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COMMUNITY STRUCTURE, BIOMASS AND PRODUCTIVITY OF DEEPWATER ARTIFICIAL REEFS IN HAWAII

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ABSTRACT

Artificial reef modules constructed of plastic or concrete were deployed at three sites in deep water on Penguin Bank, Hawaii, in October 1985. Fish communities were censused shortly after deployment and irregularly thereafter, by using the manned submersibles MAKALII and PISCES V. In determining the aggregated biomass of transient fish species, depth of reef placement was more important than the reef's structural material and configuration. Conversely, reef structural material and configuration were more important than depth in determining the species diversity, richness and perhaps biomass of resident species attracted to these deepwater artificial reefs. Results suggest that small-scale, deepwater artificial reefs in Pacific island areas function primarily as devices for aggregating fish rather than increasing fish production and that reef configuration and structural material are not very important in aggregating transient species.

Many Pacific islands are characterized by their nearshore coral reefs and narrow shelves with steeply sloping sides. The flat, sandy shelves are generally devoid of fish while the deep slopes are home to many commercially important eteline snappers and epinepheline groupers at depths of 100 to 400 m. Penguin Bank, Hawaii, is a large, flat shelf that extends about 50 km southwest of the island of Molokai (Fig. 1). Considerable commercial fishing for deepwater snappers (e.g., *Pristipomoides* spp. and *Etelis* spp.) is conducted on its slopes. Ralston (1984) suggests that this resource may be overfished. Sale (1978) suggests that habitat is a limiting factor in reef fish recruitment. If recruitment of deepwater snappers is similarly limited by habitat, artificial reefs placed on the shelf areas could provide additional habitat for juveniles and presumably increase recruitment of adults to the fishery.

Many of the more recent studies on artificial reef performance have analyzed the effectiveness of specially designed reefs (Sheehy, 1982; Woodhead et al., 1982; Alevizon et al., 1985) as opposed to reefs made by the traditional method of dumping scrap materials (e.g., old car bodies and tires) (Stone et al. 1974; Crowe and McEachron, 1986). Comparing a commercially available artificial reef made of fiberglass-reinforced plastic (FRP) to a traditional reef made of discarded concrete pipe, Sheehy (1983) found considerably higher fish densities at the FRP reef than at the concrete reef.

In our study, FRP and concrete artificial reefs constructed similarly to those in Sheehy (1983) were deployed in deep water (61, 98 and 117 m) on Penguin Bank (Fig. 1). Artificial reefs deployed in shallower water generally have been monitored by divers equipped with scuba gear (Stephens and Zerba, 1981; Hueckel and Stayton, 1982; Kock, 1982); however, the depths in our study made scuba gear impractical, and a manned submersible was used instead. Conducting a visual census of fish communities by using a submersible, though more difficult than using scuba in many respects, has been shown to be practical (Ralston et al., 1986; Thresher and Colin, 1986). Censuses were conducted to determine whether either of the reef types would be used by juveniles of commercially important species (particularly eteline snappers) and to determine whether the results in Sheehy's (1983) study in shallow Atlantic waters could be reproduced in deep Pacific waters.

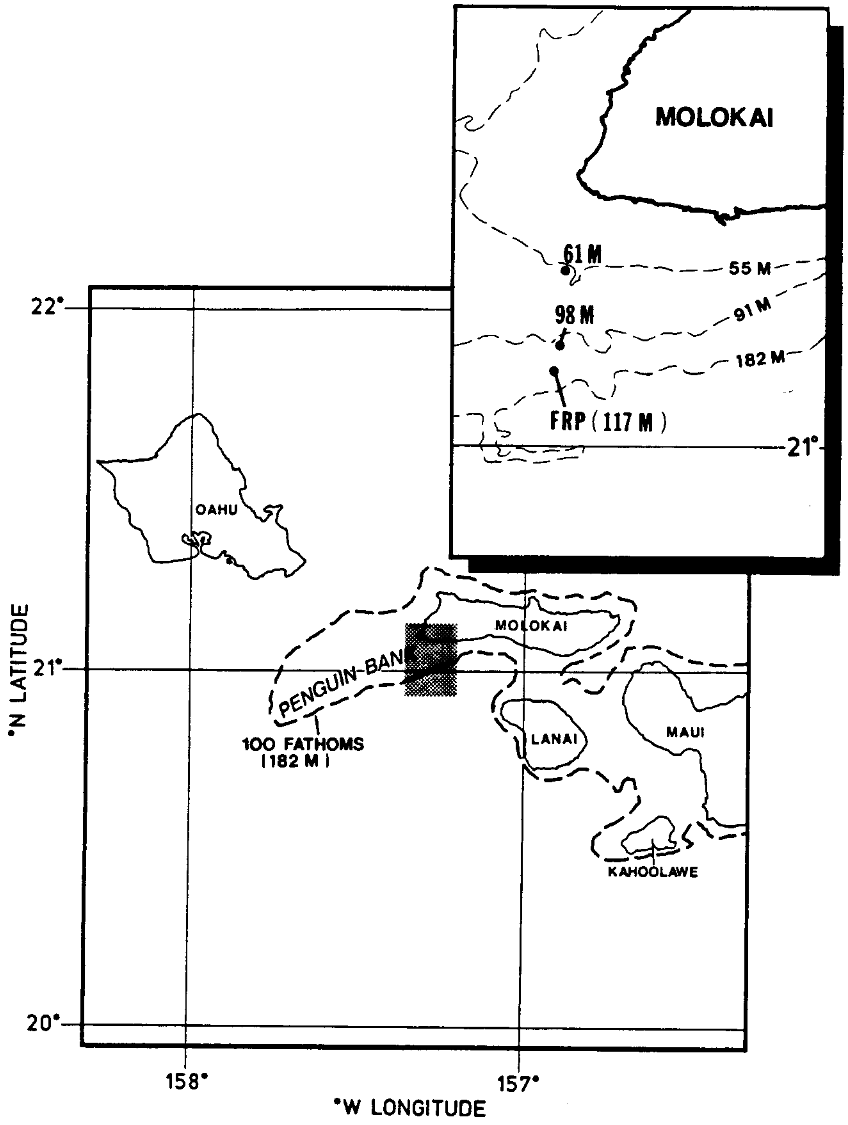

Figure 1. Chart of Penguin Bank with insert indicating artificial reef sites.

