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Coral transplantation: an approach to the reestablishment of damaged reefs*

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The natural recovery of dynamite-blasted coral reefs is extremely slow. Experiments with transplantation of coral clones were equally successful in dynamited and non-dynamited areas in central Visayas, Philippines; the average survival rate of transplants was 70%. The growth rates of transplants and equal-sized portions of the original coral heads were similar. The survival rates of transplants were apparently not correlated with substrate composition, percentage live coral cover, species diversity, and species dominance in the transplantation sites. The results suggest that transplantation can augment natural colonization of damaged reefs in the same manner that reforestation helps restore terrestrial habitats.

Coelenterates possess an extremely high capability to regenerate complete functional units — polyps or medusae. Corals, scleractinians as well as non-scleractinians, exhibit the same trait. It is unknown whether coral fragments require a minimum size to regenerate, but recent studies of Hidata et al. (1) with *Galaxea fascicularis* indicate that in at least some scleractinians, a single polyp is able to form a number of new polyps, hopefully in the direction of forming new colonies. Natural fragmentation of entire colonies and subsequent survival and attachment of the fragments may contribute considerably to the recruitment of some corals on the reef crest (2). The recovery of coral reef areas destroyed by storms or poor fishing practices is very slow (3-8). Alcala & Gomez (3) estimate that it would take proximately 38 years to attain 50% area cover of live coral in dynamite-blasted reefs in central Visayas, Philippines. It would take much longer to completely regain the original status and fish productivity of such reefs. A new approach to this problem is to initiate and accelerate recovery by transplantation of coral fragments analogous to reforestation in terrestrial habitats.

This paper deals with a series of successful transplantation experiments with six coral species in central Visayas, Philippines.

Materials and methods

Study sites. One site with three stations was in a reef off Bantayan, Dumaguete City, Negros. It was dynamite-blasted in 1968 and has a live coral cover of 10-15%. Another five sites with 10 stations were scattered around Sumilon Island off the southeastern tip of Cebu Island. Some portions of the Sumilon reef were destroyed in 1969 and have a current coral cover of less than 10%. The western side has remained unharmed and is now a marine park with an average coral cover of approximately 35% (40% along the reef edge). The 13 transplantation stations were selected to allow for comparison among a variety of environments (Table 1). The central portion of the Sumilon Marine Park served as the "control" area.

Corals. The choice of corals for transplantation was limited to those abundant in portions of the Marine Park. The

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Table 1. Descriptions of transplantation stations with corresponding survival rates in Sumilon and Bantayan, Central Visayas.

Stations*		Dynamited	Depth (m)	Current speed	Substrate area cover**	Surrounding coral community				Introduced transplant species	Survival rate (%) after 12 mo
Number	Remarks					Live coral cover (%)	Developmental stage	Species diversity (no. species /100 m²)	Dominant species		
Control Area origin of Transplants	*M. platyphylla* *H. coerulea*	no	3.0	weak	c++ r+ s++	47	climax	81	*H. coerulea*	–	
	M. prolifera *M. dichotoma*	no	2.0	weak	c+ r++ s++	40	climax	59	*M. foliosa* *M. prolifera*	–	–
	A. brueggemanni *A. prominens*	no	2.5	weak	c+ r+ s++	61	climax	19	*A. brueggemanni*	–	
1	Reef slope < 10°, exposed to current, nude area	yes	7.5	strong	c+++ r– s–	5	sere	22	*D. micranthus* *H. coerulea*	*A. brueggemanni* *A. prominens* *H. platyphylla*	44.4
2	Reef slope < 5°, large amount of *M. dichotoma* fragments	yes	10.5	strong	c– r+++ s++	14	sere	32	*M. dichotoma* *H. coerulea*	–	64.7
3a	Reef slope < 35°, large amount of dead fragments	no	9.0	strong	c+ r+++ s–	11	disclimax	51	*Fungia* sp.	*A. prominens* *H. platyphylla* *M. platyphylla*	66.6
3b	Reef platform, exposed to current, large coral heads	no	5.5	strong	c+++ r+ s–	39	climax	71	–	–	100.0
4a	Reef slope < 40°, next to small canyon, permanent sandflow	no	7.5	moderate	c+ r++ s+++	22	disclimax	75	*S. caliendrum* *Fungia* sp.	*A. prominens* *M. platyphylla* *M. prolifera*	83.3
4b	Reef crest, adjacent to sandbed	no	3.0	weak upwelling	c+++ r+ s++	19	climax	51	–	*A. brueggemanni* *M. dichotoma* *M. prolifera*	50.0
5a	Reef slope < 15°, small terrace, exposed to current	no	10.5	strong	c+ r+++ s+	22	disclimax	67	*S. caliendrum* *Fungia* sp.	*A. prominens* *M. platyphylla* *M. prolifera*	83.3
5b	Reef slope < 35/, entrance of cave, no direct sunlight	no	10.5	moderate	c++ r+++ s–	22	disclimax	67	*S. caliendrum*	*A. prominens* *M. platyphylla* *M. prolifera*	66.6

