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THE EFFECTS OF OPERATIONS OF THE SAN ONOFRE NUCLEAR GENERATING STATION ON FISH

FINAL REPORT
(Vol. 1 of 2)

Prepared for the
Marine Review Committee
of the
California Coastal Commission

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December 1987

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CHAPTER ONE -- NET MONITORING STUDIES

As part of our overall assessment of the potential impact of San Onofre Nuclear Generating Station (SONGS) on the local fish fauna, we monitored the distribution and abundance of select species of coastal pelagic ("midwater") and benthic soft-bottom ("benthic") fishes. We assessed abundance based on net samples. Midwater fishes were sampled by lampara seine, a type of semi-pursing roundhaul net. Benthic fishes were sampled by 25-ft (7.6 m) otter trawl (a scaled-down version of large, commercial drag nets), used in routine fisheries sampling of bottom fishes. Nets provide catch data that are indices of abundance (CPUE, or "catch-per-unit-of-effort"), not estimates of absolute density.

Midwater and benthic fishes were sampled as discrete tests of two different predictions: the juvenile-adult stages of certain species (e.g., queenfish, *Seriphus politus*) have been considered to be at particular risk to intake entrapment at the SONGS offshore intake structures. Other fishes (including the benthic adults of species that occur in midwater as juveniles and young adults) have been considered potentially susceptible to changes in the sediment and benthos (their prey) that might result from organic input of the SONGS diffuser plumes to the seabed farther offshore. The specific predictions tested were: (1) the potential impact of intake entrainment is negative (i.e., leading to a local decrease in midwater fishes); and (2) the potential impact of a changed seabed and benthos on benthic fishes could be either positive or negative (i.e., leading either to a local increase or a local decrease in benthic fishes).

As descriptive tests of these predictions, we monitored the distribution and density of fishes near, and various distances from, the potential source of impact, during a "preoperational" (baseline) period prior to an "operational" period when both SONGS Units 2 and 3 were consistently pumping at full flow. For the midwater fishes sampled by lampara seine, the baseline period was September 1979-May 1982. This was followed by an "interim" period, during which sampling was continued at reduced effort to maintain continuity. Operational samples were collected during April 1984-August 1986.

For the benthic fishes sampled by otter trawl, the baseline period extended from May 1980-April 1982. After an an interim period of June 1982-April 1984, operational sampling began in May 1984 and continued until December 1986.

We monitored the density of midwater fishes with lampara seines fished near (within 1/2-km distance of) the SONGS Unit 1 intake structure, at another station 2-3 km downcoast of Unit 1, and at a distant control station, 18-19 km downcoast of Unit 1. Midwater seine samples were taken at 11-16 m bottom depths (corresponding to the SONGS diffusers) as well as at 5-10 m (intake structure depths). Sampling at 11-16 m was done as a check on whether any decreases observed at intake depths might instead reflect an offshore distributional shift.

where in relation to diffusers?

We used benthic trawls fished under the average, downcoast-setting diffuser plumes (from ≤ 1-km upcoast to 2-km downcoast of the Unit 1 line) to monitor near-SONGS changes, relative to a single, distant control station, 17-20-km downcoast of Unit 1. Trawls were made at 18 m (just seaward of the diffusers) and at 30 m (seaward of the plume).

We evaluated the magnitude and significance of potential declines (for midwater fishes) and potential changes (benthic fishes) at an impact station (relative to a control location) and between baseline and operational periods, using A. Stewart-Oaten's "BACI" (Before-After, Control-Impact) sampling and analysis design.

The relative magnitude of seine catches near versus away from SONGS often changed in predicted fashion between baseline and operational periods. At a prescribed alpha-level of 0.05 and at a power (1 minus beta) of 0.80, 11/22 statistically tractable test cases (at intake depths) were significant, and 9/11 of these were disproportionate declines at the Near Impact location relative to either the Far Impact station or the distant Control location. At diffuser depths, only 3/21 cases were significant at an alpha of 0.05. Another two cases were significant at 0.10 > P > 0.05 (justified because the power of both cases was < 0.80). Although the power of our t-tests was generally less for data collected at diffuser depths than at intake depths, the results suggest that the near-SONGS declines were more prevalent at shallower depths, near the offshore intake structures. Diffuser-depth declines were detectable for small queenfish only, perhaps because entrapment effects on less vagile, younger fish are less diffused by longshore movements -- the longshore extent of both juvenile queenfish and white croaker declines was restricted to within 1/2-km distance of the SONGS Unit 1 intake. Declines in adult male and female queenfish were detectable as far as 2-3 km downcoast of Unit 1, however.

Several data provide strong circumstantial evidence that (1) local depressions in juvenile queenfish are diffused throughout the Bight by fish movements, and (2) local depressions in adults have resulted directly from entrapment of adults. First, seine data indicate that queenfish, particularly adults, make extensive longshore, as well as diel and seasonal onshore/offshore movements. Second, there is good biochemical genetic evidence that queenfish lack population differentiation within the Bight, which is expected if stocks are well-mixed.

All significant declines near SONGS involved white croaker (*Genyonemus lineatus*) and queenfish, two species heavily entrapped at the SONGS offshore intake structures. Small (juvenile) stages of both species in particular declined disproportionately near SONGS during the operational period. Two other taxa that were common and abundant in baseline seine samples, but entrapped at relatively low levels at SONGS, did not decline to greater extent near SONGS.

ANOVA results gave no indication that declines in seine CPUE at intake depths were the result of offshore distributional shifts.

The disproportionate declines in midwater fish CPUE near SONGS were large in magnitude (generally > 60%). Most near-SONGS declines were absolutely large as well (usually > 20 fish per seine-haul), despite the broadscale halving of fish abundance throughout the San Onofre-Oceanside area in recent years. The latter background decrease at all sampling locations during 1984-86 began in summer-fall 1982, coincident with the onset of the California El Nino, and no doubt reflected offshore emigrations and mortalities caused by the El Nino.

The proportion of significant test cases was less for baseline versus operational period comparisons of impact-control relationships at benthic trawl stations. When evaluated at a two-tailed alpha level of 0.05, we were able to detect significant changes in trawl CPUE for only 4/16 tractable cases (involving 4 species). An additional 3 species-depth combinations (2 more species) were significant at a two-tailed alpha of 0.10. Of the 7 total changes, six were increases; only one relative decline occurred at SONGS. The decline (54%) was for speckled sanddab (*Citharichthys stigmaeus*) at 18-m depth. Four out of six significant increases occurred at 30 m.

ANOVA results gave little suggestion that significant changes in trawl CPUE at depth were obscured by depth-distributional shifts. Other data demonstrate that the diffuser- and plume-depth increases in the trawl catches of queenfish and white croaker are not the simple consequence of a seabed-directed shift in water column distributions that might have occurred off SONGS. For each species, the large adults that dominate trawl catches farther offshore represent a segment of the stock that is different from the juveniles-small adults that predominate in seine catches nearshore.

Most relative increases in trawl CPUE off SONGS were large (from > 200% to > 600%). However, all but one case (white croaker, at 30 m) represent trivially small absolute differences in catches between SONGS and control locations. Large percentage changes despite small absolute differences reflect the small sizes of trawl catches during the operational period. During 1984-86, the abundances of benthic fishes were depressed to one-half or less of baseline averages throughout the general San Onofre-Oceanside area (as elsewhere in the Southern California Bight), probably as a consequence of the 1982-84 El Nino.

The overall effect of SONGS entrapment on small fish nearshore and on SONGS plume-induced enrichment of the seabed offshore can be evaluated for queenfish and white croaker, the two species for which both positive and negative plant effects are most evident. In terms of biomass, the two species show qualitatively different overall effects: For white croaker, the disproportionate increase in large adults near the seabed, beneath the SONGS plumes, has overwhelmed the relative decrease in small croaker closer to shore, near the SONGS intakes. Our gross estimate of the resulting surplus in white croaker is ~55 kg/ha. For queenfish the opposite is true. The large relative declines in juveniles-small adults near the intakes swamps the relative increase in large adults near the seabed offshore. The estimated deficit in queenfish biomass is ~27 kg/ha.

CHAPTER TWO -- SONGS ENTRAPMENT STUDIES

Also as part of our comprehensive assessment of the potential impact of SONGS operations on fish stocks, we estimated the magnitude of SONGS Units 1, 2 and 3 intake entrapment of juvenile-adult fishes. Estimating mortality due to entrapment at Units 2 and 3 required an assessment of the efficiency of the fish

return system of the two new units. Because the observed local declines in midwater fishes near the offshore intake structures are thought to have resulted from intake entrapment (Chapter One), we evaluated whether the observed declines can reasonably be attributed to intake entrapment. To do this, we compared the average magnitude of queenfish entrapment, variously corrected (or not) for operations of the Units 2 and 3 fish return system, with the estimated magnitude of nearfield depression in the queenfish stock.

During the 39-mo period from May 1983 to August 1986, SONGS Units 1, 2, and 3 together entrapped, on average, an estimated 5.6 million juvenile-adult fishes, weighing 40.7 metric tons (MT), every 12 months. (During this period, Unit 1 pumped at an average 56% of full-flow, and Units 2 and 3 combined withdrew cooling water at an average 76% of full flow.) Entrapment estimates are based on the assumption that magnitude of entrapment is directly proportional to the number of circulating pumps in operation at a unit (i.e., a linear function of volume flow). This assumption was critically tested and accepted.

The fate and disposition of fishes entrapped at SONGS differs between Unit 1 and the two new units. This is because most fishes entrappped at Unit 1 are impinged, whereas most are diverted at Units 2 and 3. Entrapment at Unit 1 represented only 9-10% of total fish biomass entrapped at SONGS during May 1983-August 1986. About 10% (400 kg) of the average fish biomass entrapped at Unit 1 (3.8 MT/yr) accrued in the unit's screenwell between heat treatments; the remainder impinged on traveling screens during normal flow operations.

Entrapment at Units 2 and 3 accounted for 90% (36.7 MT) of total annual biomass entrapment at all SONGS units. About 8% (3.0 MT/yr) accrued in screenwells between heat treatments and was killed during heat treatments. Impingement and diversion during normal flow operations accounted for 92% (33.9 MT/yr) of all entrapment at the two new units. About one-fifth (7.2 MT/yr) impinged on traveling screens; four-fifths (26.6 MT/yr) was diverted by the louvered screens into forebays and periodically collected by lift-bucket and discharged back offshore via the fish return system. (At all SONGS units, the fish killed during heat treatments, and all those impinged on travelling screens during normal flow operations, are carted off-site to be used as land fill.)

Queenfish, northern anchovy (Engraulis mordax), plus six other species represented over half of all fish biomass entrapped at Unit 1, and 70% of the total at Units 2 and 3. Queenfish alone accounted for 21% of total biomass entrapped at Unit 1 and 39% at the two new units.

The magnitude of fish mortality at SONGS Units 2 and 3 is inversely proportional to the efficiency of its fish return system (FRS). Efficiency of the FRS depends on both the percentage of fish that are diverted (i.e., prevented from impinging on traveling screens, once entrapped) and the percentage of successfully diverted fish that survive.

On average about 79% of the total biomass of fishes entrapped at Units 2 and 3 was diverted. Percent diversion was about 77% for "small-bodied" fishes (< 30 g), 70% for "medium-sized" fishes (30-200 g), and 85% for "large-bodied" fishes (> 200 g). Queenfish and white croaker together represented 97% of total biomass of all small fishes (less anchovy) diverted.

The survivorship of diverted fishes was estimated as a function of body size, both in terms of mechanical damage and other physiological stress due to transport per se and due to predation upon discharge back offshore. We evaluated the effects of transport based on the results of a series of field trials conducted off SONGS by Occidental College during October 1983-August 1985.

Based on the weighted average contribution of queenfish and white croaker to diversion samples, average transport survivorship was about 66% (by numbers) for all small-bodied fishes excluding northern anchovy. Analogous values were 100% for medium-sized and large-bodied fishes. The transport survivorship of queenfish was 68% for fish of all sized pooled and was significantly less (63%) for small compared to large (73%) queenfish.

Mortality due to predation upon discharge was also considered to be a positive function of body size, because the probability of being eaten must decrease with size for juvenile-adult fishes whose weights range from several grams to several kilograms. We estimated predation survivorship for fishes of the same three weight classes evaluated for transport survivorship: we estimated that about 75% of the healthy small fishes exiting the FRS discharge ports would avoid being eaten at or near the discharges. Analogous estimates were 90% for medium-

sized fishes and 99% for large-bodied fishes. We caution that these values are subjective and bracket them with values $\pm$ 50%.

Efficiency of the FRS can be conservatively estimated as the cross-product of % diversion and % transport survivorship, ignoring (for simplicity) the impact of predation upon discharge from the system. Doing this, and subdividing our estimates into "small" fishes (as anchovy and all other small-bodied fishes) and "large" fishes (as the sum of medium-sized and large-bodied fishes), we obtain the following: The % efficiency for all small fishes is an estimated 70% (numbers) and 55% (biomass). The % efficiency of all large fishes is somewhat better -- 77% (numbers) and 80% (biomass).

By multiplying the probabilities of transport survivorship and predation survivorship, we were also able to provide gross, but comprehensive estimates of the efficiency of the FRS:

$$\text{Pct efficiency} = \text{Pct diversion} \times \text{Pct } S_{total},$$
$$\text{where Pct } S_{total} = \text{Pct } S_{transport} \times \text{Pct } S_{predation}.$$

Using this procedure, our best estimates of FRS system efficiency were 38% for small-bodied fishes, 63% for medium-sized fishes, and 84% for large-bodied fishes. When Units 2 and 3 entrapment estimates are corrected for estimated efficiency of the FRS, annualized losses of total fish biomass are reduced by almost one-half (17.6 MT/36.9 MT). Although the relatively poor efficiency for small fishes is partly offset by the relatively good efficiency for large fishes, the average efficiency for total fishes is influenced more strongly by the biomass-dominant small fishes. Corrected for the most likely proportion saved by FRS operations (40%), annual entrapment losses of queenfish during May 1983-August 1986 averaged about 9.1 MT for all three SONGS units, with the two new units together accounting for 8.5 MT.

In conclusion, we evaluate whether the observed magnitude of entrapment of small queenfish and white croaker (each at large apparent risk to entrapment) has been sufficient to explain the observed nearfield declines in the two species. Conversely, we evaluate whether low SONGS entrapment levels might reasonably explain the lack of observed nearfield declines for two other taxa, atherinids and Pacific butterfish (*Peprilus similllimus*).

Results support the two opposing predictions -- queenfish and croaker entrapment has been sufficiently large to explain the observed nearfield declines, while low levels of entrapment have been consistent with lack of declines in atherinids and butterfish. In particular, we estimate that, for small queenfish, average immigration rates sufficient to replace daily entrapment losses once every 2 to 2-1/2 days would balance average entrapment at the three SONGS units combined. This obtains if all small queenfish entrapped were killed. If FRS system operations save about 38% of all small queenfish entrapped (our best estimate for small queenfish), then immigration would need to offset losses only once every 3 to 4-1/2 days. We conclude that these reates of immigration are reasonable, based on what we know about the movement patterns of queenfish. Average entrapment levels for each of the other two species appear too low (both absolutely and relatively) to expect any nearfield declines.

CHAPTER THREE -- SONGS-AREA KELP BED FISHES

As part of our overall assessment of the potential impact of San Onofre Nuclear Generating Station (SONGS) on the local fish fauna, we monitored fish stocks at San Onofre Kelp bed (SOK), a forest of giant kelp (Macrocystis pyrifera) located about 2-3 km offshore of SONGS, and at San Mateo Kelp bed (SMK), another cobble-bottom forest of giant kelp, about 5-6 km upcoast of SOK. We monitored the fishes at SOK as a test of the prediction that habitat loss at SOK would result in local declines in kelp bed fishes. This prediction is based on the following argument: (1) SONGS Units 2 and 3 operations, by secondarily entraining and discharging turbid bottom water out over SOK, would preclude the natural reseeding of Macrocystis sporophytes necessary to offset the continued mortality of adult plants. (2) Continued attrition of adult plants without juvenile recruitment would produce a net decrease in kelp density in the upcoast region of SOK. (3) Fish density is positively related to the density of kelp at SOK.

We estimated fish densities by direct (diver) observation on belt transects of fixed (bottom) or variable (water column) dimensions. Changes in densities at SOK and SMK were evaluated using a "BACI" (Before-After, Control-Impact) sampling and analysis design, in which we compared the density of each of 15 major fish taxa between a SONGS Units 2 and 3 baseline ("preoperational") period of fall 1980-81 and a SONGS "operational" period of fall 1985-86. We compared fish densities

between two pairs of locations: (1) an offshore, upcoast impact station at SOK (SOKU) and an offshore station at SMK (our "between SOK-SMK" comparison); and (2) an inshore, upcoast station at SOK and a station in downcoast SOK (SOKD; our "within-SOK" comparison).

Everywhere, or only at SOK??

Fish densities in general were one-third to three-fourths lower during the SONGS operational period, even though many species increased between 1985 and 1986. In addition, the relative densities of fishes at impact and control stations changed for many species between baseline and operational periods.

Relative densities changed for 40% of all species and life stages tested, including both SOK-SMK and SOKU-SOKD comparisons. Half of the 14 SOK-SMK changes were relative increases at SOK. However, 13/14 of the SOKU-SOKD changes were relative decreases at SOKU. The relative increases at SOK (versus SMK) averaged > 1000%; while the relative decreases averaged > 90%. For the within-SOK comparisons, the relative decreases at SOKU averaged about 90%.

We also characterized the relationship between fish density and kelp density at SOK during fall 1985 and 1986. Our purpose was to formally describe the presumed mechanism for SONGS' impact on the fishes at SOK. Specifically, positive fish-kelp density relations would support a mechanism for impact on fishes through kelp habitat loss at SOK, but neutral or negative relations would not.

why not?

We observed positive relations between fish density and kelp density for 37/43 species and life stages tested. In addition, several other seabed variables (notably the subcanopy kelps Pterygophora and Cystoseira) influenced fish distributions, but were much less important than giant kelp. Inexplicable "location" effects (representing unmeasured, nonrandom variation in fish density) were significant in less than one-fifth of all cases. We conclude that the observed numerical relationships between fish and Macrocystis at SOK were sufficient to explain many of the observed changes in the relative densities of fishes within the upcoast and downcoast regions of SOK.

We further used our estimates of fish densities to estimate the abundance of fishes at SOK during the fall periods of 1985 and 1986. We did this to provide the MRC with an actual measure of the amount of fish involved when discussing observed changes in fish densities. Abundances were estimated by multiplying mean fish

densities, within regions of defined kelp density, by the areal extent of the particular region of kelp density. Areal extents were based on ECOsystem Management Associates, Inc.'s downlooking sonar data on kelp distributions. We also estimated the biomass abundance of fishes at SOK. This was accomplished by multiplying mean numerical abundance by the mean body weight of each respective life stage and species. We estimated body weights by applying length-weight formulae to the length-frequency distributions of fishes. The latter were characterized from tallies made on free swims that complemented our density transects.

An estimated 18 metric tons (MT) of fishes were present in 113 hectares (ha) (ha) of kelp-cobble habitat at SOK in fall 1985. Over 17 MT were resident (nontransient) fishes. In fall 1986, an estimated 39 MT of fishes (35 MT residents) were present in 88 ha of kelp-cobble at SOK. Thus the average biomass density of resident fishes was about 2.5 times greater throughout SOK in fall 1986 (400 kg/ha) than in fall 1985 (150 kg/ha). The density and abundance of Macrocystis meanwhile had decreased by half throughout SOK between fall 1985 and fall 1986 (from 6 to 3 plants/100 m^2 density and from 70,000 to 32,000 adult plants), partly as a result of storm disturbance in winter 1985-86.

The general increases in fish abundance, coupled with the declines in kelp that occurred between fall 1985 and fall 1986, indicate that factors besides giant kelp were importantly influencing the fishes at SOK during this period. Although Macrocystis density positively influenced fish density within SOK, larger spatial and longer temporal scale factors were also exerting a strong influence on fish abundances. Variable recruitment or year-class effects, lagged 1-3 years, are the most likely factors influencing fish population fluctuation on regional and bightwide spatial scales. Recruitment effects are lagged several years at SOK because (1) year-classes are established during larval and early juvenile stages and (2) because the older-juvenile, subadult, and adult fishes that dominate at SOK are the survivors of fish that recruited to shallower, rocky/vegetated habitats in prior years and that subsequently immigrated to SOK.

Regional/bightwide influences notwithstanding, we feel that it is reasonable to evaluate the local (within-SOK) impact of SONGS Units 2 and 3 operations on kelp and fish, as long as large-scale levels of population abundance are kept in mind. We argue as follows: If SONGS operations have caused a three-fourths

What's the basis for this?

reduction in kelp and fish within the inshore, upcoast quadrant of SOK, we reckon that this would have been equivalent to a loss of ~3.3 MT of resident fishes at SOK in fall 1985. (The 3.3 MT value is based on our 18 MT estimate of resident fish biomass at SOK in 1985.) The equivalent loss in fall 1986 would have been ~6.6 MT (based on our 35 MT estimate of resident fish biomass in 1986). We caution that these values may not represent SONGS' average effect. Rigorous estimates of the average local loss of fish, resulting from loss of kelp habitat within SOK, would require knowledge of bightwide levels of fish abundance for an extensive series of years. Rigorous estimates would also require more specific data than is presently available on the average percentage reduction and areal extent of kelp loss at SOK that is attributable to SONGS operations alone.

CHAPTER FOUR -- PENDLETON ARTIFICIAL REEF FISHES

As a complementary assessment of the mitigative potential of Pendleton Artificial Reef (PAR), we estimated the density and abundance of fishes at PAR during the fall periods of 1985 and 1986. It has been suggested that the fishes produced by PAR-like habitat might offset fish losses resulting from SONGS impact on kelp bed habitat (and its fishes) at SOK.

We estimated fish densities at PAR using two complementary types of diver surveys. Total juvenile, subadult, and adult fishes were enumerated on three replicate "JUV-AD" surveys, completed at fortnightly to monthly intervals during each fall season. Young-of-year (YOY) and "older juvenile" substages were surveyed on "JUVENILE" surveys that were completed during the same week as the "JUV-AD" surveys. Both types of surveys were patterned after the bottom transects done for the kelp bed fish study, except that divers more carefully searched narrower bands of habitat on the "JUVENILE" surveys. Abundances were calculated by multiplying estimates of mean density by areal extents of the relevant strata (microhabitats) at PAR. The latter were determined from ECOM's downlooking sonar charts of PAR bathymetry.

We estimate that about 11,000 juvenile-adult fishes weighing about 660 kg were present on rock plus fringing sand-rock ecotone regions of the PAR modules during October-December 1985. In fall 1986, an estimated 16,000 fishes weighing 650 kg were present on rock, ecotone, and adjacent sand regions that we feel best

is it all addition or what was orig. fish density above the sand plain?

characterize PAR's addition to the fish stocks on the local sand plain. Adjusting our fall 1985 rock-ecotone estimates for the fraction of fishes present (during fall 1986) in adjacent sand and in extralimital regions of modules that were not sampled in 1985, we estimate that PAR contributed about 945 kg to local juvenile-adult fish stocks in fall 1985. Our best estimates of standing stock biomass in the two fall seasons thus were equivalent to biomass densities of about 555 kg/ha (in 1985) and 380 kg/ha (1986). Nonresident fishes contributed only 0-5% to these biomass estimates. why did 80K #s incr. from 85 to 86 if # did not?

Shit!

More accurate estimates of YOY and older juvenile densities and abundances were possible using the data of our "JUVENILE" surveys. We estimate that there were over 80,000 juvenile fishes present at PAR in fall 1985, and that 93% of these were blacksmith (*Chromis punctipinnis*). About 98% of the blacksmith were YOY; conversely, about two-thirds of the juveniles of all other species were older juveniles. In fall 1986, we estimate that there were about 38,000 juvenile fishes present. About 85% were blacksmith. As in the previous fall, most blacksmith (94%) were YOY, while three-fourths of all other species were older juveniles.

Our estimates of juvenile-adult biomass and the numbers of YOY-older juvenile fishes together allow realistic (although gross) estimates of fish standing stock and production at PAR in fall 1985-86. Fish production at PAR must be recognized as having two distinct components: local (i.e., produced at and remaining near PAR) and diffuse. We therefore estimated production for the more vagile, older juvenile, subadult, and adult fishes separately from parochial YOY fishes.

Because we can only guess what fraction of later stage production at PAR remains local, we bracketed our estimates as 25%, 50%, or 75% of total production. Total production was estimated as 40% of standing stock biomass, based on representative production-to-biomass ratios for several local sport-commercial fishes. Using this approach, we estimated that the local production of older juvenile through adult life stages was 25-75% of 380 kg (in 1985) and 25-75% of 260 kg (in 1986). These estimates assumed that our fall estimates were typical of average standing stocks in the respective year.

We estimate that the production of YOY fishes at PAR, although mostly if not entirely local, was relatively insubstantial because of low YOY standing stock biomass. Assuming a 1:1 production:biomass ratio for these fast-growing fishes,

an estimated 150 kg of YOY were produced at PAR in 1985. Blacksmith comprised all but an estimated 4 kg. In 1986, we estimate that PAR produced 67 kg of YOY. All but 3 kg of this was blacksmith.

Based on our and R. Ambrose's Mitigation Program studies, we conclude that the sum of local and diffuse fish production at PAR, 5-6 years following construction, was representative of submerged artificial reefs (of 1-ha area) in the Bight. YOY fishes constituted a low (blacksmith) to trivial (all other species) fraction of total production, however. An indefinite but large fraction of the production of later life stages was diffused beyond PAR. The likely "diffuseness" of fish production at PAR is an important consideration, though, only if fish production at SOK, PAR's litmus paper, is significantly more local than at PAR. No data exist on this, although the observed shifts in fish distribution among kelp stands at SOK suggest that fish production is unlikely to be relatively localized at SOK. ?

Despite the caveats about local production, we feel that the fishes at PAR can be meaningfully compared with those at SOK in terms of standing stock biomass. We summarize our gross evaluation as follows: Even if one unrealistically assumes that the entire sand plain encompassing PAR (3.4 ha) is enhanced habitat, this would represent only ~15% of the area within the upcoast, inshore fourth of SOK (~25 ha) in which Macrocystis might have been impacted by the SONGS diffuser plume. If transformation of kelp forest to kelpless cobble habitat off San Onofre has resulted in a three-fourths reduction in fish densities in the upcoast, inshore quadrant of SOK, PAR would mitigate the equivalent of one-third (in 1985) or 10% (in 1986) of the loss at SOK. The unknown relationship between fish density and reef size makes it impossible to estimate the exact multiple of PAR-like habitat that would be necessary to mitigate or compensate for SONGS' impact on kelp and fishes at SOK, however.

But where does it show this in summary?

CHAPTER ONE
FINAL ANALYSES OF SONGS' LOCAL IMPACT ON FISHES BASED ON NET MONITORING SAMPLES

1.1 INTRODUCTION

1.1.1 SONGS Operations and Mechanisms of Local Impact

1.1.1.1 Intake Entrainment

San Onofre Nuclear Generating Station (SONGS), a nuclear power plant located on the exposed outer coast of northern San Diego County, California, between the cities of Oceanside and San Clemente (Fig. 1), uses sea water for plant cooling. The intakes of the once-through cooling systems of SONGS Units 1, 2, and 3 consist of three "offshore intake structures" situated at mid-depths (4 to 5 m below the sea surface) along the 9-m isobath, ~ 1 km offshore of the beach at San Onofre (Fig. 2). The Unit 2 intake is located ~ 200 m downcoast of the Unit 1 intake, and the Unit 3 intake ~ 200 m downcoast of the Unit 2 intake (Fig. 2). At full plant operation, Units 1, 2, and 3 together pump a total of nearly 11 million m^3 of water per day (2.85 billion gallons/day).

Large numbers of the egg, larval, and juvenile-adult stages of fishes are entrained with SONGS' cooling waters (Chapter Two) from within an approximately 1/2-km stretch of coastline. SONGS' operations thus might locally reduce the densities of susceptible life stages (e.g., juveniles) and fish species (queenfish, Seriphus politus) whose behavior places them at particular risk to entrainment at inner-nearshore, midwater intake structures in the San Onofre area (DeMartini and Larson 1980a,b).

1.1.1.2 Discharge Operations

The discharge systems of SONGS Units 2 and 3 differ from that of Unit 1. Unit 1 has a midwater (~ 4-m depth), single-point discharge located about 200 m inshore of the Unit 1 intake (Fig. 2). The Unit 1 discharge outfall has a relatively small, usually offshore-directed surface plume (Reitzel 1979). Units 2 and 3 each have their own "diffuser" system, designed to discharge cooling waters back over an area sufficiently large to avoid > 4°F temperature rises in waters within 1000 ft of the outfalls. Each diffuser system consists of 63 ports that exit a primary subseabed discharge conduit at ~ 12-m intervals. Conduits extend approximately offshore of the units (Fig. 2). Ports are 4 ft in diameter, discharge at ~ 2 m above bottom, and are angled upwards 20 degrees and offshore to promote mixing with bottom waters (by secondary entrainment) and diffusion with waters farther offshore. The Unit 2 system begins in ~ 13 m of water and extends offshore 2.6 km to end in ~ 15 m of water. The Unit 3 system extends 1.9 km from ~ 10-m to ~12-m bottom depths (MRC 1979; Reitzel 1979; Fig. 2).

The discharge effluents of all SONGS units contain particulate organic materials, whose sources include the remains of entrained planktonic and free-swimming organisms and the tissues of biofoulers that line discharge conduit walls. It has been predicted that organisms discharged by the plumes might contribute to localized changes in sediment particle size and sediment organics and thus to changes in benthos composition and the local distribution and abundance of some fishes that feed upon the altered benthos (DeMartini and Larson 1980a,b; DeMartini et al. 1983a,b). The diffusion model upon which these initial predictions were based has been disputed because empirical data on the effective quantity and size-distribution of diffuser particulates, and their fate once reaching the seabed, is lacking. Nonetheless, evaluations of SONGS operational-phase increases in local sediment organics (Barnett, Watts, and White 1986), and preliminary analyses of recent local changes in the abundances of certain benthic invertebrates (Barnett et al. 1986) and benthic fishes (most recently reviewed by DeMartini et al. 1986), have all been consistent with this impact hypothesis.

SONGS diffuser plumes also have been implicated in another type of local habitat alteration--a reduction in the amount of giant kelp (Macrocystis) at the San Onofre Kelp bed (SOK). It has been predicted that the operations of the SONGS Units

2 and 3 intakes and diffusers, by entraining turbid, epibenthic waters near shore and discharging these waters nearer the surface and farther offshore, will decrease illumination near the seabed within SOK (Dean et al. 1983). These lower light levels will, over time, preclude natural reseeding of young kelp sporophytes during the brief clear-water recruitment "windows" that occur at sporadic intervals (Dean et al. 1983). Our final evaluation of SONGS' potential impact on the fishes inhabiting SOK is presented in Chapter Three.

1.1.2 Sampling to Detect Local Impacts

Potential local SONGS impacts resulting from (1) entrainment of the juveniles of midwater fishes and (2) changes in benthic fish stocks beneath and offshore of SONGS' diffuser plumes lend themselves to two techniques of abundance estimation:

(1) Declines in the local abundance of nearshore pelagic (midwater) fishes can be indexed using the catch data of lampara seines. The lampara seine is a type of encircling net that entraps fishes between the sea surface and seabed within a prescribed area (Methods Section 1.2.1.1; also see Appendix A, part 1). When the nets are deployed properly, nighttime seine-hauls off San Onofre provide acceptably accurate and precise indices of abundance for several taxa of fishes (Allen and DeMartini 1983).

(2) Changes in the local abundances of fishes occurring near the seabed beneath/offshore of SONGS' diffuser plumes can be monitored by the catch data of otter trawls. The otter trawl is a type of drag net that is pulled along the seabed from the stern of a motor vessel (Methods Section 1.2.3.1; also Appendix A, part 2). Otter trawls yield acceptable indices of abundance for benthic fishes at shallow-shelf depths (Mearns and Allen 1978). Nighttime trawls near San Onofre provide highly repeatable measures of abundance for many species of fish (DeMartini and Allen 1984).

1.1.3 Review of Net-Monitoring Studies Near SONGS

Several agencies have contributed to diverse net-monitoring studies near SONGS. Studies have varied greatly in temporal and spatial scope. The first major series of studies began in the mid to late seventies with the advent of the California Coastal Commission's mandate to assess Unit 1's effects. Brief reviews of these and subsequent studies follow.

Southern California Edison (SCE) contractors initiated seasonal gill-net surveys in the general San Onofre area in March 1975. These surveys provided species lists of inner-nearshore, midwater, and epibenthic fishes near SONGS. Surveys became bimonthly in March 1978. Routine gill-net surveys ended in 1981; summary data are provided by Southern California Edison (SCE 1982). MRC-contracted studies began in 1976-77 when Tetratech Inc. used bag seines to sample surf-zone fishes. Additional sampling of midwater fishes at distances to ~ 4 km offshore (20-m isobath) was also performed by Tetratech (1977a,b). The latter lampara data mainly complemented the previous and ongoing gill-net lists and provided some basis for the design of future MRC studies.

Assessment of Unit 1's effects continued in 1978 with the initiation of quantitative net monitoring by the MRC's University of California, Santa Barbara (UCSB) contractor. Lampara seine surveys conducted during 1978-79 were used to evaluate the feasibility of a queenfish mark-recapture study and the feasibility of using lampara seines to monitor the composition and abundance of midwater fishes (particularly queenfish) at 5- to > 25-m bottom depths, near and at varying distances from the SONGS Unit 1 offshore intake structure. Mark-recapture studies of queenfish were found unfeasible. However, the lampara seine used was judged to be an efficient sampler of queenfish and other common midwater fishes. Few Unit 1 effects were large enough to be statistically significant, but it was predicted that the entrapment magnitude of the two new SONGS units combined might generate a detectable ($\geq$ 50%) nearfield abundance depression for queenfish, the species at greatest apparent risk (DeMartini and Larson 1980a,b). Early lampara catches also provided otolith (earstone) and ovary samples for queenfish age/growth and fecundity analyses; these data contributed to the population turnover estimates used in evaluating Unit 1's effects (DeMartini and Larson 1980b).

An amended design using lampara seines was thereafter used to construct the SONGS Units 2 and 3 abundance baseline for queenfish and other common midwater fishes; these studies began in September 1979 (DeMartini et al. 1981a, 1983a,b). During the early eighties, seine and trawl catches also were used to provide food habits data for two common and economically important fishes of the San Onofre area--California halibut (Paralichthys californicus) and barred sand bass (Paralabrax nebulifer). The results of these studies, although not useful for evaluating SONGS (DeMartini et al. 1982d,e), provided some complementary data (Plummer et al. 1983; Roberts et al. 1984). Seine and trawl catches also provided sample fish of several other species for other, also uneventful food habits analyses (Gleye and Bernstein 1981).

Other early (1978-79) UCSB net operations (surf-zone sampling with bag seines) were conducted in order to test the feasibility of abundance monitoring and of a mark-recapture study of the local movements of another heavily entrapped species, the walleye surfperch (Hyperprosopon argenteum). Seining also provided surfperch samples for age/growth and fecundity analyses. Surf-zone monitoring with bag seines was judged unquantitative, and mark-recapture impractical. Growth and reproductive parameters were, however, estimable for walleye surfperch (DeMartini, Moore, and Plummer 1983).

Quantitative, SCE-contracted net monitoring off SONGS began with Lockheed's otter-trawl surveys in March 1978. The Lockheed surveys continued through 1981, when they were replaced with the expanded (bightwide) trawl surveys of a second SCE contractor (Occidental College). Occidental College's bightwide surveys (summarized for 1982-84 by Love et al. 1986) continued through 1986. The 1978-79 Lockheed surveys (SCE 1979) provide the first baseline distribution and abundance data for near-seabed fish stocks at 6-, 12- and 18-m bottom depths off SONGS (reviewed in SCE 1982).

MRC-contracted monitoring of benthic fishes began with the pilot January-April 1980 trawl surveys of the UCSB contractor. The design of the latter surveys was refined, and the surveys were continued to provide the SONGS Units 2 and 3 abundance baseline for benthic fishes (DeMartini et al. 1983a,b).

1.1.4 Objectives

Chapter One has three main objectives.

First, we complete our comparisons of baseline versus operational-phase fish abundances at nearfield and farfield (control) locations. We use the statistical analyses of seine and trawl catches as the major basis of our impact evaluation for select species of midwater and benthic fishes, respectively. Our goals have been (1) to determine whether SONGS Units 2 and 3 entrapment has caused a "local" reduction (near the SONGS intakes) in the abundance of target midwater taxa; and (2) to determine whether Units 2 and 3 discharge operations have caused local changes in the abundance of benthic fishes near the seabed under the plume. The basis for (1) would be a relative decrease in catches of midwater fishes at sampling stations near the intakes compared to a control station, between baseline and Units 2 and 3 operational periods (Appendix A, part 1). The basis for (2) would be an analogous change in catches of benthic fishes near the seabed offshore of the SONGS diffusers (Appendix A, part 2).

Second, we provide our final, supplementary evaluations of time-series catch and size-frequency data for these fishes. We use these data to describe biological patterns of temporal and spatial distribution. These patterns help interpret impact test results and also help delimit the spatial scale of impacts.

Third, we generally discuss our net-monitoring results in terms of known or suspected mechanisms of impact. We defer to Chapter Two a more detailed discussion of SONGS entrapment as the mechanism behind near-SONGS intake declines in juvenile midwater fishes. Evaluation of the mechanisms eliciting local changes in benthic fishes is based on Marine Ecological Consultants' (MEC's) Final Report on benthic, soft-bottom invertebrates (Barnett 1987). MEC's findings are used to interpret patterns of abundance for benthic species and for the life stages (large adults) of several species (queenfish and white croaker) that occur near the seabed (DeMartini and Allen 1984). (The juvenile-small adult stages of queenfish and croaker are distributed throughout the water column: Allen and DeMartini 1983; DeMartini, Allen, Fountain and Roberts 1985.)

1.2 SAMPLING AND ANALYSIS METHODS

1.2.1 Lampara Seine: Gear and Study Design

1.2.1.1 Sampling Gear

A lampara seine is a type of semipursing, round haul net commonly used in the southern California live-bait fishery (Scofield 1951). Lampara seines can provide the most accurate data on the species and size composition of juvenile-adult fish at primary risk to entrapment at midwater intake structures (Thomas et al. 1979; DeMartini et al. 1983a,b). A seine of constant dimensions, fished in consistent fashion, was used to monitor the abundances of midwater (coastal-pelagic) fishes in the San Onofre area from the beginning of Units 2 and 3 baseline monitoring (in September 1979) through the completion of operational-phase monitoring in August 1986. The seine fished from surface to seabed at depths < 20 m; the fish commonly sampled thus included epibenthic (e.g., large, adult white croaker Genyonemus lineatus) as well as midwater life stages (juvenile white croaker) and truly pelagic species (e.g., Pacific butterfish, Peprilus simillimus). Details of net design and fishing protocols are described in Appendix A, part 1.

1.2.1.2 Sampling Design

Sampling design was fixed to conform to the BACI (Before-After, Impact-Control) pairs analysis design (Fig. 3; Stewart-Oaten 1986; Stewart-Oaten et al. 1986). Within each of the two periods (baseline or "Before", operational or "After") being compared, samples were replicated over single-night cruises. Baseline (preoperational) and operational monitoring periods were defined on the basis of pumping history at Units 2 and 3. See Appendix A, part 1 for further details and Table 1 therein for a list of sampling dates. (Note that samples were collected at reduced effort during an intervening "interim" period of SONGS' partial operation but that these samples were not used for impact tests. Interim samples provided continuity between baseline and operational periods.) On each date, a single seine-haul was made within each of two depth blocks at each of three longshore locations (six samples: Appendix A, Fig. 1). A shallow depth block (S: 5-10 m) included the depth of the SONGS offshore intake structures (8-9 m). A mid-depth block (M: 11-16 m) centered on the average depth of the Units 2 and 3 diffuser lines (~ 13 m). On each date, the positions of seine-hauls were selected randomly from within each 1-km

x 1-km depth block (Appendix A, Fig. 1). The three longshore locations were chosen to represent (1) the SONGS nearfield region of most likely potential impact (the "Near Impact" location, NI: $\leq$ 1/2 km of the Unit 1 intake), (2) a near control or "Far Impact" location (FI: 2-3 km downcoast of the Unit 1 line), and (3) a distant "Control" location (C: 18-19 km downcoast of Unit 1, off Stuart Mesa) (Appendix A, Fig. 1).

All samples used in BACI analyses were collected at night in order to minimize visual net avoidance and reduce sampling error (DeMartini et al. 1983a,b; Allen and DeMartini 1983).

Sample size (number of dates) was chosen based on the results of power tests (Cohen 1977) of baseline data. Standard deviations of baseline deltas (see Analysis Methods, Section 1.2.2.2) were used to estimate the total (baseline plus operational) sample size necessary to detect a $\geq$ 50% decline in net catch per unit of effort (CPUE). Sample size was calculated for a power (1 minus beta; i.e., 1 minus the probability of a Type II error) of $\geq$ 0.80, at one-tailed alphas (probabilities of Type I error) of 0.05 and 0.10 (Cohen 1977). Sample size estimates assumed that the standard deviations of operational-period and baseline deltas would be equivalent (Cohen 1977). Estimates were evaluated for log 10 (X+1) data (Section 1.2.2.2). Sample sizes were chosen based on results for queenfish of all sizes and sexes pooled (DeMartini et al. 1983a,b).

1.2.2 Lampara Seine: Data and Analysis Methods

1.2.2.1 Types of Data

Seine catches provided information on catch per unit of effort (CPUE), a type of relative abundance data used in fisheries research. The unit of effort in this case was a seine-haul of standard surface area (and constant average volume, within a given depth block). Numerical CPUE was recorded for all species, and biomass CPUE was determined for white croaker and queenfish (*Seriphus politus*). Sex/maturity plus length-frequency data (standard length, SL, in mm) for queenfish were used to further subdivide CPUE of this target species. Queenfish were examined by size and sex because fish of the various sizes and sexes appear differentially susceptible to entrapment due to differences in diel behavior and water-column distribution (DeMartini, Allen, Fountain and Roberts 1985; for details, see Appendix A, part 1). Other details of data collection are described in Appendix A, part 1.

CPUE (numbers), being less variable than biomass CPUE (Allen and DeMartini 1983), provided the basis for impact analyses. Four major taxa were sufficiently common and abundant in baseline samples to warrant impact analyses: queenfish, white croaker, Pacific butterfish, and the "silversides" complex of three species--jacksmelt (Atherinopsis californiensis), topsmelt (Atherinops affinis), and grunion (Leuresthes tenuis) (DeMartini et al. 1983a,b). (Silversides were pooled because resolution to species aboard ship was too time consuming and because other time and cost limitations precluded laboratory examination.)

Although northern anchovy (Engraulis mordax) dominated seine catches, we have not included this species in our impact analysis because (1) the extreme variability, hence very low power, of its baseline catches prompted a priori exclusion, and (2) because subsequent analyses by J. Kastandiek and K. Parker of the MRC have confirmed our initial observations and have not been able to detect nontrivial ($\geq$ 50%) nominal declines or changes.

Appendix C lists abundance and frequency occurrence data for all seine-caught fishes. For all species referred to in this report, we use the scientific and common names of Robins et al. (1980). After cross-referencing scientific names when first mentioned, we subsequently refer to all fishes by common name.

Biomass data for queenfish and white croaker are used in analyses that complement our BACI tests for SONGS impact.

1.2.2.2 Analysis Methods

BACI Tests. Numerical CPUE data were compared between longshore locations on a date-by-date basis according to the BACI (Before-After, Control-Impact) pairs design of Stewart-Oaten (1986; Stewart-Oaten et al. 1986). We made the a priori assumption that a multiplicative model of natural population fluctuation and power-plant impact was appropriate (see McKenzie et al. 1977; Skalski and McKenzie 1982); i.e.,

$$A_I = k \cdot A_C \quad ,$$

where A_I = abundance at the Impact location,

A_c = abundance at the Control location, and
k = a natural constant of proportionality.

In other words, a constant fraction of a population (in this case, fish stock) is subject to impact, whereas the actual numbers impacted depend on stock abundance. Such a model has the highly desirable property of being log-linear. That is, the effects of power-plant impact and natural changes (seasonal effects, etc.) are additive when the abundance data are transformed to logarithms, as

$$\log A_I = \log k + \log A_c \quad .$$

We also evaluated a linear model based on untransformed catch data. We evaluated raw data as the most straightforward alternative to the logarithmic transformation. (In no case, however, was raw data, if acceptable, more suitable than logarithms.) More complex data manipulations (e.g., an inverse transformation: the number of seine-hauls per individual fish caught) were not considered meaningful.

The "delta" (difference) of log-catches thus was used as our analysis variable. And the "delta-bar" (mean difference) served as our test variable for comparison of the average abundance, at Impact relative to Control location, between baseline and operational periods. By convention, base-10 logarithms were used, and deltas were expressed as "Impact minus Control" (i.e., NI - C, FI - C, NI - FI). Final impact analyses were based on Student's t-tests of the Before versus After deltas, with degrees of freedom adjusted for unequal variances (Satterthwaite 1946), as necessary. T-tests were evaluated at a one-tailed alpha of either 0.05 or 0.10, depending on power. (If power was $\geq$ 0.80, an alpha of 0.05 was used, if power was < 0.80, an alpha of 0.10 was considered sufficient to reject the null hypothesis of no decline.) A one-tailed test was used in all cases because our a priori prediction was that SONGS' entrapment would generate a local decline in fish numbers, if SONGS operations were having an effect on midwater fishes.

The magnitude of significant baseline versus operational percentage changes in abundance near SONGS was estimated using J. Callahan's algorithm for the log-linear (multiplicative) model (Appendix A, part 3). Simple fractional changes (between periods) in raw catch data were also calculated at a given location as a further basis for comparison.

Statistical Assumptions. Deltas were subjected to several major screening tests prior to BACI t-tests. The critical assumptions tested were (1) additivity and (2) monotone trend of the baseline deltas. Autocorrelation of both baseline and operational-period deltas was evaluated as a complementary exercise. All screening tests were evaluated at a significance level of 0.05.

Although the area sampled by seine was chosen in part to minimize the probability of zero catches, zero catches sometimes occurred for one or both of a pair of matched seine-hauls. Dates on which no fish were caught at either location (double zeroes) were excluded from analysis on the bases that these data represented real co-absences and that SONGS could not further affect local abundances for dates on which no organisms occurred anywhere in the general sampling region (Stewart-Oaten 1986).

Dates on which fish were caught at only one of the two locations (single zeroes) were retained in analyses. Inclusion of single-zero catches, however, necessitated the adding of an constant so as to avoid the undefined logarithm of zero. Thus, the data transformation evaluated for, and used in, impact analysis was:

$$Y = \log 10\ (X+c) \quad ,$$

where X = raw CPUE, and
c = constant.

Constants were chosen independently for each species, depth block, and location-pair. A range of increments from 0.03125 ($\{0.5\}^5$, where 1 is the smallest possible positive catch of one fish in a single haul) to 10 (ten times the smallest possible catch) were evaluated. Choice of increment was based on the results of an evaluation of the additivity of baseline deltas. As above, the deltas here evaluated were differences between log 10 (catch + constant) at Impact and Control locations. Additivity was tested by least squares regression of the deltas of log-catches (as dependent variable) on the sum of the log-catches at Impact and Control (Stewart-Oaten 1986). Only constants < 25% of the smallest of the four location-period means (raw catch data) were considered. If more than one increment value was additive, the smallest increment tested (i.e., that value that usually perturbed the raw catch data the least) was chosen.

