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Man-Made Structures on Marine Sediments: Effects on Adjacent Benthic Communities

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Abstract

This study (1975–1977) examines the effect of man-made structures on natural sand bottom communities in shallow water in San Diego County, southern California, USA. While there were shallow scour effects to 15 m around some artificial reefs, the reefs had no measurable effect on sand ripple patterns, grain size, organic carbon or infauna beyond the scoured areas. Foraging by reef-associated fishes produced profound alterations in the epifauna populations of the sea pen *Stylatula elongata*. The sea pen densities were 4 to 10 m^{-2} before the reefs were established, but within 5 mo were eliminated from distances greater than 200 m around the reefs. On the other hand, densities of the tube-building polychaetes *Diopatra* spp. seemed to be enhanced in the immediate vicinity of the artificial reef. Oil platforms and bridge pilings seem to have much more profound effects on the nearby sand communities than do the relatively small artificial reefs. In addition to the elimination of sea pens, *Diopatra* spp. densities increased from < 1.0 m^{-2} in control areas to as many as 73 m^{-2} in the vicinity of oil platforms. Grain size and infauna were strongly affected by the oil platform.

Introduction

Increasing numbers of man-made structures such as artificial reefs, oil platforms, pier pilings, breakwaters, outfall pipelines, and bridge supports are being placed on coastal marine sediments. Many studies have dealt with plants and invertebrates that live on artificial structures (Scarratt, 1968; Turner *et al.*, 1969; Fager, 1971; Adey and Vassar, 1975; Alfieri, 1975; Russell, 1975; Hanson and Bell, 1976; Sheehy, 1976; Allen *et al.*, 1976) and on the fishes which they attract (Randall, 1963; Carlisle *et al.*, 1964; Turner *et al.*, 1969; Dewees and Gotshall, 1974; Higo, 1974; Russell, 1975; Prince, 1975; Prince and Gotshall, 1976; Allen *et al.*, 1976; Sonnier *et al.*, 1976; Talbot *et al.*, 1978; Patten, 1981). With a few exceptions, little attention has been paid to the effect of these objects on the natural sedimentary communities in which most are placed.

Introduced structures may alter soft-bottom habitats in several ways. They affect the wave field and alter current patterns causing scour and changes in sand ripple patterns and sediment grain size. They entrap drift algae and other organic material which, along with the activities and deaths of reef-associated organisms, can result in organic build-up in the sediment. Shells from barnacles and other fouling biota enter and modify sediments. Finally, predators attracted by the structure may forage on plants and animals that live in adjacent sediments. In this paper we examine the effect of man-made structures on the infaunal and epifaunal components of adjacent natural soft-bottom communities off southern California, USA.

Materials and Methods

The San Diego-La Jolla Underwater Park Reef, known informally as Bureaucrat Reef, was installed southwest of Torrey Pines State Park on 15–17 April 1975 at a depth of 13 m on a natual bottom of well-sorted, very fine sand (*sensu* Wentworth, 1922) with low organic carbon content ($<0.5\%$ by weight). The reef was built of large quarry boulders dropped from barges; it is 50 m long (parallel to shore), up to 13 m wide and 2.5 m high. Two permanent transects were established on 1 May 1975 and sampled regularly through January 1977. One transect ran northward from the north end of the reef, the other southward from the south end. Each transect began 4 m from the reef

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edge, was 100 m long, ran parallel to the shoreline, and was defined by permanent steel stakes driven into the sand at 50 m intervals.

We sampled visible epifauna by placing a temporary line between the stakes and counting all animals within a 1 m swath along the line. Counts were partitioned into 10 m intervals. By autumn 1975 we noticed changes in epifaunal densities which extended nearly the full length of our transects. Therefore, we increased transect lengths to 140 m in September 1975. In addition to regular epifaunal censusing, we sampled with the same technique a single haphazardly-placed 50 m "control" transect line, placed on open sand 500 m south of Bureaucrat Reef, in 14 m of water.

Infauna were sampled by collecting replicate sets of cores at various locations along the transect. Corers were diver-manipulated 1 lb (80 $cm^2 \times 12$ cm depth) and 3 lb (180 $cm^2 \times 12$ cm depth) coffee cans with ends removed. Samples were screened through 0.5 mm mesh (see VanBlaricom 1978, 1982 for further details of techniques). Densities of the tubicolous polychaetes *Diopatra splendidissima* and *D. ornata* in sediments within 0.5 m of the reef were determined by visual counts in 0.1 m^2 quadrants.

Various measurements were made of alterations of sediments adjacent to the reef. We collected sediment samples along transect lines to determine sediment grain-size composition and organic carbon content (analytical techniques are described by Hartwig, 1976; Davis, 1978; and VanBlaricom, 1978, 1982). Sand scour was monitored by measuring changes in the exposed length of a steel rod driven permanently into the sand next to the reef. Sand ripple patterns were described at 0, 50, and 100 m along transects by measurement of crest-to-crest and crest-to-trough distances, height, steepness, angle relative to shoreline, and by qualitative assessment of symmetry.

A group of three artificial reefs was constructed of quarry boulders in 25 m of water southwest of Torrey Pines State Park in 1965, and is known locally as Fish and Game Reef. The natural substratum is similar to the area around Bureaucrat Reef. We censused single, haphazardly-placed 70 and 80 m transects for visible epifauna in July and October 1976. In July 1977 we sampled a 50 m "control" transect on open sand at 26 m depth at a site well-removed from Fish and Game Reef.

When the Bureaucrat Reef data indicated significant epifauna changes, we sampled a haphazardly-placed 50 m transect on open sand at 16 m depth offshore from Scripps Institution of Oceanography in May 1976. Then, in June 1976, from scrap metal and bundled automobile tires, we constructed a small artificial reef 3 m and 2 m high. This reef, referred to here as "Experimental Reef" was in 16 m depth. A permanent 50 m transect was established and sampled as at Bureaucrat Reef. Sediment samples were analyzed for grain-size distribution and organic carbon content. The transect was lengthened to 70 m in August 1976, and to 100 m in December 1976.