(Table 1, continued on p. 162-163)

(Table 1, continued from p. 160-161)

Stations*		Dyna-mited	Depth (m)	Current speed	Substrate area cover**	Surrounding coral community				Introduced transplant species	Survival rate (%) after 12 mo
Number	Remarks					Live coral cover (%)	Develop-mental stage	Species diversity (no. species /100 m^2)	Dominant species		
5c	Reef crest, large coral heads	no	2.5	moderate upwelling	c+++ r+ s+	30	climax	42	*P. nigrescens* *P. attenuata*	*A. brueggemanni* *A. prominens* *M. platyphylla* *M. dichotoma* *M. prolifera*	20.0
5d	Reef lagoon, near sandbar and seagrass community	no	1.5	weak	c— r+++ s+++	1	disclimax	22	*P. meandrina*	*H. coerulea* *M. platyphylla* *M. prolifera*	94.0
B1	Seagrass community, with scattered coral horsts	yes	3.5	moderate	c— r++ s+++	4	sere	25	—	*H. coerulea* *M. dichotoma*	64.3
B2	Seagrass community, with scattered coral heads	yes	4.0	moderate	c+ r+++ s+++	18	sere	79	*Acropora* sp.	*H. coerulea*	83.3
B3	Flat mound of dynamited fragments, with scattered coral heads.	yes	3.0	moderate	c+ r+++ s++	19	sere	60	*A. brueggemanni*	*H. coerulea*	87.5

*Control area = Sumilon W side, center of Marine Park reef platform; 1 = N-E corner of Island; 2 = center of E side; 3a = W side, S-W corner of Marine Park; 3b = W side, S-W center of Marine Park; 4a = W side, near center of Marine Park; 4b = W side, near center of Marine Park; 5a = W side, N-E corner of Marine Park; 5b = W side, N-W corner of Marine Park; 5c, W side, N-W corner of Marine Park; 5d = W side, N end of Marine Park; B1 = Bantayan reef, N of Marine Laboratory; B2 = Bantayan reef, opposite Marine Laboratory; B3 = Bantayan, S of Marine Laboratory.
**c = coralline; r = rubble, rock; s = sand; — = 0%; + less than 10%; ++ = 10-30%; +++ = greater than 30%.

following species were selected: the scleractinians *Acropora brueggemanni*, *A. prominens*, and *Montipora prolifera;* the hydrozoa *Millepora dichotoma* and *M. platyphylla;* and the octoral *Heliopora coerulea* (of commercial value for costume jewelry).

Transplantation. The field work was carried out with SCUBA equipment. All transplants originated from the same area within the sanctuary of Sumilon, the "control" area; fragments for each species were taken from a single corallum and thus were clones. These were broken off with a crowbar, collected in a plastic bucket, and placed in a large plastic pail on a boat. To minimize stress, the transplants were never exposed to air and the pail was covered while in transit to the transplantation sites seven nautical miles from Sumilon. Six trips, one for each staton, were made for a total of 20-60 fragments (2-3 per species). At the transplantation sites, holes (10-15 cm wide, 5-10 cm deep) were dug into the bottom substratum. Comparable to setting plants into flower pots, the fragments were placed into the holes and secured there with commercial cement previously mixed with freshwater and carried to the site in plastic bags. Once exposed to seawater, the cement hardened in less than 24 hr. With the aforementioned method, a team of three divers easily transplanted 60 fragments a day.

Features of the stations. The study stations were described by analysing the immediate coral communities, with emphasis on species diversity, percentage live coral cover, and composition of the substrate. The continuous quadrat sampling method (9) was used. The assessments were done by one person. The coral communities bordering the stations were seldom as homogeneous as theoretically desired (9), thus the sample plots varied from a minimum of 10-45 m^2 to a maximum of 60-100 m^2 to cover the periphery of the stations.

Species diversity was expressed as the number of species per 100 m^2. The dominant species were determined visually, without a detailed analysis of area cover for each species; hence, only conspicuous cases of dominance were noted.

To assess live coral cover, a 1-m metal quadrat with 16 equal subsquares was used. The number of subsquares with live coral was recorded and later summarized to estimate percentage live coral cover (excluding the transplanted specimens).

