

Influence of an artificial reef on the surrounding infaunal community

R. F. Ambrose and T. W. Anderson

Marine Science Institute, University of California at Santa Barbara, Santa Barbara, California 93106, USA

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Abstract. Artificial reefs have been constructed throughout the world, but their effects on adjacent soft-bottom communities are largely unknown. In December 1986, we investigated the influence of Pendleton Artificial Reef (PAR) in Southern California on the abundance of infauna in the surrounding sand bottom. PAR was constructed in 1980 of quarry rock placed in eight piles, or modules. The artificial reef altered the grain-size distribution of sediments around the reef; sediments close to the modules were coarser than those 10 or 20 m away from the modules. Densities of one of the two most common species, the polychaete *Prionospio pygmaeus*, were lower near the reef, perhaps due to foraging by reef-associated predators or because the habitat near the reef was less suitable. We found no evidence that foraging by reef-associated fishes caused a widespread reduction in infaunal densities near the reef, and in fact the other most common taxon, *Spiophanes* spp., had higher densities near the reef. The most conspicuous effect of the artificial reef concerned the tube-dwelling worm *Diopatra ornata*, which only occurred in close association with the modules. In addition, total infaunal density and the densities of decapods, echinoderms and sipunculids were higher within *D. ornata* beds than outside the beds. These results indicate that the densities of some species were enhanced, and others depressed, around the reef, but that the overall effect of the artificial reef on the surrounding infauna was limited to a small area near the modules.

Introduction

Artificial reefs, traditionally constructed to increase fishing success, have increasingly been used as fisheries-management tools and for mitigating adverse environmental impacts (Grant et al. 1982, Grove 1982, for review see Bohnsack and Sutherland 1985). The recent focus on artificial reefs has led to the placement and planned construction of many new reefs throughout the world, with centers of activity in Australia, Japan, southeastern Asia,

the Caribbean and Mediterranean basins, the Pacific Islands, and North America (Seaman et al. 1989). As a rule, these reefs are positioned on extensive sand plains, typically isolated from rocky reefs. They can potentially alter species abundances, distribution patterns, and the structure of the adjacent sand-associated community through changes in current intensity and direction, erosion and sedimentation rates, grain-size distributions, organic content of sediments, and attraction of predators (Turner et al. 1969, Davis et al. 1982). In one of the few studies to date investigating the effects of artificial reefs on the surrounding sand community, Davis et al. did not detect a relationship between infaunal densities and distance from Torrey Pines Artificial Reef (near San Diego), although they did find such a relationship around an oil platform.

The possible impact of an artificial reef on the surrounding sand community has seldom been considered adverse, in spite of the fact that the reef kills organisms buried underneath it, and that changes to the physical and biotic environment caused by the reef can also affect the sand community. Although these effects may be of little concern while there are few artificial reefs, as more artificial reefs are placed on sand it becomes more important to assess their effects on sand communities. The purpose of this study was to examine the effects of Pendleton Artificial Reef (PAR) on the surrounding infaunal community. Pendleton Artificial Reef was constructed in 1980 in northern San Diego County, California (32°53'N; 117°27'W), by the California Department of Fish and Game to determine the potential of such reefs for mitigating habitat losses due to coastal development (Grant et al. 1982, Grove 1982). PAR consists of an array of eight rock piles (modules) covering a total sand-rock area of approximately 3 ha and positioned on sand at a depth of 13 m (Fig. 1). PAR has been the subject of numerous studies of the biota associated with the rocky substrate (Grant et al. 1982, Carter et al. 1985 a, b, Jessee et al. 1985, Ambrose and Swarbrick 1989, Anderson et al. 1989, DeMartini et al. 1989), but this is the first study of infauna near the reef.

We expected that infaunal densities would be altered near the PAR modules, and that these effects would be most pronounced nearest the modules, for two reasons. First, artificial reefs interact with currents and surge in a manner that alters the physical characteristics of the surrounding sand bottom (Turner et al. 1969, Davis et al. 1982), and infauna are generally sensitive to changes in sediment characteristics (Gray 1974). Second, infauna near artificial reefs may be subjected to higher predation intensity when reef-associated fishes forage over sand near the reef. In this paper, we assess the influence of PAR on the sand-associated community as a function of distance from the reef. In addition, we examine the infauna found in the midst of the PAR module complex and compare infauna within beds of the tube worm *Diopatra ornata* with infauna found outside the beds.

Materials and methods

PAR was sampled along four transects in December 1986. The transects were placed onshore (at a compass heading of 30°), offshore (210°), upcoast (300°) and downcoast (120°) of the module complex (Fig. 1). Because PAR is located on a relatively flat sand plain (Box Canyon, 400 m offshore from PAR, is only 1 m deeper than PAR), all the transects were located at approximately the same depth. The offshore transect is that most exposed to the prevailing swell (Carter et al. 1985 a), and the onshore transect is in the lee of the module complex. Although there are frequent reversals in long-shore currents, downcoast currents are both stronger and more persistent (Elwany et al. 1988).

Sediment samples were taken at each station using 5 cm-diam cores. After air drying, each sample was run through a shaker, with sieves ranging from -2Φ to 4Φ in $2-\Phi$ increments, and each fraction was weighed (see Leeder 1982). Grain sizes are presented as phi (Φ) sizes, where $\Phi = -\log_2$ [mean diameter in mm].

Infauna were sampled by $0.0075 \text{ m}^2 \times 13 \text{ cm}$ -deep cores. The cores were pushed into the substrate by divers, capped in place with plastic snap-on lids, and removed. Along each transect, core samples were collected at 1, 2, 5, 10, and 20 m from a module. To examine possible differences in infaunal density within versus outside the module complex, additional cores were collected from three areas between modules (Fig. 1). Cores were also collected within *Diopatra ornata* beds at Modules 3, 5, and 6 to compare densities within versus outside the beds. Five cores, spaced approximately 1 m apart, were collected at each sampling location (along transects, between modules, and within *D. ornata* beds); three of the five cores were selected at random for analysis.

Infaunal cores were brought to the surface, sieved through a 0.5 mm screen, fixed in 10% formalin, and later transferred to 40% isopropyl alcohol. Organisms were identified to the lowest practical taxon and counted using a dissecting microscope. Nematodes were abundant, but were excluded from the analysis because they were small and could fit through the sorting screen. Densities (no. of individuals/core) were calculated for all taxa combined and for each taxonomic group, functional group, and lowest taxon identified (see Table 2).