Most cases of nonadditivity were considered serious violations of the assumption. However, nonadditivity of baseline deltas was not considered a meaningful assumption violation if a "large" percentage of the deltas were based on single-zero observations (Stewart-Oaten 1986). Values $\geq$ 25% were considered unacceptably large. For these special cases of potentially spurious nonadditivity, the data were re-evaluated using a binomial test (Siegel 1956). The one-tailed binomial test that was used evaluated the relative frequency at which catches were smaller at the impact station during the After versus Before periods. (Additivity was not an assumption of the binomial test.)

Additive baseline deltas were further evaluated for trend. Presence of a trend in baseline deltas would indicate a varying proportionality between abundances at Impact and Control locations tantamount to having chosen an inadequate control location. Preimpact trend was evaluated by least squares regression of baseline deltas (as dependent variable) on sampling date. Linear regression was used to test for the simplest (monotone) type of trend (Stewart-Oaten 1986). All cases of trend violation were further evaluated for the potentially overwhelming effect of one to several "influence points". Influence points were identified as those outliers among the residuals that strongly influenced values of the regression coefficients. Our a priori protocol was that, if significant trend could be attributed to only one or two data points, we would subsequently perform the t-test for impact (including the outlier data), but interpret the results with a caveat. In general, nonremovable baseline trend was considered a serious assumption violation.

Abundance deltas may not be directly suitable for t-test analysis even if baseline data are additive and lacking in temporal trend (Stewart-Oaten 1986). Serial correlation, if present, effectively reduces degrees of freedom because of nonindependence of samples (Stewart-Oaten 1986). Serial correlation might occur if, as for lampara sampling, intervals between sampling dates vary because inclement weather and vessel unavailability sometimes required sampling at less-than-weekly intervals. Both baseline and operational-period catch-deltas were initially evaluated for the presence of serial correlation using von Neumann's test (Stewart-Oaten 1986). If serial correlation was present, autoregressive errors of orders one and two were included in the model and the effect of serial correlation thereby removed.

Analysis Methods: Complementary Tests. As designed, t-tests of SONGS operational-period changes in Impact-Control differences evaluate patterns of abundance within depth blocks independently of one another. (The depth factor has been excluded from the analysis model in order to independently test for "intake-depth" declines {at 5-10 m} versus "diffuser-depth" changes {at 11-16 m}). For fish that are common and abundant in both depth blocks (e.g., adult male queenfish), the potential complications of depth-by-location interactions are overlooked if t-tests alone are used to interpret patterns. For species well represented in both depth blocks during the baseline period, we therefore used a three-factor ANOVA to test whether a location-by-period-by-depth interaction might be obscuring our location-by-period impact tests. Such a three-way interaction might occur, for example, if a fish's depth distribution shifted offshore in response to SONGS' diffuser plume. If so, catches might decline within the intake depth block while increasing at diffuser depths. No effect on overall abundances near SONGS might occur, despite one or more significant t-test results. ANOVAs thus provided a major means of interpreting BACI t-test results.

ANOVA tests utilized the same data used in t-tests for each of the two component depth blocks with the following exceptions. (1) ANOVA runs excluded dates with "triple-zero" catches but included dates with double zeroes. Double zeroes were included because the location treatment effect was evaluated for three levels (i.e., for the three longshore locations). (2) For any particular species or queenfish sex/maturity category, the value of the constant "c" (added to its catch before the transformation to logs) was the increment that most generally satisfied the additivity assumption for the three pairwise BACI t-test contrasts. (3) Data used were restricted to those dates on which shallow and mid-depth collections were made on the same cruise. Data for cruises made prior to June 8, 1981 were therefore omitted. ANOVAs were run for all species and queenfish categories that did not seriously violate the additivity assumption; cases with minor trend violations or serial correlation were tested anyway and results interpreted with caution.

Size-frequency data also were used to interpret the impact test results for queenfish and white croaker. Kolmolgorov-Smirnov (K-S) two-sample tests were used to compare length data (1) between SONGS-operational periods at a location and (2) between pairs of locations within each SONGS operating period. Histograms of percentage frequencies were used to interpret K-S test results.

All screening test, t-test, and complementary ANOVA and other analyses were performed on the IBM 4341 computer system at the MRC's Encinitas facility. Appendix B provides an annotated listing of the SAS programs used to generate results. These programs also identify relevant data bases and describe the data manipulations that were performed prior to statistical analysis.

1.2.3 Otter Trawl: Gear and Study Design

1.2.3.1 Sampling Gear

Otter trawls are drag nets used to capture bottom-oriented fish in certain commercial fisheries. Modified smaller versions are used as research tools to monitor the abundance of fishes occurring on and a short distance above unconsolidated substrates. The size, design, and fishing protocols of the trawl used off San Onofre were those recommended by Mearns and Allen (1978) for monitoring benthic fishes on the open coastal shelf of southern California. A detailed description of the trawl gear and sampling protocols is provided in Appendix A, part 2.

1.2.3.2 Sampling Design

The design of trawl sampling also conformed to the BACI pairs design (Stewart-Oaten 1986; Stewart-Oaten et al. 1986). Within both preoperational (baseline) and operational periods of comparison, samples were replicated over single-night cruises. Baseline and operational periods were defined based on pumping history at SONGS Units 2 and 3. Appendix A, part 2, provides further details of design, and Table 3 therein lists all sampling dates.

Otter trawl surveys differed from lampara seine surveys in that multiple trawls were made at each station on each cruise. Within-station replicates were always four in number. Stations were defined by discrete depth and longshore location. Two depths (18 m, 30 m) were sampled. Two longshore locations were sampled (SONGS Impact: $\leq$ 1 km upcoast to 2 km downcoast of the Unit 1 line; and Stuart Mesa Control: ~ 17-20 km downcoast of Unit 1; Appendix A, Fig. 2). Depths were chosen to represent an off-diffuser depth (at 18 m, since the SONGS diffusers discharge over 10- to 15-m bottom depths) and an off-plume depth (at 30 m, since the diffuser plume is sometimes traceable to 5 or more km offshore: Reitzel 1979). All samples used in

BACI analyses were collected at night in order to get more precise catch estimates for a greater number of representative species (DeMartini et al. 1983a,b; DeMartini and Allen 1984).

A key aspect of the design of the trawl surveys was that all four combinations of depths and locations were sampled on each cruise so as to minimize the possible effects of date on the relative distribution and abundance of fishes at the two longshore locations.

Sample sizes were based on the results of power tests (Cohen 1977) of baseline data. Choice of sample size was based on our evaluation for a majority of species-depth combinations whose log 10 (X+1) baseline data were statistically tractable (DeMartini et al. 1983a,b). See Section 1.2.1.2 for further details.

1.2.4 Otter Trawl: Data and Analysis Methods

1.2.4.1 Types of Data

Otter trawls also provide catch-per-unit-of-effort (CPUE) data. The unit of effort is a trawl-haul of standard distance (area swept). Numerical and biomass CPUE were recorded for all species. Length frequencies were also measured for select species at one or both depths. Details of data collection are described in Appendix A, part 2.

All impact analyses were based on numerical trawl CPUE. Biomass CPUE show the same patterns but with less precision because the variances are larger (DeMartini and Allen 1984).

Ten species combinations were sufficiently common and abundant (i.e., had reasonable power) in baseline trawl catches at one or both depths to warrant meaningful comparisons between longshore locations during the two SONGS' operating periods (DeMartini et al. 1983a,b). Analysis of interim trawl data (1982-84; DeMartini et al. 1984c) prompted the addition of several more species for impact evaluation. Appendix D lists all 22 species-depth combinations used in our impact analysis of trawl-caught fishes. These 22 combinations represent the upper tail of the distributions of both counts and frequency of occurrence in baseline trawls (Appendix C, Tables 13-16 and 17-20). Abundance and frequency of occurrence data are

listed for benthic fishes in Appendix C. (Incidental catches of pelagic species such as Pacific butterfish and northern anchovy are omitted.) Accepted common names (Robins et al. 1980) are used throughout this report.

Biomass data for queenfish, white croaker and total fishes (all species) are used in analyses that complement our BACI tests for SONGS impact.

1.2.4.2 Analysis Methods: BACI T-Tests

Numerical CPUE data were compared, within each depth block, between the single pair of longshore locations using the BACI (Before-After, Control-Impact) pairs design (Stewart-Oaten 1986; Stewart-Oaten et al. 1986). A multiplicative model using the deltas of log-transformed catch data was used (see Section 1.2.2). The only difference between the analysis designs for lampara seine and otter trawl was that the basic unit of analysis for trawls was the mean of the four trawl catches at a station on a date. Constants used to avoid the log of zero were added to the mean of the four trawl data. The values of the constants that were evaluated ranged from 0.0156 ($\{0.25\}^3$, where 0.25 represents the smallest possible positive catch of one fish in four trawls) to 10 (40 times larger than the smallest possible catch). Double zeroes were again excluded from analysis (Section 1.2.2).

The delta (difference) in the logarithms of mean catch was the test variable in our t-tests for impact (Section 1.2.2). Prior to impact tests, screening tests were used to detect species that were inappropriate for statistical analyses at a given depth because of nonadditivity or monotone trend in baseline deltas. If serial correlation was present, autoregressive errors were included in the t-test model (Section 1.2.2). See Appendices D and E for additional details.

1.2.4.3 Analysis Methods: Complementary Tests

As for lampara seine data, three-way ANOVAs were used to evaluate whether distributional shifts were obscuring abundance changes at depth. Double zeroes were excluded (Section 1.2.2). Size-frequency data also were used to interpret impact test results for select species at representative depths (Section 1.2.2).

1.3 RESULTS

1.3.1 BACI T-Tests

1.3.1.1 General Patterns for Coastal-Pelagic Fishes

Summary of BACI Findings. Two species (queenfish and white croaker), considered at major risk to SONGS entrapment, declined from ~60 to > 90% near SONGS, relative to control locations, during the operational monitoring period. Two other taxa (Pacific butterfish and silversides), not at great risk to entrapment, did not decline near SONGS. Near-SONGS declines in white croaker were > 90% and involved juvenile fish at intake depths within 1/2-km of the SONGS Unit 1 intake. Queenfish declines near SONGS were represented by both juvenile and adult fish: YOY and other juveniles declined 62-86% at intake depths within 1/2-km of the Unit 1 intake. Significant declines of 55-70% in YOY and other juvenile abundance were also detected at diffuser depths off SONGS. Adult queenfish generally declined only at intake depths, but relative declines were detectable to 2-3 km downcoast of Unit 1. Declines in adults 2-3 km downcoast were 60-80%, about the same magnitude as declines within 1/2-km of Unit 1.

Results of Screening Tests. A total of 48 species-depth-block combinations of coastal-pelagic (midwater) fishes were screened for statistical suitability in BACI t-tests. Queenfish life stages represented 30/48 cases. Detailed results are presented in Appendix D. A brief summary of BACI screening test results follows.

At 5- to 10-m depths, 22/24 cases were statistically tractable (Appendix D, Table 1). At 11- to 16-m depths, 21/24 cases were tractable (Appendix D, Table 2; also see Discussion, Section 1.4.1.2). At 5-10 m, two cases seemed to violate the assumption of statistical additivity, while another case had an unresolvable temporal trend in baseline data (Appendix D, Table 1). The failed additivity test for the NI - C comparison of white croaker, however, was inconclusive because of the large percentage (26%) of single zeroes in preoperational catches. The t-test comparison between NI and C locations was considered tractable for white croaker; in addition, the white croaker data were identified for evaluation using a more conservative (binomial) test. At 11-16 m, all 3 of the intractable cases violated additivity; in addition, two cases had significant monotone trend (Appendix D, Table 2).

Analyses for 7 of the 22 tractable cases at shallow depths were complicated by serial correlation within the baseline and/or operational time series. However, all 7 cases could be corrected for first- and/or second-order autoregressive errors (Appendix D, Table 1). All 7 had detectable first-order (lag one cruise) autocorrelated errors. Two cases of serial correlation were detected in the 11- to 16-m data, but these were similarly correctable (Appendix D, Table 2). One of the latter cases had detectable second-order (lag two cruises) as well as first-order effects.

Tally of BACI Test Results. At intake depths, significant (at one-tailed $P \leq 0.05$) declines in the relative magnitude of seine CPUE between baseline and SONGS-operational periods were detected for 5 of the 7 tractable Near Impact (NI) minus Control (C) location contrasts (Table 1; Appendix E, Table 1). Analogous declines were detected for 4 of the 7 tractable NI minus Far Impact (FI) pairs (Appendix E, Table 1). Of the 8 valid FI minus Control contrasts, 3 were notable: 2 were significant relative declines, and another was a case of unexpected increase at the FI location (Appendix E, Table 1). Overall, 12 of 22 tractable cases tested were notable, 11 were significant, and 9/11 were disproportionate declines at the Near Impact location relative to either the Far Impact station or the distant Control location (Appendix E, Table 1).

At diffuser depths, only 3 of 21 tractable cases were significant declines at a one-tailed alpha of ≤ 0.05 (Appendix E, Table 2). Another 2 cases were significant at a one-tailed alpha of 0.10 (Appendix E, Table 2). (Evaluation at $\alpha_1 = 0.10$ was justified in these 2 cases because both had power < 0.80 at $\alpha_1 = 0.05$; see Appendix E, Table 6.) Two of the 5 cases of significance were contrasts between the Near Impact and Control locations; the remaining 3 were Far Impact minus Control comparisons (Appendix E, Table 2.)

Disproportionate decreases near SONGS were large in magnitude (> 60%; Appendix E, Table 1), and most reflected large absolute changes in catch as well (Table 2). Near-SONGS declines in CPUE were absolutely large (usually > 20 fish per seine-haul) despite the general halving of fish abundance throughout the San Onofre-Oceanside area in recent years (Table 2; also see Appendix C, Tables 1-12 and Figs. 1, 2). Disproportionate declines were absolutely large because baseline catches were substantial (Table 2).

These general results are treated on a case-by-case basis in the species account that follows.

1.3.1.2 Species Account: BACI T-Test Results for Pelagics

Pacific Butterfish. Trivial changes in seine CPUE occurred at either intake depths (5- to 10-m) or at diffuser depths (11- to 16- m) off SONGS relative to the other sampling locations (Tables 1-3; Appendix E, Tables 1, 2). Catches declined throughout the San Onofre-Oceanside area in 1982-84 and were further depressed in 1984-86 (Table 2; Appendix E, Figs. 1-3).

White Croaker. Very large (> 90%) percentage declines of this species occurred during the operational period at intake depths at the Near Impact location (within 1/2-km distance of the SONGS Unit 1 intake), relative to either the Control location (18-19 km downcoast of SONGS) or the Far Impact (FI) location 2-3 km downcoast (Table 1; Appendix E, Tables 1, 3 and Figs. 4-6). No disproportionate declines were detected at diffuser depths (Appendix E, Table 2). Operational-period catches at Control and FI locations were indistinguishable in either depth block (Appendix E, Tables 1, 2). Operational-period catches at FI and Control locations increased to about one-fourth of average baseline levels at intake depths after a nadir of 10% of baseline during the interim period of summer 1982-winter 1984 (Tables 2, 3).

Queenfish. Demonstrable declines in the catches of total queenfish (all sexes and maturity stages pooled) occurred at the Near and Far Impact locations relative to the Control station, depending on depth block (Appendix E, Tables 1,2). Results largely reflect those for immature fish, which contribute most to total numerical catch (Table 2). During the interim and operational periods, seine catches of queenfish declined to 25% to 75% of baseline levels, depending on longshore location (Tables 2, 3; Appendix E, Figs. 7-9).

Catches of various sex- and maturity-stages differed somewhat in the magnitude, onshore/offshore, and longshore extents of decline. The abundance of some queenfish stages were depressed to a distance of 2-3 km downcoast of SONGS Unit 1, while the spatial extent of the decline of other stages was limited to the Near Impact station. Small (immature and YOY) queenfish generally declined to greater extent within 1/2-km distance of SONGS Unit 1 (versus Control) than larger, older life stages (Appendix E, Table 1). Declines in small queenfish were detected at diffuser

as well as intake depths (Appendix E, Tables 1, 2). Recent catches of both sexes of adult queenfish declined disproportionately near SONGS relative to the distant Control location. Catches of adults at the Far Impact station also declined relative to the Control location (Appendix E, Table 1 and Figs. 10-15). Relative decreases of both immature and YOY stages were limited to the station within 1/2-km distance of the Unit 1 intake (Appendix E, Table 1 and Figs. 16-21).

The aforementioned general declines (San Onofre-Oceanside) in queenfish abundance exhibited no consistent patterns for different size (age) groups and sexes of fish. Average broadscale declines during recent years were evident for adults of both sexes as well as for immatures and YOY (Tables 2, 3).

Silversides. This three-species complex of neustonic planktivores showed no evidence of a recent disproportionate decline near SONGS. Rather, these fishes exhibited a marked (> 5-fold) numerical increase at the Far Impact location (relative to Control) during the SONGS-operational period (Appendix E, Table 1). The relative increase 2-3 km downcoast of SONGS Unit 1 actually represents a lesser local decline: in recent years there have been average > 50% declines in silverside CPUE throughout the San Onofre-Oceanside region (Tables 2, 3; Appendix E, Figs. 22-24). The recent relative increase at the station 2-3 km downcoast has occurred only at intake, not diffuser, depths (Appendix E, Tables 1, 2).

1.3.1.3 General Patterns for Benthic Fishes

Summary of BACI Findings. Six out of ten major species present in baseline trawls changed in abundance at the SONGS Impact station (relative to the Control), between baseline and operational monitoring periods, at one or both of the two (18-m, 30-m) depths sampled. Almost all of the recent changes were increases; two-thirds of the increases ocurred at 30 m. Increases were generally large (from > 200% to > 600%). Changes involved differences of < 1-2 fish per trawl, however, for all species except white croaker, for which the recent, relative increase was ~15 fish per trawl.

Results of Screening Tests. A total of 22 species-depth combinations of benthic fishes were screened prior to BACI t-tests. Detailed results are presented in Appendix D. A brief summary of screening test results follows.

Of the 22 cases, 16 were statistically tractable (Appendix D, Table 3). One case was nonadditive and had trend in its baseline deltas, another case was nonadditive but lacked trend, and the remaining 4 intractable cases had unresolvable baseline trends (Appendix D, Table 3). Of the latter trend violations, only the case for speckled sanddab at 30 m was due to identifiable influence points. Since at least 3 outliers were involved in this case, it was still considered to be intractable. Violations were equally divided among sampling depths (Appendix D, Table 3).

Serial correlation complicated analyses for only 3/16 tractable cases (Appendix D, Table 3). All 3 cases were analyzeable after including autoregressive errors in the t-test model (Appendix D, Table 3).

Tally of BACI Test Results. When evaluated at a two-tailed alpha level of 0.05, significant CPUE changes were detected for 4 out of 16 tractable species-depth combinations (involving 4 species) of benthic fishes (Table 4; Appendix E, Table 4). An additional 3 species-depth combinations (2 more species) were significant at a two-tailed alpha of 0.10 (Table 4; Appendix E, Table 4). (Evaluation at $\alpha_2 = 0.10$ was justified for these latter species because all had power < 0.80 at $\alpha_2 = 0.05$; see Appendix D, Table 7). Of the seven significant changes, six were increases (range: from > 200% to > 600%); only one relative decline (54%) occurred at SONGS (Table 4; Appendix E, Table 4). The decline was for speckled sanddab at 18-m depth; 4/6 of the significant increases occurred at 30 m (Table 4).

Although most relative increases near SONGS were large, raw trawl CPUE (Table 5) illustrate that all but one case (white croaker at 30 m) represent trivially small absolute differences in catches at SONGS and Control locations. Large percentage changes despite small absolute differences reflect the small trawl catches during the operational period (Table 5), a time when benthic fish abundances were generally depressed to one-half or less of baseline averages (Tables 5 and 6; also see Appendix C, Tables 13-16 and Figs. 3, 4).

A species-by-species analysis of the results is provided in the account that follows.

1.3.1.4 Species Account: BACI T-Test Results for Benthics

Results are specified for one or both sampling depths at which baseline abundances were nontrivial:

White Croaker. The near-seabed components of this species generally decreased less off SONGS (versus the Control location) during the operational period (Appendix E, Table 4). However, the nominally large (>> 100 %) relative increases at the 18-m depth were not statistically demonstrable (Table 4; Appendix D, Table 3). The recent huge (> 6-fold) increase at the 30-m depth off SONGS represents our largest observed change in the local abundance of any benthic or pelagic fish (Table 5; Appendix E, Table 4). Despite relative increases off SONGS, the absolute abundance of larger, bottom-oriented white croaker (see Section 1.3.3) declined during 1982-86 to 25% to 50% of baseline levels throughout the San Onofre-Oceanside area (Tables 5, 6; Appendix E, Figs. 25, 26).

Basketweave Cusk-Eel. There were no meaningful spatial patterns to changes in the relative abundance of this nocturnal, burrow-dwelling cusk-eel during the operational period (Table 4; Appendix E, Table 4). Average abundance throughout the San Onofre-Oceanside area declined to about one-third of the baseline level during 1982-84 but rebounded strongly in 1984-86 (Tables 5, 6; Appendix E, Figs. 27, 28).

California Halibut. Recent patterns of change in the abundance of the juveniles-small adults of this economically important flatfish were unsuitable for statistical analysis (Appendix D, Table 3). Abundances generally declined to less than half of baseline levels during 1982-86 (Tables 5, 6; Appendix E, Fig. 29).

California Lizardfish. This medium-sized, benthic roundfish was uncommon at 18-m and 30-m trawl depths during 1980-82 (Table 5). Abundances increased six-fold over the baseline level at 30 m during 1982-84 because of substantial juvenile recruitment in 1982-83 (Table 5). Abundances decreased overall during the operational phase but decreased less off SONGS (Table 5; Appendix E, Table 4 and Figs. 30, 31). Despite the large relative surpluses (200% or more: Tables 5,6; Appendix E, Table 4) at both depths off SONGS during the operational period, the net changes in absolute abundance were << 1 fish per trawl (Table 5).

Queenfish. Large, seabed-oriented adults of this species did not change in relative abundance at 18-m depth during the operational period (Table 4; Appendix E, Table 4) despite large nominal increases off SONGS (Tables 5, 6; Appendix E, Fig. 32). The relative increase at 30 m off SONGS was significant, even though catches actually decreased at both sampling locations during the operational period (Tables 5, 6; Appendix E, Fig. 33).

Longfin Sanddab. Abundance of this relatively large-bodied, midshelf sanddab decreased greatly from baseline levels at both depths and sampling locations during 1982-84 (Table 5). Catches then increased significantly at 18 m off SONGS (relative to Control) during the operational period (Tables 4, 5; Appendix E, Table 4). The relative increase off SONGS during 1984-86 reflected the failure to reestablish baseline levels of abundance at Control at a time when catches rebounded to baseline levels off of the power plant (Table 5). Abundance of this species at 30 m, always greater than at 18 m, remained greater at Control throughout all SONGS monitoring periods from 1980-86 (Tables 5, 6; Appendix E, Figs. 34, 35).

Pacific Sanddab. Catches of this sanddab crashed abruptly in summer 1982 throughout the general San Onofre-Oceanside area (Table 5; Appendix E, Fig. 36). Abundance of this primarily outer-shelf species only sporadically rebounded during 1985-86 to < 20% of baseline levels (Table 5; Appendix E, Fig. 36). There was no change in relative abundance off SONGS and Control (Table 4; Appendix E, Table 4), with somewhat greater numbers off SONGS persisting throughout the baseline and operational periods (Table 5; Appendix E, Table 4 and Fig. 36).

Speckled Sanddab. During the baseline period this small, inner-shelf sanddab had been equivalently abundant off SONGS and Control at 18-m depth (Table 5). In 1982-84, catches generally decreased several-fold or more (Table 5). The 1984-86 rebound from interim lows was less at SONGS than off Control, where abundances actually increased above the baseline level (Tables 5, 6; Appendix E, Fig. 37). The observed decrease off SONGS (over baseline), relative to the absolute increase off Control, represents the only case among major benthic fishes where relative abundances decreased off SONGS (Table 4; Appendix E, Table 4). The relative decline represented several fish per trawl in absolute terms (Table 5). Abundance patterns of this species at 30 m were difficult to interpret (Appendix D, Table 3). It is clear, however, that average catches at 30 m changed little between SONGS monitoring periods at either location (Tables 5, 6; Appendix E, Fig. 38).

Pink Seaperch. Assumption test violations prevented rigorous interpretation of temporal changes in abundance of this small, epibenthic live-bearer (Appendix D, Table 3). Trawl catches of pink seaperch crashed during summer 1982 to an even greater extent than did Pacific sanddab (Table 5; Appendix E, Fig. 39). This species had averaged second only to white croaker in baseline catches (Table 5; Appendix C, Tables 14, 16). Pink seaperch abundance only slightly increased during 1984-86 to about 10% of baseline levels (Tables 5, 6; Appendix E, Fig. 39). Average abundance levels remained nominally twice as great off SONGS as at the Control station (Table 5).

California Skate. No meaningful changes in abundance of this species occurred near the power plant (relative to Control) during the SONGS-operational period (Table 4; Appendix E, Table 4). Average abundance in the general San Onofre-Oceanside area decreased during 1982-86 to about 20% to 40% of its baseline level (Tables 5, 6; Appendix E, Fig. 40).

Fantail Sole. This flatfish was one of the very few benthic fishes whose temporal patterns in abundance differed between the two trawling depths. During 1982-84, abundances halved at 18 m but remained constant (and equivalent at SONGS and Control) at 30 m, where numbers were about double those at 18 m (Table 5; Appendix E, Figs. 41, 42). During the operational period, numbers at 18 m increased about seven-fold over 1982-84 levels at both locations (Tables 5, 6; Appendix E, Table 4). During 1984-86, fantail sole abundance approximately doubled at 30 m off SONGS while mean abundance persisted at < 1 fish per trawl off Control (Table 5; Appendix E, Table 4 and Fig. 42). The relative doubling at 30-m depth off SONGS, although statistically significant, represented < 1 fish per trawl in absolute terms (Table 5).

California Tonguefish. Temporal patterns of abundance of this small, secretive flatfish were statistically uninterpretable at 18-m depth (Appendix D, Table 3; Appendix E, Fig. 43). At 30 m, patterns were interpretable: the baseline two-fold greater abundance at the Control (versus SONGS) station persisted through the operational period (Tables 5, 6; Appendix E, Table 4 and Fig. 44), while abundances increased to an appreciable extent overall (Table 5).

Hornyhead Turbot. Abundance patterns of this medium-sized, small-mouthed flatfish were not suitable for statistical analysis at 30-m depth (Appendix D, Table 3).

Abundances seemed to decrease somewhat at both locations during the operational period (Tables 5, 6). At 18 m, patterns were more interpretable. Relative abundances at the two locations changed to an insignificant extent during the operational period (Table 4) despite a nominal decline off SONGS and a nominal increase at Control (Tables 5, 6; Appendix E, Table 4 and Fig. 45).

1.3.2 Complementary ANOVA Tests

1.3.2.1 ANOVAs for Coastal-Pelagic Fishes

Of the 8 total species and queenfish sex/maturity classes, 6 were deemed suitable for ANOVA analysis (Table 7). In none of the 6 cases were location-by-period-by-depth interactions significant (Table 7). This indicates an absence of onshore/offshore distributional shifts among locations and between periods of SONGS' operation that would obscure BACI t-test results at depth.

Two-way interactions were significant in 4/18 cases (Table 7). They included two location-by-period interactions, and these were consistent with the pair of highly significant BACI t-test results at shallow and mid-depths for total and adult male queenfish (Appendix E, Tables 1, 2). A significant location-by-depth interaction for Pacific butterfish (Table 7) was largely due to disparate depth relations in abundance at the Far Impact and Control locations (Table 2; Appendix E, Figs. 1-3). The significant depth-by-period interaction for adult male queenfish reflected a regional onshore distributional shift of males during 1984-86 (Appendix E, Figs. 10-12).

Main effects were commonplace--results were significant in 10/11 cases not preempted by higher-order effects (Table 7). Depth effects (onshore, offshore) reflected the generally greater densities at shallower depths (Table 2). Temporal effects (period) represent the broadscale catch declines in recent years (Table 2; also Appendix C, Figs. 1, 2).

1.3.2.2 ANOVAS for Benthic Fishes

Nine species of benthically oriented fishes occurred in nontrivial abundance at both 18-m and 30-m depths during the SONGS baseline period; and 6 of these were testable. Location-by-depth-by-period interactions were insignificant for 5/6

series of figures shows that the length distributions of YOY and yearling immature fish were similar for April 1981-May 1982 and April 1984-August 1986 only at the FI and Control locations. At the NI location, modal distributions differed conspicuously between sampling periods, and patterns were consistent for immature and YOY fish (Appendix E, Figs. 50, 51).

The twelve-panel figures (Appendix E, Figs. 53-55) illustrate two interesting patterns of juvenile recruitment. (1) The timing of settlement varied among years over a 3- to 4-month period during summer-early fall but was generally consistent among longshore stations within a given year. (2) The strength of recruitment at the NI location was weak, relative to either the FI or the Control location, only during 1985 and 1986 (Appendix E, Figs. 53-55). Together, observations (1) and (2) suggest that entrapment at the SONGS units, at a time when the average level of pumping was high at all three units during 1985-86 (Chapter 2), was effectively reducing the abundance of YOY queenfish near SONGS' offshore intake structures.

1.3.3.2 Size-Distributions of Target Benthic Fishes

Body-length distributions were characterized for select species trawled at one or both sampling depths. Distributions are displayed in two basic forms.

(1) Four-panel (location-by-period) histograms are used to contrast percentage-frequency distributions between the two SONGS operating periods ("Before" and "After") and the two longshore sampling locations (SONGS and Control). Distributions are presented for 6 species (a total of 9 species-depth combinations) for which there were $\geq$ 75 length data per period and location at a depth (Appendix E, Figs. 56-64).

(2) Twelve-panel (monthly) figures are used to illustrate changes in percentage length frequencies for major species present at each longshore location and sampling depth. Data are presented for 2 species (3 species-depths) for which there were $\geq$ 500 length data per location and depth (Appendix E, Figs. 65-70).

Again, many K-S test results were significant for location comparisons within periods (Appendix E, Table 11) and for period contrasts at each location (Appendix E, Table 12) because of large sample sizes and great power. Visual inspection of histogram plots (Appendix E, Figs. 56-64, 65-70) nonetheless reveals several major

block at 5-10 m) because of generally insufficient data at diffuser depths (11-16 m).

(1) Six-panel (location-by-period) histograms are used to contrast percentage-frequency distributions between the two SONGS-operating periods ("Before" and "After") and the three longshore sampling locations (Near Impact, Far Impact, and Control; Appendix E, Figs. 47-52). Queenfish "Before" characterizations are limited to the April 1981-May 1982 subperiod in order to maintain comparability at all three locations (Appendix E, Figs. 47-51). Only three months of baseline length data exist for white croaker because length measurements of this species were not initiated until March 1982 (Appendix E, Fig. 52). Total queenfish data were also subdivided into four sex/maturity classes (adult males, adult females, immatures, and YOY) for this presentation.

(2) Twelve-panel (monthly) histograms are used to illustrate changes in percentage length frequencies of all queenfish (total individuals) caught at each of the three longshore locations. This time-series display spans the entire baseline, interim, and operational monitoring periods (Appendix E, Figs. 53-55).

All K-S test results were significant ($P \leq 0.05$) for period contrasts at a location (Appendix E, Table 8) and for location comparisons within period (Appendix E, Tables 9, 10). Tests had great power because of large sample sizes (Appendix E, Tables 8-10). Several meaningful patterns emerge from among the many trivial differences (Table 9) upon inspection of the histogram plots (Appendix E, Figs. 47-52).

White Croaker. During March-May 1982, mixed-sized croaker--primarily yearling-(10-12 cm SL) and adult-sized (> 12 cm), and secondarily YOY-sized (< 10 cm: Love et al. 1984)--were present in seine samples at both intake-structure and diffuser depths throughout the general San Onofre-Oceanside area. In contrast, relatively few croaker (other than YOY) were present during April 1984-August 1986 (Appendix E, Fig. 52).

Queenfish. The body-length distributions of queenfish sampled during April 1981-May 1982 and April 1984-August 1986 differed in two major ways. First, the six-panel figures illustrate that the modal sizes of adult-sized (> 10 cm) fish were larger in operational than in baseline samples (Appendix E, Figs. 48, 49). Second, this same

at the shallower depth, unique to this species among the three sanddabs. Greater numbers of adult-sized (> 9 cm) fish were present in operational (relative to baseline) samples, but only at the Control location (Appendix E, Fig. 61). No meaningful location differences were evident for baseline length distributions (Appendix E, Fig. 61).

Fantail Sole. Both location and period influences of length distributions were apparent for this flatfish. (Length measurements were restricted to the more representative, 30-m depth.) (1) Relatively fewer small ($\leq$ 10 cm) and more large ($\geq$ 14 cm) fish were trawled at SONGS (versus Control) during the operational period. (2) Relatively greater numbers of small fish were caught at both longshore locations during the operational (versus baseline) period (Appendix E, Fig. 62). Baseline length distributions were similar at the SONGS and Control locations (Appendix E, Fig. 62).

Hornyhead Turbot. Length-frequency data for this species suggested temporal changes; i.e., relatively more large (12-15 cm) fish were caught during the operational (versus baseline) period. This period difference, however, was evident at both depths only at the Control location; no meaningful period differences occurred at the SONGS location (Appendix E, Figs. 63, 64). At 30-m depth, the data suggest an interaction between period and longshore location (Appendix E, Fig. 64). At 18 m, no meaningful location differences are evident within either sampling period (Appendix E, Fig. 63).

1.3.4 Evaluation of Shifts in Water-column Distributions

Data on the mean body weight of queenfish and white croaker caught by otter trawl indicate that the recent increases in trawl catches of these two species do not represent seabed-directed shifts in water column distributions beneath the SONGS plume (Appendix E, Table 12). Reasonable arguments can be made for both white croaker and queenfish.

The mean body weights of white croaker caught by otter trawl off SONGS during the operational period were similar, if not larger than, the croaker caught at the Control location in recent years (Appendix E, Table 13). If small croaker had been shifting to the seabed farther offshore of SONGS, we would expect the average body size of croaker to decrease off SONGS, relative to Control, at a given trawling depth.

types of variation in length-frequency distributions that are distinguishable from among the many trivial statistical differences. One or more biologically meaningful patterns are evident for each of the 6 species measured (Table 10). Least pervasive among these variations were location differences in baseline data.

White Croaker. Length-frequency distributions of the epibenthic, small-to-large adult-sized (> 9 cm SL) individuals of this species varied importantly between depths, locations, and sampling periods (Appendix E, Figs. 56, 57, 65-68). (1) Smaller, yearling-sized fish were relatively more abundant at the shallower (18-m) depth (Appendix E, Figs. 65-68). (2) More small (~ 10 cm) and large (15-20 cm) adults, and fewer medium-sized (12-15 cm) adults, were trawled at the SONGS station, relative to the Control station, during the operational period (Appendix E, Figs. 56, 57). (3) Relatively more small and large adults, and fewer medium-sized adults, were caught during the operational period at both depths (Appendix E, Figs. 56, 57). Baseline length distributions were similar, at depth, at SONGS and Control locations (Appendix E, Figs. 56, 57).

Longfin Sanddab. Length distributions of this flatfish also varied importantly with depth, location, and period. (1) Relatively more YOY-sized (< 10 cm) fish and small adults (10-14 cm) occurred at the deeper of the two depths (Appendix E, Figs. 58, 59, 69, 70). (2) At 18-m depth, relatively more YOY-sized individuals were trawled at the Control than at the SONGS station during both periods. At 30 m, more large (8-10 cm) juveniles were caught at the Control location during the operational period (Appendix E, Figs. 58, 59). (3) Larger fish were better represented during the operational period at both depths and longshore locations (Appendix E, Figs. 58, 59). Baseline distributions were similar, at depth, at both sampling locations (Appendix E, Figs. 58-59).

Pacific Sanddab. Length distributions of this species, abundant in baseline samples only at the deeper (30-m) depth, differed conspicuously between sampling periods. Relatively more YOY-sized (≤ 6 cm) fish occurred in baseline (versus operational) samples at both longshore locations (Appendix E, Fig. 60). Catches at SONGS and Control locations had similar length distributions during either period (Appendix E, Fig. 60).

Speckled Sanddab. This small flatfish was present at both sampling depths in baseline samples, but length measurements were restricted to its center of abundance

lampara seine catches. At shallow depths, catches disproportionately declined within 1/2-km radius of the Unit 1 intake, relative to locations 2-3 km downcoast or 18-19 km downcoast of SONGS, for 50% (11/22) of the cases examined. Of the 11 significant cases, 10 involved queenfish life stages and white croaker. At mid-depths, disproportionate declines near SONGS were detected for 5/21 testable cases. All 5 cases involved queenfish. Only 2 other cases (1 at shallow depths, 1 at mid-depths) might be interpreted as real increases at or near SONGS relative to the distant Control location.

Sample sizes were generally sufficient to detect declines that were $\geq$ 50% in magnitude (see Section 1.4.1.2). The percentage declines that were actually detected ranged from 55%-99%, with most between 60% and 80% (Appendix E, Tables 1 and 2).

The observed >> 50% relative declines in queenfish and white croaker catches near SONGS involved nontrivial numbers of fish (Table 2). This is because the baseline catches of these species were large (generally on the order of 10^2 fish per seine-haul), in part because individual seine-hauls sampled between sea surface and seabed over a large area (~ 4,600 m^2).

Impact test results showing SONGS-nearfield declines in queenfish and white croaker are corroborated by length-frequency data. Relatively few immature-sized queenfish were caught at the Near Impact station during the operational period, 1985-86 in particular, compared to the Far Impact and Control locations (Appendix E, Figs. 50-51 and 53-55). These observations may be explained by the magnitude of species- and size-specific entrapment at the Units 1, 2, and 3 offshore intake structures (Chapter Two). Near-SONGS declines in (especially small) queenfish and white croaker are consistent with the high levels of entrapment of the two species. Lack of observed nearfield declines in Pacific butterfish and silversides is likewise consistent in terms of their low levels of entrapment (relative to entrapment of queenfish and white croaker: Chapter Two). Magnitude of numerical entrapment of butterfish and silversides is absolutely low compared to field abundance (Chapter Two).

Benthic Fishes. Abundances of benthic fishes and the seabed-oriented, larger adult stages of queenfish and white croaker were monitored at off-diffuser (18-m) and off-plume (30-m) depths using otter trawl catches. Catches changed disproportionately

Length-frequency data also support the argument. The white croaker caught by seine during the baseline period were a mixture of juvenile and small adult fish at all three seining stations (Appendix E, Fig. 52). Primarily YOY croaker were seined during the SONGS Units 2 and 3 operational period (Appendix E, Fig. 52). Croaker trawled during the baseline period were mainly adult- to large adult-sized, with the latter more prevalent at the 30-m depth. During the operational period, trawl-caught croaker were primarily subadults and large adults (Appendix E, Figs. 56-57). It is clear that the recent, relative increase in the number of croaker on the seabed beneath the plume comprise much larger fish than those croaker representing the relative deficit in recent seine catches near the SONGS intakes.

An anlogous argument can also be made for queenfish: relative increases in trawl CPUE during the operational period do not reflect offshore, seabed-directed shifts in water-column distribution beneath the SONGS plume.

Data on mean body weight provide our criterion for evaluating queenfish body size. The mean body weight of queenfish caught by otter trawl during the operational period has not declined, relative to the mean size trawled at the Control station (Appendix E, Table 13). Unfortunately, we lack the length-frequency data for queenfish in otter trawls that would be necessary to do a Before-After comparison at SONGS and Control, which we could then relate to length frequencies in seine catches. (Queenfish were not targeted for measurement in trawl catches -- see Appendix A, part 2).

There is no evidence that the recent decreases in seine catches of small queenfish and white croaker near the SONGS intakes have resulted from an accentuated shift from midwater to near the seabed off SONGS.

1.4 DISCUSSION

1.4.1 Evaluation of Impact Tests

1.4.1.1 Patterns of Decline or Change in Abundance

Pelagic Fishes. Abundances of coastal, pelagic fishes and the water-column-oriented juvenile and young adult stages of queenfish and white croaker were monitored at shallow (intake structure: 5-10 m) and mid-depths (diffuser: 11-16 m) based on

sanddab at 18-m depth (Appendix E, Fig. 58). For speckled sanddab at 18 m, relatively fewer adults occurred off SONGS during the operational period (Appendix E, Fig. 61). Large adults of fantail sole, on the other hand, were relatively more abundant off SONGS in 1984-86 (Appendix E, Fig. 62).

The fishes that have recently increased in relative abundance off SONGS represent a mixture of benthic and epibenthic life stages and species. Most are generalized foragers that feed both on and a short distance above the seabed, but the same can be said for all trawled fishes, including those species whose abundance has not changed off SONGS (M.J. Allen 1982). Only the lizardfish (a species that statistically increased off SONGS) is a rather specialized, wait-and-watch predator of relatively few taxa (primarily mysids and anchovy: M.J. Allen 1982). The food and feeding habits data for benthic fishes do not provide a strong link between the distribution and abundance of particular species of fish and benthos prey. However, the general patterns of increase in both benthic invetebrates (Barnett 1987, Table 3-32) and benthic fishes (this chapter) implicate sediment alteration and enrichment due to SONGS operations as a plausible mechanism (also see Section 1.4.1.3).

1.4.1.2 Statistical Interpretation of Test Results

Several statistical parameters profoundly influence the power of BACI t-test results and must be considered in our overall interpretation of evidence for impact. These parameters are (1) sample size, (2) magnitude of the standard deviations of the deltas (including relative sizes of the baseline and operational-period deltas), and (3) serial correlation as a source of lost degrees of freedom.

Sample sizes had no unanticipated effects on t-test results. The number of quantitative trawl surveys (n = 25) completed during the SONGS-operational period approximated our a priori design criterion (n = 26). The operational data set for lampara seine surveys was truncated by a few surveys (n = 32 instead of 36), but this was allowed only because all nominal declines were already highly significant with about three-fourths of the surveys analyzed (DeMartini et al. 1986; DeMartini 1986).

Larger-than-expected standard deviations of the deltas for "After" data can be detrimental to the power of t-tests. On average, though, the standard deviations of the operational deltas of trawl catches were equivalent to the corresponding baseline deviations (Appendix E, Table 4). On the other hand, the deviations of

off SONGS, relative to the location 17-20 km downcoast of SONGS, for 44% (7/16) of the species-depth combinations that were suitable for statistical analysis. Of the 7 cases, 6 represented relative increases off SONGS; catches decreased off SONGS in only 1 case (at 18-m depth). Of the 6 increases, 4 occurred at 30 m. Statistically significant increases at both depths were detected for only 1/9 species that were monitored at both depths; however, nominal increases occurred at the second depth for 3/4 species showing significant increases at one of the depths. (Three species that were monitored at both depths did not change significantly at either depth.)

Sample sizes were generally sufficient to detect changes of $\geq$ 50% (Section 1.4.1.2). The actual magnitude of changes detected ranged from a 50% decline to a > 600% increase, with most increases lying between 200% and 300% (Tables 5, 6; Appendix E, Table 4.)

The observed increases in trawl catches off SONGS involve many species. However, the majority of these increases represent few fishes per trawl in absolute terms (Table 5), despite large relative increases (Appendix E, Table 4). In terms of magnitude of absolute change only the white croaker increases (~ 15 fish per trawl) can be reasonably considered large in biological terms. All of the remaining statistically significant cases involved increases of < 2 fish per trawl (mostly < 1 fish per trawl: Table 5). If a trawl with a 25-ft headrope like the one used samples a path of 12.5 ft (Loesch et al. 1976; Vouglitois et al. 1987), individual trawl-hauls swept about one-fourth the area sampled by individual hauls of our lampara seine. However, even if absolute changes in trawl catches are quadrupled in order to make the areal bases of trawl and seine catches equivalent, the absolute magnitude of the observed increases in benthics (except large white croaker) is small compared to the absolute magnitude of the near-SONGS declines in small white croaker and (especially) queenfish.

The many observed location differences in the length distributions of benthics during the operational period are generally consistent with the numerous changes in relative abundances during this period. Less can be said for each of the individual species involved. For 3/7 of the cases of significant increase (lizardfish and queenfish), no length data were collected. The recent relative increase in white croaker off SONGS has been due to greater numbers of both small and large adult fish, and fewer medium-sized adults (Appendix E, Figs. 56 and 57). No meaningful location-by-period interaction is apparent in the length distribution of longfin

eel data actually met the 80% power criterion, using all (serially correlated) data, but autocorrelation among operational deltas inflated its t-test probability to 0.15 (Appendix E, Tables 4, 7). Power for Pacific sanddab was unavoidably low because of a broadscale crash in abundance in summer 1982 that was sustained through the completion of monitoring in November 1986--no individuals were caught on 64% of the operational cruises. For queenfish at 18-m depth, the standard deviation of operational deltas exceeded the deviation of baseline deltas, and both deviations were too large to realistically expect to detect increases unless they were > 100% (Appendix E, Table 4).

1.4.1.3 Evidence for Spatial Extents of Impact

Fish Sampled by Seine. Our evaluation of the spatial scale of declines in small, water-column-oriented queenfish and white croaker near SONGS can partially address both onshore/offshore and longshore dimensions.

For adult male and female queenfish, an equal number of declines were detected at the Near Impact location (relative to Control) and at the Far Impact location (also relative to Control) (Appendix E, Tables 1, 2). This suggests that, for adult queenfish, the near-SONGS decline may extend as far as 2-3 km downcoast of SONGS Unit 1. Only one significant decline was detected at mid-depths (for males: Appendix E, Table 2). The magnitude of percentage change values revealed no consistent pattern for catches within 1/2-km of, versus 2-3 km downcoast of, SONGS Unit 1 (Appendix E, Tables 1, 2).

For immature and YOY queenfish, nearly all significant declines were restricted to the station within 1/2-km of SONGS Unit 1 (Appendix E, Tables 1, 2). Depressions generally extended to diffuser depths (Appendix E, Table 2). These results suggest that SONGS' entrapment effects on the smaller, more parochial (DeMartini, Allen, Fountain, and Roberts 1985) life stages of queenfish are more localized in longshore extent, and perhaps more persistent (hence detectable at diffuser depths as well as near the intakes).

Several data provide strong circumstantial evidence that the near-SONGS declines in adult queenfish have not resulted from SONGS entrapment of juveniles: (1) Temporal fluctuations in seine catches indicate that queenfish, particularly adults, make extensive longshore as well as diel and seasonal onshore/offshore

operational deltas of lampara seine data were generally larger than respective baseline deviations for samples at both shallow and mid-depths (Appendix E, Tables 1, 2). As long recognized (DeMartini et al. 1981c), the generally larger variations (in both baseline and operational data) for mid-depth-block lampara samples yield poorer power for location contrasts at the deeper seining depths (Appendix E, Table 2).

Despite the apparent heterogeneities in the standard deviations of some lampara data, there were few cases of significantly unequal variances of deltas to complicate t-test statistics for either type of net monitoring data. The variances of deltas differed between periods for only 3/22 tractable cases for seine samples at shallow depths (Appendix E, Tables 1, 2). There were only 2 instances of unequal variances among the 16 tractable cases evaluated for benthic fishes (Appendix E, Table 4). Unanticipated losses of power resulting from decremented degrees of freedom therefore were generally not a problem in our t-tests.