If so, then perhaps the greater expense of these specially fabricated reefs could be justified for future artificial reef projects.

Methods

Study Site.—A preliminary dive was conducted on Penguin Bank at depths of 60–150 m by using the submersible Makalii (see Harrison (1986) for a brief description of the submersible). The flat shelf area observed on this dive was very uniform, largely featureless and devoid of fish life. The bottom was mostly sand with a few scattered, low-profile limestone outcroppings and a few small, black coral

Table 1. Specifications and dates of observations of Penguin Bank artificial reefs

Reef site	Depth (m)	Reef height (m)	Enclosed volume (m^3)	Reef surface area (m^2)	Date observed
61 m concrete (four modules)	61	0.8–1.1	5.0	84.0	20 Dec 1985
					3 May 1986
					13 Oct 1986
					10 Apr 1987
98 m concrete (four modules)	98	0.8–1.1	5.6	88.7	18 Oct 1985
					19 Dec 1985
					6 Feb 1986
					2 May 1986
					11 Oct 1986
					8 Apr 1987
					12 Feb 1988
Fiberglass-reinforced plastic (one module)	117	5.3	139	221	16 Oct 1985
					19 Dec 1985
					6 Feb 1986
					2 May 1986
					11 Oct 1986
					8 Apr 1987
					12 Feb 1988

trees. In the deeper areas, less duning of sand was observed, indicating that it may be only a thin layer covering a harder substrate. Periodic currents in the area were strong, up to about 2 knots.

Reef Construction.—The artificial reef modules were constructed of two different types of materials. The first was a commercial FRP module composed of nine cylinders stacked in a pyramid as illustrated in Mottet (1985). The remaining reef modules were constructed of concrete pipe, either 30 cm or 45 cm inside diameter, stacked in low profile pyramids of either three or six pipes. The pipes were bound together with 12.5-mm stainless steel bands and 12.5-mm polypropylene line. Each pipe was fitted with a center barrier equipped with small holes allowing water to flow through, making a cavelike rather than a tunnellike enclosure. The center barriers of the 45-cm-diameter pipes were constructed of poured concrete, whereas the barriers of the 30-cm-diameter pipes were acrylic plastic.

Reef Deployment.—The reef modules were dropped off a large fuel barge at three Penguin Bank sites on 15 October 1985. An acoustic pinger with a 3-year battery pack was attached to one reef module at each site. The FRP reef was dropped in 117 m of water. A group of four concrete modules (two modules were of three 45-cm-diameter pipes and two were of six 30-cm-diameter pipes) was dropped in 98 m of water about 0.8 km north of the FRP reef. The other group of four concrete modules (one module was of three 45-cm-diameter pipes, two were of six 30-cm-diameter pipes and one was of three 30-cm-diameter pipes) was dropped in 61 m of water about 3.2 km north of the FRP reef. The resulting specifications of each reef are listed along with the observation dates in Table 1.

Data Collection and Analysis.—Visual censuses were conducted using the two-man submersible MAKALII, mentioned above, or the larger, three-man submersible PISCES V, which has observational and photographic capabilities similar to the MAKALII (the PISCES V was used for the February 1988 observation only). The fish species observed were categorized as either resident, transient or incidental species (Table 2). Those referred to as resident species are generally small-sized species that use the reef for shelter, probably forage on the reef module or in the immediate vicinity and are likely to be found at the same reef module over a long period. Transient species are generally medium- to large-sized species that aggregate in the vicinity of the reef but do not appear to use it as a refuge and that probably maintain and frequently patrol a large foraging area. Incidental species are defined as those that, although occasionally observed in the vicinity of the reef, show no apparent association with the reef and are just as likely to be seen in the open sand areas with no reef present. Incidental species are excluded from our analyses.

The reef sites were to be monitored quarterly; however, poor weather and problems with submersible maintenance caused several scheduling changes, complicated by the needs of other users. Thus, submersible dives were conducted irregularly. Also, on many occasions, insufficient bottom time, due to strong bottom currents or equipment failure, prevented us from visiting all three reef sites. In these cases, the 61 m reef site was missed.

A visual census was conducted during each site visit (Table 1). The submersible slowly circled each module of each reef visited as an observer counted all fish within sight of the reef and directed video and still camera photography. Fish were identified to the lowest level possible (generally species); the number and estimated size (total length) of individuals of each species were recorded. Slides and videotapes were reviewed later by two observers, who recorded fish counts by species. For transient species, which would swim in and out of view, the estimated total number of individuals of each species was considered to be the largest number seen at any one time during the entire reef visit, as recorded on the field observer logs or the video or slide review logs. For resident species, the estimated total number of individuals of each species was obtained by summing the largest number seen at any one time for each module in a reef. As is the case in any visual census, cryptic species and those that avoid the observer may be underrepresented in these estimates. However, with the relatively open structure of our reefs affording good visual access and the lack of any obvious avoidance of the submersible by those species observed (as similarly reported by Thresher and Colin (1986)), we believe that our counts are reasonably accurate. However, should any bias exist in our sampling of community structure, it should be the same for all study sites, so the comparisons between our reef sites are valid.