Feeding type, recently supplemented with motility and preferred feeding site, has been widely used for classifying benthic taxa (e.g. Young and Rhoads 1971, Fauchald and Jumars 1979). For this study, infauna were assigned to functional groups based on descriptions in the literature of their depth in the sediment, mode of feeding, and motility associated with feeding. Depth of feeding was classified as surface, if the organisms feed at the sediment-water interface, or subsurface. Modes of feeding include suspension (filters food from the water column), deposit and detritus feeder (ingests sediment and/or detritus), carnivore (feeds on live animal tissue), and omnivore (scavenges dead animal tissue or feeds on a wide variety of animal, plant, and detritus particles); organisms using more than one feeding mode were placed in joint classifications (e.g. deposit-detritus). Motilities associated with feeding include motile (active movement in search of food), discrete (foraging within a restricted area), or sessile (feeding from a stationary position). The literature search and classification of taxa was conducted by Barnett et al. (1987). Functional groups for the taxa sampled during this study are given in Table 1.

A two-factor, fixed-effects model, analysis of variance (ANOVA) without replication was used to determine if infaunal densities were different for various distances from modules. The three cores at each station (i.e., distance along a transect) could not be used as independent replicates because they were collected near one another; instead, the three cores were averaged to provide a single value for each station. In the ANOVA model, transect was treated as a blocking variable and there is no interaction term. Densities of individual taxa, taxonomic groups, and functional groups were transformed using $\log_{10}(x+0.15)$. The value of the constant used in the logarithmic transformation can distort the outcome of statistical analyses; 0.15 was chosen because it is approximately one-sixth of the minimum non-zero arithmetic value (see Mosteller and Tukey 1977). For total individuals, data were transformed using $\log_{10}(x+1)$; 1 was an appropriate constant because densities for this overall group were appreciably higher. A Tukey *a posteriori* multiple-comparison test was used to identify differences. The significance level used for all tests was $P=0.05$.

A one-factor ANOVA was used to compare total individuals, taxonomic groups, functional groups, and the 15 most abundant species in samples collected within the module complex to those collected on transects. Data were transformed as noted above and the mean of the three cores at each station was used in the analysis.

Infaunal densities within versus outside *Diopatra ornata* beds were compared by a Student's *t*-test. All *D. ornata* beds were adjacent to modules. Densities within the beds [$n=3$ (sites)] were tested against those at the 1 m distance from modules on transects outside beds [$n=4$ (transects)]. Total individuals, taxonomic groups and functional groups were tested; individual species could not be tested because of low numbers. Data were transformed as noted above.

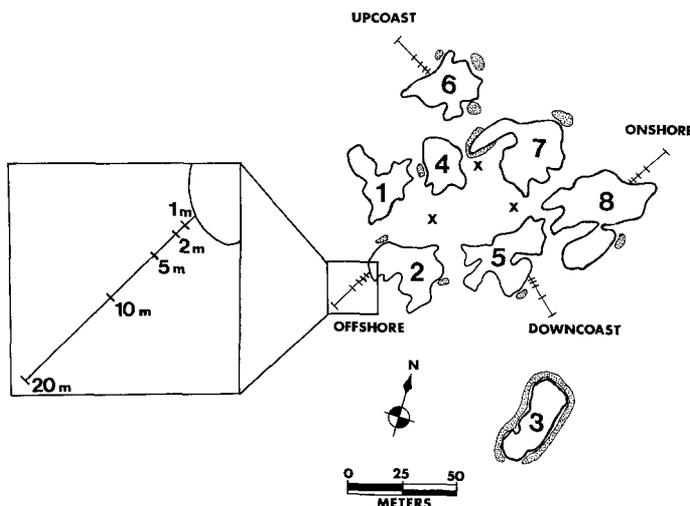


Fig. 1. Location of transect and between-module core samples at Pendleton Artificial Reef, southern California. Eight rock piles (modules) cover total sand-rock area of ~ 3 ha. Three samples were collected at each of five distances along transects and at positions of between-module samples denoted by "x". Locations of *Diopatra ornata* beds are stippled; infauna in *D. ornata* beds were sampled at Modules 3, 5, and 6

Table 1. Total abundance of infauna sampled near Pendleton Artificial Reef (PAR). Total abundance is sum of all individuals in 60-, 9- and 9-core samples along transects from modules, between modules, and in *Diopatra ornata* beds, respectively. Functional groups correspond to trophic-motility categories (see "Materials and methods"). Taxa were classified after Barnett et al. (1987). SF: surface forager; SB: subsurface forager; SU: suspension feeder (filters food from water column); DP: deposit feeder (ingests sediment and/or detritus); DE: detrital feeder; C: carnivore; O: omnivore; MF: multi-feeding strategy; M: motile; S: sessile; D: discrete (forages in restricted area); - : taxon did not occur in sample

Taxon	Functional group	Total abundance in:		
		Transects (N=60)	Between (N=9)	<i>D. ornata</i> (N=9)
Cnidaria				
Anthozoa				
Anemones	D, SF, C-O	8	-	3
<i>Edwardsia</i> sp.	D, SF, C-O	8	-	1
Platyhelminthes	M, SF, C-O	-	-	1
Nemertea	M, SF, C-O	40	11	13
Mollusca				
Gastropoda				
Acmaeidae		-	-	5
<i>Epitonium</i> spp.	D, SF, C-O	2	-	-
<i>Nassarius perpinguis</i>	M, SF, C-O	4	-	-
<i>Olivella</i> sp.	M, SF, C-O	1	-	-
<i>Polinices lewisii</i>	M, SF, C-O	2	-	-
Bivalvia				
<i>Lima</i> sp.		-	-	2
<i>Macra</i> sp.	D, SU	-	1	1
<i>Nuculana</i> sp.	D, SF, DE, DP	1	1	1
<i>Saxidomus</i> sp.	D, SF, SU-DP	4	-	1
<i>Tellina modesta</i>	D, SF, SU-DP	6	-	1
Annelida				
Polychaeta				
<i>Ampharete labrops</i>	S, SF, DE, DP	10	4	13
<i>Amphiteis glabra</i>	S, SF, DE, DP	39	-	4
<i>Anaitides</i> sp.	M, SF, C-O	-	-	3
<i>Aricidea</i> sp.	M, SB, DP	46	1	2
<i>Armandia brevis</i>	M, SB, DP	5	-	8
<i>Autolytus</i> sp.	M, SF, C-O	-	-	1
<i>Axiothella rubrocincta</i>	S, SB, DP	2	-	1
Chaetopteridae	S, SF, SU-DP	2	-	-
<i>Chaetozone setosa</i>	M, SF, DE, DP	77	3	2
<i>Chone</i> sp.	S, SU	1	-	1
<i>Cossura</i> sp.	M, SB, DP	3	-	-
<i>Dispia uncinata</i>	D, SF, SU-DP	1	-	-
<i>Eteone</i> sp.	M, SF, C-O	2	-	-
<i>Eumida tubiformis</i>	M, SF, C-O	1	1	1
<i>Eusyllis</i> sp.	M, SF, C-O	4	1	-
<i>Exogone lourei</i>	M, SF, C-O	3	-	10
<i>Glycera americana</i>	D, SF, C-O	1	-	-
<i>Glycera</i> spp.	D, SF, C-O	18	3	23
<i>Goniada</i> spp.	D, SF, C-O	8	-	-
<i>Gyptis brevipalpa</i>	M, SF, C-O	14	10	57
<i>Haploscoloplos elongatus</i>	M, SB, DP	6	-	4
<i>Harmothoe</i> spp.	M, SF, C-O	6	-	4
<i>Hesionella</i> sp.	M, SF, C-O	-	-	1
<i>Hesionura</i> sp.	M, SF, C-O	27	6	4
<i>Laonice</i> sp.	D, SF, SU-DP	-	-	1
<i>Lumbrineris californiensis</i>	M, SB, C, DP	2	-	4
<i>Lumbrineris lutea</i>	M, SB, C, DP	13	3	24
<i>Lumbrineris</i> sp.	M, SB, C, DP	1	1	-
Lumbrineridae	M, SB, C, DP	-	-	-
<i>Magelona sacculata</i>	D, SF, DE, DP	83	3	-
<i>Magelona</i> spp.	D, SF, DE, DP	3	-	-
<i>Mediomastus</i> spp.	M, SB, DP	130	3	21
<i>Nephtys caecoides</i>	M, SB, C, DP	33	10	-
<i>Nereis zonata</i>	D, SF, C-O	2	-	13
<i>Nothria elegans</i>	D, SF, C-O	33	-	2