A 1 m diam cage, designed to exclude larger predators, was placed 5 m from the Experimental Reef; a control cage, similar in its physical effects on the substratum, but open to predators, was placed 5 m from the reef.

We used spears to collect fishes from Bureaucrat and Experimental Reefs for analysis of gut contents. The grazing damage on sea pens (*Stylatula elongata*) was evaluated by contrasting numbers of grazed and ungrazed sea pens along the transects. We did not quantify the amount of damage within individuals, but it was always more severe near the reefs.

We also investigated the effects of Platform "Eva", an offshore oil-production platform, located 3 km southwest of Huntington Beach, California. "Eva" was installed in 1964 and stands in 18 m of water on a bottom of very fine sand. "Eva's" configuration and associated fouling and benthic communities have been described in detail by Wolfson *et al.* (1979). Natural sediments beneath Eva are covered with shell debris from the platform supports. We sampled a 100 m transect line running eastward from the edge of the shell pile and a 25 m control transect on open sand 300 m east of the platform. Sampling was done in December 1975 and June 1976 and included visual epifaunal censusing, core sampling for infauna, and sediment sampling for grain size distribution and organic carbon content, in all cases using the techniques described above.

Qualitative visual observations of sedimentary epifauna were made near Oil-Production Platforms "Hilda" (built in 1958, water depth 34 m) and "Hazel" (built in 1960, water depth 30 m) in April and June 1975. "Hilda" and "Hazel" stand on a muddy bottom 3.6 and 5.6 km, respectively, southeast of Summerland, California, in the Santa Barbara Channel.

The Ventura Bridge was constructed in 1972 and spans an arm of Mission Bay in San Diego, California. The bridge is supported by concrete pillars standing on a fine-sand bottom of 6 m depth. A 20 m transect was run southward, parallel to the shoreline, from the edge of one pillar. Densities of *Diopatra splendidissima* were determined within a 1 m swath at 1 m intervals along the line.

Results

Accumulation of Fishes and Fouling Organisms on Reefs

The succession of fouling organisms which became attached to artificial structures, and the attraction of fishes to these structures, have been well documented (Randall, 1963; Carlisle *et al.*, 1964; Turner *et al.*, 1969; Fager, 1971). The accumulation of fishes and fouling organisms around the San Diego-La Jolla Underwater Park Reef and around our experimental reef is similar and is described briefly here.

The embiotocid fishes *Phanerodon furcatus, Embiotoca jacksoni*, and *Rhacochilus vacca*, the serranids *Paralabrax clathratus* and *P. nebulifer*, and the pomacentrid *Chromis punctipinnis* were present at Bureaucrat Reef within a

Table 1. Fishes observed by divers in 1976–1977 at "Experimental Reef" (La Jolla, California, USA) (based on total of 18 dives to the reef)

Species	Frequency of observation (% of total dives)	Mean number (SD) seen at reef per dive
Paralabrax maculatofasciatus	83.3	6.0 (2.2)
Paralabrax nebulifer	100.0	16.3 (6.7)
Paralabrax clathratus	11.1	0.6 (1.5)
Caulolatilus princeps	55.5	1.4 (2.3)
Chromis punctipinnis	77.8	2.9 (3.1)
Scorpaenichthys marmoratus	27.8	0.4 (0.5)
Semicossyphus pulcher	27.8	0.4 (0.5)
Coryphopterus nicholsi	22.2	0.7 (1.9)
Phanerodon furcatus	44.4	2.3 (3.9)

month of construction. By June 1975, *Hypsurus careyi* (Embiotocidae), *Anisotremus davidsoni* (Pomadasyidae), *Paralabrax maculatofasciatus* (Serranidae), *Caulolatilus princeps* (Branchiostegidae), juvenile *Semicossyphus pulcher* (Labridae), and the scorpaenids *Scorpaena guttata*, *Sebastes atrovirens* (juveniles), *S. carnatus*, and *S. serriceps* were present. Young *Sebastes mystinus* appeared in July 1975 and *Medialuna californiensis* (Kyphosidae) were present in August 1975. Except for *Girella nigricans* (Kyphosidae), most species common in southern California kelp forests were present at Bureaucrat Reef by January 1977. Fager (1971) recorded fish species on small artificial reefs near our Experimental Reef and failed to observe *G. nigricans* or *Oxyjulis californica* (Labridae).

The encrusting flora and fauna on Bureaucrat Reef showed an early successional pattern similar to that described by Turner *et al.* (1969). The first colonizers were low-profile algae including diatoms, *Ectocarpus* sp., *Enteromorpha* sp., various hydroids, and the barnacle *Balanus pacificus.* Great numbers of small nudibranchs, *Hermissenda crassicornis* and *Dendronotus* sp., were observed grazing on the hydroids in mid-May 1975. Predatory flatworms (*Stylochus* sp.) consumed many *B. pacificus* by the end of May. In July 1975, the tunicate, *Styela montereyensis*, and many juvenile giant kelps, *Macrocystis pyrifera*, were observed on the reef. Large numbers of small, recently-metamorphosed seastars (probably *Pisaster brevispinus*) were also seen at this time. By September and October 1975, the reef's fouling community had considerably diversified. The brown alga *Colpomenia sinuosa*, the bivalve *Leptopecten latiauratus*, and the bryozoan *Lagenipora punctulata* were all common. Mussels (*Mytilus edulis*) were first seen in December 1975. By March 1976, the *Macrocystis pyrifera* growth on the reef was becoming lush (up to 20 plants m^{-2}) and by July 1976, the kelp formed a dense surface canopy. Large numbers ($0.4\,m^{-2}$) of the seastar *Pisaster brevispinus* were recorded in June 1976 and, by January 1977, both *P. brevispinus* ($0.4\,m^{-2}$) and *P. ochraceus* ($0.5\,m^{-2}$) were common on the reef. Tiny individuals of the gorgonians *Muricea californica* and *M. fruticosa* were first observed on the reef in May 1977.

