Interactions between Corals and Barnacles: the Effect of Barnacles on Coral Recruitment in Apo Island, Philippines

Laurie J.H. Raymundo[1] **and Aileen P. Maypa**[2]

[1]Section of Ecology and Systematics
Cornell University
Ithaca, NY 14853

[2]Marine Laboratory
Silliman University
6200 Dumaguete City

ABSTRACT

Two hundred settlement plates were deployed on suspended pyramids at Apo Island Marine Reserve, in March 1996, to study coral recruitment. The plates were deployed at 30' at the edge of the reef drop off, prior to the coral spawning season and censused bimonthly for nine months. Within a month, plates were settled by aggregations of the barnacle *Chthamalus* sp., while the first coral recruits were visible in June. Barnacles and corals showed significantly different preferences for the surfaces on which they recruited (X^2_{calc}=81.39; a=0.05). *Chthamalus* settled most densely on lower surfaces. Only three species of coral recruited to the plates within the study *period (Pocillopora damicornis*, *P. verrucosa*, and *Tubastrea coccinea*) and the two *pocilloporids* showed a significant preference for the upper surfaces not occupied by barnacles. Because past research has shown a distinct preference by coral planulae for lower surfaces, we speculate that barnacle aggregations may be forcing the corals to settle on less optimum surfaces, leading to high early mortality. Submerged structures which are prone to barnacle infestations, such as certain types of artificial reefs, may, therefore, experience lower coral recruitment as a consequence.

Introduction

Concern regarding the degradation of coral reefs worldwide has led many researchers to investigate methods by which coral recovery may be facilitated in degraded areas. Coral transplantation is one such approach, and most efforts to date have involved removing coral colonies, or portions of them, from a healthy reef area to a degraded one (Clark and Edwards 1995; Clark 1997). In principle, this practice can be compared to reforestation efforts in terrestrial systems. However, one major difference between these technologies is the fact that reforestation makes use of seedlings and does not affect intact forest areas, whereas most coral transplantation technology requires the removal or damage of healthy adult colonies. Transplanting juvenile colonies recruited onto substrates is a method which would require no direct interaction with the adult colonies, and would leave healthy reefs intact.

In order to develop such a technology, however, knowledge of the forces affecting settlement and early mortality must be expanded. Interest in larval ecology and recruitment has accelerated in recent years, focusing several highly relevant areas: substrate preferences (Harrigan 1972; Wallace and Bull 1981; Pearson 1981; Harriot 1983; Hodgson 1990), timing of spawning (Tanner 1996; Richmond and Jokiel 1984; Babcock *et al.* 1986; Bermas *et al.* 1992), relationships between recruitment and reef community structure (Sammarco 1991; Baird and Hughes 1997; Babcock and Mundy 1996), and larval recruitment patterns (Birkeland *et al.* 1981; Wallace and Bull 1981; Sammarco and Andrews 1989). This type of research has led to the acknowledgement that coral reproductive biology and life history patterns have major impacts on reef recovery and survival.

In spite of the intense interest larval ecology has aroused, however, there are still many facets which are poorly understood. Interactions between larvae and other reef organisms, and the effects on larval survival, is one such area. Atrigenio and Aliño (1996) found that the soft coral *Xenia puertogalerae* inhibited settlement in all but acroporid corals in its immediate vicinity. This finding is especially significant considering that *Xenia* colonized available space more quickly than coral recruits. Pearson (1981) also noted competition between coral recruits, soft coral and algae. The role of substrate preference was investigated by Harrigan (1972), who found that *Pocillopora damicornis* planulae avoided settling on encrusting bryozoans and tunicates, and Hodgson (1990) quantified the effect of sediment on settlement inhibition in *P. damicornis*. As was stated by Harrigan (1972), the diversity of factors affecting individual planula behavior and preference is complicated enough to make it difficult to predict settlement behavior with any accuracy.

In spite of this, it is sometimes possible to clearly demonstrate the effect of a particular factor on larval behavior. This paper reports the results of a study on the effect of the barnacle *Chthamalus* sp. (Light *et al.* 1964) on coral recruitment onto limestone plates. The original objective of this project was to study and describe coral recruitment onto conditioned substrates within the Apo Island Marine Reserve, to determine both numbers and species composition of recruits. These juvenile colonies would later be used in a transplantation experiment. Because the effect of the barnacles on patterns of coral recruitment was so evident, and their appearance seemed to be associated with the design of the settlement module that was used, we considered it important to describe and quantify these observations.

