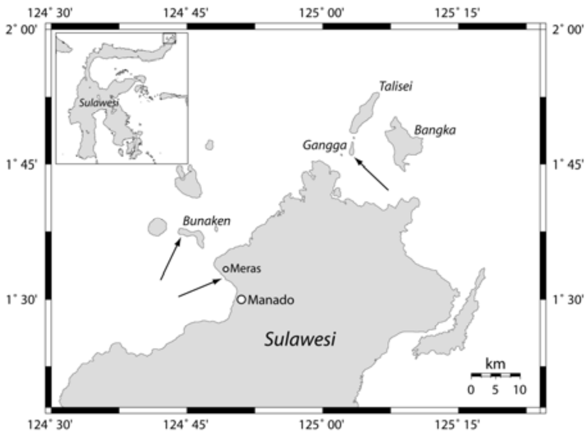

Figure 1: Map of northern Sulawesi, showing the three experimental sites. The location of the study area within Sulawesi is indicated on the inset map.

Artificial structures consisting of 5 concrete blocks each were then constructed on every second board in a chessboard pattern. In the Structures treatment (**S**), the remaining squares remained empty. In the Structures + Corals treatment (**S+C**), coral fragments were transplanted onto the empty bamboo boards between the structures (Fig. 2).

At each site, up to 2000 fragments of one species of branching *Acropora* were transplanted (Table 1). Species were selected based on abundance in the ambient reef. Each transplanted species occurred in large thickets in the vicinity of the recipient site. Additionally, fragments of *Pocillopora verrucosa* were transplanted at Gangga and Meras (Table 1). The fragments were distributed evenly among the boards and arranged at random on each board. A detailed description of the transplantation procedure is given by Ferse (2008).

Table 1: Depth of experimental plots, monitoring time frame and coral species transplanted for each site.

site	depth	monitoring	fragments transplanted*
Gangga	4-9 m	09.2005 – 05.2007	*Acropora yongei*: n = 1885 *Pocillopora verrucosa*: n = 475
Meras	12-20m	02.2006 – 06.2007	*Acropora formosa*: n = 1677 *Pocillopora verrucosa*: n = 378
Bunaken	12-19m	03.2006 – 05. 2007	*Acropora brueggemanni*: n = 1749

*n = amount of surviving fragments at the time of the first visual census

A visual census of the fish community above the plots was conducted once per month, using three replicate counts carried out within the same day between 9:00 and 17:00 h. A SCUBA diver swam across each plot in four adjacent transects of 2.5 m width and 10 m length, counting and identifying all fishes present to a height of about 2.5 m above the substrate. Cryptic and pelagic species were excluded from the census. At the beginning of each count, horizontal visibility was estimated.

To compare the fish communities in the experimental plots with that of the ambient reef, per site two 10 x 10 m plots with substrate cover representative of the surrounding reef were marked in the vicinity of the experimental plots at similar depths, and a one-time census of the fish community with three replicate counts was carried out. Substrate composition in the natural reef plots, and detailed descriptions of the ambient reefs, are reported by Ferse (2008).