Census data were used to calculate four measures of community structure: richness, total number of fish, diversity and standing stock biomass. Richness (number of species) and total number of individuals present within a population are rough indicators of community structure. More sophisticated is the diversity index, which in this case is Brillouin's function for a fully censused population (Pielou, 1977) and includes factors related to the number of species present (richness) and the number of individuals found within each species (evenness). Standing stock biomass was estimated by substituting our fish length estimates in published (Yamaguchi, 1953; Uchiyama et al., 1984) and unpublished length-weight functions (James Parrish, University of Hawaii, Cooperative Fisheries Unit, Honolulu, Hawaii 96822, 1987, pers. commun.). Transient and resident species assemblages were treated separately for all measures. Paired *t*-tests were used to determine whether any differences between the four measures by reef sites were significant at the 0.05 level.

RESULTS

No problems were encountered in deployment of the reef modules. Modules of the two concrete reefs landed in a linear arrangement, with roughly 15–30 m between adjacent modules. This was generally within visual range, depending on visibility. Some of the acrylic partitions in the 30-cm-diameter pipe modules broke during deployment; otherwise, the reef modules landed well and were undamaged. Although some scouring was observed at all sites, the reef modules remained relatively stable throughout the study. Large pits and the threat of module burial occurred only at the 61 m reef site, where the sand layer appears to be deeper.

Our reefs are almost certainly unfished. The location of the reefs has not been disclosed to date, and because of the small size of our reefs and their distance from traditional fishing areas, we believe it unlikely that any fishermen have been able to find them. No signs of fishing activity were noted during our observations. Therefore, all of the results discussed below are viewed as products of unfished artificial reefs.

Transient species were the first to arrive at our reef sites. Several of the larger transient species (e.g., *Seriola dumerili, Naso* spp. and *Pristipomoides filamentosus*) recruited to the reef sites within 24 to 72 h after deployment. Values for richness of transient species were very similar for all reef sites, beginning at moderate levels and showing a general increase over time (Fig. 2A). Most of the transient species that appeared later were the smaller species (e.g., *Acanthurus* spp., *Synodus* spp. and *Coris* spp.). Results of paired *t*-tests showed no significant differences in richness of transient species between any of the three possible reef comparisons. Calculation of recruitment curves using the formula $y = a(1 - e^{-b(t+c)})$ gives asymptotic values for transient species richness of 8.9 (asymptotic standard deviation (SD) = 4.2, $R^2 = 0.57$), 11.4 (SD = 3.6, $R^2 = 0.27$) and 35.2

Table 2. List of species of transient, resident and incidental fishes observed by reef type (T = transient species, R = resident species, I = incidental species, 61 m and 98 m = concrete reefs, FRP = fiberglass-reinforced plastic reef)

Taxonomic classification	Species group	Reef type
Acanthuridae		
Acanthurus dussumieri	T	61 m, 98 m, FRP
Acanthurus xanthopterus	T	61 m, 98 m, FRP
Naso brevirostris	T	61 m
Naso spp.*	T	61 m, 98 m, FRP
Naso unicornis	T	61 m
Zanclus cornutus	R	61 m
Apogonidae		
Apogon spp.†	R	61 m, 98 m, FRP
Aulostomidae		
Aulostomus chinensis	T	61 m, 98 m, FRP
Balistidae		
Cantherines verecundus	T	61 m, 98 m
Osbeckia scripta	T	FRP
Prevagor spilosoma	T	61 m, 98 m, FRP
Sufflamen fraenatus	T	61 m, 98 m
Bothidae	I	61 m
Carangidae		
Caranx ignobilis	T	98 m
Caranx melampygus	T	98 m
Carangoides orthogrammus	T	98 m, FRP
Decapterus macarellus	I	61 m
Seriola dumerili	T	61 m, 98 m, FRP
Chaetodontidae		
Chaetodon fremblii	R	61 m, 98 m
Chaetodon kleinii	R	61 m
Chaetodon miliaris	R	61 m, 98 m
Forcipiger sp.‡	R	98 m
Heniochus acuminatus	R	61 m, 98 m
Congridae		
Conger sp.	R	FRP
Diodontidae		
Diodon hystrix	I	98 m
Gobiidae	R	FRP
Holocentridae		
Holocentrinae	R	61 m, 98 m
Myripristinae		
Myripristis chryseres	R	FRP
Labridae		
Anampses chrysocephalus	R	61 m, 98 m
Bodianus bilunulatus	T	98 m
Coris ballieui	T	98 m
Coris flavovittata	T	98 m
Coris gaimardi	R	61 m
Hemipteronotus pavoninus	I	61 m
Labroides phthirophagus	R	61 m, 98 m
Lutjanidae		
Aprion virescens	T	98 m, FRP
Lutjanus kasmira	R	61 m, FRP
Pristipomoides filamentosus§	T	98 m, FRP
Mugiloididae		
Parapercis roseoviridis	I	98 m
Mullidae		
Mulloidichthys sp.‖	T	61 m, 98 m, FRP
Parupeneus multifasciatus	T	61 m, 98 m
Parupeneus pleurostigma	T	61 m, 98 m
Parupeneus porphyreus	T	98 m, FRP

