FINAL REPORT
TO THE
CALIFORNIA COASTAL COMMISSION

A Review and Evaluation of Pendleton Artificial Reef

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This report is the MRC's Final Report evaluating Pendleton Artificial Reef (PAR), as requested by the California Coastal Commission in November 1979. There is no accompanying Technical Report since this is not a part of the MRC's evaluation of the effects of the San Onofre Nuclear Generating Station on the marine environment.

Pendleton Artificial Reef (PAR), constructed in 1980 as a joint venture between Southern California Edison and the California Department of Fish and Game, was conceived as a means of evaluating the potential of using artificial reefs to mitigate coastal impacts. This report presents an overview of the work performed on PAR by MRC contractors (Lockheed Ocean Science Laboratories, UCSB Fish Program, UCSB Mitigation Program) and the Department of Fish and Game. It reviews the history of PAR and the studies conducted on the reef, but does not provide detailed methods or analyses of data; these details can be found in the original reports.

The principal objective of PAR, as defined in early reports and published papers, was to evaluate the mitigative potential of artificial reefs. We assess this objective in terms of the information gathered at PAR. However, we do not include conclusions about the suitability of artificial reefs as mitigation in this report. Much more is now known about artificial reefs than was known when PAR was being planned 10 years ago, and a complete evaluation of the mitigative potential of artificial reefs must consider all available information. The mitigative value of artificial reefs in general has been discussed in detail in other reports to the MRC (Ambrose 1986, 1987, Technical Report H). The reader is referred to these reports, particularly the Technical Report to the CCC on Mitigation (Technical Report H), for questions concerning mitigation and PAR.

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SUMMARY

Artificial reefs have become a popular fisheries management tool. Because fish and other organisms are found on artificial reefs, they have been considered a potential technique for mitigating environmental impacts for the past 10 years. Although artificial reefs have gained public support, they must be examined objectively to develop a clear understanding of their value.

Pendleton Artificial Reef (PAR) was built in 1980 to test the potential of artificial reefs for offsetting habitat losses due to the effects of power-generating facilities. The Pendleton Artificial Reef project was initiated by Southern California Edison to find a cost-effective technique for enhancing marine resources that would be applicable to the San Onofre Nuclear Generating Station. In this report, we review the history of PAR and the studies conducted on the reef. The mitigative potential of artificial reefs in general is evaluated in the Technical Report to the CCC on Mitigation (Technical Report H).

PAR consists of eight piles of quarry rock (modules) located on a sand plain 5.5 km downcoast of the San Onofre Kelp bed. The rock at PAR covers about 1 ha of sand bottom, and the entire module complex is about 3 ha in size. PAR was erected as an isolated reef because it was believed that isolated artificial reefs increase fish biomass relative to the surrounding sand bottom. Modules were chosen instead of one large reef because they provide more sand-rock perimeter habitat, which was thought to enhance biological resources.

Community development

The California Department of Fish and Game and contractors to the Marine Review Committee performed studies at PAR from 1980-1986. Their general goals were to monitor the colonization and development of algal, invertebrate, and fish assemblages at PAR. Programs were also implemented in which particular species were transplanted to PAR in an attempt to create a kelp forest and increase the amount of valuable resources.

Initially, PAR exhibited high cover of the encrusting bryozoan *Cryptoarachnidium*, accompanied by barnacles and varying abundances of algal turf. Beginning in 1983-84, the cover of *Cryptoarachnidium* decreased and the cover of erect bryozoans increased substantially. Giant kelp and other macroalgae did not form persistent stands despite transplant efforts. Motile invertebrates such as sea stars, urchins, and crabs were generally uncommon.

Fish appeared at PAR immediately after construction. By 1986, the species assemblage observed at PAR was representative of other Southern California reefs. One species, blacksmith, was far more abundant than any other species and disproportionately affected overall density patterns. Common species included black perch, California sheephead, halfmoon, kelp bass, and rock wrasse.

Recruitment by young-of-year fishes to PAR was also investigated. Blacksmith recruited to PAR in large numbers in 1983 and later years, completely overshadowing the total recruitment of all other species. Black perch, senorita, California sheephead and 12 other species have also recruited to

PAR. The recruitment of individual species over time was highly variable, indicating the importance of large-scale fluctuations in the recruitment process.

Transplant experiments

Several programs were developed to enhance PAR by transplanting three species to the reef: the kelps *Macrocystis pyrifera* and *Pterygophora californica* and the red abalone *Haliotis rufescens*. Attempts to transplant giant kelp between 1980 and 1983 have failed to establish a persistent kelp bed, although *Macrocystis* plants have recruited to PAR repeatedly. *Pterygophora* (transplanted in 1982) and abalone (1981) transplants also failed to establish those species at PAR.

Effects on sand community

In addition to community development, the extent of PAR's influence on the surrounding sand-associated community was evaluated. The tube-worm *Diopatra ornata* formed dense aggregations (beds) next to modules, and infaunal densities were elevated in *Diopatra* beds. Densities of the most common species, the polychaete *Prionospio pygmaeus*, were lower close to the reef, but other species had higher densities near the reef, and there was no evidence of widespread reductions of infaunal densities near the reef. The overall effect of PAR on the surrounding infaunal community was small because it was limited to areas near the reef.

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1. INTRODUCTION

Pendleton Artificial Reef (PAR) was constructed in 1980 to test the potential of artificial reefs as a means of mitigating deleterious effects of coastal power plants (Grant *et al.* 1982; Grove 1982; Yuge *et al.* 1985), and has become one of the most studied artificial reefs to date (Ambrose 1986). PAR is a joint project of Southern California Edison (SCE) and the California Department of Fish and Game (CDFG), and CDFG has studied the reef since its construction. In addition, the Marine Review Committee commissioned a series of studies on PAR beginning in 1981.

This report reviews the objectives, site selection, and design of PAR, and the studies that were implemented to characterize the algal, invertebrate, and fish assemblages observed over time. We do not present a detailed description of PAR and its biota, since these are available in various publications and other reports (e.g. Ambrose 1987, Anderson *et al.* 1989, CDFG 1981, 1983, 1984, 1985, 1986, *in prep.*, Carter *et al.* 1985a, 1985b, DeMartini 1985, 1987, DeMartini *et al.* 1989, Grant *et al.* 1982, Jessee *et al.* 1985, Lockheed Ocean Science Laboratories (LOSL) 1983a, 1983b, 1984). Instead, we have presented an overview of these studies, combining data from different projects as much as possible in order to provide a continuous history of PAR's development. We interpret the results of these studies with respect to PAR's original purpose as a test of the mitigative potential of artificial reefs, expressed in specific terms by Grove (1982) and more generally by Grant *et al.* (1982). In evaluating PAR, we have emphasized the most recent data because these are most likely to reflect the long-term community on PAR. Although we discuss information from PAR that has implications for mitigation, we do not consider the mitigative value of PAR *per se* because PAR was never intended to serve as mitigation (CDFG, *personal communication*). The mitigative value of artificial reefs in general has been discussed in detail in other reports to the MRC (Ambrose 1986, 1987, Technical Report H, MRC 1989). In these reports, information on many different artificial reefs, including PAR, is evaluated in order to give artificial reefs the broadest possible consideration; this general evaluation is not repeated here. The reader is referred to these reports, particularly the Technical Report on Mitigation (Technical Report H, MRC 1989), for questions concerning mitigation and PAR.

2. BACKGROUND

A primary goal of PAR was to determine whether artificial reefs could be used to mitigate damage to the marine environment, especially kelp forest habitat, due to power plant operations (CDFG 1984). Specific objectives stated by Grove (1982) were to "(1) determine whether a stable kelp bed can be established on a man-made reef in nearshore southern California waters, (2) investigate the long-term stability and fisheries' (shellfish and finfish) standing crop on such a reef, and (3) determine the appropriate size and design criteria of structural habitat modifications that will optimally enhance the selected fisheries' resources".

Various sites were considered for construction of the reef. The basic siting criteria for PAR were: (1) proximity to the San Onofre Nuclear Generating Station (SONGS) but away from possible power plant influence, (2) relatively barren, flat sandy bottom, and (3) proximity to natural kelp beds (Grove 1982). Additional factors that were considered include the distance to natural reefs (0.5 mile or more away, as suggested by Turner *et al.* 1969), depth (to be conducive to *Macrocystis* growth and recruitment), availability of a nearby natural reef reference site, and location near the San Onofre Kelp Forest (SOK), where 18 years of marine data had been collected (Grant *et al.* 1982, Grove 1982). Sites that were subject to terrestrial runoff were rejected because of turbidity and siltation effects (Grant *et al.* 1982).

CDFG initially recommended that the reef be placed near Dana Point for greater accessibility to the public (CDFG 1981). SCE recommended placement on the downcoast edge of SOK offshore of SONGS. CDFG (1981) believed that overall bioenhancement effects of the reef would be more apparent if a location further away from SOK was chosen. CDFG conducted physical and biological surveys of the area downcoast of SOK and, by mutual agreement with SCE, a site 3.5 km downcoast of SOK was selected. Permits to construct the reef were obtained from the Army Corps of Engineers and the San Diego Regional Coastal Commission (CDFG 1981). After approval by SCE, the proposal was sent to the MRC for comments. The MRC was concerned that the proximity of the reef would interfere with ongoing monitoring programs, and the site was moved further downcoast. A variance was obtained from the Army Corps of Engineers to construct the reef at the new site. After reconnaissance surveys were done, PAR was located at a site 5.5 km from SOK, 6.3 km upcoast of a natural reef, Las Pulgas Reef, and 400 m inshore of Box Canyon Reef (CDFG 1981, Carter *et al.* 1985a; Fig. 1).

PAR was positioned on an extensive sand bottom 1.8 km offshore at a depth of 13 m. Probes and excavations made prior to the construction of PAR revealed alternating layers of sand and shell fragments situated over a cobble/sandstone basement that was about 1 m below the surface (CDFG 1981). Observations of relic *Macrocystis* holdfasts, and reviews of historical records and substrate stability, indicate that this sand plain was once a hard bottom that supported kelp (LOSL 1983a; Carter *et al.* 1985a). An aerial survey in 1972 also showed an extensive kelp bed in the area where PAR was constructed (K. Wilson, *personal communication*).

3. REEF DESIGN

A proposal for the design, construction, and monitoring of an artificial reef was developed by CDFG between November 1979 and August 1980 (CDFG 1981). The proposed design was supposed to maximize the production of kelp (*Macrocystis pyrifera*), fish, and invertebrate resources, and incorporated experience gained from previous CDFG reef constructions and comments received from outside reviewers (M. Neushul, UCSB; A. Ebeling, UCSB; M. Tegner, Scripps; R. Buckley, Wash. Dept. Fisheries; J. Carlisle, CDFG; J. Duffy, CDFG) (CDFG 1981). CDFG proposed to undertake quantitative surveys to document development of the biological community and to enhance the biological community at PAR by transplanting kelp and abalone.

PAR was designed as a configuration of eight small reefs (referred to as modules) consisting of quarry rock from Santa Catalina Island (Fig. 2). Modules were chosen over a single large reef because they provide more sand-rock interface habitat, which was thought to enhance biological resources ("edge effects" in Odum 1971; see Grant *et al.* 1982). Quarry rock was selected as the preferred building material after considering cost, ease of handling, and sediment disturbances such as sand scouring (see Turner *et al.* 1969). Approximately 10,000 U.S. tons of quarry rock were used to construct PAR. Placement of the reef occurred during August-September 1980, and was directed by CDFG personnel. Due to adverse weather, the placement of modules deviated from the envisioned design (Figs. 3 and 4). Additional boulders and rock were scattered between modules, and four of the modules were topped with cobble to provide proper habitat for abalone recruitment (Grant *et al.* 1982; see Section 5: Transplant Experiments). All modules were designed with high vertical relief to provide adequate space above the effects of siltation and scouring for the recruitment and growth of *Macrocystis*.

PAR appears as an array of high-relief rock piles of boulder and cobble (Fig. 3). Differences between modules include size, steepness, amount of crest area, and percent of cobble vs. boulder habitat. Detailed measurements of individual modules were made by CDFG, using measurements from underwater transects, and Ecosystems Management, Inc. (Eco-M), using side-scanning sonar (Grant *et al.* 1982). CDFG measured module size, height, the major and minor axes headings and lengths, and substrate type. Lockheed Ocean Science Laboratories (LOSL), contracted by the MRC in 1981 to begin studies at PAR, conducted similar measurements and also incorporated additional measurements of percentage cobble cover, physical relief ("distance between the highest and lowest points on the module beneath and normal to the 1-m^2 sampling area"), and total surface area, as determined from charts developed by Eco-M. There are some discrepancies between CDFG measurements and the Eco-M survey (Table 1) probably due to the dissimilar measurement techniques used and the difficulty of defining the beginning and end of the modules. In general, the modules are 24-43 m long by 15-30 m wide, with a maximum height of 4-5 m. The modules themselves cover an area of about 1 ha; the entire reef complex, including the sand regions between the modules, covers an area of about 3 ha.

4. COMMUNITY DEVELOPMENT

Several groups have studied the biological community at PAR, albeit with different methodologies, including CDFG (1980-86) and three MRC contractors: LOSL (1981-83), the University of California Fish Project (UCSB/Fish 1984-86) and the Mitigation Program (UCSB/Mit 1986). In this report, we have not provided detailed descriptions and critiques of the methodologies and results of these various studies. Our approach is to summarize the goals and methodologies of each study and present the combined research results.

CDFG began to map PAR, transplant *Macrocystis* (see Transplant Experiments), and perform general reconnaissance surveys during the first year of PAR's existence (CDFG 1981). Qualitative observations were continued in subsequent years. Quantitative surveys of algae and invertebrates were done quarterly from 1981 through 1986 (CDFG 1981, 1983, 1984, 1985, 1986, *in prep.*). Quantitative surveys of the fish assemblage at PAR began in 1984 and continued through 1986 (CDFG 1985, 1986).

LOSL conducted surveys to monitor the distribution and abundance of algal, invertebrate, and fish assemblages at PAR from September 1981 through November 1983 (LOSL 1983a, 1984). LOSL emphasized benthic invertebrates and algae that were: (1) habitat-forming species (encrusting and foliose forms), (2) species that either provide food for fish or harbor fish prey, such as barnacles and algal turf, (3) commercially important species such as lobster, sea urchins, and scallops, or (4) other species characteristic of kelp-reef habitats, particularly *Macrocystis pyrifera*. LOSL also transplanted the understory kelp, *Pterygophora* *californica*, to one module and evaluated its survivorship, growth, and condition (see Section 5).

UCSB/Fish conducted a pilot survey in October 1984 to determine the species composition and number of young-of-year and older juvenile fishes present at PAR (DeMartini 1985). More intensive sampling was done in the Fall periods of 1985 and 1986, with the incorporation of juvenile-adult fish surveys (DeMartini 1987). UCSB/Mit conducted a single census of the algal, invertebrate, and fish assemblages at PAR in November 1986 as part of a bight-wide comparison of artificial and natural reefs (Ambrose 1987). UCSB/MIT also sampled the infauna around PAR (see Section 6 and Appendix A).

4.1. Algae and invertebrates

The initial colonization of algal and invertebrate species and the spatial and temporal patterns of community structure were documented by CDFG and LOSL (CDFG 1981, 1983, 1984, 1985, 1986, *in prep.*; Carter *et al.* 1985a; LOSL 1983a, 1984). Colonization of the reef was studied because of the potential effects that successional changes could have on the further development of algal, invertebrate, and fish assemblages (LOSL 1983a), and because the information could possibly be used to improve future reef designs and develop mitigation criteria (CDFG 1983).

Various methods were used to assess the abundance of benthic algae and invertebrates. A point contact technique (e.g. Winkworth 1955; Foster 1975) was used to estimate percentage cover of species that are colonial, encrusting, or not readily counted as individuals (see Carter *et al.* 1985a). Algae or invertebrates that could be counted individually were sampled in either quadrats (Carter *et al.* 1985a) or band transects (CDFG 1983).

4.1.1. Algae

Qualitative observations in Fall 1980, approximately three weeks after construction of PAR, noted the occurrence of the alga *Ectocarpus* along with filamentous diatoms (CDFG 1981). After 41 months, 19 algal species had been observed (CDFG 1984). From 1981 to 1986, algal turf was the most abundant algal group at PAR, although cover varied from 15% to 70% (Fig. 5). The cover of foliose algae (Fig. 6) was consistently low (less than 10%) during this period (LOSL 1984; CDFG 1986). Other algae were present, including encrusting and articulated corallines, but they generally covered less than 1% of the substrate (LOSL 1984, Carter *et al.* 1985a; CDFG 1985, 1986).

Macrocystis was transplanted to PAR beginning in October 1980 (see Section 5). The repeated attempts by CDFG to establish giant kelp on PAR using transplanting techniques ultimately failed. Two patches of *Macrocystis* juveniles (presumably from transplanted kelp) were noted in April 1981 but were subsequently removed by fish grazing (CDFG 1981). *Macrocystis* has continued to recruit to PAR every year. Some of the recruits have been clearly associated with transplanted kelp, including several hundred juveniles found in Spring 1984 at the site of kelp transplants on Module 7 (CDFG 1985). In addition, there has been consistent natural recruitment of *Macrocystis* to PAR; for example, in October 1988, long after transplant efforts were terminated, CDFG noted several hundred juvenile *Macrocystis* on Modules 3, 7 and 8 (J. Grant, *personal communication*). In spite of frequent recruitment, *Macrocystis* on PAR has never survived to form a persistent kelp bed.

4.1.2. Invertebrates

The encrusting mat-like ectoproct, *Cryptoarachnidium argilla*, and barnacles, *Megabalanus* spp., were the most abundant invertebrate colonizers at PAR (Figs. 7-8). *Cryptoarachnidium* was one of the most abundant benthic organisms on PAR from 1980 through 1983, increasing significantly from September 1981 to April 1982. The early colonization and persistence of *Cryptoarachnidium* was similar to the pattern observed on artificial reefs in Santa Monica Bay (Turner *et al.* 1969). However, a marked decrease in the cover of *Cryptoarachnidium* occurred in 1983 (CDFG 1985, 1986), after the conclusion of LOSL studies. Other species had increased from 1981-82 through 1985, most notably erect bryozoans (Fig. 9) such as *Bugula neritina.*

Sessile and motile invertebrates were not common at PAR during the first few years after the reef was built. Several species of motile invertebrates were observed during the first year of PAR's existence, including the sea stars *Pisaster brevispinus, P. giganteus*, *P. ochraceus* and *Patiria miniata*, crabs (*Cancer* spp.), and lobster (*Panulirus interruptus*). These species were occasionally observed (crabs were particularly common immediately after the abalone were transplanted in 1981 [CDFG 1983]), but they were never abundant from 1981 to 1986. All of the motile species sampled on PAR between 1984 and 1986 occurred at low densities (Table 2).

Recruitment by large sessile invertebrates was rare, but in late 1983 gorgonians, *Muricea* spp., and the rock scallop, *Hinnites giganteus*, began to increase in abundance (CDFG 1985). High densities of *Muricea* ($>40/m^2$) were observed from 1984-86 (Table 2) (CDFG 1986; Ambrose 1987).

4.2. Fish Assemblage

One of SCE's primary goals for their artificial reef program was to use PAR to investigate the potential for enhancing fish stocks (Grove 1982). CDFG, LOSL, and UCSB/Fish collectively examined the colonization, distribution, and abundance of fishes at PAR. Our summary of the fish assemblage at PAR will be divided into two parts: (1) the colonization and density of juvenile, subadult, and adult fishes, and (2) the species composition and density of recruiting (young-of-year) fishes.

Quantitative surveys using three-dimensional belt transects of fixed or variable length (Fig. 11) were performed by LOSL (1983a, 1984; Jessee *et al.* 1985), CDFG (1985, 1986), and UCSB/Fish (DeMartini 1987, DeMartini *et al.* 1989; Anderson *et al.* 1989); a single census was completed by UCSB/Mit in Fall 1986 (Ambrose 1987). LOSL sampled on two consecutive days to give two replicates per transect; all other groups sampled one replicate per transect. To determine fish distribution patterns and densities, transects were located along (1) the tops of modules (crests), and (2) the bottoms or sides of modules (bottom/slope). We present density on the crest and bottom/slope separately because these transects sample distinctly different habitats, and because differences in data collection and analysis between LOSL and UCSB/Fish did not allow us to combine these data. The areas sampled varied somewhat between CDFG, LOSL, and UCSB/Fish, and small differences in the density of fish estimated by the various programs could be due to this inconsistency. In this report, we confine our discussion to general distributional and density patterns.

4.2.1. Juvenile-Adult Fishes

The appearance of fish at PAR began immediately after reef construction (Grant *et al.* 1982), and colonization by species occurred rapidly over time (Fig. 10). Four species were observed one day after reef construction: kelp bass, barred sand bass, black perch, and white seaperch. Eleven additional species were noted three months later (California halibut, sculpin, blacksmith, garibaldi, California sheephead, pile surfperch, halfmoon, opaleye, giant sea bass, sargo, rock wrasse).

The fish species assemblage observed at PAR was generally representative of other southern California reefs (Ambrose 1987, Ambrose and Swarbrick 1989). Numerous species were noted at PAR from 1980 to 1986 (Table 3). Blacksmith were so common that they determined the overall density and distributional patterns of fish at PAR (Fig. 12a; DeMartini 1987, DeMartini *et al.* 1989, Anderson *et al.* 1989). Black perch occurred at relatively high densities at PAR (Fig. 13), ranking second to blacksmith from 1981 to 1983 (LOSL 1983a). Other abundant species were halfmoon (Fig. 14) and kelp bass (Fig. 15) and, in later years, California sheephead (Fig. 16) and rock wrasse (Fig. 17). Senorita were absent from the reef before 1983 (Fig. 18).

There were several general temporal patterns of fish abundances. Total density increased greatly in 1984, after blacksmith had recruited to PAR, but was fairly constant thereafter. Along the crests, the densities of total fish minus blacksmith was also fairly constant (Fig. 12b). However, there was a marked decline after 1984 in the density of total fish minus blacksmith in the bottom/slope microhabitat. This overall decline was primarily due to declines in black perch, halfmoon, and kelp bass. In contrast, two labrids, California sheephead and rock wrasse, became more abundant at PAR after 1984.

4.2.2. Young-of-Year

Young-of-year fishes provide an indication of one aspect of fish production on a reef because they have high growth potential. The restricted movements of young-of-year fish decrease the possibility that they have been attracted to a reef and insure that they utilize food captured on the reef (DeMartini 1985, 1987; Ambrose 1986). Young-of-year (YOY) samples reflect the amount of recruitment to PAR. (We define recruitment as settlement from a planktonic stage or live birth.) LOSL began studies of YOY and older juvenile fishes in December 1982 and continued to sample them bimonthly through October 1983. UCSB/Fish conducted a pilot survey of YOY recruitment in October 1984 and continued with YOY-older juvenile surveys in the fall periods of 1985-86. Obviously, sampling at these frequencies cannot provide an accurate estimate of all of the fish that settled onto PAR during a year, since the number of fish counted would be a function of the number settling and their survival until they were sampled. Transects were searched on the crest and bottom perimeter of modules; dimensions are given in Figure 11 (see also LOSL 1983a, DeMartini 1987, Ambrose 1986). Young-of-year were distinguished from older life stages based on estimated total length and known size-maturity relationships (Larson and DeMartini 1984).

The young-of-year of eleven fish species were sampled on PAR in 1983, two and a half years after PAR was built (Table 4). From 1984 through 1986, the YOY of 8-12 species were sampled on the reef each year. Young-of-year blacksmith recruited in extremely large numbers on module crests beginning in

August 1983 (Fig. 19), comprising 95-98% of all YOY fish on PAR in 1985-86 (Table 4).

Recruitment was highly variable among years. Rock wrasse were poorly represented on PAR until a pulse of recruitment occurred in 1984 (Fig. 20), followed by a greater abundance of older juveniles in 1985. Both rock wrasse and barred sand bass YOY (Figs. 20 and 21) were observed in substantial numbers in 1984 but not in 1985-86 (DeMartini 1985, 1987). Senorita recruited in every year after 1983, with the greatest recruitment occurring in 1985-86 (Fig. 22). Blacksmith, rock wrasse and senorita were rare or absent at PAR until they recruited from the plankton (DeMartini 1987), suggesting that there was little immigration of older lifestages from other areas. California sheephead recruitment was low relative to the high density of older juveniles (Fig. 23), suggesting that older juveniles immigrated to PAR and were not largely the result of growth of previous cohorts. The low proportion of YOY to older juveniles for most species suggests that older juveniles immigrated to PAR (DeMartini 1987).

The young-of-year of a number of species were most common along the sand/rock interface of modules (DeMartini 1987). Rock wrasse and senorita may have preferred the sand/rock interface in order to be close to their nocturnal shelters (they sleep partially buried in sand). Young-of-year sand bass inhabit sand-floored rock holes, which are more abundant at the sand/rock interface. The increased amount of sand/rock interface provided by modules compared to a single rock pile may have enhanced the recruitment of these species.

5. TRANSPLANT EXPERIMENTS

Three species, the kelps *Macrocystis pyrifera* and *Pterygophora californica* and the red abalone *Haliotis rufescens*, were transplanted to PAR in an attempt to develop a natural kelp forest community on PAR (LOSL 1984; Carter *et al.* 1985b). Kelp provides habitat for a variety of invertebrates and fishes, and abalone constitute an important sport and commercial resource. However, the transplant efforts by CDFG and LOSL failed to establish the transplanted species. A brief account of the transplant attempts follows.

5.1. Macrocystis Transplants

Various life stages of the giant kelp, *Macrocystis pyrifera*, were transplanted to PAR by CDFG using established techniques (Wilson *et al.* 1978) between October 1980 and October 1983 (CDFG 1981, 1983, 1984; Grant *et al.* 1982). Approximately 40 days were spent transplanting blade, juvenile, subadult, and adult life stages to PAR. LOSL monitored *Macrocystis* transplants from April 1981 through April 1982 (LOSL 1984; Carter *et al.* 1985b).

The mortality of transplanted *Macrocystis* was extremely high, and efforts to establish a persistent kelp stand at PAR ultimately failed. LOSL found survival rates of 2% to 7.5% over six months for a tagged subset (143 of 603) of juvenile and subadult plants (Carter *et al.* 1985b). However, none of the survivors progressed to the next life stage during the study. As noted in Section 4.1, CDFG has recorded periodic recruitment of *Macrocystis* at PAR, but none of these plants has survived.

Several factors probably contributed to the failure of the kelp transplants. Intense grazing by herbivorous fishes has been presumed to be the major cause of the destruction (CDFG 1984, 1985). In addition, the kelp transplants coincided with a prolonged period of warm water (and presumably low nutrients), which may have hindered plant growth and survival (CDFG 1983).

5.2. Pterygophora Transplants

After attempts to establish a persistent stand of *Macrocystis* on PAR were unsuccessful, LOSL initiated a study to transplant and establish *Pterygophora californica* (LOSL 1983b; Carter *et al.* 1985b), a smaller-sized kelp that forms a subsurface canopy a meter or so above the bottom. LOSL reasoned that since *Pterygophora* does not grow from the tips of terminal blades as does *Macrocystis*, it would continue to grow and produce new blade tissue in spite of fish grazing. During November 1982, 204 *Pterygophora* plants were moved from Box Canyon Reef (BCN) to PAR. BCN is located in 16m of water (about 1 m deeper than PAR) and 400m offshore of PAR. A random sample of 41 of the transplanted *Pterygophora* were compared to 48 plants removed from BCN, then transplanted back to the reef to serve as transplant controls. By chance, the plants transplanted to PAR were smaller than those at BCN (Carter *et al.* 1985b).

Survival, growth and condition of transplanted *Pterygophora* were evaluated in May 1983, about five months after the transplanting. Most of the transplants survived during this period (96% at PAR and 90% at BCN). Length of terminal blades decreased 94% at PAR compared to an 11% decrease at BCN. Although sporophyll (reproductive blades) characteristics were similar initially, by May 1983 the length and number of sporophylls decreased 96% and

70%, respectively, at PAR, while there was no decrease in the number of sporophylls at BCN and lengths decreased only 8% (Carter *et al.* 1985b). These characteristics were not significantly different at the beginning of the experiment, but were significantly different by May 1983 (t-tests, Carter *et al.* 1985b). Although storm damage to plants occurred in February to April 1983, herbivory by halfmoon and opaleye was suggested as the main factor responsible for the failure of *Pterygophora* to become established and the main cause of the differences between PAR and BCN (Carter *et al.* 1985b).

5.3. Abalone Outplants

Almost 19,000 laboratory-reared red abalone (*Haliotis rufescens*) were outplanted to PAR in 1981 (CDFG 1983). In July, an initial 825 abalone were individually placed on cobbles that had been cleared of encrusting organisms. In December, the remaining 18,000 abalone were outplanted as groups of 20 to 40 animals attached to oyster shells and placed in cryptic areas on the reef.

Five months after the first outplant, only a few abalone were found. Shell growth was minimal, and tissue loss and erosion at the shell margin were apparent (CDFG 1983). In spite of these results, space limitations at SCE's abalone lab, where the abalone were raised, required that the remaining animals be outplanted in December. The survivorship of the second group of abalone was also very low. About 2.5 days after the transplant, CDFG found only 16% of the abalone transplanted to marked sites on Modules 4 and 6, and by May 1982 there was no detectable survivorship (Carter *et al.* 1985b).

To evaluate possible causes of mortality, two groups of approximately 400 individuals each from the December 1981 cohort were outplanted to Module 4 at PAR in May 1982 (Carter *et al.* 1985b). These groups were compared with two laboratory control groups, one transported to PAR and returned to the laboratory, the other held in the laboratory. After 20 days, field transplants suffered a much greater mortality rate (80-89%) than control groups that were transported to PAR and returned to the laboratory (18%), or held in the laboratory (17%) (Carter *et al.* 1985b).

Predation (by crabs, octopuses, and fishes) and starvation (lack of algae) appeared to be the major factors responsible for abalone mortality (Carter *et al.* 1985b). PAR simply may not have been a suitable habitat for juvenile red abalone in 1981 (CDFG 1983). CDFG (1983) noted that PAR has the physical properties suitable for abalone habitat, but felt that at the time of the transplants it did not possess the vegetative cover needed by abalone.

6. EFFECTS ON SURROUNDING SAND COMMUNITY

An artificial reef affects the physical and biological characteristics of the environment around it. Artificial reefs placed on sand plains 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 the 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.* (1982) did not detect a relationship between infaunal densities and distance from Torrey Pines Artificial Reef (near San Diego), although such a relationship was detected around an oil platform.