(continued overleaf)

Table 1 (continued)

Taxon	Functional group	Total abundance in:		
		Transects (N=60)	Between (N=9)	<i>D. ornata</i> (N=9)
<i>Notomastus</i> sp.	M, SB, DP	–	–	11
<i>Odontosyllis parva</i>	M, SF, C-O	–	–	19
<i>Ophelia</i> sp.	M, SB, DP	2	–	1
Opheliidae	M, SB, DP	1	–	–
<i>Owenia collaris</i>	D, SF, SU-DP	5	1	1
<i>Paraonis gracilis</i>	M, SB, DP	4	1	–
<i>Pherusa inflata</i>	D, SF, DE, DP	1	–	5
<i>Pholoe</i> sp.	M, SF, C-O	–	–	5
<i>Phyllodoce</i> sp.	M, SF, C-O	10	–	4
Phyllodocidae	M, SF, C-O	–	1	–
<i>Pisione remota</i>	–	–	23	10
<i>Pista cristata</i>	S, SF, DE, DP	3	–	3
<i>Poecilochaetus johnsoni</i>	–	–	1	25
<i>Polydora</i> sp.	D, SF, SU-DP	6	2	1
<i>Polygordius</i> sp.	–	–	4	2
<i>Prionospio cirrifera</i>	D, SF, SU-DP	6	11	29
<i>Prionospio malmgreni</i>	D, SF, SU-DP	4	–	4
<i>Prionospio pinnata</i>	D, SF, SU-DP	52	1	1
<i>Prionospio pygmaeus</i>	D, SF, SU-DP	205	12	2
<i>Protodorvillea gracilis</i>	M, SF, C-O	4	13	7
<i>Saccocirrus papillocercus</i>	–	–	2	–
<i>Scoloplos armiger</i>	M, SB, DP	7	–	1
Sigalionidae	M, SF, C-O	–	8	8
<i>Spiophanes</i> spp.	D, SF, SU-DP	202	11	3
<i>Sthenelais verruculosa</i>	M, SF, C-O	1	–	–
<i>Syllis</i> sp.	M, SF, C-O	–	–	2
Syllidae	M, SF, C-O	1	–	2
Terebellidae	S, SF, DE, DP	–	–	1
<i>Thalenessa spinosa</i>	M, SF, C-O	21	–	–
<i>Travisia</i> sp.	M, SB, DP	1	–	–
Sipuncula	S, SF, DE, DP	6	1	41
Arthropoda				
Pycnogonida	D, SF, C-O	3	–	11
Crustacea				
Isopoda				
<i>Bathycopea daltonae</i>	D, SF, C-O	5	2	–
<i>Edotea sublittoralis</i>	D, SF, C-O	22	–	–
<i>Jaeropsis dubia</i>	D, SF, C-O	–	–	3
<i>Munna ubiquita</i>	M, SF, C-O	3	–	–
<i>Neastacilla californica</i>	D, SF, C-O	1	–	–
<i>Serolis carinata</i>	D, SF, C-O	1	–	–
<i>Silophasma seminata</i>	D, SF, C-O	–	–	1
Sphaeromatidae	D, SF, C-O	1	–	2
Amphipoda				
Caprellidea				
<i>Caprella</i> sp.	–	–	–	5
Gammaridea				
<i>Ampelisca agassizi</i>	S, SF, SU-DP	20	–	1
<i>Ampelisca brevisimulata</i>	S, SF, SU-DP	12	–	–
<i>Ampelisca careyi</i>	S, SF, SU-DP	1	–	–
<i>Ampelisca cristata</i>	D, SF, C-O	25	–	–
<i>Amphideutopus oculus</i>	D, SF, SU-DP	5	–	2
Amphilochidae	–	–	–	1
Aoridae	D, SF, SU-DP	–	–	2
<i>Aoroides</i> sp.	D, SF, SU-DP	3	–	20
<i>Agrissa hamatipes</i>	M, SF, DE, DP	8	–	–
Corophiidae	D, SF, SU-DP	–	–	3
<i>Corophium</i> sp.	D, SF, SU-DP	5	–	–
<i>Dulichia</i> sp.	–	–	–	4
<i>Elasmopus antennatus</i>	M, SF, O, DP	1	–	8
<i>Elasmopus rapax</i>	M, SF, O, DP	–	–	7

Table 1 (continued)