The Study Site

This study took place within the Apo Island Marine Reserve (9.4°N lat, 123.16°E long), Negros Oriental, Central Philippines (see Fig. 1). Apo Island has been protected and managed by the local populace since 1979 (Cabanban and White 1981). The reserve area (0.5 ha) had an estimated 44.2% live hard coral cover in 1983 (White 1984), but more recent surveys estimated this to be 53.75% in 1997 (SUML Final Report 1997). White (1984) also indicated 28 hard coral genera per square meter within the reserve area. The island has become a model for the establishment of marine protected areas throughout Southeast Asia and is one of the rare well-documented success stories. Currently, it is experiencing increased tourist pressure and efforts are being made by local dive tour guides to limit access and control the number of divers per day (Mario Pascobillo, Pres. Mar. Mgt. Comm. Proj., pers. comm.)

Methods

In March 1996, four pyramid-shaped modules, labelled A through D, containing 50 settlement plates each, were deployed at 25' along the drop-off within the reserve area (Fig. 2). The modules consisted of iron pipes welded together to form four sides, with three tiers, each smaller than the one below it. These were suspended in the water column, anchored in place by ropes tied around a coral head on the bottom. This design avoided siltation on the plates and predation on new recruits by benthic predators, and had been used successfully in the Caribbean (J. West and C.D. Harvell, pers.comm.). The settlement plates measured 10cm x 10cm x 1cm and consisted of mined marine limestone material, available commercially. The plates were scored to roughen the surface, to provide additional places for cryptic settlement. They were bolted onto the iron pipes of the pyramid by stainless steel bolts through the center of each plate. The plates were tilted 45^{0} so that there were both upward- and downward-facing sides. A similar angle was found by Sammarco (1991) and Carleton and Sammarco (1987) to provide an optimum settlement surface for coral larvae, which show preference for lower surfaces. In addition, the downward-facing surfaces faced either toward the center of the pyramid or toward the outer sides of the pyramid, facing open water. All the plates in a single row faced the same direction, but rows alternated in terms of facing either inward or outward.

The modules were censused monthly for coral recruits. Due to the often cryptic positions of new recruits and the abundance of other invertebrate and algal growth on the plates, corals were usually not noticeable until they were 3-4mm in diameter. In July 1996, the first comprehensive census of the plates was undertaken and all colonies were tagged, identified in terms of their position on the plate, and their maximum diameter was measured using a caliper. Subsequent disappearance of tagged colonies was noted during the following sampling and diameter measurements were retaken, to monitor growth. Barnacles and other encrusting organisms were allowed to recruit and colonize the plates freely. In December 1996, a final census of the plates for both number and position of barnacles and number and position of coral recruits was completed.Chi square analysis (Snedecor and Cochran 1989) was used to quantify any significant difference in the location of barnacles and recruits on the plates.

Results

Only three coral species grew large enough to be identified on the plates during the sampling period: *Pocillopora damicornis*, adult colonies of which are rare on Apo reef, *Pocillopora verrucosa*, a more common pocilloporid within the reserve, and *Tubastrea coccinea*, a common non-hermatypic species, found frequently under rock overhangs and undersurfaces. Of these three, *P. damicornis* and *P. verrucosa* dominated the plates, although it was not possible to distinguish between the two until they were several centimeters in diameter. Out of the 188 juvenile colonies censused in December, 154 (82%) were pocilloporids and 34 (18%) were *T. coccinea*. Because pocilloporids are brooders (Veron 1993), and release planulae throughout the year, new recruits continued to appear regularly throughout the sampling period. This was evidenced by the large variation in size of censused colonies (June: 4.81±2.07mm; July: 9.09±3.54mm; October: 16.83±5.76mm). Timing of spawning in *T. coccinea* in the Philippines is not known, but data on recruitment onto the plates suggest that it may have occurred two to three times over consecutive months during the dry season; the colonies on the plates show distinct size categories. This suggests that this species probably spawns annually, as part of mass spawning events. Mortality among the pocilloporids was high, as exhibited by the loss of tagged colonies between sampling periods (33% mortality between July and August; 38.5% mortality between August and October). Successful recruitment of pocilloporids was, therefore, highly variable over the study period. *T. coccinea* colonies were not tagged, so their mortality could not be traced.

Barnacles were the earliest aggressive colonizers of the bare plates (Table 1). Barnacle aggregations were clearly visible in early April and individuals were almost adult size at this time, while coral recruits were first clearly visible during the early June census. A total of 28 coral colonies were observed at this time, with a mean diameter of 4.81 +/- 2.07mm. Data on early growth of *P. damicornis* in laboratory aquaria (Raymundo *et al.* 1997) suggest these colonies may have been between one and two months of age at this time and probably recruited onto the plates in early to mid April.