UCSB/Mit studied the infaunal community (animals that live within sand or sediment) surrounding PAR to determine the extent and nature of PAR's influence, if any. It was 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 because reef-based fish forage on the sand near the reef. UCSB/Mit assessed the influence of PAR on the sand-associated community as a function of distance from the reef and compared infauna within beds of the tube worm *Diopatra ornata*, which were abundant close to the PAR modules, with infauna found outside of the beds.

Core samples (0.0075 m^2 x 13 cm deep) were taken in December 1986 at increasing distances (1, 2, 5, 10, and 20 m) and in four directions from the module complex; cores were also taken within *Diopatra* beds on Modules 3, 5 and 6. Infaunal samples were sieved through a 0.5 mm screen and all organisms (excluding nematodes because they could pass through the screen) counted. Sediment samples were also taken at each station. A full description of the methods and results of this study is presented in Appendix A.

The modules influenced the grain size distributions of the 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). CDFG's observations suggest that the overlaying 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; Wilson *et al.* 1981; K. Wilson, *personal communication*). Furthermore, the on- and offshore transects appeared to have coarser sediments than the up- and downcoast transects, which may reflect differing exposures, since the on- and offshore transects would be expected to be most influenced by swells.

Some species had higher densities near the reef. The most conspicuous of these was the tube worm *Diopatra ornata*. *Diopatra* was present in very low density before PAR was constructed (only a few individuals were noted during pre-construction surveys; CDFG 1981). Following construction, its density increased dramatically (CDFG, *personal communication*), and within a few years after construction *Diopatra* was common adjacent to modules (Wilson *et al.* 1984). In 1986, *Diopatra* only occurred near the modules. The densities of total infauna, three taxonomic groups and four functional groups were higher inside of *Diopatra* beds than outside of the beds. In addition, twice as many decapod species were found within *Diopatra* beds (12) as outside of the beds (6), in spite of much greater sampling effort outside of the beds.

Densities of the two most common infaunal species were related to distance from the module. The polychaete *Prionospio pygmaeus* was less abundant near the modules than away, while *Spiophanes* spp., another polychaete, was more abundant near the modules. In addition, the gammarid amphipod *Megaluropus* appeared to be most common at the near sampling stations on the offshore transect, but not on the other transects (suggesting an interaction between transect and distance, which could not be detected by our analysis), and nemerteans were less common at the 1 m station. Thus, the modules appear to have altered the environment to provide a more suitable habitat for *Spiophanes* and *Megaluropus* and a less suitable habitat for *Prionospio pygmaeus* and nemerteans. *Prionospio pygmaeus* is commonly found in silty mud, so the coarser sediments near the modules would be expected to be a less-suitable habitat for this species, but it is also possible that the lower densities of some taxa near the reef was due to predation by reef-associated fishes.

In summary, PAR appears to have influenced the infaunal community around the reef. In contrast to the pattern reported by Davis *et al.* (1982), UCSB/Mit detected significant differences in infaunal densities with distance from the reef. The influence of PAR was most conspicuous in the distribution of

Diopatra close to the modules and the much higher densities of infauna in *Diopatra* beds, but several other taxa also appeared to be affected by the reef. These effects probably reflect the impact of the artificial reef on the physical characteristics of the environment around the reef. However, the effects of Pendleton Artificial Reef are limited in two respects. First, although significant effects were detected in the two most common species, 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 effects were only detected close to the modules.

Pendleton Artificial Reef has obviously had a detrimental effect on the infauna immediately underneath its rocks. Its influence on the surrounding infauna is mixed. The densities of some species were higher near the reef, which could be viewed as a positive effect since higher infauna densities could mean more food available for fish; however, this effect could also be viewed as detrimental since the natural structure of the infaunal community has been altered. In addition, the densities of some species were reduced near the reef. In any case, PAR's influence on the surrounding infauna was small, since it was limited to areas near the reef.

7. DISCUSSION

7.1 Evaluation of the Pendleton Artificial Reef Project

In this section, we evaluate Pendleton Artificial Reef in terms of its original objectives, expressed in specific terms by Grove (1982) and more generally by Grant *et al.* (1982). As mentioned in the Introduction, we do not consider the actual mitigative value of PAR because PAR was never intended to serve as mitigation (CDFG, *personal communication*). The mitigative value of artificial reefs in general has been discussed in detail in other reports to the MRC (Ambrose 1986, 1987, Technical Report H), and the reader is referred to these reports, particularly the Technical Report on Mitigation (Technical Report H, MRC 1989), for questions concerning mitigation and PAR.

The first specific reef management objective for PAR was to determine whether a stable kelp bed could be established on a man-made reef in nearshore southern California waters (Grove 1982). Despite considerable efforts, a kelp bed was never established at PAR. Kelp has consistently recruited to PAR, but the recruits have not survived long enough to produce a persistent bed. The reasons for PAR's inability to support a persistent kelp bed are not known; some likely possibilities include its distance far from existing kelp beds, its small size, and its configuration (particularly the height of modules and high proportion of ecotonal area).

Although the efforts to establish a self-sustaining kelp bed were not successful at PAR, other artificial structures in southern California do support kelp (Ambrose 1987). Man-made structures with persistent kelp beds include the Los Angeles Harbor breakwater and outfall rip-rap structures; in addition, one artificial reef in the Southern California Bight, at Pitas Point in Ventura County, has supported kelp for several years (since 1985). Although it is obvious that kelp *can* grow on man-made structures, there is still some question about the conditions necessary to establish a self-sustaining, persistent kelp bed on an artificial reef. This topic is discussed in more detail in Technical Report H (MRC 1989).

The second specific objective for PAR was to investigate the long-term stability and fisheries (shellfish and finfish) standing crop on an artificial reef (Grove 1982). Fisheries-related investigations on PAR have been undertaken by CDFG, LOSL, UCSB/Fish and UCSB/Mit; UCSB/Fish and UCSB/Mit have estimated the standing crop of fish on PAR (DeMartini 1987, DeMartini *et al.* 1989, Ambrose 1987, Ambrose and Swarbrick 1989). These studies provide insight into the stability and standing crop on PAR, although they have not addressed the more critical question of the amount of fish production attributable to the reef.

Crabs were abundant on PAR in 1981, when the abalone were transplanted to the reef (CDFG 1983), but appeared to be less abundant in later years. Scallops (*Hinnites giganteus*) are abundant; scallop densities were higher on PAR than on any of the other 9 artificial and 16 natural reefs sampled by Ambrose (1987). Lobsters are also reported to be common, and PAR is a focus of commercial lobster fishing (CDFG 1983).

The density of fish at PAR is relatively high; PAR's density of benthic fish ranked with the highest densities found on natural reefs sampled by Ambrose

(1987), although PAR had few fish in the water column (0.66 fish/1000m^3, compared to an average (SE) of 122.7(55.20)/1000m^3 for 16 natural reefs; Ambrose and Swarbrick 1989). Most of the fish on PAR (about 75% in 1986) were blacksmith. Blacksmith are generally not considered to be a valuable fish, but they may serve an important function in nutrient cycling on rocky reefs (Bray *et al.* 1986) and they are prey for a number of other species, some of which are commercially important. However, the density of sport fish (which does not include blacksmith) on PAR in 1986, 118 fish/1000m^3, was higher than the sport fish density on 12 of the 16 natural reefs sampled by Ambrose (1987). Several fish species, including black perch, halfmoon and kelp bass, appear to have declined at PAR in recent years, and the density of all fish minus blacksmith is also lower (see Fig. 12). However, fish populations fluctuate considerably on natural reefs, so it is too early to tell whether this represents a long-term trend in fish standing crop or simply a short-term fluctuation.

The third specific objective for PAR was to determine the appropriate size and design criteria of structural habitat modifications that will optimally enhance the selected fisheries resources (Grove 1982). <u>Optimal</u> design criteria cannot be determined by a single reef such as PAR. The effects of different size and design criteria cannot be evaluated rigorously at PAR because they cannot be compared to other configurations. Some attempts have been made to use the physical differences between the modules that comprise PAR in order to explore possible relationships between species abundances and habitat structure, and relationships with the physical characteristics of the modules have been suggested for algae and invertebrates (Carter *et al.* 1985a).

However, relationships between habitat features and fish abundances are generally less apparent. Significant differences in species abundances have been detected between modules and microhabitats, but these patterns could not be clearly related to particular habitat features (DeMartini 1987, Anderson *et al.* 1989). Nonetheless, some broad generalizations are confirmed by observations at PAR. For example, both blacksmith and garibaldi were most abundant on the crest regions of modules (Table 5). Blacksmith may have been most abundant on the crest due to their foraging activities in the water column, or because the top of a module may have served as a frame of reference while foraging. Garibaldi might have occurred on the crests because the algae used for nesting sites (Clarke 1970) were more abundant in this microhabitat. In addition, fish recruitment was relatively high at the sand/rock interface, where food and nocturnal shelter may be more available for species such as rock wrasse, senorita, and sand bass. In spite of these generalizations about the influence of habitat characteristics, the data from PAR are generally not sufficient to determine the features that would *optimally* enhance selected fisheries resources.

In addition to the three specific management objectives for PAR, Grant *et al.* (1982) report two general objectives of PAR (in addition to the desire to establish a stand of giant kelp): "to enhance an otherwise relatively unproductive environment and to investigate the potential of such reefs as a mitigation measure for potential damage to the nearshore marine environment by a coastal power plant." These two objectives have been met, since the densities of fish are higher on PAR than on sand bottoms (DeMartini 1987), and the mitigative potential of artificial reefs has been (and will continue to be) investigated.

Perhaps the greatest benefits from PAR have been the information it has provided, the attention it has focused on the possibilities associated with using artificial reefs to enhance marine resources, and how that information and attention have influenced subsequent ideas about artificial reefs. In the remainder of this section, we discuss some ideas about artificial reefs, and especially their use in mitigation, that draw on information about PAR. (As noted previously, a comprehensive discussion of the mitigative value of artificial reefs is given in Technical Report H [MRC 1989]).

7.1.1 Location

Location appears to be one of the most important factors influencing the type of community that develops on an artificial reef. When PAR was constructed, the conventional wisdom was that artificial reefs should be isolated from natural reefs; it was believed that the overall enhancement effect of the reef would be greater if the reef was located away from a natural reef (CDFG 1981). For example, Turner *et al.* (1969) suggested that an artificial reef should be at least one-half mile from the nearest natural reef. Although isolation from a natural reef might maximize an artificial reef's ability to attract fish, and is frequently cited as a criterion for siting a reef to be used to enhance fishing, it is not necessarily the best location for mitigative purposes.

The distance to natural reefs may influence invertebrate and fish community composition since many species only disperse a short distance, but it is probably most important for establishing a persistent kelp bed. Under most circumstances, giant kelp only disperses very short distances (Anderson and North 1967, Dayton *et al.* 1984). One possible reason for the lack of a persistent kelp bed on PAR is that it is too far from existing kelp beds. There has been consistent *Macrocystis* recruitment to PAR, apparently from drift plants or "bouncers" (kelp plants attached to small rocks), but the input of recruits has been at a fairly low level. The problem at PAR may have been one of rates--recruitment was not high enough to overcome fish grazing.

A second possible explanation for the absence of a kelp bed at PAR is that its location is not conducive to kelp growth and survival. K. Wilson (CDFG, *personal communication*) has suggested that nutrients may not be sufficient (at least at the appropriate time of year) for recruits at PAR to grow, or at least to grow fast enough to overcome fish grazing. Turbidity may also be too high at PAR (K. Wilson, *personal communication*). These considerations point out the limitations of pre-construction surveys. Although it is clear that kelp will grow on artificial substrates, at this point we do not have enough information to be able to predict confidently locations where a kelp bed could successfully be established. Pre-construction surveys (and early observations at PAR) indicated that PAR's location would be adequate for establishing a kelp bed (Grant *et al.* 1982), especially since a kelp bed occurred at the site in previous years (K. Wilson, *personal communication*). The experience at PAR illustrates that the pre-construction survey, by itself, was not sufficient, and that test reefs should be built before building a large, expensive reef.

7.1.2 Habitat heterogeneity

Habitat heterogeneity has been shown to positively influence the diversity of benthic invertebrates (e.g. Kohn 1983, Miller 1983) and fishes (Gladfelter *et al.* 1980, Shulman 1984). Although PAR, with its sand and rock habitats, abundant shelter spaces, and high modules, was designed to provide a complex habitat, future reefs might have higher species diversity if they incorporate even more habitat heterogeneity. For example, most of the rock at PAR was placed in rock piles 3-5m tall, and low rock habitat (e.g. reefs (<1m tall) and separate rocks) is uncommon. (The design of PAR was influenced by the Japanese emphasis on high aspect ratio [Grant *et al*. 1982], which seems to serve primarily to attract fish.) Different species are likely to be found on low versus high sections of an artificial reef (see Patton *et al.* 1985). These differences might be particularly important for an artificial reef used to mitigate impacts to a low reef, where maximum in-kind mitigation might be provided by a low artificial reef. Recognizing the potential importance of different heights, CDFG has recently constructed reefs that incorporate both high and low modules.

Another way to increase habitat complexity would be to use different rock sizes. Mixing rock sizes would provide greater diversity of shelter sites, which might lead to higher species diversity on the reef. In 1987, CDFG constructed a reef using two different boulder sizes in Santa Monica Bay; this reef has not yet been studied, so the effects of the different boulder sizes has not been evaluated.

Observations at PAR indicate one aspect of rock size that needs to be considered carefully for future artificial reefs. The cobble topping at PAR became a solid substrate, with few holes for refuges, because the sessile organisms "glued" the individual rocks together (CDFG, *personal communication, personal observation*). The cobble was originally applied in order to provide appropriately sized refuges for small abalone; its solid nature has rendered it inappropriate for that purpose. For small refuges on future artificial reefs, a somewhat larger rock (<18") would probably be required.

7.1.3 Transplants

A great deal of effort was spent trying to establish a kelp bed on PAR by transplanting *Macrocystis*. These transplants did result in recruitment of *Macrocystis* to PAR, but *Macrocystis* has also recruited naturally to PAR. The problem at PAR has been that kelp does not grow well enough, or survive long enough, to produce a bed, and transplanting apparently could not overcome this difficulty.

The most important factor influencing the successful establishment of a kelp bed on an artificial reef is probably the location of the reef, because the oceanographic conditions must be adequate for kelp recruitment and growth. Transplanting kelp might reduce the time before kelp becomes established at a suitable site, but it is expensive and time-consuming (CDFG spent nearly 200 man-days transplanting kelp to PAR [CDFG 1983, 1984] and PAR is a relatively small reef). Transplanting kelp is likely to be cost-effective when rapid establishment of a bed is necessary, such as might be the case for an artificial reef constructed to mitigate damage to a kelp bed, but it would be too costly for long-term management.

7.1.4 Size and configuration

PAR has provided information about two aspects of the size and configuration of artificial reefs: the relative amount of perimeter or ecotonal habitat, and the standing stock of fish found on a reef.

PAR was specifically designed to have a relatively high proportion of ecotonal (perimeter) habitat. To achieve a greater edge effect (as discussed by

Odum 1971), PAR was constructed as separate piles of rocks, or modules. The edge effect was thought to be important for feeding; it also provided important habitat for certain species such as sand bass and for the recruitment of many fish species.

However, the higher proportion of perimeter habitat on modules results in a greater exposed surface, which K. Wilson (*personal communication*) speculates may increase grazing on kelp and/or physical stress. These possibly negative consequences of modules were not anticipated before PAR was built. K. Wilson (*personal communication*) suggests that future artificial reefs might incorporate only one or a few large modules in order to minimize the perimeters exposed to fish grazing; the Topanga Artficial Reef, designed to support a kelp bed, was constructed in this configuration. The observations at PAR are suggestive, but there have been no rigorous studies to establish what benefits, if any, accrue from having several separate units within one reef area (Ambrose 1986).

Work on PAR has also illustrated the consequences of the different sizes of natural reefs and the artificial reefs that have been constructed to date. Before studies were conducted at PAR, there had been few estimates of fish standing stocks on reefs in Southern California (see Quast 1968, Larson and DeMartini 1984, Stephens *et al.* 1984). In Fall 1986, DeMartini *et al.* (1989) estimated the standing stock of resident fish at PAR (14,950 fish weighing 0.5 metric tons [MT]) and the San Onofre Kelp Bed (317,600 fish weighing 29 MT). Also in Fall 1986, Ambrose (1987) estimated standing stocks of fish on 10 artificial reefs (including PAR) and 16 natural reefs (Table 6). PAR had an estimated standing stock of 0.5 MT; the estimated standing stocks on reefs sampled by Ambrose varied from 0.12 to 2.77 MT (Mean=0.941 MT) on artificial reefs and from 2.22 to 276.05 MT (Mean=45.320 MT) on natural reefs. These studies indicate that artificial reefs that are constructed to mitigate damage to natural reefs may need to be considerably larger than the reefs that have been built to date.

7.2 Summary

Studies on PAR have provided valuable information for evaluating the feasibility of using artificial reefs, in general, as mitigation for coastal impacts. PAR is one of the best-studied artificial reefs in the world. Early studies by LOSL and CDFG have illustrated the development of communities on rocky reefs in Southern California. Studies of the fish assemblages at PAR and nearby reefs have also been valuable, particularly with regards to year-to-year variation in recruitment of different species. Observations of the distribution and abundance of organisms on PAR has led to a number of hypotheses about artificial reefs that can be tested in future studies.

PAR cannot be expected to provide <u>all</u> of the information needed to evaluate the mitigative potential of artificial reefs or to mitigate effectively the resource losses at SOK; it was not constructed for these purposes. But PAR has substantially increased our understanding about artificial reefs in Southern California; to date, nine papers have been published in the refereed literature concerning PAR, which make it one of the best-documented artificial reefs in the United States. In addition, early discussions about artificial reefs and mitigation that focused on PAR (Grove 1982, Yuge *et al.* 1985) set the stage for the continued interest in this potentially valuable mitigation technique.

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9. TABLES

Table 1

Physical description of Pendleton Artificial Reef (PAR) modules.

Module dimensions are from LOSL (1983a), based on Eco-M measurements, and CDFG (1981). Estimates of percent cobble cover are based on visual estimates within sixty 1.0 m^2 circular areas on each module (LOSL 1983a, b) and from 12 random point contact (RPC) surveys (CDFG 1983). Maximum physical relief measurements were made within sixty 1.0 m^2 circular areas on each module (LOSL 1983a, b). Maximum physical relief is defined as the distance between the highest and lowest points on the module beneath and normal to the 1.0 m^2 sampling area. ND = no data.

		MODULES							
PHYSICAL PARAMETER	DATA SOURCE	1	2	3	4	5	6	7	8
Length (m)	LOSL	36.9	37.8	24.1	27.4	26.5	26.5	24.7	33.8
	CDFG	43	31	ND	35	30	31	40	36
Width (m)	LOSL	29.3	21.3	15.8	19.5	19.2	18.0	19.2	18.0
	CDFG	25	15	ND	16	23	19	23	17
Max. height above bottom (m)	LOSL	4.3	4.6	4.3	4.9	3.7	4.3	4.3	4.6
	CDFG	3.4	4.6	5.2	4.3	3.0	4.6	4.0	4.6
% Cobble Cover Mean ± 2SE	LOSL	25.6±4.9	7.6±2.7	3.4±2.6	7.9±3.6	45.0±7.9	7.2±4.1	8.9±3.8	15.7±4.2
	CDFG	26.2±20.2	13.3±17.0	1.5±4.4	ND	ND	ND	ND	28.2±24.8
Physical Relief (cm) Mean ± 2SE	LOSL	33.5±5.5	60.1±10.0	87.4±14.3	55.4±10.2	30.4±5.1	75.7±10.2	62.3±8.2	54.8±8.1
Total Surface Area (m^2)	LOSL	744.2	1062.7	934.1	992.7	1193.7	912.2	1248.2	1935.4

Table 2

Mean densities (no./m^2) of select sessile and motile macroinvertebrates at Pendleton Artificial Reef, 1984-86. Dashed lines indicate that no data are available. These species were sampled with quadrats or band transects (see CDFG 1986 and Ambrose 1987 for more details).

Species/Group	1984 Fall[1]	1985 Spring[1]	1985 Fall[1]	1986 Spring[2]	 Fall[2]	 Fall[3]
Cnidaria						
Sea Anemones	0	0.03	0	--	--	0.2
Gorgonians						
Muricea spp.	46.9	40.3	45.8	44.7	47.7	42.5
Lophogorgia chilensis	0.01	0.01	0.03	0.06	0.04	0.10
Mollusca						
Megathura crenulata	0	<0.01	<0.01	<0.01	<0.01	0
Murex festiva	0.03	0.40	0.07	--	--	--
Hinnites giganteus	0.7	0.2	0.3	0.2	0.2	0.7
Echinodermata						
Sea Stars						
Pisaster brevispinus	0.01	0.02	<0.01	<0.01	0.01	0
Pisaster giganteus	<0.01	0.01	<0.01	0.02	<0.01	0.01
Pisaster ochraceous	0	0	<0.01	<0.01	<0.01	0
Sea Urchins	0	0	0	0	<0.01	0
Sea Cucumbers	0	0	0	0.02	0	--
Arthropoda						
Crustaceans						
Panulirus interruptus	0.02	<0.01	0.02	<0.01	<0.01	--
Chordata						
Ascidians						
Styela montereyensis	0	0.08	0.10	0.07	0.10	0.2

[1] CDFG (1986)
[2] CDFG (*In prep.*)
[3] Ambrose (1987)

Table 3
page 1 of 2

Fish species observed at Pendleton Artificial Reef. List was compiled from reports by LOSL, UCSB/Fish, UCSB/Mit and DFG; all species reported by these groups are included.

FAMILY/SPECIES	COMMON NAME
Torpedinidae	
Torpedo californica	Pacific electric ray
Muraenidae	
Gymnothorax mordax	California moray
Atherinidae	silversides
Scorpaenidae	
Scorpaena guttata	California scorpionfish
Sebastes atrovirens	kelp rockfish
Sebastes auriculatus	brown rockfish
Sebastes rastrelliger	grass rockfish
Sebastes serriceps	treefish
Hexagrammidae	
Oxylebius pictus	painted greenling
Cottidae	
Scorpaenichthys marmoratus	cabezon
Serranidae	
Paralabrax clathratus	kelp bass
Paralabrax maculatofasciatus	spotted sand bass
Paralabrax nebulifer	barred sand bass
Stereolepis gigas	giant sea bass
Carangidae	
Trachurus symmetricus	jack mackerel
Haemulidae	
Anisotremus davidsonii	sargo
Sciaenidae	
Cheilotrema saturnum	black croaker
Genyonemus lineatus	white croaker
Kyphosidae	
Girella nigricans	opaleye
Medialuna californiensis	halfmoon

Table 3
page 2 of 2

FAMILY/SPECIES	COMMON NAME
Embiotocidae	
Damalichthys vacca	pile perch
Embiotoca jacksoni	black perch
Embiotoca lateralis	striped perch
Hypsurus caryi	rainbow seaperch
Phanerodon furcatus	white seaperch
Rhacochilus toxotes	rubberlip seaperch
Pomacentridae	
Chromis punctipinnis	blacksmith
Hypsypops rubicundus	garibaldi
Sphyraenidae	
Sphyraena argentea	California barracuda
Labridae	
Halichoeres semicinctus	rock wrasse
Oxyjulis californica	senorita
Semicossyphus pulcher	California sheephead
Clinidae	
Heterostichus rostratus	giant kelpfish
Neoclinus stephensae	yellowfin fringehead
Blenniidae	
Hypsoblennius jenkinsi	mussel blenny
Gobiidae	
Coryphopterus nicholsii	blackeye goby
Lythrypnus dalli	bluebanded goby
Lythrypnus zebra	zebra goby
Scombridae	
Sarda chiliensis	Pacific bonito
Bothidae	
Paralichthys californicus	California halibut
Pleuronectidae	
Pleuronichthys coenosus	C-O turbot
Balistidae	
Balistes polylepis	finescale triggerfish
Molidae	
Mola mola	ocean sunfish

Table 4

Young-of-year fish at Pendleton Artificial Reef. Data for 1983 (7 surveys; LOSL 1983a) and 1984 (1 survey; DeMartini 1985) were collected using different methods, so presence is indicated by X but densities are not presented. Identical methods were used in 1985 and 1986; data are estimated mean densities over the entire reef based on 3 surveys each year (DeMartini 1987). - indicates young-of-year not present in any survey for that year.

			DENSITY (NO./1000 M^2)			
	1983	1984	1985		1986	
SPECIES			MEAN	SE	MEAN	SE
barred sand bass	X	X	-	-	-	-
black perch	X	X	63	6.5	102	26.5
blackeye goby	-	-	2	0.5	8	1.5
blacksmith	X	X	8082	2162	3361	542.5
bluebanded goby	X	X	10	8	2	1
California sheephead	X	X	32	2.5	4	2
California scorpionfish	-	-	0.1	0.03	-	-
garibaldi	X	-	16	4.5	2	1
kelp bass	X	X	-	-	1	1
painted greenling	X	-	-	-	-	-
pile perch	X	-	0.3	0.15	-	-
rainbow perch	X	X	-	-	-	-
rock wrasse	X	X	0.1	0.03	-	-
sargo	-	-	2	2	-	-
senorita	X	X	82	44.5	50	23.5
zebra goby	-	-	0.2	0.04	-	-
Total Individuals			8289	2213	3529	583.5
Total Individuals minus blacksmith			207	56	168	46.5
Number of species	11	8	12		9	

Table 5

Densities (no./1000 m^3) of select fish species over microhabitats at Pendleton Artificial Reef (PAR). Crest and slope are illustrated in Figure 11; perimeter microhabitat extended 0 to 3 m off the sand/rock interface. Data are from DeMartini (1987). Densities were determined by visual transects, as noted in Section 4.2, made during two surveys (Nov 1986 and Jan 1987), with all 8 modules sampled during each survey.

SPECIES	---------------------- MICROHABITAT				-------------------------	
	CREST		SLOPE		PERIMETER	
	MEAN	SE	MEAN	SE	MEAN	SE
blacksmith	1364.6	394.4	200.7	55.8	34.9	11.1
garibaldi	27.9	4.1	4.7	0.8	0.9	0.3
kelp bass	9.1	1.3	2.1	0.6	1.1	0.4
senorita	13.8	5.7	23.5	10.2	15.0	6.1

Table 6

Estimated standing stock (MT) of fish on artificial and natural reefs in Southern California. Biomass densities, estimated by visual (benthic) and video (water column) transects, were multiplied by reef area to estimate standing stock. Some natural reefs were sampled at 2 or 3 sites; to estimate standing stock for these reefs, the mean biomass density for the sites was used. From Ambrose and Swarbrick (1989).

	BENTHIC	WATER COLUMN
ARTIFICIAL REEFS		
Torrey Pines AR	0.120	0
Pendleton AR	0.503	0.0004
Newport Beach AR	1.958	0
LA Harbor Breakwater outside	2.771	0.278
LA Harbor Breakwater inside	2.005	0.347
King Harbor Breakwater	0.942	0.025
Hermosa Beach AR	0.061	0
Marina Del Rey AR	0.154	0
Pitas Point AR	0.279	0.005
Rincon Oil Island	0.621	0.84
MEAN (SE)	**0.941 (0.304)**	**0.150 (0.087)**
NATURAL REEFS		
Marine Street Reef[1]	45.540	2.64
La Jolla Cove Reef[1]		
Del Mar Reef	37.236	0.193
Barn Kelp	13.120	0
Las Pulgas Reef	8.162	0
Box Canyon	2.080	0
San Onofre Kelp - Main[2]	30.992	9.058
San Onofre Kelp - North[2]		
San Mateo Kelp[3]	65.892	4.070
Two Man Rock[3]		
Laguna Beach North	4.853	3.252
Pelican Point	12.369	0.828
Point Vicente[4]	276.051	22.040
Don't Dive There[4]		
Flat Rock[4]		
Rincon Kelp	2.224	0.025
MEAN (SE)	**45.320 (23.893)**	**3.828 (2.003)**

1 Both reefs are part of the La Jolla reef complex.
2 Both reefs are part of the San Onofre Kelp Bed
3 Both reefs are part of the San Mateo Kelp Bed
4 All three reefs are part of the Palos Verdes Peninsula reef complex

10. FIGURES

Figure 1: Location of Pendleton Artificial Reef.