Table 2. Continued

Taxonomic classification	Species group	Reef type
Muraenidae		
Gymnothorax flavimarginatus	R	98 m
Gymnothorax steindachneri	R	61 m
Ophidiidae		
Brotula multibarbata	T	98 m
Pentacerotidae		
Evistias typus	R	FRP
Pomacanthidae		
Holacanthus arcuatus	R	61 m, 98 m
Centropyge potteri	R	98 m
Pomacentridae		
Dascyllus albisella	R	61 m
Chromis ovalis	R	61 m, 98 m
Chromis verater	R	61 m, 98 m, FRP
Priacanthidae		
Priacanthus sp.#	R	61 m, 98 m
Scorpaenidae		
Dendrochirus barberi	R	61 m, 98 m
Pterois sphex	R	98 m
Scorpaena ballieui	R	98 m, FRP
Serranidae		
Anthias thompsoni	R	61 m, 98 m, FRP
Anthias ventralis	R	98 m, FRP
Holanthias fuscipinnis	R	98 m, FRP
Synodontidae	T	61 m, 98 m, FRP
Tetraodontidae		
Canthigaster coronatus	R	61 m, 98 m
Canthigaster epilampra	R	98 m, FRP

* Includes *N. maculatus* and *N. hexacanthus.*
† Includes *A. maculiferus* and *A. kallopterus* and perhaps others as well.
‡ May be *F. longirostris* or *F. flavissimus.*
§ May include *Pristipomoides sieboldii* and *Aphareus rutilans* as well.
‖ May be *M. vanicolensis* or *M. pflugeri.*
Probably *P. alalaua*, which may be a synonym of *P. hamrur.*

species (SD = 267.5, $R^2 = 0.98$) for the 61 m concrete, 98 m concrete and FRP reefs, respectively. Ninety percent of these species are predicted to be present at the reefs within 15, 10 and 213 months, respectively. The unusually large asymptotic richness and lengthy time estimated to 90% recruitment values seen at the FRP reef are not significantly different from those obtained from the other two reef sites and are due to the apparent linear growth in richness, which forces the recruitment model to estimate an unrealistically large asymptotic level. Presumably, a longer time series at the FRP reef would show richness leveling off in the 9–15 species range, similar to that of the other two reef sites.

The number of individual fish of transient species varied considerably at each site over time (Fig. 3A). Between sites, however, the number of fish was usually similar and tended to fluctuate in a parallel fashion over time. No significant differences between reef pairs were observed in paired *t*-tests. Peaks in May 1986 and April 1987 at all sites indicated a possible seasonal change in abundance of transient fish.

Differences between reefs were apparent in the diversity of transient fish species (Fig. 4A). The 98 m and FRP reefs showed remarkably similar changes in diversity over time: Diversity was moderate initially, increased slightly in the first 4 months, then remained relatively stable for the duration of the study. The 61 m reef, however, had relatively low initial diversity, with a one-time peak into the mod-