Table 3 shows obvious settlement preferences of barnacles for the lower surfaces, with coral recruits (with the exception of *T. coccinea*), more common on the upper surfaces. Chi-square analysis indicated a significant difference in distribution of the two (X^2_{calc} = 81.39, a=0.05; Table 2) between the four possible locations on the plates. Although some recruitment occurred on the sides of the plates, these locations were not considered in statistical analysis. Numbers of recruits in these sites were too small to derive any preference pattern. When data were combined for upper vs. lower and inner vs. outer positions, results were also significant, although much less so for inner vs. outer positions. It should be noted that the colonies were more difficult to observe and count on the inner surfaces of the plates, therefore, it is probable that the number of colonies on these surfaces is slightly underestimated.

Data obtained for Module D were handled separately, as the module sunk to a depth of 80' during the month of May, due to a collapse of the buoys. Because of the increased depth at which the module was suspended, recruitment onto these plates was found to be very different from the other three modules, so data are considered separately. Out of the 50 plates, 40 contained coral recruits and only 16 were found to contain barnacles. Low settlement success of the barnacles was presumed to be due to the depth factor. A census of this module indicated that 12 barnacles settled on lower-outer surfaces and 9 were found on upper-inner surfaces. The average number of barnacles per plate was 1.3±.018SE. Coral recruitment, on the other hand, was much higher; a total of 80 recruits were observed, averaging 2.0+0.11SE per plate, with 62 located on the lower-outer surfaces (5 of these were *T. coccinea*), 15 on upper-inner surfaces, and 3 located on the sides of the plates (Table 3).

Discussion

Interactions between settling larvae and other organisms may be either beneficial, whereby they may facilitate recruitment, harmful and inhibitory, or neutral. The interaction between the barnacle *Chthamalus* sp. and pocilloporid planulae demonstrated a potentially inhibitory effect on planulae. Carleton and Sammarco's detailed work on planulae settlement behavior indicated a distinct preference for lower surfaces of plates set at angles between 37 and 45° (Carleton and Sammarco 1987; Sammarco and Andrews 1989). Wallace and Bull (1981) and Birkeland *et al.* (1981) noted a change in surface preference with depth; larvae settled on bottom surfaces in shallow water, but switched to upper surfaces in deeper water. Our findings suggest that the barnacles may outcompete coral larvae for space, acting as either a deterrent to settlement, or rapidly overgrowing and killing coral spat. This thereby prevents coral recruitment to the sites normally preferred at shallow depths.

The predominance of pocilloporids on the settlement plates, almost to the exclusion of other coral species, was surprising considering the diversity of adult coral species on Apo reef. However, the role of *P. damicornis* as one of the dominant "pioneering" colonizer on settlement plates in the northern Philippines and elsewhere, (Aliño *et al.* 1985; Baird and Hughes 1997) must be taken into account. In addition, several authors have found that patterns of juvenile recruitment do not necessarily reflect the adult community structure (Wallace and Bull 1981; Babcock and Mundy 1996; Baird and Hughes 1997). Although the timing of mass spawning events in the Philippines has not been clearly established, a study by Bermas *et al.* (1992) indicated that 12 scleractinian species spawned between April and May on Puerto Galera reef. Based on their findings, we deployed our modules in March, to allow for conditioning of the substrate prior to a possible mass spawning event on Apo reef. However, no recruitment (or, perhaps, survival of recruits) from other species was noted on the plates. Evidence of mass spawnings, such as gamete "slicks" on the water surface, has never been reported from Apo, although it is probable that the Apo reef would follow a pattern similar to reefs elsewhere in the Philippines.

The role of barnacles as a determinant of coral recruitment is relevant in light of the ubiquitous nature of barnacles. Since they are rarely found on coral reefs, no doubt because they are easily overgrown or predated upon, they are unlikely to affect recruitment patterns onto natural reef substrate, even in degraded reef areas. However, barnacle cyprid larvae a not highly selective in their search for specific substrates, relying primarily on chemical cues from adult conspecifics to guide their settlement (Crisp 1976). This results in the characteristic dense communities commonly found on submerged structures such as pier pilings, cement posts, driftwood, and tires. Because of the widespread deployment of artificial reefs in degraded shallow coastal areas, the effect of barnacles on coral recruitment onto ARs could, in some instances, be considerable. If barnacles settled aggressively on the optimum settlement sites for corals, they could prevent the establishment of coral colonies onto these surfaces. This effect was clearly illustrated on Module D, which was sunk to a depth apparently below that to which barnacles could recruit. It is not clear whether planulae showed a marked difference in their choice of settlement sites or in their survival on this module, but young colonies were found in much higher density on the less-exposed lower surfaces occupied by barnacles on the shallower modules. The lower density exhibited by the barnacles resulted in more cohabitation of surfaces by both corals and barnacles, suggesting that it is the high-density aggregative settlement of barnacles which outcompetes coral juveniles for space.