For the substrate, percentage area cover was determined for three components: coralline rock, rubble, and sand. Current speed was determined to be either weak, moderate, or strong by means of a drogue.

The apparent overall stability of the ecosystem was characterized in terms of the developmental stages of the coral community. Undisturbed reef portions where large and well-developed corals prevailed were regarded to be at a *climax* stage. Where young and small corals predominated, for instance in reef areas recovering from a previous damage, the community was categorized as a *sere*. *Disclimax* referred to communities disrupted by permanent disturbances such as the repeated sliding of fragments down the upper reef slope due to natural fragmentation of corals on the reef crest.

Surival rates. The number of survivors was counted and expressed in percentage vis-a-vis the total number of transplants. Rates for all transplanted species in a station were called *station-specific survival rates,* while those of a species for all stations were termed *species-specific survival rates* (for Sumilon, see Table 2).

Growth rates. Mean annual growth was expressed as the increase in area cover and space (including the space between branches) occupied by the transplants. This was estimated by approximating the irregular contours of the fragments to circles and hemispheres. For each transplant, three measurements were made using rulers and calipers: height (vertical dimension); length (horizontal dimension); and width (horizontal dimension perpendicular to length). Only intact and apparently healthy transplants were considered.

For comparison, growth rates were determined similarly for equal-sized portions of the original coral heads in the "control" area.

Results and discussion

Survival. The causes of death of transplants were not always determinable. Transplants were broken off during storms, damaged by anchors or fishtraps, or buried and suffocated in sand. One transplant was killed by *Acanthaster planci.* Several dead ones were found covered with algae. A few specimens were affected by an undetermined parasitic sponge which appeared as a thin layer of gray tissue extending over several square meters in different portions of the reef and gradually spreading over neighboring corals. Some scleractinians, particularly species of *Acropora, Montipora, Porites* and *Seriatopora,* were especially susceptible to attack, while species of *Heliopora* and *Millepora* remained unharmed.

Dynamite fishing has a strong impact on coral population density, live coral cover, and substrate composition. Water currents also seem to play a role in the distribution of coral fragments resulting from dynamiting as well as in the formation of the new substrate. From the data (Table 1), however, there appear to be no correlation between survival rates of transplants and substrate composition. Stations 3b

Table 2. Survival rates of coral transplants one year after transplantation in Sumilon Island, Central Visayas.

Species		Stations										Total	Survival rate (%)
		1	2	3a	3b	4a	4b	5a	5b	5c	5d		
Heliopora coerulea	t	3	3	2	2	2	2	2	2	3	3	24	
	m	—	—	—	—	—	—	—	—	—	—	0	100.0
	s	3	3	2	2	2	2	2	2	3	3	24	
Montipora prolifera	t	3	3	2	3	2	3	2	2	2(+2)	2	26	
	m	1	2	2	—	—	2	—	2	2(+2)	—	13	50.0
	s	2	1	—	3	2	1	2	—	— —	2	13	
Acropora brueggemanni	t	3	3	2	2	2	2	2	2	3(+3)	3	27	
	m	3	1	1	—	1	2	1	—	3(+3)	—	15	44.4
	s	—	2	1	2	1	—	1	2	— —	3	12	
Acropora prominens	t	3	3	2	3	2	3	2	2	2(+2)	3	27	
	m	3	2	—	—	1	1	1	1	2(+2)	—	13	51.8
	s	—	1	2	3	1	2	1	1	— —	3	14	
Millepora platyphylla	t	3	3	2	2	2	2	2	2	3(+3)	2	26	
	m	2	1	1	—	—	—	—	1	3(+3)	—	11	57.7
	s	1	2	1	2	2	2	2	1	— —	2	15	
Millepora dichotoma	t	3	2	2	3	2	2	2	2	2(+2)	3	25	
	m	1	—	—	—	—	2	—	—	2(+2)	1	8	68.0
	s	2	2	2	3	2	—	2	2	— —	2	17	
Total	t:	18	17	12	15	12	14	12	12	15(+12)	16	155	
Total	m:	10	6	4	—	2	7	2	4	12(+12)	1	60	
Total	s:	8	11	8	15	10	7	10	8	3(+0)	15	95	
Survival rate (%):		44.4	64.7	66.6	100	83.3	50.0	83.3	66.6	20(+0)	94		61.3*

Legend: t = number of transplants; m = number of deaths; s = number of survivors, s = t — m; * — survival rate excluding Station 5c = 71.9% (t = 128; s = 92).

and 5d, the two stations with the highest survival rates, had essentially different types of substrate. Variable survival rates were obtained also for Stations 1, 3b and 5c, all with a substrate of mainly corraline rock, and for Stations 2, 4a, 5a and B1, all with a substrate of primarily rubble and sand.