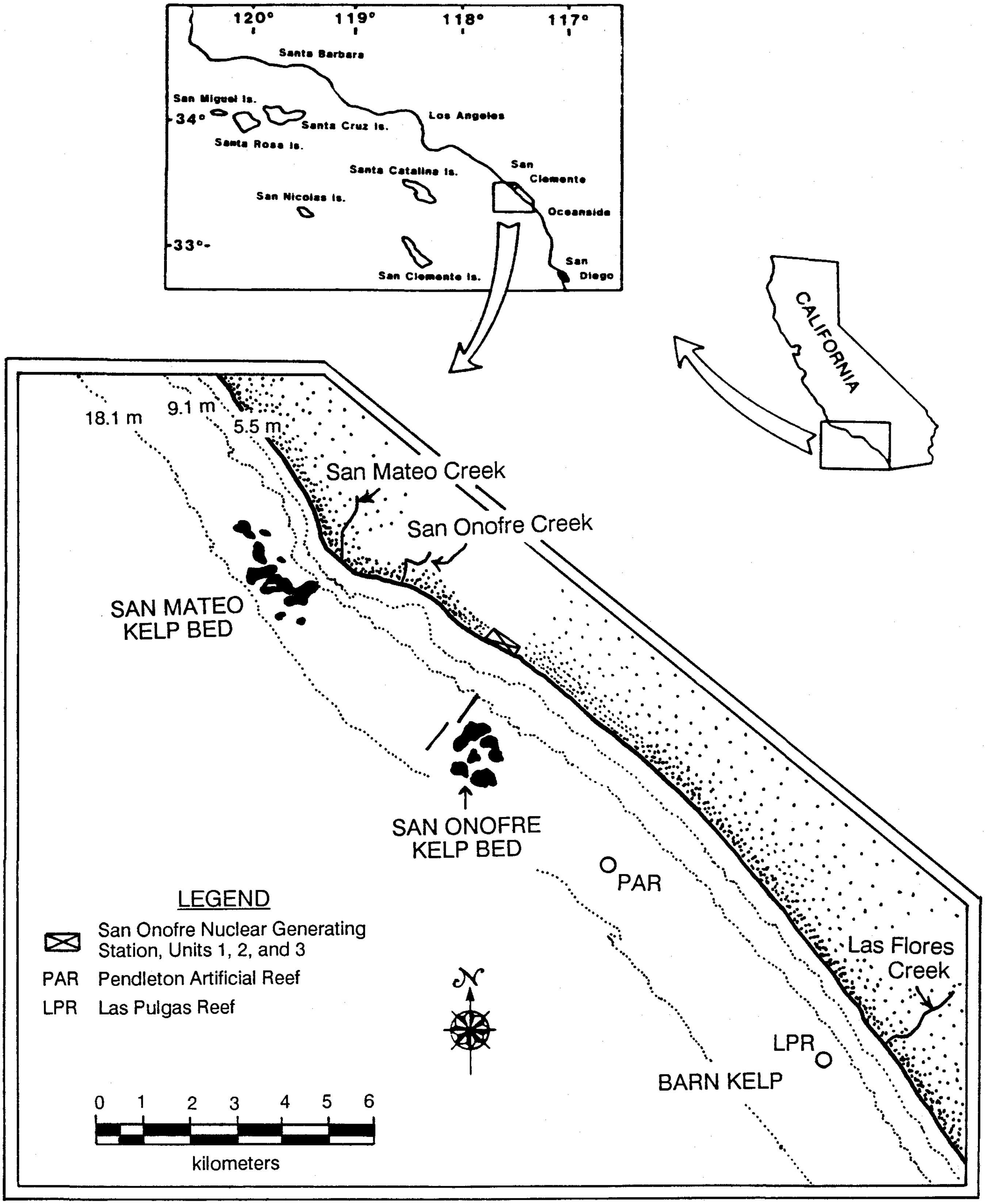

120°
119°
118°
117°
Santa Barbara
San Miguel Is.
34°
Santa Cruz Is.
Santa Rosa Is.
Los Angeles
San Clemente
Santa Catalina Is.
San Nicolas Is.
Oceanside
33°
San Diego
San Clemente Is.
CALIFORNIA
18.1 m
9.1 m
5.5 m
San Mateo Creek
San Onofre Creek
SAN MATEO KELP BED
SAN ONOFRE KELP BED
PAR
LEGEND
San Onofre Nuclear Generating Station, Units 1, 2, and 3
PAR Pendleton Artificial Reef
LPR Las Pulgas Reef
N
Las Flores Creek
LPR
BARN KELP
0 1 2 3 4 5 6
kilometers

Figure 2: Proposed design of Pendleton Artificial Reef (from Grant _et_ _al._ 1982).

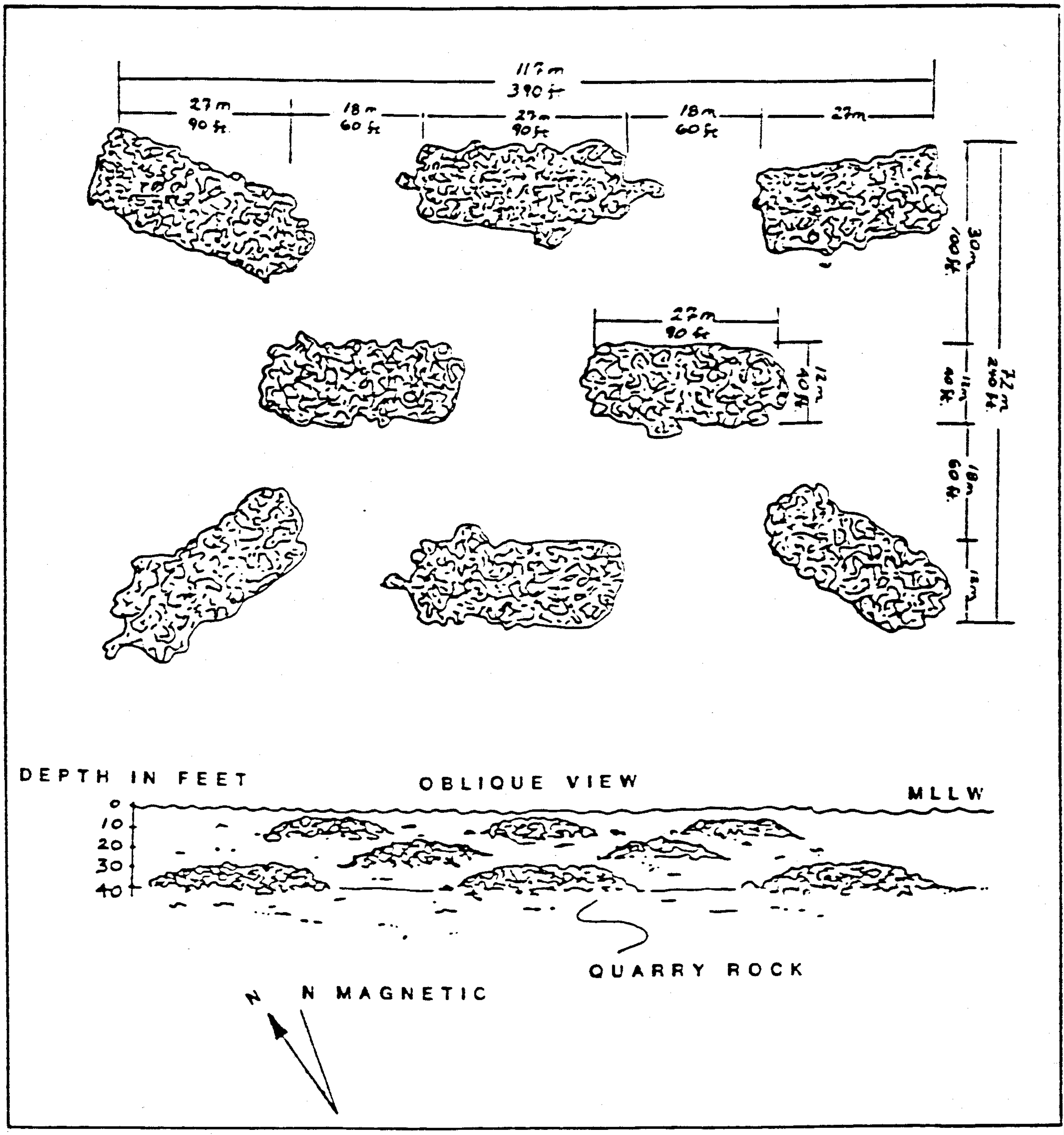
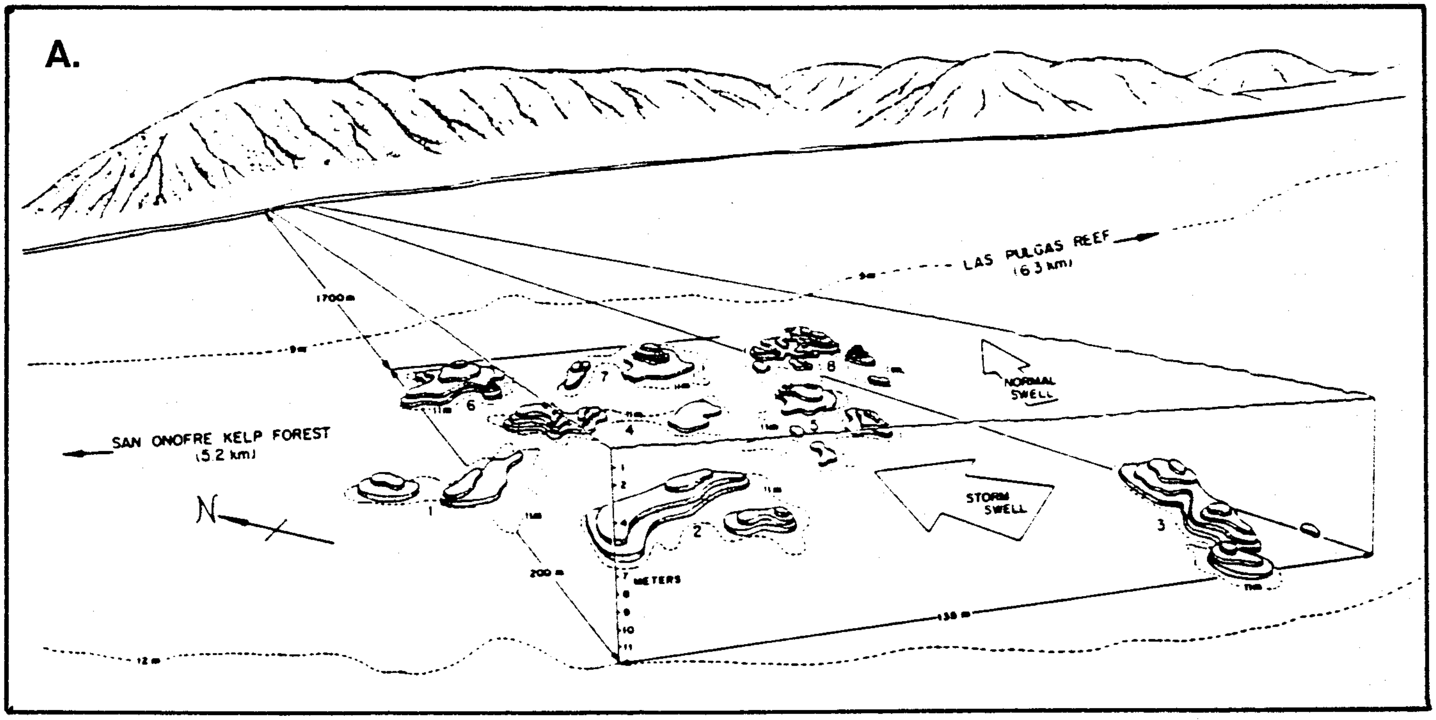

117m
390 ft
27m
90 ft
18m
60 ft
27m
90 ft
18m
60 ft
27m
27m
90 ft
12m
40 ft
30m
100 ft
11m
40 ft
18m
60 ft
18m
72m
240 ft
DEPTH IN FEET
OBLIQUE VIEW
MLLW
0
10
20
30
40
QUARRY ROCK
N
N MAGNETIC

Figure 3: Diagram of Pendleton Artificial Reef. A. Diagram drawn from a bathymetry map created by Ecosystems Management, Inc., with a reported accuracy of ± 3 m horizontal extent and ± 0.9 m vertical relief (from Carter et al. 1985a). B. Topographic diagram based on measurements made by California Department of Fish and Game divers (from CDFG in prep).


A.
LAS PULGAS REEF
(6.3 km)
1700 m
9 m
NORMAL SWELL
SAN ONOFRE KELP FOREST
(5.2 km)
N
1
2
3
4
5
6
7
8
11 m
STORM SWELL
200 m
METERS
1
2
4
7
8
9
10
11
138 m
12 m

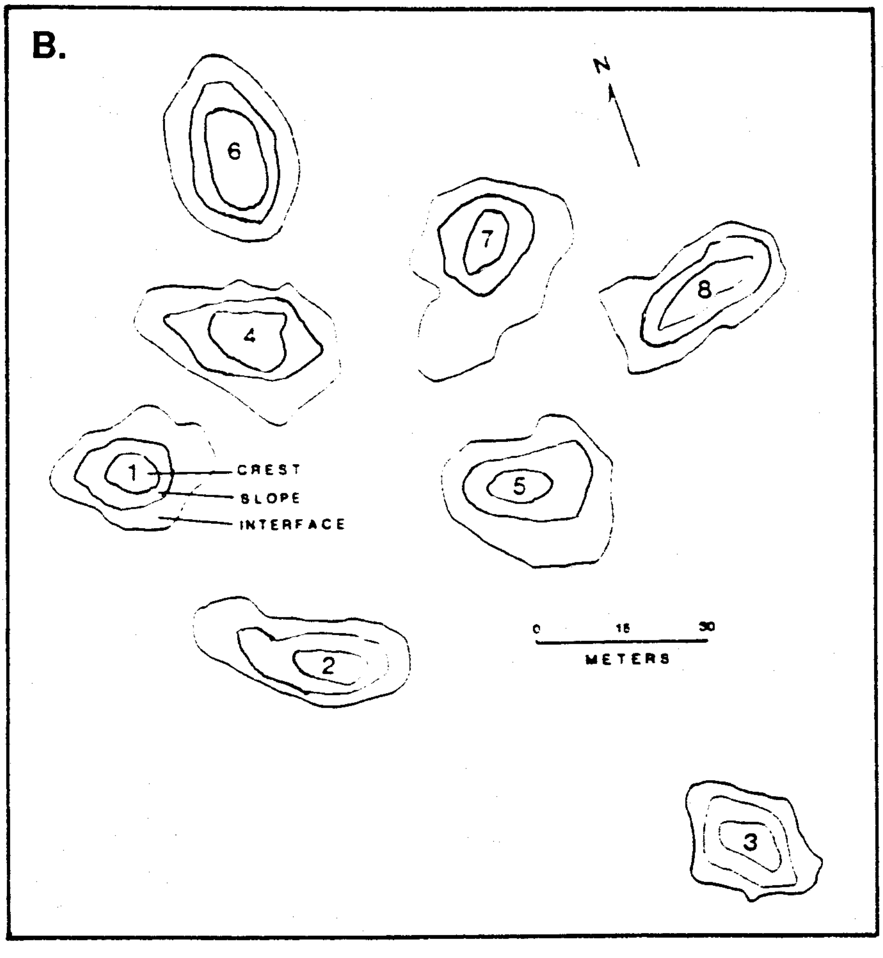
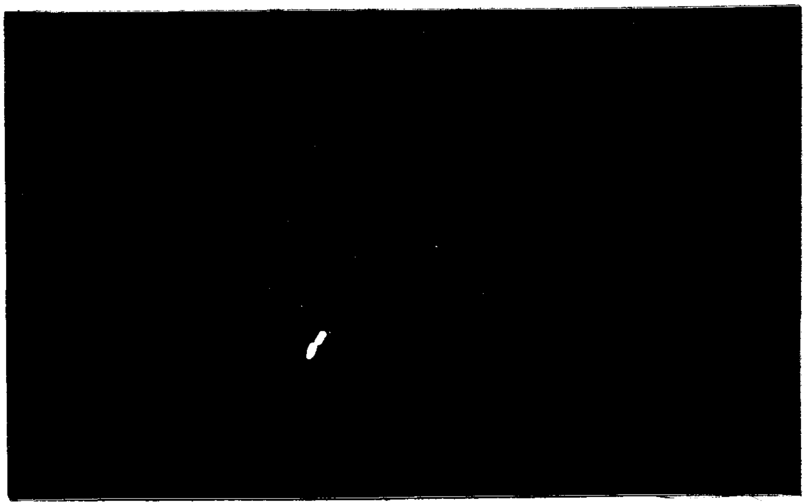

B.
N
6
7
8
4
1
CREST
SLOPE
INTERFACE
5
2
0
15
30
METERS
3

Figure 4: Aerial view of Pendleton Artificial Reef (photo courtesy of R. Smith). The two white boats over Module 1 span approximately 14 m.



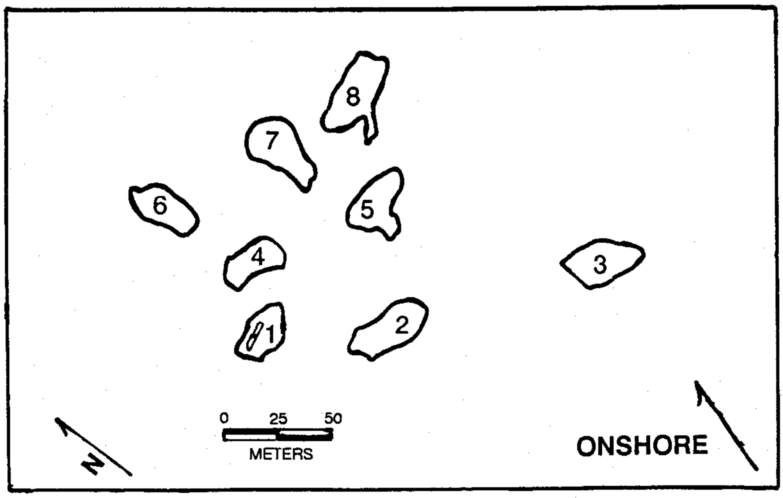

8
7
6
5
4
3
1
2
0
25
50
METERS
ONSHORE
N

Figure 5: Percentage cover of algal turf at Pendleton Artificial Reef, from 1981 through 1986. F=Fall, S=Spring. Data from CDFG (1986, in prep.), LOSL (1984), and Ambrose (1987).

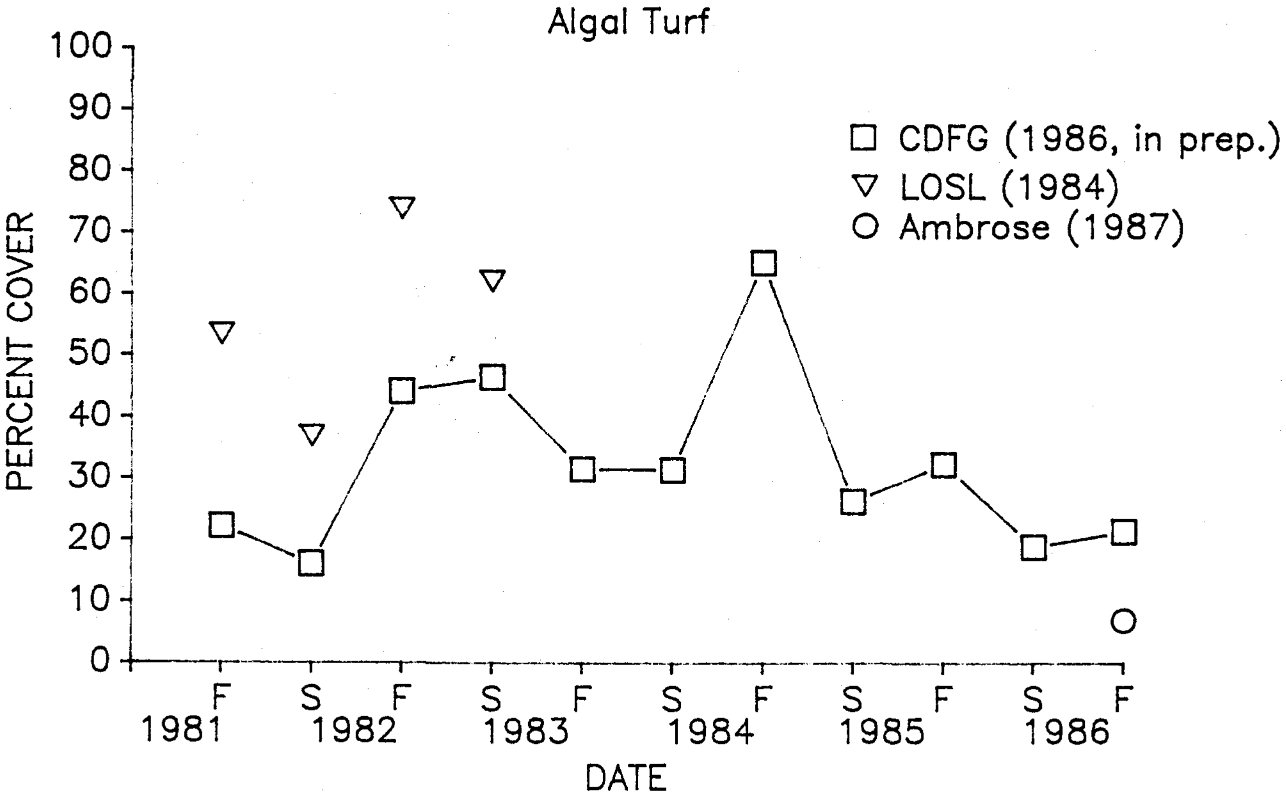

Algal Turf
100
90
80
70
60
50
40
30
20
10
0
PERCENT COVER
□ CDFG (1986, in prep.)
▽ LOSL (1984)
○ Ambrose (1987)
F
S
F
S
F
S
F
S
F
S
F
1981
1982
1983
1984
1985
1986
DATE

Figure 6: Percentage cover of foliose algae at Pendleton Artificial Reef, from 1981 through 1986. Note that maximum percent cover was 17%. Data from CDFG (1986, in prep.), LOSL (1984), and Ambrose (1987).

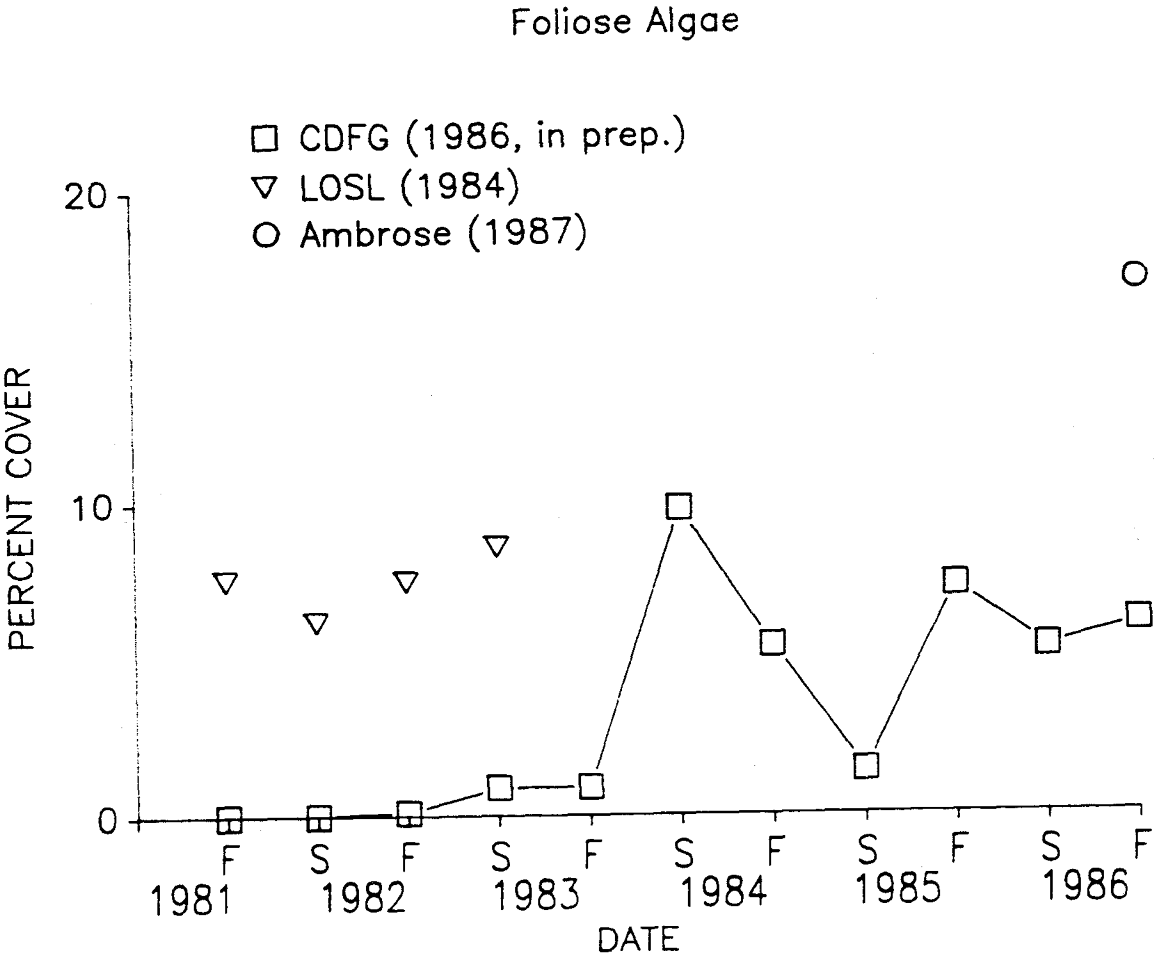

Foliose Algae
□ CDFG (1986, in prep.)
▽ LOSL (1984)
○ Ambrose (1987)
PERCENT COVER
20
10
0
F
S
F
S
F
S
F
S
F
S
F
1981
1982
1983
1984
1985
1986
DATE

Figure 8: Percentage cover of Megabalanus spp. at Pendleton Artificial Reef, from 1981 through 1986. Note that maximum percent cover was 21%. Data from CDFG (1986, in prep.) and LOSL (1984).

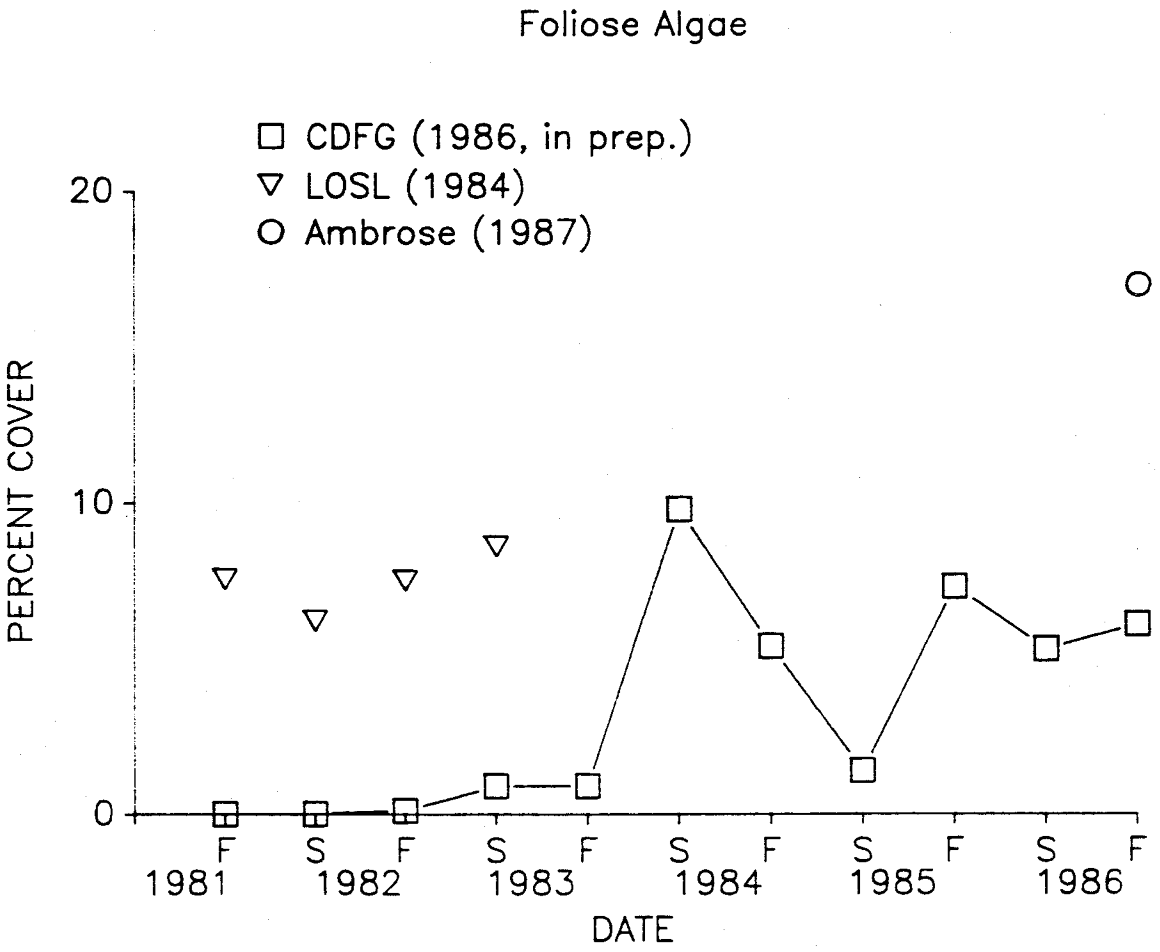
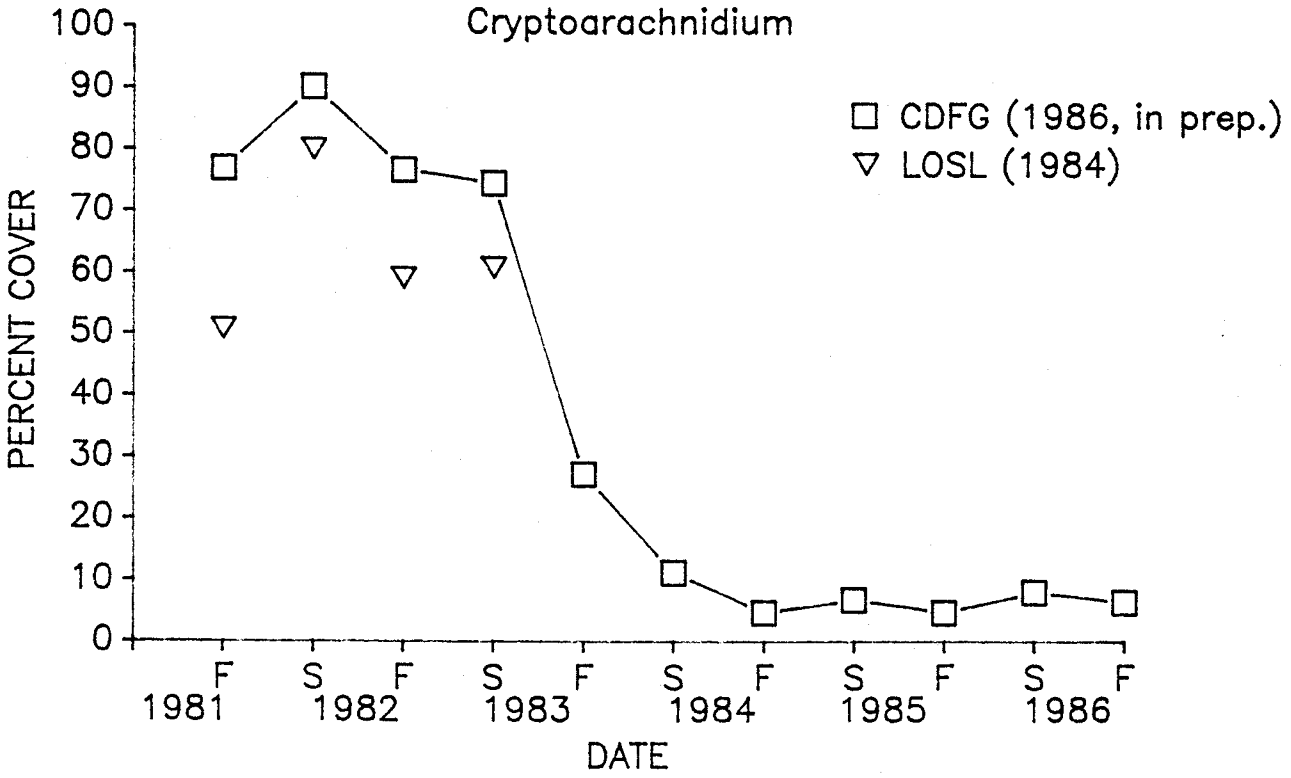
Foliose Algae
□ CDFG (1986, in prep.)
▽ LOSL (1984)
○ Ambrose (1987)
PERCENT COVER
20
10
0
F S F S F S F S F S F
1981
1982
1983
1984
1985
1986
DATE

Figure 7: Percentage cover of Cryptoarachnidium argilla at Pendleton Artificial Reef, from 1981 through 1986. Data from CDFG (1986, in prep.) and LOSL (1984).