This interaction raises some interesting issues. It is possible that barnacles may act as an initial pioneering community; a March 1997 survey of the plates showed very few living barnacles, suggesting that they may not continue to recruit to the plates the following year. Whether or not they serve to condition the substrate, in preparation for recruitment by other species, is not clear. Reef community succession is a topic researchers are just beginning to address via the use of artificial structures (S. Clark, pers. comm.). The extent of barnacle infestation on different substrates that are used in the construction of artificial reefs is another point which needs to be addressed.

The fact that barnacles had less of an effect on the non-hermatypic *Tubastrea coccinea* may be attributed to its growth form (compact, massive, ovoid, with corallites up to 10mm in diameter) and, possibly, growth rate. The *T. coccinea* colonies which settled on the lower surfaces of the plates grew among the barnacles and appeared successful in their competition for space. Although these colonies were not consistently measured, they exhibited a growth rate rapid enough to prevent barnacles from either overgrowing them or settling on them. In the case of artificial surfaces heavily encrusted with barnacles, therefore, these and related species would be expected to show the most successful early recruitment. The hermatypic species would be expected to show less successful recruitment and higher mortality until the barnacles died out.

The design and position of the modules (Fig. 2) appeared to be conducive to barnacle recruitment. Simultaneous transplant work on the same reef, involving cement flats raised six inches off the substrate, did not attract barnacles at any time. It is possible that modules suspended off the edge of the reef attract fewer fish predators and grazers; the modules were quickly settled with microalgae and encrusting invertebrates, while the cement flats remained free of encrusting biota, only contained turf algae, and were frequently seen to be grazed by resident fish. Although the source of barnacle larvae could not be verified, an adult agreggation exists on intertidal rocks facing the reef. Therefore, future recruitment work should make use of a modified design, closer to the substrate, at least in areas with a known barnacle population. In addition, the deployment of ARs to encourage reef development may be more successful in recruiting corals if placed in at least 40' of water.