The live coral cover for all stations ranged from 1 to 61%, the average being 12% for the dynamited and 28.5% for the non-dynamited stations. Nevertheless, the average survival rates for the two types of stations were similar, 68.8% for the former and 70.5% for the latter.

The two stations with the highest live coral cover, 3b and 5c, had survival rates of 100% and 20%, respectively, whereas the two stations with the highest survival rates, 3b and 5d, had 39% and 1.0% live coral cover, respectively. Thus, there seemed to be no correlation also between live coral cover of the stations and survival rates of transplants.

Species diversity of the stations also did not appear to be correlated with survival rates of transplants based on comparisons of stations with the highest (Stations B2, 4a, b) and lowest (Stations 1, 5d) species diversity.

Distinct cases of dominance occurred in Stations 5c (with *Porites nigrescens* and *P. attenuata*), 1 (with *Dendrophyllia micranthus* and *Heliopora coerulea*), and 2 (with *Millepora dichotoma* and *H. coerulea*). Less distinct cases occurred in Stations 3a, 4a, 5a, and 5b, all on the reef slope, due to the same corals (*Seriatopora caliendrum*, *Fungia* sp., or both) filling out the space between mobile coral fragments. Comparison of the survival rates of these stations indicated that dominance and survival of transplants were not correlated.

The mortality of transplanted species not occurring naturally at the stations appeared higher: *A. brueggemanni* neither occurred nor survived in Stations 1, 4b and 5c, as did *M. dichotoma* in Stations 4b and 5c. On the other hand, some of the introduced species either survived (e.g., *H. coerulea* with 100% survival) or died despite their natural presence. In Stations 1 and 5c where species dominance was most conspicuous, mortality of transplants was greatest. Out of a total of 25 transplants of *A. brueggemanni*, *A. promi-*

Table 3. Growth and survival of transplants one year after transplantation in Sumilon Island and Bantayan (Negros), Central Visayas.

Species	Station	n	Mean initial size of transplants and mean annual increase						Area cover by transplants (cm^2)				Occupied space (cm^3)		
			h_o	$\Delta h/\Delta t$	l_o	$\Delta l/\Delta t$	w_o	$\Delta w/\Delta t$	Mean initial C_o	Overall	Mean annual increase $\Delta c/\Delta t$	Overall	Mean initial V_o	Mean annual increase $\Delta v/\Delta t$	Survival rate (%)
Heliopora coerulea	S	24	74	22	74	17	32	20	22.1	23.6	18.2	17.2	159	205	100
	B	6	98	30	71	14	46	12	26.9		13.4		298	319	
	CA	2	93	13	85	4	33	11	27.3	—	2.0	—	200	104	—
Montipora prolifera	S	12	82	59	107	132	69	152	60.1	59.2	355.4	343.7	382	3583	50.0
	B	1	50	74	100	101	56	100	47.8		202.7		163	1986	
	CA	2	92	57	87	74	69	48	47.8	—	103.9	—	382	1473	—
Acropora brueggemanni	S	18	96	41	106	52	80	49	67.9	69.7	94.1	97.3	524	1188	44.4
	B	5	94	57	112	59	85	51	76.4		108.9		554	1770	
	CA	2	92	75	88	56	50	70	37.4	—	99.4	—	324	1752	—
Acropora prominens	S	17	87	29	72	26	37	21	23.4	27.2	24.6	24.6	220	347	51.8
	B	6	102	37	84	22	55	17	38.0		24.5		391	529	
	CA	3	81	32	120	22	41	16	51.0	—	26.9	—	327	417	—
Millepora platyphylla	S	19	82	36	114	32	49	38	52.3	48.8	54.5	58.0	339	661	57.7
	B	5	66	41	92	57	42	42	35.3		71.5		183	682	
	CA	2	65	74	91	42	34	31	30.8	—	46.5	—	161	885	—
Millepora dichotoma	S	17	65	47	103	49	39	51	39.6	37.1	75.4	72.9	195	785	68.0
	B	3	46	55	82	54	26	42	22.9		58.8		78	570	
	CA	2	54	55	64	55	69	41	34.8	—	68.3	—	136	730	—

Legend: S = stations in Sumilon; B = stations in Bantayan; CA = control area; n = number of transplants; h_o = initial height; l_o = initial length; w_o = initial width; c_o = initial area covered by transplant; v_o = initial space occupied by transplant.

nens and *M. platyphylla*, only one survived; none of these species occurred naturally in either station.