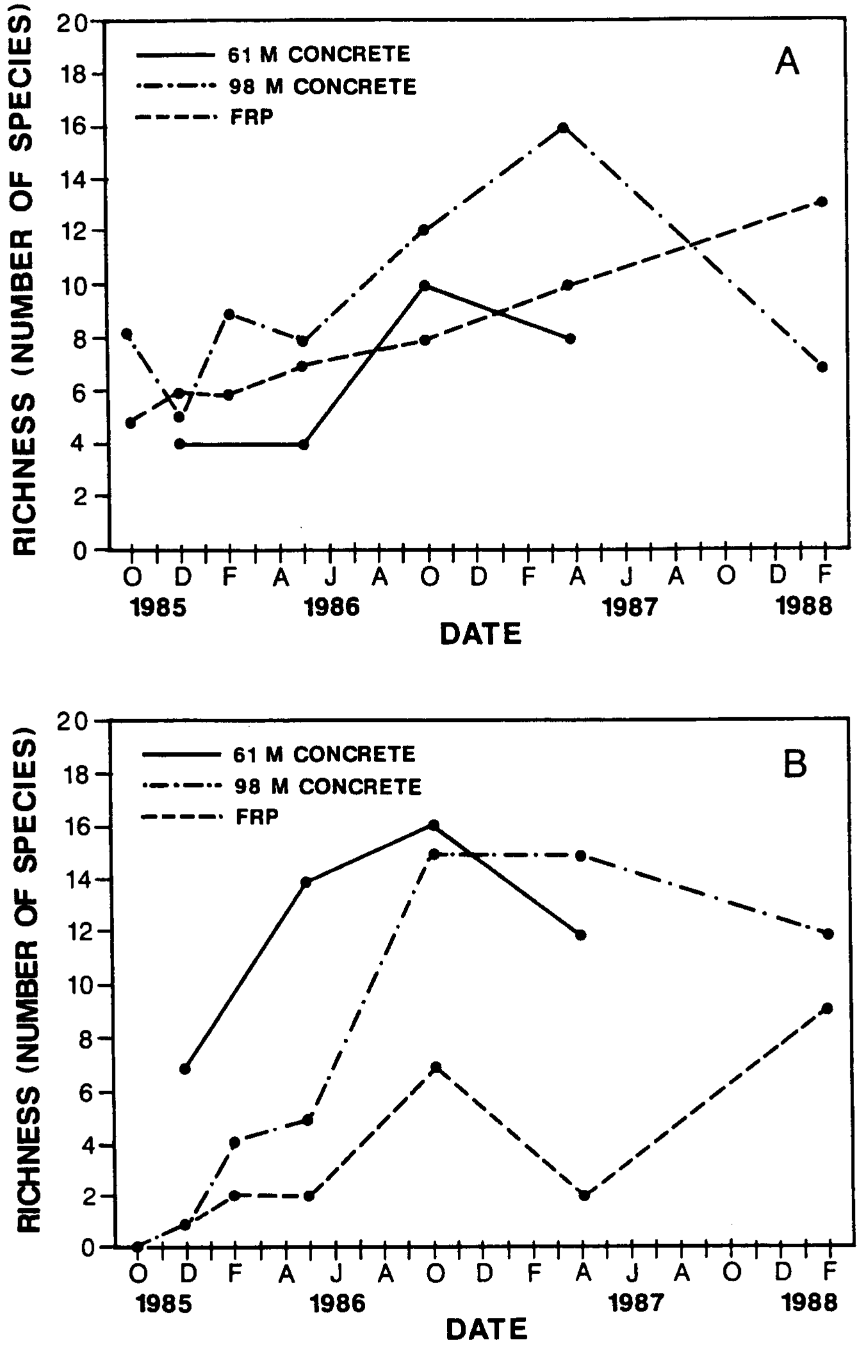

Figure 2. Richness at Penguin Bank artificial reefs. (A) Transient species. (B) Resident species.

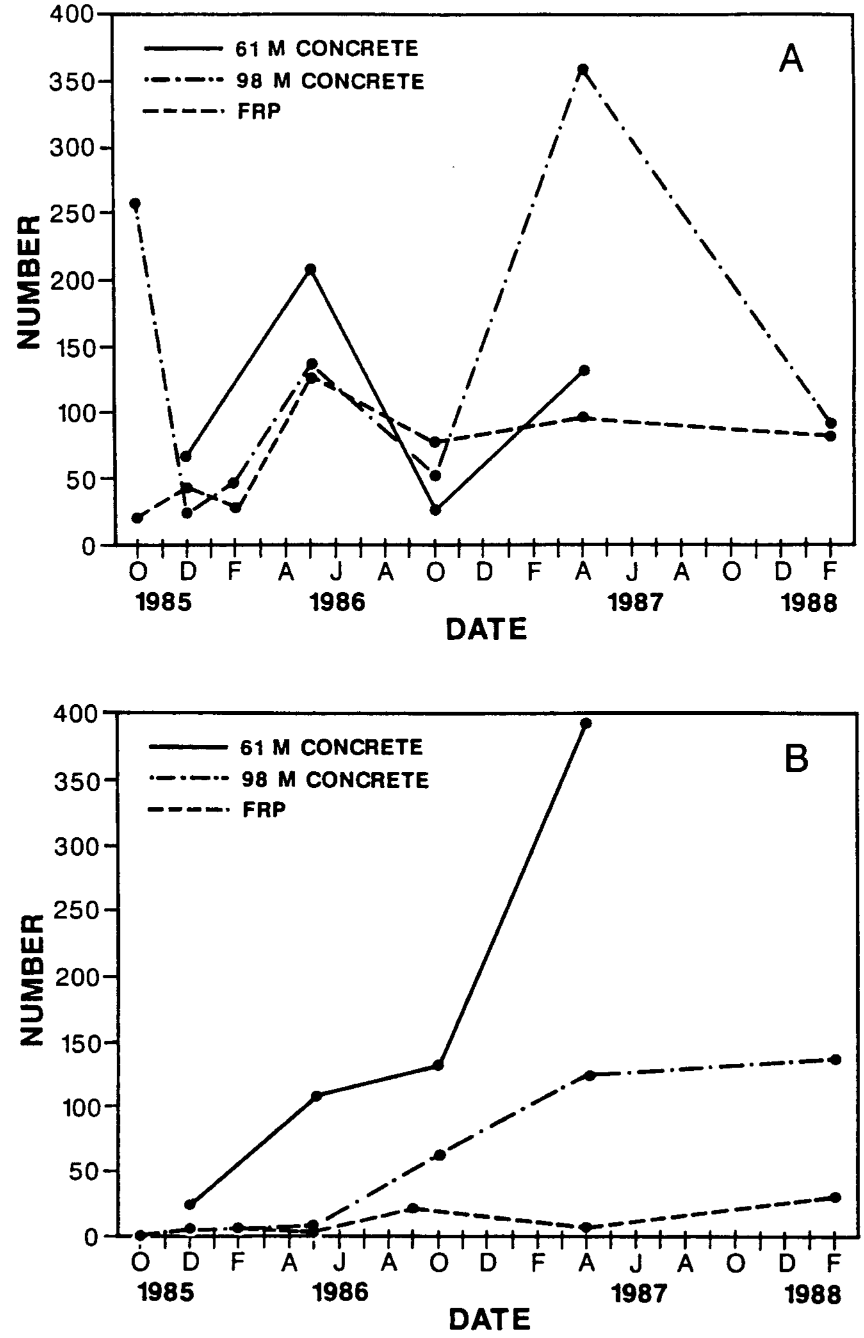

Figure 3. Number of fish at Penguin Bank artificial reefs. (A) Transient species. (B) Resident species.