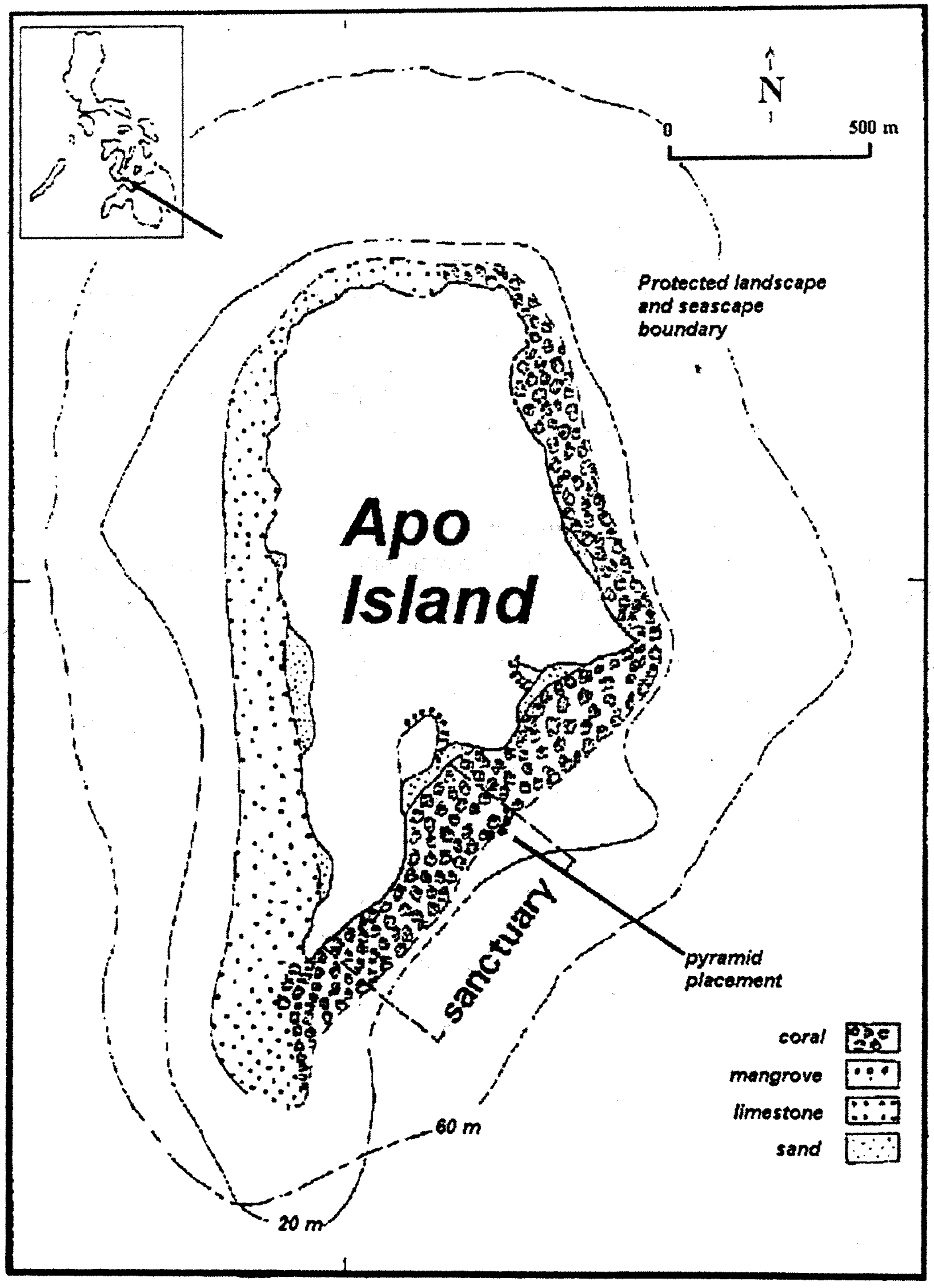

Figure 1. Map of Apo Island, showing the study site

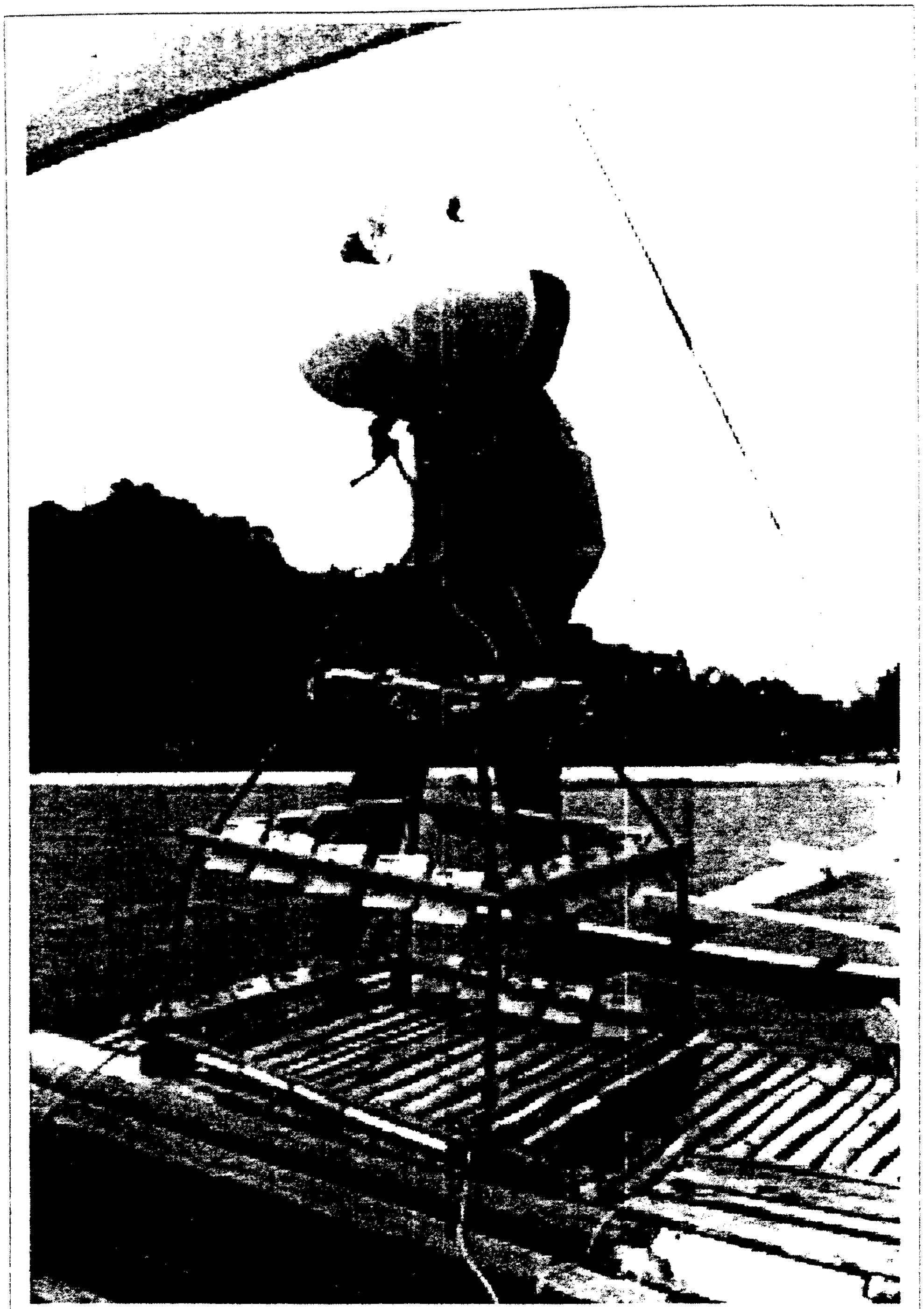

Figure 2a. A pyramid module prior to deployment

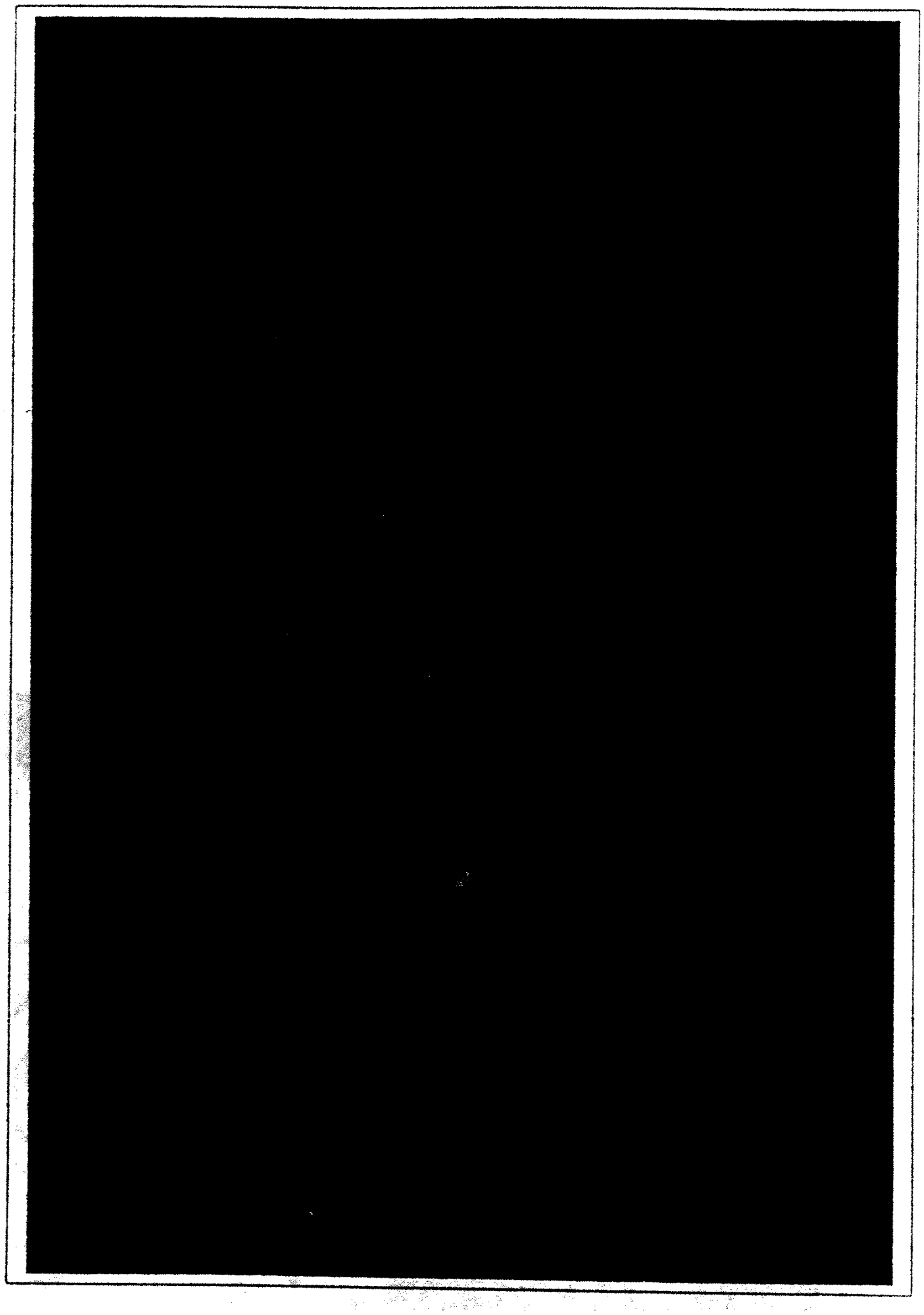

Figure 2b. A module after deployment within Apo Marine Reserve

Table 1. Summary of coral and barnacle recruitment onto pyramid module settlement plates (n=200 plates censused in December 1996).

Observation	Module A	Module B	Module C	Module D
No. Plates with Barnacles	39	28	35	16
No. Plates with Corals	24	23	25	40
Mean no. Barn./plate	7.7 ± 0.63*	18.9 ± 1.84	14.9 ± 1.40	1.3 ± 0.18
Mean no. Corals/plate	1.3 ± 0.13	1.6 ± 0.18	1.6 ± 0.20	2.0 ± 0.17
No. Plates with both barnacles and corals	19	23	25	10
No. Plates with both on same side of plate	4	9	4	6

*Mean +/- SE

Table 2. Chi-square analysis of barnacle and coral recruit location on settlement plates, Modules A, B, C combined, n= 1385 barnacles; n=77 pocilloporids and n=11 *T. coccinea*. (IL=inner/lower surface; OL=outer/lower; IU=inner/upper; OU=outer/upper)