Cryptoarachnidium
□ CDFG (1986, in prep.)
▽ LOSL (1984)
PERCENT COVER
100
90
80
70
60
50
40
30
20
10
0
F S F S F S F S F S F
1981
1982
1983
1984
1985
1986
DATE

Figure 8: Percentage cover of Megabalanus spp. at Pendleton Artificial Reef, from 1981 through 1986. Note that maximum percent cover was 21%. Data from CDFG (1986, in prep.) and LOSL (1984).

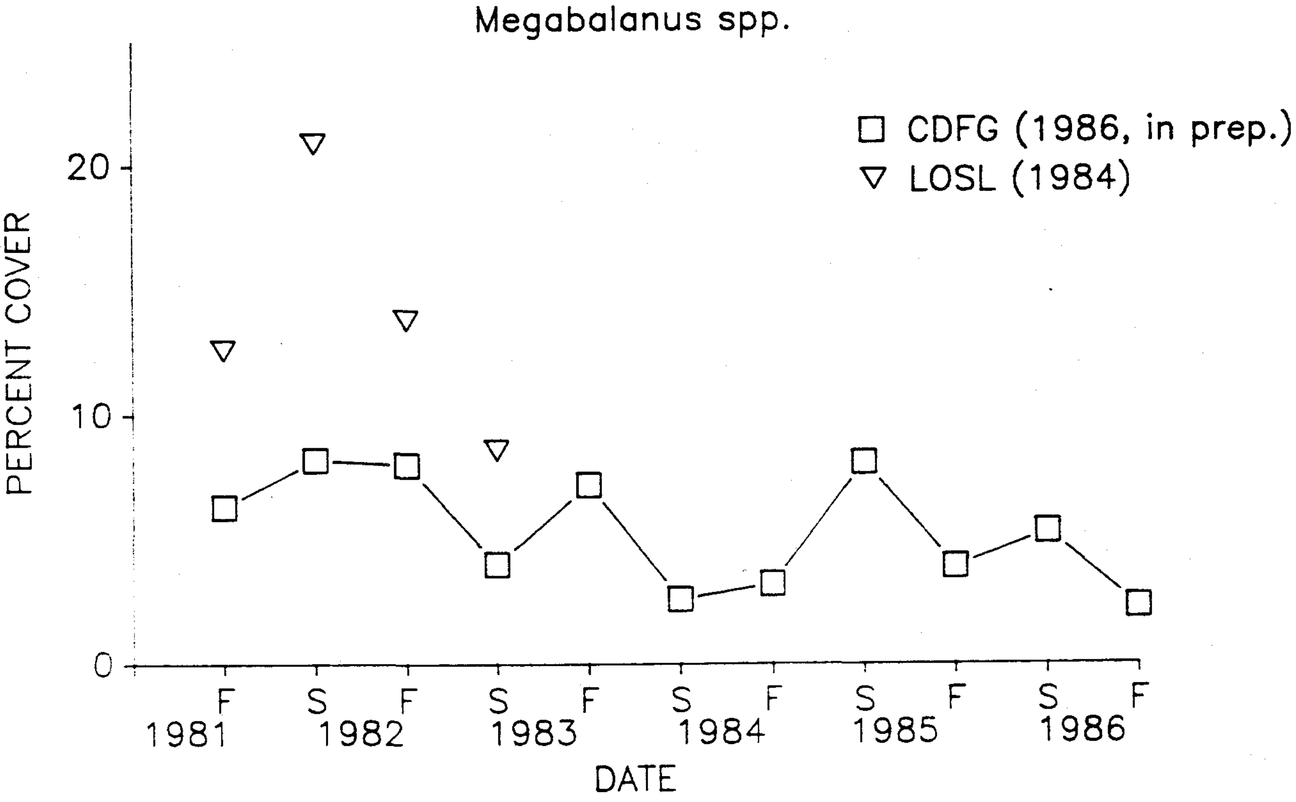

Megabalanus spp.
□ CDFG (1986, in prep.)
▽ LOSL (1984)
PERCENT COVER
0
10
20
F
S
F
S
F
S
F
S
F
S
F
1981
1982
1983
1984
1985
1986
DATE

Figure 9: Percentage cover of erect bryozoans at Pendleton Artificial Reef, from 1981 through 1986. Data from CDFG (1986, in prep.), LOSL (1984), and Ambrose (1987).

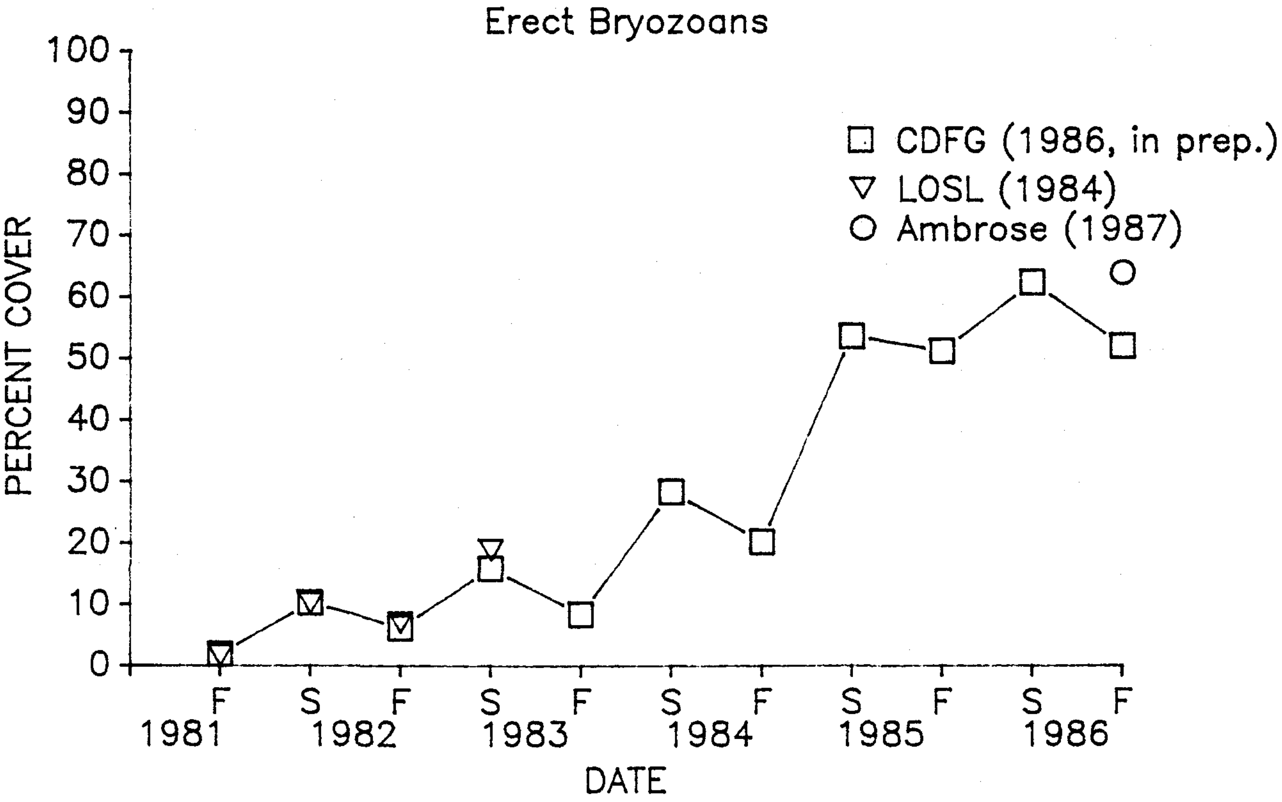
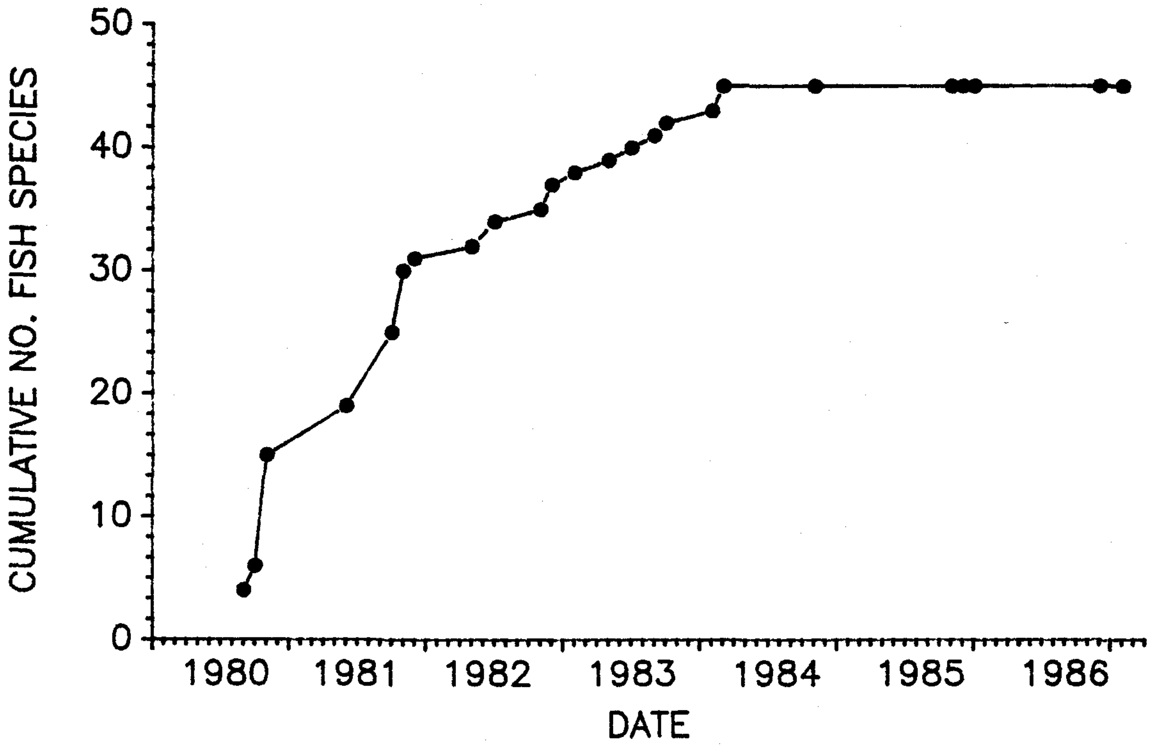
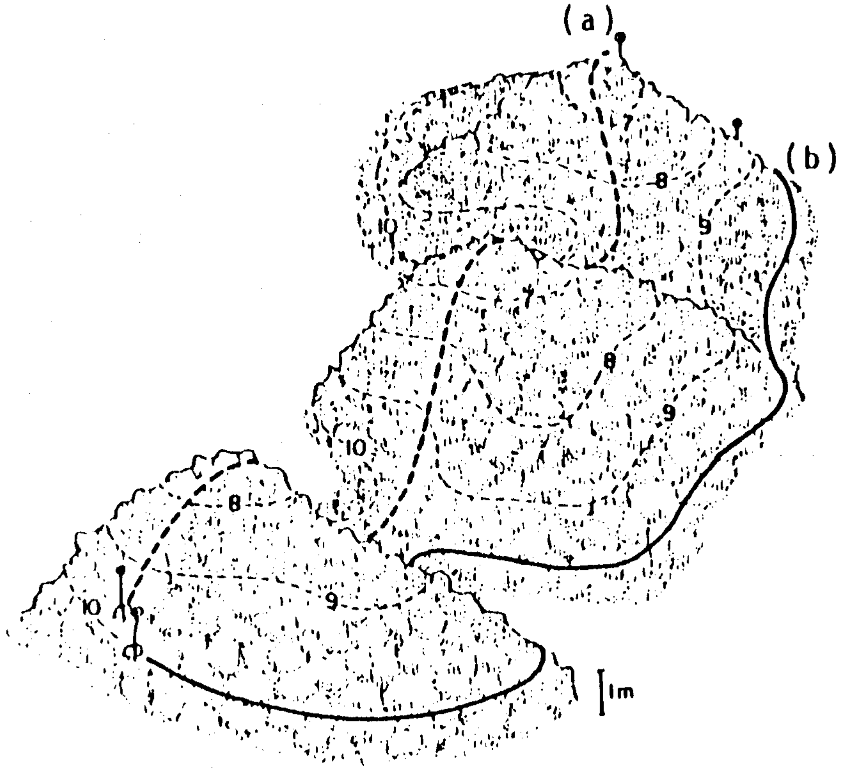

Erect Bryozoans
100
90
80
70
60
50
40
30
20
10
0
PERCENT COVER
☐ CDFG (1986, in prep.)
▽ LOSL (1984)
○ Ambrose (1987)
F
S
F
S
F
S
F
S
F
S
F
1981
1982
1983
1984
1985
1986
DATE

Figure 10: Cumulative species curve of newly observed fishes at Pendleton Artificial Reef. Data combined from CDFG (1984), LOSL (1984) and UCSB/Fish (DeMartini et al. 1987).



50
40
30
20
10
0
CUMULATIVE NO. FISH SPECIES
1980
1981
1982
1983
1984
1985
1986
DATE

Figure 11: Representation of visual transects sampled on crest (a) and bottom (b) strata at Pendleton Artificial Reef (from Jessee et al. 1985). In (b), the dark, dashed lines depict the route a diver swims and lighter, dashed lines define the corridor within which fish were tallied. Corridor dimensions were 3 m wide x 1.5 m high for juvenile/adult transects by LOSL, CDFG, UCSB/Fish and UCSB/Mit. Young-of-year/older juvenile transects by UCSB/Fish were 1 m wide x 1 m high along the perimeter and 1 m wide x 2 m high on the crest; all YOY/OJ transects by UCSB/Mit were 1 m wide x 2 m high. LOSL transects were 30 m long for the bottom, and along the crest varied from 14 m to 35 m, according to module (see LOSL 1983a). CDFG used the same transect dimensions as LOSL. UCSB/Fish transects ranged from 14 - 35 m on crest and 76 - 150 m on the bottom, depending on module. All UCSB/Mit transects were 30 m long.


(a)
(b)
7
8
9
10
8
9
10
8
9
10
1m

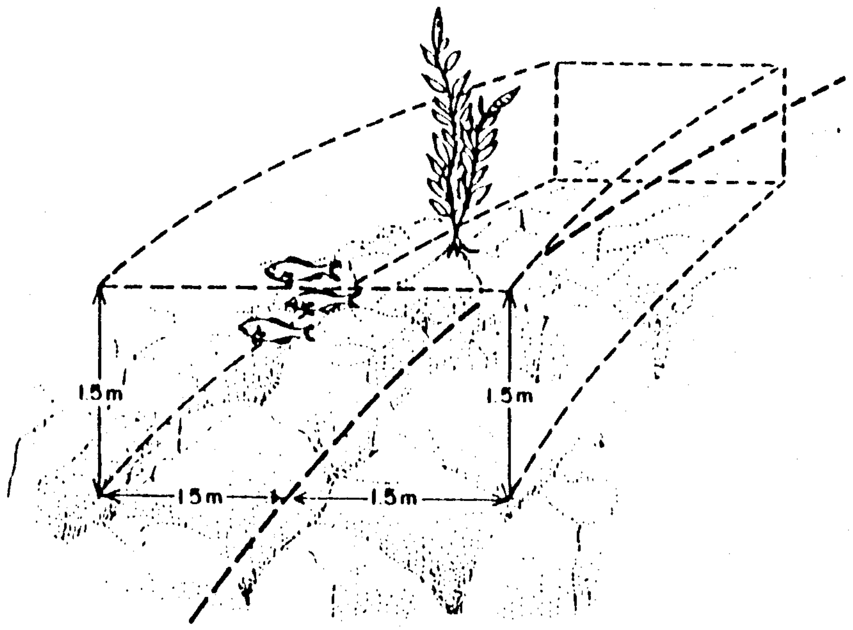

1.5m
1.5m
1.5m
1.5m

Figure 12: Densities of fish on crest and bottom/slope strata at Pendleton Artificial Reef, from 1981-1987. Data derived from LOSL (1981-83) and UCSB/Fish (1985-87) surveys. A. Total fishes and blacksmith. B. Total fishes minus blacksmith. On this and following figures, error bars are ± 1 S.E.

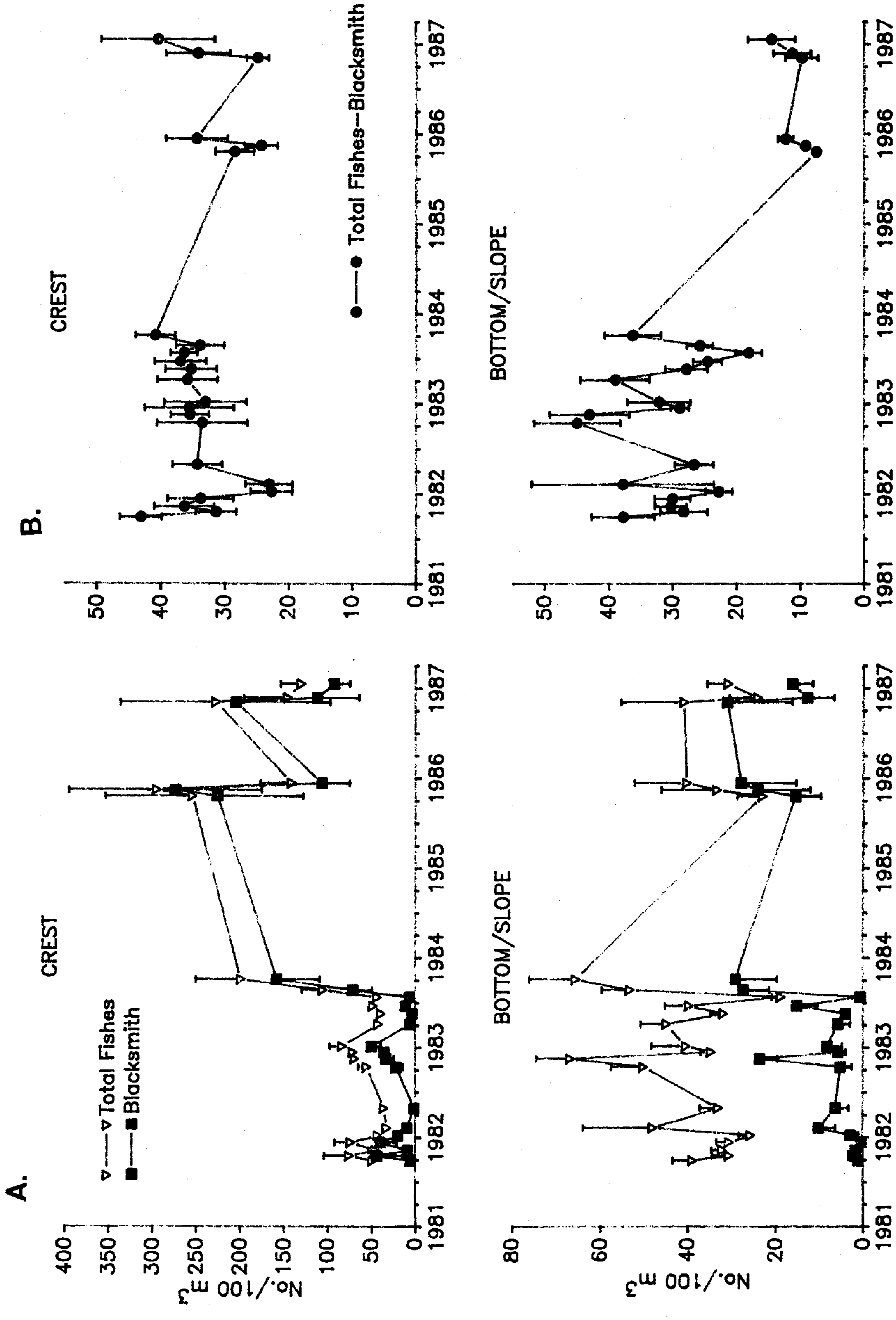

A.
▽——▽ Total Fishes
■——■ Blacksmith
CREST
BOTTOM/SLOPE
No./100 m³
400
350
300
250
200
150
100
50
0
80
60
40
20
0
1981
1982
1983
1984
1985
1986
1987
B.
●——● Total Fishes—Blacksmith
CREST
BOTTOM/SLOPE
50
40
30
20
10
0

Figure 13: Densities of black perch on crest and bottom/slope strata at Pendleton Artificial Reef, from 1981 - 1987. Data derived from LOSL (1981-83) and UCSB/Fish (1985-87) surveys.

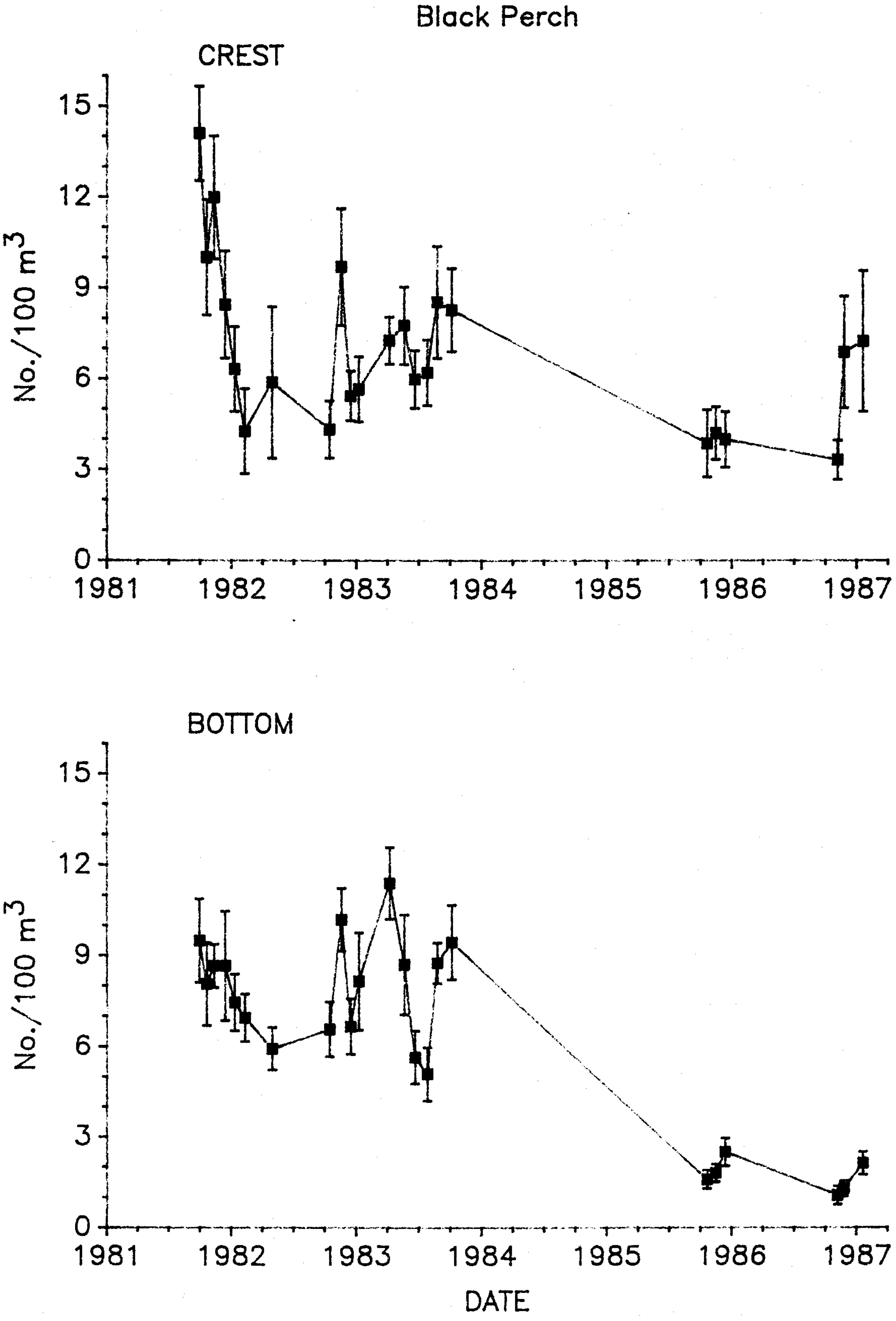

Black Perch
CREST
No./100 m^3
15
12
9
6
3
0
1981
1982
1983
1984
1985
1986
1987
BOTTOM
No./100 m^3
15
12
9
6
3
0
1981
1982
1983
1984
1985
1986
1987
DATE

Figure 14: Densities of halfmoon on crest and bottom/slope strata at Pendleton Artificial Reef, from 1981 - 1987. Data derived from LOSL (1981-83) and UCSB/Fish (1985-87) surveys.

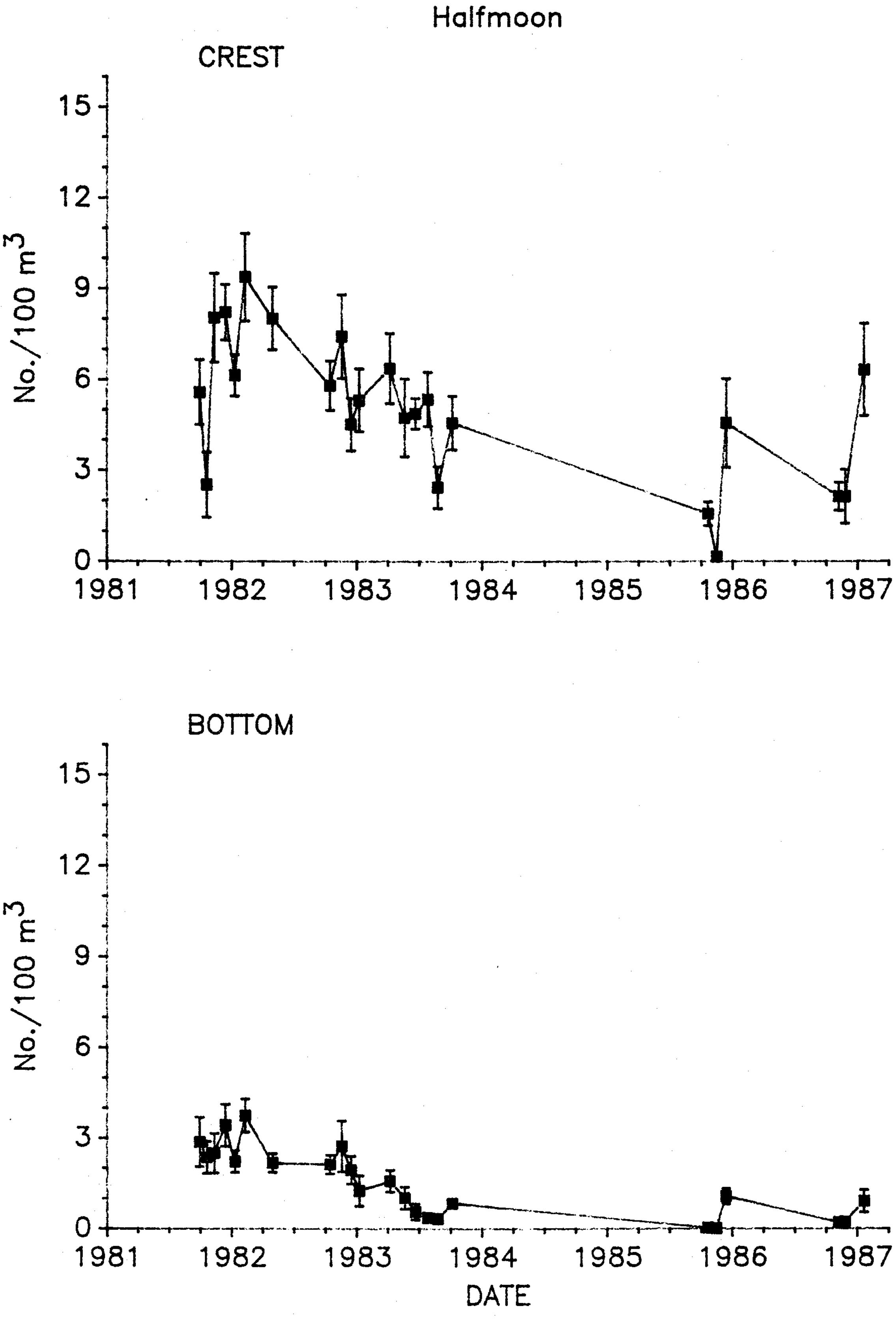
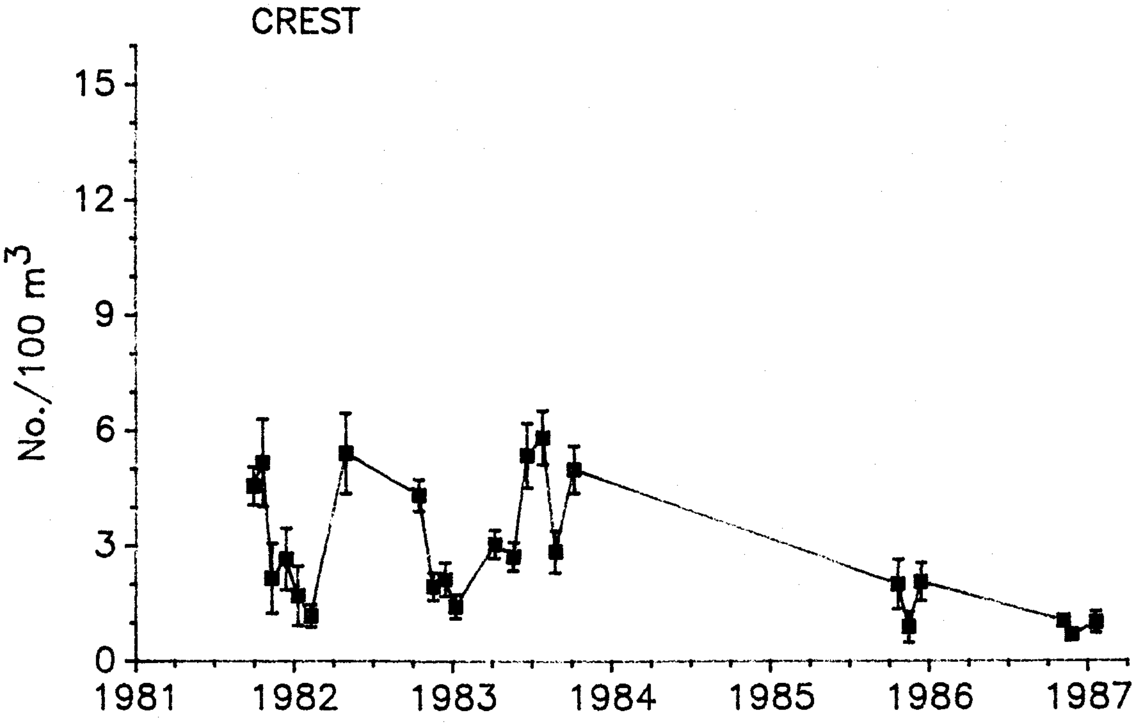

Halfmoon
CREST
No./100 m³
0
3
6
9
12
15
1981
1982
1983
1984
1985
1986
1987
BOTTOM
No./100 m³
0
3
6
9
12
15
1981
1982
1983
1984
1985
1986
1987
DATE

Figure 15: Densities of kelp bass on crest and bottom/slope strata at Pendleton Artificial Reef, from 1981 - 1987. Data derived from LOSL (1981-83) and UCSB/Fish (1985-87) surveys.