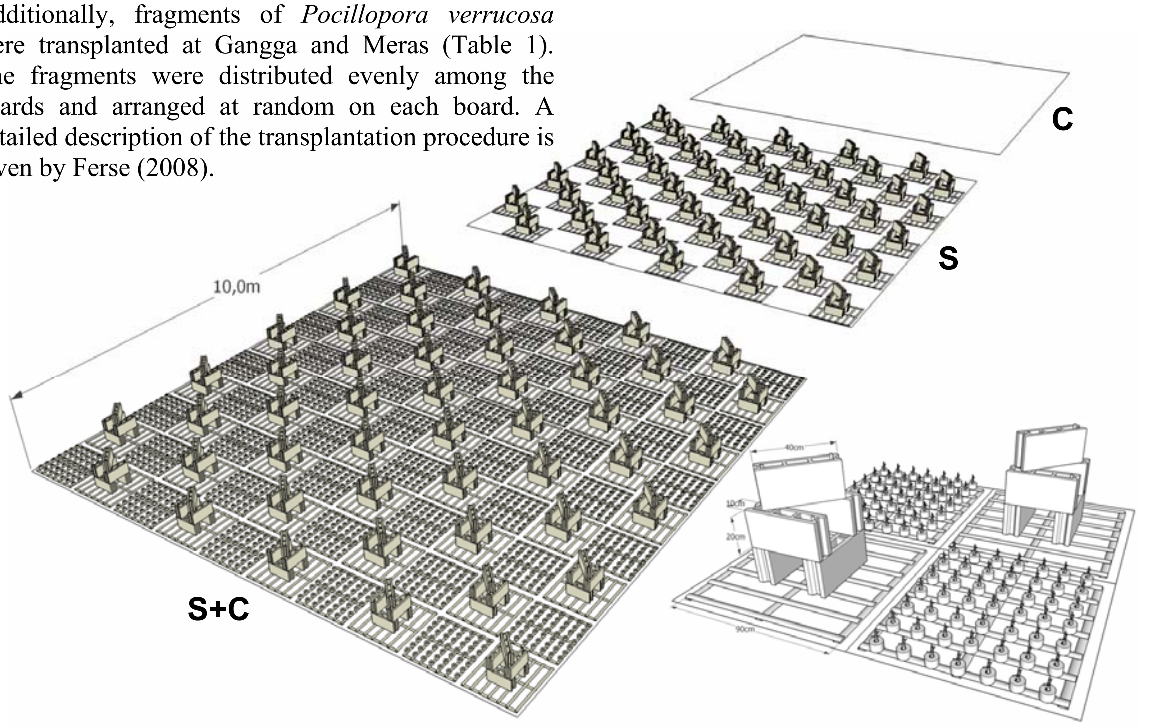

Figure 2: Sketch of the experimental set-up. In one treatment, artificial structures were interspersed with coral transplants (**S+C**, front), in a second one, only concrete structures were deployed (**S**, middle), and a third treatment consisted of a cleared coral rubble plot (**C**, back). A detailed drawing of the artificial structures and bamboo boards with attached coral transplants in shown on the lower right.

The effects of treatment on fish abundance and species diversity were assessed using a full-factorial general linear model, with time in days as independent variable and number of individuals and species as dependent variables. Underwater visibility was included as independent co-variable. Abundance data were square-root transformed to achieve normal distribution. Data from the natural reef plots were compared to data from the experimental plots taken at similar times using a one-way ANOVA. Where significant treatment effects were detected, a Tukey HSD post-hoc test at $\alpha = 0.05$ was performed to assess how treatments differed from each other. All univariate data analysis was carried out using JMP 7.0 (SAS Institute 2007).

For multivariate analysis of the fish community data, the program PRIMER 5.2.9 (Clarke and Gorley 2001) was used. Fish abundance data were fourth-root transformed and similarity of the samples was assessed using a zero-adjusted form of the Bray-Curtis coefficient (Clarke et al. 2006). To assess effects of treatments and sites on differences in the fish community composition, a crossed two-way multivariate analysis of similarities (ANOSIM) was used, and the relative multivariate dispersion of the community in the three treatments was analyzed for each site using the MVDISP routine.

Results

At all three sites, fish abundance increased markedly in the Structures + Corals treatment, while the increase in the Control plots was only slight (Fig. 3). The highest increase in abundance occurred at the shallow site (Gangga), where the number of individuals in the presence of coral transplants had increased almost 8-fold by the end of the experiment compared to the Control treatment. The linear model detected significant treatment effects (Table 2), and the post-hoc test confirmed significant differences between all three treatments.

Table 2: Results of the general linear model testing for effects of treatment, time and visibility on fish abundance at the three sites.

Test	Factor	*df*	*F*	*p*
Gangga				
ANOVA	Model ($R^2 = 0.9453$)	11,117	183.84	<0.0001
Effect Test	Treatment	2	646.52	<0.0001
	Time	1	458.03	<0.0001
	Visibility	1	0.68	n.s.
	Treatment*Time	2	62.52	<0.0001
	Visibility*Time	1	0.54	n.s.
	Visibility*Treatm.	2	8.15	0.0005
	Vis.*Time*Treatm.	2	2.79	n.s.
Meras				
ANOVA	Model ($R^2 = 0.9384$)	11,110	152.24	<0.0001
Effect Test	Treatment	2	640.31	<0.0001
	Time	1	89.03	<0.0001
	Visibility	1	34.32	<0.0001
	Treatment*Time	2	6.49	0.0022
	Visibility*Time	1	0.90	n.s.
	Visibility*Treatm.	2	2.35	n.s.
	Vis.*Time*Treatm.	2	10.87	<0.0001
Bunaken				
ANOVA	Model ($R^2 = 0.7883$)	11,105	35.54	<0.0001
Effect Test	Treatment	2	134.58	<0.0001
	Time	1	11.94	0.0008
	Visibility	1	21.17	<0.0001
	Treatment*Time	2	1.25	n.s.
	Visibility*Time	1	0.80	n.s.
	Visibility*Treatm.	2	6.75	0.0017
	Vis.*Time*Treatm.	2	0.94	n.s.