A similar pattern was observed on Experimental Reef. Within a day of its construction, a large school of *Paralabrax nebulifer* and a school of *Chromis punctipinnis* were observed, and a week later, *Paralabrax maculatofasciatus* and *Phanerodon furcatus* were also common. Table 1 summarizes fish observations at Experimental Reef. This reef also was fouled originally by low-profile algal growth followed by hydroids and then barnacles. By spring 1977, the small reef supported several *Styela montereyensis*, some juvenile *Gigartina* sp., and one *Pisaster giganteus.* Lobster, *Panuliris interruptus*, and spider crabs, *Loxorhynchus grandis*, were occasionally seen.

The artificial structures (Fish and Game Reef, the oil-production platforms, the Ventura Bridge) which had been in place for many years had rich faunas consisting of many of the typical reef-associated organisms of southern California. The biota associated with oil platforms "Hilda" and "Hazel" has been described by Carlisle *et al.* (1964) and Mearns and Moore (1976); the fauna of Oil Platform "Eva" has been documented by Wolfson *et al.* (1979). The Ventura Bridge supports a typical pier piling community (Ricketts and Calvin, 1962; Landenberger, 1967) in which mussels (*Mytilus* spp.) are the dominant fouling organisms and are fed on by large numbers of seastars (*Pisaster* spp.).

Table 2. Mean grain size of sediment samples from Bureaucrat Reef (Torrey Pines State Park, California). Scoured area: sample was taken from scour zone immediately adjacent to reef. Position on transect indicates distance from reef at which sample was taken; O mark on transect was about 4 m from reef. All grain size values are mean phi size. [$\Phi = -\log_2$ (mean diameter in millimeters)]. Dash = no data

Date	Transect	Distance (m) from reef along transect						
		Scoured area	0	5	10	30	50	100
1 May, 1975	North	–	–	–	–	–	–	3.39
14 May, 1975	South	–	3.26	–	–	–	3.37	3.35
13 June, 1975	South	–	3.27	–	–	3.39	–	–
27 June, 1975	North	–	3.01	–	–	–	3.26	3.38
11 July, 1975	South	–	3.28	–	3.35	–	–	3.32
12 Feb., 1976	South	–	3.36	3.31	3.35	3.33	3.34	3.36
23 Sept., 1976	North	3.06	3.19	–	–	–	–	–

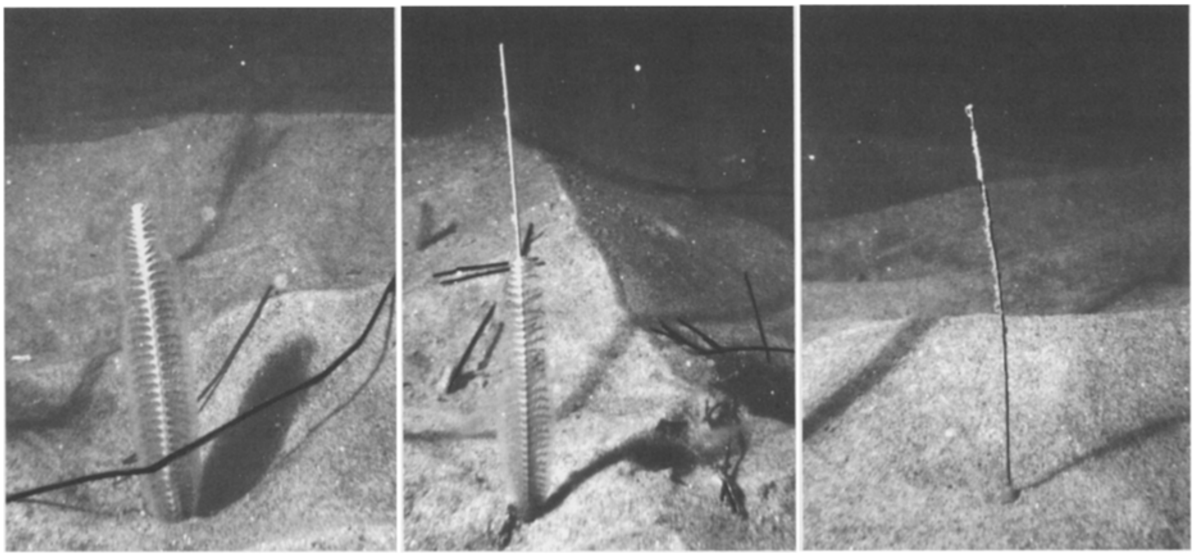

Fig. 1. *Stylatula elongata.* Photographs of living sea pens near Experimental Reef 1976; individuals illustrated are ~ 10 cm in height. Left: intact, ungrazed individual. Center: individual with partial grazing damage; polyps have been removed from upper half of the central axis. Right: individual with severe grazing damage; all polyps and associated tissues have been stripped from central axis; when prodded, this individual was still able to retract into the sediment

Physical Effects of Artificial Structures

Sand adjacent to Bureaucrat Reef was scoured to a depth of 20 to 40 cm as far as 15 m from the reef. The reef had no measurable effect on sand-ripple patterns outside the scoured areas. Grain size was essentially similar along the transect lines, although there was a general tendency toward slightly larger grain size near the reef (Table 2), probably resulting from the many shell fragments found there. The percentage of organic carbon ranged from 0.10 to 0.24 in our samples. Carbon values were not significantly related to distance from the reef.

The Experimental Reef was initially scoured for a distance of 1 to 2 m around its borders, but this scour hole had refilled with sand by early 1977. Neither grain size nor percent organic carbon showed any significant changes as a result of the presence of the reef.