Kelp Bass


CREST
No./100 m^3
15
12
9
6
3
0
1981
1982
1983
1984
1985
1986
1987

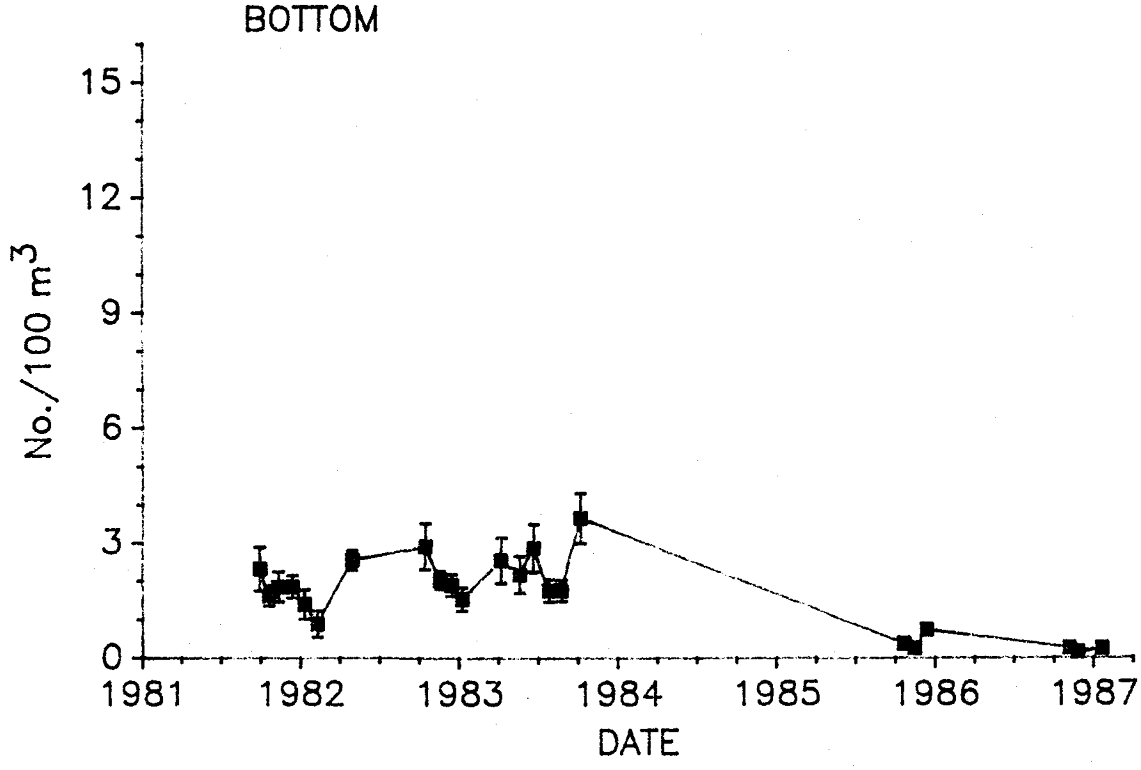

BOTTOM
No./100 m^3
15
12
9
6
3
0
1981
1982
1983
1984
1985
1986
1987
DATE

Figure 16: Densities of California sheephead on crest and bottom/slope strata at Pendleton Artificial Reef, from 1981 - 1987. Data derived from LOSL (1981-83) and UCSB/Fish (1985-87) surveys.

California Sheephead

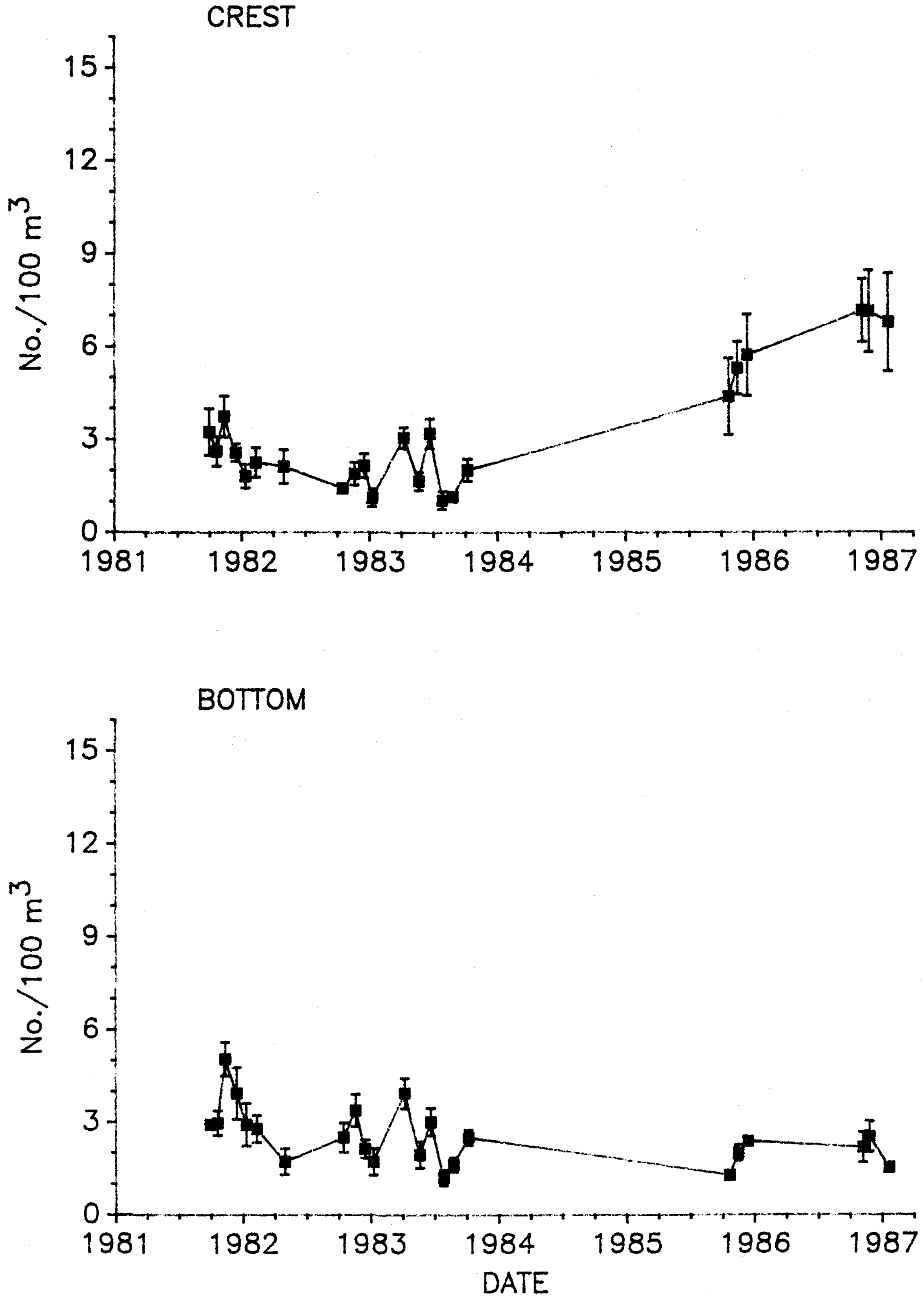


Figure 17: Densities of rock wrasse on crest and bottom/slope strata at Pendleton Artificial Reef, from 1981 - 1987. Data derived from LOSL (1981-83) and UCSB/Fish (1985-87) surveys.

Rock Wrasse

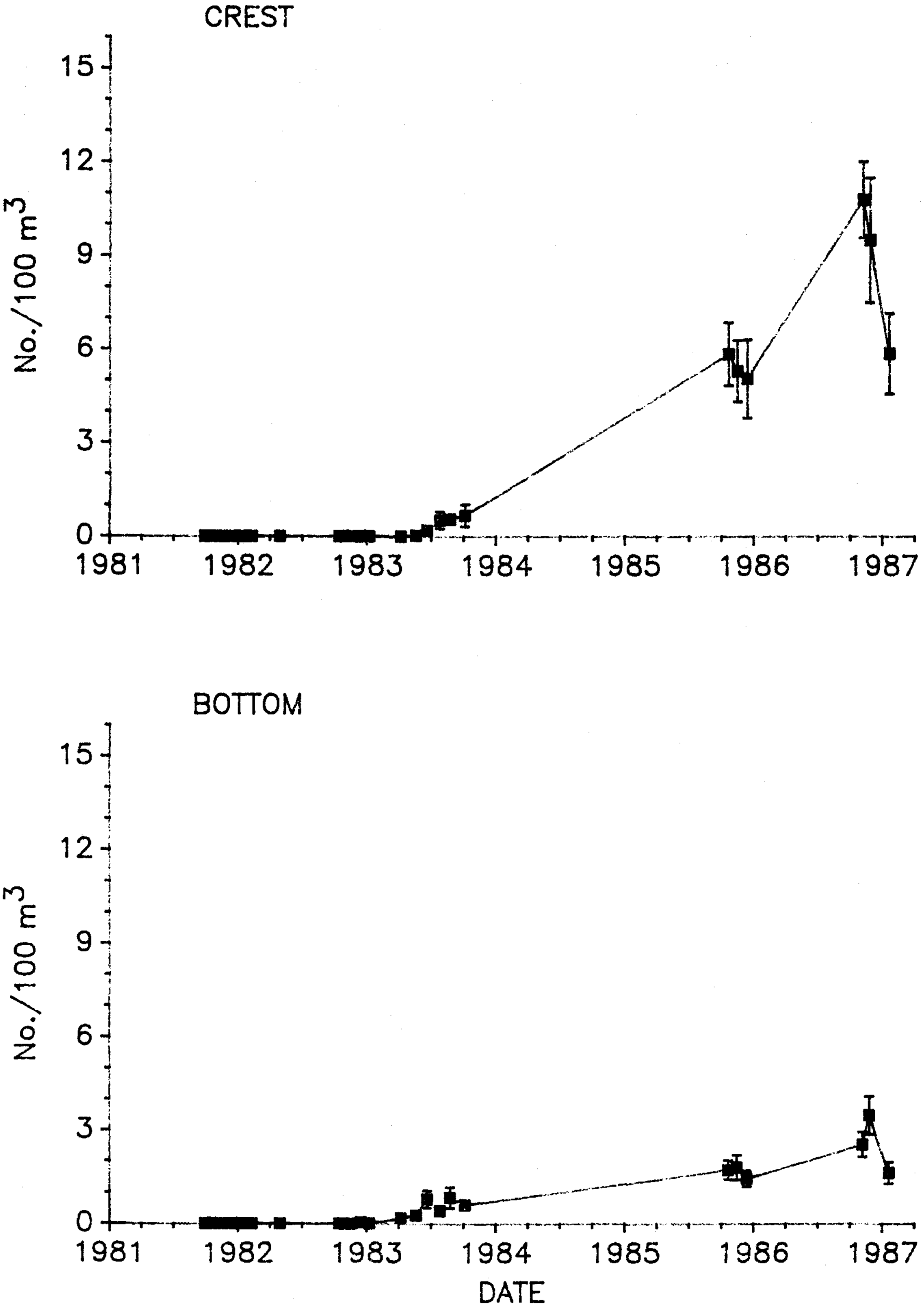
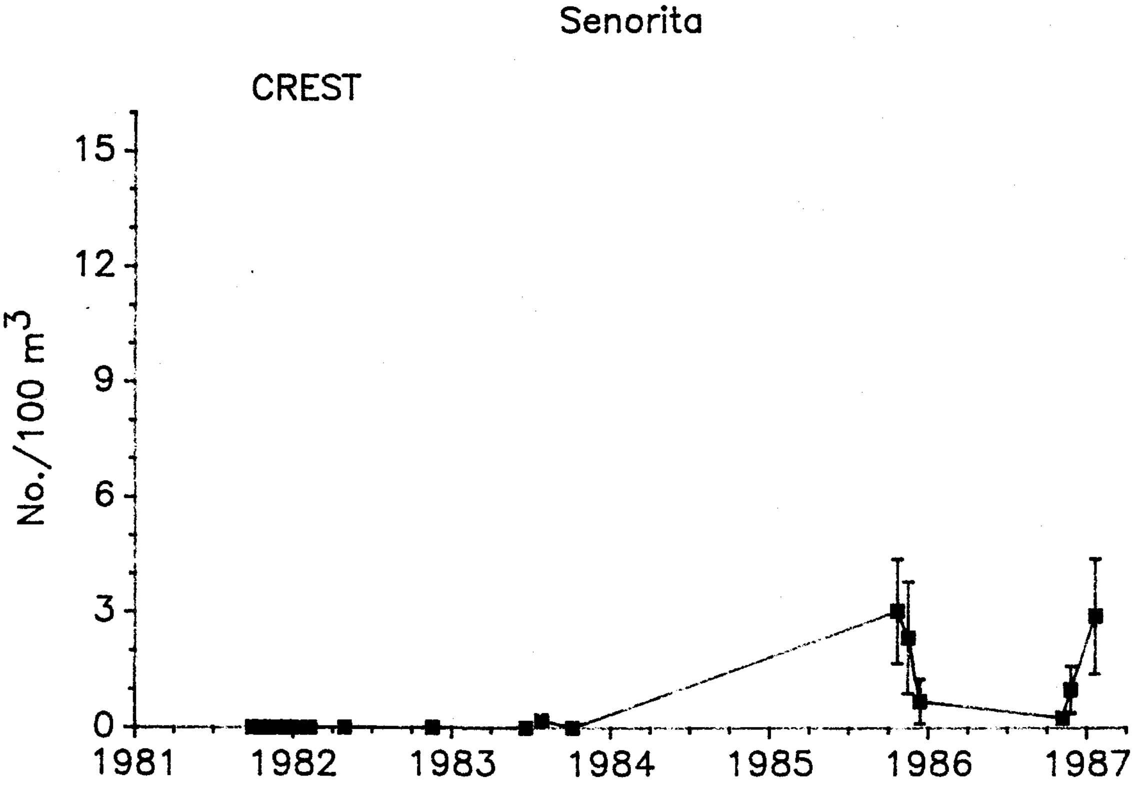

CREST
No./100 m³
0
3
6
9
12
15
1981
1982
1983
1984
1985
1986
1987
BOTTOM
No./100 m³
0
3
6
9
12
15
1981
1982
1983
1984
1985
1986
1987
DATE

Figure 18: Densities of senorita on crest and bottom/slope strata at Pendleton Artificial Reef, from 1981 - 1987. Data derived from LOSL (1981-83) and UCSB/Fish (1985-87) surveys.


Senorita
CREST
No./100 m³
15
12
9
6
3
0
1981
1982
1983
1984
1985
1986
1987

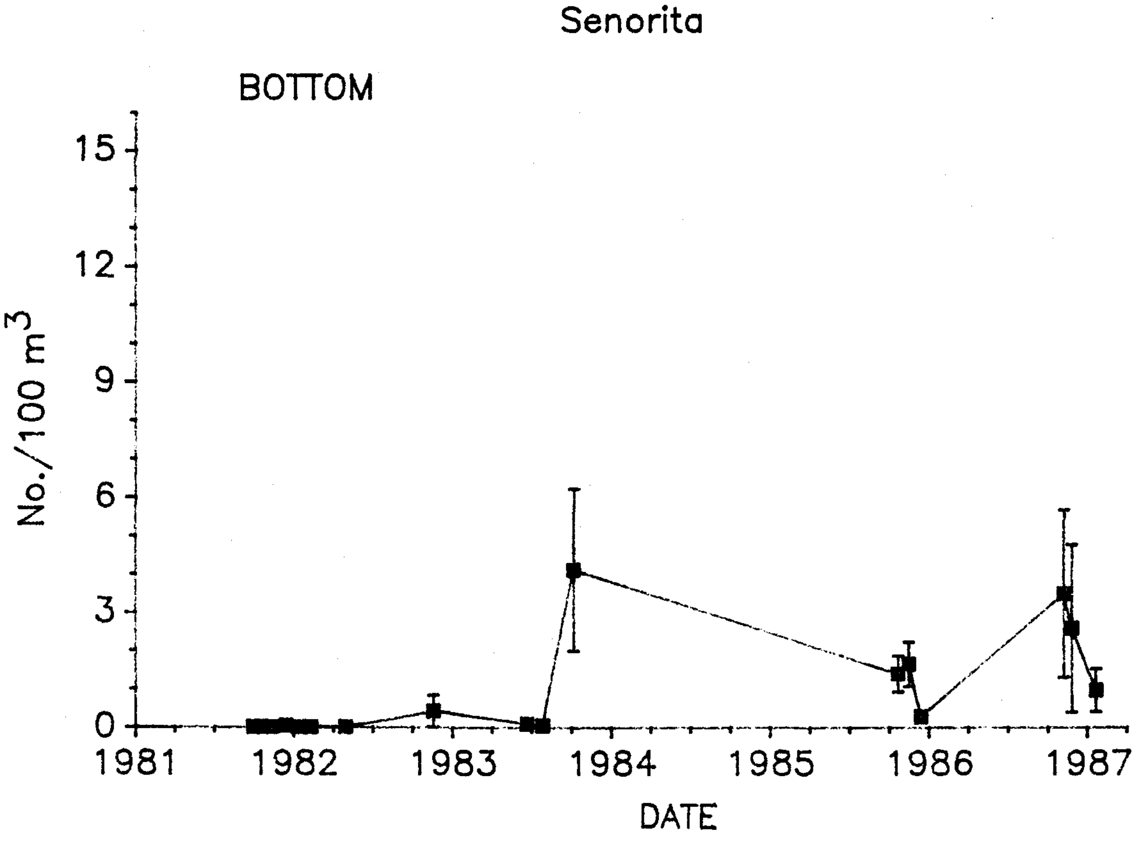

Senorita
BOTTOM
No./100 m³
15
12
9
6
3
0
1981
1982
1983
1984
1985
1986
1987
DATE

Figure 19: Densities of young-of-year (YOY) and older juvenile (OJ) blacksmith on crest and bottom strata at Pendleton Artificial Reef. Note that young blacksmith were about two orders of magnitude less dense on the bottom stratum than on the crest. Data derived from LOSL (1982-83) and UCSB/Fish (1984-87) surveys.

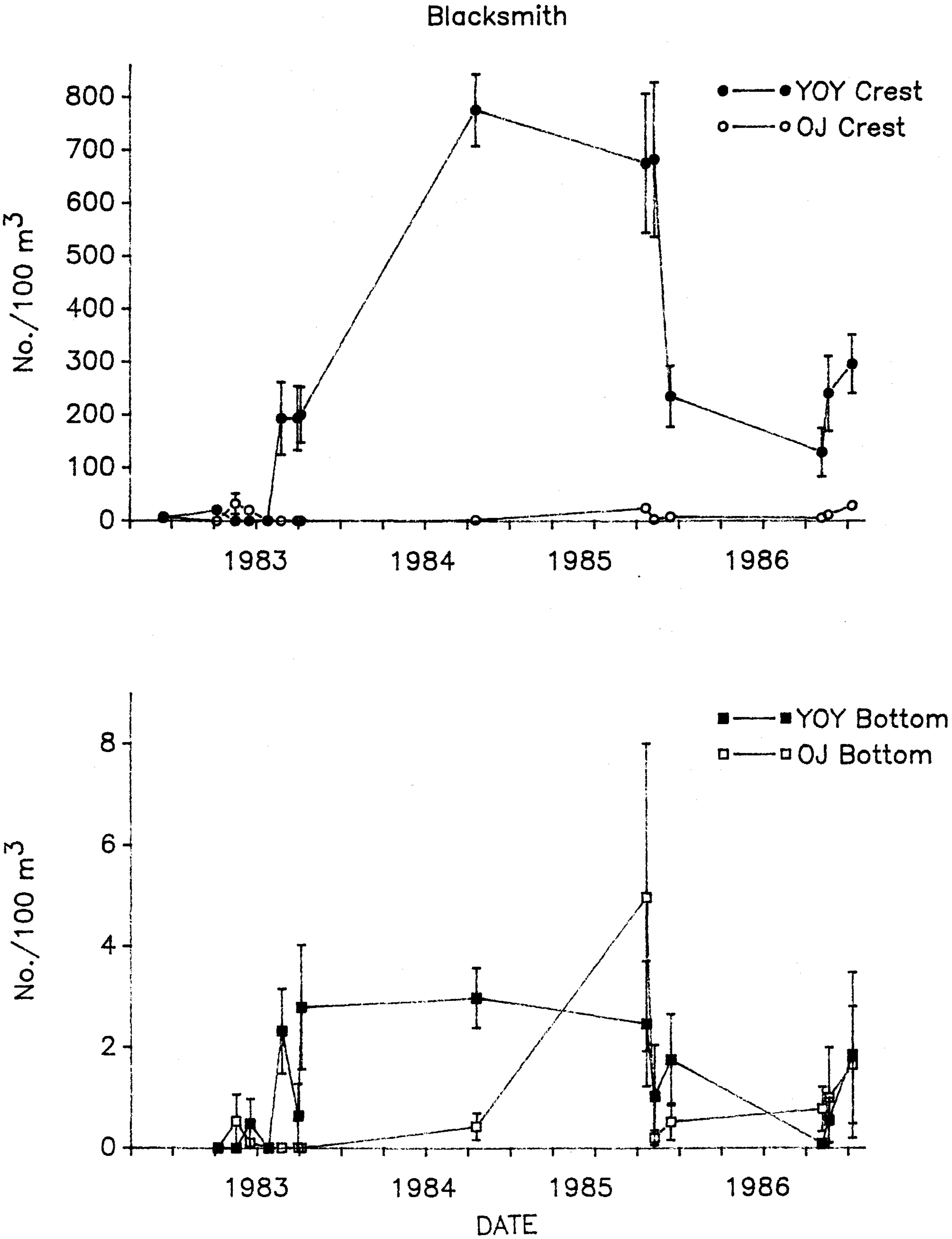
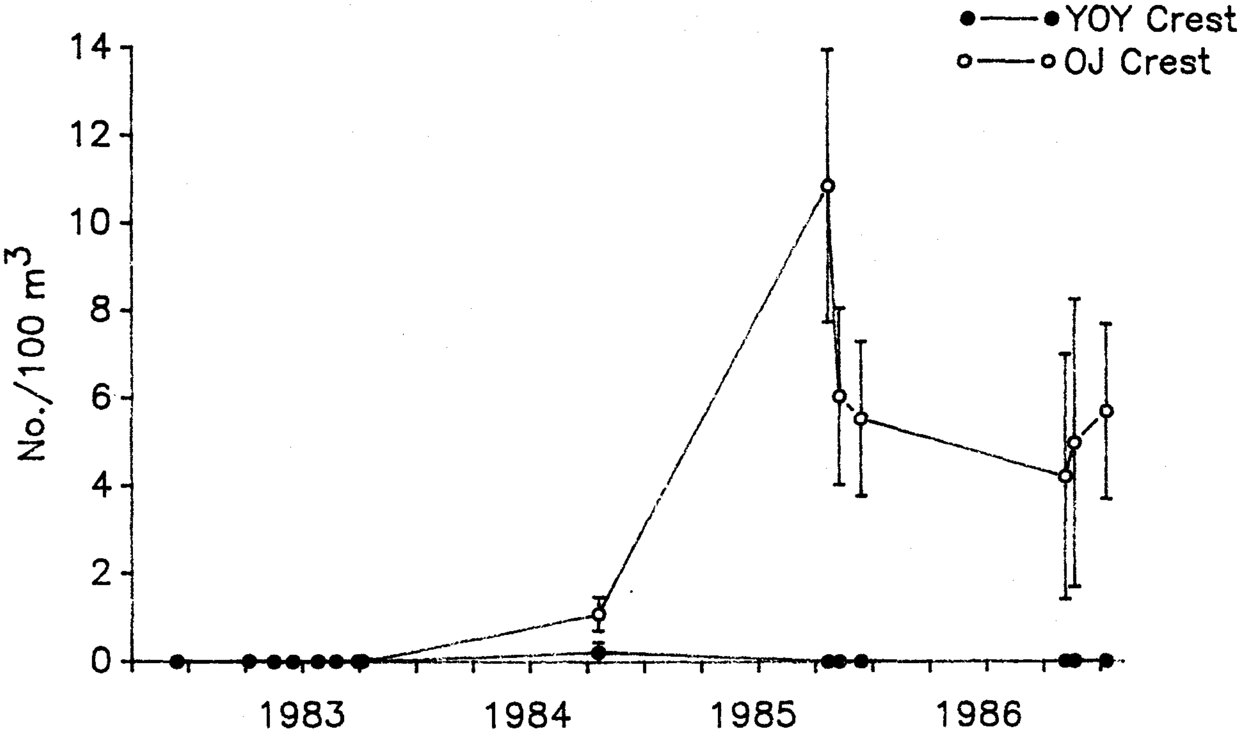

Blacksmith
YOY Crest
OJ Crest
No./100 m^3
800
700
600
500
400
300
200
100
0
1983
1984
1985
1986
YOY Bottom
OJ Bottom
No./100 m^3
8
6
4
2
0
1983
1984
1985
1986
DATE

Figure 20: Densities of young-of-year (YOY) and older juvenile (OJ) rock wrasse on crest and bottom strata at Pendleton Artificial Reef. Data derived form LOSL (1982-83) and UCSB/Fish (1984-87) surveys.

Rock Wrasse


●——● YOY Crest
○——○ OJ Crest
No./100 m3
0
2
4
6
8
10
12
14
1983
1984
1985
1986

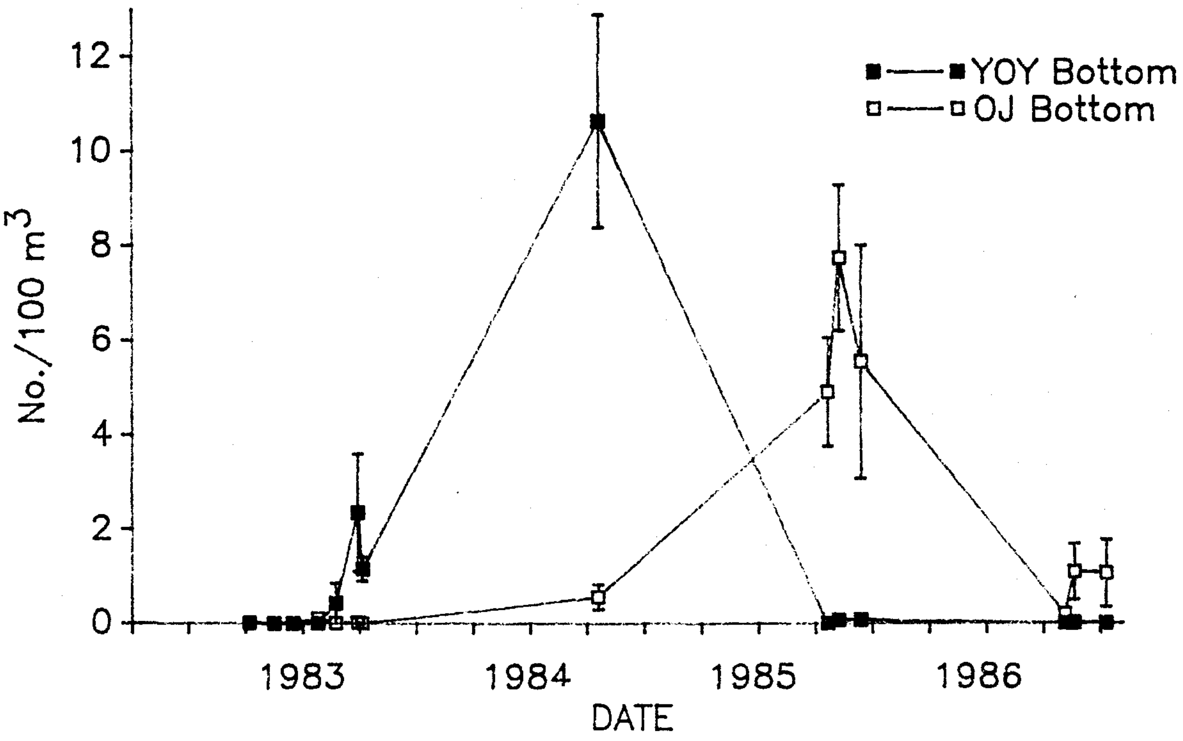
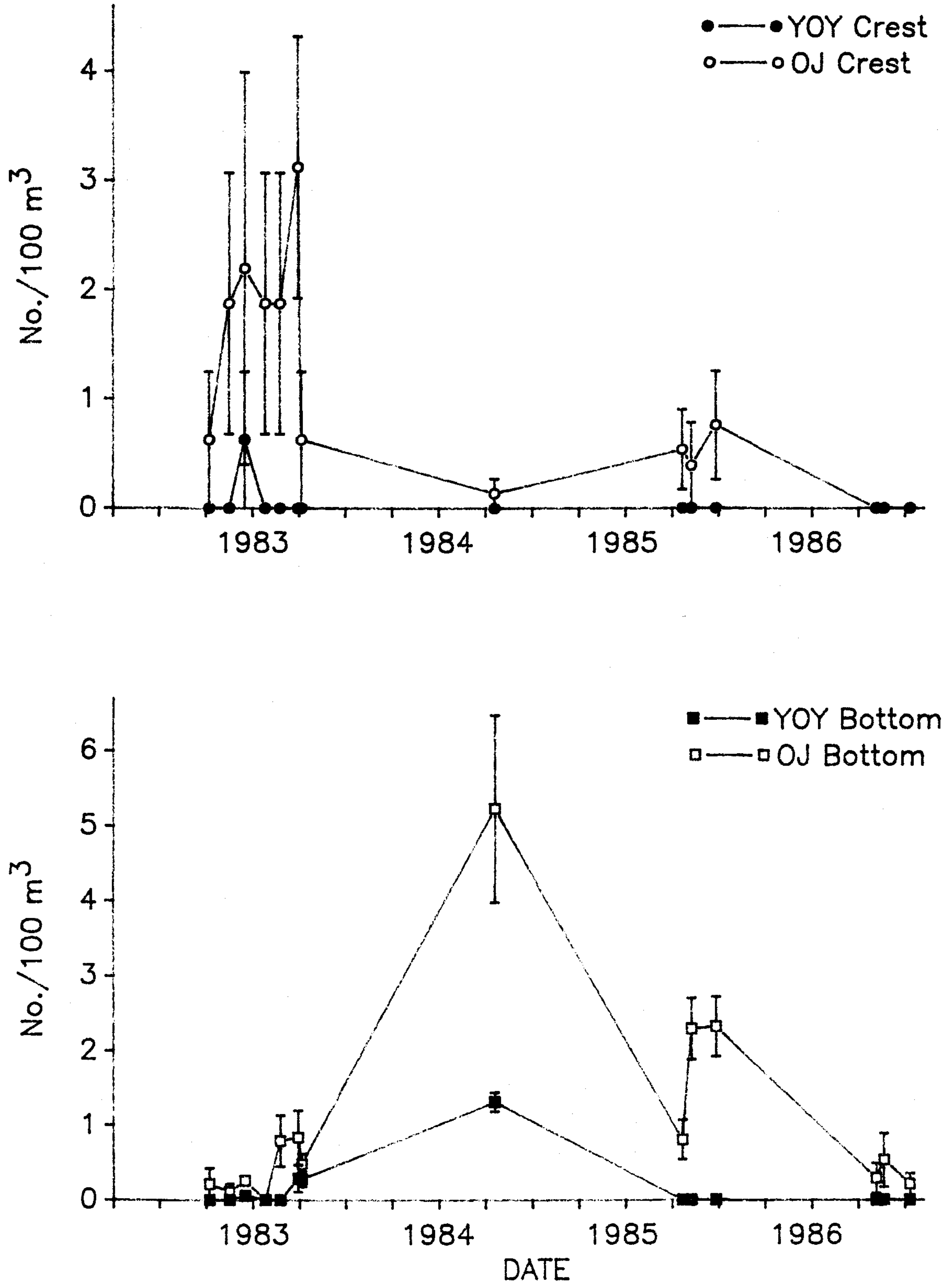

■——■ YOY Bottom
□——□ OJ Bottom
No./100 m3
0
2
4
6
8
10
12
1983
1984
1985
1986
DATE

Figure 21: Densities of young-of-year (YOY) and older juvenile (OJ) barred sand bass on crest and bottom strata at Pendleton Artificial Reef. Data derived form LOSL (1982-83) and UCSB/Fish (1984-87) surveys.