Serial correlation was a more pervasive complication than variance heterogeneities for both lampara-seine and other-trawl samples. However, even for lampara samples at shallow depths, where serial correlation between adjacent cruises was most often a problem (7/22 cases: Appendix E, Table 1), non-independence could be successfully extracted from the time series. Perturbation of t-test statistics was minimal in most cases and was accomplished with loss of only a single degree of freedom (Appendix E; Tables 1, 2, and 4).

On balance, the power of t-tests realized using the full complement of operational samples was satisfactory for our evaluation of SONGS' local impact on pelagic and benthic fishes. In part, this reflected recent declines and changes in relative abundances between locations that generally exceeded our design criterion of 50%.

There were very few cases (in which recent relative changes nominally exceeded 50%) for which t-test results were insignificant ($P > 0.10$) because of insufficient power. For lampara data at shallow depths, two nominal but marginally large declines (both at the Far Impact relative to Control location) were undemonstrable. These were Pacific butterfish (-56%) and white croaker (-60%). Three cases went similarly undemonstrated for trawl-caught fishes. All were relative SONGS increases (cusk-eel, 30 m: +53%; queenfish, 18 m: +71%; Pacific sanddab, 30 m: +60%). Cusk-

3 km downcoast of SONGS (Barnett 1987). Benthos patterns are unknown at 30 m, though, because samples have not been systematically collected at this depth. Nonetheless, the species richness and abundance (numbers) of benthic invertebrates have increased to a disproportionately greater extent off SONGS than at downcoast control stations, including our and MEC's Stuart Mesa station, in recent years (Barnett 1987, Table 3-32). If we evaluate the biomass patterns of our trawl catches, a consistent picture emerges: although benthic fish biomass generally declined during the operational period, catches declined relatively less at 18-m and 30-m depths off SONGS, and the pattern is statistically significant at both depths (Appendix E, Table 14). At least in terms of total biomass of benthic fishes, then, the observations are consistent with an enrichment of the benthos.

1.4.1.4 Overall Local Effect of SONGS

For two species (white croaker and queenfish), SONGS local effects involve a tradeoff between nearshore entrapment losses (negative) and a concentration of fish, apparently attracted to an enriched benthos, farther offshore (positive). For these two species, some simple estimates of overall effects are necessary and can be made, with certain qualifying assumptions.

Assuming that the areal extent of the negative and positive impacts are similar, the overall effect can be approximated, after adjusting for differences in area fished by the two types of net, as the difference between the negative change in seine catches and the positive change in trawl catches. The measure used should be biomass, not numbers of fish, because body size of the two croakers varies with distance offshore and water-column position (Appendix E, Table 13).

The calculations proceed as follows: The lampara seine that was used sampled an average 4,600 m^2 area (Appendix A, part 1). The otter trawl that was used (7.6 m headrope) swept a path about half this wide (3.8 m) and travelled an average distance of about 250 m (Appendix A, part 2). Thus the average trawl traversed about 950 m^2 area. In order to standardize trawl catches to seine catches, the catches in our trawls should be scaled upwards by a factor of 4.8.

When the latter factor is applied to the appropriate mean biomass data (Appendix E, Table 15), the following results are evident: For queenfish, the outcome is a net deficit of about 21 kg/ha (assuming a catch efficiency for both

migrations (Allen and DeMartini 1983; DeMartini, Allen, Fountain and Roberts 1985). (2) Biochemical genetics data (Beckwitt 1983) demonstrate that queenfish, like white croaker, lack regional genotypic differentiation within the Bight. This lack of regional variation probably reflects the mixing that must result from movements by vagile post-recruits in addition to planktonic dispersal during a lengthy (3-mo), larval period (Beckwitt 1983). We conclude that the near-SONGS declines in juvenile and adult queenfish have resulted directly from SONGS entrapment of juveniles and adults, respectively. (See Chapter Two for discussion in terms of magnitude of entrapment.)

Fish Sampled by Trawl. Assessment of the spatial scale of increases in benthic fishes near SONGS is limited to a partial assessment of onshore/offshore extent; no stations were sampled at longshore positions between the general SONGS diffuser area and the Control location 17-20 km downcoast of SONGS.

Several data indicate that the onshore/offshore extent of the effects on benthic fishes spans both sampling depths, separated by ~ 1 km, at distances ~ 2-3 km offshore of the SONGS intake structures. These data include the following: (1) the observed equivalent mix of significant increases at 18- and 30-m stations; (2) the similar sign of nominal change (increase) at the second of the two depths for species occurring at both depths and for which abundances significantly increased at one of the depths; and (3) the general lack of location-by-depth-by-period interactions to support the hypothesis that the observed changes generally span both sampling depths.

Several lines of circumstantial evidence are consistent with the argument that changes in sediments and benthos off SONGS provide the mechanism for local increases in benthic fishes. However, the onshore/offshore extent of changes in sediments and benthos is less certain. First of all, an evaluation of time-series patterns in sediment organic carbon off SONGS for the period from June 1976-March 1985 (Barnett, Watts, and White 1986), updated through December 1986 (A. Barnett, pers. comm.), only weakly suggests that the SONGS Units 2 and 3 diffusers have contributed to an increase in sediment organics under and offshore of the plume. Relatively few data on sediment organics are available for depths as great as 30 m, however (Barnett, Watts, and White 1986). Second, final analyses of Marine Ecological Consultants' benthos data have substantiated increases in motile, subsurface deposit-feeders (primarily paraonid and capitellid polychaetes) at 18-m depth to a distance of up to

Southern California Bight (Lynn 1983; Simpson 1984; McGowan 1984). The California El Nino was linked, in ways still incompletely understood, with the trans-Pacific (perhaps global) SST (sea-surface temperature) anomaly, commonly recognized as the parent El Nino, of 1982-83 (Rasmusson 1984, and references). Planktonic productivity was significantly lower in the California Current system during 1982-83 (McGowan 1984). Depressed planktonic production continued nearshore through 1984 (Petersen et el. 1986).

Shifts in the distribution of spawning adults, and reductions in biomass and production, have been documented for at least one offshore pelagic fish species (northern anchovy: Fiedler 1984; Fiedler et al. 1986). Perhaps analogous distributional shifts and/or stock reductions have been noted for diverse species of coastal shelf fishes inhabiting pelagic, rocky-bottom, and benthic (soft-bottom) habitats (DeMartini et al. 1983f, 1984c, 1985a, 1986, this report; Patton 1985; Love et al. 1986). Effects on some nearshore fish stocks and/or their depth distributions seemed to persist through winter 1985. During this period, the overall average densities of southern California coastal pelagic fishes decreased by about two-thirds to more than three-fourths at 5- to 16-m depths (i.e., to about 20% to 30% of average baseline levels: Table 2; Appendix C, Figs. 1, 2). El Nino declines in benthic fishes at 18-30 m were almost as extreme: average levels dropped about one-half to two-thirds (to ~ 30% to 50% of baseline means: Table 5; Appendix C, Figs. 3, 4). Even more extreme declines in some benthics occurred at 12 m and (especially) 6 m (Love et al. 1986). The longshore spatial scale of nearshore fish declines coincident with the California El Nino were at least as large as the San Onofre-Oceanside area (DeMartini et al. 1983f, 1984c, 1985a, 1986) and were probably bightwide for many or most species (Patton 1985; Love et al. 1986).

1.4.3 Conclusions

Lampara seine catches of small, water-column-oriented queenfish and white croaker have declined within 1/2-km of SONGS Unit 1, relative to catches at stations 2-3 km and 18-19 km downcoast of SONGS, during the Units 2,3 operational monitoring period of April 1984-August 1986. These recent relative declines near SONGS averaged 60%-80% greater than baseline differences between SONGS and Control locations. Near-SONGS declines were about the same proportionate size as the broader-scale El Nino stock depressions that influenced all sampling locations for several years prior to, and throughout most of, the SONGS-operational monitoring

seine and trawl of 25%). That is, an increase of ~8 kg/ha in the biomass of large queenfish near the seabed offshore is overwhelmed by a decrease of ~29 kg/ha in the biomass of small queenfish near the intakes inshore. For white croaker, the opposite obtains (again assuming that the catch efficiency is 25% for both seine and trawl). The net outcome for croaker is a surplus of ~55 kg/ha. The trivial decrease in biomass of small white croaker around the intakes near shore (< 1 kg/ha) is swamped by the ~56 kg/ha increase in the biomass of large adult croaker offshore. The latter figure is the mean of the 38 kg/ha value that results if the 18-m trawl data are used, and the 73 kg/ha value that results if the 30-m trawl data are used.

1.4.2 Natural Patterns of Abundance

1.4.2.1 Baseline Temporal and Spatial Patterns

Onshore/offshore patterns in abundance are generally evident for coastal pelagic fishes (Table 2), but longshore patterns were relatively weak compared to temporal fluctuations during the baseline period (Tables 2, 7; Appendix C, Figs. 1, 2). Diel and biannual temporal scales are important for local nearshore, water-column-oriented fishes (Allen and DeMartini 1983; DeMartini, Allen, Fountain, and Roberts 1985). Data summarized by DeMartini, Allen, Fountain, and Roberts (1985) exemplify a perhaps general ontogenetic increase in juvenile-adult fish size with depth (distance offshore) on the coastal shelf.

Seabed-oriented fishes more frequently exhibited baseline longshore differences, at a given distance offshore, than midwater fishes. Compared to midwater fishes, benthic fishes also had generally strong onshore/offshore patterns (Table 5). Baseline temporal patterns were relatively weak for benthics, unlike midwater fishes (Appendix C, Figs. 3, 4; also DeMartini et al. 1983a,b; DeMartini and Allen 1984). Ontogenetic increases in average body size with depth are commonplace for benthic fishes on the southern California shelf (DeMartini and Allen 1984; Love 1983, 1984, 1985).

1.4.2.2 El Nino Perturbations

During the period from summer-fall 1982 through winter 1984, a mesoscale (hundreds of kilometers) oceanographic phenomenon now known as the California El Nino affected the California Current system and allied coastal waters of the

In sum, we feel that our assessment of SONGS' potential local impact on fish abundance, based on net monitoring data analyzed by BACI t-test, was suitable and successful. The realized power of our t-tests was sufficient, with few exceptions, to detect all reasonably large ($\geq$ 50%) declines or changes in abundance of target coastal-pelagic and benthic fishes.

period. Despite the large proportionate reductions caused by El Nino, the absolute magnitude of additional declines in small queenfish and white croaker off SONGS has not been trivial. Several other, more truly pelagic taxa (Pacific butterfish, silversides) have lacked analogous declines off SONGS but have exhibited equivalently large or larger decreases caused by El Nino. On balance, the observed near-SONGS declines in small queenfish and white croaker, and the lack thereof for butterfish and silversides, is consistent with species-specific entrapment at SONGS' offshore intake structures.

In contrast, otter-trawl catches of a majority of a dozen benthic taxa (including truly benthic fishes and the larger, seabed-oriented individuals of queenfish and white croaker) increased off SONGS, relative to a station 17-20 km downcoast of SONGS, during the same period. These relative increases in benthics were statistically significant for many taxa but involved large absolute increases only for white croaker. The huge (> 600%) relative increases off SONGS in large white croaker during the operational period involve differences of ~ 15 fish per trawl (Table 5). The broadscale El Nino declines in epibenthic white croaker prior to and during the period of new-unit operation were 70%-90% of its baseline abundances (Tables 5, 6).

We conclude that the observed declines/changes in fish abundance do not generally reflect either offshore- or seabed-directed shifts in distribution. Rather, the recent increases in trawled fishes, particularly white croaker, contribute to an overall relative increase in benthic fish biomass off SONGS. We believe that the increase in benthic fishes reflects concentration resulting from a general enhancement of the benthos, likely due to SONGS operations, in the region of the SONGS plume. The recent decreases in small queenfish and white croaker near the SONGS intakes must be the result of SONGS entrapment. The overall effect of entrapment and benthic enhancement for queenfish and white croaker is qualitatively different for the two species. While the overall effect for white croaker is an estimated surplus of ~55 kg/ha, the overall effect for queenfish is an estimated deficit of ~21 kg/ha. The magnitude of these effects could be trivial to substantial, depending on the areal extent of the effects. It also should be noted that these values represent local standing stock biomass. The actual net change in local fish production is unknown.

Most fish entrapment at SONGS occurs during routine (normal flow) pump operations (DeMartini and Larson 1980a). Most entrapped fishes are impinged (at Unit 1) or are either impinged or diverted (at Units 2 and 3, see below). Other entrapped fishes are killed during periodic heat treatments that are used to control biofouler growth. During these treatments the temperature of water in screenwells and intake conduits is elevated by temporarily halting flow, then biofoulers in intake conduits are killed by reversing the flow of water. All three SONGS units are heat-treated at similar (six-week) intervals, but times vary because unit operations are independent.

The three SONGS units differ in some engineering and operating features. The mesh size of travelling screens at Unit 1 is 5/8 inch, whereas the mesh at Units 2 and 3 is 3/8 inch (Downs and Meddock 1974). The "velocity caps" that sit atop the offshore intake structures of Units 2 and 3 are circular, unlike the rectangular cap atop Unit 1's intake. A circular cap reduces the variance and vertical components of incurrent flow, two factors believed to influence magnitude of fish entrapment (Weight 1958; Schuler and Larson 1975 and references). In addition, the two new units have a fish return system (FRS), designed to further reduce losses of juvenile-adult fish by diverting entrapped fish past travelling screens and into quiet areas of screenwell forebays (Schuler and Larson 1975). Diverted fishes are periodically collected by lift-bucket from these quiet areas and flushed back to sea via a discharge conduit that is run off the intake flow (Downs and Meddock 1974).

The California Coastal Commission established the Marine Review Committee (MRC) in 1976 to study the coastal marine biota, including fishes, near SONGS in order to evaluate what, if any, effect the plant was having or will have. The MRC's comprehensive assessment of impact on fishes includes an evaluation of SONGS' possible effects--from entrapment and impingement of juveniles and adults, and entrainment of eggs and larvae--on (1) local distribution and abundance and (2) bightwide stock levels of species particularly susceptible to intake.

2.1.3 Summary of Entrapment Studies

Quantitative evaluation of entrapment and impingement of fishes at SONGS began in 1976 with measured estimates of losses at Unit 1. Data for the period from 1976 through 1979 are reviewed by DeMartini and Larson (1980a) and SCE (1982). Annual updates of losses at Unit 1 appear in SCE and LOSL (1983), and WESTEC and SCE (1984).

CHAPTER TWO
SONGS ENTRAPMENT

2.1 INTRODUCTION

2.1.1 Fish Entrapment at Power Plants

Electric generating stations that use water for cooling entrain large numbers of planktonic fish eggs and larvae, and entrap (and subsequently impinge on travelling screens) free-swimming juvenile and adult fishes (reviewed by Sharma 1978). These stations include power plants that withdraw cooling water from enclosed bodies of water (rivers, lakes), semiclosed systems (estuaries), and open waters (oceans).

2.1.2 Operating Characteristics of SONGS

San Onofre Nuclear Generating Station (SONGS), whose major owner and operator is Southern California Edison Company (SCE), is located on the exposed outer coast of northern San Diego County, California (Fig. 1). SONGS withdraws its cooling waters through "offshore intake structures" situated in 9 m of water about 1 km off the beach. SONGS Unit 1, in sporadic operation since 1968, generates 430 MWe and withdraws 1.7×10^6 m^3/day (4.5×10^8 gallons/day) at full flow. Two new units (Units 2 and 3) were constructed during the late seventies and early eighties. Unit 2 began full pumping in May 1983, and Unit 3 began full-flow operations in April 1984.

Consistent full-power generation began at both of the two new units in April 1985. Units 2 and 3, when fully operational, together generate 2,280 MWe while pumping a combined volume of 9.1×10^6 m^3/day (2.4×10^9 gallons/day). DeMartini and Larson (1980b) estimated that all three units in combination would pump an additional 129% of the total volume of cooling water withdrawn by all other coastal power plants in the Southern California Bight.

October 1985 to August 1986. Matched samples were collected during the same 24-hr period at Unit 1 and at either Unit 2 or Unit 3. We retest our original prediction that each new unit would entrap 2.5 times the amount of fishes entrapped at Unit 1 (DeMartini and Larson 1980b).

Last, we explore entrapment as a mechanism for the observed nearfield declines of small queenfish (Chapter One). For completeness, we begin by updating our evaluation of the potential interrelations of entrapment magnitude, near-SONGS abundance, and variation in the major environmental variables (surge and water clarity) that influence susceptibility to entrapment. We use these data to complete our evaluation of a predictive model for the nearfield depression of small queenfish (Seriphus politus) at SONGS (DeMartini et al. 1986). We conclude this final section with some simple balance calculations. Estimates of entrapment magnitude are compared with level of near-SONGS abundance for queenfish and several other coastal pelagic fishes most subject to SONGS entrapment. Entrapment for the periods April-September 1985 and April-September 1986 is related to changes (from baseline) in nearfield-control differences in nighttime lampara seine catches made during these operational subperiods. Numerical CPUE data are corrected for catchability (catch efficiency) and standardized to a presumed nearfield area of 1/2-km radius. These concurrent field and entrapment estimates provide an intuitive basis for interpreting the nearfield declines in queenfish catches that have been observed since spring-summer 1983 (DeMartini et al. 1985a,b; 1986; Chapter 1, this report).

2.2 DATA SOURCES AND METHODS OF ANALYSIS

2.2.1 Estimates of SONGS Entrapment

2.2.1.1 Components of Operation

Entrapment during normal flow operations consists of two or three components, depending on SONGS unit. At all three units certain larger-bodied, stronger-swimming, and more robust fishes avoid impingement on travelling screens and accrue in screenwells between heat treatments (Section 2.2.1.2). At Unit 1 all other fishes impinge on travelling screens. At Units 2 and 3, if fishes do not accrue in screenwells, they either impinge or are diverted by the louver arrays of the FRS into quiet areas in screenwell forebays, from which they are periodically lifted and

SCE and LOSL (1983), WESTEC and SCE (1984), DeMartini et al. (1985a), and WESTEC (1985) provide more recent annual loss estimates for SONGS Units 2 and 3. DeMartini et al. (1985a) and WESTEC (1985) also make preliminary comparisons of species composition, size composition, and magnitude of impingement versus diversion (fish return system). DeMartini et al. (1986) first evaluate the effect of volume pumped on magnitude of entrapment at the new units, compare Unit 2 and Unit 3, and provide a preliminary comparison of entrapment magnitude at Unit 1 versus the two new units.

2.1.4 Objectives

Chapter Two has four main objectives. All are directed towards assessing local (near-SONGS) declines in juvenile-adult fishes resulting from entrapment at SONGS. Consideration of bightwide effects that might result from SONGS' entrainment of planktonic eggs and larvae are deferred to Chapter Five (Modeling).

First, we update our prior estimates of the magnitude of fish entrapment at SONGS for the period from October 1985 to August 1986. We provide a comprehensive summary of entrapment totals, for each and all SONGS units and types of pump operations (see Section 2.2.1), for the 39-mo period from May 1983 to August 1986. Impingement and diversion estimates are considered separately and pooled (as total entrapment) at the two new units. Entrapment estimates are expressed as annualized (12-mo) totals.

Second, we complete our evaluation of the SONGS Units 2 and 3 fish return system (FRS). As a first step, we update our estimates (DeMartini et al. 1986) of the fraction of fishes diverted from the total entrapped at the two new units. We next evaluate the survival of diverted fishes. Our evaluation of survivorship is partly based on the results of a series of "offshore survivorship tests" performed by Occidental College while under contract to SCE. In these tests, fishes returned offshore through the FRS discharge conduit were captured and held in pens for 96 hours to assess mortality resulting from mechanical damage or stress while being returned. We complete our evaluation of survivorship and our assessment of the FRS based on bracketed estimates of the magnitude of predation upon discharge as a function of fish body size.

Third, we update our comparisons of entrapment magnitude at Unit 1 with Units 2 and 3 (DeMartini et al. 1986), using additional matched samples for the period from

Species-specific efficiency was calculated only for fishes for which transport survivorship was estimable with reasonable confidence. That is, efficiency was estimated only for species represented by $\geq$ 20 total individuals in each pen type or species having $\geq$ 20 individuals present in experimental pens and zero estimated mortality in control pens (Appendix F, part 2). In addition, efficiency was estimated for all species pooled within general size categories.

2.2.2.1 Percent Diversion

Estimates of percent diversion are herein based on all matched (same-day), quantitative (4 pump, 24 $\pm$ 2 hr) impingement and diversion samples collected at the same unit. This comprehensive evaluation is for the 39-mo period from May 1983 to August 1986 that includes all times of full pumping at one or both new units. Specific analysis protocols are described in Appendix F, part 2.

2.2.2.2 Percent Survivorship

Estimates of percent survivorship of the fish that are diverted at the new units are based in part on our analysis of the "offshore survivorship test" data of Occidental College. Only data for the concurrent or alternating series of experimental and control trials completed off SONGS during the period from October 1983 to August 1985 were used in our evaluation. See Appendix F, part 2 for additional details of sampling and analysis designs.

Overall survivorship (S_T) was viewed as the product of two probabilities--the probability of avoiding death resulting from physiological causes (S_1) and the conditional probability of not being eaten if otherwise a survivor (S_2), i.e.,

$$S_T = S_1 \times S_2 \quad .$$

(Weakened fish that are eaten when discharged are included in the S_1 category, because they would otherwise be physiological mortalities.) All estimates of transport survivorship utilize Occidental College's numbers data (the SCE contractor recorded incomplete biomass data). Methods for the derivation of S_1 and S_2 values are described in Appendix F, part 2.

discharged back offshore. Various methods have been developed by SCE contractors and the MRC's contractors to monitor these components of entrapment.

2.2.1.2 Component-Specific Sampling Methods

The impingement component of entrapment at all SONGS units was estimated based on 24-hr collections of fishes from travelling screens. We likewise characterized the diversion component of entrapment at Units 2 and 3 based on concurrent diversion (elevator or lift-bucket) samples. We estimated mean 24-hr entrapment for each month of unit operation by using quantitative (24 $\pm$ 2 hr, full pumping) samples only. At most, two quantitative, normal-flow samples were collected each week. Monthly entrapment was estimated as the product of mean 24-hr entrapment and the flow (pump) volume of that month, with the latter expressed in terms of plant-operational days. The number of plant-operational days in a month at a unit was calculated as its total pumping volume divided by its 24-hr pump volume at full flow. This protocol is based on the assumption that the magnitude of entrapment is proportional to volume pumped at 25%-100% flow (DeMartini et al. 1986). Appendix F, part 1 provides additional details.

Heat treatment collections represented an entrapment component that was added to the estimates of normal-flow entrapment. For details, see Appendix F, part 1.

2.2.2 Evaluation of the SONGS Units 2 and 3 Fish Return System (FRS)

There are two components to a reasonable evaluation of SONGS' FRS: (1) percent diversion, or the fraction of all fishes entrapped that are diverted into holding areas and subsequently lifted out of screenwells and discharged back offshore, and (2) the percent survivorship of fishes that are diverted. (Survivorship is {1 - mortality}, where death may be due to physiological stress during discharge or predation upon discharge.) Death due to physiological causes was monitored for fish held in pens during the first 96 hr following discharge. Probable death due to predation was evaluated as an inverse function of average body size of the species in SONGS entrapment samples. Overall efficiency is the product of (1) and (2), i.e.,

$$\%\ \text{efficiency} = \%\ \text{diversion} \times \%\ \text{survivorship} \quad .$$

In this section, we first evaluate the potential effects of near-SONGS abundance and vulnerability, the latter characterized by wave surge and turbidity, on the magnitude of SONGS Units 2 and 3 entrapment. Estimates of near-SONGS abundance were based on lampara seine CPUE (Chapter One) for our station 2-3 km downcoast of SONGS. This station was the closest at which no pervasive SONGS effect was demonstrable for small queenfish (see Chapter One).

Surge was indexed by MAXIMUM SIGNIFICANT WAVE HEIGHT, in part measured off San Onofre by ECOsystems Management Associates. In addition, wave-height data were estimated for San Onofre from data collected at San Clemente and Oceanside by the Coastal Data Information System (CDIS). (Derivation procedures are described in Appendix F, part 4A.) The best available measure of turbidity was nephelometer readings from SONGS screenwells. Concurrent field, entrapment, and physical data were available for 16 samples spanning the period from October 1983 to August 1986.

Next, we evaluated whether the deltas (differences) between lampara seine catches made near (within 1/2 km of) SONGS Unit 1 and either 2-3 km downcoast or 18-19 km downcoast of it could be predicted based on two independent variables: the magnitude of Units 1, 2, and 3 entrapment during the 24-hr period including the night of the lampara sample, and recent pumping history at SONGS. "Recent" was evaluated for three periods: prior 3 days, prior 2 days, and prior week (7 days). Appendix F, part 4A, provides details on how parameters were estimated.

Both models--that relating magnitude of entrapment to near-SONGS abundance, and that relating nearfield delta CPUE to magnitude of entrapment and pumping--were evaluated for numbers and biomass of small queenfish. Small queenfish were defined as fish $\leq$ 10 cm standard length (SL), where 10 cm SL is the approximate size at 50% sexual maturity.

2.2.4.2 Simple Balance Calculations

As a complementary exercise, we calculated whether the magnitude of queenfish entrapment at SONGS has been sufficient to generate the observed near-SONGS declines (Chapter One).

Average daily entrapment of total and small queenfish was estimated for April-September 1985 and for April-September 1986. These data were then related to

2.2.3 Comparisons of Unit 1 with Units 2 and 3

Magnitude of entrapment was compared between Unit 1 and one or both new units based on matched (same-day), quantitative, normal-flow samples. (See Appendix F, part 1 for definition of a quantitative sample.) Entrapment at the new units was the sum of impingement and diversion components. If valid samples existed for both new units on the same date, the Unit 1 data was matched twice--once with the Unit 2 data and once with the Unit 3 data. Entrapment magnitude (numbers, biomass) was compared for each of four major species (queenfish, white croaker, walleye surfperch, salema) and three major compound taxa (total fishes, total fishes minus northern anchovy, and total fishes minus all anchovy species). Matched samples were compared by paired t-tests of log-transformed data. The actual null hypothesis tested was

$$H_0: \log10(\text{new unit}) - \log10(\text{Unit 1}) - \log10(2.5) = 0 \quad .$$

This is the log-linear expression of DeMartini and Larson's (1980b) prediction that each new SONGS unit will entrap 2.5 times the amount of fish that Unit 1 entraps because (1) each new unit pumps 2-1/2 times the amount of water that Unit 1 pumps, and (2) the fish-attracting areas of the two "reefs" are together about five times as large as the intake riser and supporting riprap of Unit 1.

We restrict these matched comparisons of Unit 1 and Units 2,3 data to magnitude of entrapment because prior evaluations (DeMartini et al. 1986) have thoroughly demonstrated that the species composition of entrapment does not meaningfully differ between Unit 1 and the new units. Further, data for Units 2 and 3 are pooled because previous comparisons (DeMartini et al. 1985a, 1986) have shown no significant differences between them in composition or magnitude of entrapment.

2.2.4 Entrapment as a Mechanism for Nearfield Depression

2.2.4.1 Mathematical Interrelationships

Major determinants of the magnitude of entrapment at intake structures include nearfield abundance and factors influencing the vulnerability of available fishes (reviewed in Jensen 1978). Turbidity and variable water motion (e.g., wave surge along an exposed coast) significantly influence fishes' ability to detect and avoid intakes (Foster 1979).

Entrapment at Unit 1 represented < 1% (by numbers) and 9%-10% (biomass) of all fishes entrapped at SONGS during May 1983-August 1986. About 10% (400 kg) of the average fish biomass entrapped at Unit 1 (3.8 MT/yr, Table 11) accrued in the unit's screenwell between heat treatments; the remainder impinged on travelling screens during normal flow operations (Appendix G, Table 9).

Entrapment at Units 2 and 3 accounted for > 99% (numbers) and 90% (36.7 MT biomass) of all SONGS entrapment (Table 11). About 8% (an average 3.0 MT/yr) of the biomass entrapped at the two new units accrued in screenwells between heat treatments. Impingement and diversion during normal flow operations accounted for 92% (33.9 MT/yr) of all entrapment at Units 2 and 3 (Table 11; Appendix G, Table 9). About one-fifth (7.2 MT/yr) of this fish biomass impinged on travelling screens; four-fifths (26.6 MT/yr) was diverted by the louvered screens into forebays and periodically collected by lift-bucket and discharged back offshore via the fish return system (Tables 11, 12).

Queenfish dominated in numbers (72%) but contributed less to biomass entrapment (21%) at Unit 1 (Table 11; Appendix G, Tables 1, 12, 14). Queenfish dominated numerical entrapment (as 79% of all fish excluding northern anchovy) and contributed greatly to biomass entrapment (39%) at Units 2 and 3 (Table 11; Appendix G, Tables 1, 11, 13, 15). Northern anchovy dominated numerical entrapment (75%) but contributed only 13% to total biomass entrapment at the two new units (Table 11; Appendix G, Table 8). Queenfish, northern anchovy, and six other taxa together represented 51% of all fish biomass entrapped at Unit 1, and 70% at the two new units (Table 11). Pacific electric ray contributed greatly (1.2 MT or 32%) to biomass entrapment at Unit 1 but only 4% to total biomass at the two new units (Table 11; Appendix G, Table 4). White croaker constituted over 40% of all numerical entrapment at Units 2 and 3, excluding northern anchovy and queenfish (Table 11; Appendix G, Table 2).

Standard deviations of estimated numerical entrapment during normal flow were 5%-13% of the annual estimate for total fishes (Appendix G, Table 9). Standard deviations were slightly larger (20%-25%) for the major taxa evaluated (Appendix G, Tables 1-8). The precision of biomass estimates approximated those for numerical entrapment (Appendix G, Tables 1-9).

updated estimates of the SONGS nearfield depression of queenfish during the respective period (Chapter One). The nearfield depression was characterized by the recent change in the difference between mean queenfish abundances (based on untransformed catch data) at Near Impact versus Control and at Near versus Far Impact locations. Lampara seine catch (CPUE, as an index of density) was corrected for catchability and extrapolated to a presumed circular nearfield area having a 1/2-km radius. Numerical entrapment and seine CPUE data were converted to biomass based on the basic length-weight relationship of queenfish.

Absolute and relative magnitudes of average daily entrapment and Near Impact minus Control (and minus Far Impact) location differences in mean field abundances were also compared for silversides, white croaker, and Pacific butterfish. These latter species vary in relative magnitudes of entrapment and field abundance and were used as independent checks on our evaluation of the nearfield decline for queenfish.

Part 4B of Appendix F provides a detailed description of this series of analyses.

2.3 RESULTS

2.3.1 Magnitude of Units 1, 2, and 3 Entrapment

The magnitude of total entrapment of juvenile-adult fishes at each of the three SONGS units is the sum of various components of entrapment. The relative contribution of these components differs between Unit 1 and the two new units; most fishes entrapped at Unit 1 are impinged, whereas most are diverted at Units 2 and 3 (Section 2.3.2). Entrapment subtotals are listed, by unit and type of sample, for all key species and compound taxa, in Appendix G, Tables 1-15. Table 11 summarizes average 12-mo entrapment at each SONGS unit.

Over the 39-mo period from May 1983 to August 1986, SONGS Units 1, 2, and 3 together entrapped an average of 5.6 million juvenile-adult fishes, weighing 40.7 MT, every 12 mo (Table 11; Appendix G, Tables 1-15). Unit 1 pumped at an average 56% level, and Units 2 and 3 combined withdrew cooling water at an average 76% of full flow during this period (Appendix F, Tables 4-6).

Entrapment at Unit 1 represented < 1% (by numbers) and 9%-10% (biomass) of all fishes entrapped at SONGS during May 1983-August 1986. About 10% (400 kg) of the average fish biomass entrapped at Unit 1 (3.8 MT/yr, Table 11) accrued in the unit's screenwell between heat treatments; the remainder impinged on travelling screens during normal flow operations (Appendix G, Table 9).

Entrapment at Units 2 and 3 accounted for > 99% (numbers) and 90% (36.7 MT biomass) of all SONGS entrapment (Table 11). About 8% (an average 3.0 MT/yr) of the biomass entrapped at the two new units accrued in screenwells between heat treatments. Impingement and diversion during normal flow operations accounted for 92% (33.9 MT/yr) of all entrapment at Units 2 and 3 (Table 11; Appendix G, Table 9). About one-fifth (7.2 MT/yr) of this fish biomass impinged on travelling screens; four-fifths (26.6 MT/yr) was diverted by the louvered screens into forebays and periodically collected by lift-bucket and discharged back offshore via the fish return system (Tables 11, 12).

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Standard deviations of estimated numerical entrapment during normal flow were 5%-13% of the annual estimate for total fishes (Appendix G, Table 9). Standard deviations were slightly larger (20%-25%) for the major taxa evaluated (Appendix G, Tables 1-8). The precision of biomass estimates approximated those for numerical entrapment (Appendix G, Tables 1-9).

2.3.2 The SONGS Units 2 and 3 Fish Return System (FRS)

Efficiency of the SONGS Units 2 and 3 FRS depends on both the percentage of fish that are diverted (i.e., prevented from impinging on travelling screens, once entrapped) and the percentage of successfully diverted fish that survive (Section 2.2.2).

2.3.2.1 Percent Diversion

Table 12 summarizes the estimated percent diversion (numbers and biomass) of fishes entrapped during normal flow operations at SONGS Units 2 and 3. Additional details are provided in Appendix H, Table 1. These estimates are based on 191 collections made at the two new units during May 1983-August 1986 (Table 12; Appendix H, Table 1). A total of 86 taxa occurred in these collections; reasonably large (> 20 fish) sample sizes were available for 55 of these taxa (Table 12; Appendix H, Table 1). The 55 taxa constituted over 99.9% (by numbers) and 94.2% (biomass) of all fishes in the collections. Diversion was about 82% (numbers) and 79% (biomass) for pooled taxa with reasonable sample sizes; respective values were trivially different for total fishes in all of the collections (Table 12; Appendix H, Table 1). Large-bodied, robust fishes were most successfully diverted (e.g., zebra perch, Hermosilla azurea). In general, juvenile stages (e.g., white croaker); small-bodied species (e.g., Anchoa spp.; shiner perch, Cymatogaster aggregata; bocaccio, Sebastes paucispinis); and otherwise weak swimmers (e.g., pipefish, Syngnathus spp.; plainfin midshipman, Porichthys notatus; cusk-eel, Ophidion spp.) were least successfully diverted (Table 12; Appendix H, Table 1). Percent diversion values were generally equivalent for the numbers and biomass of fishes grouped within each of several body size categories. Overall, about 68% (numbers) and 77% (biomass) of all "small-bodied" fishes (excluding northern anchovy) were successfully diverted. Queenfish and white croaker together represented 96% (numbers) and 97% (biomass) of all small-bodied fishes (less anchovy) diverted. Percent diversion of northern anchovy was 91% (numbers) and 79% (biomass) (Appendix H, Table 1). Average diversion success was 71% (numbers) and 70% (biomass) for "medium-sized" fishes. Analogous values were 90% and 85% for "large-bodied" fishes (Appendix H, Tables 1,2). If diversion results are more simply presented in terms of all "small" fishes and all "large" fishes, the following values obtain: For all small fishes (including northern anchovy), about 82% (numbers) and 77% (biomass) were successfully diverted. For all large fishes (including both medium-sized and large-bodied), the estimates were 77% (numbers) and 80% (biomass).

2.3.2.2 Percent Survivorship

Survivorship of the fish diverted at the two new SONGS units is estimated from the results of 18 experimental and 9 control field trials conducted off SONGS by Occidental College during October 1983-August 1985. Transport survivorship following FRS discharge is characterized as the difference between the cumulative, 96-hr survivorship of discharged fish (in experimental pens) and field-caught fish (in control pens). Results of these field trials are summarized in Table 13 and Appendix H, Tables 3, 4. A total of 31 taxa occurred in the collections; however, 16 taxa occurred in experimental pens only, and 2 taxa were present only in control pens. Thirteen taxa co-occurred in one or more trials of each of the two pen types (Appendix H, Table 3). Five of the latter taxa were present in sufficiently large numbers in each of the two pen types to warrant calculation of confidence limits on the percentage survivorship estimate (Appendix H, Table 3). Well-represented taxa constituted about four-fifths (by numbers) of all fish (excluding northern anchovy) present in the quantitative survivorship test collections herein analyzed (Appendix H, Table 3).

Estimates of transport survivorship ranged greatly among species and body sizes. Survivorship was generally high for large-bodied (e.g., yellowfin croaker, *Umbrina roncador*) or otherwise hardy species (e.g., salema, *Xenistius californiensis*). However, survivorship was generally low for fragile, small-bodied fishes, especially those with deciduous (easily lost) scales (like *Anchoa* spp.) and the juveniles of some larger fishes (e.g., white croaker). The transport survivorship of queenfish was 68% for fish of all sizes pooled (Table 13; Appendix H, Table 3) and 63% for small as compared to large (73%) queenfish (Appendix H, Table 4). Based on the weighted average contribution of queenfish and white croaker to diversion samples, average survivorship was about 66% (by numbers) for all "small-bodied" (< 30 g mean body weight) fishes, excluding northern anchovy (Appendix H, Table 1). Analogous values were 100% for "medium-sized" (30-200 g) and 100% for "large-bodied" (> 200 g) fish (Appendix H, Table 3). Viewed simply for all "small" versus all "large" fishes, the following holds: Transport survivorship for all small fishes (including anchovy) averaged about 86% (numbers) and 71% (biomass). For all large fishes (both medium-sized and large-bodied fishes), estimated transport survivorship was 100%.

2.3.2.3 Percent Efficiency of the FRS

Table 13 further provides a summary of estimated average efficiency (as % diversion x % survivorship) for the 9 taxa of fishes with reasonable estimates of both % transport survivorship and % diversion. Also provided are analogous efficiency estimates for the three general size categories (small, medium, and large) of fishes (Table 13).

Percent survivorship, as the cross-product of % transport survivorship and % survivorship following discharge, is greatly dependent on our estimates of % predation upon discharge. We also acknowledge that any estimates of the latter are subjective and that a broad range of values must be accepted as the best that is possible.

In general, efficiency increased from an average minimum of about one-third for small fishes to an average maximum of almost 90% for large fishes (Table 13). These efficiency estimates are based on our best estimates of % survivorship following discharge (50% for northern anchovy, 75% for other small fishes, 90% for medium-sized fishes, and 99% for large-bodied fishes). The values could reasonably be ± 50% of these estimates. If the % survivorship values are bracketed by ± 50% of their original estimated value, the new range in values would be 25-75% for northern anchovy, ~35-100% for other small fishes, 45-100% for medium-sized fishes, and ~50-100% for large-bodied fishes. Overall efficiency therefore might be < 20% to ~50% for small fishes, from 45% to 70% for medium-sized fishes, and from > 40% to 85% for large-bodied fishes.

Efficiency can also be expressed more conservatively as the cross-product of % diversion and % transport (i.e., excluding predation upon discharge). Doing this for all "small" versus all "large" fishes, the estimates are: The average survivorship of all small fishes (including anchovy) was 70% (numbers) and 55% (biomass). The survivorship of all large fishes (both medium-sized and large-bodied) was, on average, 77% (numbers) and 80% (biomass).

2.3.3 Comparisons of Unit 1 with Units 2 and 3

The magnitude of entrapment during normal-flow operations is compared for Unit 1 and the two new units by paired t-test for concurrent 24-hr samples. Test results

are summarized for the numbers and biomass of each of four major species and three compound taxa in Table 14. Appendix G, Table 16 provides backup statistics.

The average magnitude of entrapment at each new unit differed significantly from 2.5 times the average entrapment at Unit 1 for all of the species and taxa tested (Table 14; Appendix G, Table 16). The average magnitude of entrapment at each new unit has apparently exceeded 2.5 times that at Unit 1 for all taxa tested except walleye surfperch. Entrapment of walleye surfperch at each new unit has been significantly less than 2.5 times its level of concurrent entrapment at Unit 1; its absolute level of entrapment has been equivalent at Unit 1 and at each of the new units (Table 14; Appendix G, Table 16). Biomass patterns mirror results for numerical entrapment for most test cases (Table 14; Appendix G, Table 16).

2.3.4 Entrapment as the Mechanism for SONGS' Nearfield Decline

2.3.4.1 Mathematical Interrelations of Entrapment and Nearfield Abundance

We first attempted to mathematically describe the relationship between near-SONGS abundance and entrapment magnitude. (The latter was adjusted for surge and turbidity, two factors thought to influence vulnerability to entrapment). This led to our primary goal of describing what, if any, mathematical relationship existed between the magnitude of recent SONGS entrapment of small queenfish and the observed near-SONGS depression in its abundance, as measured by lampara CPUE near the offshore intake structures. When data bases were updated to include all 16 quantitative match-ups of entrapment collections and lampara samples, however, no significant mathematical relationships could be detected (Appendix I, Tables 1-3). (Possible reasons for our lack of success are discussed in Section 2.4.4.) We have therefore had to rely on the following less elegant, but nonetheless intuitive, approach to identifying entrapment as the most plausible mechanism for the observed near-SONGS declines.

2.3.4.2 Magnitude of Entrapment as Sufficient Cause for the Observed Decline

Entrapment. SONGS Units 1, 2, and 3 entrapped an estimated 432,000 juvenile-adult queenfish weighing about 6.8 metric tons (MT) during the six months of April-September 1985 (Appendix I, Table 4). The analogous totals during the five months of April-August 1986 were 1,491,000 queenfish weighing 21.8 MT (Appendix I, Table

5). Small queenfish (< 10 cm SL) constituted about 58%-62% of these numerical totals (Appendix I, Tables 7, 8). Weight frequencies indicate that small queenfish equalled about 20%-25% of the biomass totals, or about 1.4 MT in 1985 and 5.5 MT in 1986 (Appendix I, Tables 7, 8).

Field Abundance. Appendix I, Table 8 summarizes the average CPUE of small queenfish near SONGS and elsewhere during the (A) April-September 1981 segment of the baseline period and the (B) April-September 1985 and (C) April-August 1986 segments of the operational period. CPUE has declined overall since the onset of El Nino in summer 1982, but catches have been disproportionately low at the Near Impact location ever since spring 1984 (Chapter One, Tables 1, 2; Appendix E, Tables 1, 2, Figs. 16, 18, 19, 21) and particularly during April-September 1985 and April-August 1986 (Appendix I, Table 8).

During April-September 1985 the difference between the average numerical catch of small queenfish at the Near Impact location (mean = 5) and at Control (mean = 36) was 31 fish per net-haul. The corresponding difference between the Near Impact and Far Impact (mean = 64) was 59 fish (Appendix I, Table 8). During April-August 1986, the difference between the average catch of small queenfish at the Near Impact location (mean = 17) and at Control (mean = 143) was 126 fish per net-haul. The corresponding difference between the Near Impact and Far Impact (mean = 85) was 68 fish (Appendix I, Table 8). Table 8 of Appendix I also lists average baseline CPUE and the respective location differences for small queenfish. During April-September 1981, there was a 9% (16/182) natural deficit observed in Near Impact catches relative to Control. There was an analogous 30% (38/128) natural surplus in Near Impact catches relative to catches at the Far Impact location. During April-September 1985, we would therefore expect a 3-fish natural deficit (36 x .09) or a 28-fish (31 - 3) net deficit at the Near Impact location compared to Control. And we would expect a 19-fish (64 x .30) natural surplus, and therefore a 78-fish (59 + 19) net deficit at the Near Impact location relative to Far Impact. During April-August 1986, we would expect a 13-fish natural deficit (143 x .09), or a 113-fish (126 - 13) net deficit at the Near Impact location compared to Control. And we would expect a 26-fish (85 x .30) natural surplus, and therefore a 94-fish (68 + 26) net deficit at the Near Impact location relative to Far Impact.

Recent relative declines in nearfield standing stocks are estimable if one accepts a constant catchability of 0.25 and integrates abundance per net area over

the 78.5-hectare (ha) nearfield area (Appendix F, part 4B). For the 1985 versus 1981 comparison, the change in the difference in estimated nearfield abundance of small queenfish is about 19,000 fish if Control location data are used as the standard, and about 53,000 fish if Far Impact data are used as standard. At an estimated average weight of about 6 g per small queenfish (Appendix I, Tables 6-7), these differences in numerical abundances are equivalent to differences in biomass abundance of about 115 kg (for 19,000 fish) and 320 kg (53,000 fish). For the 1986-versus-1981 comparison, the change in the difference between the abundance of small queenfish near versus away from SONGS is about 77,000 fish weighing 460 kg (using Control data as the standard) and about 64,000 fish weighing 385 kg (using Far Impact data as standard).

Comparison of Entrapment and Field Abundance. During April-September 1985 and April-August 1986, the estimated average density of small queenfish within a 1/2-km radius of the SONGS offshore intake structures was 8%-20% of the average density at the Far Impact location, and about 12%-14% that at the Control location. The 1981-versus-1985 change in the difference between average numerical abundance near SONGS and at the other locations, expressed as standing-crop biomass (115-320 kg), was 8%-23% of the entrapment of small queenfish (1.4 MT) at the three SONGS units during April-September 1985, assuming that all the small queenfish that were diverted at the new units (and discharged back offshore) died. Analogous estimates for April-August 1986 are 7%-8% of five months' worth of entrapment (5.5 MT). If only 37%-53% of the small queenfish that are diverted die (Section 2.3.2), the loss during April-September 1985 (0.8-0.9 MT; Appendix I, Table 6) was about 2-1/2 to 8 times the concurrent nearfield depression in standing stock. Assuming only 37%-53% loss for FRS-diverted fish, estimates for April-August 1986 (3.1-3.7 MT; Appendix I, Table 7) are 7 to 10 times the concurrent nearfield depression in stock.

The estimated average standing stock of small queenfish in the SONGS nearfield during April-September 1985 was about 3,400 fish weighing an estimated 20 kg. The analogous stock during April-August 1986 was about 11,600 fish weighing 70 kg. Viewed another way, the 1985 standing stock would have had to replace itself about 70 times in 6 months, or an average of once every 2-1/2 days, to offset a potential total removal of 1.4 MT. In 1985, the replacement rate would have had to have been 40-46 times in 6 months, or an average of once every 4 to 4-1/2 days, to balance an adjusted loss of 0.8-0.9 MT. The 1986 standing stock of small queenfish would have had to replace itself about 79 times in 5 months, or an average of once every 2 days,

to offset a total removal of 5.5 MT. The corresponding rate would have been 44-53 times in 5 months, or an average of once every 3 to 3-1/2 days, to balance an adjusted loss of 3.1-3.7 MT.

2.4 DISCUSSION

2.4.1 Temporal Comparisons of Entrapment Magnitude

During the first 39 months of full-pump operation, SONGS Units 2 and 3 together entrapped an average of 5.6 million fish, weighing 36.9 MT, each year. These entrapment values reflect an average 76% pumping level at the two new units during this period (Appendix F, Tables 4-6). Analogous values at SONGS Unit 1 have been 48,500 fish, weighing 3.8 MT, each year (Table 11; Appendix G, Tables 1-9, 10-15). Unit 1 pumped at an average 56% level during May 1983-August 1986 (Appendix F, Tables 4-6).