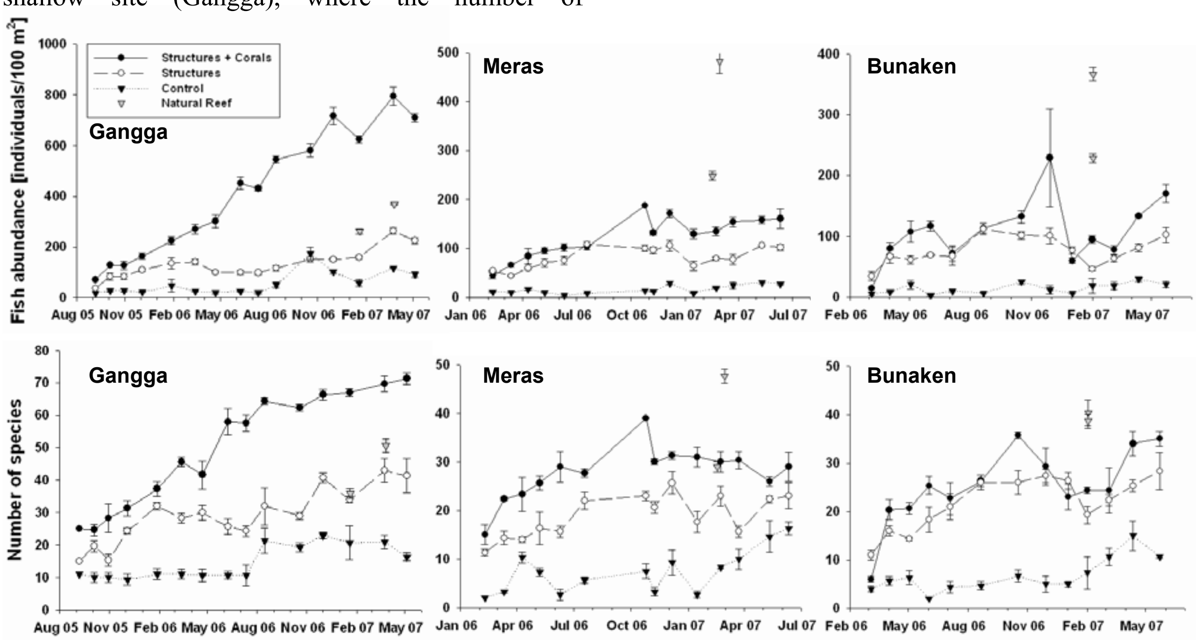

Figure 3: Fish abundance (above) and number of species (below) during consecutive censuses at the three locations (mean ± SE). The values observed during a comparative one-time census in two natural reef plots at each location are indicated by the gray triangles.

Fish abundance in the natural reef plots at Gangga was significantly lower than in the Structures + Corals treatment, but significantly higher than in the other two treatments (ANOVA, F = 161.0741, p < 0.0001, df = 3,8 and F = 379.0192, p < 0.0001, df = 3,8 for January 2007 and March 2007, respectively).

At the two deeper sites as well, the highest numbers of fishes occurred in the plots containing coral transplants. However, overall increases in abundance were less pronounced, and differences between the Structures and Structures + Corals treatments were not as marked as at Gangga (Fig. 3). Yet, the post-hoc test confirmed significant differences between all three treatments at both sites. Abundances in the natural reef plots were significantly higher than they were in the experimental plots at the time the ambient reef census was conducted (ANOVA, F = 362.9089, p < 0.0001, df = 4,10 and F = 97.5778, p < 0.0001, df = 4,10 for Meras and Bunaken, respectively).

The number of species followed similar trends as fish abundance at all sites. With few exceptions, species were most numerous in the presence of coral transplants, and the highest number of species was observed at Gangga (Fig. 3).

Table 3: Results of the general linear model testing for effects of treatment, time and visibility on number of species at the three sites.

Test	Factor	df	F	p
Gangga				
ANOVA	Model (R^2 = 0.9272)	11,117	135.65	<0.0001
Effect Test	Treatment	2	484.07	<0.0001
	Time	1	312.61	<0.0001
	Visibility	1	1.48	n.s.
	Treatment*Time	2	47.53	<0.0001
	Visibility*Time	1	0.83	n.s.
	Visibility*Treatm.	2	2.66	n.s.
	Vis.*Time*Treatm.	2	3.16	0.0461
Meras				
ANOVA	Model (R^2 = 0.8724)	11,110	68.38	<0.0001
Effect Test	Treatment	2	298.72	<0.0001
	Time	1	29.65	<0.0001
	Visibility	1	29.01	<0.0001
	Treatment*Time	2	0.36	n.s.
	Visibility*Time	1	4.15	0.0440
	Visibility*Treatm.	2	0.38	n.s.
	Vis.*Time*Treatm.	2	10.40	<0.0001
Bunaken				
ANOVA	Model (R^2 = 0.7960)	11,105	37.26	<0.0001
Effect Test	Treatment	2	141.82	<0.0001
	Time	1	54.55	<0.0001
	Visibility	1	4.91	0.0288
	Treatment*Time	2	2.23	n.s.
	Visibility*Time	1	0.23	n.s.
	Visibility*Treatm.	2	2.06	n.s.
	Vis.*Time*Treatm.	2	0.10	n.s.