Taxon	Functional group	Total abundance in:		
		Transects (N=60)	Between (N=9)	<i>D. ornata</i> (N=9)
<i>Eobrolgus chumashi</i>	M, SF, O, DP	11	—	14
<i>Erichthonius hunteri</i>	D, SU	—	—	1
Eusiridae	M, SF, O, DP	—	—	6
<i>Foxiphahus</i> sp.	M, SF, O, DP	—	—	1
Gammaridae	M, SF, DE, DP	4	2	3
<i>Hippomedon</i> sp.	M, SF, O, DP	2	—	1
Isaeidae	D, SF, SU-DP	3	—	89
<i>Maera</i> sp.	M, SF, O, DP	—	7	1
<i>Megaluropus longimerus</i>	M, SF, DE, DP	98	112	3
<i>Melphisana bola</i>	M, SF, DE, DP	1	—	—
<i>Microjassa litotes</i>		—	—	3
<i>Monoculodes hartmanae</i>	M, SF, DE, DP	6	—	—
<i>Monoculodes spinipes</i>	M, SF, DE, DP	1	—	—
<i>Orchomene anaquela</i>	M, SF, O, DP	1	—	—
<i>Orchomene magdalensis</i>	M, SF, O, DP	2	—	—
<i>Pachynus barnardi</i>	M, SF, O, DP	4	—	—
<i>Photis brevipes</i>	D, SF, SU-DP	5	—	—
<i>Photis lacia</i>	D, SF, SU-DP	24	—	32
Pleustidae	M, SF, O, DP	—	—	12
<i>Platyschnopus</i> sp.		—	1	—
<i>Rhepoxynius abronius</i>	M, SF, O, DP	82	—	—
<i>Rhepoxynius menziesi</i>	M, SF, O, DP	26	—	—
<i>Stenothoe estacola</i>	D, SF, O, DP	—	—	8
Stenothoidae	D, SF, O, DP	—	—	—
<i>Synchelidium rectipalmmum</i>	M, SF, O, DP	2	1	1
<i>Synchelidium shoemakeri</i>	M, SF, O, DP	10	1	5
<i>Tiron biocellata</i>	M, SF, DE, DP	134	29	3
Decapoda				
Anomura				
<i>Pagurus</i> spp.	M, SF, C-O	2	—	90
Shrimps	D, SF, C-O	1	—	2
Penaeidea				
Crangonidae	D, SF, C-O	2	—	—
<i>Crangon munitella</i>	D, SF, C-O	1	—	4
<i>Heptacarpus pictus</i>	M, SF, C-O	—	—	1
<i>Lepidopa californica</i>	M, SF, C-O	1	—	—
Tanaidacea				
<i>Leptochelia</i> sp.		—	—	11
Brachyura				
<i>Cancer antennarius</i>	M, SF, C-O	—	—	2
<i>Cancer antonyi</i>	M, SF, C-O	1	—	7
<i>Cancer gracilis</i>	M, SF, C-O	—	—	2
<i>Hemigrapsus oregonensis</i>	M, SF, C-O	—	—	17
Inachidae	M, SF, C-O	—	—	11
<i>Pinnixa occidentalis</i>	M, SF, C-O	—	—	1
<i>Pinnixa schmitti</i>	M, SF, C-O	—	—	1
Cumacea				
<i>Campilaspis</i> sp.	M, SF, DE, DP	5	2	—
<i>Cyclaspis</i> sp.	M, SF, DE, DP	29	1	5
<i>Diastylopsis tenuis</i>	M, SF, DE, DP	13	—	—
<i>Diastylis</i> sp.	M, SF, DE, DP	1	—	—
<i>Hemilamprops</i> sp.	M, SF, DE, DP	14	7	—
<i>Lamprops carinata</i>	M, SF, DE, DP	15	4	1
<i>Lamprops quadriplicata</i>	M, SF, DE, DP	1	—	—
<i>Leptostylis</i> sp.	M, SF, DE, DP	2	—	—
<i>Leucon subnasica</i>	M, SF, DE, DP	1	—	—
Ostracoda				
<i>Asteropella slatteryi</i>	M, SF, SU, DP	3	—	6
<i>Bathyleberis garthi</i>	M, SF, SU, DP	3	—	1
<i>Euphilomedes carcharodonta</i>	M, SF, O, DP	46	—	1
<i>Leuroleberis sharpei</i>	M, SF, SU, DP	3	—	8
<i>Rutiderma lomae</i>	M, SF, O, DP	4	—	1
<i>Rutiderma rostratum</i>	M, SF, O, DP	2	—	—

(continued overleaf)

Table 1 (continued)

Taxon	Functional group	Total abundance in:		
		Transects (<i>N</i> =60)	Between (<i>N</i> =9)	<i>D. ornata</i> (<i>N</i> =9)
Copepoda	M, SF, SU, DP	1	2	1
<i>Epinebaila</i> sp.	M, SF, SU, DP	4	—	—
Brachiopoda				
<i>Glottidia albida</i>	S, SU	3	—	—
Echinodermata				
Echinoidea	M, SF, DE, DP	—	1	—
<i>Lovenia cordiformis</i>	M, SF, DE, DP	4	—	1
Ophiuroidea	D, MF	44	—	42
Holothuroidea	D, SF, O, DP	2	—	—
Hemichordata				
Enteropneusta	D, SB, DP	—	—	4
Total individuals		1934	326	894

Results

Sediment characteristics

Overall, sediments were coarser close to the modules than farther away (Fig. 2). There was a significant negative correlation between the proportion of the sediments coarser than 1ϕ (0.5 mm) and distance from the module (Spearman's rank correlation, $r_s = -0.49$, $N = 20$, $P < 0.05$).

There were noticeable differences in grain-size distributions among the four transects (Fig. 3). The onshore and offshore transects showed a marked trend in grain size, with stations closer to the modules having a higher proportion of larger sediments. In fact, the 1 and 2 m stations on the offshore transect had very small proportions of sediments $< 3\phi$. In contrast, the upcoast and downcoast transects, which were similar to each other, consisted primarily of sediment sizes $< 3\phi$, with very little difference in size distribution among samples collected at different distances from the module.

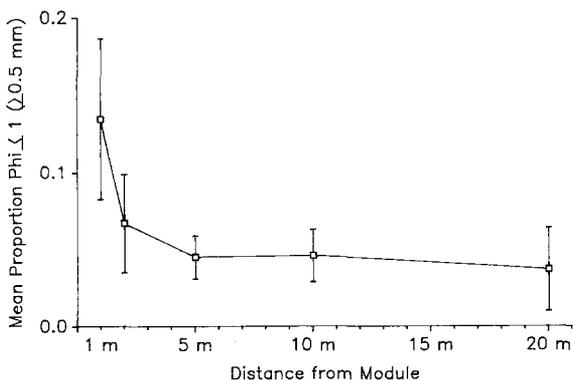


Fig. 2. Proportions of sediments coarser than 1ϕ at increasing distances from modules at Pendleton Artificial Reef. Data are means (\pm SE) of the four transects. Grain sizes are presented as phi (ϕ), with $\phi = -\log_2$ (mean diameter in mm); 1ϕ is equal to 0.5 mm diam, and is coarse sand on Udden-Wentworth scale

The grain-size distributions at the three stations between the modules were quite different from the transects and from each other (Fig. 3). Two of the stations had relatively coarse sediments, with practically no grains $< 4\phi$. In contrast, the third station had the finest sediments of all stations sampled, with most of the grains smaller than 4ϕ .