During March 1976-December 1979, average entrapment magnitude at Unit 1 was 445,000 fish, weighing 16.7 MT, each year (DeMartini and Larson 1980b). During this period, Unit 1 pumped at an unusually high, average 83% flow.

The annualized entrapment estimates at Unit 1 during May 1983-December 1986 can be made more directly comparable to the 1976-79 Unit 1 data by adjusting for period differences in average flow levels. If the 1983-86 entrapment data are corrected for period differences in pumping (as .83/.56), the estimated magnitude of average annual entrapment that would have occurred at Unit 1 during 1983-86 would still be only about 5.7 MT/yr (3,834 kg x 1.48) or about two-thirds lower than the average annual entrapment at Unit 1 during 1976-79.

We feel it is unlikely that the relative magnitude of entrapment at Unit 1 during 1976-79 and 1983-86 represents "inhibition" resulting from entrapment at Units 2 and 3. In order to evaluate this hypothesis (proposed by J. S. Stephens, Jr., a reviewer of the draft report), we need to know what the magnitude of Units 2 and 3 entrapment would have been in 1976-79. Clearly, such a hypothesis is untestable.

Persistent differences between 1976-79 and 1983-86 in average magnitude of entrapment at Unit 1, after allowances for period differences in average pumping volumes, implicate other, more intuitively reasonable causes for the changes. The most likely explanation is the broadscale change in nearshore fish abundance that took place during this period. Most significant have been the large (> 50%, in many cases: Chapter One) numerical declines that occurred from summer 1982 through winter

1985. These declines undoubtedly reflect the offshore emigrations and numerical responses of nearshore populations confronted by the California El Nino (Chapter One).

Queenfish, as our most intensively studied target species, provide the most comprehensive example of temporal changes in the population structure and abundance of nearshore fishes. During May 1978-August 1979, the average lampara catch of queenfish at SONGS intake depths was several hundred fish per seine-haul, of which about 65% were immature fish (DeMartini and Larson 1980a). Average catches persisted at these levels during September 1979-May 1982 (Table 2, this report). Catches started to decline in summer 1982 (DeMartini et al. 1983a,b), however, reducing average CPUE during June 1982-March 1984 by about 40% to 125-150 fish per haul (Table 2). The percentage of immature queenfish remained at 65%-66% from fall 1979 through winter 1984 (Table 2). During April 1984-August 1986, the average catch of queenfish further declined to a cumulative 50% of the baseline level at stations not immediately near SONGS, and the average contribution of immatures to total catch decreased to < 55% (Table 2).

The magnitude of the observed temporal changes in queenfish population structure and abundance suggests that period differences in level of entrapment at Unit 1 largely reflect temporal changes in nearshore abundance and size structure. Other factors, such as surge and turbidity, surely further influence magnitude of entrapment by affecting vulnerability at a given level of abundance (DeMartini et al. 1986; Section 2.3.4, this chapter). But if field abundance is the paramount influence of entrapment magnitude, it is reasonable to estimate the magnitude of entrapment at SONGS Units 2 and 3 during times of greater nearshore fish abundance based on temporal patterns in Unit 1 data. If abundance is the major determinant of entrapment, SONGS Units 1, 2, and 3 together might entrap over 110 MT of fish each year (at 75% flow) during times of greater nearshore fish abundance. (Proportionately higher levels of entrapment at times of greater nearshore fish abundance do not imply that SONGS' impact would be greater, however.) Further meaningful discussion of potential impact requires an evaluation of the magnitude of fish killed, not just entrapped (Section 2.4.2).

2.4.2 Efficiency of the Units 2 and 3 Fish Return System (FRS)

Comprehensive evaluation of percent efficiency of the FRS requires consideration of both the effectiveness of fish diversion and the survival of fishes that are diverted. The latter assessment must consider deaths resulting from predation at the time of discharge as well as deaths resulting from mechanical damage and stress during transit.

2.4.2.1 Percent Diversion

Diversion has averaged 80% (79% numbers, 82% biomass) for total fishes at Units 2 and 3 (Table 12). Diversion efficiency, however, ranged greatly among species, reflecting morphology and (especially) body size as influences of swimming speed (Appendix H, Table 1). Pipefish (Syngnathus spp.) present an extreme example of body shape that influences locomotion: none of more than 100 entrapped individuals of these pencillike, feeble swimmers was successfully diverted (Appendix H, Table 1). More significantly, the probability of successful diversion was directly proportional to body size for the typically "fishlike" (subcarangiform- and carangiform-) swimmers that constitute the majority of the species entrapped. For most fishes, body size alone was greatly important for successful diversion: "large-bodied" fishes (> 200 g) were successfully diverted 90% of the time, while success averaged 71% for "medium-sized" (30-200 g) and 68% for "small-bodied" (< 30 g) fishes (Appendix H, Tables 1,2). Fractions of biomass diverted were 85% (large), 70% (medium), and 77% (small) -- not very different from the respective numerical fractions. The most dissimilar values (68% numbers, 77% biomass for small-bodied fishes) likely reflect the extreme effect of body size on intake avoidance in these fishes. It is generally recognized that larger-bodied fishes (and larger individuals of the same species) have greater swimming capabilities (e.g., see Webb 1975; Wardle 1977). Therefore, larger fishes should generally be better able to avoid withdrawal at intake structures.

2.4.2.2 Percent Survivorship

Surviving Transport. Precise, species-specific estimates of the probability of avoiding death from mechanical abrasion and stress during the discharge process are limited to those species that occurred in diversion samples used for survivorship tests and that were (by chance) captured by fyke nets for the control trials. The

species characterizations were mostly limited by the latter. Ten species had adequate (> 20 fish) sample size in the experimental pens that collected fish from the FRS discharge, but only five of these had nontrivial sample size in control pens.

Empirical data were, however, sufficient to estimate percent survivorship for key species (northern anchovy, queenfish, white croaker). Queenfish and white croaker together constitute a large majority of the numbers (96%) and biomass (97%) of all small-bodied fishes (excluding northern anchovy) in SONGS diversion samples. We therefore feel that the average transport survivorship of small-bodied fishes (excluding anchovy) is accurately characterized with a weighted average of the survivorship data for these two species (66%). Analogous observations for salema and for yellowfin croaker provide similarly generalizable survivorship estimates for medium-sized and large-bodied fishes. Meager data for each of numerous other medium- and large-bodied species together corroborate our estimate of 100% transport survivorship for fishes that average more than about one ounce (Appendix H, Tables 1-3).

Surviving Predation upon Discharge. We feel that our subjective estimates of the probability of surviving predation upon discharge (Table 13) are adequate for the following reasons. (1) The relatively high mortality value assigned to northern anchovy (50%) is realistic. On several occasions, all of the anchovy discharged were observed being consumed by Pacific mackerel, *Scomber japonicus* (J. Stein, formerly of Occidental College, pers. comm.). Although mackerel are a transient, warm-water migrant nearshore in the SONGS area, they do occur in great abundance on numerous occasions throughout the year (Appendix C, Tables 1-6, 7-12). It is reasonable that mackerel and many other piscivorous fishes and birds should exact a heavy toll on the juvenile (average 2 g: Appendix H, Table 1) individuals that dominate the anchovy discharged at SONGS. Then too, the low biomass contribution of anchovy to fish diversion (average 11%: Appendix H, Table 2) somewhat cushions the effect of inaccuracy for any arbitrary probability value.

(2) It is also reasonable to expect a nearly complete immunity to predation (99%) for large-bodied (> 200 g, or approximately 1/2-pound or larger) fishes (Table 13). Nowadays, very few predaceous fishes are large enough to consume such large prey. Fishes > 200 g contribute 27% to total diversion biomass at SONGS (Appendix H, Table 2). One percent of this subtotal should be sufficient to account for

occasional predation by large piscivorous fish (e.g., California moray {Gymnothorax mordax} predation on yellowfin croaker: K. Herbinson, SCE, pers. comm.) and by harbor seals and sea lions.

(3) Somewhat more arbitrary is the 90% survivorship value assigned to medium-sized (30-200 g) fishes. A 10% chance of being consumed when discharged is not unrealistic, given that the average body weight of individuals in this group has averaged only 92 g (about 3 ounces) in SONGS diversion samples (Appendix H, Table 2). Medium-sized fishes constitute only about 10% of total diversion biomass (Appendix H, Table 2), and this fact ameliorates the effect of an inaccurate estimate of survivorship for the group.

(4) Most important for our fish loss estimates is the 75% survivorship value assigned to small-bodied fishes (excluding northern anchovy), because these fishes constitute > 52% of all fish diversion biomass at SONGS Units 2 and 3 (Table 12; Appendix H, Tables 1,2). Since queenfish and white croaker together make up nearly all (97%) of this subtotal, the crucial question really is whether an additional probability of 0.25 for death by predation is accurate for the 66% of these two species that survive the transport process. The average body weight of discharged queenfish and white croaker was 16 g and 7 g, respectively, during May 1983-August 1986 (Appendix H, Table 1). Certainly fishes of this size should be at fair risk to predation by many species of piscivorous fishes and diving birds.

Year-Class Effects on Efficiency Estimates. Both diversion success and percent survivorship following subsequent FRS transport have been empirically shown to be size-dependent. The probability of otherwise dying because of predation when discharged has reasonably been argued to be size-dependent as well. Obviously, factors such as year-class strength influence the average body size of a particular species in any given year. For example, the 1985-86 year classes of white croaker were strong (Appendix E, Figs. 5 and 52), and many small juveniles then inflated this species' numerical representation in entrapment samples (Appendix G, Table 2). It follows that our 39-mo characterization of percent diversion for white croaker is biased lower than, say, a decade-long estimate would be. Of the greater percentage of white croaker that, on average, would be diverted over a longer series of years, individuals of a greater average body size also should be better able to survive both physical transport and predation upon discharge from the FRS.

The latter and other, analogous potential biases in our percent efficiency estimates probably are dampened when fish losses are evaluated for groups of species. Many California nearshore fishes exhibit good and poor recruitment years that vary among species in their timing. For example, the 1985-86 year classes of queenfish were not particularly strong (Table 2; Appendix E, Figs. 20, 51, 54, 55), and queenfish have codominated the diversion component of SONGS entrapment with white croaker (Table 12; Appendix H, Table 1). We conclude that, although year-class variations have undoubtedly colored our 39-mo evaluation of the Units 2 and 3 FRS (and, indeed, many other aspects of SONGS entrapment) for particular species, our overall assessment of the system is sufficiently accurate.

2.4.2.3 Entrapment Adjustments for FRS Efficiency

Estimates of the overall percent efficiency of the Units 2 and 3 FRS can be used to adjust average annual entrapment totals to the likely magnitude of fishes killed. An average 3.0 MT (total fishes) is killed each year at the two new units during heat treatments (Table 11; Appendix G, Table 9). The remaining 33.9 MT/yr comprises an estimated 11% (3.7 MT) northern anchovy, 53% (18.0 MT) other small-bodied fishes, 11% (3.7 MT) medium-sized fishes, and 25% (8.5 MT) large fishes (Appendix H, Table 2). Seventy-nine percent of the anchovy biomass is diverted (Appendix H, Table 1), and an estimated 48% survives, for an overall efficiency of 38% (Table 13). This is equivalent to an average 1.4 MT of anchovy saved each year. Percent biomass diversion is an estimated 77% for other small-bodied fishes (Appendix H, Table 1); we estimate that 50% of these survive (Table 13), yielding an overall efficiency of 38%, or about 6.8 MT/yr saved. Seventy percent of all medium-sized fish biomass is diverted (Appendix H, Table 1). An estimated 90% of these survive for an overall efficiency of 63%, or about 2.3 MT/yr saved. Of the average 8.5 MT of large-bodied fishes at risk during normal flow operations, about 85% is diverted (Appendix H, Table 1). Subsequent survivorship of those diverted is an estimated 99% (Table 13), for an overall efficiency of 84%. The latter is equivalent to 7.1 MT/yr saved.

Summed over all size groups of fishes, the SONGS Units 2 and 3 FRS probably saves about 48% (17.6 MT/36.9 MT) of entrapped juvenile-adult biomass. The relatively poor efficiency for small fishes (38%) is partly offset by the relatively good efficiency for large fishes (84%). However, the overall average efficiency for total fishes is influenced more strongly by the biomass-dominant small fishes.

2.4.3 Comparisons of Unit 1 with Units 2 and 3

The average magnitude of entrapment at each new unit exceeded that concurrently measured at Unit 1 by > 2.5 times for total fishes and for 5/6 other major species and compound taxa that we examined (Table 14). Results were based on an extensive series of 45 matched samples spanning 2-1/2 years of quantitative sampling at the new units (Appendix F, Table 2). These data provide firm evidence that the average magnitude of fishes entrapped, as estimated by the average magnitude of fishes retained on travelling screens and diverted into the quiet areas of screenwells, is generally > 2.5 times larger than the average magnitude of fishes retained on travelling screens at Unit 1.

Among the abundant and frequently encountered species tested, the average differences in magnitude of entrapment at Units 2 and 3 and at Unit 1 ranged from nil for walleye surfperch to > 100X for white croaker (Table 14). Overall biomass entrapment (total fishes) was about 6 times greater at each of the two new units (Table 14).

Because of the two-thirds larger mesh size of the travelling screens at Unit 1, large numbers of the juvenile fishes that are diverted past travelling screens at the new units would pass through the screens at Unit 1 and be killed within the condenser system. It is therefore not surprising that collections should exceed the 2.5X prediction of DeMartini and Larson (1980b)--because it is the collections, not entrapment per se, that form the basis for comparison.

Large queenfish (> 10 cm SL) provide our best data for evaluating the 2.5X prediction. This is because queenfish of this size, once they impinge on screens, should be fully retained on even the larger meshes at Unit 1. Based on Margraf et al.'s (1985) application of the "fineness ratio" (body shape) formula of Turnpenny (1981; Equation 14), queenfish should be fully recruited to the Unit 1 screens at 113 mm SL and to the Units 2 and 3 screens at 57 mm SL. Therefore, the different meshes of the screens at the old and new units should not greatly influence the average difference in entrapment magnitude for large queenfish. Nonetheless, we have observed an average level of entrapment of large queenfish at each new unit, compared to concurrent entrapment at Unit 1, that has been significantly greater than 2.5X (nominally > 7X: Table 14; Appendix G, Table 16). The queenfish entrapment data indicate that, despite the improved design of the velocity caps and

the reduced average intake velocity at Units 2 and 3 (Downs and Meddock 1974; Schuler and Larson 1975), each new unit on average entraps > 2.5 times as many large queenfish as Unit 1.

It should be noted that the greater than predicted magnitude of the nearfield depression in queenfish (from ~60% to >80%; Chapter One) may contribute to an explanation for the greater than predicted magnitude of queenfish entrapment at Units 2 and 3.

In order to further evaluate the 2.5X prediction, it would be necessary to know the relative retention rates, for each size-group of fish within major species, on the 3/8-in. and 5/8-in. meshes. Because fish species vary in body shape and flexibility as well as in their length distributions, relative retention rates would have to be estimated empirically. The only intuitively satisfying method would be a regression approach. Such an approach would, unfortunately, require the impossible--concurrent data for a series of "replicate" SONGS units with a broad range of mesh sizes represented, enabling regression estimates of impingement magnitude versus mesh size. We therefore have no means for rigorously evaluating DeMartini and Larson's (1980b) prediction of 2.5X for entrapment in general at Units 2 and 3. For most major species and for total fishes, our qualitative conclusion is that entrapment at each new unit is inestimably greater than 2.5 times that at Unit 1.

The surprisingly low level of entrapment of walleye surfperch at SONGS Units 2 and 3 is worth discussing. Perhaps the unusually deep body proportion of walleyes results in a smaller fraction of the dollar-sized juveniles of this species passing through the larger-mesh screens at Unit 1 (Turnpenny 1981). Alternatively, the indistinguishable magnitude of entrapment at Unit 1 and at Units 2 and 3 is better interpreted as a disproportionately large Unit 1 effect. Despite certainly greater mesh retention on screens, plus the diversion facilities at the new units, entrapment of walleye surfperch at Unit 1 has remained relatively high over the years of concurrent operations at the three units (Appendix G, Table 3). Perhaps some interaction between the outfall and intake at Unit 1 increases the entrapment vulnerability of this species. Walleye surfperch are known to feed heavily on amphipods like the tube-building Jassa spp., which are a major element of the fouling fauna within the SONGS intake conduits and which are regularly discharged in cooling waters (Barnett et al. 1987; A. Barnett, MEC, pers. comm.).

2.4.4 Entrapment as Mechanism for Nearfield Depression

2.4.4.1 Mathematical Models

DeMartini et al. (1986) provided preliminary analyses that suggested potential relationships among entrapment, nearfield abundance, and the near-SONGS depression of small queenfish. Based on analyses of 10/16 samples, DeMartini et al. (1986) tentatively concluded that a positive relationship existed between the magnitude of entrapment and nearfield abundance of small queenfish. Analyses of the same data led DeMartini et al. (1986) to flag a positive relationship between the magnitude of the difference in lampara catches (near versus away from SONGS) and the magnitude of queenfish entrapment on the same night.

Reanalysis using all of the 16 matched samples that eventually became available has failed to support the previous results. In part this reflects the more parsimonious models (having fewer variables) that were reevaluated (DeMartini et al. 1986). But previous evaluations of simpler models (using the first 10 samples) also gave stronger suggestion of relationships than the present comprehensive evaluation.

Numerous potential reasons exist for our ultimate inability to mathematically describe the interrelations of entrapment, nearfield abundance, and near-SONGS depression. Surge and turbidity, as influences of vulnerability, are somewhat inaccurate indices. Surge was characterized by a 24-hr average, whereas most entrapment at SONGS occurs at night and, especially, dawn and dusk (DeMartini and Larson 1980a; Johnson 1980; Helvey 1985). Turbidity was characterized by measurements taken at the time of in-plant sample collection following this 24-hr period. More important, single lampara seine-hauls were the basis of all estimates of nearfield abundance and catch differences between longshore sampling stations. The precision (repeatability) of single seine-hauls is not particularly high, even for intake depths at night (average SD = one-third of the mean, based on a series of same-night hauls taken near the SONGS intakes in September 1983). Last but not least, even the full complement of data (16 matched samples) provides a meager basis for elucidating relationships in 2-3-factor multiple regressions. We can only conclude that chance error also partly influenced our prior, preliminary conclusions.

It is important to note here that inability to mathematically describe interrelationships because of insufficient data does not disprove the existence of the relationships. Certainly the positive relation between fish abundance and magnitude of entrapment has been established by studies at other southern California power plants (Helvey 1985, Figure 3; after Johnson 1980). Our evaluation of entrapment as the mechanism for near-SONGS declines in small queenfish (Sections 2.3.4.2 and 2.4.4.2), therefore, should not be considered deficient because its simple calculations lack rigorous modeling support.

2.4.4.2 Balance Calculations

Reasonable Immigration Rates. The rate of removal of juvenile queenfish by entrapment at SONGS Units 1, 2, and 3 is sufficient to account for the observed depression in catch near SONGS, if average replacement rates (immigration) of once every 3-4 days are accepted (Section 2.3.4.2). Immigration rates of these magnitudes seem reasonable based on the vagile, schooling nature of the species (DeMartini et al. 1983 a,b; Allen and DeMartini 1983; DeMartini, Allen, Fountain, and Roberts 1985). Temporal patterns in catch data indicate that queenfish display subseasonal and shorter-term longshore movements of many kilometers (DeMartini et al. 1983a,b; Allen and DeMartini 1983). Queenfish distributions generally shift somewhat offshore at night; adults (particularly males) make diel onshore and offshore migrations of at least several kilometers (DeMartini, Allen, Fountain, and Roberts 1985).

Species Patterns in Entrapment and Field Abundance. The apparent relative decline in queenfish numbers near SONGS is most clearly suggested for immature fish, and young-of-the-year (YOY) in particular (Chapter One, Tables 1, 2; Appendix E, Tables 1, 2). This is consistent with numerical entrapment data: most queenfish that are entrapped are small, immature fish (Appendix I, Tables 6, 7). Significant nearfield declines in YOY white croaker (*Genyonemus lineatus*; Chapter One, Tables 1,2; Appendix E, Tables 1,2) have been concurrent with large recent increases in the entrapment of YOY white croaker at SONGS (Appendix G, Table 2; Appendix I, Tables 4, 5). The observed near-SONGS declines of both small queenfish and white croaker are explicable, therefore, in terms of absolute magnitude of entrapment.

On the other hand, neither silversides nor Pacific butterfish (*Peprilus simillimus*) have significantly declined in numerical abundance near SONGS, relative

to either Control location (Chapter One, Tables 1, 2; Appendix E, Tables 1, 2). Moreover, neither taxon was entrapped in large numbers at SONGS during April-September 1985 or April-August 1986 (Appendix I, Tables 4, 5). In terms of absolute entrapment levels, then, patterns of near-SONGS abundance and entrapment are also consistent for these two species.

These two pairs of species also can be meaningfully compared in terms of their relative abundances in lampara catches and their relative contribution to SONGS in-plant collections. Queenfish have always numerically dominated seine catches at Far Impact and Control locations and in-plant samples (Tables 2, 11; Appendix G, Tables 1, 9; Appendix I, Tables 4, 5). White croaker had ranked a strong second in baseline seine catches, but its field abundance crashed in 1982-83 (Table 2). Seine catches of white croaker ranked a strong third (in 1985) and a weak second (in 1986) among the four species (Appendix I, Table 8). During April-September 1985 and April-August 1986, entrapment of these four species at the combined SONGS units was dominated by queenfish and (secondarily) white croaker (Appendix I, Tables 4, 5). But the numerical entrapment of white croaker in 1985 was about 2 orders of magnitude greater than the entrapment of silversides and butterfish (Appendix I, Table 4). In 1986, croaker entrapment was 1-1/2 to 3 orders of magnitude greater than silversides and butterfish (Appendix I, Table 5). Compared to white croaker's relative field abundance, its level of recent entrapment has been disproportionately great among the four species (Appendix I, Tables 4, 5). The relative magnitude of recent queenfish entrapment has been more disparate, even after allowing for its numerical dominance in the field. Recent entrapment of queenfish exceeded that of butterfish and silversides by 2-1/2 orders of magnitude (in 1985) and 3 orders of magnitude (in 1986) (Appendix I, Tables 4, 5). The field dominance of queenfish was generally around 1 order of magnitude during these periods (Appendix I, Table 8).

Sources of Error. The estimates generated by these methods are based on several admittedly inexact parameter values. The most important of these are the 25% catchability value (used for scaling density to abundance-in-the-net) and the subjectively defined extent of the nearfield region that is being affected by entrapment (used to standardize net abundance to abundance on a local scale). Catchability estimates will never be improved, but Occidental College's hydro-acoustic data, if size-specific and sufficiently precise and accurate, might provide a usable index of species distributions that would better define the nearfield region for queenfish. Note that nearfield abundance estimates are inversely related

to catchability but are directly proportional to area (radius-squared) of the nearfield.

CHAPTER THREE
FISHES AT SAN ONOFRE AND SAN MATEO KELP BEDS

3.1 INTRODUCTION

3.1.1 SOK and Other Southern California Kelp Beds

San Onofre Kelp bed (SOK) is a forest of giant kelp (Macrocystis pyrifera) on a cobble seabed in 8-16 m of water, located about 2-3 km offshore of San Onofre Nuclear Generating Station (SONGS). Forests of giant kelp are structurally complex habitats frequented by a diverse assemblage of nearly 100 species of fishes (Feder et al. 1974). Macrocystis forests provide a complex combination of animal food, shelter, and water-column extension of benthic habitat for fishes (Quast 1968a,d; Feder et al. 1974; Bray and Ebeling 1975; Hobson and Chess 1976; Bernstein and Jung 1979; Coyer 1979; Hobson et al. 1981; Ebeling and Laur 1985; Bodkin 1986). Kelp beds are also thought to enhance the productivity of organisms, including fishes, in part directly via herbivory (North 1971), but primarily through a detrital pathway to invertebrate grazers that provide the major prey of many fishes (Foster and Schiel 1985).

Operations of the SONGS Units 2 and 3 cooling system have been predicted to impact (Dean et al. 1983), and are still considered to be having an impact on giant kelp at the San Onofre Kelp bed (Dixon et al. 1985; Schroeter et al. 1987; Dean et al. 1987). The withdrawal and secondary entrainment of turbid, epibenthic waters near shore and the discharge of these waters nearer the surface and farther offshore has decreased illumination near the seabed within SOK. This has precluded, and will continue to preclude natural reseeding of young kelp sporophytes during the recruitment windows that occur during brief, sporadic intervals (Dean et al. 1983, 1987). Continued natural attrition of adult plants, without offsetting recruitment, probably has been the major contributor to the recent decline in density of Macrocystis in the inshore, upcoast sector of SOK, closest to the SONGS diffuser plume (Dixon et al. 1985; Schroeter et al. 1987; Dean et al. 1987).

One segment of the UCSB Fish Group's total evaluation of SONGS' potential impact on nearshore fish stocks has been an assessment of what, if any, effect SONGS' impact on giant kelp, through loss or change in kelp bed habitat, might indirectly have on the rocky, inshore fishes (sensu Quast 1968a) inhabiting SOK. A brief history of this evaluation follows.

3.1.2 History of Fish Studies at SOK

DeMartini and Larson (1980a,b) first evaluated field counts of fishes in kelp-canopied and kelp-depauperate regions in and near SOK during fall 1979. On the basis of these observations, they predicted that, on a local scale (i.e., within SOK), many fishes might decrease in density by about 1/3 to 2/3 in regions where lush canopy declined to low-density kelp (DeMartini and Larson 1980b; Larson and DeMartini 1984). These predictions provided the rationale for continued monitoring of fishes at SOK and at San Mateo Kelp bed (SMK), another cobble-bottom kelp forest located off San Mateo Point, about 5-6 km upcoast of SONGS.

DeMartini et al. (1981b) analyzed and evaluated the first half (fall 1980) of the baseline (SONGS Units 2 and 3 preoperational) monitoring data. These early monitoring data indicated that the fish assemblages at the two kelp beds were qualitatively similar, but suggested that the densities of some species differed between the two kelp beds.

In our group's last report on kelp bed fishes (DeMartini et al. 1983a,b), we provided a comprehensive evaluation of baseline data, including the second and final year (fall 1981) prior to consistent pumping by SONGS Units 2 and 3. Similarity of assemblage structure persisted during the two years. However, quantitative density differences between SMK and SOK (and, to some extent, between the upcoast and downcoast stands of kelp within SOK) were reaffirmed. Potentially important, temporal shifts in baseline densities (among locations) were noted for several major species, including kelp bass and California sheephead (DeMartini et al. 1983a,b).

3.1.3 Objectives

In this chapter, we have three major objectives:

1. We provide our final analyses of SONGS' impact on fishes at SOK, based on BACI (Before-After-Control-Impact: Stewart-Oaten et al. 1986; Stewart-Oaten 1986) test comparisons of fish densities between baseline (1980-81) and operational periods (1985-86) for SOK versus SMK and for the upcoast versus downcoast regions of SOK. Included are comprehensive estimates of fish densities at SOK and SMK, by major life stage, for all common and abundant species. By comparing the relative densities of fish at impact stations (where kelp has decreased disproportionately in the After period) and control stations (where After declines in kelp have been less extreme), we test the prediction that fish density should decline proportionately to declines in kelp density, both within a single kelp bed (SOK) and between neighboring kelp beds (SOK, SMK).

2. We evaluate the relations between the densities of fish and giant kelp at SOK during fall 1985 and fall 1986. By so doing, we test our premise that fish density is positively related to kelp density on a local scale within SOK.

3. We further use fall 1985, 1986, and baseline (fall 1980, 1981) data on fish densities, plus sonar (kelp mapping) data on the density distributions of giant kelp to estimate the abundances of fishes at SOK. We do this in order to translate our estimates of fish density change, over defined areal extents, to estimates of changes in fish numbers and biomass at SOK.

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

through fall 1986), kelp densities had declined in the inshore portion of SOKU, at several areas within SOKD, and throughout much of the offshore and upcoast parts of SMK. Operational period monitoring of fish densities therefore included stations of relatively dense (SOKUout) and relatively sparse kelp (SOKUin) within SOKU. Analogous dense (SOKDout) and reduced-density (SOKDin) stations were sampled in 1985-86 within SOKD (Appendix J, Figs. 2A-2C). Within SMK, the region of densest available kelp was tracked about 100 m offshore (1985) to 150 m downcoast (1986) of the 1980-81 SMK stations (Appendix J, Tables 1, 2; Figs. 2D-2F). Our comparison of fish densities between SOKU and SMK used a SOKUout-SMK station pairing during the operational period. The analogous comparison of densities within SOK used the SOKUin and SOKDout stations. We selected these particular stations and station pairings for the following reasons: (1) The SOKUout and SOKDout stations represented the densest available Macrocystis stands within upcoast and downcoast SOK during 1985-86; (2) the SOKUin station provided reduced-density kelp, representative of inshore-upcoast SOK, during these two years; (3) SOKUout and SOKUin were adjacent to the SOKU station sampled in 1980-81; and (4) the station pairings comprised stations sampled on the same day during the operational period.

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Comparisons used the BACI analysis design (Stewart-Oaten et al. 1986; Stewart-Oaten 1986). Comparisons were made for each of 15 select taxa of fishes (and relevant component life stages). As for the other fish assemblages being monitored (Chapter One), species in SONGS-area kelp beds were selected for statistical testing based on a combination of criteria: (1) known or suspected ecological significance; (2) economic (sport, commercial) importance; and (3) frequency and abundance in samples.

Time-series plots of the deltas (differences) used in impact tests, plus density data at Impact and Control locations, are provided to help interpret the statistical analyses (Appendix N, Figs. 1-83). A brief reader's guide to these figures follows. For each species and life stage that could be evaluated (see below), a three-panel figure is provided. In the top panel, we illustrate estimated densities at the Impact location (SOKU) for each testable baseline and operational sampling date. In the middle panel, analogous data are illustrated for the Control location (SMK or SOKD). In the bottom panel, we illustrate the corresponding deltas for each testable date during the 1980-81 baseline and the 1985-86 operational periods. "Double zero" observations (Chapter One, Analysis

Methods) are included in all plots to illustrate the relative frequency of co-absences. Form of the data used in plotting the deltas and densities vary with type of impact test used (i.e., log-transformed data for t-tests, raw data for binomial tests: see below). If data were totally unsuitable for statistical evaluation (Section 3.2.2.1), deltas are not illustrated.

3.2.2.1 Screening Tests

Prior to t-tests, data were screening for key assumptions. The deltas (differences) evaluated were calculated for each survey by taking the difference of the log-transformed {LOG-10 (x + c)} mean densities at impact and control sites. Values of c from 0.0025 to 2 were considered (the smaller value being less than or equal to one-sixth of the minimum, nonzero weighted density per 1000 m^3; Stewart-Oaten 1986). Each location-pair was evaluated separately for each species and life stage. If more than one value of increment was additive, the smallest value (that perturbed the data the least) was selected (see Chapter One, Section 1.2.2.2). Nonmultiplicative data transformations were excluded from consideration a priori (i.e., inverses were disallowed: see Chapter 1, this report). The same transformation was used for both pairs of location comparisons of a given species-life stage. Transformations often differed, however, among species and among life stages within species.

Additivity was tested by least squares regression of the deltas (as dependent variable) on the sum of the log-transformed densities at impact and control (Stewart-Oaten 1986). Once an additive transformation was found, this additive form of the data was subjected to a further battery of screening tests. Subsequent screening tests included (1) least squares regressions for monotone trend in baseline deltas, and (2) von Neumann's test for serial correlation of deltas within either sampling period. If von Neumann's test detected serial correlation, autoregressive errors of orders one and two were included in the model. All screening tests were evaluated at P = 0.05.

One additional preanalysis step was undertaken before BACI t-tests were run for certain species (e.g., kelp perch) in which the baseline time series of deltas exhibited a significant temporal monotone trend. The baseline deltas for these species were evaluated for "influence points" (Chapter One, Analysis Methods). If significant trend could be attributed to only one or two data points, our protocol

was to proceed with the t-test for impact (including the outlier data), but qualify our results (Chapter One, Analysis Methods).

Prior to this, we had attempted to "detrend" cases with problematic baseline trends using water temperature as covariate; all attempts were unsuccessful (DeMartini et al. 1983a,b). We made more recent attempts to "detrend" these problem cases using kelp density as covariate. Baseline fish deltas were regressed on the deltas of kelp density. If fish deltas regressed significantly on kelp deltas, and if the resulting residuals of the fish deltas regressed insignificantly against time, the residuals of that species' deltas were to have been used for the impact test, instead of its deltas per se. When "detrended" in this manner, however, preliminary BACI t-tests of baseline versus fall 1985 data revealed a further problem: all cases (with trend) in which deltas significantly changed between baseline and operational periods lost significance when tested using residuals of the deltas. This observation (1) supports our premise that a change in fish density would be correlated with a change in kelp density; however, (2) it also removes the effect we are primarily interested in testing. Kelp was therefore not used as a covariate in BACI t-tests per se. Instead, we tested for SONGS impact using deltas (not residuals of the deltas) for all cases lacking trend that were otherwise tractable. We complemented the BACI t-tests with Analysis of Covariance (ANCOVA) that evaluated the relationship between fish and kelp (Section 3.2.3). The results of this analysis were used to interpret the t-test results. This approach seems reasonable and adequate, given the observed changes in relative kelp densities at BACI stations between Before and After periods (see Appendix O, Table 1).

3.2.2.2 T-Tests

Our major method of evaluating impact was by t-test (but see "Alternative Test," below). Deltas of mean densities (numbers) were contrasted between SONGS' operating periods using Student's t-test, with degrees of freedom corrected for inequality of variances as appropriate (Satterthwaite 1946). Weighted (bottom plus canopy) density data were used. Densities (standardized as #s/1000 m^3) were weighted by thickness of the sampling stratum (canopy: 5.3 m; or bottom: 1.5 m). Separate t-tests were performed for each of 15 fish species that had been common and abundant in baseline samples. Each major life stage (juvenile = JUV, subadult = SAD, adult = AD) was tested separately, as data allowed, in addition to total

individuals (TOTAL: all stages pooled) of that species. T-test results were evaluated at a two-tailed alpha of 0.05 or 0.10 (the latter value if power was < 0.80).

3.2.2.3 Alternative Test

If the data were found unamenable to t-test, other methods of analysis were considered. The primary alternative considered was a binomial test (Siegel 1956). Binomial tests were used in lieu of t-tests if a large percentage of zero observations in baseline data allowed for spurious rejection or acceptance of the additivity test. For example, a large percentage of zero-observations at either the Impact or Control location could generate a failed additivity test for this reason alone. Conversely, a large percentage of single zero-observations at both locations could produce a spuriously acceptable additivity test (J. Callahan, pers. comm.). Binomial test results were evaluated at a two-tailed alpha of 0.05.

All assumptions screened are described in detail for analogous tests using seine and trawl data in Chapter One of this report. Stewart-Oaten (1986) provides additional rationale.

3.2.3. Fish--Kelp Relations

BACI t-tests are predicated on the assumption that, if significant before-after changes in impact-control differences occur, they are a consequence of the supposed mechanism of impact. In this particular case, the a priori recognized mechanism is loss or change in kelp-bed habitat at SOK resulting from SONGS Units 2 and 3 pump operations. But are there relationships between Macrocystis densities and fish densities at SOK, and, if so, what are they? It is therefore important that:

1. We describe the actual numerical interrelations of giant kelp and fish on the cobble seabed at SOK.

2. Data on the fish-kelp relationship also provide a rationale for estimating fish abundance at SOK, whereby fish density data are to be extrapolated to areas of like-kelp density and then summed over various kelp-density strata (see Methods section 3.2.4).

3.2.3.1. Sampling Design

To characterize the numerical interrelations of fish and giant kelp, we sampled fish densities at five locations within the SOK cobble bed during fall 1985. The same five stations were resampled in fall 1986. Kelp and fish were counted at three stations (SOKUin, SOKDin, and CobbleUp) in addition to two other stations within SOK (SOKUout, SOKDout; Appendix J, Table 2, Figs. 2B, 2C). We attempted to alternate sampling dates at the former three stations with dates on which the latter two stations (and the SMK station) were sampled (Appendix J, Table 1). Two additional stations at SOK (SOKinbetween, CobbleDown: Appendix J, Tables 1, 2) were sampled in fall 1986. Because we lacked 1985 data for the latter two stations, we did not use their data for our fish-kelp analyses, although these data were used for abundance estimations (Section 3.2.4).

At all seven locations within SOK, fish densities were estimated within a third (midwater: 7.7-m depth) stratum, in addition to the two major strata (canopy, bottom) sampled to provide the data for t-tests on densities at the BACI stations. Fish densities at 7.7 m were characterized by cinetransect, as at canopy depth. An integrated (water-column) density was estimated for each location and date by weighting each stratum density by thickness of the respective stratum; thickness of the midwater stratum was 7.6 m from the floor of the canopy (5.3 m depth) to the roof of the seabed stratum (12.9 m). (See Appendix M, Table 1 for relevant strata for particular species.)

Fish were counted and categorized into major life stages (JUV, SAD, AD), where stage was identified on the basis of total body length (Appendix T, Table 1A). Tallies were standardized to densities per 1000 m^3.

Kelp densities were characterized by diver counts of "juvenile - adult plants $\geq$ 1 m tall" (Dean 1980) encountered on return swims of bottom fish transects. Bottom transects covered a 225-m^2 area, and kelp counts were standardized to #s/100 m^2. Other potentially important covariates of fish density (i.e., two overstory brown algae, Pterygophora californica and Cystoseira osmundacea; the erect, turflike red alga Acrosorium uncinatum; and Lytechinus anamesus urchins) were also evaluated on bottom transects. Qualitative indices (1-4: with 1, nil to sparse; 2, sparse to moderate; 3, moderate to dense; and 4, dense to very dense) were used to characterize the relative abundances of urchins, overstory algae, and

turf algae. We used an analogous index to characterize bottom type (1-4: with 1, mostly sand; 2, sand with some cobble; 3, cobble with some sand; and 4, mostly cobble with larger rocks and boulders).

3.2.3.2 Analysis Design

As a first attempt at evaluating fish-Macrocystis relations, we performed simple linear regressions of fish density on kelp density, pooling the data for all five sampling locations at SOK. Fall period ("year") was included as a separate term in the model. We also evaluated whether the slope of the relation between fish and kelp differed between years. For these and all subsequent, more complex regression and ANCOVA analyses of fish-kelp relations, we used a LOG10 (x-bar + c) transformation of fish densities, with densities standardized to #s/1000 m^3. The value of "c" chosen was equal to the smallest nonzero density value possible -- corresponding to one individual fish present on one transect in one sampling stratum. (This value differed among species, depending on which combination of strata was relevant in calculating the species' weighted density.) However, "c" was constant for all life stages of a given species.

As a further exploration of fish-kelp relations, we performed stepwise multiple regressions to identify the environmental covariates (among the 6 measured, including giant kelp) that most efficiently explained the greatest percentage of the variation in log fish density. The variables evaluated were year; Macrocystis densities; abundance indices of Pterygophora, Cystoseira, Acrosorium, and Lytechinus; and bottom type. Two-way interactions between year and any of the other variables were allowed.

As our final evaluation, we performed ANCOVAs testing the effect of location (as class effect) on log fish density, with the most parsimonious suite of covariates (identified in the preceding stepwise regression step) entered first in the model.

Prior to any of the above regression and ANCOVA analyses, we evaluated the nature of the mathematical relationship between our measurements of fish and kelp densities at SOK. We considered curvilinear (asymptotic) fits as well as linear fits for regressions of log fish density on kelp density. Both positive and negative relations were considered. We identified the best functional

relationships based on nominally largest R^2 values. All common and abundant life stages of major test species were evaluated using data for the two fall periods. Appendix O describes analysis protocols in greater detail.

3.2.4. Fish Abundance Estimates at SOK

To fully evaluate SONGS' impact on fishes, the MRC must be able to translate losses (or changes) in fish density to analogous changes in the abundance of fish at SOK. Biomass as well as abundance (numbers) and loss estimates are needed, particularly because the value of certain economically important species (e.g., kelp bass) is best gauged by the biomass of its harvest.

3.2.4.1 Estimates of Fish Numbers

The numbers of fishes present at SOK during fall 1985 and fall 1986 were estimated based on fish densities, measured at stations of known kelp density multiplied by areal extents of the regions of respective kelp densities. Fish densities were weighted (bottom plus water column) estimates whose water-column portion either included midwater and canopy estimates or was based on canopy data alone, depending on the particular abundance calculation (see details below).

Fall 1985-86 Downlooking-Sonar-Based Estimates. For our best fish abundance estimates, midwater transect data were included in the weighted density calculations. In fall 1985, areal extents of kelp density strata of 0-4, 4-16, and > 16 plants/100 m^2 were calculated using the charts of ECOsystems Management Associates' (ECOM's) November-December 1985 Downlooking (DL) Sonar Survey 7 (Norall et al. 1986). In fall 1986, the corresponding kelp density strata were 0-2, 2-8, and > 8 plants per 100 m^2. Areas of these strata were determined from ECOM's Downlocking Sonar Survey 11, done in November-December 1986 (Reitzel et al. 1987). Fish density data were matched with DL sonar strata that enclosed the mean kelp density measured by fish observers on bottom transects at each of the five (1985) or seven (1986) stations sampled. In 1985 these were the sparse (kelpless cobble) station (CobbleUp: mean = < 1 plant/100 m^2); the "low" SOKUin and SOKDin stations (9-10 plants/100 m^2); and the "moderate" SOKUout and SOKDout stations (20-22 plants/100 m^2). In 1986 the same five stations plus two other stations were used. Mean kelp densities then were: CobbleUp: < 1 plant/100 m^2; SOKUin and SOKDin: 3-5 plants/100 m^2; and SOKUout and SOKDout; 10-11 plants/100 m^2. Kelp

densities at the two new stations were: CobbleDown: < 1 plant/100 m^2 -- indistinguishable from CobbleUp; and SOKinbetween: 13 plants/100 m^2 -- the same as SOKUout and SOKDout. Areas within kelp density isopleths were determined by electronic planimetry using Apple II graphics tablet; the means of three replicate measurements (all coefficients of variation < 2%) were used.

Comparisons of Fish Abundance among Years. We also compared fish abundances at SOK among the fall periods of 1980, 1981, 1985, and 1986. During 1980 and 1981, fish densities at SOK were characterized only within the regions of high-density kelp that prevailed at these times. Fish densities were recalculated for 1985 and 1986 using canopy and bottom data only, in order to match the data for 1980 and 1981, which lacked midwater transects. Areal extents of "medium-to-high-" (4-8 plants/100 m^2) and "high-" density kelp (> 8 plants/100 m^2) at SOK during these three fall periods were estimated from sidescan (SS) sonar charts of ECOsystems Management Associates (Sidescan Surveys 12, 14, 22, and 24: Zabloudil et al. 1980, 1982, 1986, 1987; T. Norall, ECO-M, pers. comm.). For the 1980 and 1981 estimates, mean fish densities at the two SOK (SOKU, SOKD) BACI stations were extrapolated over the area of medium-to-high- plus high-density kelp. For the 1985 and 1986 reestimates, fish densities at the SOKUin and SOKDin stations were extended over the estimated region of ECO-M's medium-to-high-density kelp. Also for 1985-86, mean fish densities at SOKUout and SOKDout were extrapolated over the area of ECO-M's high-density kelp. For these analyses, the 1985-86 data at the "sparse" (kelpless cobble) station(s) were not used, because corresponding sparse stations were not sampled during the preoperational period.

Sidescan versus Downlooking Comparisons. As a gross measure of whether sidescan sonar data on kelp density are a sufficiently accurate basis for year comparisons of fish abundances, we contrasted fish abundance estimates for 1985 using SS and DL sonar data. We repeated this contrast using analogous 1986 data. For these comparisons, we used all available fish density data, including midwater transects and samples from the cobble station(s).

For both SS- and DL-based estimates of fish abundance, we matched fish density data with the appropriate kelp density region by relating the kelp density estimates on fish station transects with the equivalent sonar-based estimate of kelp density. In this manner we could estimate consistent indices of the total

number of fishes present at SOK in fall 1985, using two different methods of calculating kelp densities and distribution.

For the SS-based estimate in 1985, kelp regions of low density (0-4 plants/100 m^2); medium-to-high density (4-8 plants/100 m^2); and high density (> 8 plants/100 m^2) were matched with the following fish sampling stations: kelpless cobble (1 station: CobbleUp); low-density kelp (2 stations: SOKUin and SOKDin); and moderate-density kelp (2 stations: SOKUout and SOKDout). DL-based estimates matched the same three groups of five fish stations with DL sonar strata of 0-4 plants/100 m^2; 4-16 plants/100 m^2; and > 16 plants/100 m^2.

Our SS-based estimate in fall 1986 used the same three (low, medium-high, and high) kelp density regions as were used in fall 1985. These three regions were matched with the following stations: kelpless cobble (2 stations: CobbleUp, CobbleDown); very-low-density kelp (2 stations: SOKUin, SOKDin); and low-density kelp (3 stations: SOKUout, SOKDout, SOKinbetween). DL-based estimates matched the same three groups of seven fish stations with DL sonar strata of 0-2 plants/100 m^2, 2-8 plants/100 m^2, and > 8 plants/100 m^2.

<u>Error Bounds</u>. Estimates of error bounds were complicated by the inability to sample all locations on a single date. Fish density per unit area was calculated for each location on each sampling date as the sum over strata of the density per unit volume of a stratum times the thickness of the stratum. This density value was used to estimate the abundance of that species throughout the corresponding kelp density region at SOK on that date. Means and variances of locations were then calculated over all dates. Total abundance was calculated as the sum of the products of abundance means for each region of kelp density times the area of the kelp density region:

$$\text{Total Abundance} = \sum_{r=1}^{R} \left[\frac{1}{L_r} \sum_{l=1}^{L_r} \frac{1}{T_l} \sum_{t=1}^{T_l} \text{Density}_{rlt} \right] * \text{Area}_r$$

$$\text{Density}_{rlt} = \sum_{s=1}^{S_l} D_{rlts} * H_s$$

where r = kelp density region subscript,
l = location subscript
t = date subscript

s = stratum subscript

D_{rlts} = density per unit volume at stratum s, time t, and location l within region r

H_s = thickness of stratum s

S_l = number of strata at location l

$Density_{rlt}$ = density per unit area at time t, location l within region r

$Area_r$ = area of kelp density region r

T_l = number of dates at location l

L_r = number of locations within region r, and

R = number of kelp density regions.

Abundances were estimated for each of 15 major fish taxa, plus total fishes (all species). Total minus transient fishes were also evaluated by subtracting out transient species (fishes whose presence in the kelp bed is ephemeral, based on their natural histories {Pacific barracuda, Pacific bonito, jack mackerel, Pacific mackerel}: Feder et al. 1974).

For each location, the variance of abundance was estimated as the among-date variation of the date estimates. The variance of estimated abundance throughout the entire SOK bed that fall was calculated as a weighted sum of the variances for all regions of kelp density. Ninety-five percent confidence bounds were approximated by +/- 2 standard errors (SE) of the date estimates:

$$SE = SQRT\left[\sum_{r=1}^{R}\left[\frac{1}{L_r^2}\sum_{l=1}^{L_r}\frac{s_{rl}^2}{T_l}\right] * Area_r^{\,2}\right]$$

where s_{rl}^2 = sample variance over dates at location l within region r,

and the rest of the notation is the same as above.