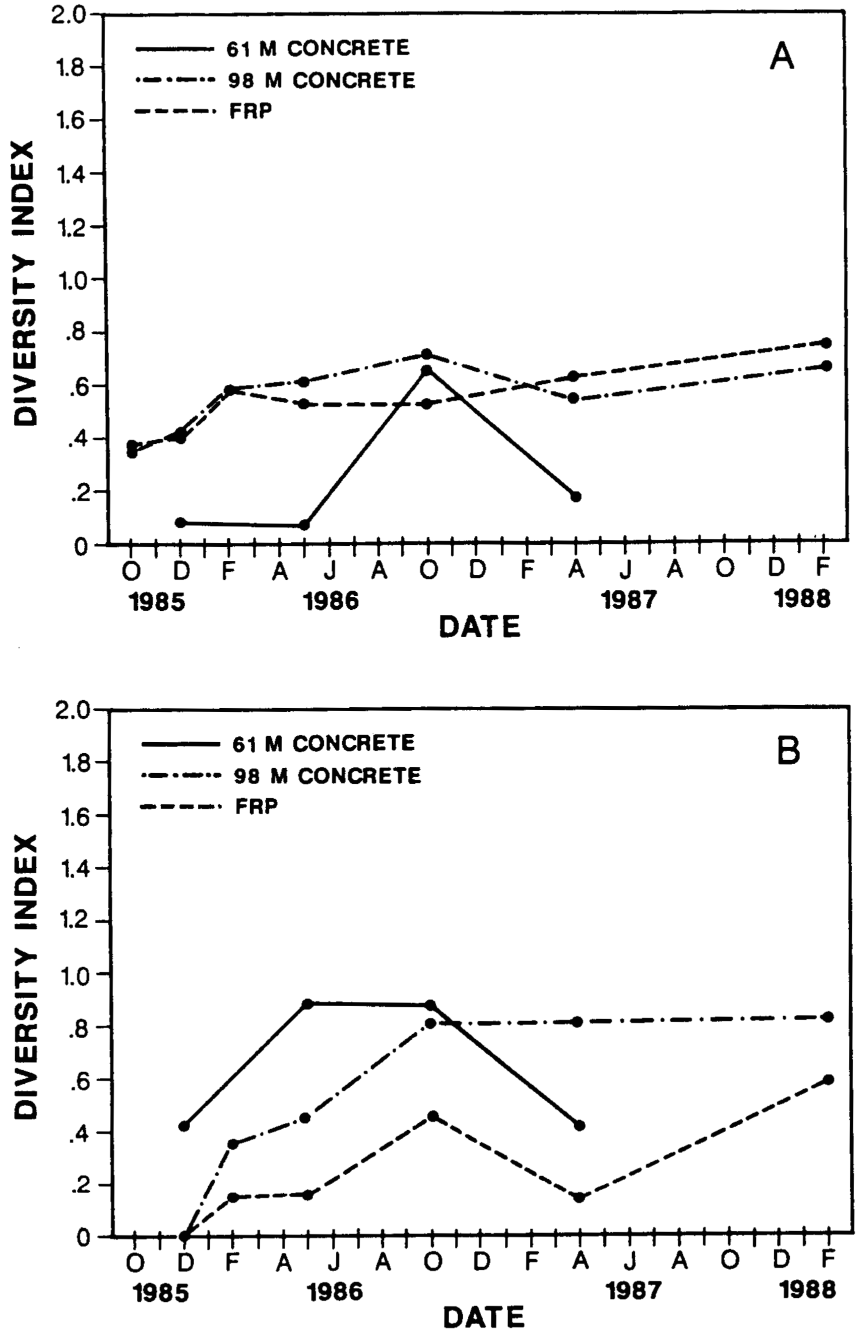

Figure 4. Diversity at Penguin Bank artificial reefs. (A) Transient species. (B) Resident species.

erate range in October 1986, followed by a return to a low level. Paired t-test analysis indicated a significant difference in the diversity of transient species between the 61 m and 98 m concrete reefs, but no significance in other paired comparisons. Because the richness and numbers of individuals of transient species were similar at these sites, the significantly lower diversity value of the 61 m reef must be largely due to a lack of evenness.

Despite the similarity in the total numbers of transient fish between reef sites throughout the study, standing stock biomass estimates for the 61 m concrete reef were much lower than those of the other two reefs (Fig. 5A). Paired comparisons indicated a significant difference between the 61 m concrete reef and the FRP reef, but no significance in the other paired comparisons. Over 90% of the biomass of transient species at the 98 m and FRP reefs was attributable to four species designations, *Aprion virescens, Naso* spp., *Pristipomoides filamentosus* and *Seriola dumerili.* These four were the largest of the transient species observed in our study and, by contrast, comprised less than 1% of the biomass at the 61 m site. These differences in the relative contribution to the biomass of transient species may be due to differences in depth, distance from the bank dropoff or random site factors not identified because of the lack of replicates at any single depth. In the same manner, the great similarities in biomass and species contributions of transient species at the 98 m and FRP reefs, despite large differences in reef size (e.g., height, volume and surface area) and structural material, suggest that depth (or location on the bank) is more important than reef size or structural material in determining attracted biomass.

Temporal patterns in community structure measures for resident species were very different from those for transient species. The richness of resident species (Fig. 2B) started at 0 at the 98 m and FRP reefs, as would be expected (the 61 m reef was not visited until 2 months after deployment). Resident species richness at the 61 m and 98 m concrete reefs increased rapidly, then leveled off at about 12 months. The FRP reef showed a much slower increase in richness, with no apparent leveling out by the end of the study. Paired t-test analysis indicated a significant difference in richness between the 61 m concrete and FRP reefs, but no significant difference between other pairs. Recruitment curves generated for resident species richness indicated asymptotic values of 14.0 (SD = 0.0029, R^2 = 0.82), 15.1 (SD = 3.6, R^2 = 0.85) and 58.8 species (SD = 345.6, R^2 = 0.60) for the 61 m, 98 m and FRP reefs, respectively. Ninety percent of these species are predicted to be present within 2.8, 20 and 461 months, respectively. As with the transient species, no significant differences in asymptotic richness values for resident species were apparent between the reef sites. Again, a longer time series of observations at the FRP reef presumably would show a leveling off of resident species richness yielding an asymptotic value of about 14–15 species, as seen at the other two reef sites. The significant difference in richness between the 61 m and FRP reefs is probably due to differences in the rate of colonization rather than to the number of species in the available pool.