Test	Alpha Level	df	X^2_{calc}	X^2_{tab}	Result
all locations (IL/OL/ IU/OU), all coral species	0.05	3	81.39	7.81	significant
all locations, *T. coccinea* excluded	0.05	3	84.48	7.81	significant
Lower (IL+OL) vs. Upper (IU+OU) surfaces	0.05	1	56.6	3.84	significant
Inner (IL+IU) vs. Outer (OL+OU) surfaces	0.05	1	6.8	3.84	significant

Table 3. Summary of recruit position on Modules A through D. (IL=inner/ lower surface; OL=outer/lower; IU=inner/upper; OU=outer/upper; LAT=side edges of plates)

Plate	Module A			Module B		Module C		Module D	
Pos.	Barn	Coral	*	Barn	Coral	Barn	Coral	Barn	Coral
IL	125	0		455	4	152	1	0	0
OL	159	10		56	1	378	2	12	62
IU	17	7		5	6	0	19	9	15
OU	13	5		23	27	2	11	0	0
LAT	12	6		13	1	0	9	0	3

* Coral recruits include *T. coccinea*

Literature Cited

Aliño, P.M., P. Viva Banzon, H.T. Yap, E.D. Gomez, J.T. Morales, and R.P. Bayoneto. 1985. Recovery and recolonization on a damaged backreef area at Cangaluyan Is. (Northern Philippines). Proc. 5th Int'l. Coral Reef Congress. Tahiti. Vol. 4:279-284.