Infaunal community

A total of 121 taxa representing 10 phyla was sampled near PAR. Total density ranged from 2400 to 7300 individuals m^{-2} . Polychaetes constituted the largest component of the fauna, accounting for 57% of the organisms sampled (Fig. 4). The spionid polychaetes *Prionospio pygmaeus* and *Spiophanes* spp. were the most abundant species, each accounting for about 10% of the total organisms sampled. Crustacea comprised 36% of the fauna; gammarid amphipods were the most abundant crustacean group, accounting for 26% of the total. Two gammarid species, *Megaluropus longimerus* and *Tiron biocellata*, each comprised more than 5% of the total. None of the other major taxa sampled at PAR was very common; nemerteans and echinoderms comprised about 2.6% of the total, molluscs about 1%, and cnidarians, sipunculids and brachiopods less than 1%. A complete list of taxa sampled, assigned functional groups, and abundances is given in Table 1.

The infaunal community consisted of a diverse group of species with many different trophic and motility characteristics. Among the 15 most common taxa, eight taxa are motile, six forage in a restricted area, and one is sessile (Table 2). Regardless of their motility, most of the common species (11 out of 15) forage on the surface. Most of the common species (10 out of 15) are also deposit-feeders (i.e., they ingest sediment and/or detritus), although various other trophic types were also represented, including suspension-feeders (filtering food from the

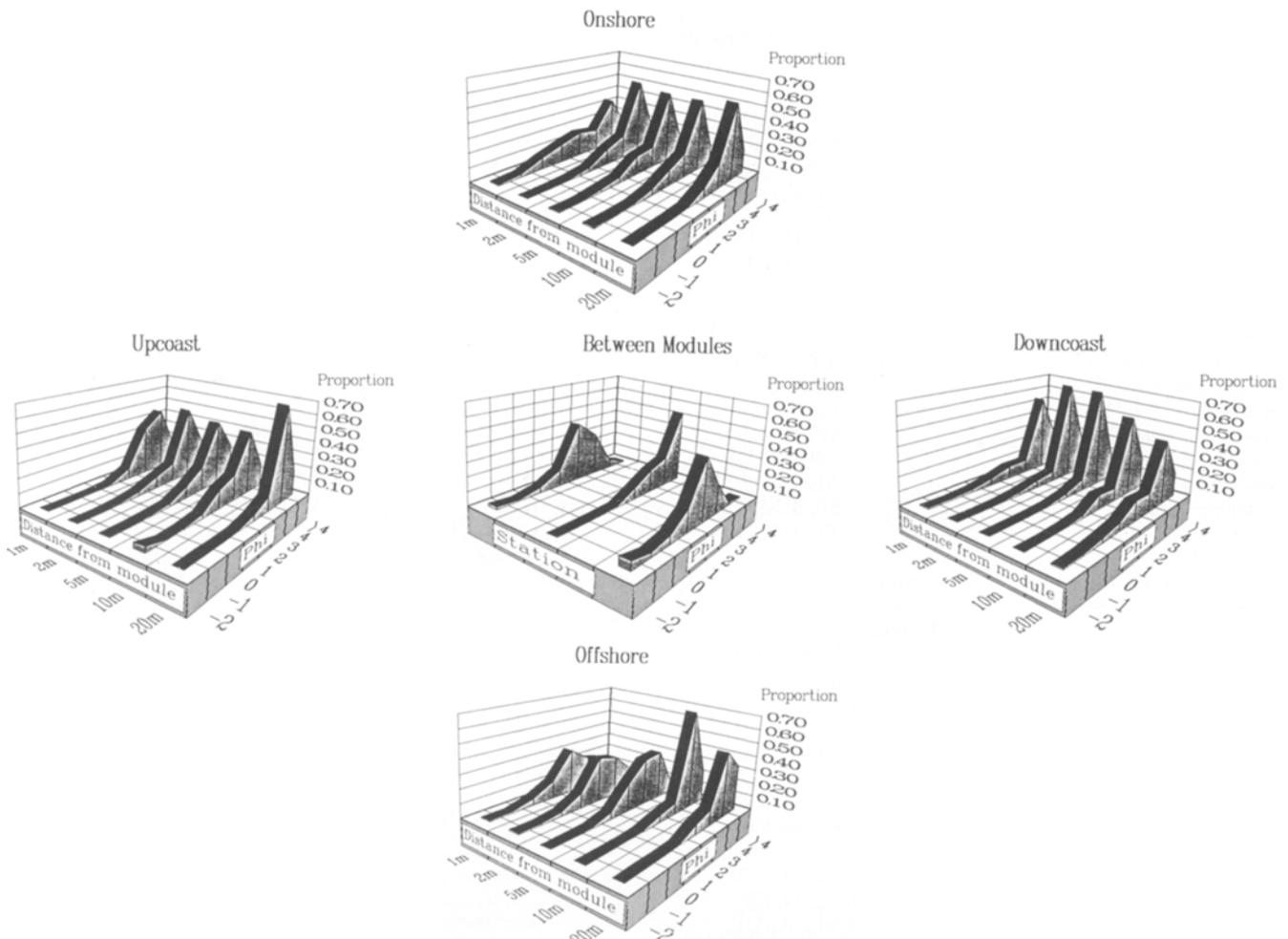


Fig. 3. Sediment grain-size distributions near Pendleton Artificial Reef. Sediments were sampled at five stations along each of four transects leading away from the reef and at three stations between

modules (see Fig. 1 for locations). Data are proportions of sediments in different grain-size categories at each station

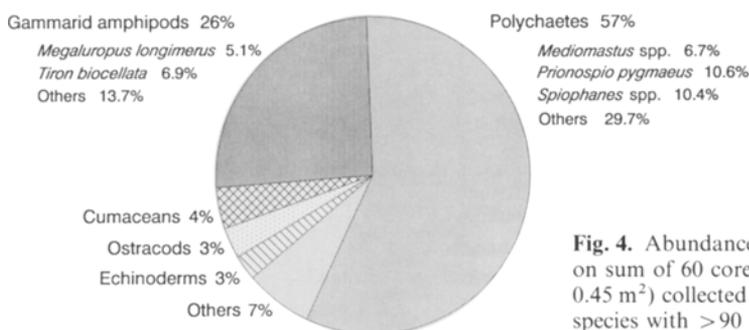


Fig. 4. Abundance of major infaunal taxa near Pendleton Artificial Reef based on sum of 60 cores (0.0075 m² × 13 cm deep core, for total area sampled of 0.45 m²) collected on transects. Taxonomic groups with > 50 individuals and species with > 90 individuals collected are noted

water column), carnivores, omnivores, and detrital feeders. Although no single trophic/motility group dominated the infaunal community, the two most common species (*Prionospio pygmaeus* and *Spiophanes* spp.) were both discrete surface suspension-deposit feeders, and the two next most common species (*Tiron biocellata* and *Megaluropus longimerus*) were both motile surface deposit-detritus feeders; these four species comprised a third of all infaunal species sampled.