Barred Sand Bass

Figure 22: Densities of young-of-year (YOY) and older juvenile (OJ) senorita on crest and bottom strata at Pendleton Artificial Reef. Data derived from LOSL (1982-83) and UCSB/Fish (1984-87) surveys.

Senorita

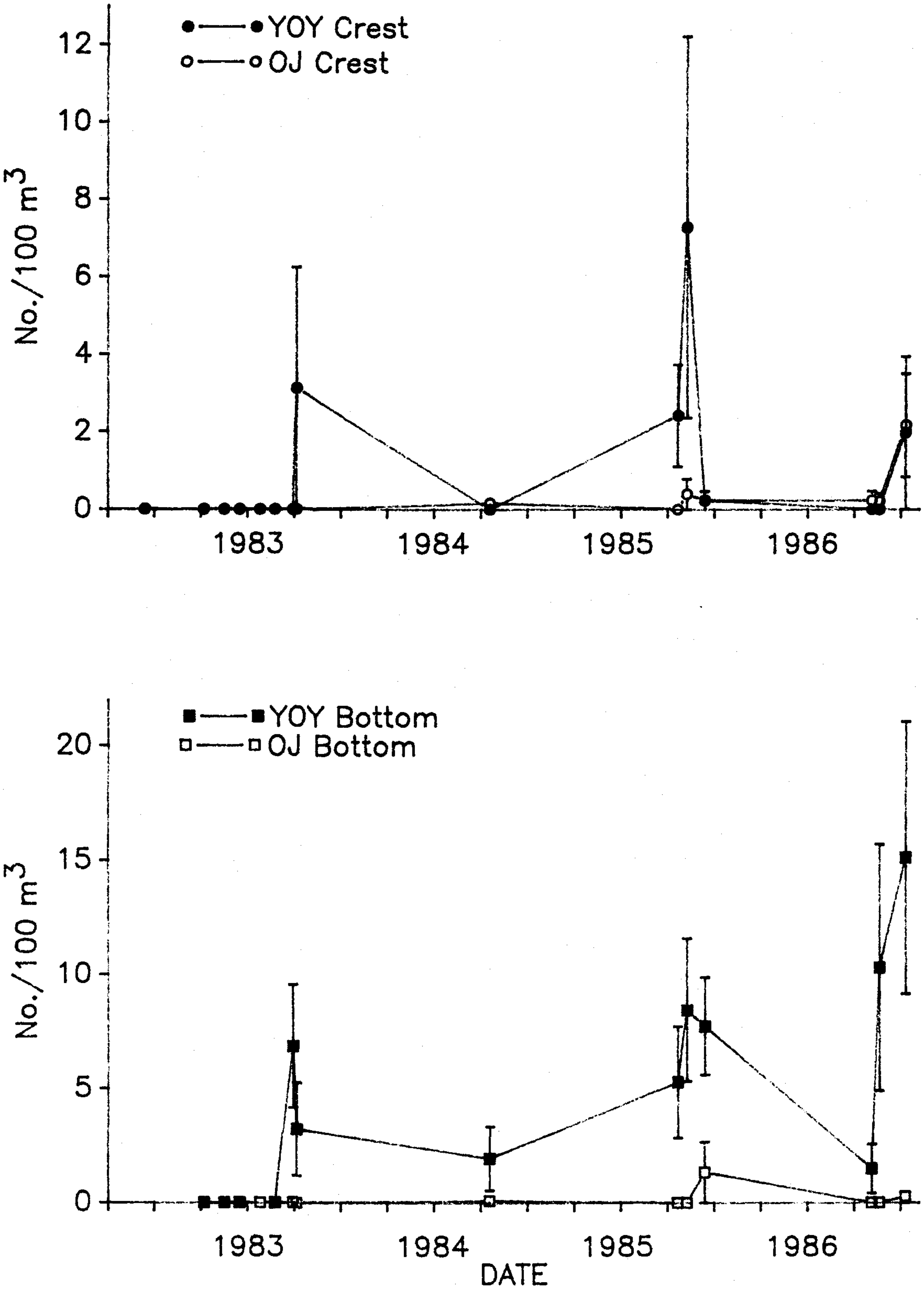
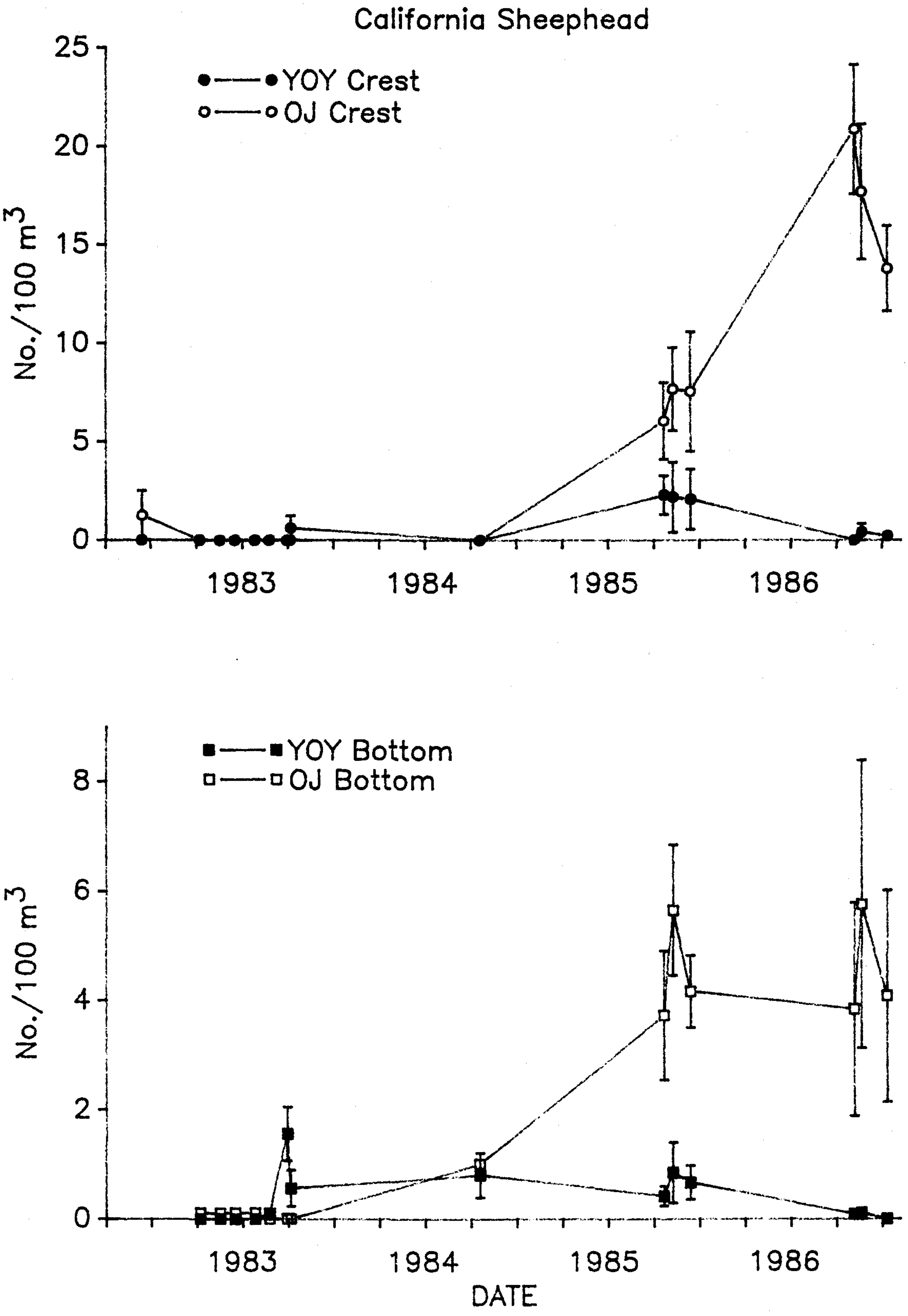

YOY Crest
OJ Crest
No./100 m³
0
2
4
6
8
10
12
1983
1984
1985
1986
YOY Bottom
OJ Bottom
No./100 m³
0
5
10
15
20
1983
1984
1985
1986
DATE

Figure 23: Densities of young-of-year (YOY) and older juvenile (OJ) California sheephead on crest and bottom strata at Pendleton Artificial Reef. Data derived from LOSL (1982-83) and UCSB/Fish (1984-87) surveys.


California Sheephead
YOY Crest
OJ Crest
No./100 m3
25
20
15
10
5
0
1983
1984
1985
1986
YOY Bottom
OJ Bottom
No./100 m3
8
6
4
2
0
1983
1984
1985
1986
DATE

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APPENDICES

APPENDIX A
PENDLETON ARTIFICIAL REEF INFAUNA ANALYSIS

A1. Introduction

Artificial reefs have increasingly been used in fisheries management 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, including additional reefs in California. 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 the 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.* (1982) did not detect a relationship between infaunal densities and distance from Torrey Pines Artificial Reef (near San Diego), although such a relationship was detected around an oil platform.

The impact of an artificial reef on the surrounding community is generally not considered to be a significant adverse effect because sand substrata are usually far more abundant than rocky reefs. However, 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) positioned on sand at a depth of 13 m (Fig. 1). It covers a total sand-rock area of approximately 3 ha and is located about 1.7 km offshore and 5.5 km south of the San Onofre Nuclear Generating Station. PAR has been the subject of numerous studies of the biota associated with the rocky substrate (Ambrose and Swarbrick 1989; Anderson *et al.* 1989, Carter *et al.* 1985a; Carter *et al.* 1985b; DeMartini *et al.* 1989; Grant *et al.* 1982; and Jessee *et al.* 1985), but this is the first study of the 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 because reef-based fish forage on the sand near the reef. In this appendix, 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*, which were abundant close to the PAR modules, with infauna found outside of the beds.

A2. 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, 400m offshore from PAR, is only 1m deeper than PAR), all of the transects were located at approximately the same depth. The prevailing swell is from offshore (Carter *et al.* 1985a), so the offshore transect is the most exposed and the onshore transect is in the lee of the module. Although there are frequent reversals in longshore currents, downcoast currents are both stronger and more persistent (Elwany *et al.* 1988).

Infauna were sampled by 0.0075 m^2 x 13 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 of the module complex, additional cores were collected from three areas between modules (Fig. 1). Cores were also collected within *Diopatra* beds at Modules 3, 5, and 6 to compare densities within versus outside of the beds. Five replicate cores, spaced approximately 1 m apart, were collected at each sampling location (along transects, between modules, and within *Diopatra* 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 lowest practical taxon (see Attachment 1) and counted using a dissecting microscope. Nematodes 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 (based on trophic-motility groupings devised by Marine Ecological Consultants 1987; see Attachment 1), and lowest taxon identified. The taxonomic groups, functional groups, and individual taxa analyzed are presented in Table A-1.

Sediment samples were taken at each station using 5 cm-diameter cores. After air drying, each sample was run through a shaker, with sieves ranging from -2ϕ to 4ϕ in $1\text{-}\phi$ increments, and each fraction weighed. Grain sizes are presented as ϕ sizes, with $\phi = -\log_2$(mean diameter in mm).

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 could not be used as independent replicates because they were so closely spaced; instead, the three cores were averaged to provide a single value for each station. In the ANOVA model used, transect is treated as a blocking variable and there is no interaction term. Densities of taxonomic groups, functional groups, and individual taxa 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 $\log_{10}(x+1)$; one 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 0.05.

A one-factor ANOVA was used to compare total individuals, taxonomic groups, functional groups, and the 15 most abundant species in samples taken within the module complex to those taken 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 of *Diopatra* beds were compared by t-test. All *Diopatra* 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 of 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.

A3. Results

Sediment characteristics

Overall, sediments were coarser close to the modules compared to farther away (Figure A-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 rank correlation, $r_s = -0.49$, $N = 20$, $P < 0.05$).

There were noticeable differences in grain size distributions among the four transects (Figure A-3). The upcoast and downcoast transects, which were similar to each other, consisted primarily of sediment sizes smaller than 3ϕ, with very little difference in size distribution among samples taken different distances from the module. In contrast, 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 smaller than 3ϕ.

The grain size distributions at the three stations between the modules were quite different from the transects and each other (Figure A-3). Two of the stations had relatively coarse sediments, with practically no grains smaller than 4ϕ. 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. The densities of all individuals ranged from 2400 to 7300 individuals/m^2. Polychaetes constituted the largest component of the fauna, accounting for 57% of the total abundance from transect samples (Table A-2). The spionid polychaetes *Prionospio pygmaeus* and *Spiophanes* spp. were the most abundant species, each accounting for about 10% of the total. 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% 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 presented in Attachment 1.

Distance effects were detected in some of the common taxa (Table A-3). *Spiophanes* spp., the second most abundant taxon, exhibited a general decrease in density with distance from the reef (Fig. A-4); densities at 1 m were significantly greater than those at 10 m, although they were not distinguishable from those at 20 m (Table A-3). *Spiophanes* densities tended to be highest on the onshore transect. *Prionospio pygmaeus* densities showed the opposite pattern, increasing in density with distance from the reef (Fig. A-4); densities at 1 m were significantly lower than those at 10 m or 20 m (Table A-3). Nemerteans were also significantly lower at 1 m than 10 m (but not different from 20 m). The other groups with significant distance effects, *Aricidea* spp, isopods and cumaceans, did not exhibit a consistent pattern, and densities at 1 m were not distinguishable for densities at the other distances (Table A-3).

The densities of total individuals and the five most common species are presented in Fig. A-4. As discussed above, significant effects were only detected in two species, *Spiophanes* spp. and *Prionospio pygmaeus*. Nonetheless, the patterns of two species are worth noting. First, the gammarid amphipod *Megaluropus longimerus* had highest densities at the 1- and 2-m distances on the offshore transect (Fig. A-4). Second, another gammarid amphipod, *Tiron biocellata*, had a much higher density at one station, 20 m on the onshore transect, than at any other station; the very high variance at that station suggests that by chance a single core sampled a patch with a very high density of *Tiron*.

No differences were detected in the densities between modules versus distances along transects outside of modules for either total individuals or functional groups (Table A-4). The between-module densities of most individual taxa were also not significantly different from the densities outside of the modules. The between-module densities were nominally the lowest in 4 of the 8 cases in which a significant difference was detected (Table A-4), but these densities were not significantly different from 2 to 4 of the transect stations. Only one taxon, the gammarid amphipod *Rhepoxinius abroniensis*, showed a consistent pattern, with the between-module density not significantly different from densities at the stations closest to the module but significantly different from stations farther away from the modules. The density of *Megaluropus longimerus* was relatively high between the modules (Mean=12.4 individuals/0.0075 m^2), but this density was not statistically distinguishable from the densities at 1, 2 and 20 m away from the modules. With the exception of *Megaluropus*, and perhaps cumaceans, significant differences involved low densities of taxa between the modules. The total infaunal density was 4830 ind/m^2 between the modules and 4298 ind/m^2 along the transects.

Beds of the tube-building polychaete *Diopatra ornata* were found around seven of the eight modules at PAR (Fig. A-1). *Diopatra* was only found within a few meters of the modules; an extensive search of the area around PAR failed to detect any *Diopatra* beds away from the modules. Total infaunal density was significantly higher in *Diopatra* beds (13240 ind/m^2) than at an equivalent distance away from the modules outside of the beds (4947 ind/m^2) (Table A-5). Densities of three taxonomic and five functional groups were also significantly different within *Diopatra* beds compared to outside of the beds (Table A-5). The densities of all but one of these groups were greater within the *Diopatra* beds. Densities of the most abundant taxon and functional group in *Diopatra* beds, decapods and the motile surface carnivore-omnivore group, were about an order of magnitude higher within *Diopatra* beds than outside. These density differences were mostly due to two species, hermit crabs (*Pagurus* spp.) and the polychaete *Gyptis brevipalpa* (see Attachment 1). In addition, twice as many decapod species were found within *Diopatra* beds (12) as outside of the beds (6), in spite of the greater sampling effort outside of the beds.

A4. Discussion

Artificial reefs affect infaunal densities in two ways. First, the reefs can 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 can 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.* (1982) noted a decline in large epifaunal species such as sea pens, 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. *Prionospio pygmaeus* occurs near the surface of the sediment, so its densities might have been reduced due to higher predation pressure close to the reef; on the other hand, *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. *Tiron biocellata* also tended to be less common near the reef, but this trend was probably not caused by predation because it only occurred along one transect. Davis *et al.* (1982) also failed to detect decreases in infaunal densities near two artificial reefs off La Jolla, California, although their sampling began 4 m from the reefs and so could not have detected effects that were restricted to a few meters away from the reefs. It is not clear why the large fish populations on artificial reefs do not have a greater influence on 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-based 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 the nearby sediments. The 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). CDFG's observations suggest that the overlaying 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; Wilson *et al.* 1981; K. Wilson, *personal communication*). Furthermore, the on- and offshore transects appeared to have coarser sediments than the up- and downcoast transects, which may reflect differing exposures, since the on- and offshore transects would be expected to be most influenced by swells.

PAR's influence on sediments close to the reef would be expected to have consequences for the surrounding infaunal community. Densities of the two most common species were related to distance from the module. *Prionospio pygmaeus* was less abundant near the modules than away, while *Spiophanes* spp. was more abundant near the modules. In addition, *Megaluropus* appeared to be most common at the near sampling stations on the offshore transect, but not on the other transects (suggesting an interaction between transect and distance, which could not be detected by our analysis), and nemerteans were less common at the 1 m station. Thus, the modules appear to have altered the environment to provide a more suitable habitat for *Spiophanes* and *Megaluropus* and a less suitable habitat for *Prionospio pygmaeus* and nemerteans. As already noted, *P. pygmaeus* is commonly found in silty mud, so the coarser sediments near the modules would be expected to be a less-suitable habitat for this species, but it is also possible that the lower densities of some taxa near the reef was due to predation by reef-associated fishes.

The 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 we sampled the infauna within the module complex without regard to proximity to modules or degree of exposure, it is not surprising that the grain size characteristics of the three samples varied considerably. Given these sediment differences and the close relationship between infauna and sediments (Gray 1974), however, 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. Our failure to detect many differences within the modules may simply result 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 (preferably in a stratified design) need to be taken in order to elucidate the pattern.

The most conspicuous influence of Pendleton Artificial Reef on the surrounding sand community was the close association of dense beds of *Diopatra ornata* to the modules. *Diopatra* is frequently associated with hard substrates (Turner *et al.* 1969; Emerson 1975; Davis *et al.* 1982). Before PAR was built, *Diopatra* occurred in very low density (Wilson *et al.* 1981). After construction, *Diopatra* density increased dramatically (CDFG, *personal communication*), and within a few years after construction *Diopatra* was common adjacent to modules (Wilson *et al.* 1984).

Infaunal densities at PAR were higher within *Diopatra* beds than outside of them. This pattern has been reported in several studies of *Diopatra cuprea* (Woodin 1978, 1981; Ban and Nelson 1987; Luckenbach 1986) and in other tube-building polychaetes (Fager 1964; Wilson 1979; Brenchley 1982). The higher densities of infauna within patches of *Diopatra* 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 (1982) suggests that less-motile species, such as our discrete functional groups, would be less affected by the tubes, and only one of the six discrete groups we analyzed had different densities within and outside of *Diopatra* beds. The other three functional groups with significantly higher densities in *Diopatra* beds all occur at the surface of the sediment; the *Diopatra* tubes might have protected these species from predation (Woodin 1978, 1981). The motile surface carnivore-omnivore group, which achieved the highest densities inside of *Diopatra* beds at PAR, may have benefited from the associated algae and debris provided by *Diopatra ornata* tubes, and perhaps a greater number of associated prey.

In summary, PAR appears to have influenced the infaunal community around the reef. In contrast to the pattern reported by Davis *et al.* (1982), we detected significant differences in infaunal densities with distance from the reef. The influence of PAR was most conspicuous in the distribution of *Diopatra* close to the modules and the much higher densities of infauna in *Diopatra* beds, but several other taxa also appeared to be affected by the reef. These effects probably reflect the impact of the artificial reef on the physical characteristics of the environment around the reef. However, the effects of Pendleton Artificial Reef are limited in two respects. First, although significant effects were detected in the two most common species, 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 effects were only detected close to the modules.

Pendleton Artificial Reef has obviously had a detrimental effect on the infauna immediately underneath its rocks. Its influence on the surrounding infauna is mixed. The densities of some species were higher near the reef, which could be viewed as a positive effect since higher infauna densities could mean more food available for fish. However, the reef's effect could also be viewed as detrimental; in addition to causing reduced densities of some species near the reef, it has altered the natural structure of the infaunal community. In any case, the overall effect of PAR on the surrounding infaunal community was small because it was limited to areas near the reef.

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A6. TABLES

Table A-1

Taxonomic groups, functional groups, and individual taxa analyzed. Taxa were identified to the lowest practical level, with the 15 most abundant taxa analyzed separately. Functional groups correspond to trophic-motility categories devised by Marine Ecological Consultants (1987); discrete indicates foraging in restricted area, suspension feeder filters food from water column, and deposit feeder ingest sediment and/or detritus.

Taxonomic Groups

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

Individual Taxa

Amphicteis glabra
Aricidea sp.
Ophiuroids
Chetozone setosa
Euphilomedes carcharodonta
Magelona sacculata
Mediomastus spp.
Megaluropus longimerus
Nephytys caecoides
Nothria elegans
Prionospio pinnata
Prionospio pygmaeus
Rhepoxinius abronius
Spiophanes spp.
Tiron biocellata

Functional Groups

Motile subsurface deposit feeder
Sessile subsurface deposit feeder
Motile subsurface carnivore-deposit
Motile surface deposit-detrital
Discrete surface deposit-detrital
Sessile surface deposit-detrital
Motile surface omnivore-deposit
Discrete surface omnivore-deposit
Motile surface suspension-deposit
Discrete surface suspension-deposit
Sessile surface suspension-deposit
Discrete suspension feeder
Sessile suspension feeder
Motile surface carnivore-omnivore
Discrete surface carnivore-omnivore
Discrete multi-feeding strategy

Table A-2

Abundance of major infaunal taxa near Pendleton Artificial Reef. Total abundance is based on the sum of 60 cores (0.0075 m^2 x 13 cm deep for each core, for a total area sampled of 0.45 m^2) collected on transects. Species with > 90 individuals sampled are also listed.

TAXON	TOTAL ABUNDANCE NUMBER	 PERCENT
Cnidaria	16	0.8%
Nermertinea	40	2.1%
Mollusca	20	1.0%
Annelida		
Polychaeta		
Mediomastus spp.	130	6.7%
Prionospio pygmaeus	205	10.6%
Spiophanes spp.	202	10.4%
Others	575	29.7%
Sipuncula	6	0.3%
Arthropoda		
Pycnogonida	3	0.2%
Crustacea		
Isopoda	33	1.7%
Amphipoda		
Gammaridea		
Megaluropus longimerus	98	5.1%
Tiron biocellata	134	6.9%
Others	264	13.7%
Decapoda	8	0.4%
Cumacea	81	4.2%
Ostracoda	61	3.2%
Copepoda	5	0.3%
Brachiopoda	3	0.2%
Echinodermata	50	2.6%
TOTAL INDIVIDUALS	1934	

Table A-3

Differences in infaunal densities at various distances away from Pendleton Artificial Reef. Total individuals, major taxonomic groups, functional groups, and the 15 most abundant species were tested; only significant results are presented. Data are presented as Mean (SE) number/0.0075 m^2, with locations 1, 2, 5, 10, and 20 referring to distances along the transects. Means that are not significantly different (by Tukey multiple comparison test) are underlined. Tests for Total Individuals and all functional groups were not significant.

	Mean (SE)					Significant Differences
	1m	2m	5m	10m	20m	
Polychaetes						
Aricidea sp.	0.6	0.6	1.3	1.1	0.3	5 10 1 2 20
	(0.16)	(0.16)	(0.28)	(0.28)	(0.24)	
Prionospio pygmaeus	1.3	1.9	4.0	5.3	4.5	10 20 5 2 1
	(1.12)	(0.64)	(1.55)	(0.83)	(0.40)	
Spiophanes spp.	7.2	3.3	3.7	1.1	1.6	1 5 2 20 10
	(3.27)	(1.68)	(1.19)	(0.32)	(0.34)	
Isopods	0.8	0.2	1.2	0.5	0.2	5 1 10 2 20
	(0.16)	(0.10)	(0.17)	(0.16)	(0.10)	
Cumaceans	1.2	0.7	1.0	1.2	2.8	20 1 10 5 2
	(0.32)	(0.41)	(0.34)	(0.34)	(0.17)	
Nemerteans	0.2	0.8	0.4	1.0	0.8	10 20 2 5 1
	(0.25)	(0.40)	(0.16)	(0.19)	(0.10)	

Table A-4

Differences in infaunal densities between the modules at PAR versus various distances along the transects away from PAR. One-factor ANOVA was conducted for total individuals, major taxonomic groups, functional groups, and the 15 most abundant species; only significant results are presented. Data are presented as Mean (SE) number/0.0075 m^2, with locations 1, 2, 5, 10, and 20 referring to distances along the transects and Btwn = between modules. Means that are not significantly different (by Tukey multiple comparison test) are underlined. Test for Total Individuals was not significant.

	Mean (SE)						
	1m	2m	5m	10m	20m	Between Modules	Significant Differences
Polychaetes							
Aricidea sp.	0.6 (0.16)	0.6 (0.16)	1.3 (0.28)	1.1 (0.28)	0.3 (0.24)	0.1 (0.11)	5 10 1 2 20 Btwn
Nothria elegans	0.5 (0.29)	0.2 (0.10)	0.6 (0.28)	0.6 (0.08)	0.9 (0.25)	0.0 (0.0)	20 10 5 1 2 Btwn
Prionospio pygmaeus	1.3 (1.12)	1.9 (0.64)	4.0 (1.55)	5.3 (0.83)	4.5 (0.40)	1.3 (1.33)	No separation of means
Nephytys caecoides	0.8 (0.22)	0.2 (0.10)	0.2 (0.16)	0.8 (0.22)	0.7 (0.30)	1.1 (0.11)	No separation of means
Gammarid Amphipods							
Megaluropus longimerus	4.9 (4.81)	1.7 (1.24)	0.6 (0.58)	0.3 (0.25)	0.8 (0.31)	12.4 (5.40)	Btwn 1 2 20 5 10
Rhepoxinius abroniensis	0.6 (0.34)	1.2 (0.68)	1.8 (0.87)	1.7 (0.36)	1.5 (0.22)	0.0 (0.0)	5 10 20 2 1 Btwn
Isopods	0.8 (0.16)	0.2 (0.10)	1.2 (0.17)	0.5 (0.16)	0.2 (0.10)	0.2 (0.11)	5 1 10 Btwn 2 20
Cumaceans	1.2 (0.32)	0.7 (0.41)	1.0 (0.34)	1.2 (0.34)	2.8 (0.17)	1.6 (0.29)	20 Btwn 1 10 5 2
Echinoderms							
Ophiuroids	1.3 (0.59)	0.6 (0.16)	0.7 (0.24)	0.7 (0.24)	0.6 (0.16)	0.0 (0.0)	1 10 5 20 2 Btwn
Discrete Surface Carnivore-Omnivore	2.5 (0.82)	1.8 (0.83)	2.5 (0.73)	2.2 (0.21)	2.8 (0.32)	0.6 (0.29)	20 5 1 10 2 Btwn
Discrete Multi-feeding Strategy	1.3 (0.59)	0.4 (0.16)	0.7 (0.24)	0.7 (0.24)	0.6 (0.16)	0.0 (0.0)	1 5 10 20 2 Btwn

Table A-5

Differences in infaunal density (no./core) within and outside of Diopatra ornata patches. Total individuals, major taxonomic groups and functional groups were tested; only significant effects (P<0.05) are presented.