3.2.4.2 Biomass Estimates

Average body weights of species and life stages are needed to convert stage-specific numbers to biomass. Species-specific length-frequency distributions were characterized for fishes encountered during additional diver-observations at each of the five SOK locations during fall 1985 and at each of the seven SOK stations in fall 1986. Fishes were tallied as encountered on random swims throughout station areas. At most ten man-dives, each of 40-min duration, were

made at each location in 1985. In 1986, we made as many as eight man-dives of similar duration at each location. One-half of the total observation time at each location was spent near the seabed; the second half was split equally between canopy and midwater depths (Appendix T, Tables 4A,B). Divers tallied fish by total length (to the nearest inch). An accuracy of less-than-or-equal-to 1 inch (in) for fish of typical size range (~ 6 to 12 in) was established during practice exercises using tagged, preserved fish (Appendix Q,; E. DeMartini, unpubl. data).

Length-frequency distributions (all SOK locations pooled) were decomposed into the three major life stages (JUV, SAD, AD) using known length-maturity thresholds (Appendix T, Table 1a). Length-weight equations were used to calculate the average body weight of fish within each inch-class (Appendix T, Tables 2 and 3). Average weight for each species-life stage (Appendix T, Table 6) was then calculated based on the relative frequency of observations within component inch-classes of that species and life stage.

Last, species' biomass abundances were derived from numerical abundances by multiplying stage-specific abundance (numbers) by the mean body weight of the respective stage. The latter were then summed over all life stages of that species.

3.3 RESULTS

3.3.1 General Density Patterns

Density data (#s per 1000 m^3) of all major species and life stages of juvenile-adult fishes are summarized in Tables 17 and 18. We provide a simple summary of baseline (1980-81) versus operational period (1985-86) changes in densities in Table 19. Percentage contributions of juveniles, subadults, and adults to species-specific densities are summarized in Appendix L, Tables 1-3. These basic data illustrate several major patterns of distribution and abundance that help interpret the results of BACI impact tests (Section 3.3.2). Patterns worth noting are:

1. Estimated absolute densities declined overall for total fishes (and for total resident fishes). This general decline reflects observed

decreases for most major species. Declines were most evident for "cold temperate" faunal elements such as the embiotocid surfperches.

2. Despite the general pattern of decline, some species with warm-temperate affinities (e.g., senorita and rock wrasse) became relatively more abundant throughout SONGS-area kelp beds during the operational period (Tables 17-19).

Data on temporal and spatial changes in the relative contribution of component life stages helps explain some of the species-level patterns listed above (Appendix L, Tables 1-3). For example, the recent increases in species like rock wrasse are due to greater numbers of small (juvenile and subadult) individuals (Appendix L, Tables 1-3). These increases reflect successful 1983 and 1984 recruitment (year-class success), at least along the mainland coast of the southern part of the bight (E. DeMartini, unpubl. obs.). Strong 1983 and 1984 year classes of kelp bass and California sheephead in the Southern California Bight are additional examples of successful recruitment of planktonic larvae to nearshore habitats following favorable, net upcoast transport during the El Nino years (Cowen 1985; E. DeMartini, unpubl. obs.).

3.3.2 BACI Impact Tests

3.3.2.1 Screening Tests

Fifteen species of rocky inshore fishes were sufficiently common (frequently encountered) and abundant in SONGS-area kelp beds during the baseline period (fall 1980, 1981) to warrant time-by-location comparisons of densities. A total of 78 life stages of these 15 species were evaluated for the two impact-control station pairings combined (Appendix M, Tables 1-4). Another 8 cases either had too few operational data to warrant analyses or were pooled taxa (TOTALs) that were disallowed because their component life stages displayed heterogeneous patterns.

Seventy of the 78 combinations of species, life stages, and locations pairs had additive baseline deltas (Appendix M, Table 2). All additive cases were subjected to further screening for violations of statistical assumptions prior to the actual impact tests.

Sixty-one of the 70 additive cases satisfied two additional, major statistical assumptions (Appendix M, Tables 2,3). All 12 cases of significant serial correlation among baseline deltas (Appendix M, Tables 2, 3) were correctable when models with autocorrelated errors were used (Appendix M, Table 3). Unfortunately, 11 of the 12 initial violations of serial correlation also had significant monotone trend. These 11 cases, plus 2 others involving a monotone trend violation alone, could not be detrended and therefore were statistically intractable. None of the trend violations could be explained by only one or a few "influence points" (Chapter One); all cases of trend were influenced by numerous sampling dates during one or both segments of the baseline period (e.g., see Appendix N, Figs. 14, 16).

3.3.2.2 T-Tests and Binomial Tests

The 61 remaining cases were finally subjected to statistical tests for SONGS' impact. A majority (47/61) were evaluated by t-test (Appendix N, Table 1). Satterthwaite's approximation (t') was necessary for 9/47 cases with unequal variances (Appendix M, Table 4). Because of potentially spurious additivity tests, another 14 cases were evaluated using the binomial test (Appendix N, Table 3).

Twenty-six of the 61 cases (43%) that were suitable for one or other type of impact test showed significant changes in densities between the baseline and operational periods at SOKU, relative either to SMK or SOKD (Table 15; Appendix N, Tables 1, 3). Twelve of 31 (39%) of the SOKUout-SMK tests and 14 of the 30 cases (46%) comparing SOKUin and SOKDout were significant (Table 15; Appendix N, Tables 1, 3). Signs of the changes at SOKU versus SMK were mixed: 5/12 were relative declines at SOKU, and 7/12 were increases at SOKU, relative to SMK, during the operational (versus baseline) period. However, only 1/14 changes at SOKUin, versus the denser-kelp station at SOKD (SOKDout), was a relative increase at SOKUin (Table 15; Appendix N, Tables 1, 3). The following account briefly identifies patterns of change (and lack of change) for each species and life stage tested. Results are discussed in Section 3.4.2, following presentation of the analyses of fish-kelp relations in Section 3.3.3.

<u>Species Account</u>. Overall, one or more life stages of 11/15 select taxa changed in density at a SOKU station, relative to the SMK or SOKDout station, between

baseline and operational periods. About half of the SOKU-SMK changes were relative declines at SOKUout; the other half were relative increases at SOKUout. All but one change at SOKUin, relative to the denser kelp station at SOKDout, were relative declines at SOKUin. A species-by-species description follows.

Barred Sand Bass. All life stages of this benthic-epibenthic predator of sand-rock regions (Roberts et al. 1984) declined at SOKU, relative to either Control location, between SONGS operating periods (Table 15; Appendix N, Table 1). The magnitudes of the near-SONGS declines were large -- consistently 80% or greater (Appendix N, Table 1) -- for "juveniles" (i.e., older juveniles of sizes that consume epibenthic crustaceans), adults (that prey on large benthic infauna and fishes), and subadult-sized individuals (that feed on a mixture of both prey types: Roberts et al. 1984). By 1985-86, the absolute densities of this species had generally declined (to as little as 30% of baseline levels) at the SOKU stations; the densities of both juvenile and adult fish had increased, however, by over an order of magnitude at the SOKDout and SMK stations (Tables 17-19; Appendix N, Figs. 1-8).

Kelp Bass. This ecomically important, nektonic (Love and Ebeling 1978; Roberts et al. 1984) congener of the sand bass did not change statistically in relative densities at SOK and SMK between SONGS operating periods, except for pooled juvenile stages at SOKUin versus SOKDout (Tables 15, 16; Appendix N, Table 1). However, only 7/10 test cases were tractable (Appendix M, Tables 1-3), and two cases of > 60% decline (adults: - 80%, SOKD as Control; subadults: - 67%, SMK as Control; Appendix N, Table 1) were undemonstrable because of extremely low power (< 10%). Like its congener, kelp bass generally declined in abundance at the SOKU stations during 1985-86 (Tables 17-19; Appendix N, Figs. 9-18). YOY, however, were exceptional in showing a recent increase in density at SOKU (Tables 17-19; Appendix N, Figs. 19, 20). Unlike barred sand bass, kelp bass in general exhibited no consistent density patterns at the SOKDout and SMK stations during the operational period (Tables 17-19; Appendix N, Figs. 9-20).

Blacksmith. This small, water-column zooplanktivore decreased in overall abundance at SOK and SMK during 1985-86 versus 1980-81 (Tables 17-19; Appendix N, Figs. 21-23). However, even during the baseline period its numbers had been low (relative to most rocky-bottom kelp beds elsewhere: E. DeMartini, pers. obs.). Virtually all blacksmith encountered at SOK and SMK have been juveniles (primarily

YOY: E. DeMartini, pers. obs.) seen sheltering near benthic habitat-formers such as overstory kelps and gorgonians. Relative abundance seemed to increase sevenfold at SOKUout, relative to SMK, during the operational period (Appendix N, Table 1, 3), but even these huge nominal increases were insignificant because of the blacksmith's schooling habits, patchy distribution, and low sampling power (Table 16).

Halfmoon. This generalized, omnivorous kyphosid fish (a member of a tropical family) fluctuated greatly in numbers within SONGS-area kelp beds during the four years of study (Appendix N, Figs. 24-29). Densities of subadult and adult fish (juveniles recruit to offshore drift kelp) decreased sharply from 1980-81 levels in fall 1985, but rebounded strongly in fall 1986 (Appendix N, Figs. 24-29). Densities generally increased throughout SOK, but decreased at SMK during the operational period (Tables 17-19). Despite the recent general increase throughout SOK, densities of subadult halfmoon decreased (insignificantly) by 80% at the SOKUin station (relative to SOKDout: Table 15; Appendix N, Table 1). Densities of subadults increased significantly (threefold) at the SOKUout station relative to SMK (Table 15; Appendix N, Table 3). A greater than twofold increase in adults at SOKUout (relative to SMK) was undemonstrable (Table 16).

Giant Kelpfish. The densities of this warm-temperate clinid also have increased throughout SONGS-area kelp beds in recent years (Tables 17-19; Appendix N, Figs. 30-34). Its densities seemed to have increased to greater extents at SMK and at the downcoast BACI station in SOK than at either of the two SOKU stations (Tables 17-19), but none of these apparent increases at Control locations is significant (Tables 15, 16; Appendix N, Tables 1, 3).

Black Perch. This extremely generalized (habitat, diet) live-bearing embiotocid was one of the more abundant fishes in SONGS-area kelp beds during 1980 (Appendix N, Figs. 35-40). (During the fall, black perch are represented almost entirely by subadult-adult stages in deeper regions of local kelp beds; juveniles are then restricted to shallower rock reefs and other vegetated habitats.) The density of black perch declined markedly throughout SOK and SMK during 1981. Subadults-adults declined further in 1985-86 -- to about 50% to < 5% of average baseline levels (Tables 17-19). Densities significantly decreased (and greatly so -- from > 75% to > 90%) at the SOKU stations compared to SMK and the SOKDout station (Tables 15, 16; Appendix N, Tables 1, 3).

Kelp Perch. The numbers of this specialized (kelp canopy) embiotocid crashed in all SONGS-area kelp beds between 1981 and 1985 (Appendix N, Figs. 41, 42). (Because of its narrow length range in fall -- 6 to 10 cm -- all individuals were tallied as adults.) Average densities were reduced to < 10% of baseline levels during 1985-86 (Tables 17-19; Appendix N, Figs. 41, 42). Kelp perch had been one of the more abundant fishes throughout SOK and SMK during the 1980-81 baseline period (Appendix N, Figs. 41, 42). Average densities dropped further at the SOKUin station (compared to SOKDout) during recent years (> 90%; Table 15; Appendix N, Table 1).

Pile Perch. By fall 1985, this large epibenthic surfperch also had declined dramatically from baseline densities throughout SONGS-area kelp beds (Appendix N, Figs. 43-48). Densities during 1985-86 averaged from 50% to < 5% of baseline levels at SOK and SMK (Tables 17-19). (Juveniles remained consistently rare at sampling depths during all monitoring periods.) Densities of older stages, although of nontrivial magnitude, were statistically intractable for comparing subadults, adults within SOK, and pooled stages; only the SOKUout versus SMK comparison for adults was tractable (Appendix M, Tables 2, 4; Appendix N, Table 1, Fig. 43). Although relative density seemed greater by over a factor of six at SOKUout, the difference was insignificant because of low power (Table 16; Appendix N, Table 1).

Rainbow Seaperch. The abundance of this medium-sized epibenthic surfperch also was depressed (by 10% to > 99%) during 1985-86, compared to 1980-81 levels (Appendix N, Figs. 49-53). (Like most other local embiotocids, juveniles were rare at sampling depths in SOK and SMK during the fall.) Densities seemed to have declined to greater extents at the SOKU stations, relative to SOKDout and (especially) SMK (Tables 17-19). However, results of the statistical comparisons were significant only for sudadult fish at SOKUin versus SOKDout, and this test result is questionable because its significance is dependent on the value of "c" added before logarithmic transformation (Table 15; Appendix N, Tables 1, 3).

Rubberlip Seaperch. The subadults-adults of this large epibenthic surfperch have never been abundant in SONGS-area kelp beds. Densities variously declined or increased during the operational (versus baseline) period, depending on kelp bed and station (Tables 17-19). Densities had been especially low in fall 1985, when values averaged < 10 % of baseline levels (Appendix N, Figs. 54, 55). Average

densities during the comprehensive operational period ranged from +134% to -88% (at SOK) and were +10% (at SMK) compared to baseline levels (Tables 17-19). Extents of the changes were statistically similar between SOKUout and SMK, and between the two stations within SOK, however, despite an apparent twofold greater increase at SOKUout versus SMK (Appendix N, Tables 1, 3). Even the latter comparison was insignificant because of the large variances and low power (< 10%) of the t-test (Appendix N, Table 1). Binomial test results were not sufficiently more sensitive (Table 16; Appendix N, Table 3).

White Seaperch. This medium-sized, habitat generalist (Ebeling et al. 1980b) occupies the water column of SONGS-area kelp beds in mid to late fall while migrating from inshore reefs to deeper regions inhabited during winter (Larson and DeMartini 1984). Like the other embiotocids, this species had also declined greatly (by 80 to 99%) from baseline abundances by fall 1985. Numbers remained low throughout SONGS-area kelp beds in fall 1986 (Appendix N, Figs. 56-61). Some adults and subadults were present at SOK and SMK during 1985-86 (although juveniles, as previously, were rare). Density comparisons for adults and pooled adults-subadults were not amenable to statistical analyses; the densities of subadults, however, could be evaluated for both SOK-SMK and within-SOK contrasts (Appendix M, Tables 2-4; Appendix N, Table 1, Figs. 58, 59). Densities declined to greater extent at SOKUin, relative to SOKDout, during the operational versus baseline period, and the disproportionate decline was > 95% (Table 15; Appendix N, Table 1).

Senorita. Unlike the embiotocids and other cold-temperate elements of the SONGS-area fish fauna, this labrid (and one of two other species of local wrasses) increased in overall abundance in SONGS-area kelp beds between fall 1980-81 and fall 1985-86 (Tables 17-19; Appendix N, Figs. 62-69). The increase of this schooling, water-column generalist was especially pronounced between 1985 and 1986 (Appendix N, Figs. 62-69). Juveniles as well as subadults and adults were well represented throughout baseline and operational periods, and all stages have shown recent numeric increases at one or both kelp beds (Tables 17-19). The magnitude of the recent increases has varied among life stages and kelp bed locations: major increases have ranged from nearly a factor of two, to over an order of magnitude, with subadults increasing to the greatest extent (Tables 17-19). Recent increases have appeared to be larger at the SOKUout and SOKDout stations than at either SOKUin or at SMK (Tables 17-19). Most of these seemingly

disproportionate differences are statistically significant (Tables 15, 16; Appendix N, Tables 1, 3).

California Sheephead. This large, epibenthic labrid generally decreased to 10-40% of baseline levels in SONGS-area kelp beds during 1985-86 (Tables 17-19; Appendix N, Figs. 70-75). Immatures (almost entirely older juveniles: Appendix T, Tables 6A,B) as well as subadult sheephead have been present at SOK and SMK during all sampling years and have shown similar patterns of density change between 1980-81 and 1985-86 (Tables 17-19). (Adult sheephead have always been rare in SONGS-area kelp beds.) Relative densities at SOK and SMK were most interpretable for juveniles; however, only the SOKUin versus SOKDout comparison for subadults was significant -- a 90% relative decline at SOKUin (Tables 15, 16; Appendix N, Table 1).

Silversides. By fall 1985, neustonic atherinids (primarily topsmelt, *Atherinops affinis*: E. DeMartini, pers. obs.) in general had declined from baseline levels of abundance in SONGS-area kelp beds (Appendix N, Figs. 76, 77). Seine catches of members of the three-species taxon complex (primarily topsmelt and jacksmelt, *Atherinopsis californiensis*: Allen and DeMartini 1983; Chapter One, this report) had also declined by 50-90% in nearshore open waters, including regions within several kilometers upcoast and downcoast of the SOK bed, beginning in mid-1982. Seine catches remained depressed through summer 1985 (Chapter One, Tables 2, 3; Appendix E, Figs. 22-24). Despite these general decreases, silversides increased over thirtyfold in relative abundance at our SOKUin Impact station, relative to the SOKDout Control station, during 1985-86 (Appendix N, Tables 1, 3; Fig. 77). A very large (> 90%) apparent decrease at SOKUout, relative to SMK, was undemonstrable (Table 15; Appendix N, Table 1, Fig. 76) because of the extremely poor power (< 10%) provided by this schooling species.

Rock Wrasse. The abundance of this medium-sized benthic labrid also increased dramatically in SONGS-area kelp beds between 1980-81 and 1985-86 (Tables 17-19; Appendix N, Figs. 78-83). However, unlike senorita, most of these individuals were subadults and adults, not juveniles. Recent increases in adults, although large (over twofold to ninefold), paled in comparison to the twelvefold to eighty-six-fold increases of subadults (Tables 17-19). These recent increases seemed disproportionately large at the two SOKU stations (Table 19). Impact tests confirm the significance of only one of these -- a relative increase in adults of

almost 600% at SOKUout versus SMK (Table 15; Appendix N, Table 1). Several other large (> 200%) apparent increases (of subadults and pooled subadults-adults at SOKUout relative to SMK) lose their significance either as a result of questionable additivity (Table 16; Appendix N, Table 3) or because of serial correlation (Appendix M, Tables 2-4).

3.3.3 Fish--Kelp Relations

3.3.3.1 ANOVA Analyses of Kelp Patterns

Giant kelp (Macrocystis) varied substantially in density among sampling locations and years (Table 20). One-way ANOVAs and a posteriori contrasts identify the station groupings (Table 20).

The following patterns in Macrocystis density were observed in fall 1985. Highest densities were recorded at SMK, where high density averaged > 30 plants/100 m^2. Within SOK, single upcoast and downcoast stations (SOKUout, SOKDout) together represented the densest available kelp habitat (moderate density: ~ 20 plants/100 m^2). Another upcoast-downcoast pair represented low-density kelp (~ 8 - 10 plants/100 m^2). A single kelpless cobble station adjacent to SOKU had a sparse kelp flora (< 1 plant/100 m^2) (Table 20; Appendix O, Table 1).

Similar patterns in kelp density were observed in fall 1986, except that densities were approximately halved at each of the SOK stations where plants had occurred in nontrivial densities in fall 1985. The two densest stations were again SOKUout and SOKDout (low densities of 10-11 plants/100 m^2). The prior low-density stations had decreased to very low levels (3-4 plants/100 m^2). The sparse CobbleUp station remained the same in fall 1986 (< 1 plant/100 m^2 (Table 20; Appendix O, Table 1). Densities of juvenile-adult giant kelp increased to nearly 60 plants/100 m^2 at the SMK station after fall 1985 (Table 20; Appendix O, Table 1). However, most of this increase was due to juvenile plants that recruited to cleared areas following the severe storms of February 1986; the average density of adult Macrocystis had actually declined to about 9 plants/100 m^2 -- a level similar to the densest stands of kelp then existing at SOK.

It is obvious that during each fall season Macrocystis densities varied appreciably among sampling stations.

As a complement to evaluating station patterns in giant kelp densities, we also compared the various stations in terms of their relative abundances of overstory ("subcanopy") brown algae (Pterygophora, Cystoseira); the bushlike turf alga Acrosorium; and Lytechinus urchins. We used analogous one-way ANOVAs and a posteriori contrasts to identify station differences for these variables.

Results of the latter ANOVAs are summarized in Appendix O, Tables 2, 3. As with giant kelp, variation among stations was appreciable for the other variables in one or both of the two years. Interestingly, the development of most benthic algae was inversely related to giant kelp density, whereas Macrocystis itself was positively related to the percentage cobble (stability) of the substrate (Appendix O, Table 4). As for giant kelp, there have been widespread recent declines in the abundance of the more persistent of the two major overstory kelps (Pterygophora; Appendix O, Table 5).

3.3.3.2 Simple Fish--Kelp Regressions

The next step in our exploration of fish-kelp relations was to regress fish density (as dependent variable) on kelp density (as lone indepependent variable). The results of this analysis would tell us whether Macrocystis alone significantly influenced fish density within SOK in fall 1985-86. But first we had to determine the appropriate functional form of the kelp covariate, because these regressions and all subsequent ANCOVA analyses were predicated on proper choice of the kelp variable.

Of the three biologically intuitive forms of the kelp data that were evaluated (Section 3.2.3.2; Appendix O), the simple linear function in Macrocystis counts was considered most appropriate in all cases that we examined. Either the linear function had the largest R^2, its R^2 was nominally highest, or its R^2 was trivially lower than the R^2 values of the other models and parsimony dictated its use. For this reason, we restrict all further discussion to the simple linear function. (Note that choice of the linear model does not mean that some asymptotic function is not more accurate, however -- only that our data did not convincingly demonstrate a curvilinear relationship.)

Using the raw kelp density data in the linear model, we found a significant relationship between fish and kelp densities, within the SOK bed, in 37/43 cases.

Thirty-six of the 37 cases were positive; the only significantly negative relationship was that for silversides (Appendix O, Table 6; but see text Table 21 and Appendix O, Table 7).

3.3.3.3 ANCOVA Analyses

The preliminary ANOVA (station) contrasts for giant kelp and other seabed variables, together with the encouraging results of the simple fish-kelp regressions, suggested that comprehensive ANCOVA analyses were warranted. We approached this next step in our analysis by first performing a series of stepwise multiple regressions to identify the most efficient suite of variables for subsequent use in the ANCOVAs.

Stepwise Multiple Regressions. Giant kelp almost invariably entered into the model; several other variables usually entered as well. Effects of the variables often changed in the two years (Appendix O, Table 7).

Specific results of stepwise regressions are summarized for all relevant species and stages in Appendix O, Tables 7, 8. (Seabed variables were irrelevant for kelp perch and silversides, two strictly canopy taxa.) In addition to the already-recognized, positive influences of giant kelp, one or both species of overstory algae influenced the density of fish in 28/43 cases (Appendix O, Tables 7, 8). The effects of *Acrosorium*, *Lytechinus*, and bottom types were less frequently detectable (Appendix O, Tables 7, 8).

Benthic algal abundance and bottom type had a mixture of positive and negative effects that varied among species and life stages (Table 21; Appendix O, Tables 7, 8). Overstory algae (*Pterygophora*, *Cystoseira*) and the erect, turflike red alga (*Acrosorium*) were positively and negatively related to fish density to about equal extents (Appendix O, Tables 7, 8). *Lytechinus* urchins generally had (perhaps indirect) negative effects on fish densities; and the effects of bottom type, if present, were mixed (Table 21; Appendix O, Tables 7, 8).

Comprehensive ANCOVAs with Location Effects. As a last step in describing fish-kelp relations, we used the variables identified by the preceding stepwise regressions to build comprehensive models describing the variations in fish densities that we observed at SOK during fall 1985-86. All meaningful

environmental covariates were entered first in the model; then the "location" term (as the remainder of all non-error variation) was entered.

Location was significant in only 9/43 (21%) of the cases and explained, on average, < 1% of total observed variation in fish densities (Table 21; Appendix O, Table 9). Altogether, location plus the sum of all measured environmental variables explained an average of 48% of the total variation in the densities of various species and life stages. Location contributed only about 5% to total explicable variation (Appendix O, Table 9). The effect of giant kelp remained significant in 33/43 of our comprehensive models, and was responsible for an average of 52% of all explicable variation (Table 21; Appendix O, Table 9).

3.3.4 Fish Abundance Estimates at SOK

The abundances of fishes at the SOK bed during the two operational fall periods were estimated based on two major types of data: (1) kelp stratum-specific fish densities and (2) areal extents of each kelp density stratum. Weighted mean densities are summarized for each station at SOK (Appendix P, Tables 1, 3) and for stations of like-kelp density within SOK (Appendix P, Tables 2, 4). (Data for 1985 and 1986 are tabulated separately.) Areal extents of particular kelp densities are listed in Appendix P, Table 5 (1985) and Table 6 (1986). For our primary (1985, 1986) abundance evaluations, areal extents of kelp are based on downlooking (DL) sonar data. In addition, sidescan (SS) sonar estimates of kelp are compared with DL estimates for 1985 and 1986 (Appendix P, Tables 5, 6), so that we could make gross comparisons of fish abundances among all four years (1980, 1981, 1985, and 1986) using SS-based areal estimates (Appendix P, Tables 7, 8).

3.3.4.1 Fall 1985 and 1986 Numbers

Fall 1985. Based on our more accurate (DL) sonar estimates of kelp areal extents, the numerical standing stock of total fishes present at SOK in fall 1985 was about 225,000 individuals (Table 22). An estimated 183,000 individuals (81%) were present in the 41% of SOK excluding sparse kelp and cobble (Table 22; Appendix P, Table 5). During fall 1985, then, only about 19% of total fish numbers occurred in the majority (59%) of SOK that was sparse kelp (Table 22; Appendix P, Table 5). Confidence intervals on abundance estimates of major species were broad, even considering the sample size (n = 8) -- an average +/- 92% of the respective

estimate (Table 22). Confidence bounds on the estimate for total fishes was much tighter (+/- 33%; Table 22).

Fall 1986. DL sonar estimates of kelp areal extents indicated that the numerical standing stock of total fishes present at SOK in fall 1986 was about 397,000 individuals (Table 23). An estimated 377,000 individuals (95%) were present in the 39% of SOK excluding sparse kelp and cobble (Appendix P, Table 6). During fall 1986, then, only about 5% of total fish numbers occurred in the majority (61%) of SOK that was sparse kelp (Table 23; Appendix P, Table 6). Abundance stations were sampled on 3-8 dates during fall 1986, depending on station (Appendix J, Table 1). Considering this, the confidence intervals on abundance estimates of major species were reasonable -- an average +/- 63% of the respective estimate (Table 23). Error bounds on the estimate for total fishes were again relatively small (+/- 39%; Table 23).

3.3.4.2 Fall 1985 and 1986 Biomass

Fall 1985. Estimated total biomass abundance at SOK during fall 1985, based on DL-sonar estimates of kelp areas, are about 18.1 metric tons (MT) of fishes within a total 113 hectares (ha) of sparse to highest-density kelp (Table 24; Appendix P, Table 5). Total biomass densities therefore were 160 kg/ha. Error bounds on the total estimate were reasonable (+/- 32%), even though estimates for major species averaged > 100% (Table 24). Excluding transient species (seasonal migrants: Pacific barracuda, jack mackerel, Pacific bonito, and Pacific mackerel; Feder et al. 1974), there were about 17.4 MT of resident kelp-bed fishes present throughout SOK at this time. Resident biomass density thus was about 150 kg/ha. About 69% (12.6 MT) of total fishes was present in the 42% (47 ha) of SOK that then was intermediate- and highest-density kelp (Table 24 and Appendix P, Table 5). We estimate that none of the transient fishes were present in the subregion of sparse kelp.

Fall 1986. We estimate that total biomass of fishes at SOK during fall 1986, based on DL-sonar estimates of kelp areas, was about 38.9 MT within a total 88 ha of sparse to highest-density kelp (Table 25). Error bounds on this estimate were reasonable (+/- 38%), and bounds on major component species were better than in 1985 (average +/- 66%; Table 25). The biomass density of total fishes was an estimated 440 kg/ha. Excluding transient species, there were about 35.2 MT of

resident kelp-bed fishes present at this time. The biomass density of resident fishes therefore was about 400 kg/ha. About 93% (36.3 MT) of total fish biomass was present in the 39% (34 ha) of SOK that then was intermediate- and highest-density kelp (Table 25 and Appendix P, Table 6). As in fall 1985, we estimate that all transient fishes were present in the subregion of intermediate- to highest-density kelp.

3.3.4.3 Operational versus Baseline Comparisons

During the fall 1980-81 baseline period, the fishes at SOK were surveyed within the regions of medium-to-high- and high-density kelp that then constituted about 70 to 80% of the total habitat at SOK (DeMartini et al. 1983a,b; Appendix P, Table 7). The abundances of fishes at SOK during fall 1980 and 1981 are grossly estimable using the SS-sonar data on kelp densities for these periods (Appendix P, Table 7). Baseline values are underestimates, however, because the 1980 and 1981 data on fish densities exclude midwater-column regions and can be extrapolated to subregions of moderate or greater kelp density only.

Estimated abundances of major fishes within the more heavily forested regions at SOK averaged about 427,500 individuals during the fall 1980 and 1981 baseline periods, and were only about 15-20% dissimilar during these two fall periods (Appendix P, Table 8). Estimated abundances in similarly vegetated regions at SOK during fall 1985 (99,700 fish) were less than one-fourth of the 1980-81 baseline average. Analogous estimates during fall 1986 (121,000 fish) were equal to about 28% of the baseline average (Appendix P, Table 8).

3.4 DISCUSSION

3.4.1 The Fish Assemblage in SONGS-Area Kelp Beds

Fall 1985 and fall 1986 data on the assemblages of fishes present at SOK and SMK might be meaningfully compared (1) temporally -- with prior data at the respective kelp bed -- and (2) spatially -- with contemporary data at other kelp beds and other shallow, rock reef habitats. We defer comparison (2) to Chapter 4, and proceed with temporal comparisons.

The most striking patterns in rankings (numbers) at SOK and SMK between 1980-81 and 1985-86 are (1) the observed decreases in the densities and abundances of many, primarily cold-temperate species and (2) the increases in the densities of several warm-temperate species, particularly senorita and rock wrasse. The observed fall 1985 increases in both species undoubtedly reflect successful recruitment by their 1983 and 1984 year classes. It is known that both wrasses have a current-dispersed larval stage of $\geq$ 1 month (Victor 1986). It is therefore reasonable that the observed recent increases in these species occurred at both kelp beds. Patton (1985; Fig. 8-8) observed analogous increases in senorita and rock wrasse on a bightwide scale during 1983-84.

Increases in two other species -- halfmoon and kelp perch -- were notable between fall 1985 and fall 1986. Large numbers of subadult-adult halfmoon -- probably the survivors of strong 1984 and 1985 year classes that recruited as planktonic larvae to offshore drift kelp (see Mitchell and Hunter 1970) -- apparently immigrated to SONGS-area kelp beds between the first and second operational seasons. The average density of halfmoon increased thirtyfold at SOK between 1985 and 1986 (Appendix P, Tables 2, 4).

Kelp perch increased twentyfold in abundance between the two recent fall seasons. This increase can be grossly explained in terms of spring 1986 reproduction by adults resident at SOK during fall 1985: If (1) all of, say, 50 kelp perch present at SOK in fall 1985 were adults, (2) most were large females that gave birth to an average of 20 young each (Baltz 1984), and (3) three-fourths of the young survived the six months between spring and fall 1986, less than half of the kelp perch estimated present in fall 1986 (about 1,600) would have had to reach SOK by immigration.

Other changes in the abundance of the Southern California Bight ichthyofauna noted by Patton (1985) between the periods 1979-82 and 1983-84 further indicate broadscale increases in warm-temperate species and decreases in cold-temperate representatives during and following the recent California El Nino. Patton's (1985) gross counts of pooled life stages undoubtedly are weighted most heavily by relatively numerous, juvenile-stage fishes. Our fall 1985-86 data at SOK and SMK demonstrate that juveniles provided the numerical response for senorita, rock wrasse, and (with a 1-2 year lag) halfmoon. The general recent swing of the pendulum toward San Diegan and away from Montereyan fauna within the bight (Horn

and Allen 1978) is best interpreted as southern species' recruitment responses to stronger net upcoast larval transport during the El Nino event (Cowen 1985), not the differential thermal tolerances and reproductive outputs of adult fish (Patton 1985). Kelp perch are a unique exception -- perhaps an example of local population response by a live-bearer that is largely restricted within islands of special habitat (see Baltz 1984).

3.4.2 SONGS Influences on Fish Densities

3.4.2.1 Biological Interpretation

Of the 61 testable combinations of species and life stages, 26 cases showed a significant change in relative densities between baseline and operational time periods. Excluding the 14 tractable but partially dependent, pooled (TOTAL) life stages, there were still 20/47 significant cases (Table 15; Appendix N, Tables 1, 3). This number of significant cases is greater that the 2 or 3 that would be expected by chance alone (at $P \leq 0.05$). The findings, though, represent a mix of well interpretable and poorly interpretable cases. We feel that 6/20 cases strongly suggest impact from alteration or loss of kelp-bed habitat; another 8/20 cases are weakly attributable to kelp bed habitat alteration or loss; 4/20 cases suggest effects of the SONGS diffuser plume or outfall pipe riprap; and the remaining 2 cases are inexplicable (Table 26).

The following species account discusses all significant BACI impact test results.

<u>All Life Stages of Barred Sand Bass</u>. Pooled (TOTAL) life stages, as well as all component stages (juvenile, subadult, and adult) have declined by 80% to > 95% at SOKUout, relative to SMK, and at SOKUin, relative to SOKDout, during the SONGS operational period (Table 15; Appendix N, Table 1). Most (>> 70%) of all sand bass at SOK have been subadults and adults (Appendix L, Tables 1-3). Juveniles have only contributed 10-30% to total sand bass counts at SOK (Appendix L, Tables 1-3). Significant declines for total barred sand bass therefore largely comprise subadult and adult stages.

Adult sand bass are one of the very few fish whose density at SOK is inversely related to the density of giant kelp (Table 21). Juveniles and subadults, unlike

adults, are positively asssociated with giant kelp (Table 21). It is therefore possible that the recent juvenile-subadult declines may be influenced by the recent declines in kelp at the SOKU stations (Table 20). The relation would have to be indirect -- i.e, a result of the positive relation between algal macrodetritus and the amphipod prey of small sand bass (Quast 1968d; Roberts et al. 1984). We acknowledge that this argument is not strong enough to strongly implicate SONGS as the cause of the observed density declines.

The recent decline in adults, in fact, appears unrelated to the declines in kelp at SOK. If SONGS operations are impacting adult barred sand bass, the mechanism has not been through loss of kelp habitat. Perhaps reduced adult densities at SOKU are the result of a dilution effect of the diffuser riprap and plume, at which large numbers of these fishes sometimes congregate (Patton 1985). Unfortunately, no additional, more recent data are available to document this speculation.

Juvenile Kelp Bass. Total juvenile (pooled YOY and older juvenile) substages of kelp bass declined 82% at SOKUin (relative to SOKDout) between the baseline and operational periods (Table 15; Appendix N, Table 1). Other large (> 50%) apparent declines at SOKUout (relative to SMK) were insignificant, and involved adult and subadult fish (Table 16; Appendix N, Table 1). Densities of the YOY juvenile substage changed insignificantly at each SOKU station, relative to its control station (Table 16; Appendix N, Table 1).

A significant decline in the densities of juvenile kelp bass at the meagerly forested SOKUin station (relative to the more heavily forested SOKDout station) is consistent with the observed positive association between juveniles and giant kelp (Table 21). However, densities of YOY did not decline, even though this juvenile substage is considered to be the stage that is most intimately associated with kelp foliage (Larson and DeMartini 1984; M. Carr, pers. comm.). Because of the lack of evidence for impact on YOY, we feel that the significant decline in total juvenile kelp bass can only weakly be linked with SONGS impact on kelp at SOK. The association between kelp bass and Macrocystis is discussed in greater detail in Section 3.4.3.

Patton (1985) observed a 1983-84 decline in total (including juvenile) kelp bass counts at SOK, relative to Las Pulgas reef or Batiquitos reef, 10 km and 45 km

downcoast of SOK, respectively. Patton (1985) speculated that the diffuser riprap and plume of SONGS has attracted kelp bass (as well as barred sand bass) away from SOKU. Data necessary to evaluate this speculation are lacking.

Subadult and Total Halfmoon. The proportion of subadult halfmoon present in samples at SOKUout (relative to SMK) increased fourfold between baseline and operational periods (Table 15; Appendix N, Table 3). Because of the large contribution of subadults to total counts (Appendix L, Tables 1-3), the relative density of total halfmoon increased over 200% at SOKUout (relative to SMK) between the two periods (Table 15; Appendix N, Table 1). Adults (as the complement of subadults in total counts) also appeared to increase over 200% at SOKUout recently, but the nominal increase was not significant (Table 16; Appendix N, Table 1). A large (80%) apparent decline in subadult densities at SOKUin (relative to SOKDout) also was not significant (Table 16; Appendix N, Table 1).

None of the demonstrable changes in halfmoon densities can be explained in terms of a direct relationship with giant kelp. Subadults increased at SOKUout relative to SMK despite relative declines in total kelp density at SOKUout (Table 20; Appendix O, Table 1). Halfmoon were one of the few species evaluated for which location effects overwhelmed any relationship with giant kelp (Table 21). Halfmoon are only one of several local fishes known to feed directly on bryozoan-fouled kelp blades (North 1971; Quast 1968d; Hobson et al. 1981). The recent appeal of the SOKUout station for halfmoon might have been due to fouling; however, the level of fouling at SOKU (relative to control stations) was, at most, < 50% greater and undemonstrable (Dixon and Schroeter, in prep.). A more likely source of attraction at SOKU is the SONGS diffuser plume. Halfmoon have extremely plastic foraging behavior: they consume both drift and attached algae and motile as well as sessile invertebrates, pick plankton, and even clean other fishes (E. DeMartini, unpubl. obs.; Hixon 1979).

Subadult and Total Black Perch. The proportion of subadult black perch present in samples at SOKUout (relative to SMK) decreased fivefold between baseline and operational periods (Table 15; Appendix N, Table 3). The mean density of subadults also declined by 95% at SOKUin relative to SOKDout (Table 15, Appendix N, Table 1). Total black perch (as usually more than half subadults: Appendix L, Tables 1-3) declined 75% at the meagerly forested SOKUin station compared to the more heavily forested, downcoast control at SOK (Table 15; Appendix N, Table 1).

In the fall, subadult black perch (4-7 inches total length: Appendix T, Table 1A) are mostly about 12-14 cm standard length (Appendix T, Table 3; E. DeMartini, unpubl. data). Black perch of this size avoid regions of foliose laminarian kelps and positively associate with areas of dense plant and animal "turf" (Schmitt and Holbrook 1986). Turf is the primary substrate from which these fish winnow cryptic invertebrate prey (Laur and Ebeling 1983; Holbrook and Schmitt 1984). The abundance of Pterygophora declined throughout SONGS-area kelp beds between fall 1980-81 and fall 1985-86 (Appendix P, Tables 2, 3), while that of Acrosorium (a species of turf) increased (T. Dean, UCSB, pers. comm.). The relative decrease in Pterygophora at SOK has generally been greater than the decrease at SMK, where the abundance of this kelp has always been low. However, the relative abundance of this laminarian was greater at SOKUin (versus SOKUout or SOKDout) during 1985-86 (Appendix O, Tables 2, 3). Perhaps the relative dearth of large black perch at SOKUin reflects the negative association of this fish with Pterygophora (also see Section 3.4.3). This case for impact due to habitat alteration cannot be considered strong, however, because of the many linkages in the argument.

Total Kelp Perch. The very large (> 90%) decline in the density of kelp perch at the meagerly forested SOKUin station, relative to more heavily forested SOKDout, is consistent with the strong positive association between this species and Macrocystis (Coyer 1979; Baltz 1984; Larson and DeMartini 1984). The relative decline of this species at SOKU is surely attributable to loss of kelp-bed habitat. A more detailed characterization of the association between kelp perch and giant kelp is provided in Section 3.4.3.

Subadult Rainbow Seaperch. Densities of subadult rainbows seemed to decrease by over three-fourths at SOKUout (relative to SMK) between SONGS operating periods (Appendix N, Table 1). However, the proportion of subadults at SOKUout declined (insignificantly) by about one-third between operating periods (Table 15; Appendix N, Table 3). Densities of subadults may have decreased by 95% at SOKUin (relative to SOKDout) between periods, although test results are strongly influenced by nature of the data transformation and are therefore suspect (Table 15; Appendix N, Table 1).

Impact test results are consistent with the positive fish-kelp relationships observed (Table 21). We speculate that the mechanism explaining the positive

relationship with kelp is that between Macrocystis- produced macrodetritus and the amphipods upon which rainbow seaperch prey (Ebeling and Bray 1976; Laur and Ebeling 1983). Because of the weakness of this argument, however, we cannot make a strong argument for SONGS impact via kelp habitat loss.

Subadult White Seaperch. The densities of the subadults of this species declined > 95% at the meagerly forested SOKUin station (relative to more heavily forested SOKDout) between the baseline and operational periods (Table 15; Appendix N, Table 1).

Subadult (and adult) white seaperch were positively associated with Macrocystis at SOK during 1985-86 (Table 21), which is consistent with results of the BACI tests. The nature of the relationship between whites and giant kelp may be complex. This species consumes portions of bryozoan-fouled kelp blades, in addition to picking invertebrates off kelp blades and benthic substrates (Bray and Ebeling 1975; Ebeling and Bray 1976; Laur and Ebeling 1983). Therefore, the relative fouling of kelp blades, as well as the density of kelp plants, might be important. We feel it likely that SONGS has had an impact on this species at SOK via both alteration and loss of kelp habitat.

All Life Stages of Senorita. Total senorita counts increased over four-fold at SOKUout (relative to SMK) between baseline and operational periods (Table 15; Appendix N, Table 1). Conversely, its total counts decreased by three-fourths at SOKUin (relative to SOKDout) between these two periods (Table 15: Appendix N, Table 1). Component life stages exhibited density patterns that were qualitatively the same at the two pairs of stations, although not all nominal changes were significant (Tables 15, 16; Appendix N, Tables 1, 3). Adult counts, as 73% to 93% of the species totals (Appendix L, Tables 1-3), dominated the density patterns of the species.

Density patterns within SOK are consistent with observed positive relations between this species and giant kelp (Table 21). Recent changes in relative densities at SOKUout versus SMK, however, suggest that more than just kelp density has influenced the distribution and density of this species at SOK. It is likely that SONGS influence on senorita at SOK has involved mechanisms in addition to loss of kelp bed habitat. The possible interrelations of senorita, Macrocystis, and the effects of the SONGS diffuser plume are discussed in greater detail in Section 3.4.3.

Subadult California Sheephead. A decline in the density of the subadults of this species at SOKUout (relative to SMK) was barely significant (P=.078), although large (90%: Table 15; Appendix N, Table 1).

Sheephead was another of the few species of fishes that generally lacked a significant association with giant kelp (Table 21). The densities of juvenile sheephead, however, were positively related to the densities of giant kelp (Table 21); yet there was no indication that its densities at the SOKU stations were impacted by SONGS (Table 16; Appendix N, Table 1). We therefore do not feel an argument can be made for SONGS impact on sheephead at SOK.

Total Silversides. The huge (thirty-two-fold) increase in silversides at the meagerly forested SOKUin station (relative to more heavily forested SOKDout; Table 15; Appendix N, Tables 1, 3) is contrary to a positive association between this species and giant kelp. Although perhaps consistent with a fish-kelp relation, the nominally large (94%) relative decline at SOKUout versus SMK is insignificant (Table 15; Appendix N, Table 1). A seemingly negative relation with giant kelp (Appendix P, Table 6) is an artifact of, and overwhelmed by, a location effect (Table 21; Appendix P, Table 9). The latter is probably a SONGS effect, but not an effect of SONGS on the kelp habitat (Section 3.4.3).

Adult Rock Wrasse. The only observed change in the density of rock wrasse that was significant was a large (nearly 600%) increase in adults at SOKUout (relative to SMK) between baseline and operational periods (Table 15; Appendix N, Table 1). A large nominal increase (nearly 300%) in subadults involving the same pair of stations was not significant (Table 16; Appendix N, Tables 1, 3).

The density of rock wrasse was positively related to Macrocystis density at SOK for all postrecruit stages of the species (Table 21). Impact test results are therefore inconsistent with the fish-kelp relationship. One overstory kelp (Cystoseira) was also a consistent positive influence on wrasse densities (Table 21). However, there is no compelling evidence that the density or abundance of Cystoseira increased at SOKU, relative to SMK, during 1985-86 (Appendix O, Tables 2, 3; T. Dean, pers. comm.). Present data are insufficient to explain the recent pattern of relative increase of wrasse at the SOKUout station.

3.4.2.2 Statistical Evaluation

Four statistical attributes of the kelp bed fish data are noteworthy:

1. Location differences (deltas) in baseline data are usually additive when differences of log-transformed data are used. Most comparisons, therefore, were acceptable for further screening tests.

2. Serial correlation, although present a nontrivial fraction of the time (17% of all additive test cases), was always resolvable using either first or second differences of the deltas. Both the presence of serial correlation (and its removal by invoking a lag of one or two sampling dates) are interpretable: diver observations of fishes at SOK and SMK often occur in short bursts of several consecutive days. These groups of sample dates are separated by a greater, but variable, number of days when poor water conditions make quantitative sampling impossible.

3. Variances of baseline and operational deltas were usually equal and hence did not require the use of Satterthwaite's (1946) approximation for unequal variances. In 81% of the t-tests, nominal degrees of freedom were maintained without further losses of power (ability to reject false null hypotheses). Apparent differences between the standard deviations of preoperational and operational deltas were about equally distributed between the two periods (see Appendix N, Table 3).

4. The magnitude of many of the observed changes in density was >>50%, allowing detection with less than the full complement of operational samples necessary to detect 50% changes. In other cases, large apparent changes were not demonstrable. Most of these cases with low power were recognized early on (DeMartini et al. 1983a,b), and the present test results are not surprising.

3.4.3. Fish--Kelp Relations

Our evaluation of the interrelations of the densities of fish and Macrocystis has several limitations. First, it is limited to San Onofre Kelp bed during two fall seasons and so may not be representative of SOK over a longer period of time. Second, kelp stands at SOK are anchored on low-relief cobble substrates. For many bottom fishes, our results at best are generalizable to other cobble-bottom kelp beds, not the majority of Macrocystis stands that occur on high-relief, rock-and-boulder substrates in southern California. For example, the number of stipes and fronds per plant is greater for kelp beds on more stable rock substrates, because number of stipes is a positive function of plant age, among other factors (T. Dean, pers. comm.).

Given the preceding caveats, our data on fish-kelp relations at SOK support several intuitively reasonable propositions:

1. Almost all species and life stages are associated positively with giant kelp. Only one of the 37 significant relations between fish and kelp was negative. And in this case the effect of kelp was probably confounded with the effect of the SONGS diffuser plume (see "Silversides" account, below).

2. The strength of the association with kelp often differed more strikingly among different-sized individuals within species than, say, between similar-sized adults of different species. The contrast between small barred sand bass (positively associated with giant kelp) and adult sand bass (negatively related to kelp density) is an excellent example.

Body size typically exerts a strong influence on both the food and shelter requirements of fishes and other organisms (Andrew and Choat 1982; Choat and Ayling 1987), and forests of giant kelp are recognized as habitats that contribute both types of resources (Foster and Schiel 1985; Schiel and Foster 1986).