Grain-size analysis of sediment collected along the transect from Oil Platform "Eva" showed a bimodal distribution to approximately 20 m from the platform (Wolfson *et al.*, 1979). The coarse mode was absent beyond 20 m and grain-size analysis showed uniformly very fine sand. We found no significant trend in organic carbon content of the sediment as a function of distance from the structure.

Effect of Artificial Structures on Epifaunal Components of Soft-Bottom Communities

The most abundant large epifaunal species on southern California sand bottoms at these depths (12 to 20 m) are the sea pen *Stylatula elongata* and the tube-building polychaetes *Diopatra splendidissima* and *D. ornata.* Natural sea pen densities are 4.0 to 10.0 m^{-2} (Davis and VanBlaricom, 1978). Artificial structures can have profound effects on all of these common sedentary animals.

We noted that the tops of *Stylatula elongata* colonies closest to Bureaucrat Reef were bare of polyps within a month of reef installation (Fig. 1). By June, 1975, a decrease in sea pen densities within 30 m of the reef was seen and, by July 1975, *S. elongata* had completely disappeared within 30 m and reduced densities were recorded as far away as 80 m from the reef. By September 1976, sea pen densities were diminished for a distance of greater than 100 m from the reef (Fig. 2). Sea pens with bare tops were found in areas of reduced density. One transect each in a shoreward and seaward direction from the reef showed low densities of sea pens close to the reef in each of these directions, indicating that sea pens were disappearing around the total circumference of the reef. A comparable disappearance of *S. elongata* was observed by field workers near reefs studied by Fager (1971) (W. Reetz, personal communication).

Reduction in densities of *Stylatula elongata* extended far beyond measurable physical modifications of sediments adjacent to Bureaucrat Reef. It appeared that the loss of sea pens was caused by predation by reef-associated fishes. Six species of reef fish were observed foraging on fauna in sediments adjacent to the reef. Of these, three species (*Embiotoca jacksoni, Caulolatilus princeps,* and *Anisotremus davidsoni*) did so rarely, but the other three (*Paralabrax maculatofasciatus, P. nebulifer,* and *Phanerodon furcatus*) did forage regularly on infauna near the reef. We frequently observed these species foraging many tens of meters from the reef margin. We also found

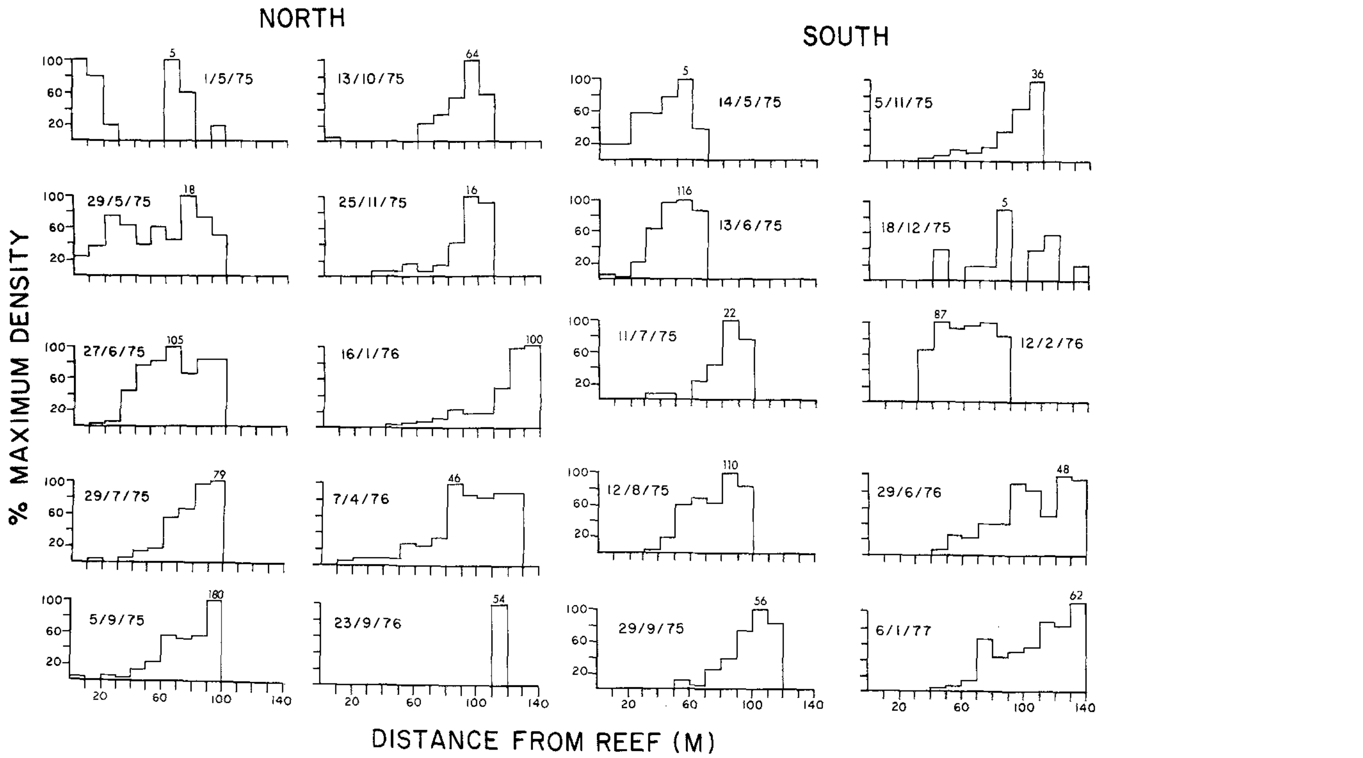

Fig. 2. *Stylatula elongata.* Disappearance of sea pens from permanent transects north and south of Bureaucrat Reef. Because *S. elongata* retracts into the sand in varying and unpredictable percentages at any given time, percentage of maximum density in each 10 m transect interval is plotted rather than absolute abundance. Percent of maximum density is calculated for each 10 m interval. Numbers show maximum numbers of sea pens recorded in relevant 10 m interval for each sampling day