The influence of the artificial reef modules was investigated by examining abundance patterns as a function of distance from module. Distance effects were detected in only 6 of the 45 different taxonomic and functional groups tested (Fig. 5). Although the influence of the modules was not widespread, they did apparently affect the distribution of some of the common taxa, including *Prionospio pygmaeus* and *Spiophanes* spp., the two most abundant taxa. These species are both spionids, with sim-

Table 2. Individual taxa, taxonomic groups, and functional groups analyzed. Taxa were identified to lowest practical level, with 15 most abundant taxa analyzed individually. Functional group abbreviations as in Table 1

Individual taxa	Functional group
<i>Amphiteis glabra</i>	S, SF, DE, DP
<i>Aricidea</i> sp.	M, SB, DP
<i>Chaetozone setosa</i>	M, SF, DE, DP
<i>Euphilomedes carcharodonta</i>	M, SF, O, DP
<i>Magelona sacculata</i>	D, SF, DE, DP
<i>Mediomastus</i> spp.	M, SB, DP
<i>Megaluropus longimerus</i>	M, SF, DE, DP
<i>Nephtys caecoides</i>	M, SB, C, DP
<i>Nothria elegans</i>	D, SF, C-O
Ophiuroids	D, MF
<i>Prionospio pinnata</i>	D, SF, SU-DP
<i>Prionospio pygmaeus</i>	DP, SF, SU-DP
<i>Rhepoxynius abronius</i>	M, SF, O, DP
<i>Spiophanes</i> spp.	D, SF, SU-DP
<i>Tiron biocellata</i>	M, SF, DE, DP

Taxonomic group	Taxonomic group
Cnidarians	Isopods
Nemerteans	Gammarid amphipods
Gastropods	Shrimps and crabs
Bivalves	Cumacea
Polychaetes	Ostracoda
Sipunculids	Copepods/other crustaceans
Pycnogonids	Echinoderms

Functional groups	Abbreviations
Motile surface deposit-detrital	M, SF, DE, DP
Motile surface omnivore-deposit	M, SF, O, DP
Motile surface suspension-deposit	M, SF, SU-DP
Motile surface carnivore-omnivore	M, SF, C-O
Motile subsurface carnivore-deposit	M, SB, C, DP
Motile subsurface deposit feeder	M, SB, DP
Discrete surface deposit-detrital	D, SF, DE, DP
Discrete surface omnivore-deposit	D, SF, O, DP
Discrete surface suspension-deposit	D, SF, SU-DP
Discrete surface carnivore-omnivore	D, SF, C-O
Discrete suspension feeder	D, SU
Discrete multi-feeding strategy	D, MF
Sessile surface deposit-detrital	S, SF, DE, DP
Sessile surface suspension-deposit	S, SF, SU-DP
Sessile subsurface deposit feeder	S, SB, DP
Sessile suspension feeder	S, SU

ilar trophic and motility characteristics (Table 2), but they exhibited opposite abundance patterns with respect to distance from the artificial reef: *P. pygmaeus* had lower densities close to the reef, while *Spiophanes* spp. had its highest densities close to the reef (Fig. 5).

Four other groups also exhibited a significant difference in density at different distances from the reef. Nemerteans and cumaceans followed a pattern similar to *Prionospio pygmaeus*, with lowest densities close to the reef; the effect of the reef on cumaceans appeared to extend farther from the modules, up to 10 m away, than in *P. pygmaeus* and nemerteans. The two other taxa with significant distance effects, *Aricidea* sp. and isopods, did

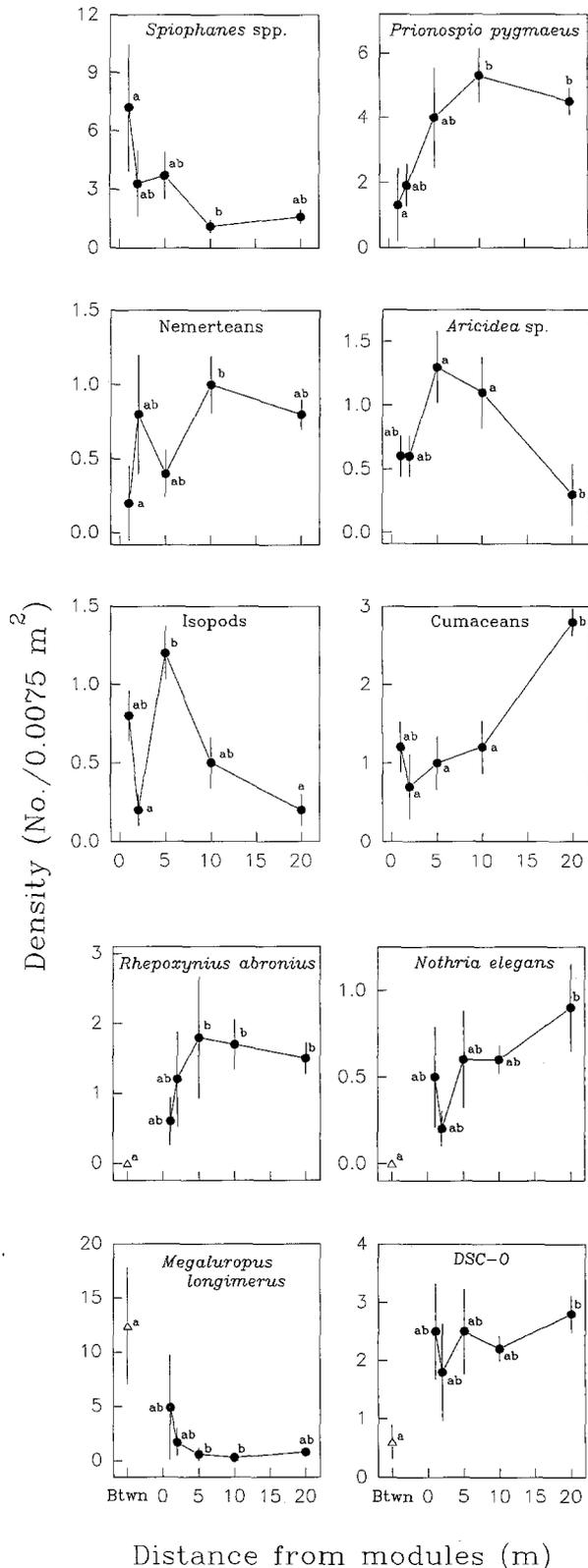


Fig. 5. Densities of infauna with significant distance and between-module effects. Total individuals, major taxonomic groups, functional groups, and 15 most abundant species were tested (see Table 2). Top six plots show the six taxa with significant distance effects; four groups with consistent between-module patterns are shown at the bottom; all significant results are presented in Table 3. Means (± 1 SE) with same letter(s) are not significantly different by Tukey multiple-comparison test. Btwn: between-module samples; DSC-O: discrete surface carnivore-omnivore group

not exhibit a consistent pattern, with highest densities occurring at intermediate distances (Fig. 5).