Growth. Transplants of the six selected species exhibited a variety of growth forms and growth rates (Table 3). *Heliopora coerulea*, a compact and often vertically oriented species, increased the least in area and space, followed by the similarly shaped *A. prominens*. *Montipora prolifera* had the highest rates for both although the increase in space here was possibly overestimated since the species extended mostly horizontally. *Acropora brueggemanni* had the second highest rates; it grew equally horizontally and vertically. The plate-like *M. platyphylla* and the branchy *M. dichotoma* increased at a rate a little lower than for *A. brueggemanni*. It is evident that the transplants not only were able to withstand the rough treatment given them but also continued to grow at a normal rate.

Using the mean annual increase in area cover, the suitability of different species for reef-reestablishment can be compared, assuming that the radius of the transplant has a constant growth rate with respect to time or size (10). With the equation

$$t = \frac{C_X \times 10^4}{\frac{\Delta C}{\Delta t} \times s \times n} - \frac{C_0}{\frac{\Delta C}{\Delta t}},$$

we can estimate the number of years (t) required to attain a desired live coral cover (C_x) in a given area, considering the number (n), size (initial area cover C_0), growth rate (mean annual increase in area cover ($\frac{AC}{At}$), and survival rate (s) of the transplanted species. The question was derived from the computation of the total live cover of a station ($=C_x$) as the sum of the area initially covered by the transplants, taking into consideration their survival rate ($=C_0$ x n x s) plus the area cover gained after a given period of growth of the transplant, and again considering their survival rates

$(= \frac{C}{t}$ x n x s x t). The equation is for areas with an initial live coral cover of zero. Not accounted for in the computation are the later deaths which lower the survival rates but in a recovering area are probably compensated for by the settlement of planulae.

Using the results given in Table 3, it was estimated that in order to attain a live coral cover of 50% with, say, five equal-sized transplants per m², the required number of years would be 54 for *H. coerulea*, 6 for *M. prolifera*, 23 for *A. brueggemanni*, 82 for *A. prominens*, 29 for *M. platyphylla*, and 19 for *M. dichotoma*. The period of time may be reduced by choosing suitable species and increasing the number, size, or both, of the transplants. *Heliopora coerulea*, for instance, with 100% survival rate, would be ideal for farming but would grow too slowly for effective reef-reestablishment. *Acropora brueggemanni* and *M. dichotoma* would better serve the purpose despite their lower survival rates. With seven transplants per m² instead of 5, these would give 50% cover in approximately 16 and 14 years, respectively, about half the estimated time (38 years) for natural recovery in the area (3).

In conclusion, it should be emphasized that assessment of the environment in this study involved a minimum of quantification and that the number of transplants used was limited, mainly for financial reasons. Accordingly, much of the data could not be treated statistically and conclusions should be drawn with caution. Broadly, the results suggest that the feasibility of reef-reestablishment by transplantation may depend largely upon the choice of the transplant species. Stepwise, both the present and immediate past community structures of a destroyed reef should be analyzed first (i.e., identify live and demolished corals) in order to recognize the local conditions determining species occurrence, abundance, and dominance. The species for transplantation should then be selected based on their being good reef builders (growth and survival rates to be analyzed in preliminary transplantations to test their suitability), local occurrence, and wide range of tolerance.

Perhaps the most significant finding is that transplantation can be equally successful in dynamited and non-dynamited areas, apparently regardless of substrate composition, coral cover, and species diversity in these areas. This suggests that destroyed reefs can be recolonized by transplantation, analogous to reforestation in terrestrial sites.

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Short articles

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Wellsophyllia radiata Pichon, a new record for the Philippines.

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Wellsophyllia radiata was proposed by Pichon (1) from the Indonesian region. The genus, which is thus far monospecific, is closely related to *Trachyphyllia* Edwards & Haime, 1848. It is distinguished from the latter genus primarily on the basis of the fused walls of adjacent valleys. Veron et al. (2) report *Trachyphyllia* to occur in a silty-sand biotope. All the specimens of *Wellsophyllia* examined by me were found also in turbid, silty-sand environments, attached to coral rubble or shell fragments half buried in the sand.

Wellsophyllia radiata Pichon 1980 **Fig. 1-4**

Callogyra formosa Bedot, 1907, *non Callogyra formosa* Verril, 1902
= *Colpophyllia natans* (Muller, 1775).

Corallum colonial, flabello-meandroid due to intramural budding. Corallites in series, united laterally to walls of adjacent valleys. Valleys deep, reaching to about 20 mm. Columella elongate parietal trabeculae.

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