fragments of calcified horn from the central axis of *S. elongata* in 1 of 14 *Paralabrax nebulifer* stomachs and in 1 of 17 tubular guts from *Phanerodon furcatus* collected near Bureaucrat Reef (see also Davis, 1978). Axial fragments of *S. elongata* have also been found in stomachs from other *Paralabrax maculatofasciatus* collected near La Jolla (A. O. Flechsig, personal communication). Patterns of damage to sea pens indicate that central axes were not consumed frequently. Polyps from sea pens are probably digested rapidly and are difficult to recognize in stomach-content samples. We searched unsuccessfully for nematocysts from *S. elongata* in our stomach samples. Nematocysts of all Alcyonoria, including *S. elongata,* are quite small, structurally simple, and difficult to see (Hyman, 1940). Unidentified, soft, white material was commonly seen in stomach samples from *Phanerodon furcatus,* whose "picker-type" behavior and oral morphology (Bray and Ebeling, 1975) are well-suited to selective consumption of sea pen polyps. Thus, we suggest that our stomach content data underestimate the importance of polyps of *S. elongata* in the diets of *Paralabrax* spp. and, especially, *Phanerodon furcatus.*

Our studies of Experimental Reef were designed to test the hypothesis that the sea pen disappearance from the vicinity of Bureaucrat Reef was the result of predation rather than physical disturbance. Two months after construction of Experimental Reef, reduced sea pen densities were recorded within 20 m of the reef (Fig. 3). Sea pens

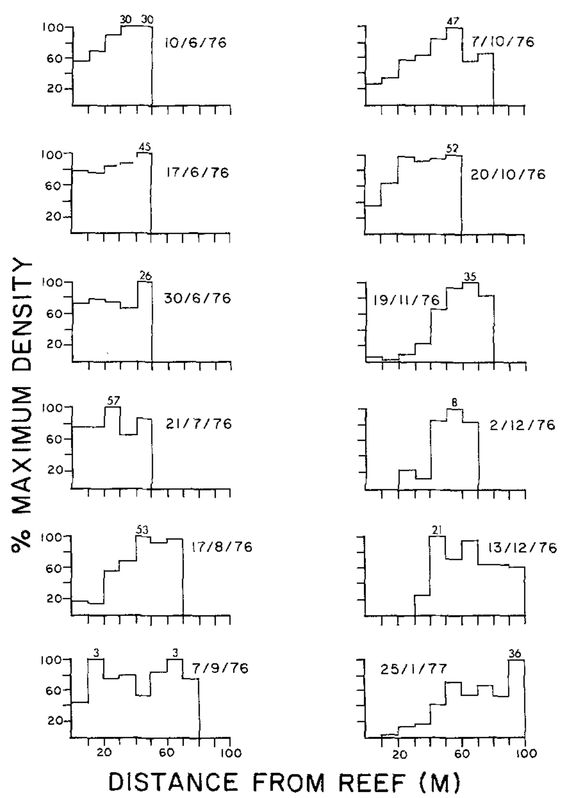

Fig. 3. *Stylatula elongata.* Disappearance of sea pens from transect extending outward from Experimental Reef. Further details as in legend to Fig. 2

close to the reef and in the control cage had bare tops, while those in the exclusion cage were intact. Within 3 mo, all but 1 of the 6 sea pens in the control cage were gone, while the 9 sea pens in the exclusion cage remained healthy and intact. Because Experimental Reef was constructed in such a way that all organisms living in it or around it could be seen, we concluded that fishes were the only possible sea pen predators during this period. We terminated the caging experiment in fall of 1976, when rough weather caused scour around both cages, allowing fish to enter the experimental cage. We continued censusing sea pens along the transect through January 1977. The sea pens on the transect showed the same pattern of reduced densities and eventual disappearance as those around Bureaucrat Reef. In both cases the data support the hypothesis that grazing by reef-associated fish rather than physical effects of the reef caused the sea pen decline.

Sea pens with tops denuded of polyps can be found in open-sand habitats far from natural or artificial reefs in the La Jolla area. However, the proportion of sea pens with apparent grazing damage is significantly higher near structures which harbor reef-fish populations (Table 3).

Table 3. *Stylatula elongata.* Percentage with some portion of their pens denuded of polyps, observed on 1 × 10 m transects near Experimental Reef in 1976 and 1977. There is significantly higher proportion of damaged sea pens in vicinity of reef than in areas far removed from reef: Mann-Whitney U test, $T' = 15$; $p < 0.01$

Reduced sea pen density area 20–30 m from reef	Open sand area far removed from reef
56.2 (N= 48)	33.8 (N= 71)
73.7 (N= 57)	33.3 (N=138)
91.7 (N= 12)	20.0 (N= 30)
87.1 (N= 31)	8.4 (N=274)
56.1 (N=173)	26.3 (N=137)
	30.4 (N=140)

Densities of *Stylatula elongata* were quite low for the entire length of our epifaunal transect near Oil Platform "Eva". In view of our results from Bureaucrat and Experimental Reefs, and because of the size of "Eva" and its associated fish populations (including *Paralabrax nebulifer* and *Phanerodon furcatus*), we suggest that fish predation has reduced sea pen densities in sediments near "Eva".