No significant difference was found in the number of individuals of resident fish at the three reef sites throughout the study. However, trends in the number of individuals over time (Fig. 3B) suggest that the two concrete reefs recruit earlier and hold more resident fish than the FRP reef. The unusually large number of fish observed at the 61 m concrete reef in April 1987 was mostly due to a very large aggregation of *Priacanthus* sp. encountered at a single reef module. We believe this was a temporary phenomenon, possibly a breeding aggregation. Unfortunately, submersible dives scheduled for fall 1987 were cancelled and attempts to locate the 61 m reef in February 1988 were unsuccessful.

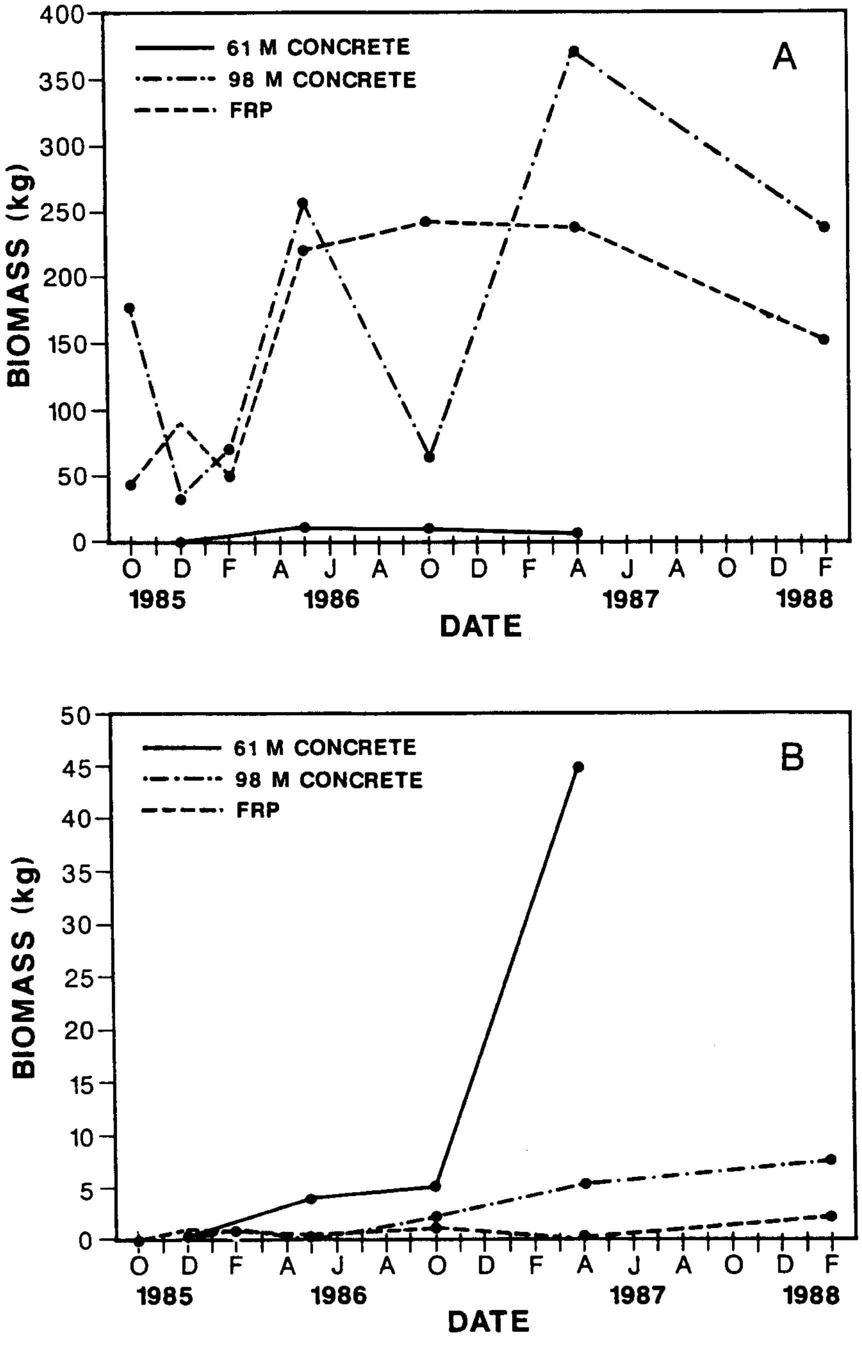

Figure 5. Biomass at Penguin Bank artificial reefs. (A) Transient species. (B) Resident species.

As with richness and number, the diversity of resident fish at the FRP reef was lower than at the concrete reefs (Fig. 4B). These differences were significant, whereas those between the 61 m and 98 m concrete reefs were not.

The pattern of biomass of resident species over time for the three reefs (Fig. 5B) was, again, similar to those of richness, number and diversity. The 61 m concrete reef had the earliest increase and highest biomass values, followed by the 98 m concrete reef. The FRP reef had the slowest rise and lowest values throughout the study. Results of paired t-tests indicated no significant differences between any pairs.

In the above results, all reefs were treated as single units. The two concrete reefs, however, were each composed of four individual modules. Transient fish species swam freely between modules during an observation period and, therefore, could not be attributed to a single module. Resident fish, on the other hand, were restricted to a single module during an observation period and were recorded as such. These modules, then, can be considered as replicates for each site and depth. Because the means and variances of each of the measures are expected to change over time, comparisons must be made on an observation date by observation date basis. The variance between treatments was about double that within a treatment; hence, no significant differences between resident species at the 61 m and 98 m concrete reefs were shown for any of the four measures.