For species whose juvenile-through-adult stages inhabit kelp forests, Macrocystis relations that vary with life stage are to be expected. Kelp bass provide an example, perhaps because individuals at SOK commonly range from tiny, 3-cm YOY to large adults > 50 cm long. The positive relation between the densities

of giant kelp and preadult kelp bass (Table 21) is numerically dominated by the strong relation between juveniles and kelp, including the association of YOY juveniles with surface canopy foliage (Larson and DeMartini 1984). Less-than-half-year-old YOY kelp bass are strongly associated with canopy and water-column Macrocystis (Larson and DeMartini 1984; M. Carr, UCSB, pers. comm.). M. Carr (pers. comm.) has observed, at other kelp beds in the bight, that juvenile kelp bass disassociate from Macrocystis during the second half of their first year of life. Larger, older juvenile kelp bass (> 1 year old) had been thought to be more cosmopolitan in distribution within SOK (Larson and DeMartini 1984). The distribution of adult kelp bass is unrelated to kelp density at SOK (Table 21) and elsewhere (M. Carr, pers. comm.).

Many of the other positive fish-kelp relations observed at SOK in fall 1985 involved immatures (Table 21; Appendix O, Table 6). Juvenile blacksmith (primarily YOY: Appendix T, Tables 6A, 6B) were frequently encountered sheltering near the bases of kelp plants (E. DeMartini, pers. obs.), and their densities were positively related to kelp densities (Table 21). Small subadult rock wrasse (mainly age I+ fish: E. DeMartini, pers. obs.), as well as larger subadults and adults, were common and abundant near the bottom within kelp stands (Table 21). (YOY rock wrasse were conspicuously absent from SOK and SMK during fall 1985 and fall 1986. YOY wrasse also had not been observed at our SOK and SMK stations during the fall periods of 1979, 1980, or 1981 {DeMartini and Larson 1980a; DeMartini et al. 1983a,b}; and we presently believe that this species does not recruit to the deeper regions of kelp beds.) Some older juvenile rock wrasse must emigrate offshore to associate with the bases of giant kelp plants, perhaps to forage on associated (epiphytic) invertebrates.

The densities of another labrid (senorita) were positively related to kelp densities for all life stages, including juveniles (Table 21). All postrecruit stages of this species are opportunistic foragers, although larger individuals primarily pick invertebrates off kelp blades and other objects, and smaller fish pick plankton (Bray and Ebeling 1975; Hobson and Chess 1976; Bernstein and Jung 1979; Hobson et al. 1981). Adults are also renowned cleaner fish (Hobson 1971) and consume portions of Macrocystis blades along with encrusting invertebrates (Bray and Ebeling 1975; Bernstein and Jung 1979). Senorita might be attracted to regions within kelp beds where blades are more heavily fouled, so factors in addition to kelp density per se may be important. However, the recent apparent

increases in fouling at the SOKU stations in the diffuser plume are not statistically significant (Dixon and Schroeter, in prep.). We feel it more likely that a greater availability of waterborne prey in the diffuser plume near the kelp stand at SOKUout (see Silversides) has enhanced the attractiveness of this station for such an opportunistic forager (Hobson and Chess 1976; Bray and Ebeling 1975; Bernstein and Jung 1979). In sum, the observed positive relations between senorita and giant kelp are to be expected for numerous reasons -- and were predicted (Larson and DeMartini 1984).

Juvenile through adult kelp perch had the strongest observed association with giant kelp (R^2 = 0.735; Appendix O, Table 6). The strength of this relation with Macrocystis is expected, based on the fish's specialized habitat requirements and local population structure (Coyer 1979; Baltz 1984; Larson and DeMartini 1984). It is interesting that kelp perch were present (in very low numbers) only at SOK stations that had average kelp densities of > 10 plants/100 m^2 during fall 1985 (Appendix P, Tables 1, 2). (The species had virtually disappeared {along with all kelp} from SOK during 1982-84 {E. DeMartini, pers. obs.}, after having been one of the most abundant fishes in heavily forested regions during 1980-81 {Appendix L, Tables 1-3}.) In fall 1986, kelp perch were largely restricted to stations where kelp densities were > 10 plants/100 m^2 (Appendix P, Tables 3, 4). During 1976-77 studies at Santa Catalina Island, Coyer (1979; Fig. 15) observed that kelp perch disappeared from, and recolonized, kelp stands at threshold kelp densities of about 6-9 plants/100 m^2.

Another extremely interesting fish-kelp relation is that of black perch (Table 21). Densities of large black perch were greater within regions of higher Macrocystis densities at SOK. Subcanopy kelps (notably Pterygophora) have been consistently least abundant at SOK stations with persistent Macrocystis stands (Appendix O, Tables 1-4), probably as a result of competition for light (Cowen et al. 1982; Dayton et al. 1984; Reed and Foster 1984; Dayton 1985). Juvenile black perch associate positively with the blades of foliose overstory kelps, from which they glean invertebrate prey (Holbrook and Schmitt 1984) and among which they shelter (Ebeling and Laur 1985). The density of large black perch, however, is inversely related to the density of foliose laminarians (Schmitt and Holbrook 1986), perhaps because larger perch winnow invertebrates from turf algae (Holbrook and Schmitt 1984) and because of the complementary distributions of turf algae and foliose kelps (Cowen et al. 1982; Kastandiek 1982). We feel it is likely that the

positive relation we observed between the densities of giant kelp and large black perch results indirectly from the negative association of Macrocystis and Pterygophora, plus the avoidance of turf-poor Pterygophora stands by large black perch.

Although preadult barred sand bass were positively associated with giant kelp, the densities of the adults of this species were negatively related to Macrocystis densities in our comprehensive ANCOVAs (Table 21; Appendix O, Table 9). This result may reflect the generally inverse relation between kelp density and the amount of hard substrate (stability of the seabed; Appendix O, Table 4). Large barred sand bass are characteristic of sand-rock ecotones (Turner et al. 1969; Stephens and Zerba 1981; Davis et al. 1982; DeMartini et al. 1983a,b, 1985a).

The remaining, possibly negative fish-kelp relation involves silversides, primarily topsmelt, Atherinops affinis (E. DeMartini, pers. obs.), a largely neustonic species that feeds off kelp blades as well as on plankton (Feder et al. 1974). The topsmelt is a small forage fish (most topsmelt observed at SOK in 1985 were about 13 to 15 cm total length: Appendix T), and it may also loosely associate with surface kelp for shelter. One might therefore expect a positive relation with giant kelp, if any. But silversides were most dense (both years) at the SOKUin station, where the effect of kelp density is likely confounded by an effect of the SONGS diffuser plume. SOKUin is directly in the path of the SONGS Unit 3 diffuser plume (see Appendix J, Fig. 2B), and silversides congregate to feed in the SONGS plumes (E. DeMartini, pers. obs.). Kelp densities were low (in 1985) and very low (in 1986) at SOKUin. We feel it quite likely that plume attraction is the cause of a spuriously negative fish-kelp relation for this species.

In summary, the fall 1985-86 SOK bed data substantiate previous observations that giant kelp significantly affects the distribution and abundance of many fishes (Quast 1968a; Feder et al. 1974; Coyer 1979; Larson and DeMartini 1984; Bodkin 1986). Although seabed heterogeneity also strongly influences fish abundance and distribution within Macrocystis forests (Quast 1968a; Moreno and Jara 1984; Patton et al. 1985), there can no longer be any doubt (see Larson and DeMartini 1984; Stephens et al. 1984; Patton et al. 1985) that kelp density can and does strongly affect fish density on a low-relief cobble bottom.

3.4.4 Fish Abundances at SOK

3.4.4.1 Sonar Data

Downlooking Sonar. All of our fish abundance estimates are the product of fish-density estimates (specific for regions of differing kelp densities) and the areal extents of these regions at SOK. The densities and areal extents of kelp are based on various types of sonar data. Our primary sources of kelp data in fall 1985 and fall 1986 are ECOSystems Management Associates' downlooking sonar surveys. Specifically, they are Downlooking Sonar (DL) Survey # 7 (Norall et al. 1986) and DL Survey # 9 (Reitzel et al. 1987). Downlooking sonar accurately characterizes the density of subadult-adult Macrocystis (Reitzel et al. 1985, 1987); for this reason, we believe that our DL sonar-based 1985 and 1986 abundance estimates are accurate.

Our estimates of fish abundance are based on a DL sonar-based areal estimate of 113 ha (~ 1.1 km^2) for the SOK bed in fall 1985 (Appendix P, Table 5; also see Reitzel et al. 1986, Figs. 7.1, 7.4, and 7.6). In fall 1986, the analogous estimate of the total area of Macrocystis at SOK was 88 ha (~ 0.9 km^2; Appendix P, Table 6; Reitzel et al. 1987, Figs. 10i, 12a, 13). The area of Macrocystis at SOK thus decreased by about 22% between fall 1985 and fall 1986. DL sonar-based estimates of kelp density indicate that the grand mean density of kelp at SOK decreased about one-half, from 6 plants/100 m^2 (in fall 1985) to 3 plants/100 m^2 (in 1986). The total number of Macrocystis decreased over one-half, from 70,000 plants in fall 1985 (Reitzel et al. 1986) to 32,000 plants in fall 1986 (Reitzel et al. 1987, Fig. 13).

Sidescan Sonar. Comparisons of fish abundances among baseline and operational years require the use of sidescan sonar estimates of kelp at SOK, because downlooking surveys did not begin until January 1982. Sidescan sonar traces provide generally inaccurate estimates of the density of giant kelp plants (Reitzel et al. 1985). However, we believe that our estimates of fish abundance, using downlooking versus sidescan sonar to characterize kelp regions, and using partial but equivalent fish density data in each of the years, provide sufficient relative measures. Appendix P, Tables 5 and 6 illustrate that the DL sonar-based and SS sonar-based estimates of the relative proportions of "high-," "medium-," and "low-density" kelp were reasonably close for fall 1985, and fairly good for

fall 1986. These SS sonar-based data provide repeatable indices, not estimates of absolute abundance, however.

We emphasize that the SS sonar-based abundance estimates for 1980-81 are known underestimates for two reasons. (1) Estimates for these periods are possible for regions of moderate-to-high-density kelp only, because fish densities were then measured only in predominant, high-density kelp habitat. (2) Estimates exclude the midwater component, because samples were limited to canopy and bottom strata in 1980-81. The areas of kelp bed used were 95 ha (in 1980) and 81 ha (1981), representing about 80% and 67% of the total area of the SOK bed that was present at these times (Appendix P, Table 7).

For year-comparisons, we reestimated the fall 1985 and fall 1986 abundances of fishes using sidescan sonar data to delimit kelp regions, and limited our estimates to canopy and bottom regions of moderate-to-high-density kelp only. The area of moderate-to-high-density kelp in fall 1985 (about 40 ha) represented < 50% of the total area of kelp then at SOK (Appendix P, Table 7). In fall 1986, the area of moderate-to-high-density kelp (23 ha) represented even less -- < 30% of the total area of kelp at SOK (Appendix P, Table 7).

3.4.4.2 Annual Differences in Abundance

Baseline versus 1985 Comparisons. Sidescan sonar-based data indicate that the abundance of fishes at SOK was less by a factor of about 5 during fall 1985 than in fall 1980-81 (Appendix P, Table 8). This statement is based on the reasonable assumption that the vertical (water-column) distribution of major species (and life stages) has not differed appreciably among years.

That fish abundances decreased by about three-fourths between fall 1980-81 and fall 1985 is further corroborated by the data of an independent study. Patton (1985) observed similarly dramatic declines in the numbers of fishes present on transects made at SOK during the summer-fall periods of 1983-84, as compared to 1980-81. Declines at SOK mirrored general reductions in coastal kelp beds throughout the Southern California Bight (Patton 1985). Many declines suggested some sort(s) of numeric response to the California El Nino (Patton 1985), but because Patton (1985) did not provide life-stage data, poor recruitment cannot be distinguished from emigration of older stages.

Our life-stage-specific data indicate that recent decreases in some major species (e.g., black perch) represent declines in the numbers of older fish in addition to poor recent year-class success. Other species (e.g., kelp bass, barred sand bass) have decreased overall despite relatively strong, recent juvenile recruitment. Whether the observed declines in older fish were due to a continuing constant (or greater?) mortality and/or emigration cannot be distinguished with the available data. Whatever the exact mechanism, the large spatial scale and timing of the declines strongly implicate the California El Nino in the recent bightwide declines of rocky inshore fishes.

Comparisons between Operational Years. More accurate, comparative data (based on DL sonar) also indicate that the abundance of all fishes increased over twofold (38.9 MT / 18.1 MT) at SOK between fall 1985 and fall 1986. The increase is somewhat less (about twofold) if the comparison is limited to resident fishes (35.2 MT / 17.4 MT). Based on DL sonar estimates of the area of kelp at SOK in fall 1985 (113 ha) and fall 1986 (88 ha), the biomass densities of total fishes differed by a factor of 2.75 X (160 kg/ha in 1985 versus 440 kg/ha in 1986). Resident fishes differed by < 2.7 X (150 kg/ha versus 400 kg/ha, respectively.) It is therefore obvious that the abundance as well as density of fishes was greater at SOK in 1986 than in 1985. More fish were present in a smaller area of kelp forest in 1986. And, as we have seen, the abundance as well as the density of giant kelp was less by about one-half at SOK during fall 1986 than in fall 1985 (Reitzel et al. 1986, 1987). Obviously, the relative density of fishes in higher- (versus lower-) density kelp increased at SOK in 1986 as the amount of higher-density kelp habitat decreased.

Clearly, even though fish densities in general are positively influenced by the density of kelp at SOK, other factors can have equal or greater influence on the distribution and abundance of rocky inshore fishes (see Section 3.4.4.4). It is also clear that, over the range of plant densities present at SOK in 1985-86, Macrocystis was not a limiting resource for fishes. We emphasize that this observation pertains only to the brief period of time during which we made our evaluation. It does not necessarily follow that, at different plant distributions and densities, or at other times, Macrocystis would not be a limiting resource for fishes in the San Onofre Kelp bed. Data for additional years and for a greater range of plant densities at SOK would be required to test this hypothesis.

3.4.4.3 SONGS-related Fish Loss at SOK

The consistently positive fish-kelp relations observed at SOK strongly support the argument that SONGS Units 2 and 3 operations, by reducing the density and areal extent of Macrocystis within SOK, have in effect contributed to an overall reduction in the standing stock of fishes within SOK. We stress the spatial scale involved -- our observation of a two-fold increase in the standing stock of fishes at SOK between fall 1985 and fall 1986 indicates that processes acting on a larger-than-kelp bed spatial scale also importantly affect the local abundance of fishes. During 1985-86, the threefold increases in fish density (numbers and biomass) at SOK during the second year approximate the magnitude of the difference in fish density for meager versus dense stands of kelp within the kelp bed (Fig. 4).

The most likely large-scale processes involved are those associated with regional or bightwide fluctuations in fish populations. Population fluctuation in many or most marine fishes reflects variable year-class strength, and year classes are usually determined during the larval or early juvenile stage (Pitcher and Hart 1982; Cushing 1982). In general, oceanographic factors (e.g., variable currents) that affect the dispersal and settlement of planktonic larvae strongly influence year-class strength in marine fishes (Cushing 1982). This is undoubtedly true for many fishes of the southern California Bight.

Our 1985-86 data at SOK likely illustrate lagged responses (of 1-3 years) to strong year-classes determined during larval or early juvenile stages. Most SOK bed fishes, including the species that contributed most to the general increase between fall 1985 and fall 1986, recruit to shallower, rocky/vegetated habitats. The increases in fishes that we observed as older juveniles-adults at SOK in fall 1986 surely represent the survivors of good year classes (1983, 1984) that initially became established outside of, and that subsequently immigrated to, SOK. Important contributors include rock wrasse, senorita, sheephead, halfmoon, barred sand bass, and kelp bass (although kelp bass in part represent the survivors of YOY that previously recruited to the kelp canopy at SOK).

Although fish abundance on spatial scales equal-to-or-larger-than a kelp bed are surely determined by such regional or bightwide processes, our data nonetheless indicate that Macrocystis distribution and abundance strongly

influences the distribution and abundance of fishes on a within-kelp bed spatial scale. It is therefore meaningful to evaluate the impact of SONGS operations on the local abundance of fishes at SOK.

We argue as follows: Suppose that SONGS Units 2 and 3 operations have, in effect, caused a three-fourths reduction in resident fish within the inshore, upcoast quadrant of SOK, by, say, reducing Macrocystis stands to "kelpless cobble" within this region (Fig. 4). Because this would impact about 25 ha of SOK's 100 ha areal extent, the local reduction in resident fishes would be equivalent to ~3.3 MT in 1985 (as .75 x .25 x 17.4 MT) or ~6.6 MT in 1986 (as .75 x .25 x 35.2 MT). The magnitude of the actual fish losses at SOK obviously depends on (1) the real percentage reduction in kelp at SOK, and its areal extent, that is due to SONGS operations alone, as well as (2) regional or bightwide levels of fish abundance. We lack the long-term data on fish abundance throughout the Bight that are needed to adequately quantify (2). Rigorous estimates would also require more specific data on the amount and areal extent of kelp loss at SOK than are presently available.

CHAPTER FOUR
FISHES AT PENDLETON ARTIFICIAL REEF

4.1 INTRODUCTION

4.1.1 Overview of PAR

Pendleton Artificial Reef (PAR) consists of about 9 metric tons of quarry rock at 13-m depth about 5.5 km downcoast from and inshore of San Onofre Kelp bed. PAR was established in an approximate pattern of 8 units, or modules, that extend over about 3 hectares (ha) of sand plain. Although the actual rock area of PAR is only about 1 ha, it was the second largest artificial reef in California coastal waters (Ambrose 1986) until early 1987, when several larger reefs were constructed elsewhere in southern California waters. PAR was established by the California Department of Fish and Game (CF&G) in September 1980, aided by a subsidy from Southern California Edison Company. The reef was designed to test mitigative potential, should San Onofre Nuclear Generating Station operations adversely affect giant kelp and associated biota at the San Onofre Kelp bed (see Chapter Three) (Grove 1982; Grant et al. 1982). Historically, biological studies at PAR have evaluated its potential for mitigation in terms of local fishery enhancement, not necessarily including any local increase in fish production (but see DeMartini et al. 1985a; Ambrose 1986). A brief review of these studies and their major findings follows.

4.1.2 History and Review of Prior Studies

The initial colonization of PAR by fishes and other organisms was documented by CF&G biologists as beginning almost immediately after reef construction (CF&G 1983). CF&G established qualitative fish surveys on a quarterly basis during fall 1980-October 1982 (CF&G 1983). Quantitative surveys were established in fall 1984

and continued semiannually (K. Wilson, CF&G, pers. comm.). The early CF&G studies suggested that PAR, like most artificial marine habitats, attracted great numbers of immigrant fishes beginning shortly after construction. But CF&G biologists' repeated attempts to establish adult Macrocystis plants on PAR were unsuccessful because of intense grazing by immigrant, herbivorous fishes, notably opaleye and halfmoon (Carter et al. 1985b).

The Marine Review Committee funded quantitative surveys of algae and invertebrates, as well as fishes, at PAR by the Lockheed Ocean Science Laboratory (LOSL) beginning in September 1981. LOSL estimated numerical fish densities by major life stage (juvenile, subadult, adult) bimonthly from September 1981 to October 1983. Lockheed's data established the fact that the numerically dense fishes at PAR were primarily vagile immigrants of older-juvenile and subadult stages (LOSL 1983c; Jessee et al. 1985b). The data further demonstrated that important changes in the composition and structure of the invertebrate/algal turf assemblage occurred at PAR from 1 to 3 years following construction (LOSL 1983b; Carter et al. 1985a). LOSL also observed that several major temporal changes in the densities of certain fishes (e.g., black perch) occurred (LOSL 1983c) and that some changes in fish densities were probably influenced by changes in the structure and composition of turf habitat (Carter et al. 1985a; DeMartini et al. 1985a).

In December 1982 the Lockheed group added special surveys of young-of-year (YOY) juvenile fishes; these additional studies were continued, also bimonthly, until October 1983. The primary objective here was to assess PAR's potential contribution to YOY recruitment, an especially significant factor because local fish production can be more directly evaluated from standing stock of parochial YOY fishes (DeMartini et al. 1985a; Ambrose 1986). All Lockheed field studies at PAR were discontinued after October 1983. In October 1984 the UCSB Fish Group completed a single pilot survey at PAR modules 1, 3, 5, and 6 for YOY and older juvenile fishes (DeMartini et al. 1985a). Lockheed's 1982-83 data, together with our group's fall 1984 observations, illustrated at least three important facts:

1. Significant numbers of some fish species first recruited to PAR (from the plankton) during summer-fall 1983.

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).

4.2.3 Estimating Fish Abundances

A comprehensive evaluation of PAR's contribution to near-SONGS fish stocks requires an assessment of fish abundances, not just densities. Biomass as well as numerical abundance is needed for interpretable estimates of fish production. We estimated fish abundances at PAR during each of the two fall periods.

4.2.3.1 Numerical Abundances

The numbers of fishes present at PAR during fall 1985 and fall 1986 were calculated using two basic data:

1. stage- (juvenile, subadult, and adult) and species-specific fish densities, by stratum and survey, estimated at each of the PAR modules, and

2. stratum-specific reef areas estimated for each of the 8 PAR modules, using ECOsystems Management Associates' sonar charts of PAR bathymetry.

For each life stage of each species, the density estimate for each stratum at each module was converted to numerical abundance within one of several subregions of the module, defined by isobaths (Appendix Q). Abundance subtotals on modules were then summed over all 8 modules. Fish numbers and biomass were estimated for various combinations of strata (Rock -- as Crest and Slope; Ecotone; and Sand -- as the adjacent sand and/or outlying sand regions sampled on radial transects). Estimates were also calculated for the sum of the Rock, Ecotone and Sand subtotals. Means and variances were calculated based on the survey replicates, except for the Ecotone stratum in 1985. The Ecotone abundance estimate for the December 1985 survey was added to the mean estimates for the other strata. Additional details are provided in Appendix Q.

4.2.3.2 Biomass Abundances

Numerical abundances were converted to biomass abundances by multiplying stage-specific numbers by mean body weights of the respective stage. Mean body weights were estimated by applying length-weight regressions to length-frequency

distribution data. This is the same method used for kelp bed fishes. Methods are generally described in Section 3.2.4.2 of Chapter Three. Additional details are provided in Appendices J and Q.

The species-specific, length-frequency distributions of fishes at PAR were compiled from additional diver observations made at the 8 PAR modules during each of the three fall 1985 and three fall 1986 surveys. We tallied fish lengths (total length, to the nearest inch) on timed swims (Appendices Q, T).

4.3 RESULTS

4.3.1 Distribution and Density Patterns

ANOVAs are used to explore the major environmental influences of fish distribution and abundance at PAR in fall 1985 and fall 1986. Specifically, we evaluate the effects of "year" (fall period), stratum (microhabitat), and maturity stage for (1) all life stages (including total juveniles) and (2) the YOY and older juvenile substages of immatures. First, we examine the effects of stratum and maturity stage during each year, using all stratum and survey data available. Second, we evaluate year effects simultaneously, using the subset of strata that were sampled in each year. Results of two-way ANOVAs on fall 1985 data for older life stages are summarized in Table 27. We provide analogous summaries for fall 1986 in Table 28. Table 29 summarizes three-way ANOVA results for juvenile-adult fishes for the two years. Last, we summarize year, stratum, and maturity effects for YOY-OJ fishes in Table 30. Appendix R, Tables 1-9 summarize input density data by year, stratum, and maturity stage for JUV-AD fishes. We also provide analogous data for YOY-OJ fishes in Appendix R, Tables 10, 11.

ANOVA results indicate that the most notable features influencing the distribution of fishes at PAR include persistent patterns of

1. stratum (microhabitat) differences in the relative abundances of many major species, and

2. analogous distributional differences among the life stages of some species.

The patterns are reflected in the numerous stratum-by-maturity interactions (and year cross-products) in the ANOVAs, particularly for juvenile substages (Tables 27-30).

4.3.1.1 Juvenile-Adult Fishes

Stratum-by-maturity interactions were not frequently observed for juvenile, subadult, and adult fishes atop the rock modules (3/11 species; Table 27). Maturity stage more frequently influenced density in Rock habitat (7/11 species; Table 27).

In fall 1985, three species (kelp bass, halfmoon, rock wrasse) were significantly more dense in Crest (versus Slope) habitat (Table 27). Five out of seven significant maturity effects were due to greater numbers of older-stage individuals; the remaining two species (barred sand bass and kelp bass) had greater densities of juvenile stages (Table 27). Module effects were detectable in 1985 for 4/11 species but reflected no consistent pattern (Table 27).

In fall 1986, we were able to evaluate the effects of additional strata (Ecotone, Adjacent Sand, and Outlying Sand). With the addition of these microhabitats, additional stratum-by-maturity interactions became apparent for later-stage fishes (9/11 species; Table 28). For barred sand bass and for total fishes (minus blacksmith), juvenile stages were less numerous in Ecotone and Sand habitats peripheral to Rock (Table 28). In general, there were fewer (but larger) fish in Ecotone and Sand habitats (Table 28; Figs. 5-8). Adult barred sand bass were a primary contributor to the prevalent pattern of large adult fish in Ecotone, and (especially) Adjacent and Outlying Sand regions (Table 28 and Figs. 6, 8). The greater densities of many species atop the modules (Table 28) were due to the presence of more, but smaller individuals close to rock substrate (Figs. 5-8). The inverse relation between numerical density and average fish size accentuates in sandy regions peripheral to ecotones (Table 28; Figs. 5-8). Module effects, although not uncommon (4/11 species; Table 28), again showed no consistent pattern among species in fall 1986.

When stratum and maturity effects are reevaluated for 1985 and 1986 simultaneously, additional interactions between stratum and maturity become apparent for juvenile-adult fishes atop the rock modules (Table 29). In addition

to halfmoon and rock wrasse, significant interactions were noted for blacksmith, opaleye, and senorita (Tables 27, 29). The aforementioned significant interaction for kelp bass (Table 28) was replaced by significant maturity (more younger fish) and stratum effects (denser in Crest) during both years (Table 29). Younger stages of the two basses generally prevailed, while older pile perch dominated in both years (Tables 27-29). Year effects were significant only for kelp bass (more in 1985) and for halfmoon (more in 1986; Table 29). Other, complicating interaction effects included several year-by-maturity effects that reflect year-class phenomena (blacksmith: more juveniles in 1985 but more subadults in 1986; rock wrasse: more juveniles in 1985 but more older-stage fish in 1986; Table 29). Black perch exhibited the only year-by-stratum interaction (more fish in Crest in 1986; Table 29). Module effects again showed no consistent pattern (4/11 species; Table 29).

4.3.1.2 YOY-OJ Fishes

Among juvenile fishes, there were many striking examples of microhabitat effects (and interactions between stratum and juvenile substage) in one or both years. Significant effects included the relatively greater numbers of blacksmith, especially YOY, in Crest habitat during both years (Table 30). Older juvenile garibaldi were consistently more dense on Crests (Table 30). OJ barred sand bass, on the other hand, were always denser in Perimeter habitat (Table 30). YOY senorita also were relatively dense on module Perimeters in both years, but were denser in fall 1986 (Table 30). Greater densities of older juvenile (versus YOY) blackeye goby represent the only straightforward maturity effect (Table 30). The lone significant stratum effect was for bluebanded goby, a species in which all juveniles are YOY (Table 30). Among the most interesting maturity effects amenable to ANOVA was that of greater numbers of OJ (versus YOY) California sheephead, both in fall 1985 and in fall 1986 (Table 30). Module effects were significant only for compound taxa (Table 30).

For juvenile fishes, additional striking patterns (not directly tested by ANOVA) include:

1. YOY rock wrasse and barred sand bass were nearly to completely absent at PAR in fall 1985 and fall 1986 (Appendix R, Tables 10, 11). The YOY of both species, and rock wrasse in particular, had

ranked highly at PAR in October 1984 (DeMartini et al. 1985a, Tables 1, 3).

2. Related changes in older juvenile rankings included fall 1985-86 increases (from October 1984) in the relative abundances of OJ rock wrasse (Appendix R, Tables 10, 11; DeMartini et al. 1985a, Tables 1, 3).

3. Possible expansion of YOY senorita and both YOY and OJ stages of California sheephead into Crest habitat was noticeable between October 1984 and fall 1985-86 (Appendix R, Tables 10, 11; DeMartini et al. 1985a, Tables 1, 3).

4. The number of species represented by older juveniles remained greater than the species richness of YOY during 1985-86 (Appendix R, Tables 10, 11). OJ species richness had been greater in October 1984 as well (DeMartini et al. 1985a, Tables 2, 3).

4.3.2 Fish Abundances at PAR

The abundances of fishes at PAR in fall 1985 and fall 1986 are estimated using two major types of information: (1) stratum-specific densities, and (2) areal extents of the respective strata.

4.3.2.1 Juvenile-Adult Fishes

Organization of Data Displays. Abundance estimates are more interpretable when the density data used in making the estimates are provided. With this in mind, a reader's guide to the sequence of data displays follows: First, we summarize the numerical densities (areal basis) of each species plus total fishes in Table 31 (fall 1985) and Table 32 (fall 1986). Weighted densities are estimated separately for each major life stage, and for pooled Crest, Slope, Ecotone, and Adjacent Sand strata (Tables 31, 32). Next, we summarize the corresponding abundance estimates for fall 1985 in Table 33 (numbers) and Table 34 (biomass). Tables 35 and 36 summarize analogous data for fall 1986.

Our best abundance estimates for 1986 are for the sum of Rock (Crest and Slope), sand-rock Ecotone, and Adjacent Sand regions. We feel that this combination of habitats best characterizes fish abundance at PAR per se -- i.e., fish in addition to background abundance on the sand plain. This conclusion is based on the results of two types of complementary analyses. (1) ANOVA analyses have shown that the biomass densities of most major species drop abruptly from Crest and Slope levels in adjacent sand (if not already in ecotone) regions (Appendix S, Table 1). (2) ANOVAs comparing the biomass densities of biomass-dominant species on outlying sand segments of "internal" versus "external" transects (Appendix Q, Fig. 2) were unable to demonstrate differences in major species between the two types of transects (Appendix S, Table 2).

Stratum-specific abundances of juvenile-adult fishes are provided in Appendix S, Tables 3,4 (juvenile-adult numbers, fall 1985 and 1986), Tables 5,6 (juvenile-adult biomass, fall 1985 and 1986), and Tables 7,8 (YOY-OJ numbers, fall 1985 and 1986).

For completeness, Appendix S also provides estimates of the abundance of juvenile-adult fishes for pooled Rock and Ecotone habitats (numbers, Table 9; biomass, Table 10); for Outlying Sand regions (Tables 11,12); and for all sampling strata -- i.e., the 3.4-ha area enclosed by a 30-m "halo" surrounding all module ecotones (Appendix S, Tables 13, 14).

Estimated stratum-specific areal extents used in the abundance calculations are listed in Table 3 of Appendix Q.

Numerical Abundances. We estimate that over 11,000 juvenile-adult fishes were present in Crest, Slope, and Ecotone habitats at the 8 PAR modules during fall 1985 (Table 33). (This is, for several reasons, an underestimate of total fish abundance at PAR in fall 1985. See our complementary estimates for fall 1986, below). About 78% of the fish (mostly blacksmith) estimated present in fall 1985 were juveniles; 12% were subadults; and 10% were adults (Table 33). Excluding blacksmith, about 20% of total fish numbers were juveniles; 45% were subadults; and 35% were adults (Table 33).

In fall 1986, we estimate that there were over 16,000 juvenile-adult fishes in Rock-Ecotone-Adjacent Sand habitats at PAR (Table 35). About 65% were

juveniles (mostly blacksmith); 27% were subadults; and 8% were adults (Table 34). Excluding blacksmith, about 23% were juveniles; 56% were subadults; and 21% were adults (Table 35).

4.3.2.2 YOY-OJ Fishes

Data Displays. We summarize the weighted numerical densities of each juvenile substage (and pooled substages) for each species plus total juvenile fishes in Table 37 (fall 1985) and Table 38 (fall 1986). Tables 39 and 40 summarize the estimated numerical abundances of YOY, older juveniles, and total immature fishes for fall 1985 and fall 1986.

Numerical Abundances. Based on the more detailed and accurate surveys of juvenile fishes made on our YOY-OJ surveys, we estimate that there were over 80,000 juvenile fish present atop the rock modules at PAR in fall 1985 (Table 39). About 93% of these were blacksmith (Table 39). Almost all (98%) of the blacksmith were YOY, whereas about two-thirds of the immatures of all other species were older juveniles (Table 39).

In fall 1986, we estimate from our YOY-OJ censuses that there were about 38,000 juvenile-stage fishes atop the rock modules at PAR (Table 40). About 85% of these were blacksmith (Table 40). As in fall 1985, nearly all (94%) of the blacksmith were YOY, whereas three-fourths of the immatures of other species were older juveniles (Table 40).

4.3.2.3 Biomass Abundances of Juvenile-Adult Fishes

An estimated 661 kg of fishes were present in Crest, Slope, and Ecotone habitats in fall 1985 (Table 34). Only about 5% of this biomass was juvenile fishes; the remainder was subadults (32%) and adults (63%; Table 34). The estimated biomass density at PAR in fall 1985 was about 508 kg per ha, since the sand-rock reef complex consists of only about 0.9 ha of rock substrate and half again that of ecotone (area of Rock plus Ecotone = 1.3 ha or 37% of the total area that was surveyed at/near PAR; Appendix Q, Table 3).

In fall 1986, an estimated 648 kg of fishes were present in the 1.7 ha of Crest, Slope, Ecotone, and Adjacent Sand habitats at PAR (Table 36). (This value

includes the fishes present in "extralimital" regions above crests and slopes of the modules.) Again, only a small fraction (8%) of total biomass was juvenile fishes. The remainder was subadults (49%) and adults (43%; Table 36). The corresponding biomass density was about 380 kg per ha. About 78% (504 kg) of the 648 kg total occurred in Crest, Slope, and Ecotone regions (Appendix S, Table 10).

Biomass estimates for subregions, and various combinations thereof, follow: We estimate that there were an additional 435 kg of fishes present in the Outlying Sand region in fall 1986 -- 75% of the 578 kg present in all sand regions (Appendix S, Table 12). Barred sand bass, sargo, and a third (transient) species, jack mackerel, each constituted nearly a quarter of this subtotal (Appendix S, Table 6). If added to the standing crop in Rock-Ecotone-Adjacent Sand regions, the 435-kg subtotal would increase our estimate of fish biomass at PAR, for regions extending to 30 m from all modules, to 1,082 +/- 590 kg (Appendix S, Table 14). Expressed as biomass density, the subtotal for Outlying Sand was about 255 kg/ha (for 1.7 ha). Biomass density for the entire 3.4-ha rock-sand complex would be about 318 kg/ha.

4.4 DISCUSSION

4.4.1 Fish Assemblage Structure

In terms of species composition, Pendleton Artificial Reef (PAR) has, since about 2 - 3 years following its establishment, been inhabited by an assemblage of fishes generally representative of shallow, rocky reefs (LOSL 1983b, Table 16). This has also been true for other artificial habitats previously established elsewhere throughout the Southern California Bight (Carlisle et al. 1964; Turner et al. 1969; Davis et al. 1982). On this gross (species) level, most of the fishes that inhabit shallow natural or artificial rocky habitats (including kelp beds) have nonspecific habitat requirements (Quast 1968a; Allen 1985; Helvey and Smith 1985). Even the homogeneous concrete structures of coastal generating stations attract basically the same assemblage of fishes (Helvey and Dorn 1981; Helvey and Smith 1985).

A more interesting and important distinction between local natural rock reefs and new, artificial habitats such as PAR may be the size-(age-) structure of their fish stocks. Others have generally noted the heavy recruitment of YOY fishes at

early successional artificial structures in tropical seas (Randall 1963; Bussing 1972; Russell et al. 1974; Gundermann and Popper 1975; Talbot et al. 1978; but see Brock et al. 1979; Brock 1980; Walsh 1985).

Gascon and Miller (1981), in a study of the colonization rate of fishes on concrete-block reefs in shallow British Columbia waters, observed few YOY recruits among older juvenile and adult immigrants. Perhaps the recruitment of YOY is more annually variable for the generally longer-lived fishes on temperate reefs. Or perhaps lush epibiotas take longer to develop on temperate reefs. The paucity of YOY recruits on Gascon and Miller's (1981) reefs and at PAR (except for blacksmith) may be an artifact of more episodic recruitment at higher latitudes. If not, it is tempting to speculate that relatively few small juvenile fishes are able to inhabit artificial structures in temperate regions until "habitat formers" (bushy algae and erect, colonial invertebrates) develop during later succession (more than several years following construction).

Enhancing (or counteracting) the effects of biological cover, of course, are variations in the abundance and size of interstices in the substrate itself. Extreme examples among local artificial habitats are the numerous interstices in the rocks of breakwaters and reefs such as PAR versus the uniform surface of the large concrete blocks forming the offshore intake structures for coastal electric generating stations (Helvey and Smith 1985). The density of shelter holes, if not substrate heterogeneity and diversity, should be important for fishes in all seas, and many examples exist for tropical coral reefs (e.g., Talbot et al. 1978). Ambrose (1987), however, has observed two apparent local exceptions at the Newport and Hermosa Beach artificial reefs. These deep (21-24 m), "openly constructed" reefs of concrete pilings had fish densities and diversities that were equivalent to those at artificial structures having more heterogeneous habitat (Ambrose 1987).

PAR's primary substrate of quarry rock provides a high density of shelter holes, but, as of fall 1985 and fall 1986, there were no established Macrocystis or subcanopy kelps and only a weakly developed overstory of bushy "habitat formers" (primarily the gorgonians, Muricea spp; R. Ambrose, 1987 and pers. comm.; E. DeMartini, pers. obs.).

In October 1984, YOY constituted 67% to 97% of all juvenile fishes present on transects at PAR, but only 28% to 66% of all juveniles excluding numerically dominant blacksmith (DeMartini et al. 1985a, Table 1). Juvenile fishes made up 78% of all fishes present at PAR in fall 1985 (Table 33) and 65% of totals in fall 1986 (Table 35). Excluding blacksmith, however, only about 26% to 31% of all juveniles in 1985-86 were YOY (Tables 39 and 40). That is, 69% to 74% of the immature stages of most fishes present at PAR during the latter two years were older juveniles that either settled out of the plankton at PAR in a previous year or that recruited elsewhere and subsequently immigrated to PAR. The low proportion of YOY at PAR in each of the three successive years suggests that, for most species, older juveniles present on PAR are immigrants, not the survivors of YOY that initially recruited from the plankton at PAR.

Despite their numerical dominance, juveniles contributed only 5% to total fish biomass at PAR in fall 1985 (Table 34) and an analogous 8% in fall 1986 (Table 36). These data have important implications for biomass estimates (see below).

At first thought, the relative abundances of juvenile (versus older-stage) fishes in SONGS-area kelp beds would seem a reasonable basis for comparison with PAR. The San Onofre Kelp (SOK) bed and the San Mateo Kelp (SMK) bed do not provide the most relevant basis for comparison with PAR, however. Juvenile fishes represented only about 10% of total fish numbers, equivalent to 3% to 11% of total fish biomass, at SOK during fall 1985 and fall 1986 (Chapter Three; also Appendix L, Tables 1-3). As at PAR, though, the immatures of most fishes in SONGS-area kelp beds are older juveniles, not YOY (Chapter 3; Appendix T, Tables 1A, 1B, 2, 6A; and E. DeMartini, pers. obs.). The offshore regions of cobble-bottom kelp beds such as SOK and SMK are densely recruited by the YOY of only a single species (kelp bass), and the magnitude of recruitment varies greatly among years (Appendix L, Tables 1-3; E. DeMartini, pers. obs.). The YOY of three other species (blacksmith, senorita, and giant kelpfish) only secondarily recruit to the surface canopy and holdfast regions of deeper portions of SOK and SMK (see Appendix L, Tables 1-3). Primarily, the YOY of these three fishes (and many other species) recruit to regions of dense overstory algae on shallower rocky reefs (E. DeMartini, pers. obs.).

A more meaningful basis for evaluating habitat at PAR might be data provided by the Mitigation Reef Project's report on fall 1986 surveys of numerous natural

and artificial reefs throughout the Southern California Bight (Ambrose 1987). In this report, density data for YOY and older fishes, plus data on the relative development of biological substrates, are compared between two series of 16 natural and 10 artificial reefs (Ambrose 1987).

Ambrose's (1987) major, relevant findings are summarized as follows:

(1) PAR, like submergent artificial reefs elsewhere in southern California, is depauperate in kelps and other benthic algae, probably because most of these reefs are deep (where light limits plant growth). On artificial reefs, the percent cover and mean height of benthic algae are one-half those on natural reefs (Ambrose 1987).

(2) PAR, again like most local artificial reefs, nonetheless has relatively dense populations of YOY as well as older-stage fishes. On average, YOY are disproportionately dense on local artificial reefs -- > 5 times denser than on natural reefs -- compared to the average difference in the densities of adult fishes on the two types of reef (2.3 times greater on artificials: Ambrose 1987).

(3) The YOY fishes on artificial reefs are dominated by blacksmith (an average of 51% of all YOY present), relative to the contribution of this species to natural reefs (average 19% of all YOY). Excluding blacksmith (and gobies: bluebanded goby -- an annual fish -- was exceedingly dense at the King Harbor Breakwater site), the mean density of YOY on artificial reefs was about 1.8 times greater than the average for YOY on natural reefs (Ambrose 1987). This apparent difference includes shallow, vegetated breakwater sites in the artificial reef category and is not statistically significant ($P = 0.28$; Ambrose 1987).

We conclude, based on our observations at PAR, plus the artificial-natural reef comparison of Ambrose and co-workers, that the relatively great densities of YOY fishes at PAR (and generally at artificial reefs in the Bight) represent little more than the dominance of blacksmith. This species is known to obligately shelter in rock holes, especially as a juvenile (Bray 1981). We suggest that the deficiency in benthic algal cover on artificial reefs is irrelevant for juvenile blacksmith, given the high density of rock-hole resources provided by breakwaters and quarry rock reefs.

4.4.2 Distribution and Density Patterns

Microhabitat features significantly influenced the distribution of the older life stages of several species of fishes at PAR in fall 1985 and fall 1986. Moreover, some species differed among older life stages in their relative densities in the various microhabitats (Tables 27-29). Spatial features contributed especially to the distribution of the juvenile substages of many species, and differences between the two substages of a species were commonplace (Table 30).

Microhabitat effects were characterized by differences in fish densities among sampling strata. These strata -- within-module for YOY-OJ fishes; and among rock-sand regions for JUV-AD fishes -- differed in two major ways: (1) depth (consequently light, surge, etc.) and related composition/development of the fouling community, and (2) proximity to the sand-rock interface. Food and shelter resources obviously must change with development of biological substrates and the composition of primary substrates (e.g., see Davis et al. 1982). It is therefore not surprising that the densities of small juvenile fishes (i.e., those stages most dependent on shelter and perhaps having the most specialized food requirements) most frequently differed among strata.

The most notable among the recently observed stratum-by-life-stage interactions involving juvenile fishes are best explained in terms of their past patterns at PAR. The numerical dominance of YOY blacksmith on module crests in fall 1985 and 1986 (Tables 27-30), as in October 1984 (DeMartini et al. 1985a, Table 1), surely reflects continued recruitment to rock shelters near the current-swept promontories that are the major foraging sites of this zooplanktivore (Bray 1981; Morris 1984). The relative numbers of older juvenile blacksmith (versus YOY) continued to increase in fall 1985 and fall 1986 (Tables 30, 39, 40; Appendix R, Tables 10, 11). These observations add further support for DeMartini et al.'s (1985a) argument that blacksmith first colonized PAR in the summer of 1983 by recruitment from the plankton (see LOSL 1983c, Fig. 2-8).

During the two recent fall periods, both the YOY and OJ of another pomacentrid, the garibaldi, were more dense on module crests. Juveniles were generally more abundant in fall 1985 than fall 1986 (Table 30). In October 1984 only a single YOY recruit garibaldi was observed at PAR, but OJ garibaldi were

significantly more abundant on crests (versus perimeters) of modules (DeMartini et al. 1985a, Tables 1, 4, 5). Perhaps (1) the greater development of filamentous and other turf algae atop the shallower, better-lit module crests generally favors juvenile garibaldi; (2) the development of algal turfs was greater at PAR in fall 1985-86 than previously; and (3) the 1985 year class of garibaldi was stronger than its 1986 year class.

Older juvenile kelp bass were denser than YOY on module crests in October 1984, fall 1985, and fall 1986 (DeMartini et al. 1985a, Tables 1, 4, 5; this report, Tables 30, 39, 40, and Appendix R, Tables 10, 11). The greater relative abundance of older juvenile kelp bass in crest regions may be related to the relative abundance of tiny fishes there (Figs. 5, 7). YOY kelp bass were extremely rare at PAR in October 1984 (DeMartini et al. 1985a, Table 1). YOY kelp bass were absent from PAR in fall 1985 and were extremely rare in fall 1986 (Tables 39, 40; Appendix R, Tables 10, 11). It is obvious that PAR, perhaps like other deep, natural rock reefs lacking benthic algae and Macrocystis, provides unfavorable recruitment habitat for YOY kelp bass. During fall 1985, YOY kelp bass recruited to kelp canopy regions at SOK and SMK, although recruit densities were then relatively low, at least on a local scale (Appendix L, Tables 1-3). YOY kelp bass recruitment was heavier at SOK in fall 1986 (0.5-0.6 fish/1000 m^3; Appendix L, Tables 2-3) than in fall 1985 (0.1-0.2 fish/1000 m^3). The densities of YOY kelp bass remained very low at PAR in 1986 (Table 40; Appendix R, Table 11).

The juveniles of certain other fishes continued to be relatively dense on module perimeters. Older juvenile barred sand bass remained significantly more dense in and near the sand-rock interfaces of modules (versus atop the modules themselves) during October 1984, fall 1985, and fall 1986 (DeMartini et al. 1985a, Tables 1, 4, 5; this report, Table 30; and Appendix R, Tables 10, 11). All life stages (YOY through adult) of this species have always been relatively more abundant in regions of mixed sand and rock at PAR (DeMartini et al. 1985a; this report, Table 28). YOY barred sand bass were not observed at PAR in fall 1985 or fall 1986 (Appendix R, Tables 10, 11). We speculate that the absence of these YOY reflects at least a local recruitment failure in the two years, not a change in the suitability of habitat. We suggest this because YOY barred sand bass inhabited the same sand-floored rock holes as blackeye goby did in October 1984 at PAR (E. DeMartini, pers. obs.). And blackeye goby were abundant in sand-rock habitat at PAR during fall 1985 and fall 1986 (Appendix R, Tables 10, 11), in addition to October 1984 (DeMartini et al. 1985a, Table 1).

YOY senorita also continued to be relatively numerous on module perimeters (versus crests) in fall 1985 and fall 1986 (Table 30). In October 1984 YOY senorita (as well as the YOY of two other labrids -- rock wrasse and California sheephead) were more dense in perimeter regions at PAR (DeMartini et al. 1985a, Tables 1, 4, 5). Perhaps the continued, relative scarcity of senorita on module crests reflects a persistent lack of recruitment habitat at PAR (see below). In October 1984, the YOY of senorita and rock wrasse were equivalently dense in crest and perimeter regions at Las Pulgas Reef (DeMartini et al. 1985a, Tables 1, 4, 5). Both the crest and perimeter at Las Pulgas Reef had lush habitat formers in October 1984 (DeMartini et al. 1985a).