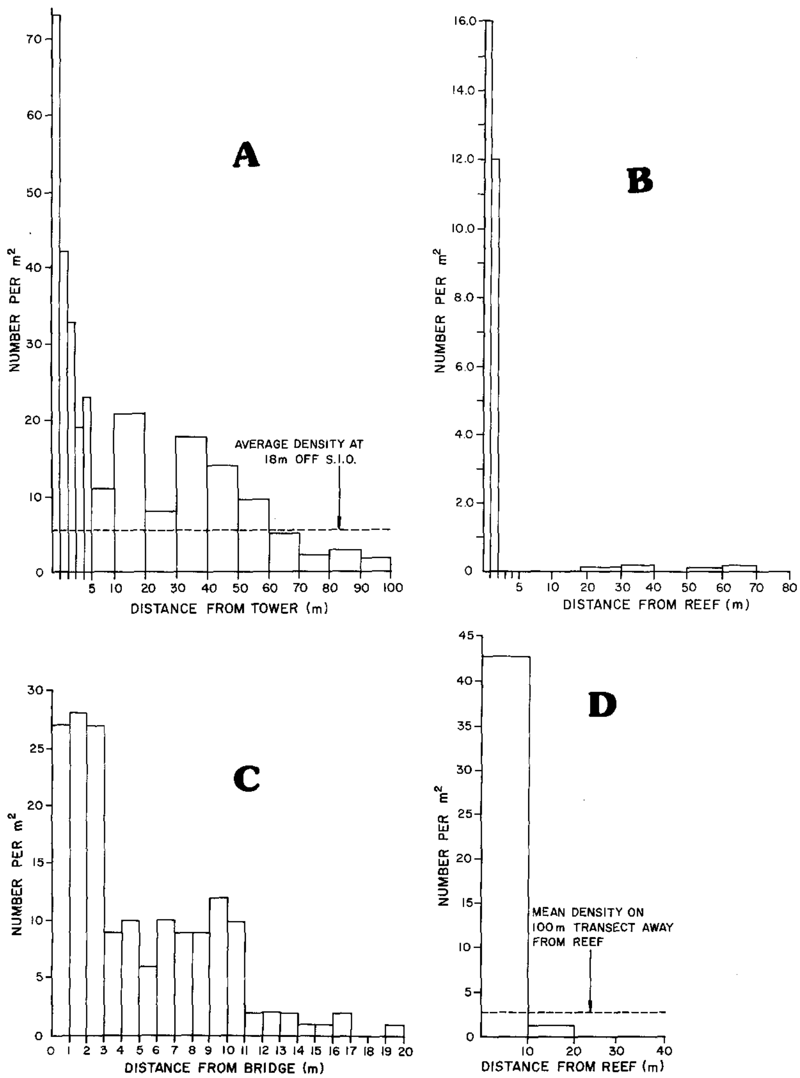

Fig. 4A–D. *Diopatra ornata.* Densities of polychaete as a function of distance from (A) Oil Platform "Eva", (B) Fish and Game Reef, (C) Ventura Bridge and (D) Bureaucrat Reef. Dashed line in (A) represents average density of *D. ornata* 18 m off Scripps Institution of Oceanography. O position on transect was at base of the mussel pile, about 15 m from the platform for Platform Eva and adjacent to each of the other structures

Densities of several asteroids are remarkably enhanced (29 m^{-2}) below "Eva", where they feed on mussles which fall from the structure (Wolfson *et al.*, 1979). The abundance of these asteroids decreased dramatically a few meters away and, by 20 m from the structure, the epifauna consisted entirely of typical sand-bottom animals. This enhancement of asteroids eating mussels from the structure contrasts with the trend observed by Davis (1978), in which the density of the sand-dwelling asteroid *Astropecten verrilli* decreases in the vicinity of various structures.

We found elevated densities of the polychaetes *Diopatra splendidissima* or *D. ornata* in sediments near Bureaucrat Reef, Fish and Game Reef, Oil Platform "Eva" and Ventura Bridge (Fig. 4).

The increase in *Diopatra* spp. densities around Bureaucrat Reef was first apparent in January 1977, when *D. ornata* aggregation was observed at the immediate base of the reef. Counts in May 19 1977, showed that this enhancement of *D. ornata* had occurred only in the 20 cm closest to the reef (Fig. 4). It is interesting to note that *D. splendidissima* is the common species of *Diopatra* in undisturbed sand bottom in the area surrounding Bureaucrat Reef.

Densities of *D. ornata* ranged from 3 to 73 individuals m^{-2} on the epifaunal transect near "Eva", while densities on the "control" transect 300 m away were less than 1 m^{-2}, suggesting that *Diopatra* spp. enhancement extends for over 100 m from "Eva". We did not gather quantitative data near platforms "Hilda" and "Hazel", but we observed dense aggregations of *D. ornata* about 2 m wide in a band surrounding shell piles beneath the platforms. Elevated densities of *Diopatra* spp. have been described near artificial reefs in Santa Monica Bay, California (Turner *et al.*, 1969) and near natural reefs with kelp beds at Santa Catalina Island, California (Emerson, 1975). Emerson found *Diopatra* spp. densities of 178 to 197 individuals m^{-2} near kelp patches, declining to 1–2 m^{-2} 30 m distant.

Effect of Artificial Structures on Infaunal Components of Soft-Bottom Communities

The infaunal community in sediments near Bureaucrat and Experimental Reefs is typical for the La Jolla area (VanBlaricom, 1978, 1982). At Bureaucrat Reef (depth 13 m), total infaunal densities ranged from 3 000 to 11 000 individuals m^{-2}. The phoxocephalid amphipod *Paraphoxus abronius* was the numerical dominant (300 to 3 000 m^{-2}). Other abundant species were the amphipod *Synchelidium shoemakeri,* the cumacean *Diastylopsis tenuis,* the polychaetes *Magelona sacculata, Mediomastus acutus,* and *Spiophanes bombyx,* and the bivalve *Tellina modesta.* Near Experimental Reef (depth 16 m), total infaunal densities were 10 000 to 15 000 individuals m^{-2}. *P. abronius* was again the numerical dominant (4 000 to 7 000 m^{-2}). other abundant species included the amphipods *Ampelisca compressa, Synchelidium shoemakeri,* and *Acuminodeutopus heteruropus,* the ostracod *Rutiderma rostrata,* and the polychaete *Apoprionospio pygmaea,* as well as *D. tenuis, Magelona sacculata, Mediomastus acutus, Spiophanes bombyx,* and *T. modesta.*

We found no significant relationship between distance from either Bureaucrat or Experimental Reefs, and any infaunal species or taxonomic category (e.g. total Crustacea, Polychaeta, Mollusca). In all cases, variability between samples collected the same distance from the reefs was more important than differences between groups of samples collected at different sites along transects.