Most individuals of both transient and resident species recruited to our reefs as adults. Of the few species at least partially recruited to our reefs as small juveniles, most were resident species. Small juveniles observed included the resident species *Dascyllus albisella, Anthias thompsoni, A. ventralis, Chaetodon fremblii, C. miliaris, Chromis verater, Labroides phthirophagus* and *Lutjanus kasmira* and the transient species *Synodus* sp. and *Coris flavovittata.* Even among these species, most of the recruitment appeared to occur from adult immigration. No juvenile eteline snappers were seen at any reef site. Although we had hoped to attract some, it is not entirely surprising that they were not seen. To date, the nursery habitat for these species has not been located so their absence from our reefs may be due to incorrect placement of our reefs and not necessarily to reef design.

DISCUSSION

Our study compares most directly with that of Sheehy (1983), who evaluated both concrete conduit and FRP reefs. The major differences are that (1) his study was conducted in about 30 m of water on the continental shelf in the Atlantic Ocean, (2) the concrete conduit in his study was dumped as single pieces rather than being fabricated into reef modules and (3) his reef sites were heavily fished by anglers. Sheehy (1983) showed that the FRP reefs aggregated about 10 times as many fish as the concrete conduit reefs. On the other hand, our results show a great similarity between the 98 m concrete reef and the FRP reef in their ability to aggregate transient species, despite vast differences in size, structural material and design. Furthermore, the 61 m reef was a relatively poor aggregator of transient species, despite similarities to the 98 m reef in size, structural material and design. These results suggest that depth and location on the bank are more important than size, structural material and design in attracting transient species biomass. In contrast, the two concrete reefs outperformed the FRP reef in all measures analyzed for resident species and showed a greater similarity to each other than to the FRP reef, suggesting that structural material and design are more important than reef depth and location in attracting resident species. From a commercial perspective, the transient species attracted to our reefs are of much greater im-

Table 3. Biomass as a function of reef size (average of October 1986 and April 1987 observations)

		Biomass in terms of size			
Reef site	Mean biomass (kg)	Volume ($kg \cdot m^{-3}$)	Surface area ($kg \cdot m^{-2}$)	Cover area ($kg \cdot m^{-2}$)	Height ($kg \cdot m^{-1}$)
61 m concrete					
Transient species	7.68	1.54	0.09	0.97	6.98
Resident species	24.67	4.93	0.29	3.11	22.42
98 m concrete					
Transient species	218.09	38.94	2.46	25.84	198.26
Resident species	3.77	0.67	0.04	0.45	3.43
Fiberglass-reinforced plastic					
Transient species	239.74	1.72	1.08	5.61	45.23
Resident species	0.70	0.005	0.003	0.02	0.13

portance than the resident species, both in terms of price per kilogram and the actual biomass attracted.

The size of an artificial reef has been reported to be very important to its ability to attract transient species. Ogawa et al. (1977) found that production increased directly with reef volume up to a critical point of 4,000 m^3. Molles (1978) reported the importance of reef height in attraction of transient species, as did Mottet (1985) who further suggested that the importance of reef height increases with increasing depth. Reef height and volume did not appear to be important in attracting transient species in our study, however. Our 98 m and FRP reefs attracted very similar biomass and numbers of transient fish despite vast differences in reef height and volume (Table 3). When biomass is viewed as a function of reef size in terms of volume, area or height, the 98 m concrete reef appears to out perform the FRP reef by factors of anywhere from 3:1 to nearly 40:1. We believe that in our particular study, however, it is not so much a matter of better performance of the 98 m reef compared to the FRP reef as it is the lack of importance of reef size in attracting the transient fish species involved.

In general, one would expect species richness to be inversely correlated to depth, as has been shown to be true for insular species at Enewetak Atoll, Marshall Islands, by Thresher and Colin (1986). Brock (1980), who generated a recruitment curve for fish species colonizing a newly developed harbor near Kona, Hawaii, reported an asymptotic value of 87.52 species for a surface to 5-m-deep study area. Asymptotic values for richness in our study are comparable to other studies using total species richness, simply by adding the two values for transient and resident species. The values for total richness for the 61 m concrete, 98 m concrete and FRP reefs are 22.9, 26.5 and 94.0 species, respectively. As mentioned earlier, the 94.0 species value obtained for the FRP reef is considered to be unrealistic because colonization has not progressed past the straight-line portion of the recruitment curve at this time. The 22.9 and 26.5 species values obtained for the two concrete reefs are considered to be more realistic and are, in deed, less than the 87.52 species predicted by Brock (1980) for his shallower site. For a 4.2-m-deep shipwreck artificial reef in the eastern Mediterranean Sea, Diamant et al. (1986) reported asymptotic richness values for this reef were 22 species based on visual census data and 37 species based on rotenone collection data. The Mediterranean Sea is a species-poor area (Diamant et al., 1986), which gives predicted asymptotic richness values similar to our much deeper sites.

Considering the similarity of the deep slope transient species throughout the central and western Pacific, the results of our study should be useful in determining future applications of deepwater artificial reefs in the Pacific. We stress that artificial reefs should be viewed and used as management tools. Small-scale artificial reefs, such as those used in this study, do indeed work well as aggregators of commercially important deep slope fish and, therefore, could probably be used to increase the catch per unit effort for these species. They probably will not, however, provide additional nursery habitat for these species or add much to the overall standing stock through new or improved adult habitat. Therefore, their use should be restricted to target species that are currently underutilized. If used to aggregate individuals of overfished species in an unregulated fishery, such as the deep snappers at Penguin Bank, these artificial reefs could add to the problem rather than provide a solution.

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