GROUP	WITHIN DIOPATRA BEDS		OUTSIDE	
	MEAN	(SE)	MEAN	(SE)
	N = 3		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				
Sessile surface detrital-deposit feeder	6.9	(1.82)	0.8	(0.25)
Discrete multi-feeding strategy	4.7	(1.02)	1.3	(0.59)
Motile surface detrital-deposit feeder	2.0	(0.67)	10.3	(4.19)
Motile surface suspension-deposit feeder	1.8	(1.28)	0.1	(0.08)
Motile surface carnivore-omnivore	31.7	(0.51)	3.2	(0.94)

A7. FIGURES

Figure A-1: Location of transect and between-module core samples at Pendleton Artificial Reef. Three replicate samples were collected at each of five distances along transects and at the positions of between-module samples, denoted by an "x". The locations of Diopatra ornata beds are indicated by stippled areas; Diopatra beds were sampled at Modules 3, 5, and 6.

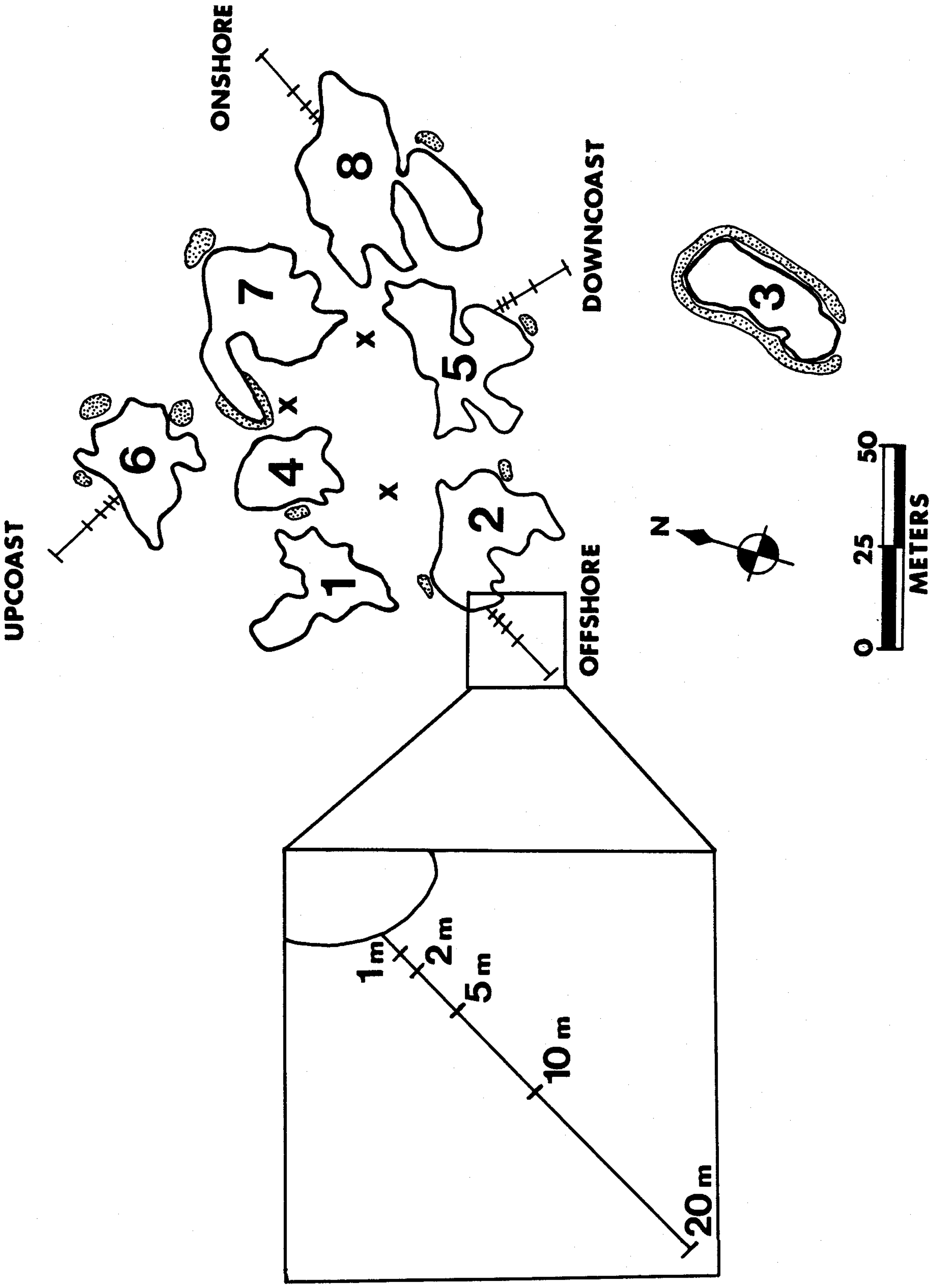

UPCOAST
ONSHORE
DOWNCOAST
OFFSHORE
1
2
3
4
5
6
7
8
x
x
x
x
N
0
25
50
METERS
1m
2m
5m
10m
20m

Figure A-2: Proportions of sediments coarser than 1ϕ at increasing distances from modules at Pendleton Artificial Reef. Data presented are Means (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 diameter, and is coarse sand on the Udden-Wentworth scale.

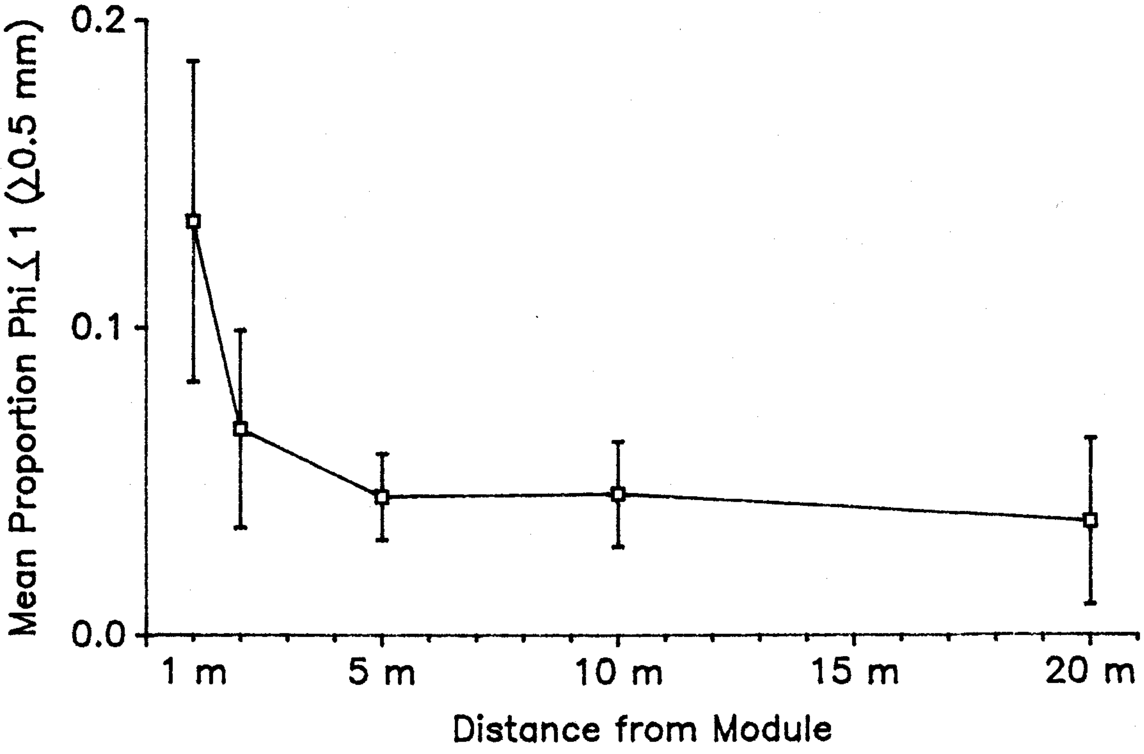
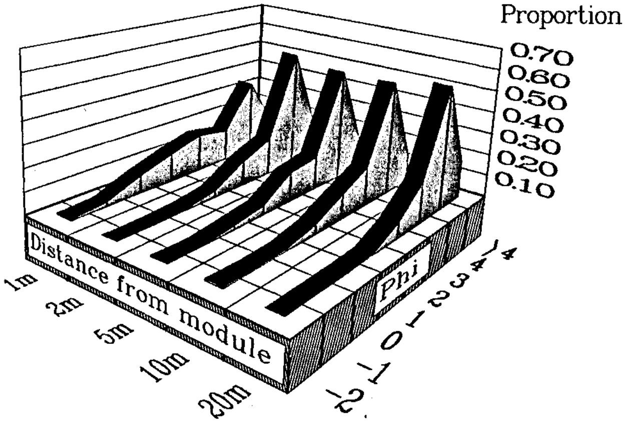
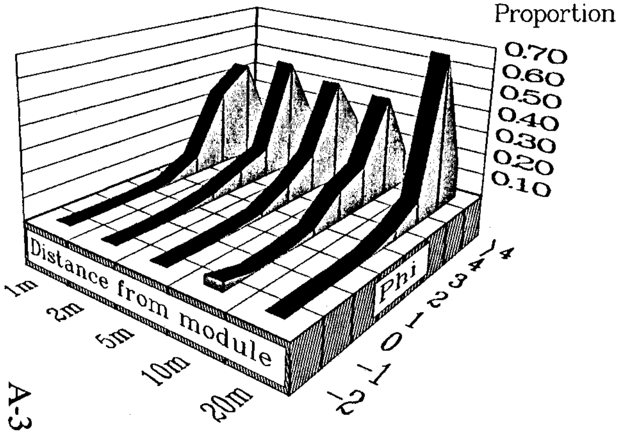

Mean Proportion Phi ≤ 1 (≥0.5 mm)
0.2
0.1
0.0
1 m
5 m
10 m
15 m
20 m
Distance from Module

Figure A-3: Grain size distributions along the four transects away from Pendleton Artificial Reef and three stations between the modules. Grain sizes are presented as Phi (ϕ), with $\phi = -\log_2$(mean diameter in mm), so large Phi values indicate small grain sizes.

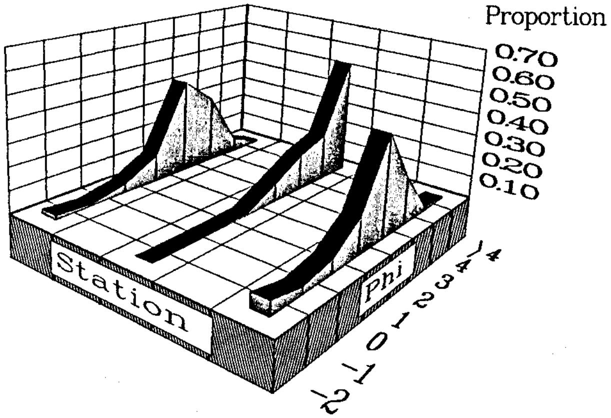
Onshore



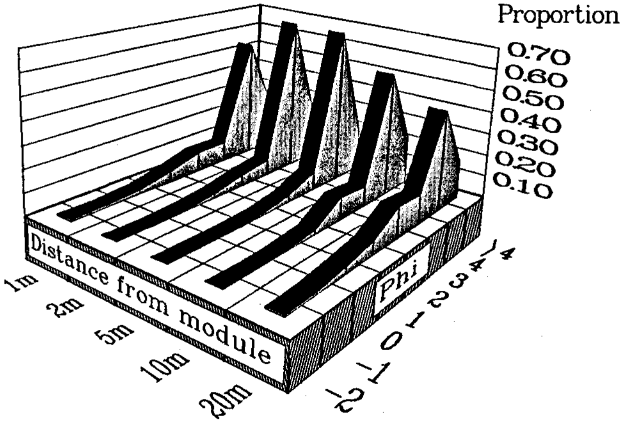
Upcoast



Between Modules



Downcoast



Offshore

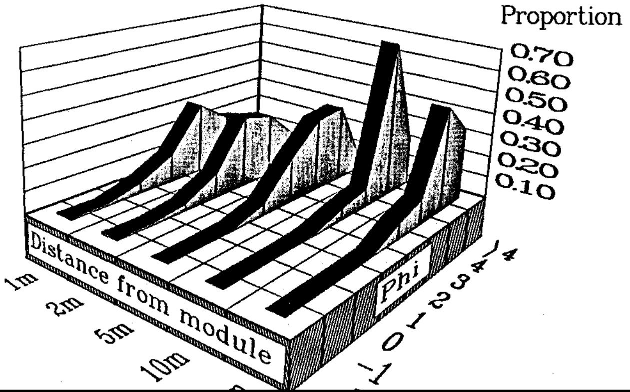
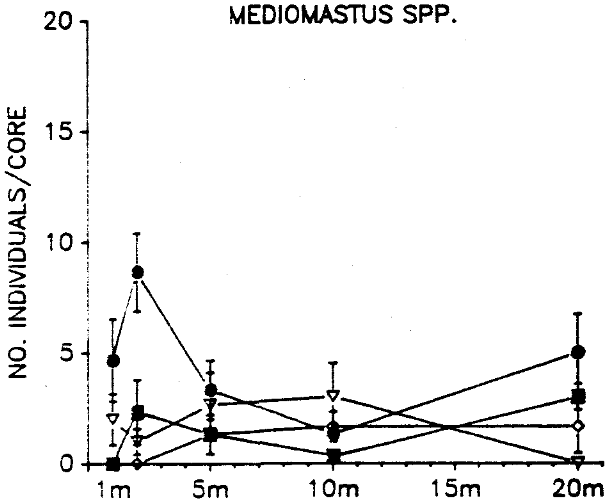
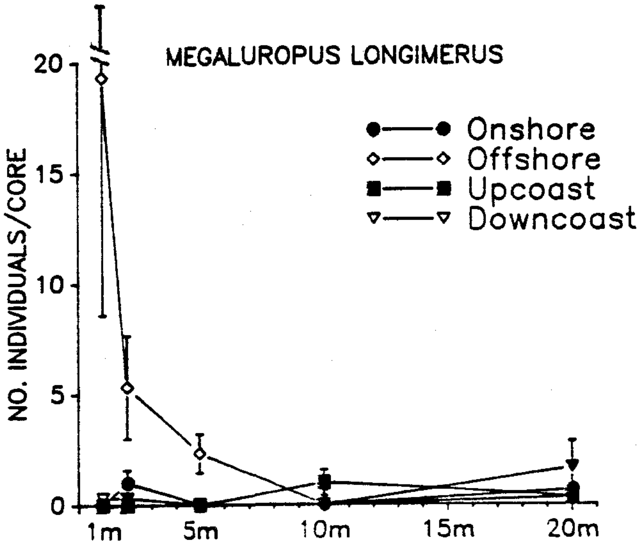
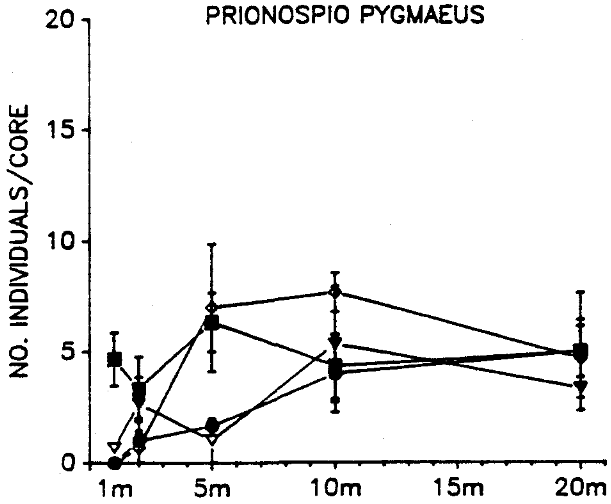
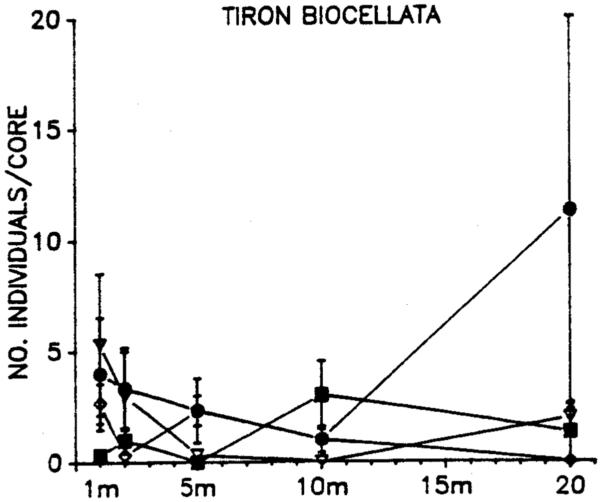


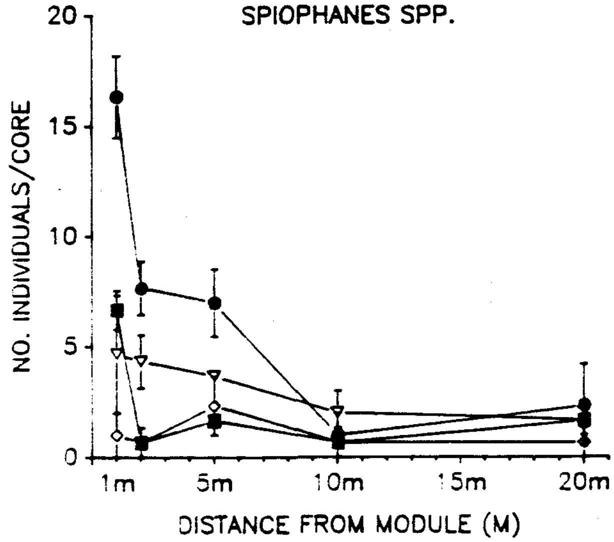
Figure A-4: Mean densities (no./core) and standard errors of the five most abundant taxa and total infauna along transects away from modules at Pendleton Artificial Reef.

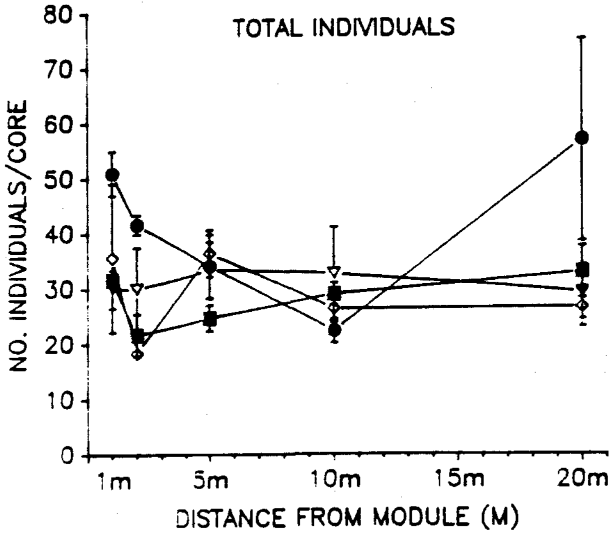

MEDIOMASTUS SPP.
NO. INDIVIDUALS/CORE
0
5
10
15
20
1m
5m
10m
15m
20m


MEGALUROPUS LONGIMERUS
●——● Onshore
◇——◇ Offshore
■——■ Upcoast
▽——▽ Downcoast
NO. INDIVIDUALS/CORE
0
5
10
15
20
1m
5m
10m
15m
20m


PRIONOSPIO PYGMAEUS
NO. INDIVIDUALS/CORE
0
5
10
15
20
1m
5m
10m
15m
20m


TIRON BIOCELLATA
NO. INDIVIDUALS/CORE
0
5
10
15
20
1m
5m
10m
15m
20


SPIOPHANES SPP.
NO. INDIVIDUALS/CORE
0
5
10
15
20
1m
5m
10m
15m
20m
DISTANCE FROM MODULE (M)


TOTAL INDIVIDUALS
NO. INDIVIDUALS/CORE
0
10
20
30
40
50
60
70
80
1m
5m
10m
15m
20m
DISTANCE FROM MODULE (M)

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Attachment 1

page 1 of 5

Total abundance of infauna sampled near PAR. Total abundance is the sum of all individuals in 60, 9 and 9 core samples along transects away from the modules, between the modules, and in Diopatra beds, respectively. Assigned functional groups correspond to trophic-motility categories devised by Marine Ecological Consultants (1987). Letter designations represent the following taxon descriptions: D = discrete (forages in restricted area), M = motile, S = sessile, SF = surface forager, SB = subsurface forager, SU = suspension feeder (filters food from water column), DP = deposit feeder (ingests sediment and/or detritus), MF = multi-feeding strategy, C = carnivore, H = herbivore, O = omnivore, DE = detrital feeder. - indicates did not occur in sample.

TAXON	FUNCTIONAL GROUP	TOTAL ABUNDANCE TRANSECTS N = 60	 BETWEEN N = 9	 DIOPATRA N = 9
Cnidaria				
Anthozoa				
Anemones	D,SF,C-O	8	-	3
Edwardsia sp.	D,SF,C-O	8	-	1
Platyhelminthes	M,SF,C-O	-	-	1
Nermertinea	M,SF,C-O	40	11	13
Mollusca				
Gastropoda				
Acmaeidae		-	-	5
Epitonium spp.	D,SF,C-O	2	-	-
Nassarius perpinguis	M,SF,C-O	4	-	-
Olivella sp.	M,SF,C-O	1	-	-
Polinices lewisii	M,SF,C-O	2	-	-
Bivalvia				
Lima sp.		-	-	2
Mactra sp.	D,SU	-	1	1
Nuculana sp.	D,SF,DE,DP	1	1	1
Saxidomus sp.	D,SF,SU-DP	4	-	1
Tellina modesta	D,SF,SU-DP	6	-	1
Annelida				
Polychaeta				
Ampharete labrops	S,SF,DE,DP	10	4	13
Amphicteis glabra	S,SF,DE,DP	39	-	4
Anaitides sp.	M,SF,C-O	-	-	3
Aricidea sp.	M,SB,DP	46	1	2
Armandia brevis	M,SB,DP	5	-	8
Autolytus sp.	M,SF,C-O	-	-	1
Axiothella rubrocincta	S,SB,DP	2	-	1
Chaetopteridae	S,SF,SU-DP	2	-	-
Chaetozone setosa	M,SF,DE,DP	77	3	2
Chone sp.	S,SU	1	-	1
Cossura sp.	M,SB,DP	3	-	-
Dispio uncinata	D,SF,SU-DP	1	-	-
Eteone sp.	M,SF,C-O	2	-	-
Eumida tubiformis	M,SF,C-O	1	1	1

Taxon	Functional Group	Total Abundance		
		Transects N = 60	Between N = 9	Diopatra N = 9
Eusyllis sp.	M,SF,C-O	4	1	-
Exogone lourei	M,SF,C-O	3	-	10
Glycera americana	D,SF,C-O	1	-	-
Glycera spp.	D,SF,C-O	18	3	23
Goniada spp.	D,SF,C-O	8	-	-
Gyptis brevipalpa	M,SF,C-O	14	10	57
Haploscoloplos elongatus	M,SB,DP	6	-	4
Harmothoe spp.	M,SF,C-O	6	-	4
Hesionella sp.	M,SF,C-O	-	-	1
Hesionura sp.	M,SF,C-O	27	6	4
Laonice sp.	D,SF,SU-DP	-	-	1
Lumbrinereis californiensis	M,SB,C,DP	2	-	4
Lumbrinereis lutea	M,SB,C,DP	13	3	24
Lumbrinereis sp.	M,SB,C,DP	1	1	-
Lumbrineridae	M,SB,C,DP	-	-	-
Magelona sacculata	D,SF,DE,DP	83	3	-
Magelona spp.	D,SF,DE,DP	3	-	-
Mediomastus spp.	M,SB,DP	130	3	21
Nephytys caecoides	M,SB,C,DP	33	10	-
Nereis zonata	D,SF,C-O	2	-	13
Nothria elegans	D,SF,C-O	33	-	2
Notomastus sp.	M,SB,DP	-	-	11
Odontosyllis parva	M,SF,C-O	-	-	19
Ophelia sp.	M,SB,DP	2	-	1
Opheliidae	M,SB,DP	1	-	-
Owenia collaris	D,SF,SU-DP	5	1	1
Paraonis gracilis	M,SB,DP	4	1	-
Pherusa inflata	D,SF,DE,DP	1	-	5
Pholoe sp.	M.SF.C-O	-	-	5
Phyllodoce sp.	M,SF,C-O	10	-	4
Phyllodocidae	M,SF,C-O	-	1	-
Pisione remota		-	23	10
Pista cristata	S,SF,DE,DP	3	-	3
Poecilochaetus johnsoni		-	1	25
Polydora sp.	D,SF,SU-DP	6	2	1
Polygorsius sp.		-	4	2
Prionospio cirrifera	D,SF,SU-DP	6	11	29
Prionospio malmgreni	D,SF,SU-DP	4	-	4
Prionospio pinnata	D,SF,SU-DP	52	1	1
Prionospio pygmaeus	D,SF,SU-DP	205	12	2
Protodorvillea gracilis	M,SF,C-O	4	13	7
Saccocirrus papillocercus		-	2	-
Scoloplos armiger	M,SB,DP	7	-	1
Sigalionidae	M,SF,C-O	-	8	8
Spiophanes spp.	D,SF,SU-DP	202	11	3
Sthenelais verruculosa	M,SF,C-O	1	-	-
Syllis sp.	M,SF,C-O	-	-	2
Syllidae	M,SF,C-O	1	-	2
Terebellidae	S,SF,DE,DP	-	-	1
Thalenessa spinosa	M,SF,C-O	21	-	-
Travisia sp.	M,SB,DP	1	-	-

TAXON	FUNCTIONAL GROUP	TOTAL ABUNDANCE TRANSECTS N = 60	BETWEEN N = 9	DIOPATRA N = 9
Sipuncula				
Sipunculidae	S,SF,DE,DP	6	1	41
Arthropoda				
Pycnogonida	D,SF,C-O	3	-	11
Crustacea				
Isopoda				
Bathycopea daltonae	D,SF,C-O	5	2	-
Edotea sublittoralis	D,SF,C-O	22	-	-
Jaeropsis dubia	D,SF,C-O	-	-	3
Munna ubiquita	M,SF,C-O	3	-	-
Neastacilla californica	D,SF,C-O	1	-	-
Serolis carinata	D,SF,C-O	1	-	-
Silophasma seminata	D,SF,C-O	-	-	1
Sphaeromatidae	D,SF,C-O	1	-	2
Amphipoda				
Caprellidea				
Caprella sp.		-	-	5
Gammaridea				
Ampelisca agassizi	S,SF,SU-DP	20	-	1
Ampelisca brevisimulata	S,SF,SU-DP	12	-	-
Ampelisca careyi	S,SF,SU-DP	1	-	-
Ampelisca cristata	D,SF,C-O	25	-	-
Amphideutopos oculatus	D,SF,SU-DP	5	-	2
Amphilochidae		-	-	1
Aoridae	D,SF,SU-DP	-	-	2
Aoroides sp.	D,SF,SU-DP	3	-	20
Argissa hamatipes	M,SF,DE,DP	8	-	-
Corophiidae	D,SF,SU-DP	-	-	3
Corophium sp.	D,SF,SU-DP	5	-	-
Dulichia sp.		-	-	4
Elasmopus antennatus	M,SF,O,DP	1	-	8
Elasmopus rapax	M,SF,O,DP	-	-	7
Eobrolgus chumashi	M,SF,O,DP	11	-	14
Ericthonius hunteri	D,SU	-	-	1
Eusiridae	M,SF,O,DP	-	-	6
Foxiphalus sp.	M,SF,O,DP	-	-	1
Gammaridae	M,SF,DE,DP	4	2	3
Hippomedon sp.	M,SF,O,DP	2	-	1
Isaeidae	D,SF,SU-DP	3	-	89
Maera sp.	M,SF,O,DP	-	7	1
Megaluropus longimerus	M,SF,DE,DP	98	112	3
Melita sp.		-	-	-
Melphisana bola	M,SF,DE,DP	1	-	-
Microjassa litotes		-	-	3
Monoculodes hartmanae	M,SF,DE,DP	6	-	-
Monoculodes spinipes	M,SF,DE,DP	1	-	-
Orchomene anaquela	M,SF,O,DP	1	-	-
Orchomene magdalensis	M,SF,O,DP	2	-	-

TAXON	FUNCTIONAL GROUP	TOTAL ABUNDANCE		
		TRANSECTS N = 60	BETWEEN N = 9	DIOPATRA N = 9
Pachynus barnardi	M,SF,O,DP	4	-	-
Photis brevipes	D,SF,SU-DP	5	-	-
Photis lacia	D,SF,SU-DP	24	-	32
Pleustidae	M,SF,O,DP	-	-	12
Platyischnopus sp.		-	1	-
Rhepoxynius abronius	M,SF,O,DP	82	-	-
Rhepoxynius menziesi	M,SF,O,DP	26	-	-
Stenothoe estacola	D,SF,O,DP	-	-	8
Stenothoidae	D,SF,O,DP	-	-	-
Synchelidium rectipalmum	M,SF,O,DP	2	1	1
Synchelidium shoemakeri	M,SF,O,DP	10	1	5
Tiron biocellata	M,SF,DE,DP	134	29	3
Decapoda				
Anomura				
Pagurus spp.	M,SF,C-O	2	-	90
Shrimps	D,SF,C-O	1	-	2
Penaeidea				
Crangonidae	D,SF,C-O	2	-	-
Crangon munitella	D,SF,C-O	1	-	4
Heptacarpus pictus	M,SF,C-O	-	-	1
Lepidopa californica	M,SF,C-O	1	-	-
Tanaidacea				
Leptochelia sp.		-	-	11
Brachyura				
Cancer antennarius	M,SF,C-O	-	-	2
Cancer anthonyi	M,SF,C-O	1	-	7
Cancer gracilis	M,SF,C-O	-	-	2
Hemigrapsus oregonensis	M,SF,C-O	-	-	17
Inachidae	M,SF,C-O	-	-	11
Pinnixa occidentalis	M,SF,C-O	-	-	1
Pinnixa schmitti	M,SF,C-O	-	-	1
Cumacea				
Campilaspis sp.	M,SF,DE,DP	5	2	-
Cyclaspis sp.	M,SF,DE,DP	29	1	5
Diastylopsis tenuis	M,SF,DE,DP	13	-	-
Diastylis sp.	M,SF,DE,DP	1	-	-
Hemilamprops sp.	M,SF,DE,DP	14	7	-
Lamprops carinata	M,SF,DE,DP	15	4	1
Lamprops quadriplicata	M,SF,DE,DP	1	-	-
Leptostylis sp.	M,SF,DE,DP	2	-	-
Leucon subnasica	M,SF,DE,DP	1	-	-
Ostracoda				
Asteropella slatteryi	M,SF,SU,DP	3	-	6
Bathyleberis garthi	M,SF,SU,DP	3	-	1
Euphilomedes carcharodonta	M,SF,O,DP	46	-	1
Leuroleberis sharpei	M,SF,SU,DP	3	-	8
Rutiderma lomae	M,SF,O,DP	4	-	1
Rutiderma rostratum	M,SF,O,DP	2	-	-

TAXON	FUNCTIONAL GROUP	TOTAL ABUNDANCE TRANSECTS N = 60	BETWEEN N = 9	DIOPATRA N = 9
Copepoda	M,SF,SU,DP	1	2	1
Epinebaila sp.	M,SF,SU,DP	4	-	-
Brachiopoda				
Glottidia albida	S,SU	3	-	-
Echinodermata				
Echinoidea	M,SF,DE,DP	-	1	-
Lovenia cordiformis	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

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APPENDIX B

B1. California Department of Fish and Game

From: Pendleton Artificial Reef: an overview of progress, 1984.