This lack of a marked trend in infaunal distribution is interesting, since many of the reef-associated fishes were often observed foraging in the sand. Gut-content analysis of individuals of *Paralabrax nebulifer* and *Phanerodon furcatus* collected near artificial reefs showed that they were eating numerous infaunal animals. Examination of the proportion of each fish's diet from the sand compared to the reef showed that some individuals were feeding primarily on the reef while others were feeding mostly in the sand. At Bureaucrat Reef, an average of 34.2% of the diet of *Paralabrax nebulifer* came from the reef while 65.8% came from the sand. For *Phanerodon furcatus,* 30.6% of the diet was from the reef, 43.2% from the sand, and 21.2% from the plankton. Prince and Gotshall (1976), studying the food of the copper rockfish *Sebastes caurinus* associated with an artificial reef in Humboldt Bay, California, found that this species relied less on artificial reef-associated food items as their age and size increased.

Infauna sampled near platform "Eva" has been discussed in some detail by Wolfson *et al.* (1979). Densities of the most abundant infaunal species, an unidentified amphiurid ophiuroid, declined significantly along our transect (3 100 m^{-2} at the edge of the shell pile, 400 m^{-2} at 100 m distant). Other significant trends (both positive and negative) were found for 5 other abundant species of infauna. Presence/absence data from cores suggested that the distributions of at least 18 other species of infaunal polychaetes are in some way altered by the presence of Platform "Eva".

Discussion

The discernible physical effects of the artificial structures studied were confined to a fairly small area around the immediate vicinity of the structures. This lack of profound physical alteration of the soft-bottom environment is consistent with the data of Turner *et al.* (1969), who found only negligible effects on the sediment around artificial reefs constructed of quarry rock.

We have shown that modifications of natural patterns of abundance occur in sedimentary communities adjacent to seven different man-made structures of varying age, size, and structural complexity in southern California. Our data are most complete for three of these structures, in each of which the spatial limits of change in biota of adjacent sediments far exceed the limits of detectable reef-induced physical change in the sediments.

Elimination of the sea pen *Stylatula elongata* by reef-associated fishes in southern California resembles the formation of grass-free "halos" in the turtle grass beds of sand substrata around patch reefs in the West Indies (Randall, 1965; Ogden *et al.*, 1973). Reef-dwelling urchins (*Diadema antillarum*) forage nocturnally on the grasses *Thalassia testudinum* and *Syringodium filiforme*, but return to cover on reefs during daylight. The result is formation of sharply-defined zones of open sand near the reefs.

Two hypotheses are considered in explaining enhancements of densities of *Diopatra* spp. in sediments near 6 of the 7 structures we examined. Emerson (1975) showed that *Diopatra* spp. larvae are sensitive to the quality of organic carbon in sediments and argued that elevated *Diopatra* spp. densities in sediments near kelp patches resulted from positive responses of settling larvae to increased carbon levels in the sediments, which declined with increasing distance from kelp patches. We were unable to find any clear trends in organic carbon associated with any of the structures we studied. Brenchley (1976) suggested that ornamentation of tube caps of *D. ornata* and *D. cuprea* facilitates detection of nearby predators, allowing escape by withdrawal deep into tubes. Increased availability of biogenic debris used for ornamentation may therefore reduce mortality rates and contribute to higher densities near man-made structures. Shell fragments were common near all the structures we studied. We conclude that increased carbon levels are not necessary for the development of dense *Diopatra* spp. populations near structures. However, a source of shell debris may be necessary for such changes.

We measured infaunal densities in sediments near three structures. Only samples collected near Platform "Eva" indicated significant trends in abundance along transects. Specific causes for infaunal trends near "Eva" are unknown. The absence of reef-associated trends in infaunal densities at Bureaucrat and Experimental Reefs indicates that infaunal populations in the La Jolla area are less sensitive to reef-associated disturbance than large, sessile epifauna. VanBlaricom (1982) has argued that patterns of behavior and resource exploitation among abundant infaunal populations near La Jolla accommodate frequent small-scale disturbance by foraging rays. Large epifauna failed to recolonize an area disturbed by large-scale sand-slumping during a 2 yr study, while most infaunal populations rapidly recolonized the slump site (VanBlaricom, 1978). Common sessile epifauna at La Jolla are relatively large (several cm or more) and long-lived; abundant infauna are small (1 to 3 mm), with high turnover rates. Davis and VanBlaricom (1978) found that densities of large epifaunal populations in the La Jolla area fluctuate widely on a scale of years. Such variations result from infrequent successful larval recruitments. Infrequent recruitment restricts the ability of sessile species to respond rapidly to disturbances. Life histories of many infauna in southern California permit rapid reoccupation of areas disturbed by the placement of structures.

The placement of artificial structures on marine sediments is often considered to improve what is termed a "sand desert" because of the provision of habitat for "desirable" species such as fish, kelp, and epilithic invertebrates. Our data show that such structures can have far-reaching effects, both positive and negative, on the native species. Decisions to construct reefs, oil platforms, or other structures should consider possible effects on the biota of the natural bottom. Prediction of specific effects of structures will, in our view, depend on the size and complexity of the structure, the time elapsed since construction, the foraging behavior of mobile predators attracted to the structure, the productivity of flora and fauna attached to the structure, and most importantly, the susceptibility and resilience of various components of the natural bottom community to physical and biological disturbance.