YOY rock wrasse failed to recruit at PAR in either fall 1985 or fall 1986. Again, this probably reflects poor recruitment locally (or Bightwide) in both years, rather than a decrease in the suitability of recruitment habitat at PAR. We believe this because of the temporal patterns in the data for the YOY of senorita, a species whose YOY often associate with YOY rock wrasse (E. DeMartini, pers. obs.). Comprehensive (October 1984, fall 1985, fall 1986) data for YOY senorita indicate that densities have remained relatively low atop module crests (versus perimeters), but recruitment has been nontrivial on module perimeters during all three years (Table 30; Appendix R, Tables 10, 11; DeMartini et al. 1985a, Table 1). This suggests that the development of overstory organisms atop the crests did not change during 1984-86 in terms of shelter/forage for recruit senorita, but that suitable recruitment habitat persisted on perimeters during all three years.

A between-year comparison of stratum effects for YOY sheephead, however, suggests an alternative explanation. YOY sheephead were conspicuously more dense on module perimeters (versus crests) in October 1984 (DeMartini et al. 1985a, Tables 1, 3, 4). During fall 1985, however, YOY sheephead were equivalently dense on module crests and perimeters; and densities remained similar in the two strata in fall 1986 (Table 30; Appendix R, Tables 10, 11). We conclude that either our hypothesis on the status of YOY senorita habitat at PAR is false or that YOY sheephead have less-specific recruitment requirements than do senorita.

Sand-rock interfaces likely are attractive to YOY fishes for several interdependent reasons whose relative importance varies with species. Senorita and rock wrasse, like many tropical labrids, sleep partly buried in sand at night

(Bray and Ebeling 1975; Ebeling and Bray 1976; Victor 1986). Proximity to nocturnal shelters may be crucial for these tiny YOY fishes, particularly when benthic algal cover is undeveloped, as at PAR. Food abundance may be equally or more important. The YOY of both species probably feed on hypoplanktonic and epibenthic crustacea; at PAR, the troughs scoured by surge along module perimeters appear to trap drift algae and other detritus and may have dense concentrations of these crustacean prey (E. Demartini, pers. obs.; R. Ambrose, pers. comm.). For other species of fishes, higher densities of YOY at sand-rock interfaces are clearly explicable in terms of specific habitat requirements. YOY barred sand bass, for example, inhabit sand-floored rock holes.

4.4.3 Fish Abundances at PAR

4.4.3.1 Fall 1985 and 1986 Estimates

Our best available estimate of the average standing stock of fishes at PAR in fall 1985 is about 11,300 juvenile-adult fishes, weighing 660 kg. This estimate is known to be low for two reasons. First, preliminary data from the December 1985 pilot survey between modules was unsuitable for inclusion in our abundance estimates. (Fish densities between modules were adequately characterized on all three surveys in fall 1986.) Second, our fall 1985 estimates do not include data for fish numbers and biomass present in difficult-to-sample (extralimital) regions more than several meters above the crests and slopes of modules.

The omission of fish numbers and biomass between modules probably has not drastically underestimated fall 1985 standing stocks. We believe this because the December 1985 pilot data suggest that appreciable numbers of fishes did not extend beyond 10 m beyond module ecotones; numerical densities approximately halved for each 10-m distance beyond ecotones (Fig. 5). In addition, only several species (California sheephead, black perch, barred sand bass) were significantly represented beyond module ecotones. Several other factors might have inflated the contribution of intermodule regions, however, particularly for estimates of biomass abundance. These factors are the relatively large body size of the fish that were present between modules (Figs. 6, 8) and the squared-increase in area at linear increases in distance off modules. Our numerical and biomass estimates for fall 1986 provide further insights.

For fall 1986, we estimate that about 78% (504 kg) of the standing stock of fishes in Rock, Ecotone, and Adjacent Sand regions (648 kg) occurred in Rock and Ecotone regions. The numerical densities of most species and total fishes dropped precipitously from Rock levels in Ecotone and(or) Adjacent Sand regions (Fig. 7). Biomass densities showed analogous patterns for all species except barred sand bass and for total fishes (because of barred sand bass: Appendix S, Tables 1, 9-14). We conclude that, in terms of extent of habitat that was surveyed, our fall 1985 estimates were accurate for major species, except barred sand bass.

Fall 1985 estimates are also low because we did not consider the fishes present in extralimital regions above crests and slopes in our estimates. Only three species of fishes (blacksmith, sargo, and black croaker) were common in extralimital regions (E. DeMartini, pers. obs.). However, all three species contributed importantly to total fish numbers or biomass at PAR (Tables 33, 34). Blacksmith especially dominated fish numbers (Table 33). The subadult-adult sargo and black croaker present in extralimital slope regions might represent a significant fraction of total standing stock. Because of their extremely high densities, even small-bodied blacksmith likely contributed significantly to extralimital biomass in fall 1985.

In fall 1986, fishes present in extralimital regions at PAR were added to our abundance estimates based on transect data. These values were: blacksmith -- 4,200 individuals weighing 42 kg; sargo -- 95 for 21 kg; and black croaker -- 115 for 12 kg. The extralimital biomass of these three species pooled (75 kg) was 15% of estimated biomass present in Rock plus Ecotone habitats (Appendix S, Table 10) and about 12% of the total estimated stocks in Crest through Adjacent Sand regions that represent our best characterization for PAR (Table 34). We conclude that omission of extralimital fishes in fall 1985 by itself did not seriously underestimate stocks at that time.

A reasonable reestimate for fall 1985, using fall 1986 data to adjust for the contribution to abundance by fishes on adjacent sand and extralimital space above the modules, would be about 950 kg of fishes -- as (661 kg x 1.12) x 1.28 -- or about 43% larger than our original 1985 estimate.

Even without this correction, our 660-kg estimate for fall 1985 is equivalent to a biomass density of ~ 510 kg/ha, averaged over PAR's 1.3-ha extent of actual

rock plus sand-rock ecotones. Our conservative estimate of the biomass density of fishes at PAR in fall 1985 therefore is about 3.2 times larger than the analogous estimate (~ 160 kg/ha) for the kelp forest-cobble bed at SOK in fall 1985. (This SOK figure is based on our 18.1-MT estimate for the entire, 113-ha kelp-cobble bed in fall 1985, using downlooking sonar charts to delineate kelp density subregions; Chapter 3, Table 24). The adjusted estimate for fall 1985 (950 kg) is equal to 730 kg/ha, or about 4.5 times the biomass density of SOK at that time.

In fall 1986, the 648-kg estimate for Rock-Ecotone-Adjacent Sand regions at PAR is equivalent to a biomass density of about 380 kg/ ha. The latter value is not too different from our fall 1986 estimate for SOK (38.9 MT in 88 ha, or 442 kg/ha: Chapter Three, Table 25). Although biomass densities at PAR remained the same (or decreased) between fall 1985 and fall 1986, the average density of fishes at SOK had increased nearly threefold by the second fall (Chapter Three, Tables 24, 25).

4.4.3.2 Comparisons with Prior Studies

Several earlier PAR-versus-SOK comparisons are worth mentioning. Jessee et al. (1985a) estimated that, during fall 1981, the mean numerical densities of three fishes (barred sand bass, black perch, and California sheephead) were one-half to one-and-one-half orders of magnitude greater at PAR than in moderate-to-high-density kelp regions at SOK. Jessee et al. (1985a) omitted water-column data at SOK and excluded several suprabenthic species (opaleye, halfmoon) from their PAR-SOK comparison. Jessee et al. (1985b) added surface canopy data and included several other species in their reanalysis of 1981 data. Biomass densities were reestimated as one to three orders of magnitude lower at SOK (LOSL 1983a, Table 6-9). The fishes present in extensive mid-water-column regions at SOK (e.g., kelp bass) were not considered, however, and it is not surprising that Jessee et al.'s (1985b) reestimates of numerical densities remained 3- to > 100-fold (average 15 times) greater at PAR than at SOK for six key species.

Jessee et al.'s (1985b) estimates of densities at PAR in fall 1981 are not too different from our PAR estimates for fall 1985 (Table 33), considering the recent, large (perhaps fivefold) Bightwide reduction in fish stocks consequent to the California El Nino (Chapter 1, Section 1.3.4), and after allowing for differences in calculations. We believe that some of the apparent large

discrepancies between our and Jessee et al.'s (1985a,b) estimates of the relative densities of fishes at PAR and at SOK reflect computational differences. We cannot disprove the hypothesis that density patterns at PAR, relative to SOK, also might have changed in concert with PAR's further maturation during the period from two to five years following its construction. We do know, however, that the biomass density of total fishes at PAR during fall 1985, five years after construction, was about three times greater than it was at SOK at this time (Tables 24 and 34). And biomass densities were similar at PAR and SOK during fall 1986 (Tables 25 and 36). One could speculate that fish density at PAR was approaching that of a natural reef by five to six years after construction. It is more likely, though, that the large general declines at PAR (as at SOK and elsewhere: Patton 1985; Chapter 3, this report) coincident with the 1982-85 El Nino and the subsequent 1985-86 population rebounds probably have obscured changes in density patterns caused by reef development at PAR.

4.4.4 Fish Production

Estimates of production are possible at PAR, based on our fall 1985 and fall 1986 standing stock estimates. These production estimates assume that the growth and mortality rates of fishes at PAR are similar to those for these same species of fishes elsewhere. This is a reasonable assumption, because all species (except Paralabrax spp) are infrequently harvested at PAR or elsewhere. Hence most species are not subject to harvest rates that vary among reefs. More tenuous is the assumption that we can select one value as representative for the ratio of fish production to biomass (Allen 1971). Although production is estimable using growth and mortality data, such information exists for few species of southern Californian inshore fishes (Appendix U, Tables 1, 2). Given this caveat, a production-to-biomass ratio (Allen 1971) of 0.4 is a reasonable average value for the later-stage fishes sampled on our JUV-AD surveys (Appendix U, Tables 1, 2).

Fish production in 1985, based on a maximum possible total standing stock that was 950 kg (by adjusted estimate) for Rock-Ecotone-Adjacent Sand regions, would have been about 380 kg. Since later-life stages must emigrate/immigrate to some (probably appreciable) extent, local production must have been considerably less. If local production was 25%, 50%, or 75% of the estimated total, about 95, 190, or 285 kg of fish would have been produced at PAR in 1985. Of course, this assumes that our fall 1985 estimates are typical for the year.

Total fish production in 1986, based on an average standing stock in Rock-Ecotone-Adjacent Sand regions that was directly estimated to be 650 kg, would have been about 260 kg. At fractional local productions of 25%, 50%, or 75%, local production would have been about 65, 130, or 195 kg.

Production estimates are surely better interpreted in terms of local production for juvenile fishes, especially YOY recruits, which are most restricted in their movements. Because of their relatively rapid somatic growth, juvenile fishes can dominate the production of their species populations (Iles 1974; Backiel and Le Cren 1978). A complication arises in estimating the production of YOY fishes at PAR, because a large majority of the immatures of most species are older juveniles (Table 39, 40). And it is obvious that the biomass dominance of older juveniles over YOY must be even greater. But the older juveniles of most rocky inshore fishes probably are much less restricted in their movements than their respective YOY stage. We therefore caution that, although our estimates of YOY production at PAR likely represent local production, much of our estimated production by total juvenile fishes is diffused to some unknown extent beyond the immediate area of the artificial reef.

In fall 1985, our direct estimate of the standing stock of juvenile fishes at PAR was 30 kg (Table 34). Adjusting for blacksmith in extralimital regions, a generous estimate would be 35 kg. In fall 1986, the directly estimated total was 48 kg (Table 36). Assuming a maximally high biomass-to-production ratio of 1.0 (based on northern anchovy, a local paradigm of rapid fish production: see Hanan 1981), the total production of juvenile fishes was 35 and 48 kg in the respective years. Perhaps 75% of this production was local -- 26 kg in 1985 and 36 kg in 1986.

The latter minimal estimates of juvenile production can be augmented by the YOY data of our JUVENILE surveys. An estimated 75,000 YOY fishes (1,900 excluding blacksmith) were present at PAR in fall 1985 (Table 39). The respective estimates for fall 1986 were 32,000 and 1,500 (Table 40). At an average YOY body weight of about 2 g/fish (Appendix T, Tables 7A, 7B), the estimated standing stock and production of YOY in 1985 were 146 kg (blacksmith) and 4 kg (others). In 1986 the estimates were 64 kg (blacksmith) and 3 kg (others).

We conclude that the annual production of YOY fishes at PAR during 1985-86 was about 65-150 kg and that over 95% of this production was by a single species, blacksmith. Production attributable to the YOY of other species was vanishingly slight (3-4 kg). The production of older juvenile fishes at PAR (including blacksmith) was low (< 50 kg), even if a large majority of the production of these fishes remained local. We believe these calculations demonstrate that the local production of juvenile fishes is not necessarily high, despite high YOY densities (Appendix R, Tables 1-9; Ambrose 1987) and production rates, if the average standing stock biomass of YOY is low. It is also obvious that the magnitude of local production can be low if a large fraction of juvenile biomass is represented by vagile older juveniles.

4.4.5 Mitigation: Attraction versus Production

Fish biomass abundance, not biomass density, is the better measure of a reef's contribution to local fish stocks. Abundance, not density (Jessee et al. 1985b), is a more meaningful measure of PAR's potential to mitigate SONGS' effects. Attraction in itself, without an increase in production, does not constitute mitigation for lost resources (Ambrose 1986).

Artificial reefs obviously attract fishes, and their attractiveness must vary with the local distribution and abundance of other reef habitat (Ambrose 1986 and references therein). The mitigative potential of an artificial reef such as PAR also obviously depends, in part, on its area as well as the nature of its habitat. Fishes apparently concentrate at greater densities on artificial reefs (Bohnsack and Sutherland 1985), perhaps simply because they are small (and attract fish from relatively large areas) rather than because they are novel environments. Fish densities on artificial reefs cannot be simple, inverse linear functions of reef size beyond some (say, larger than PAR) areal threshold, however. If they were, one of the following should not have occurred: (1) Densities were twice as great at PAR (in 1981-82) as at a local natural rock reef (Las Pulgas Reef, LPR: LOSL 1983d; Jessee et al. 1985b, Fig. 3). (This assumes that LPR is representative of local natural reefs of its size -- 15 ha). (2) If fish densities were linearly, inversely proportional to area at all reef sizes, it is unlikely that densities would have averaged over three times greater at PAR compared to SOK (113 ha) in fall 1985, yet about the same as SOK (88 ha) in fall 1986 (Tables 24, 25, 34). And fish densities at both Las Pulgas Reef and San Onofre Kelp bed appear to be representative of natural reefs in southern California (Ambrose 1987).

Based on the preceding results and interpretations, we feel it is possible to realistically evaluate the mitigative potential of PAR, at least in terms of compensation for loss of fishes in San Onofre Kelp bed. A semiquantitative argument follows: Even if one liberally assumes that the entire area of sand plain encompassing PAR (3.4 ha) is enhanced habitat, this would represent only ~ 15% of the area within the upcoast, inshore fourth of SOK (~ 25 ha) that might have been impacted by the SONGS diffuser plume (Schroeter et al. 1987; Dean et al. 1987). And the transformation of kelp forest to kelpless cobble habitat off San Onofre might result in a three-fourths reduction in fish densities within the impacted area (Larson and DeMartini 1984; this report, Tables 22-25; Fig. 4; Appendix P, Tables 1-4). If one elects to use fall 1985 data -- when biomass densities at PAR were over three times greater than at SOK -- the relative abundances of fishes at PAR (660 kg) and at the upcoast, offshore quadrant at SOK (18.1 MT/4) are still very dissimilar. If these 1985 relative densities are used, the existing artificial reef would only mitigate the equivalent of about one-third (0.15 x 0.75 x 3.2) of the maximum likely loss of fish biomass at SOK. If fall 1986 data are used -- when biomass densities at PAR and at SOK were within ~15% of one another -- PAR would mitigate < 10% (0.15 x 0.75 x 0.86) of the maximum likely loss at SOK.

There is no practical solution ("build bigger") to the seemingly obvious shortcoming of small artificial reefs at present, because we do not know the relationship between fish density and reef area for any reef system. A challenging next step in developing artificial habitats for mitigation is the design and implementation of large-scale field experiments that simultaneously evaluate the effects of (1) artificial reef area and (2) distance from existing natural reefs on fish density.

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TABLE 1

MIDWATER FISHES: QUALITATIVE SUMMARY OF IMPACT TESTS (AND CONCLUSIONS BASED THEREON) FOR FISHES SAMPLED BY LAMPARA SEINE. Relative confidence in the evaluation of SONGS impact is based on a combination of assumption test results (Appendix D, Table 1), impact test results (Appendix E, Table 1), and the magnitude of natural fluctuations in abundance at all longshore sampling locations (Table 2). Presence/absence of impact is evaluated based on disproportionate changes in numerical catches at the nearfield sampling location.

Taxon	Type (Magnitude) of Impact
Group I. Definite Presence of Meaningful SONGS Effect	
QUEENFISH, YOY	Decline (> 50%) at ≤ 1/2 km of intakes
QUEENFISH, immature	Decline (> 50%) at ≤ 1/2 km of intakes
CROAKER, white[a]	Decline (> 50%) at ≤ 1/2 km of intakes
Group II. Definite Presence of Trivial SONGS Effect	
No cases	
Group III. Suggestive (But Inconclusive) SONGS Effect	
QUEENFISH, female	Possible decline (> 50%) at ≤ 1/2 km of intakes
QUEENFISH, male	Possible decline (> 50%) at ≤ 1/2 km of intakes
SILVERSIDES, spp.	Possible increase (> 50%) 1 - 2 km downcoast
Group IV. Definite Absence of SONGS Effect	
BUTTERFISH, Pacific	No change due to SONGS
SILVERSIDES spp.	No change at ≤ 1/2 km of intakes

[a]Primarily YOY (young-of-year or Age 0) fish

TABLE 4

BENTHIC FISHES: QUALITATIVE SUMMARY OF IMPACT TESTS (AND CONCLUSIONS BASED THEREON) FOR FISHES SAMPLED BY OTTER TRAWL. Relative confidence in the evaluation of SONGS impact is based on a combination of assumption test results (Appendix D, Table 3), impact test results (Appendix E, Table 4), and the magnitude of natural fluctuations in abundance at the SONGS and Control locations (Table 5). Presence/absence of impact is evaluated based on disproportionate changes in numerical catches at the SONGS location.

Taxon	Depth	Type (Magnitude) of Impact
Group I. Definite Presence of Meaningful SONGS Effect		
CROAKER, white[a]	30 m	Increase (> 600%) off-plume
Group II. Definite Presence of Trivial SONGS Effect		
LIZARDFISH, Ca.	18 m	Increase (~ 200%) off-diffusers
LIZARDFISH, Ca.	30 m	Increase (> 250%) off-plume
QUEENFISH[a]	30 m	Increase (> 200%) off-plume
SANDDAB, speckled	18 m	Decrease (> 50%) off-diffusers
SOLE, fantail	30 m	Increase (> 200%) off-plume
Group III. Suggestive (But Inconclusive) SONGS Effect		
CROAKER, white[a]	18 m	Possible increase (> 100%) off-diffusers
SANDDAB, longfin	18 m	Possible increase (~ 500%) off-diffusers
Group IV. Definite Absence of SONGS Effect		
CUSK-EEL, basketweave	18 m 30 m	No change at either depth off SONGS
QUEENFISH[a]	18 m	No change off SONGS diffusers
SANDDAB, longfin	30 m	No change off SONGS plume
SANDDAB, Pacific	30 m	No change off SONGS plume
SKATE, California	30 m	No change off SONGS plume
SOLE, fantail	18 m	No change off SONGS diffusers
TURBOT, hornyhead	18 m	No change off SONGS diffusers

[a]Primarily large adult fish

TABLE 3

COASTAL PELAGIC FISHES: ESTIMATED PERCENTAGE CHANGES AT THE NEAR IMPACT, FAR IMPACT, AND DISTANT CONTROL STATIONS FOR SELECT TAXA SAMPLED BY LAMPARA SEINE. "Percentage change" calculated as $(L_A - L_B)/L_B$, where L_A = mean seine raw data (CPUE) for the "After" period and where L_B = analogous data for the "Before" period at a particular sampling location and depth-block. See Table 2 for mean seine CPUE data.

Taxon	Depth (m)	PERCENT CHANGE at Near Impact	PERCENT CHANGE at Far Impact	PERCENT CHANGE at Control
BUTTERFISH, Pacific	5-10 m	-85	-84	-88
	11-16 m	-89	-91	-81
CROAKER, white	5-10 m	-89	-67	-80
	11-16 m	-88	-98	-90
SILVERSIDES spp.	5-10 m	-90	+15	-84
	11-16 m	-75	-60	-50
QUEENFISH, total	5-10 m	-75	-52	-25
	11-16 m	-66	-75	-39
QUEENFISH, adult female	5-10 m	-58	-65	+14
	11-16 m	-50	-73	-57
QUEENFISH, immature	5-10 m	-85	-45	-49
	11-16 m	-84	-88	-36
QUEENFISH, adult male	5-10 m	-43	-52	+100
	11-16 m	-62	-70	-44
QUEENFISH, older juvenile and adult	5-10 m	-72	-73	-33
	11-16 m	-64	-76	-66
QUEENFISH, young-of year	5-10 m	-84	-32	-32
	11-16 m	-92	-90	-25

TABLE 6

BENTHIC FISHES: ESTIMATED PERCENTAGE CHANGES AT THE IMPACT (SONGS) STATION AND AT THE CONTROL (STUART MESA) STATION FOR SELECT TAXA CAPTURED BY OTTER TRAWL. "Percentage change at SONGS" calculated as $(L_A - L_B)/L_B$, where L_A = mean trawl raw data (CPUE) for the "After" period and where L_B = analogous data for the "Before" period at a particular sampling location and depth. See Table 5 for mean trawl CPUE data.

Taxon	Depth (m)	PERCENT CHANGE at Impact	PERCENT CHANGE at Control
CROAKER, white	18 m	-21	-68
	30 m	-51	-89
CUSK-EEL, basketweave	18 m	+73	+39
	30 m	+36	-28
HALIBUT, California	18 m	-80	-71
LIZARDFISH, California	18 m	+200	+33
	30 m	+175	-14
QUEENFISH	18 m	+83	+1
	30 m	-6	-43
SANDDAB, longfin	18 m	-7	-70
	30 m	-13	-41
SANDDAB, Pacific	30	-81	-85
SANDDAB, speckled	18 m	-18	+27
	30 m	-1	+8
SEAPERCH, pink	18 m	-92	-90
SKATE, California	18 m	-63	-80
SOLE, fantail	18 m	+175	+375
	30 m	+75	0
TONGUEFISH, California	18 m	+60	-35
	30 m	+33	+160
TURBOT, hornyhead	18 m	-28	+15
	30 m	-6	-45

TABLE 5

BENTHIC SOFT-BOTTOM FISHES: ARITHMETIC MEAN CPUE OF SELECT SPECIES CAUGHT BY OTTER TRAWL AT EACH LOCATION AND DEPTH DURING THE PREOPERATIONAL, INTERIM, AND OPERATIONAL PERIODS THROUGH NOVEMBER 1986. Summary statistics are the grand arithmetic (raw) mean numbers per trawl of select species of benthic fishes at 18-m and 30-m depths at the Impact and Control locations. All zero catches are included. Dashes indicate trivial occurrence in trawls. See Appendix A, Table 2 for a list of sampling dates for preoperational, interim, and operational periods.

		PREOPERATIONAL		INTERIM		OPERATIONAL	
Species	Depth (m)	Impact	Control	Impact	Control	Impact	Control
CROAKER, white	18	27.2	36.6	25.3	17.3	21.5	11.6
	30	38.5	67.5	26.7	24.4	18.9	7.4
CUSK-EEL, basketweave	18	16.0	20.7	5.0	6.5	27.7	28.8
	30	14.5	14.1	10.5	7.7	14.3	10.1
HALIBUT, California	18	1.0	1.4	0.4	0.1	0.2	0.4
	30	---	---	---	---	---	---
LIZARDFISH, Ca.	18	0.2	0.6	0.1	0.5	0.6	0.8
	30	0.4	0.7	2.8	3.2	1.1	0.6
QUEENFISH	18	8.7	13.3	6.6	6.0	15.9	13.4
	30	7.0	9.2	9.5	5.1	6.6	5.2
SANDDAB, longfin	18	1.5	5.3	0.1	0.5	1.4	1.6
	30	8.6	18.1	3.4	5.4	7.5	10.6
SANDDAB, Pacific	18	---	---	---	---	---	---
	30	11.2	7.8	0.2	0.0	2.1	1.2
SANDDAB, speckled	18	4.4	4.1	0.6	1.6	3.6	5.2
	30	8.9	6.4	1.3	1.6	8.8	6.9
SEAPERCH, pink	18	---	---	---	---	---	---
	30	50.3	24.2	1.7	0.3	4.0	2.4
SKATE, California	18	---	---	---	---	---	---
	30	0.8	1.0	0.2	0.2	0.3	0.2
SOLE, fantail	18	0.4	0.4	0.2	0.2	1.1	1.9
	30	0.8	0.8	0.7	0.7	1.4	0.8
TONGUEFISH, Ca.	18	0.5	1.7	0.5	0.3	0.8	1.1
	30	3.9	8.0	1.4	2.7	5.2	10.4
TURBOT, hornyhead	18	1.8	1.3	0.4	0.4	1.3	1.5
	30	1.8	2.0	1.0	0.9	1.7	1.1

TABLE 6

BENTHIC FISHES: ESTIMATED PERCENTAGE CHANGES AT THE IMPACT (SONGS) STATION AND AT THE CONTROL (STUART MESA) STATION FOR SELECT TAXA CAPTURED BY OTTER TRAWL. "Percentage change at SONGS" calculated as $(L_A - L_B)/L_B$, where L_A = mean trawl raw data (CPUE) for the "After" period and where L_B = analogous data for the "Before" period at a particular sampling location and depth. See Table 5 for mean trawl CPUE data.

Taxon	Depth (m)	PERCENT CHANGE at Impact	PERCENT CHANGE at Control
CROAKER, white	18 m	-21	-68
	30 m	-51	-89
CUSK-EEL, basketweave	18 m	+73	+39
	30 m	+36	-28
HALIBUT, California	18 m	-80	-71
LIZARDFISH, California	18 m	+200	+33
	30 m	+175	-14
QUEENFISH	18 m	+83	+1
	30 m	-6	-43
SANDDAB, longfin	18 m	-7	-70
	30 m	-13	-41
SANDDAB, Pacific	30	-81	-85
SANDDAB, speckled	18 m	-18	+27
	30 m	-1	+8
SEAPERCH, pink	18 m	-92	-90
SKATE, California	18 m	-63	-80
SOLE, fantail	18 m	+175	+375
	30 m	+75	0
TONGUEFISH, California	18 m	+60	-35
	30 m	+33	+160
TURBOT, hornyhead	18 m	-28	+15
	30 m	-6	-45

TABLE 7

PELAGIC FISHES: SUMMARY RESULTS OF THREE-WAY ANOVAS TO TEST EFFECTS OF LOCATION, DEPTH, AND SONGS OPERATING PERIOD ON THE NUMERICAL DENSITY INDEX (seine CPUE) OF FOUR MAJOR TAXA AND FOUR SIZE/SEX CATEGORIES OF QUEENFISH. Factors tested: LOCATION (3 levels: Near Impact, Far Impact, Control); DEPTH-BLOCK (2 levels: shallow, mid-depth); and PERIOD (2 levels: preoperational = June 1981-May 1982 (see NOTE below); operational = April 1984-August 1986). Null hypothesis of primary interest was presence of a significant 3-way interaction. All cruise triple-zeroes (Near Impact, Far Impact, Control) were deleted prior to testing. Transformations used were those that most generally satisfied the screening assumptions for the BACI t-tests (see Methods). Dashes signify an inestimable effect. (* .05 > P > .01; ** .01 > P > .001; *** P < .001).

	SIGNIFICANT EFFECT ?						
	Main Effect			Interactions			
Taxon	Location	Depth	Period	Loc*Depth	Loc*Period	Depth*Period	Loc*Depth*Period
BUTTERFISH, Pacific	--	--	Yes***	Yes*	No	No	No
CROAKER, white	- - - - cannot evaluate - - - -						
QUEENFISH							
-- total	--	Yes***	--	No	Yes*	No	No
-- adult male	--	--	--	No	Yes**	Yes***	No
-- adult female	Yes*	Yes***	Yes***	No	No	No	No
-- immature	- - - - cannot evaluate - - - -						
-- young-of-year	Yes**	Yes***	Yes***	No	No	No	No
SILVERSIDES	No	Yes***	Yes***	No	No	No	No

NOTE: Nighttime shallow data could not be collected at the Near Impact location prior to April 1981; and during April and May 1981, shallow and mid-depth collections were made on alternating cruises.

TABLE 8

BENTHIC FISHES: SUMMARY RESULTS OF THREE-WAY ANOVAS TO TEST EFFECTS OF LOCATION, DEPTH, AND SONGS OPERATING PERIOD ON THE NUMERICAL DENSITY INDEX (TRAWL CPUE) OF SIX SELECT SPECIES that were abundant and common during the baseline period at both depths. Factors tested: LOCATION (2 levels: SONGS = Impact, Stuart Mesa = Control); DEPTH (2 levels: 18 m, 30 m); and PERIOD (2 levels: preoperational = May 1980-June 1982, operational = May 1984-November 1986). Null hypothesis of primary interest was presence of a significant 3-way interaction. All cruise double-zeroes (SONGS, Control) were deleted prior to testing. Transformations used were those that most generally satisfied screening assumptions for the BACI t-tests (see Methods). Dashes signify an inestimable effect. (* .05 > P > 0.01; ** .01 > P > .001; *** P ≤ .001).

		SIGNIFICANT EFFECT ?						
		MAIN EFFECT			INTEACTIONS			
Species	Data Form	Location	Depth	Period	Loc*Depth	Loc*Period[a]	Depth*Period	Loc*Depth*Period
CROAKER, white	log(x-bar + .0156)	--	--	--	No	Yes***	Yes***	No
CUSK-EEL, basketweave	log(x-bar + 2.0)	No	--	--	No	No	Yes**	No
LIZARDFISH, California	log(x-bar + .04)	--	--	--	Yes**	Yes**	No	No
QUEENFISH	log(x-bar + .0156)	No	Yes***	Yes*	No	No	No	No
SANDDAB, longfin	log(x-bar + .07)	--	--	--	--	--	--	Yes^{*,b}
SANDDAB, speckled	- cannot evaluate -							
SOLE, fantail	log(x-bar + .25)	--	--	--	Yes*	No	Yes*	No
TONGUEFISH, Ca.	- cannot evaluate -							
TURBOT, hornyhead	- cannot evaluate -							

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[a] Significant Loc*Period interaction same as significant t-test on SONGS-Control deltas for SONGS baseline and operational periods

[b] Preop, Con, 30 m > Preop, Con, 18 > Op, Con, 18 = Op, Impact, 18 > Preop, Impact, 18

TABLE 9

MIDWATER FISHES: QUALITATIVE RESULTS AND BIOLOGICAL INTERPRETATIONS OF LOCATION- AND PERIOD- COMPARISONS OF THE SIZE-FREQUENCY DISTRIBUTIONS OF FIVE SIZE AND MATURITY CATEGORIES OF QUEENFISH AND OF WHITE CROAKER (OF ALL BODY SIZES). Evaluation is based on (1) subjective interpretation of six-panel histograms (Before - Near Impact, Before - Far Impact, Before - Control, After - Near Impact, After - Far Impact, After - Control) (Appendix E, Figures 47-52). (2) Plots are cross-referenced against the respective two-sample K-S test result (Appendix E, Tables 8-10).

Species/Taxon (5- to 10-m Depths)	Meaningful Difference?				
	Among Locations		Between Periods		
	Preop.	Op.	NI	FI	C
CROAKER, white	no	yes	yes	yes	yes
QUEENFISH, total	-- see immature --				
adult female	no	no	yes	yes	yes
adult male	no	yes	yes	yes	yes
immature	no	yes	yes	no	no
YOY	no	yes	yes	no	no

TABLE 10

BENTHIC FISHES: QUALITATIVE RESULTS AND BIOLOGICAL INTERPRETATIONS OF LOCATION- AND PERIOD- COMPARISONS OF THE SIZE-FREQUENCY DISTRIBUTIONS OF SIX SELECT SPECIES SAMPLED BY OTTER TRAWL. Evaluation is based on (1) subjective interpretation of four-panel histograms (Appendix E, Figures 56-64) and (2) the respective K-S test results (Appendix E, Tables 11 and 12). See caption to Table 9 for details.

		Meaningful Difference?			
		Between Locations		Between Periods	
Species	Depth	Preop.	Op.	SONGS	Control
CROAKER, white	18 m	no	yes	yes	yes
	30 m	no	yes	yes	yes
SANDDAB, longfin	18 m	no	no	yes	yes
	30 m	no	yes	yes	yes
SANDDAB, Pacific	30 m	no	no	yes	yes
SANDDAB, speckled	18 m	no	no	no	yes
SOLE, fantail	30 m	no	yes	yes	yes
TURBOT, hornyhead	18 m	no	no	no	yes
	30 m	yes	yes	no	yes

TABLE 11

SONGS ENTRAPMENT: SUMMARY OF ENTRAPMENT ESTIMATES FOR SONGS UNITS 1, 2, AND 3 FOR THE 39-MO PERIOD MAY 1983-AUGUST 1986. Annualized (12-mo) estimates are provided for the numbers and biomass of each of eight major fish taxa and for total fishes. Estimates represent total entrapment as the sum of 12-mo normal flow estimates (Appendix G, Tables 1-9) and 12/39-ths of 39-mo of heat treatment counts (Appendix G, Tables 10-15).

	ANNUALIZED ESTIMATE			
	Numbers		Biomass (kg)	
Species	Unit 1	Units 2 & 3	Unit 1	Units 2 & 3
QUEENFISH	34,913	1,125,508	592	14,226
CROAKER, white	798	124,072	8	885
SURFPERCH, walleye	2,219	12,471	58	163
RAY, Pac. electric	116	136	1,231	1,336
SEAPERCH, white	109	5,324	2	75
BUTTERFISH, Pac.	49	12,970	1	214
SILVERSIDES spp.	526	33,858	60	4,279
ANCHOVY, northern	289[a]	4,178,858	2[a]	4,799
TOTAL FISHES	48,530	5,599,611	3,834	36,868

[a]Values for northern anchovy at Unit 1 are gross underestimates because of extrusion of this fragile, slender fish through the 5/8-inch mesh traveling screens at Unit 1.

TABLE 12

SONGS ENTRAPMENT: SUMMARY OF PERCENT NUMBERS AND BIOMASS DIVERTED, BY SPECIES, FOR ALL FISHES REPRESENTED BY ≥ 20 INDIVIDUALS IN PAIRED IMPINGEMENT AND DIVERSION SAMPLES AT SONGS UNITS 2 AND 3. Estimates are based on all quantitative samples (n=191) at either new unit during the period May 25, 1983-August 27, 1986. Fish species are ranked by total weight entrapped (kg).

Species	Total Number Entrapped	Percent Number Returned	Total Weight Entrapped	Percent Weight Returned
QUEENFISH	457,522	72	6,630.3	79
ANCHOVY, northern	958,955	91	1,503.3	79
JACKSMELT	7,535	59	1,024.0	64
CROAKER, yellowfin	2,613	100	640.8	100
RAY, bat	78	67	499.1	80
RAY, Pacific electric	51	41	482.6	51
PERCH, zebra	720	100	402.0	100
CROAKER, white	68,991	49	390.3	60
GUITARFISH, shovelnose	83	92	273.0	99
SALEMA	5,154	98	202.0	99
CORBINA, California	578	86	134.1	92
BASS, kelp	516	98	125.6	100
SARGO	627	94	125.3	99
STINGRAY, round	244	81	101.3	82
HALIBUT, California	269	76	96.1	86
SEABASS, white	417	86	91.3	97
TOPSMELT	982	97	83.2	99
SMOOTHHOUND, gray	69	88	75.1	96
BUTTERFISH, Pacific	4,811	44	69.3	59
MACKEREL, Pacific	396	78	66.8	81
THORNBACK	168	27	65.0	37
BASS, barred sand	249	80	60.0	76
CROAKER, spotfin	176	97	49.7	98
ANCHOVY, slough	17,075	27	46.7	25
ANCHOVY, deepbody	4,970	57	46.4	53
SURFPERCH, walleye	3,730	94	45.4	92
MIDSHIPMAN, specklefin	152	16	35.9	20
SEAPERCH, white	1,798	62	30.3	83
DOGFISH, spiny	44	34	23.1	33
MIDSHIPMAN, plainfin	601	4	23.0	6
OPALEYE	31	94	20.2	97
PERCH, pile	45	96	18.4	100
SCORPIONFISH, California	150	21	14.3	30
CROAKER, black	78	99	12.1	100
PERCH, black	113	83	11.3	98
BARRACUDA, Pacific	154	34	11.1	68
MACKEREL, jack	520	34	9.9	70
KELPFISH, giant	279	22	9.4	32
TURBOT, spotted	109	41	7.9	35
BLACKSMITH	83	98	6.8	98

TABLE 12 (continued)

Species	Total Number Entrapped	Percent Number Returned	Total Weight Entrapped	Percent Weight Returned
HALFMOON	27	100	6.6	100
GRUNION	187	56	5.4	56
PERCH, shiner	611	44	5.1	53
TURBOT, diamond	20	40	4.8	28
SARDINE, Pacific	150	75	4.3	66
PIPEFISH	139	0	3.8	0
CUSK-EEL, spotted	52	33	2.9	27
WRASSE, rock	28	46	2.2	63
SOLE, fantail	33	42	1.5	62
SCULPIN, Pacific staghorn	20	5	0.8	12
PERCH, kelp	21	52	0.7	78
SANDDAB, speckled	43	19	0.6	6
CUSK-EEL, basketweave	32	12	0.5	14
BOCACCIO	21	48	0.1	45
BLENNY spp.	41	0	0.1	0

No. of Taxa with N $\geq$ 20 Entrapped: 55

Subtotal No. Fish Entrapped (55 taxa): 1,269,275

% No. Returned (55 taxa) = 1,269,275/1,542,563 = 82.3%

% Weight Returned (55 taxa) = 10,703.0/13,602.3 = 78.7%

TABLE 13

SONGS ENTRAPMENT: SUMMARY OF PERCENT EFFICIENCY DATA FOR THE UNITS 2 AND 3 FISH RETURN SYSTEM. Efficiency calculated as the product of biomass percent diversion and numerical percent survivorship of fishes that are diverted. Species-specific efficiency was estimated only for fishes for which estimates of both percent diversion and percent survivorship were deemed sufficient (see Methods, Section 2.2.2). Estimates for small-bodied, medium-sized, and large-bodied fishes were based on all available percent diversion and percent survivorship data for all taxa of fishes that averaged ≤ 30 g, 30-199 g, and ≥ 200 g body weight, respectively (Appendix H, Table 2).

	ESTIMATED AVERAGE		
Species/Taxon	% Diversion (Wt)	% Survivorship (#s)	% Efficiency
ANCHOVY, deepbody	53	87 x 75	35
ANCHOVY, northern[a]	79	97 x 50	38
ANCHOVY, slough	25	0	0
CROAKER, white	60	48 x 75	22
CROAKER, yellowfin	100	>99 x 100	>99
PERCH, walleye	92	98 x 75	68
PERCH, white	83	93 x 75	58
QUEENFISH	79	68 x 75	40
SALEMA	99	100 x 90	89
SMALL FISHES (LESS ANCHOVY)[b]	77	66 x 75	38
ALL MEDIUM-SIZED FISHES[c]	70	100 x 90	63
ALL LARGE-BODIED FISHES[d]	85	100 x 99	84

[a] For northern anchovy, the probability of surviving FRS transport was estimated based on experimental pen data only (see Appendix H, Table 3).

[b] For all small fishes (excluding northern anchovy), FRS transport survivorship was estimated based on the weighted mean (66%) of empirical observations for queenfish and white croaker. The conditional probability of surviving predation upon discharge, if surviving transport, was the arbitrary value of 75% (Appendix F, part 2).

[c] For all medium-sized fishes, FRS transport survivorship was estimated as 100% based on empirical data for salema and 7 other species. Predation survivorship was arbitrarily set at 90% (Appendix F, part 2).

[d] For all large-bodied fishes, FRS transport survivorship was estimated as 100% based on empirical data for yellowfin croaker and 9 other species. A predation survivorship value of 99% was assigned (Appendix F, part 2).

TABLE 14

SONGS ENTRAPMENT: SUMMARY OF PAIRED T-TEST RESULTS COMPARING THE MAGNITUDE OF ENTRAPMENT AT UNIT 1 AND AT EITHER OF THE TWO NEW UNITS. The null hypothesis tested was whether entrapment at either new unit was equal to 2.5 times concurrent entrapment at Unit 1. Only concurrent data at Unit 1 and one or both new units were used in the analysis. Data were transformed to logs prior to analysis to reduce scatter and to normalize distributions. A two-tailed alternative hypothesis (i.e., new unit not equal to 2.5 times Unit 1) was tested. These hypotheses are based on the predictions of DeMartini and Larson (1980). Probabilities associated with t-statistic are noted as follows: *** = P < 0.001; ** = P < 0.01; NS = P > 0.05. See Appendix G, Table 16 for back-up statistics.

	Average 24-Hr Sample (Numbers)		Average 24-Hr Sample (Biomass, kg)	
Species/Taxon	Unit 1	New Unit	Unit 1	New Unit
CROAKER, white ***	4	618	.03	3.2
QUEENFISH:				
Total ***	116	1630	1.9	18.2
Small ***	62	1231	0.4	6.8
Large ***	54	399	1.5	11.4
SALEMA **	2	35	.03	1.1
SURFPERCH, walleye NS	11	11	.27	.18
TOTAL FISHES (minus northern anchovy) ***	148	2560	7.3	39.6
TOTAL FISHES (minus all anchovy spp.) ***	142	2249	7.2	38.5
TOTAL FISHES ***	149	5147	7.3	44.1

TABLE 15

KELP BED FISHES: LIST OF SIGNIFICANT BACI-TEST RESULTS FOR COMPONENT LIFE STAGES OF 15 SELECT TAXA. Results are based on t-tests or Binomial tests, as applicable, tested at a two-tailed alpha of 0.05 or 0.10 (the latter if power is < 0.80; t-tests only). Percent change is estimated for the multiplicative (log-linear) model.

		SIGNIFICANT CHANGES			
	Life	SOKU Versus SMK		SOKU Versus SOKD	
Taxon	Stage	Sign	% Change	Sign	% Change
BASS, barred sand	AD	Minus	99	Minus	92
	JUV	Minus	98	Minus	99
	SAD	Minus	79	Minus	97
	TOTAL	Minus	83	Minus	87
BASS, kelp	JUV	Minus	45(ns)	Minus	82
HALFMOON	SAD	Plus	300[b]	Minus	80(ns)
	TOTAL	Plus	215	-- intractable --	
PERCH, black	SAD	Minus	81[b]	Minus	95
	TOTAL	-- intractable--		Minus	77
PERCH, kelp	TOTAL	-- intractable--		Minus	92
SEAPERCH, rainbow	SAD[a]	Minus	31[b](ns)	Minus	95[a]
SEAPERCH, white	SAD	Minus	16(ns)	Minus	96
SENORITA	AD	Plus	360	Minus	77
	JUV	Plus	1400	Plus	1[b](ns)
	SAD	Plus	5700	Minus	81(ns)
	TOTAL	Plus	420	Minus	76
SHEEPHEAD, Calif.	SAD	-- intractable --		Minus	90
SILVERSIDES	TOTAL	Minus	94(ns)	Plus	120[b]
WRASSE, rock	AD	Plus	590	Minus	40(ns)

[a]Significance of change for SAD rainbow perch questionable; magnitude of decline decreases to insignificance at larger values of the constant, "c," added to the density estimate prior to log transformation.

[b]Percent change in average proportionate abundance at Impact location; as gauged by Binomial test.

TABLE 16

KELP BED FISHES: LIST OF INSIGNIFICANT BACI-TEST RESULTS FOR COMPONENT LIFE STAGES OF 15 SELECT TAXA. Results are based on t-tests or Binomial tests, as applicable, tested at a two-tailed alpha of 0.05 or 0.10 (the latter if power is < 0.80; t-tests only). Percent change is estimated for the multiplicative (log-linear) model.

		INSIGNIFICANT CHANGES			
	Life	SOKU Versus SMK		SOKU Versus SOKD	
Taxon	Stage	Sign	% Change	Sign	% Change
BASS, kelp	AD	-- intractable --		Minus	80
	OJ	Minus	21	-- intractable --	
	SAD	Minus	67	-- intractable --	
	YOY	Minus	44	Plus	41
BLACKSMITH	JUV	Plus	800	-- too few data --	
	TOTAL	Plus	700	Minus	58[a]
HALFMOON	AD	Plus	220	Plus	15
KELPFISH, giant	JUV	Minus	24[a]	Minus	11[a]
	SAD	Minus	11[a]	-- too few data --	
	TOTAL	Minus	37[a]	Minus	62[a]
PERCH, black	AD	-- intractable--		Minus	57
PERCH, pile	AD	Plus	650	-- intractable --	
SEAPERCH, rainbow	AD	-- too few data --		Minus	44
	TOTAL	Minus	80	Minus	57
SEAPERCH, rubberlip	TOTAL	Plus	15[a]	Minus	94[a]
SHEEPHEAD, Calif.	JUV	Plus	34	Minus	38
WRASSE, rock	SAD	Plus	170[a]	-- intractable --	
	TOTAL	Plus	240	Minus	16

[a]Percent change in average proportionate abundance at Impact location; as gauged by Binomial test.

TABLES 17 AND 18

KELP BED FISHES: RAW (ARITHMETIC) MEAN DENSITIES OF COMPONENT LIFE STAGES OF 15 SELECT TAXA CHOSEN FOR POTENTIAL USE IN BACI IMPACT TESTS. The relevant stages listed are adult (AD), juvenile (JUV), subadult (SAD), and TOTAL (all stages pooled); in addition, kelp-bass juveniles are subdivided into young-of-the-year (YOY) and older juveniles (OJ). Densities are expressed as numbers per 1000 m**3, and are weighted for the contribution of all relevant water-column strata. The relevant strata differ among species (Appendix M, Table 1). Sample sizes (Ns) are numbers of sampling dates that are potentially suitable for BACI analyses. "Preoperational" = (Fall 1980 + Fall 1981); "Operational" = (Fall 1985 + Fall 1986). For the SOK-SMK comparison of Table 17, SOKUout is used in the Operational period. For the SOKU-SOKD comparison of Table 18, SOKUin and SOKDout are used during the operational period (see Appendix J, Table 2). See Appendix L, Tables 1-3 for density per 1000 m**3, calculated using all quantitative samples. Appendix L, Tables 1-3 also list the percentage contribution of juveniles, subadults, and adults to totals.

NOTE

Estimated means exclude "double-zero" observations; estimates for component life stages, therefore, do not necessarily sum to "TOTAL."