The artificial reef also affected infaunal densities in the sand area between the modules. Between-module densities were significantly different from densities away from the modules for 11 of the 45 different taxonomic and functional groups tested (Table 3). The total infaunal density was slightly (but not significantly) higher between modules (4830 individuals m⁻²) than along the transects (4298 individuals m⁻²). In spite of this trend for total infauna, the most common taxa tended to have lower densities between the modules: tests for 7 of the 15 most common individual taxa were significant, and in all but two cases the between-module density was nominally the lowest. The between-module densities were nominally lower than densities away from the modules in 7 of the 11 groups with significant results, and four groups (the polychaete *Nothria elegans*, the gammarid amphipod *Rhepoxynius abronius*, ophiuroids, and the discrete multi-feeding functional group) were absent from the between-module samples. However, only four groups showed a consistent effect of the reef modules (Fig. 5). *R. abronius* showed the most consistent pattern, with the between-module density not significantly different from densities at the stations closest to the module, but significantly lower than stations farther away from the modules. *N. elegans* and the discrete surface carnivore-omnivore functional group also had significantly lower densities between the modules than at 20 m from the modules. In contrast, the density of *Megaluropus longimerus* was high between the modules (mean = 12.4 individuals 0.0075 m⁻²), and higher close to the modules than farther away.

Beds of the tube-building polychaete *Diopatra ornata* were found around seven of the eight modules (Fig. 1). *D. ornata* was only found in association with the modules; an extensive search of the area around PAR failed to detect any *D. ornata* beds away from the modules. The beds virtually surrounded Module 3; at all other modules, *D. ornata* occurred in relatively small, isolated patches. Most beds started within a meter of a module and had a width of only a few meters.

Total infaunal density was significantly higher in *Diopatra ornata* beds (13240 individuals m⁻²) than at an equivalent distance away from the modules outside beds (4947 individuals m⁻²) (Table 4). Densities of three taxonomic and five functional groups were also significantly different within *D. ornata* beds compared to outside the beds (Table 4). The densities of all but one of these groups were greater within the *D. ornata* beds. Densities of the most abundant taxon and functional group in *D. ornata* beds, decapods and the motile surface carnivore-omnivore group, were about an order of magnitude higher within than outside *D. ornata* beds. These density differences were mostly due to hermit crabs (*Pagurus* spp.) and the polychaete *Gyptis brevipalpa*. In addition, twice as many decapod species were found within as outside *D. ornata* beds (12 vs 6; Table 1).

Table 3. Differences in infaunal densities between modules at PAR vs various distances along transects. Total individuals, major taxonomic groups, functional groups, and 15 most abundant species were tested; only significant results are presented. 1, 2, 5, 10, and 20 refer to distances (m) along transects. Btwn: between-module samples. Means that are not significantly different by Tukey multiple-comparison test are underlined

Taxa/group	Significant differences					
Polychaetes						
<i>Aricidea</i> sp.	5	<u>10</u>	<u>1</u>	<u>2</u>	<u>20</u>	Btwn
<i>Nephtys caecoides</i>	<u>Btwn</u>	<u>1</u>	<u>10</u>	<u>20</u>	<u>5</u>	<u>2</u>
<i>Nothria elegans</i>	<u>20</u>	<u>10</u>	<u>5</u>	<u>1</u>	<u>2</u>	Btwn
<i>Prionospia pygmaeus</i>	<u>10</u>	<u>20</u>	<u>5</u>	<u>2</u>	<u>1</u>	Btwn
Gammarid amphipods						
<i>Megaluropus longimerus</i>	<u>Btwn</u>	<u>1</u>	<u>2</u>	<u>20</u>	<u>5</u>	<u>10</u>
<i>Rhepoxynius abronius</i>	<u>5</u>	<u>10</u>	<u>20</u>	<u>2</u>	<u>1</u>	Btwn
Isopods	<u>5</u>	<u>1</u>	<u>10</u>	Btwn	<u>2</u>	<u>20</u>
Cumaceans	<u>20</u>	<u>Btwn</u>	<u>1</u>	<u>10</u>	<u>5</u>	<u>2</u>
Echinoderms						
Ophiuroids	<u>1</u>	<u>10</u>	<u>5</u>	<u>20</u>	<u>2</u>	Btwn
Discrete surface carnivore-omnivore	<u>20</u>	<u>5</u>	<u>1</u>	<u>10</u>	<u>2</u>	Btwn
Discrete multi-feeding strategy	<u>1</u>	<u>5</u>	<u>10</u>	<u>20</u>	<u>2</u>	Btwn

Table 4. Differences in infaunal density (nos. 0.0075 m⁻²) within and outside *Diopatra ornata* beds. Total individuals, major taxonomic groups and functional groups were tested; only significant results are presented. Values are mean (±SE); N: no. of samples

Group	Within beds (N=3)	Outside beds (N=4)
Total individuals	99.3 (7.50)	37.1 (4.79)
Taxonomic groups		
Decapoda	15.3 (1.15)	0.2 (0.16)
Echinodermata	4.8 (1.06)	1.3 (0.59)
Sipunculida	4.6 (1.90)	0.2 (0.16)
Functional groups		
Motile surface suspension-deposit feeder	1.8 (1.28)	0.1 (0.08)
Motile surface detrital-deposit feeder	2.0 (0.67)	10.3 (4.19)
Motile surface carnivore-omnivore	31.7 (0.51)	3.2 (0.94)
Discrete multi-feeding strategy	4.7 (1.02)	1.3 (0.59)
Sessile surface detrital-deposit feeder	6.9 (1.82)	0.8 (0.25)

Discussion and conclusions

Artificial reefs could affect infaunal densities in two ways. First, the reefs could alter the surrounding physical environment. For example, water motion, sediment-size distribution, or organic content of sediments might be different near a reef. These differences might affect the abundance and types of suspended particles, substrate stability and food availability, and could result in either an increase or decrease in infaunal densities, depending on the adaptations of the species involved. Second, the reefs could alter the biological environment of the infauna. Previous studies (Randall 1963, Davis et al. 1982) suggested that the strongest biological effect would be an increase in predation on sand communities near reefs as reef-associated fish move over the sand to feed, which should cause a decrease in infaunal densities near the reef. For example, Davis et al. noted a decline in sea pens (*Stylatula elongata*), which they attributed to predation by reef-associated fishes.