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Literature Cited

Adey, W. H. and J. M. Vassar: Colonization, succession, and growth rates of tropical crustose corraline algae (Rhodophyta, Cryptonemiales). Phycologia *14*, 55–70 (1975)

Alfieri, D. J.: Organismal development on an artificial substrate 1 July 1972 – 6 June 1974. Estuar. cstl mar. Sci. *3*, 465–472 (1975)

Allen, M. J., H. Pecorelli and J. Word: Marine organisms around outfall pipes in Santa Monica Bay. J. Wat. Pollut. Control Fed. *48*, 1881–1893 (1976)

Bray, R. N. and A. W. Ebeling: Food, activity, and habitat of three "picker-type" microcarnivorous fishes in the kelp forests off Santa Barbara, California. Fish. Bull. U.S. *73*, 815–829 (1975)

Brenchley, G. A.: Predator detection and avoidance: ornamentation of tube caps of *Diopatra* spp. (Polychaeta: Onuphidae). Mar. Biol. *38*, 179–188 (1976)

Carlisle, J. G., C. H. Turner and E. E. Ebert: Artificial habitat in the marine environment. Bull. Dep. Fish Game St. Calif. *124*, 1–93 (1964)

Davis, N.: Studies of the southern California nearshore sand bottom community, 211 pp. Ph. D. thesis, University of California, San Diego 1978

Davis, N. and G. R. VanBlaricom: Spatial and temporal heterogeneity in a sand bottom community of invertebrates in shallow water. Limnol. Oceanogr. *23*, 417–427 (1978)

Dewees, C. M. and D. W. Gotshall: An experimental artificial reef in Humboldt Bay, California. Calif. Fish. Game *60*, 109–127 (1974)

Emerson, R. R.: The biology of a population of *Diopatra ornata* at Santa Catalina Island, California, 325 pp. Ph. D. thesis, University of Southern California 1975

Fager, E. W.: Pattern in the development of a marine community. Limnol. Oceanogr. *16*, 241–253 (1971)

Hanson, C. H. and J. Bell: Subtidal and intertidal marine fouling on artificial substrate in northern Puget Sound, Washington. Fish. Bull. U.S. *74,* 377–385 (1976)

Hartwig, E. O.: Nutrient cycling between the water column and a marine sediment. I. Organic carbon. Mar. Biol. *34,* 285–295 (1976)

Higo, N.: On the fish attracting effect of artificial reefs ascertained by diving: I. Off the Katsuren Peninsula in Okinawa Prefecture. Mem. Fac. Fish. Kagoshima Univ. *23,* 12–28 (1974)

Hyman, L. H.: The invertebrates: Protozoa through Ctenophora, 696 pp. New York: McGraw-Hill 1940

Landenberger, D. E.: A study of the predation and predatory behavior in the Pacific starfish, *Pisaster,* Ph. D. thesis, University of California, Santa Barbara 1967

Mearns, A. J. and M. M. Moore: Biological study of oil platforms Hilda and Hazel, Santa Barbara Channel, California, 79 pp. Final Report to the Institute of Marine Resources, Scripps Institution of Oceanography, La Jolla, California 92093, USA 1976

Ogden, J. C., R. A. Brown and N. Salesky: Grazing by the echinoid *Diadema antillarum* Philippi: formation of halos around West Indian patch reefs. Science, N.Y. *182,* 715–717 (1973)

Patten, B. G.: Observations of fish on and around an artificial reef in Puget Sound, Washington. NW. Sci. *55,* 136–144 (1981)

Prince, E. D.: Pinnixid crabs in the diet of young-of-the-year copper rockfish (*Sebastes caurinus*). Trans. Am. Fish. Soc. *104,* 539–540 (1975)

Prince, E. D. and D. W. Gotshall: Food of the copper rockfish, *Sebastes caurinus* Richardson, associated with an artificial reef in South Humboldt Bay, California. Calif. Fish Game *62,* 274–285 (1976)

Randall, J. E.: An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. Caribb. J. Sci. *3,* 31–47 (1963)

Randall, J. E.: Grazing effects on sea grasses by herbivorous reef fishes in the West Indies. Ecology *46,* 255–266 (1965)

Ricketts, E. F. and J. Calvin: Between Pacific tides, 516 pp. Stanford: Stanford University Press 1962

Russell, B. C.: The development and dynamics of a small artificial reef community. Helgoländer wiss. Meeresunters. *27,* 298–312 (1975)

Scarratt, D. J.: An artificial reef for lobsters (*Homarus americanus*). J. Fish. Res. Bd Can. *25,* 2683–2690 (1968)

Sheehy, D. J.: Utilization of artificial shelters by the American lobster (*Homarus americanus*). J. Fish. Res. Bd Can. *33,* 1615–1622 (1976)

Sonnier, F., J. Teerling and H. D. Hoese: Observations on the offshore reef and platform fish fauna of Louisiana. Copeia *1976 (1)* 105–111 (1976)

Talbot, F. H., B. C. Russell and G. R. V. Anderson: Coral reef fish communities: unstable, high-diversity systems? Ecol. Monogr. *48,* 425–440 (1978)

Turner, C. H., E. E. Ebert and R. R. Given: Manmade reef ecology. Bull. Dep. Fish Game St. Calif. *146,* 1–221 (1969)

VanBlaricom, G. R.: Disturbance, predation and resource allocation in a high-energy sublittoral sand-bottom ecosystem: experimental analysis of critical structuring processes for the infaunal community, 328 pp. Ph. D. thesis, University of California, San Diego 1978

VanBlaricom, G. R.: Experimental analyses of structural regulation in a marine sand community exposed to oceanic swell. Ecol. Monogr. (1982). (In press)

Wentworth, C. K.: A scale of grade and class terms for clastic sediments. J. Geol. *30,* 377–392 (1922)

Wolfson, A., G. R. VanBlaricom, N. Davis and G. S. Lewbel: The marine life of an offshore oil platform. Mar. Ecol. Prog. Ser. *1,* 81–89 (1979)

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