California Department of Fish and Game, 1985.

SURVEY METHODS

Several sampling methods were used to quantify the successional development of algae, invertebrates, and fishes on four of the eight modules at PAR and at the two reference reefs. The most comprehensive surveys were conducted during September-December 1984.

Band Transect Surveys: To collect data on macro-algal and invertebrate species (kelp and scallops, for example), divers counted individual organisms along defined bands of reef, ranging in area from 10 to 30 square meters, within base, slope, and crest profiles. These raw counts were then converted to average densities (#/m2) at the various relief profiles.

Random Point Quadrat Surveys: To collect data on the abundance of small turf community algae and invertebrates, divers placed 1/8m 2 square grid quadrats on reef substrate and measured the percent cover of each organism. These quadrat surveys were done at the base, slope, and the crest profiles of each study reef. The RPC method is described in detail in the 1983 PAR Annual Report. Results from quadrat surveys at each site were combined and averaged to give an overall picture of the reef communities at each site, as well as a picture of the differences in community structures at various relief profiles on the reefs.

Kelp Surveys: Several hundred giant kelp plants, Macrocystis, were observed on PAR Module 7 in spring 1984. As these plants are of special importance, quarterly surveys were begun in June of that year to monitor their progress. A permanent 30m by 2m band transect was laid out through the region of highest plant density, and data on kelp development within this region were collected. Circular quadrats (4.5m2) were also used to determine plant densities in nearby areas and total counts of plants growing on all eight modules were made during fall-winter 1984.

Fish Censuses: Fishes were counted using a technique identical to that employed by Lockheed (LOSL) biologists in 1981-82. Transects, measuring 3m wide, 1.5m high, and ranging from 14 to 35m in length, were established on the crest and slope of each reef. Divers counted all fish within these transects, differentiating adults from sub-adults of each species. Counts were converted to densities; i.e., number of fish per 100 cubic meters (100m3) of water volume.

B2. Lockheed Ocean Science Laboratories

From: Succession on Pendleton Artificial Reef: An Artificial Reef Designed to support a kelp forest, Final Report, Volume III.

Lockheed Ocean Science Laboratories, 1984

APPENDIX 1.0 DETAILED METHODS

BENTHIC MONITORING STUDY

Distribution and abundance patterns of attached benthic assemblages and select large algae and invertebrates were observed using SCUBA. In 1981-82 encrusting and foliose organisms were sampled three times during the year using randomly placed 0.125 m^2 quadrats on the crests (n=8) and slopes (n=8) of all PAR modules and at two stations at Las Pulgas Reef (LPR). Large invertebrates and algae were sampled using 20-1m^2 circular areas on all PAR modules and 40-1m^2 circular areas on LPR.

During 1982-83 benthic assemblages were randomly sampled on the slopes (n=4) and crests (n=8 or n=16) of two pairs of physically different modules (Modules 3 and 6 composed of large, flat boulders with high interstitial volume; Modules 1 and 5 covered with cobbles with low interstitial volume) twice during the year (LOSL 1983a; see also Volume I). Counts of large algae and invertebrates surrounding and on Modules 1, 3, 5 and 6 were also made. Percent cover of foliose and encrusting assemblages were estimated using a point contact sampling technique during both years. Observations were made at 30 evenly distributed points within randomly located 0.125 m^2 quadrats and these data were converted to percent cover estimates (LOSL 1983a; see volume I).

FISH MONITORING STUDY

In 1981-82 fishes were sampled by direct (visual) diver censuses on the crests and bottoms of all eight PAR modules and at two LPR stations. A total of 29 visual transects were taken per survey (21 at PAR, 8 at LPR) during seven monthly surveys in 1981-82. All fishes observed were tallied by species according to three maturity classes (adult, subadult, juvenile) using known size-maturity relations (Larson and DeMartini, in press; Feder et al. 1974; Quast 1968). Las Pulgas Reef (LPR) was used as a reference reef to facilitate comparisons of fish abundance between an artificial and a natural reef site.

In 1982-83 fish sampling was limited to PAR. A total of 32 visual transects per survey were taken on PAR during monthly surveys from October 1982 through October 1983. We were unable to sample fishes during February, March and September 1983 due to poor visibility resulting from storms. Two visual transects (1 bottom and 1 crest) were taken on each module on the same day or on two consecutive days each month.

SPECIAL STUDIES

In addition to descriptive studies of fish and benthos, we also performed several smaller scale studies including: 1) a fish foraging study of black perch on PAR and LPR (LOSL 1981), 2) monitoring kelp survivorship for *Macrocystis* transplanted to PAR (LOSL 1983a), 3) a study of growth and survivorship of juvenile abalone transplanted to PAR (LOSL 1983a), and 4) monitoring growth and survivorship of a smaller kelp, *Pterygophora californica*, transplanted to PAR and its potential effects on benthic and fish assemblages (LOSL 1983a).

We performed these studies to: 1) investigate the food habits and physical condition of a resident fish species with the aim of determining the extent to which it was being supported by the food organisms on PAR or LPR; 2) evaluate the survivorship of adult and juvenile *Macrocystis* transplanted to PAR as a means of creating a kelp forest habitat here; (3) evaluate PAR as a suitable habitat for red abalone and 4) assess the ability of a subcanopy kelp species, *Pterygophora californica*, to survive and grow on PAR because of the failure of *Macrocystis* transplantation efforts.

Briefly, methods used for the fish foraging study included spearing black perch and elaborating their gut contents and determining their "condition" based upon the ratio of mean carcass weight to mean standard length (LOSL 1981). Methods used to evaluate survivorship and growth of *Macrocystis* and *Ptergophora* included the monitoring of over 600 juvenile and adult *Macrocystis pyrifera* and over 200 *Pterygophora californica* transplanted to PAR. Growth and reproductive condition were also monitored for 143 *Macrocystis* plants on PAR and about 200 and 48 *Pterygophora* individuals transplanted to PAR and the Box Canyon control site, respectively. Growth and reproduction of transplanted Macrocystis was compared with that of naturally recruited plants at a nearby kelp forest (San Mateo Kelp, SMK; LOSL 1983a). Growth and reproductive condition of Pterygophora transplants were compared with the control transplants at a cobble-boulder site (Box Canyon) where all plants were originally collected. Additionally, we monitored the potential influence of Pterygophora on density of fishes and cover of attached benthic organisms (Volume II).

A study of short-term survivorship and dispersal of 1000 laboratory reared abalone was conducted in April and May 1982 (LOSL 1983a). Two groups of approximately 400 individuals each were transplanted to Module 4. A group of 60 individuals was used as a transport control while another group of 60 individuals was used as a laboratory control. The two transplant groups were carried on oyster shells and were placed on the offshore and inshore cobble slopes of Module 4. Abalone and oyster shells were placed in sheltered pockets excavated by first removing cobbles and subsequently replacing them after placement of the oyster shells. Survivorship was subsequently monitored 2, 6, and 20 days after the transplant by examining an area within a 1 m radius of the transplanted sites.

COMPARISON OF FISH POPULATIONS WITH NATURAL KELP-REEF HABITATS

We chose to analyse six species of warm-temperate fishes that are characteristically associated with giant kelp forest and other shallow rocky and vegetated habitats in southern California (Quast 1968; Feder et al. 1974; DeMartini 1981). In addition, three species (barred sandbass, Paralabrax nebulifer, kelp bass Paralabrax clathratus, and California sheephead, Semicossyphus pulcher) are valuable to the partyboat sportfishing industry in southern California (Feder et al. 1974); black perch (Embiotoca jacksoni) is numerically abundant on PAR and forages from the matrix of early successional algae and invertebrates ("turf") colonizing PAR; halfmoon (Medialuna californiensis) and opaleye (Girella nigricans) are numerically abundant on PAR and forage principally on macroalgae (e.g., Macrocystis, Pterygophora; Quast 1968; Feder et al 1974).

Fish sampling at PAR, LPR, and the bottom at SOK was conducted by direct (visual) diver census using SCUBA. All fishes were tallied as encountered on strip trasects of standard volume. Sampling at PAR and LPR encompassed two strata: a crest stratum, characterized by high water motion and high light intensity, where transects varied in length, and a bottom stratum where water motion and light were reduced (relative to the crest) and transect length was constant. Sampling at PAR and LPR was restricted to a height 1.5 m above the surface of the reef; few fish were observed in the water column at distances greater than 1.5 m above either reef. At all three sites, visual counts of fish were made within an envelope" (estimated visually) that extended 1.5 m above the bottom and 1.5 m to either side of the midline of the transect strip. Counts of all fishes within each strip transect were converted to density (number of individuals/100m^3) by multiplying individuals/strip transect volume x 100.

During the 1981-82 sampling period, the sampling design at PAR and LPR differed from that at SOK. All PAR modules and LPR stations were sampled during the same day once per month. One transect per stratum (crest and bottom) was sampled on five of the eight PAR modules. An additional bottom transect was sampled on PAR Module 2 because scattered boulders and cobbles contiguous with the main body of this module formed a slightly different habitat. Two within-day replicate transects were sampled at each stratum on PAR Modules 3 and 8 and at the two LPR stations. Thus, a total of 29 transects (14 crest and 15 bottom; 21 at PAR and 8 at LPR) were censused each month to estimate fish density at these two sites (LOSL 1983a). Fishes were tallied by species according to three maturity classes (adult, subadult, juvenile) using known size-maturity relations (Feder et al. 1974; Larson and DeMartini, in press). Crest and bottom transects at LPR and bottom transects at PAR were of equal length so divers sampled a constant volume (135 m^3 = 30 m long x 3 m wide x 1.5 m high). Crest transect lengths on PAR varied depending upon the module; thus, crest sample volumes ranged from 63m^3 to 189m^3.

Bottom transect volumes at SOK were constant, each measuring 75 m long x 3 m wide x 1.5 m high = 338 m^3 (Larson and DeMartini, in press). Divers counted all fishes in the three maturity classes along a predetermined compass course as a 75 m long line was paid out from a spool starting from a fixed central starting point. Transect bearings (compass course) were randomly predetermined from arcs containing cobble-boulder substrata and Macrocystis. All fishes occupying an area within a 5 m radius of the central starting point were not counted to avoid recounting fishes on replicate transects. During the fall of 1981, six replicate bottom transects were taken at the upcoast portion of SOK on each date; censuses were conducted on 13 dates between 7 October 1981 and 18 December 1981.

Direct visual observations at the three sites were made only on dates when lateral underwater visibility equalled or exceeded 3 m to avoid underestimates of diver-shy fishes. Censuses at all sites were performed during mid-daylight hours (0900 - 1500 hours) and divers alternated transects between stations (SOK, LPR) and modules (PAR) to minimize location biases among observers.

Sampling at SOK also encompassed the kelp canopy (i.e., water column; Larson and DeMartini, in press). Kelp canopy transects were sampled with movie cameras. Divers swam predetermined compass headings and photographed fish occurring in a 120° horizontal arc about the transect axis and 1.5m above and below the diver's depth. The transect ended when the film cartridge was exhausted (23 minutes after filming began). Cinetransect sampling protocol was similar to that for bottom visual transects in that divers recorded fishes on the "swim-out" from a central starting point, avoided the area within a 5m radius of the central starting point, and swam random compass bearings from within areas of permissible habitat. Eight replicate transects were filmed on 13 sampling dates during the fall of 1981. Movie films were viewed by at least two divers. All fishes were enumerated by species and by general size-and maturity-classes (Larson and DeMartini, in press).

Grand mean densities for each species sampled at PAR and LPR were computed by pooling stratum (crest and bottom) and module densities sampled on one date per month during October, November and December, 1981. Grand mean densities at SOK were calculated by using two dates per month (i.e. six dates) from the 13 dates available between 7 October and 18

December 1981. The two dates per month at SOK were chosen so that they always occurred within one to two days of the date that PAR and LPR were sampled.

To facilitate standing stock comparisons of these species at SOK with those at PAR-LPR, we pooled canopy and bottom samples at SOK. Thus, grand mean densities of these species were calculated using 14 replicates (8 canopy and 6 bottom) per date for six dates.

We statistically compared densities of these six species among sites using a hierarchical one-way Analysis of Variance (ANOVA; Sokal and Rohlf 1969) in which months were nested (i.e., used as replicates) within each site. Densities (no. of individuals/100m^3) were $\log_{10}$ (x + 0.1) transformed prior to analysis to normalize the distribution of counts and equalize variances for each species (Snedecor and Cochran 1967). We used Levene's test (Levene 1960) to determine if the logarithmic transformation equalized variances among sites for each of the species. For species in which the logarithmic transformation failed to equalize site variances, we interpreted ANOVA's with respect to guidelines given in Glass et al. (1972) (i.e., we rejected site differences for species densities if nominal probabilities were marginally significant $0.05 > P > 0.005$ among sites; we accepted site differences if nominal probabilities were highly significant $P < 0.005$ among sites). A posteriori comparisons among the sites were evaluated using the Student-Newman-Keuls test (Winer 1971).

QUALITATIVE COMPARISON OF PAR WITH NATURAL KELP-REEF HABITATS

Seven kelp-reef sites and one artificial reef site used in this comparison were chosen based upon three criteria: 1) they were representative of natural and artificial reefs in the PAR vicinity for which published and unpublished information was available; 2) methods used to sample the community resembled those used at PAR as much as possible; and 3) physical setting (e.g., depth, substrata, etc.) was as similar as possible to that observed at PAR. Table 1-1 summarizes these sites, their physical characteristics, and associated sampling methodologies.

B3. UCSB Fish Program

From: The effects of operations of the San Onofre Nuclear Generating Station on fish.
E.E. DeMartini, 1987.

2. Several fishes (blacksmith, senorita, and rock wrasse) were rare or absent at PAR until they recruited as YOY.

3. The abundances of the YOY of some species at PAR varied greatly over a short series of years (1982-84), perhaps reflecting development of recruitment habitat at PAR. More likely, these annual differences reflected regional or larger-scale fluctuations in settlement intensity or subsquent survival ("year-class success") (DeMartini et al. 1985a).

4.1.3 Objectives

This chapter's main objectives are: (1) to characterize the distribution and density patterns of fishes at PAR during the fall periods of 1985 and 1986 -- five and six years following reef construction. We give particular attention to variation among life stages (within species) in our density estimates. Based on these distribution patterns, we (2) provide quantitative estimates of fish abundances (numbers and biomass) at PAR during these two periods. (3) As a major focus for interpreting our fish abundance estimates at PAR, we make a detailed comparison with contemporary estimates of fish abundance at San Onofre Kelp bed (SOK), a cobble-bottom forest of giant kelp (Macrocystis) located 5.5 km upcoast of PAR (Chapter Three). In our discussion, we emphasize the importance of differences between the two sites in the density versus abundance of fishes when evaluating the actual or potential mitigative value of PAR.

4.2 SAMPLING AND ANALYSIS METHODS

4.2.1 Measuring Fish Densities

We used diver observations on belt transects to estimate the densities of fishes at PAR during fall 1985 and 1986. In each year, we estimated fish densities during three one-day surveys for juvenile-adult fishes (the JUV-AD study) and during three one-day surveys for young-of-year and older juvenile fishes (the JUVENILE study). The two studies provided complementary information: the JUV-AD study characterized densities for major, postrecruit life stages and distinguished between the densities of (1) total juveniles and (2) later stages. The JUVENILE study characterized the young-of-year (YOY) component of the juvenile stage as distinct from older, immature-sized (OJ) fish. Three matched pairs (same week) of JUV-AD and JUVENILE surveys were scheduled at approximately monthly intervals during each fall period. Three surveys were completed in October, November, and December 1985. Three other surveys were completed in "fall" 1986-87: two about two weeks apart in November, and one in the third week in January (poor underwater visibility precluded surveys in October and December).

Field methods used on 1985-86 JUVENILE surveys to estimate YOY-OJ densities were basically the same as those used on our October 1984 pilot survey (DeMartini et al. 1985a), with several important exceptions. (1) Each transect was surveyed once, not twice, on a given survey. (2) Each of the 8 modules was sampled on each survey. (3) Three surveys were completed during each fall period. As in 1984, two major microhabitats (the Crests and Perimeters of modules) were sampled for YOY-OJ fishes.

The design used to sample juvenile, subadult, and adult fishes on our JUV-AD surveys at PAR was patterned after our bottom transects at SOK (Chapter Three, Section 3.2.1; Appendix J). Transects were stratified within major microhabitats in rock and adjacent sandy regions. In 1985, the rock-sand interface (ecotone) regions of modules were sampled only on the December survey. During fall 1986, we sampled adjacent and outlying sand regions, in addition to module ecotones, on each of the three surveys. We sampled the regions of sand between modules, starting 3 m from a module's sand-rock interface, and extending 30 m perpendicular to the interface (if 30 m was not more than half the distance to an adjacent module). Otherwise, the radial transect extended 5 m only (Appendix Q, Fig. 2). We sampled four radial transects per module on each survey (32 each survey) in 1986. For a detailed description of this and other aspects of the JUV-AD survey design, including a comprehensive list of sampling dates, transect dimensions, and stratum-specific areal estimates, see Appendix Q, particularly Tables 1, 2, and 3.

4.2.2 Characterizing Distribution Patterns

It is important to stratify within heterogeneous sampling universes in order to reduce the variances of estimates. For this reason (and so that we could identify major microhabitats for building our abundance characterizations -- see below) we evaluate the influence of obvious microhabitat features (reef strata) on fish densities at PAR. In addition, we explore other potential complications due to fish life stage, module, and fall period. DeMartini et al. (1985a) evaluated the effects of stratum and juvenile substages for YOY-OJ fishes on the October 1984 survey. In this report on 1985 and 1986 data, we reexamine these factors (and the influences of module and year) for YOY-OJ fishes. We also examine the effects of stratum, major life stage (juvenile, subadult, adult), module, and fall period on the densities of all postrecruit fishes.

Two-way and three-way ANOVAs (fixed-effects model) were used. For YOY-OJ fishes, the stratum factor had two levels (Crest and Perimeter), and the maturity factor had two levels (YOY and OJ). The year factor had two levels (the two fall periods). Module was used as a blocking variable, and surveys constituted temporal replicates (see below).

For JUV-AD fishes, we performed two series of ANOVAs. In the first series, we ran three-way ANOVAs using data for both fall periods. We simultaneously tested for the effects of stratum, stage, and year on fish densities. The two strata (Crest, Slope) common to all surveys in both years were tested. In the second series of tests, we evaluated each year of data separately for the effects of maturity stage and reef stratum using two-way ANOVA. Evaluation of the stratum effect in fall 1985 was limited to the two strata (Crest, Slope) sampled in that year. We sampled two additional, major microhabitats (Ecotone and Sand, the latter including 4 sampling strata) in fall 1986. We were thereby able to evaluate 7 levels of the stratum factor in the second year. Three levels of maturity stage (juvenile, subadult, adult) were used in these analyses. Module was used as a blocking variable. Surveys provided temporal replication within each fall season.

For a posteriori contrasts, Student-Newmann-Keuls (SNK) tests were used. Contrasts were examined for both main effects and interactions.

All ANOVAs were run using LOG-10 {(#/1000 m^3) + 1} data (DeMartini et al. 1985a).

3.2. METHODS

3.2.1. Field Measurements of Fish Densities

All characterizations of fish densities in SONGS-area kelp beds are based on either one or both of two types of nondestructive sampling -- underwater surveys conducted by a single team of scuba divers. In both types of surveys, fishes were enumerated on belt transects of known (or directly estimable, see below) dimensions. In the first type of sampling, water-column "cinetransects" were recorded with diver-held movie cameras and Super-8 film (DeMartini et al. 1983 a,b; Larson and DeMartini 1984). In the second type of survey, divers directly tallied bottom transect data. Dimensions of bottom transects were fixed: 3 m wide x 1.5 m high (as estimated by diver) and 75 m long (as determined by length of transect line). The area surveyed by bottom transects was 225 m^2; volume sampled was 337.5 m^3. The length of cinetransects also was 75 m (+/- 2 m: Larson and DeMartini 1984), based on 3-min swims at an average rate of 25 m/min. Width and height of cinetransects were variable, but estimable as a function of underwater visibility (Larson and DeMartini 1984; Appendix J). The average volume sampled by cinetransect was about 1000 m^3. All density data were standardized to #s/1000 m^3.

Fishes at San Mateo Kelp bed (SMK) and(or) at San Onofre Kelp bed (SOK) were surveyed during the "fall" (October through December) periods of 1980, 1981, 1985, and 1986. Sampling was restricted to the fall, because underwater visibility is generally inadequate for fish observations during other seasons in southern Californian coastal waters. Sampling occurred at irregular intervals throughout the fall periods; sampling was dependent on sea state and adequacy of underwater visibility. Visibilities $\geq$ 2.5 m were considered necessary in order to avoid undersampling certain large, diver-shy fishes (e.g., adult kelp bass and opaleye; Coyer 1979; DeMartini et al. 1981b; 1983a,b; Larson and DeMartini 1984). Conditions permitting, several locations within either or both kelp beds were sampled during each of 20 to 35 single-day trips each fall (Appendix J, Table 1). Sampling was restricted to the general midday period of inactivity for diurnal fishes (0800-1600 hrs; Ebeling et al. 1980a; Larson and DeMartini 1984).

Locations representing the fixed starting points for transects (station hubs) were chosen based on the density (and surface canopy development) of Macrocystis. Assessments of kelp habitat were made during practice transects and other preliminary dives in the September immediately preceding the fall season.

A consistent sampling design was followed. On a given date, comprehensive sampling at a given location consisted of a team of four divers (one pair each in the water column and on bottom). At canopy (3.1-m) depth, fishes were filmed on a total of 8 cinetransects per location. During 1985 and 1986, fishes also were filmed at mid-depth (7.7 m: Section 3.2.3 and Appendix J); 2 cinetransects were expended per location and date at mid-depth. On bottom (average 14.5-m depth, range 12-16 m), fishes were tallied on a total of 6 transects. Fishes were tallied by major life stage (juvenile, subadult, and adult), based on recognized length-maturity criteria (Appendix T, Table 1A). (When cinetransects were subsequently viewed in the laboratory, fishes were scored for life stage using visual cues on film -- e.g., lengths of kelp blades, size-specific color patterns and behavior.) On bottom, fishes were counted as the transect line was paid out (off a take-up spool: see Quast 1968b for prototype). As the line was retrieved on the return swim, the diver counted the number of juvenile-adult Macrocystis plants encountered within the transect path, and assessed the relative abundances of each of several structurally important benthic biota and the relative amounts of cobble and sand present.

Details of these and supplementary sampling protocols are provided in Appendix J. For a comprehensive list of quantitative sampling dates, see Appendix J, Table 1.

3.2.2. Impact Tests

Densities of fishes were compared between a potential impact region in the upcoast, offshore section of SOK and (1) a control region within the downcoast, offshore section of SOK and (2) an upcoast control in SMK (Appendix J, Fig. 1). Impact minus control deltas (differences) in densities were contrasted between the baseline period (i.e., the SONGS Units 2 and 3 "preoperational" period in fall 1980 and fall 1981) and the "operational" period in fall 1985 and fall 1986. Since we were concerned with measuring what indirect effect SONGS might have on fish via loss of kelp habitat, the positions of sampling stations shifted somewhat in various sampling seasons as we tracked stands of the densest available kelp at SMK and within the two major regions (upcoast, downcoast) of kelp at SOK.

In fall 1980-81, regions of dense kelp persisted in approximately the same areas of SOKUpcoast (SOKU), SOKDowncoast (SOKD), and SMK. By fall 1985 (and

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1.2.1.3 Algae and Invertebrates

Algae and invertebrates were sampled by three different methods: band transects, 1-m^2 quadrats, and random point contacts. These methods are described below. In addition, the height of algae at each sample point on transects used to sample substrate types (see section 1.2.1.2.2) was also measured.

1.2.1.3.1 Band transects

Large conspicuous invertebrates, both motile and non-motile, kelp (including *Pterygophora californica*, *Laminaria farlowii*, *Eisenia arborea*, *Egregia menziesii*, and *Macrocystis pyrifera*), and *Cystoseira osmundacea* were counted in eight band transects 2-m wide by 5-m long (see Table 1-3). One band transect was started at a random location along each of the eight benthic transects initially sampled for fish. The number of stipes per individual was recorded for all *Macrocystis* plants > 1 m tall within the band transect. This stipe count was used to estimate both the mean number of stipes per *Macrocystis* plant and the mean number of stipes per 100 m^2.

1.2.1.3.2 Quadrats

Small motile invertebrates and some conspicuous sessile species were counted in 1-m^2 quadrats (Table 1-3). On each reef, a total of ten quadrats were located randomly on the benthic transect lines, one or two on each transect. On a few occasions invertebrates that were usually counted in quadrats were sampled in band transects instead (Table 1-3).

1.2.1.3.3 Random point contacts

Percent cover of sessile organisms, both invertebrates and algae, was determined using a random point contact (RPC) method (Cowen *et al.* 1982). A 1-m bar was placed diagonally within a 1-m^2 quadrat. A 1.2-m line, containing five knots located at regular intervals, was attached from one end of the bar to the other end. The line was stretched tightly at each knot and the point under the knot was sampled. At each point, organisms from the substrate to a height of 1-m were recorded (see Table 1-3). Five points were contacted on each side of the bar for a total of ten points per quadrat. RPC data were collected from the same quadrats sampled for small motile invertebrates and conspicuous sessile species.

1.2.1.5 Fish

1.2.1.5.1 Benthic Transects

Visual transects were used to estimate the densities of adult, sub-adult, juvenile, and young-of-year ("young") fish. The general procedure was for a diver to swim along a 30-m transect and record all fish within a corridor of specific dimensions. All fish encountered were recorded in appropriate life-stage categories (with lifestage categories based on fish lengths, Table 1-4). The diver swam at a constant rate to minimize counting fish attracted to him or counting fish twice.

Adults

The adult fish transects near the benthos were sampled during the first dive of the day, whenever possible, in order to minimize the influence of diver disturbance. Immediately after descending and attaching the beginning of the first transect line, the diver swam at approximately 25 m/min along a depth contour, counting fish and reeling out the transect line. Total length of the transect line was 30 m. Fish were counted within a 3-m wide by 1.5-m high corridor. Each fish was placed in one of three life-stages: adult, sub-adult or juvenile. However, estimates of only adults and subadults were used in the analyses; estimates of juvenile densities were taken from young-of-year transects.

At the end of the first transect, the diver tied off the end of the transect line, then continued swimming for approximately 5m before beginning the second transect, which was sampled in the same manner as the first. At the end of the second transect, the diver swam at right angles to the transect for at least 5m before establishing the start of the third transect. The third and fourth transect lines, which were laid down along the opposite heading from the first two transects, were sampled in the same manner as the first two. The fifth through eighth transects were sampled by a second diver, with the transects laid down in a mirror image from the first set of transects. All transect lines were left attached to the substrate for use in subsequent sampling for fish, invertebrates and algae. In some cases, such as deep reefs, it was necessary to sample a reef over two days. In these situations, transect lines were left down overnight, a marker buoy was attached, and Loran readings were recorded to allow divers to return to the same location the next day.

Young-of-year

The young-of-year and juvenile sampling near the benthos followed the same transect lines as the adult sampling, but only after a period of at least one-half hour to allow the fish to recover from the disturbance of the initial sampling of adult fishes.

Because a more detailed search was necessary for young-of-year sampling, the young-of-year corridor was only 1-m wide. To ensure that young occurring off the substrate (such as *Chromis punctipinnis*) were included, the corridor was 2-m high. Only young and juvenile fish encountered within the sample space were counted. Life-stage classification was based on the lengths shown in Table 1-4. Swimming speed was slower than the speed for the adult transects to allow for a thorough search of the substrate.

The date of sampling could influence the estimate of young density because recruitment may be seasonal; for example, a species that recruited only in November would not have been encountered on any reefs sampled during October. To avoid bias due to the time samples were taken, the sample dates for artificial and natural reefs alternated. We have also evaluated this potential bias by regressing the density of young-of-year against sample date; this analysis was performed on the nine species of fish that occurred on four or more reefs. None of the species showed a significant relationship between density of young and sample date (Table 1-5).

Fish lengths

To determine the size frequency distribution of fish, divers swam around the reef estimating the length of all fish seen. Swims usually lasted at least 10 min on each reef. If fish were in schools, the total number of individuals in the school and the proportions of individuals in each size-class present in the school was estimated. To allow for greater attention to less common species, fish lengths of only the first 100 or so individuals encountered of each species were estimated.

1.2.1.5.2 Water column transects

Adults

Adult, sub-adult and juvenile fish occurring in the water column (and under the kelp canopy when present) were sampled by video; however, estimates of only adult and subadult densities were used in the analyses. The diver shooting the video swam at a depth of approximately 3 m for approximately of 1 min and 25 sec, which was about the time necessary to cover 30 meters. In the narrative that accompanied the video, the diver identified the species and age class of each fish seen. The actual counting of fish was done later, when the videotape and narrative were reviewed. (Unfortunately, technical problems with the underwater microphone resulted in no narrative for a number of samples.) Eight transects were usually sampled at each site. In addition, horizontal visibility was measured by the diver and recorded on the video. The relationship between visibility and the area sampled using the video camera had been calibrated previously and was used to determine the width and height of each video sampled. The volume of the transect was calculated by