Significant treatment effects were detected at all sites (Table 3), and post-hoc tests confirmed significant differences between the numbers of species in all treatments at each location. At Gangga, the amount of species in the natural reef plots did not differ significantly from that in the Structures treatment but was significantly different from the number of species in the other two treatments (ANOVA, F = 48.9081, p < 0.0001, df = 3,8 and F = 59.5524, p < 0.0001, df = 3,8 for January 2007 and March 2007, respectively).

Species number in one of the natural reef plots at Meras did not differ significantly from the number of species in the Structures + Corals plot. In the second natural plot at Meras, and in both natural plots at Bunaken, the amount of species observed was significantly higher than that found in the experimental plots at the same time (ANOVA, F = 82.1000, p < 0.0001, df = 4,10 and F = 40.4127, p < 0.0001, df = 4,10 for Meras and Bunaken, respectively).

Multivariate analysis of the fish community data revealed significant effects of treatment as well as location on community composition (Table 4).

Table 4: Results of a crossed two-way ANOSIM for effects of treatment and location using all experimental fish census samples.

Test	Factor	Test pairs	ρ
global	Treatment		0.643*
pairwise		Control, S + C	0.802*
		Control, Structures	0.751*
		S + C, Structures	0.564*
global	Location		0.830*
pairwise		Gangga, Meras	0.933*
		Gangga, Bunaken	0.891*
		Meras, Bunaken	0.664*

*significant at p = 0.001

As indicated by a multi-dimensional scaling plot of the averaged fish community data from all experimental plots (Fig. 4), the relative multivariate dispersion was highest in the Control treatment (MVDISP, relative dispersion 1.247, 1.688 and 1.489 at Gangga, Meras and Bunaken, respectively), while data from the Structures + Corals treatment were least dispersed (MVDISP, relative dispersion 0.734, 0.672 and 0.765 at Gangga, Meras and Bunaken, respectively).

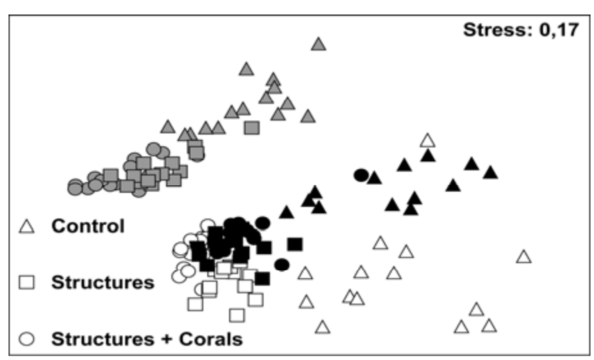

Figure 4: Non-metric Multi Dimensional Scaling (MDS) based on Bray-Curtis similarity of the average fish community data from all censuses of the experimental plots. **Gray:** Gangga, **White:** Meras, **Black:** Bunaken.

Discussion

Besides serving as food for corallivores, coral colonies can provide protection or additional habitat for fishes (e.g., Bell and Galzin 1984, Sano et al. 1984, Friedlander et al. 2003). As such, the observed positive effect of transplantation on fish abundance is not unexpected. However, fish community responses differed between the experimental sites. The most marked responses were observed at Gangga, where hard coral coverage in the ambient reef plots was less than 5 % (Ferse 2008). At Meras and Bunaken, where hard corals cover was between 13 and 29 % and the ambient reef was more heterogeneous than at Gangga, the effects of structures and coral transplants were less striking, and the values in the experimental plots remained below those in the ambient reef plots.

In previous studies, artificial reefs placed in areas of low complexity and little live coral cover have resulted in very high fish abundance and biomass (Randall 1963, Edwards and Clark 1993), while structures placed in biologically rich and structurally complex environments had values lower than the natural reef (Burchmore et al. 1985). Similarly, while the provision of structures and transplants was able to exert a significant impact on the fish community at Gangga, it appears that the experimental plots at the other two sites were not as attractive to fishes as the ambient reef area. This underlines that condition of the ambient reef should be a major consideration in the selection of appropriate restoration methods.

As indicated by a decrease in the relative multivariate dispersion of the community samples, structures and coral transplants aided in the establishment of a distinct fish community at all sites. Higher multivariate dispersion has been found in fish communities over degraded reef areas compared to healthy reef flats (Dawson Shepherd et al. 1992), and an analysis of relative dispersion may thus be an additional tool in judging the effects of restoration efforts.

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