Atrigenio, M.P. and P.M. Aliño. 1996. Effects of the soft coral *Xenia puertogalerae* on the recruitment of scleractinian corals. Journ. Exp. Mar. Biol. Ecol. 203:179-189.

Babcock, R.C., G.D. Bull, P.L. Harrison, A.J. Heyward, J.K. Oliver, C.C. Wallace, and B.L. Willis. 1986. Synchronous spawnings of 105 scleractinian coral species on the Great Barrier Reef. Mar. Biol. 90:379-394.

Babcock, R. and C. Mundy. 1996. Coral recruitment: Consequences of settlement choice for early growth and survivorship in two scleractinians. Journ. of Exp. Mar. Biol. and Ecol. 206:179-201.

Baird, A.H. and T.P. Hughes.1997. Spatial variation in coral recruitment around Lizard Island, Australia. Proc. 8th Int'l. Coral Reef Congress. Panama City.

Bermas, N.A., P.M. Aliño, M.P. Atrigenio and A. Uychiaoco. 1992. Observations on the reproduction of scleractinian and soft corals in the Philippines. Proc. 7Th Int'l. Coral Reef Symp. Guam. Vol. 1:443-447.

Birkeland, C., D. Rowley, and R.H. Randall. 1981. Coral recruitment patterns at Guam. Proc. 4th Int'l. Coral Reef Symp. Manila. Vol. 2. pp. 339-344.