Infaunal densities near PAR did not reflect a widespread influence of predation, but there was an indication of reduced densities of some taxa near the reef. The most common species, *Prionospio pygmaeus*, was significantly less dense near the reef. *P. pygmaeus* occurs near the surface of the sediment, so decreased densities are consistent with higher predation pressure close to the reef. However, *P. pygmaeus* generally occurs in silty mud (Smith and Carlton 1975), so its lower density near the reef might simply indicate a less suitable habitat due to the coarser sediment sizes near the reef (Fig. 2); these alternatives cannot be distinguished without appropriate experiments.

Davis et al. (1982) also failed to detect decreases in infaunal densities near two artificial reefs off La Jolla, California. (However, Davis et al. began sampling 4 m from the reefs, which is farther away than most of the effects we detected.) It is not clear why the large fish population on artificial reefs do not have a greater influence on the densities of the surrounding infauna. Many of the fish known to feed on infaunal species (Davis et al. 1982) were abundant at PAR (Ambrose and Swarbrick 1989, Anderson et al. 1989, DeMartini et al. 1989), yet predation intensity around PAR apparently was not high enough to cause a dramatic decline in the infaunal populations near the reef. Our failure to detect an effect of reef-associated predators may have been due to low predation intensity, or it may be that any predation effects were obscured by an enhancement of infaunal densities due to changes in the physical environment near PAR. The capacity of infaunal populations to recover rapidly after disturbances may also be important (Davis et al. 1982).

Physical factors may have influenced infaunal abundance patterns at PAR more than predation. Of course, physical factors may interact with biological ones (Meyers et al. 1987); for example, increased turbulence near the modules might increase the density and types of suspended particles that serve as food for suspension feeders. It is clear that the modules influenced the grain-size distributions of nearby sediments. Sediments close to

the modules were coarser than those farther away, probably due to erosion of fine sediments, but shelly debris also accumulated near the modules. As early as one year after the reef was constructed, erosion of sediments away from the reef exposed old giant kelp (*Macrocystis pyrifera*) holdfasts on bedrock (Grant et al. 1982). Observations made by Wilson (Wilson et al. 1981, and K. C. Wilson personal communication) suggest that the overlying fine sediments have been eroded away near the modules so that the quarry rocks have settled down to the underlying cobble/sandstone basement substrate (estimated to be 86 cm below the surface when PAR was constructed).

PAR's influence on sediments close to the reef would be expected to have consequences for the surrounding infaunal community. Densities of some of the most common species were related to distance from the module. *Prionospio pygmaeus*, nemerteans and cumaceans were more abundant away from the modules, while *Spiophanes* spp. was more abundant near them. Thus, the modules may have altered the environment to provide a more suitable habitat for *Spiophanes* spp. and a less suitable habitat for *P. pygmaeus*, nemerteans and cumaceans. However, the interaction between the effect of PAR on the physical environment and the distribution of individual species is complex. For example, *P. pygmaeus* and *Spiophanes* spp. are both spionid polychaetes, both build tubes and are suspension-deposit feeders (Table 2), and both are reported to occur in sandy or silty mud substrates (Smith and Carlton 1975), yet they exhibited opposite abundance patterns. The coarser sediments near the modules would be expected to be a less suitable habitat for these two taxa; the fact that *Spiophanes* spp. was actually more common there suggests that the infauna are responding to more than simply changes in sediment characteristics caused by PAR.

Water motion and sediment movement within the module complex at PAR must be relatively complicated, since both the longshore current and offshore swell undoubtedly interact with the modules. Since our three sites were at different exposures and distances from modules within the module complex, it is not surprising that the grain-size characteristics varied considerably. Given this variability and the close relationship between infauna and sediments (Gray 1974), more differences between the density of infauna from within the module complex versus the density along the transects away from the modules might be expected. Only four groups showed a consistent pattern, *Nothria elegans*, *Rheopoxynius abronius*, and discrete surface carnivore-omnivores having lower densities between the modules, and *Megalauropus longimerus* having a higher density between the modules. Our failure to detect more differences may have resulted from high variability among the infauna and the small sample size. It seems likely that a myriad of infaunal assemblages exist within the module complex, but that more samples would be needed in order to detect a pattern.

The most conspicuous influence of Pendleton Artificial Reef on the surrounding sand community was the close association of beds of *Diopatra ornata* to the mod-

ules. *D. ornata* frequently occurs near hard substrates (Turner et al. 1969, Emerson 1975, Davis et al. 1982). Before PAR was built, *D. ornata* occurred in very low densities (Wilson et al. 1981). After construction, *D. ornata* abundance increased dramatically (K. C. Wilson personal communication), and within a few years after construction it was common adjacent to modules (Wilson et al. 1984).

Diopatra ornata is larger than most species in the infaunal assemblage and its tube, which is covered with fragments of shells and algae, extends several centimeters above the sediment surface. These characteristics may explain its dramatic effect on the infaunal community, with infaunal densities being higher within *D. ornata* beds than outside the beds. This pattern has been reported in several studies of *D. cuprea* (Woodin 1978, 1981, Luckenbach 1986, Ban and Nelson 1987) and for other tube-building polychaetes (Fager 1964, Wilson 1979, Brenchley 1982). The higher densities of infauna within patches of *Diopatra* spp. tubes have been attributed to stabilization of the substratum (Fager 1964, Young and Rhoads 1971, but see Luckenbach 1986), provision of a refuge from predation (Woodin 1978, 1981), and restriction of burrowing by larger infaunal organisms (Brenchley 1982). Brenchley suggested that less motile species, such as our discrete functional groups, would be less affected by the tubes; consistent with this suggestion, only one of the six discrete groups we analyzed had different densities within and outside *D. ornata* beds. The other three functional groups with significantly higher densities in *D. ornata* beds all occur at the surface of the sediment; because they project above the surface, *Diopatra* spp. tubes may protect these species from predation (Woodin 1978, 1981). The motile surface carnivore-omnivore group, which achieved the highest densities within *D. ornata* beds at PAR, may have benefited from the associated algae and debris attached to *D. ornata* tubes, and perhaps a greater number of associated prey.

In summary, Pendleton Artificial Reef altered the infaunal community around the reef. In contrast to the pattern reported by Davis et al. (1982) for Torrey Pines Artificial Reef, infaunal densities varied with distance from PAR. The most conspicuous influence of PAR was the occurrence of *Diopatra ornata* close to the modules and the higher densities of infauna in *D. ornata* beds, but several other taxa were also affected by the reef. However, the impact of Pendleton Artificial Reef is limited in two respects. First, a significant effect of distance from the reef could be detected in only 13% (6 out of 46) of the groups we tested, in spite of the effects of PAR on nearby sediments. Second, most changes were only detected close to the modules. Thus, the overall influence of PAR on the surrounding infaunal community was small because it was limited to areas close to the reef.

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