Cabanban, A.S. and A.T. White. 1981. Marine conservation program using non-formal education at Apo Island, Negros Oriental, Philippines. Proc. 4th Int'l. Coral Reef Symp., Manila. Vol. 1, pp. 317-321.

Carleton, J.H. and P.W. Sammarco. 1987. Effects of substratum irregularity on success of coral settlement: Quantification by geomorphological techniques. Bull. Mar. Sci. 40:85-98.

Clark, T. 1997. Tissue regeneration rate of coral transplants in a wave exposed environment, Cape D'Aguilar, Hong Kong. Proc. 8th Int'l. Coral Reef Congress. Panama City.

Clark, S. And A.J. Edwards. 1995. Coral transplantation as an aid to reef rehabilitation: Evaluation of a case study in the Maldive Islands. Coral Reefs. 14:201-213.

Crisp, D.J. 1976. Settlement responses in marine organisms. In: R.C. Newell (ed.). Adaptations to Environment: Essays on the Physiology of Marine Animals. Butterworths, London. pp. 83-124.

Harrigan, J. F. 1972. Behavior of the planula larva of the scleractinian coral *Pocillopora damicornis* (L.). American Zoologist 12(4):723. (Abs).

Harriott, V.J. 1983. Reproductive seasonality, settlement, and post-settlement mortality of *Pocillopora damicornis* (Linnaeus), at Lizard Island, Great Barrier Reef. Coral Reefs 2:151-157.

Hodgson, G. 1990. Sediment and the settlement of larvae of the reef coral *Pocillopora damicornis*. Coral Reefs 9:41-43.

Light, S.F., R.I. Smith, F.A. Pitelka, D.P. Abbott, F.M. Weesner. 1964. Intertidal Invertebrates of the Central California Coast. University of California Press, Berkeley. 446 pp.

Pearson, R.G. 1981. Recovery and recolonization of coral reefs. Mar. Ecol. Prog. Ser. 4:105-122.

Raymundo, L.J.H., A.P. Maypa, M.M. Luchavez. 1997. Lab-reared corals: A viable transplantation method for rehabilitating degraded reefs in the Central Philippines. Abs. submitted to Am. Zool. Soc. Ann. Conf., Dec. 1997.

Richmond, R.H. and P.L. Jokiel. 1984. Lunar periodicity in larva release in the reef coral *Pocillopora damicornis* at Enewetak and Hawaii. Bull. Mar. Sci. 34(2):280-287.

Sammarco, P.W. 1991. Geographically-specific recruitment and post-settlement mortality as influences on coral communities: The cross-continental shelf transplant experiment. Limn. Ocean. 36(3):495-514.

Sammarco, P.W. and J.C. Andrews. 1989. The helix experiment: Differential localized dispersal and recruitment patterns in Great Barrier Reef corals. Limn. Ocean. 34(5):896-912.

Snedecor, G.W. and W.G. Cochran. 1989. Statistical Methods. 8th ed. Iowa State Univ. Press. 503 pp.

Silliman University Marine Laboratory. 1997. Corals. In: H.P. Calumpong, J.S. Estacion. M.V. Lepiten eds. Status of the Coastal Resources of the Negros Learning Site. Final Report of the Center of Excellence in Coastal Resource Management Project to USAID. pp. 127-147.

Tanner, J.E. 1996. Seasonality and lunar periodicity in the reproduction of Pocilloporid corals. Coral Reefs 15:59-66.

Veron, J.E.N. 1993. Corals of Australia and the Indo-Pacific. University of Hawaii Press. 644 pp.

Wallace, C.C. and G.D. Bull. 1981. Patterns of juvenile coral recruitment on a reef front during a spring-summer spawning period. Proc. 4th Int'l. Coral Reef Symposium. Manila. Vol. 2:354-350.

White, A. T. 1984. Marine Parks and Reserves: Management for Philippines, Indonesian and Malaysian Coastal Reef Environments. Dept. of Geography, University of Hawaii, Ph.D. Dissertation, unpublished.

Acknowledgements

The authors wish to thank the following people for their help: Grace Ozoa and May Luchavez, who helped with data collection in the field; Jasper Maypa, who provided valuable assistance in the design of the modules; and Dioscoro Inocencio, who helped in their construction and deployment. Dr. Drew Harvell, Ms. Raymundo's Ph.D. advisor, provided insight and support. Ms. Myrissa Lepiten and Dr. Hilconida Calumpong gave peer reviews of this paper and provided constructive comments. This project was supported by NSF grant no. INT-9512721