TABLE 17

		KELP BED ARITHMETIC MEAN DENSITIES					
		PREOPERATIONAL			OPERATIONAL		
Species	Maturity	N	SOKU	SMK	N	SOKU	SMK
BASS, barred sand	AD	28	2.152	0.106	9	0.713	1.591
	JUV	21	1.152	0.165	15	1.119	1.053
	SAD	29	4.223	0.851	15	4.477	2.272
	TOTAL	30	6.897	1.037	15	6.025	4.280
BASS, kelp	AD	23	0.265	0.158	11	0.266	0.380
	JUV	25	3.004	2.313	15	2.341	2.816
	OJ	10	3.817	3.033	15	1.778	2.212
	SAD	25	8.721	4.554	15	2.075	1.658
	TOTAL	25	11.968	7.011	15	4.611	4.752
	YOY	10	0.421	0.622	14	0.603	0.647
BLACKSMITH	JUV	7	0.731	3.175	9	0.691	1.364
	SAD	.	.	.	1	0.000	0.109
	TOTAL	7	0.731	3.175	9	0.691	1.376
HALFMOON	AD	39	2.671	3.888	10	9.370	2.057
	SAD	8	0.150	0.751	7	0.228	0.109
	TOTAL	39	2.702	4.042	15	6.353	1.422
KELPFISH, giant	AD	7	0.060	0.045	1	0.000	0.109
	JUV	8	0.079	0.084	8	0.113	0.193
	SAD	6	0.045	0.149	13	0.072	0.274
	TOTAL	16	0.083	0.118	13	0.141	0.401
OPALEYE	AD	22	0.069	3.252	3	0.081	0.253
	SAD	1	0.000	0.148	.	.	.
	TOTAL	23	0.066	3.117	3	0.081	0.253
PERCH, black	AD	24	14.937	2.531	13	2.241	1.292
	JUV	1	0.494	0.000	4	0.000	1.605
	SAD	17	1.830	1.685	15	0.461	4.115
	TOTAL	25	15.604	3.575	15	2.403	5.662
PERCH, kelp	AD	39	10.076	32.896	18	0.915	3.687
	TOTAL	39	10.076	32.896	18	0.915	3.687
PERCH, pile	AD	25	1.758	1.896	9	0.988	0.329
	JUV	2	0.247	0.247	3	0.000	0.988
	SAD	16	3.055	2.901	6	0.165	2.798
	TOTAL	27	3.457	3.493	13	0.760	1.747

TABLE 17 (continued)

		KELP BED ARITHMETIC MEAN DENSITIES					
		PREOPERATIONAL			OPERATIONAL		
Species	Maturity	N	SOKU	SMK	N	SOKU	SMK
SEAPERCH, rainbow	AD	10	1.877	0.691	3	0.329	0.494
	JUV	1	0.000	0.494	1	0.000	0.494
	SAD	13	0.494	1.443	5	0.296	1.383
	TOTAL	18	1.399	1.454	7	0.353	1.270
SEAPERCH, rubberlip	AD	15	1.350	1.350	3	1.317	0.000
	SAD	5	0.593	1.086	3	2.469	3.127
	TOTAL	15	1.547	1.712	5	2.272	1.876
SEAPERCH, white	AD	25	6.141	3.207	12	0.937	0.091
	JUV	5	0.327	0.305	1	0.109	0.000
	SAD	19	8.558	0.933	13	0.677	0.188
	TOTAL	25	12.710	3.977	14	1.439	0.253
SENORITA	AD	25	12.281	19.372	15	33.343	14.324
	JUV	21	0.424	4.076	13	2.746	1.823
	SAD	25	0.362	1.455	15	4.354	3.744
	TOTAL	25	12.999	24.251	15	40.077	19.649
SHEEPHEAD, Calif.	AD	28	2.804	0.529	4	0.370	0.494
	JUV	30	6.535	2.634	14	3.527	1.799
	SAD	30	12.888	5.119	12	0.576	0.905
	TOTAL	30	22.040	8.247	15	3.852	2.535
SILVERSIDES spp.	AD	25	5.155	12.108	12	1.415	4.786
	TOTAL	25	5.155	12.108	12	1.415	4.786
WRASSE, rock	AD	29	0.937	3.899	15	9.547	12.378
	JUV	1	0.000	0.494	10	0.741	1.679
	SAD	14	0.141	0.952	15	12.312	22.616
	TOTAL	29	1.005	4.376	15	22.353	36.114

TABLE 18

		KELP BED ARITHMETIC MEAN DENSITIES					
		PREOPERATIONAL			OPERATIONAL		
Species	Maturity	N	SOKU	SOKD	N	SOKU	SOKD
BASS, barred sand	AD	33	1.885	1.003	12	0.700	1.564
	JUV	26	0.969	0.456	14	0.247	5.714
	SAD	33	4.085	2.484	16	1.204	4.753
	TOTAL	34	6.536	3.733	16	1.944	10.926
BASS, kelp	AD	24	0.212	0.440	10	0.132	0.390
	JUV	28	3.482	2.788	14	1.814	5.240
	OJ	12	5.129	0.989	14	1.252	4.615
	SAD	28	8.687	8.308	14	0.933	4.942
	TOTAL	28	12.351	11.473	14	2.841	10.460
	YOY	12	0.396	2.643	12	0.656	0.729
BLACKSMITH	AD	.	.	.	2	0.000	0.668
	JUV	6	0.853	0.550	3	0.145	0.000
	SAD	1	0.000	0.327	.	.	.
	TOTAL	7	0.731	0.518	4	0.109	0.334
HALFMOON	AD	36	3.843	3.729	11	7.657	5.299
	SAD	6	0.200	0.373	5	0.162	0.097
	TOTAL	37	3.771	3.689	12	7.087	4.898
KELPFISH, giant	AD	7	0.047	0.055	1	0.000	0.094
	JUV	9	0.080	0.055	11	0.090	0.080
	SAD	3	0.091	0.066	9	0.000	0.303
	TOTAL	15	0.088	0.072	11	0.090	0.336
OPALEYE	AD	16	0.259	0.132	1	0.000	0.233
	TOTAL	16	0.259	0.132	1	0.000	0.233
PERCH, black	AD	33	10.893	18.525	13	0.228	5.242
	JUV	4	0.123	1.481	3	0.000	0.988
	SAD	23	1.438	7.987	14	0.247	9.065
	TOTAL	33	11.911	24.271	16	0.401	12.376
PERCH, kelp	AD	46	11.050	7.851	8	0.016	4.124
	TOTAL	46	11.050	7.851	8	0.016	4.124
PERCH, pile	AD	27	1.664	3.109	10	0.099	1.679
	JUV	3	0.165	0.494	1	0.000	2.963
	SAD	22	2.334	2.402	12	0.082	7.942
	TOTAL	29	3.337	4.768	15	0.132	7.671

TABLE 18 (continued)

Species	Maturity	KELP BED ARITHMETIC MEAN DENSITIES					
		PREOPERATIONAL			OPERATIONAL		
		N	SOKU	SOKD	N	SOKU	SOKD
SEAPERCH, rainbow	AD	28	0.741	3.421	5	0.000	1.383
	JUV	2	0.000	0.741	.	.	.
	SAD	19	0.364	3.171	5	0.000	2.765
	TOTAL	30	0.922	5.251	9	0.000	2.304
SEAPERCH, rubberlip	AD	23	0.902	5.368	1	0.494	0.000
	SAD	6	0.494	3.868	3	0.000	19.917
	TOTAL	23	1.031	6.376	4	0.123	14.938
SEAPERCH, white	AD	22	8.409	4.850	8	0.053	0.680
	JUV	6	0.345	0.000	.	.	.
	SAD	17	9.917	5.035	10	0.180	0.490
	TOTAL	23	15.464	8.360	10	0.223	1.034
SENORITA	AD	28	11.721	10.337	14	12.046	30.979
	JUV	16	1.006	2.250	13	1.201	2.630
	SAD	20	0.496	0.217	13	0.488	2.755
	TOTAL	28	12.649	11.778	14	13.613	35.980
SHEEPHEAD, Calif.	AD	33	2.768	1.706	3	0.329	0.329
	JUV	34	6.158	5.229	16	1.451	1.852
	SAD	34	12.926	10.980	13	0.228	0.456
	TOTAL	34	21.771	17.864	16	1.697	2.284
SILVERSIDES spp.	AD	34	4.605	5.729	10	11.123	0.153
	TOTAL	34	4.605	5.729	10	11.123	0.153
WRASSE, rock	AD	32	1.049	1.960	16	4.753	11.142
	JUV	2	0.494	0.247	10	0.494	3.210
	SAD	10	0.198	1.037	16	17.098	18.240
	TOTAL	32	1.142	2.299	16	22.160	31.387

TABLE 19

KELP BED FISHES: ESTIMATED PERCENTAGE CHANGES AT SAN MATEO KELP BED (SMK), SAN ONOFRE KELP BED DOWNCOAST (SOKD), AND SAN ONOFRE KELP BED UPCOAST (SOKU) FOR COMPONENT STAGES OF 15 SELECT TAXA. Percentage change calculated as $(L_A-L_B)/L_B$, where L_A = raw mean density data for the "After" period and where L_B = analogous data for the "Before" period at a particular sampling location. During the operational period, SOKUin and SOKDout were the stations used for the SOKU-SOKD comparison. See Tables 17 and 18 for mean density data.

		PERCENT CHANGE			
		At Stations Used in SOK-SMK Comparisons		At Stations Used in SOKU-D Comparisons	
Taxon	Life Stage	SOKUout	SMK	SOKUin	SOKDout
BASS, barred sand	AD	- 67	+1400	- 63	+ 56
	JUV	- 3	+ 538	- 75	+1153
	SAD	- 6	+ 167	- 71	+ 91
	TOTAL	- 13	+ 313	- 70	+ 193
BASS, kelp	AD	0	+ 141	- 38	- 11
	JUV	- 22	+ 22	- 48	+ 88
	OJ	- 53	- 27	- 76	+ 367
	SAD	- 76	- 64	- 89	- 41
	TOTAL	- 61	- 32	- 77	- 9
	YOY	+ 43	+ 4	+ 66	- 72
BLACKSMITH	JUV	- 5	- 57	- 83	- 100
	TOTAL	- 5	- 57	- 85	- 36
HALFMOON	AD	+ 251	- 47	+ 99	+ 42
	SAD	+ 52	- 85	- 19	- 74
	TOTAL	+ 135	- 65	+ 88	+ 33
KELPFISH, giant	JUV	+ 43	+ 130	+ 12	+ 45
	SAD	+ 60	+ 84	-100	+ 360
	TOTAL	+ 70	+ 240	+ 2	+ 367
PERCH, black	AD	- 85	- 49	- 98	- 72
	SAD	- 75	+ 144	- 83	+ 13
	TOTAL	- 85	+ 58	- 97	- 49
PERCH, kelp	TOTAL	- 91	- 89	-100	- 47
PERCH, pile	AD	- 44	- 83	- 94	- 46
	SAD	- 95	- 4	- 96	+ 231
	TOTAL	- 78	- 50	- 96	+ 61

TABLE 19 (continued)

Taxon	Life Stage	PERCENT CHANGE At Stations Used in SOK-SMK Comaprisons		At Stations Used in SOKU-D Comparisons	
		SOKUout	SMK	SOKUin	SOKDout
SEAPERCH, rainbow	AD	- 82	- 29	-100	- 60
	SAD	- 40	- 4	-100	- 13
	TOTAL	- 75	- 13	-100	- 56
SEAPERCH, rubberlip	TOTAL	+ 47	+ 10	-88	+ 134
SEAPERCH, white	AD	- 85	- 97	-99	- 86
	SAD	- 92	- 80	-98	- 90
	TOTAL	- 89	- 94	-99	- 88
SENORITA	AD	+172	- 26	+ 3	+ 200
	JUV	+548	- 55	+ 19	+ 17
	SAD	+1103	+ 157	- 2	+1170
	TOTAL	+ 208	- 19	+ 8	+ 205
SHEEPHEAD, California	JUV	- 46	- 32	- 76	- 65
	SAD	- 96	- 82	- 98	- 96
	TOTAL	- 83	- 69	- 92	- 87
SILVERSIDES	TOTAL	- 73	- 60	+142	- 97
WRASSE, rock	AD	+ 920	+ 217	+353	+ 468
	SAD	+8600	+2280	+8540	+1200
	TOTAL	+2120	+ 725	+1840	+1265

TABLE 20

KELP BED FISHES: A POSTERIORI LOCATION CONTRASTS IN THE DENSITIES OF GIANT KELP AT SAN MATEO KELP BED (SMK) AND AT SAN ONOFRE KELP BED (SOK) DURING EACH OF FOUR FALL PERIODS (1980, 1981, 1985, AND 1986). Bonferroni contrasts were made following 1-way ANOVAs for location differences within each year. Densities are the number of "juvenile-or-older" plants (i.e., 1 m or taller: Dean 1980) present on random belt transects of 225 m^2, standardized to number per 100 m^2.

LOCATION CONTRASTS -- BY YEAR
(# plants per 100 m^2)

1980:	18.4	>	13.5	>	11.5		
	SMK		SOKU		SOKD		
1981:	68.2	>	41.9	>	12.2		
	SMK		SOKD		SOKU		
1985:	33.1	>	22.0 = 21.4	>	10.5 = 8.5	>	0.5
	SMK	>	SOKDout = SOKUout	>	SOKDin = SOKUin	>	CobbleU
1986:	58.1	>	13.5 = 10.5 = 10.4	>	4.0 = 2.5 = 0.4 = 0.0		
	SMK	>	SOKinbetw = SOKUout = SOKDout	>	SOKDin = SOKUin = CobbleU = CobbleD		

TABLE 21

KELP BED FISHES: SUMMARY RESULTS OF ANCOVAs TESTING FOR THE EFFECTS OF GIANT KELP, FIVE OTHER BOTTOM-ASSOCIATED BIOLOGICAL VARIABLES PLUS LOCATION (AS "OTHER" NATURAL VARIATION) ON THE DENSITY OF FISHES AT SOK ONLY[a] DURING FALL 1985 AND FALL 1986. Fish density is evaluated as log ((#s/1000 m3) + c) and giant kelp as raw #s/100 m2. Each[b] of the five seabed-associated variables is evaluated by diver index. Bottom factors are "N/A" for two strictly canopy fish species (kelp perch, silversides) and for one canopy-midwater species (halfmoon).

			SUBJECTIVE DIVER INDEX					
Species or Taxon	Life Stage	Giant Kelp[b]	Acrosorium	Pterygophora	Cystoseira	Lytechinus	Bottom Type	Location[a]
BASS, barred sand	AD	NEG	ns	NEG	POS	NEG	ns	ns
	JUV	POS	ns	NEG	POS	NEG	NEG	ns
	SAD	ns	NEG	NEG	ns	NEG	ns	ns
	TOTAL	ns	NEG	NEG	ns	NEG	ns	ns
BASS, kelp	AD	POS	ns	ns	ns	NEG	ns	YES
	JUV	POS	ns	POS	POS	ns	ns	ns
	OJ	POS	ns	POS	POS	ns	ns	ns
	SAD	POS	ns	POS	POS	NEG	ns	ns
	TOTAL	POS	ns	POS	POS	NEG	ns	ns
	YOY	POS	ns	ns	ns	POS	ns	ns
BLACKSMITH	JUV	POS	ns	ns	NEG	POS	ns	ns
	TOTAL	POS	ns	ns	ns	ns	ns	ns
HALFMOON	AD	N/A	N/A	N/A	N/A	N/A	N/A	ns
	SAD	N/A	N/A	N/A	N/A	N/A	N/A	ns
	TOTAL	N/A	N/A	N/A	N/A	N/A	N/A	ns
KELPFISH, giant	JUV	POS	ns	ns	ns	ns	POS	ns
	SAD	POS	ns	NEG	ns	NEG	POS	ns
	TOTAL	POS	POS	NEG	ns	NEG	POS	ns
PERCH, black	AD	POS	ns	ns	POS	NEG	ns	ns
	SAD	POS	ns	ns	POS	ns	NEG	YES
	TOTAL	POS	ns	ns	POS	NEG	ns	ns
PERCH, kelp	TOTAL	POS	N/A	N/A	N/A	N/A	N/A	YES

TABLE 21 (continued)

Species or Taxon	Life Stage	Giant Kelp[b]	SUBJECTIVE DIVER INDEX					
			Acrosorium	Pterygophora	Cystoseira	Lytechinus	Bottom Type	Location[a]
PERCH, pile	AD	POS	ns	ns	ns	NEG	ns	ns
	SAD	POS	POS	ns	POS	NEG	ns	ns
	TOTAL	POS	ns	ns	POS	NEG	ns	ns
SEAPERCH, rainbow	AD	POS	ns	ns	POS	NEG	ns	ns
	SAD	POS	POS	NEG	POS	ns	ns	ns
	TOTAL	POS	ns	ns	POS	NEG	NEG	ns
SEAPERCH, white	AD	POS	ns	ns	ns	ns	ns	YES
	SAD	POS	ns	ns	ns	ns	ns	ns
	TOTAL	POS	ns	ns	ns	ns	ns	ns
SENORITA	AD	POS	ns	POS	NEG	ns	NEG	YES
	JUV	POS	POS	ns	ns	ns	NEG	ns
	SAD	POS	ns	POS	ns	ns	ns	YES
	TOTAL	POS	ns	POS	NEG	ns	NEG	YES
SHEEPHEAD, Calif.	JUV	ns	ns	NEG	NEG	ns	POS	ns
	SAD	ns	ns	ns	ns	ns	ns	ns
	TOTAL	ns	ns	NEG	ns	ns	POS	YES
SILVERSIDES	TOTAL	ns	N/A	N/A	N/A	N/A	N/A	YES
WRASSE, rock	AD	POS	NEG	ns	ns	NEG	ns	ns
	JUV	POS	ns	ns	POS	ns	ns	ns
	SAD	POS	ns	ns	POS	ns	ns	ns
	TOTAL	POS	ns	POS	POS	ns	ns	ns

[a] This ANCOVA evaluation excluded SMK. Five stations were sampled at SOK in Fall 1985 and Fall 1986. In 1985, these included two stations of moderate kelp density (SOKUout, SOKDout), two of low kelp density (SOKUin, SOKDin), and one of sparse kelp (kelpless cobble). In 1986, the same five stations included two stations of low kelp density (SOKUout, SOKDout), two of very low density (SOKUin, SOKDin), and the same sparse kelp station as in 1985. See Appendix O, Table 1, for location-specific kelp densities and Appendix O, Tables 2 and 3, for analogous data on the other bottom-associated biological variables.

[b] Water-column strata utilized and form of kelp-density data used depended on species and life stage of fish. See Appendix M, Table 1, for categorization of species by stratum.

TABLE 22

KELP BED FISHES: ESTIMATED NUMERICAL ABUNDANCES OF 15 SELECT FISH SPECIES WITHIN REGIONS OF VARIOUS KELP DENSITY AT SAN ONOFRE KELP BED (SOK) DURING FALL 1985. Numerical abundances are estimated as the cross-products of numerical fish densities and the areal extent of kelp within the defined isopleth of kelp density. Fish densities in moderate-, low-, and sparse-density kelp are estimated using canopy, midwater, and bottom data at five stations[a]; fish densities in moderate- and low-density kelp based on analogous data at four stations[b]. Areas were estimated by electronic planimetry (see Methods section) of ECOsystems sonar charts for Downlooking Survey 7. Half-widths of the 95% confidence intervals of the abundance estimate are expressed as a percentage of the estimate.

	FALL 1985 ESTIMATED FISH NUMERICAL ABUNDANCES IN REGIONS OF			
	Moderate-, Low-, and Sparse-Density Kelp[a]		Moderate- and Low-Density Kelp[b]	
Species/Taxon	Numbers	CI/2 (%)	Numbers	CI/2 (%)
BASS, barred sand	6,785	112	1,403	49
BASS, kelp	10,609	70	4,668	45
BLACKSMITH	629	72	629	72
HALFMOON	646	122	646	122
KELPFISH, giant	260	92	190	103
PERCH, black	678	65	328	46
PERCH, kelp	10	83	10	83
PERCH, pile	739	87	390	85
SEAPERCH, rainbow	177	162	37	166
SEAPERCH, rubberlip	94	167	94	167
SEAPERCH, white	7,523	116	884	49
SENORITA	141,873	42	132,577	45
SHEEPHEAD, Calif.	3,167	44	442	43
SILVERSIDES spp.	3,934	113	3,934	113
WRASSE, rock	21,020	34	9,908	30
Total Fishes[c]	225,126	33%	183,122	39%

[a]Five SOK stations used to estimate fish abundances within regions of moderate- (SOKUout, SOKDout), low- (SOKUin, SOKDin), and sparse- (CobbleU) kelp densities.

[b]Four SOK stations used to estimate fish abundances within regions of moderate- (SOKUout, SOKDout) and low- (SOKUin, SOKDin) kelp densities.

[c]All species, including the 15 select listed above.

TABLE 23

KELP BED FISHES: ESTIMATED NUMERICAL ABUNDANCES OF 15 SELECT FISH SPECIES WITHIN REGIONS OF VARIOUS KELP DENSITY AT SAN ONOFRE KELP BED (SOK) DURING FALL 1986. Numerical abundances are estimated as the cross-products of numerical fish densities and the areal extent of kelp within the defined isopleth of kelp density. Fish densities in low-, very low-, and sparse-density kelp are estimated using canopy, midwater, and bottom data at seven stations[a]; fish densities in low- and very low-density kelp are estimated using analogous data at five stations[b]. Areas were estimated by electronic planimetry (see Methods section) of ECOsystems sonar charts for Downlooking Survey 9. Half-widths of the 95% confidence intervals of the abundance estimate are expressed as a percentage of the estimate.

	FALL 1986 ESTIMATED FISH NUMERICAL ABUNDANCES IN REGIONS OF			
	Low-, Very Low-, and Sparse-Density Kelp[a]		Low- and Very Low-Density Kelp[b]	
Species/Taxon	Numbers	CI/2 (%)	Numbers	CI/2 (%)
BASS, barred sand	4,582	35	2,401	39
BASS, kelp	26,814	34	26,121	35
BLACKSMITH	50	93	50	93
HALFMOON	18,225	48	18,093	49
KELPFISH, giant	216	42	216	42
PERCH, black	2,278	34	1,915	25
PERCH, kelp	1,587	41	1,587	41
PERCH, pile	881	119	881	119
SEAPERCH, rainbow	244	113	244	113
SEAPERCH, rubberlip	72	119	72	119
SEAPERCH, white	2,968	61	2,968	61
SENORITA	216,685	56	211,366	57
SHEEPHEAD, Calif.	2,556	25	1,433	30
SILVERSIDES spp.	13,811	85	13,811	85
WRASSE, rock	26,306	42	16,923	34
Total Fishes[c]	396,609	39%	377,347	40%

[a]Seven SOK stations used to estimate fish abundances within regions of low- (SOKUout, SOKDout, SOKinbetween), very low- (SOKUin, SOKDin), and sparse- (CobbleU, CobbleD) kelp densities.

[b]Five SOK stations used to estimate fish abundances within regions of low- (SOKUout, SOKDout, SOKinbetween) and very low- (SOKUin, SOKDin) kelp densities.

[c]All species, including the 15 select listed above.

TABLE 24

KELP BED FISHES: ESTIMATED BIOMASS ABUNDANCES OF 15 SELECT FISH SPECIES WITHIN REGIONS OF VARIOUS KELP DENSITY AT SAN ONOFRE KELP BED (SOK) DURING FALL 1985. Biomass abundances are estimated from numerical abundances (Table 22) and the observed average length (and estimated weight) of component life stages of the respective fish species (see Appendix T,Tables 1 and 3).

	FALL 1985 ESTIMATED FISH BIOMASS ABUNDANCES IN REGIONS OF			
	Moderate-, Low-, and Sparse-Density Kelp[a]		Moderate- and Low-Density Kelp[b]	
Species/Taxon	Biomass (kg)	CI/2 (%)	Biomass (kg)	CI/2 (%)
BASS, barred sand	1,556	96	405	61
BASS, kelp	1,667	79	598	53
BLACKSMITH	3	119	3	119
HALFMOON	118	143	118	143
KELPFISH, giant	6	125	2	98
PERCH, black	77	80	29	43
PERCH, kelp	<1	83	<1	83
PERCH, pile	62	86	40	78
SEAPERCH, rainbow	28	179	3	157
SEAPERCH, rubberlip	11	155	11	155
SEAPERCH, white	620	135	59	43
SENORITA	8,529	48	8,176	50
SHEEPHEAD, Calif.	1,117	119	86	52
SILVERSIDES spp.	104	113	104	113
WRASSE, rock	2,083	39	790	30
Total Fishes[c]	18,157	32%	12,600	39%

[a]Five SOK stations used to estimate fish abundances within regions of moderate- (SOKUout, SOKDout), low- (SOKUin, SOKDin), and sparse- (CobbleU) kelp densities.

[b]Four SOK stations used to estimate fish abundances within regions of moderate- (SOKUout, SOKDout) and low- (SOKUin, SOKDin) kelp densities.

[c]All species, including the 15 select listed above.

TABLE 25

KELP BED FISHES: ESTIMATED BIOMASS ABUNDANCES OF 15 SELECT FISH SPECIES WITHIN REGIONS OF VARIOUS KELP DENSITY AT SAN ONOFRE KELP BED (SOK) DURING FALL 1986. Biomass abundances are estimated from numerical abundances (Table 23) and the observed average length (and estimated weight) of component life stages of the respective fish species (see Appendix T, Tables 1 and 3).

	FALL 1986 ESTIMATED FISH BIOMASS ABUNDANCES IN REGIONS OF			
	Low-, Very low-, and Sparse-Density Kelp[a]		Low- and Very Low-Density Kelp[b]	
Species/Taxon	Biomass (kg)	CI/2 (%)	Biomass (kg)	CI/2 (%)
BASS, barred sand	1,394	36	634	40
BASS, kelp	4,211	41	4,059	43
BLACKSMITH	<1	93	<1	93
HALFMOON	4,178	49	4,154	49
KELPFISH, giant	9	69	9	69
PERCH, black	324	42	252	25
PERCH, kelp	49	41	49	41
PERCH, pile	150	104	150	104
SEAPERCH, rainbow	29	110	29	110
SEAPERCH, rubberlip	22	113	22	113
SEAPERCH, white	225	78	225	78
SENORITA	14,007	56	13,666	58
SHEEPHEAD, Calif.	568	23	257	34
SILVERSIDES spp.	664	85	664	85
WRASSE, rock	2,711	43	1,737	25
Total Fishes[c]	38,899	38%	36,265	40%

[a]Seven SOK stations used to estimate fish abundances within regions of low- (SOKUout, SOKDout, SOKinbetween), very low- (SOKUin, SOKDin), and sparse- (CobbleU, CobbleD) kelp densities.

[b]Five SOK stations used to estimate fish abundances within regions of low- (SOKUout, SOKDout, SOKinbetween) and very low- (SOKUin, SOKDin) kelp densities.

[c]All species, including the 15 select listed above.

TABLE 26

KELP BED FISHES: SUMMARY OF QUALITATIVE CONCLUSIONS REGARDING PRESENCE/ABSENCE AND NATURE OF SONGS IMPACT. Conclusions are based on two factors: (1) Significance of BACI impact tests (Tables 15, 16; Appendix N, Tables 1, 3) and (2) plausible link between giant-kelp density and the density of that species and life stage of fish (Table 21; Appendix O, Tables 6-9). A 2 indicates significant BACI test results for both SOKU-SMK and SOKU-SOKD comparisons.

		SIGNIFICANT BACI TEST RESULT		
Taxon	Life Stage(s)	Strongly Explicable	Weakly Explicable	Inexplicable
BASS, barred sand	AD		2x[a]	
	JUV		2x	
	SAD		2x	
BASS, kelp	JUV		x	
HALFMOON	SAD	x[b]		
PERCH, black	SAD		2x	
PERCH, kelp	TOTAL	x		
SEAPERCH, rainbow	SAD		x	
SEAPERCH, white	SAD	x		
SENORITA	AD	2x[c]		
	JUV	x[c]		
	SAD	x[c]		
SHEEPHEAD, Calif.	SAD			x
SILVERSIDES	TOTAL	x[c]		
WRASSE, rock	AD			x
TOTALS		8	10	2

[a]Attraction to the SONGS diffuser riprap may have diluted densities at SOKU during the operational period.

[b]Operational period change in relative densities at SOK and SMK is likely to be mostly a SONGS plume effect on fish distribution.

[c]SONGS plume effect is a likely contributor to the operational period change in relative densities at SOK and SMK.

TABLE 27

JUVENILE-ADULT FISHES AT PAR: Summary results of 2-way ANOVAs for the effects of reef stratum (C = crest, S = slope) and maturity stage (JUV = juvenile, SAD = subadult, AD = adult) on fish densities during the three surveys (replicates) of October, November, and December 1985. (Data for the ecotone stratum were not included; the ecotone region was sampled as a pilot study for 1986 on the December 1985 survey only.) Module was used as a blocking variable in the ANOVA. Data form: Log-10 {#/1000 m**3) + 1}; NS = P > 0.05. Dashes indicate that evaluation of the effect is precluded by a significant higher order interaction. Bullets distinguish complementary interpretations of multiple comparison tests for a particular species.

Species	SIGNIFICANT EFFECT ?			
	Stratum	Maturity	Module	Stratum*Maturity
BASS, barred sand	No	• JUV≥(SAD=AD) • JUV>AD	• 5≥(1=4=8=6=2=7=3) • 5>(2=7=3)	No
BASS, kelp	C>S	(JUV=SAD)>AD	No	No
BLACKSMITH	--	--	No	• C,JUV>S,JUV>(S,SAD=C,SAD=S,AD=C,AD) • C,JUV>S,JUV>OTHERS
GARIBALDI	--	--	No	• C,AD/SAD>(S,AD/SAD=C,JUV)≥S,JUV • C,AD/SAD>S,AD/SAD>S,JUV
HALFMOON	C>S	(AD=SAD)>JUV	No	No
OPALEYE	No	AD>(SAD=JUV)	• 3≥(6=8=7=4=5=2=1) • 3>1	No

TABLE 27 (continued)

Species	SIGNIFICANT EFFECT ?			
	Stratum	Maturity	Module	Stratum*Maturity
PERCH, black	No	AD>SAD>JUV	No	No
PERCH, pile	No	• AD≥(SAD=JUV) • AD>JUV	No	No
SENORITA	No	No	No	No
SHEEPHEAD, Calif.	--	--	(7=1=6=2=8)≥(4=5=3)	• C,SAD>(S,JUV=C,JUV=S,SAD)≥(C,AD=S,AD) • C,SAD>S,JUV>(C/S,AD)
WRASSE, rock	C>S	SAD>AD>JUV	(2=1=5=8=4)≥(3=6=7)	No
TOTAL FISHES (minus Blacksmith)	--	--	No	• C,SAD/AD>(S,JUV/SAD=C,JUV=S,AD) • C,SAD/AD>OTHERS
TOTAL FISHES	C>S	JUV>SAD>AD	No	No

TABLE 28

JUVENILE-ADULT FISHES AT PAR: Summary results of 2-way ANOVAs for the effects of reef stratum (C = crest, S = slope, ECO = ecotone, R1 = first 5-m radial to ecotone, R2 = second 5-m, R3 = second 10-m, R4 = third 10-m radial to ecotone) and maturity stage (JUV = juvenile, SAD = subadult, AD = adult) on fish densities during the three surveys (replicates) of November 1986 and January 1987. Module (#s 1-8) was used as a blocking variable in the ANOVA. Data form: Log-10 {#/1000 m**3) + 1}; NS = P > 0.05. Dashes indicate that evaluation of the effect is precluded by a significant higher order interaction. Bullets distinguish complementary interpretations of multiple comparison tests for a particular species.

Species	SIGNIFICANT EFFECT ?			
	Stratum	Maturity	Module	Stratum*Maturity
BASS, barred sand	• (RAD2=RAD4)	• SAD≥(JUV=AD)	ns	ns
	≥(RAD1=ECO=	• SAD>AD		
	RAD3=S)≥C			
	• (RAD2=RAD4)>(S=C)			
BASS, kelp	--	--	• 6≥(1=5=4=2=8=3=7)	(JUV,C)>Others
			• 6>(3=7)	
BLACKSMITH	--	--	• 1≥(2=3=4=6=7=8=5)	(JUV,C)>(JUV,S=SAD,C/S)>Others
			• 1>(6=7=8=5)	
GARIBALDI	--	--	ns	• SAD,C)>(SAD,S=AD,C)≥(AD,S=SAD,ECO)≥Others
				• SAD,C)>(SAD,S)>Others except for AD,C; AD,S; SAD,ECO
				• SAD,C)>(SAD,S=AD,C)>SAD,ECO

TABLE 28 (continued)

Species	SIGNIFICANT EFFECT ?			
	Stratum	Maturity	Module	Stratum*Maturity
HALFMOON	--	--	ns	SAD,C=AD,C)>(AD,S=SAD,S)>Others
OPALEYE	ns	AD>(SAD=JUV)	• 3≥(2=5=6=1=4=8=7) • 3>(6=1=4=8=7)	ns
PERCH, black	--	--	ns	• SAD,C)>(SAD,S=AD,C=JUV,C)≥(AD,S=SAD,RAD1=SAD,ECO)≥(JUV,S)≥(AD,ECO=SAD,RAD2=AD,RAD1)≥(JUV,ECO=AD,RAD2=AD,RAD4=SAD,RAD3=SAD,RAD4=JUV,RAD1=JUV,RAD4=JUV,RAD2=AD,RAD3=JUV,RAD3 • SAD,C)>Others • SAD,C)>(SAD,S=AD,C=JUV,C)>(AD,ECO=SAD,RAD2=AD,RAD1=JUV,ECO=AD,RAD2=AD,RAD4=SAD,RAD3=SAD,RAD4=JUV,RAD1=JUV,RAD4=JUV,RAD2=AD,RAD3=JUV,RAD3)
PERCH, pile	--	--	ns	• SAD,C=AD,ECO=AD,RAD1=AD,S=SAD,ECO)≥Others • SAD,C=AD,ECO)>Others except (AD,RAD1=AD,S=SAD,ECO)

TABLE 28 (continued)

Species	SIGNIFICANT EFFECT ?			
	Stratum	Maturity	Module	Stratum*Maturity
SENORITA	--	--	• 2≥(6=4=1=5=7=3=8)	• JUV,ECO)≥(JUV,S=SAD,S=JUV,C=SAD,C)≥Others
			• 2>8	• JUV,ECO)>Others except for JUV,S; SAD,S; JUV,C;SAD,C
SHEEPHEAD, Calif.	--	--	ns	JUV,C)>(JUV,S=SAD,C)>(JUV,ECO=SAD,S)>Others
WRASSE, rock	--	--	ns	• SAD,C)>(AD,C=SAD,S=SAD,ECO)>(AD,S=AD,ECO=SAD,RAD1) ≥(SAD,RAD2=AD,RAD1)>Others
				• (SAD,C)>(AD,C=SAD,S=SAD,ECO)>(AD,S=AD,ECO)>(AD,RAD3 =JUV,S=JUV,ECO=AD,RAD4=SAD,RAD3=JUV,RAD1=AD,RAD2 =JUV,RAD2=SAD,RAD4=JUV,C=JUV,RAD4=JUV,RAD3)[a]
TOTAL FISHES (minus Blacksmith)	C>S>E	SAD>JUV>AD	ns	ns
TOTAL FISHES	--	--	• 1≥(2=3=6=4=5=8=7)	• JUV,C>SAD,C>Others
			• 1>(4=5=6=7)	• JUV,C>SAD,C>(JUV,S=SAD,S)>(SAD,RAD4=JUV,RAD1=SAD, RAD3=AD,RAD2=AD,RAD4=JUV,RAD2=JUV,RAD3=AD,RAD3=JUV, RAD4)[b]

[a] Does not include SAD,RAD1;SAD,RAD2; and AD,RAD1, for which Student-Newman-Keuls (SNK) test results are unclear.

[b] Does not include all combinations.

TABLE 29

JUVENILE-ADULT FISHES AT PAR: Summary results of 3-way ANOVAs for the effects of reef stratum (Str: C = crest, S = slope), maturity stage (Mat: JUV = juvenile, SAD = subadult, AD = adult), and year (Yr: Fall 1985, Fall 1986) on fish densities at PAR. The analysis treats module (MOD) as a blocking variable and surveys as replicates (n = 3 in each year). Data form: Log-10 {(#/1000 m**3) + 1}; SIG = significant (P < 0.05); NS = not significant (P > 0.05). Dashes indicate that evaluation of the effect is precluded by a higher order interaction. Bullets distinguish complementary interpretations of multiple comparisons for a particular species.

Species	SIGNIFICANT EFFECT ?							
	STR	MAT	YR	MOD	YR*STR	YR*MAT	STR*MAT	3-Way
BASS, barred sand	NS	(SAD=JUV)>AD	NS	NS	NS	NS	NS	NS
BASS, kelp	C>S	JUV>SAD>AD	85>86	• 1≥(6=2=4=8=7=3=5) • 1>5	NS	NS	NS	NS
BLACKSMITH	--	--	--	NS	NS	(YR85,J=YR86,J) >(YR86,SAD) >(YR85,SAD) >(YR85,AD=YR86,AD)	(JUV,C)>(JUV,S) >(SAD,C/S)>(AD,C/S)	NS
GARIBALDI	--	--	--	• 4≥(2=8=6=7=1=5=3) • 4>(1=5=3)	NS	--	--	SIG
HALFMOON	--	--	86>35	NS	NS	NS	(AD/SAD,C)>(AD/SAD,S) >(JUV,C/S)	NS

TABLE 29 (continued)

Species	SIGNIFICANT EFFECT ?							
	STR	MAT	YR	MOD	YR*STR	YR*MAT	STR*MAT	3-Way
OPALEYE	--	--	NS	3>(6=2=8=7=5=4=1)	NS	NS	• (AD,C) >(AD,S=SAD,C=SAD,S) ≥(JUV,C=JUV,S) • (AD,C)>(AD,S) >(JUV,C=JUV,S)	NS
PERCH, black	--	--	--	NS	• (YR86,C)≥(YR85,C) =YR85,S)≥(YR86,S) • YR86,C>YR86,S	NS	NS	NS
PERCH, pile	NS	(AD=SAD)>JUV	NS	NS	NS	NS	NS	NS
SENORITA	--	--	NS	• 6≥(2=5=4=1=3=7=8) • 6>(1=3=7=8)	NS	NS	JUV,S >(JUV,S/C=AD,C =SAD,C/S=AD,S)	NS
SHEEPHEAD, Calif.	--	--	--	NS	--	--	--	SIG

TABLE 29 (continued)

Species	SIGNIFICANT EFFECT ?							
	STR	MAT	YR	MOD	YR*STR	YR*MAT	STR*MAT	3-Way
WRASSE, rock	--	--	--	NS	NS	(SAD,86)>(SAD,85) >(AD,86)>(AD,85) >(JUV,85=JUV,86)	(SAD,C)>(SAD,S=AD,C) >(AD,S)>(JUV,S=JUV,C)	NS
TOTAL FISHES (minus Blacksmith)	--	--	--	NS	--	--	--	SIG
TOTAL FISHES	--	--	--	NS	NS	(JUV,85/86) >(SAD,86) >(SAD,85) >(AD,85) >(AD,86)	• (JUV,C)>(SAD,C) >(JUV,S=AD,C)≥(SAD,S) >(AD,S) • (JUV,C)>(SAD,C)>(JUV,S) >(AD,S)	NS

TABLE 30

YOUNG-OF-THE-YEAR AND OLDER JUVENILE FISHES AT PAR: Summary results of 3-way ANOVAs for the effects of reef stratum (Str: C = crest, P = perimeter), maturity stage (Mat: YOY = young-of-the-year, OJ = older juvenile), and year (Yr: Fall 1985, Fall 1986) on juvenile fish densities at PAR. The analysis treats module (MOD) as a blocking variable and surveys as replicates (n = 3 in each year). Data form: Log-10 {(#/1000 m**3) + 1}; SIG = significant (P < 0.05); NS = not significant (P > 0.05). Dashes indicate that evaluation of the effect is precluded by a higher order interaction. N/A signifies that effect was not relevant--specifically, maturity stage was dropped from the model for barred sand bass and rock wrasse (no YOY in either year) and for black perch and bluebanded goby (all juveniles are YOY); stratum was dropped from the model for blackeye goby (no individuals seen on Crest transects).

Species	SIGNIFICANT EFFECT ?							
	STR	MAT	YR	MOD	YR*STR	YR*MAT	STR*MAT	3-Way
BASS, barred sand	P>C	N/A	YR85>YR86	No	No	N/A	N/A	N/A
BASS, kelp	--	--	--	No	--	--	--	C,OJ,YR85>C,OJ,YR86 >Others
BLACKSMITH	--	--	No	No	No	No	C,YOY>C,OJ>(P,YOY=P,OJ)	No
GARIBALDI	--	--	YR85>YR86	No	No	No	C,OJ>(C,YOY=P,YOY/OJ)	No
GOBY, blackeye	N/A	OJ>YOY	YR86>YR85	No	N/A	No	N/A	N/A
GOBY, bluebanded	P>C	N/A	No	No	No	N/A	N/A	N/A
PERCH, black	--	N/A	--	No	C,YR85/86 >P,YR85/86	N/A	N/A	N/A
SENORITA	--	--	--	No	--	--	--	P,YOY,YR86>P,YOY,YR85 >Others

TABLE 30 (continued)

Species	SIGNIFICANT EFFECT ?							
	STR	MAT	YR	MOD	YR*STR	YR*MAT	STR*MAT	3-Way
SHEEPHEAD, Calif.	--	--	--	No	--	--	--	C/P,OJ,YR86 >C/P,OJ,YR85 >C/P,YOY,YR85 ≥C/P,YOY,YR86
WRASSE, rock	No	N/A	YR85>YR86	No	No	N/A	N/A	N/A
TOTAL FISHES (minus Blacksmith)	--	--	YR86>YR85	o = 4≥(2=6=7=8=3=1=5) ● = 4>(3=1=5)	No	No	● C,OJ≥(P,OJ=P,YOY)>C,YOY ● C,OJ>P,YOY>C,YOY	No
TOTAL FISHES	--	--	--	o = 4≥(2=6=8=1=7=3=5) o = 4>(3=5)	--	--	--	C,YOY,YR85>C,YOY,YR86 >Others

TABLES 31-32

JUVENILE-ADULT FISHES AT PAR: ESTIMATED (RANK) **NUMERICAL DENSITY**, FOR EACH LIFE STAGE (AND POOLED LIFE STAGES) WITHIN A TAXON, ENCOUNTERED ON SURVEYS DURING **FALL 1985-86**. Taxa include each species encountered, plus total fishes (all species). Density estimates are weighted by the areal contribution of component strata that were relevant to the estimate in the particular fall season (1985: Crest, Slope, Ecotone (Dec only); 1986 -- all surveys: Crest, Slope, Ecotone.

TABLE 31

PENDLETON ARTIFICIAL REEF
JUVENILE -- ADULT FISH SURVEY
NUMERICAL DENSITY ESTIMATE (#s/1000 m**2) FOR ROCK & ECOTONE HABITATS

FALL 1985 SURVEYS

	JUVENILE		SUB-ADULT		ADULT		TOTAL	
SPECIES	DENS.	RANK	DENS.	RANK	DENS.	RANK	DENS.	RANK
BLACKSMITH	652.4	1	22.4	2	22.8	1	697.6	1
WRASSE, rock	2.3	7	23.1	1	8.0	5	33.4	2
PERCH, black	5.2	4	10.4	5	16.9	2	32.4	3
SHEEPHEAD, Ca	12.2	2	13.0	4	5.8	7	31.1	4
GARIBALDI	0.6	8	8.0	6	8.5	3	17.1	5
CROAKER, black	0.3	10	13.3	3	0.6	15	14.2	6
SENORITA	10.1	3	1.1	12	2.6	9	13.8	7
HALFMOON			3.6	10	6.5	6	10.1	8
BASS, barred sand	3.3	6	4.7	7	1.8	10	9.9	9
BASS, kelp	4.5	5	4.3	8	0.8	14	9.6	10
OPALEYE			1.4	11	8.1	4	9.5	11
SARGO	0.4	9	3.6	9	4.0	8	8.0	12
PERCH, pile	0.1	12	0.6	14	1.4	12	2.1	13
SCORPIONFISH, Ca			0.8	13	1.2	13	1.9	14
SEAPERCH, rubberlip			0.1	16	1.5	11	1.6	15
SEAPERCH, rainbow					0.5	16	0.5	16
GOBY, bluebanded	0.2	11					0.2	17
GREENLING, painted			0.1	15			0.1	18
ROCKFISH, brown					0.1	17	0.1	19
SEAPERCH, white					0.1	18	0.1	20
TRIGGERFISH, finescale					0.0	19	0.0	21
Total Individuals	691.5		110.5		91.4		893.4	

TABLE 32

PENDLETON ARTIFICIAL REEF
JUVENILE -- ADULT FISH SURVEY
NUMERICAL DENSITY ESTIMATE (#s/1000 m**2) FOR ROCK & ECOTONE HABITATS

FALL 1986 SURVEYS

	JUVENILE		SUB-ADULT		ADULT		TOTAL		
SPECIES	DENS.	RANK	DENS.	RANK	DENS.	RANK	DENS.	2*SE	RANK
BLACKSMITH	775.5	1	164.1	1	24.4	1	963.9	560.1	1
WRASSE, rock	0.4	8	37.2	2	13.4	2	50.9	16.9	2
SHEEPHEAD, Ca	25.4	3	10.5	6	2.4	7	38.3	3.5	3
PERCH, black	7.0	4	16.2	3	7.0	4	30.2	10.4	4
SENORITA	25.8	2	3.1	10	1.1	9	30.0	5.9	5
CROAKER, black			15.0	4			15.0	14.8	6
SARGO			3.8	9	10.2	3	14.0	14.6	7
MACKEREL, jack			13.0	5			13.0	26.1	8
HALFMOON			6.1	8	5.9	5	11.9	9.9	9
GARIBALDI	0.4	7	8.4	7	2.6	6	11.3	2.8	10
BASS, kelp	2.6	5	1.2	13	0.7	11	4.6	1.5	11
BASS, barred sand	1.0	6	1.9	11	0.5	12	3.4	4.8	12
PERCH, pile			1.3	12	1.0	10	2.4	1.9	13
OPALEYE			0.7	14	1.5	8	2.2	0.7	14
SCORPIONFISH, Ca	0.1	10	0.2	17	0.2	13	0.5	0.3	15
SEAPERCH, rubberlip			0.3	16	0.2	14	0.5	0.3	16
GREENLING, painted			0.3	15			0.3	0.7	17
BONITO, Pacific	0.2	9					0.2	0.4	18
TRIGGERFISH, finescale					0.1	15	0.1	0.2	19
ROCKFISH, olive			0.0	18			0.0	0.1	20
Total Individuals	838.6		283.3		71.0		1192.9	531.4	

TABLES 33-36

JUVENILE-ADULT FISHES AT PAR: ESTIMATED ABUNDANCE (NUMBERS AND BIOMASS), FOR EACH LIFE STAGE (AND POOLED LIFE STAGES) WITHIN A TAXON, ENCOUNTERED ON SURVEYS DURING FALL 1985-86. Taxa include each species encountered, plus total fishes (all species). Abundance estimates are the sum of stratum subtotals weighted by the areal contribution of the respective stratum. In 1985, the estimate is based on Rock (Crest, Slope) plus Ecotone strata. In 1986, the estimate is based on Rock, Ecotone, and Adjacent Sand strata.

TABLE 33

PENDLETON ARTIFICIAL REEF
JUVENILE -- ADULT FISH SURVEY
NUMERICAL ABUNDANCE ESTIMATE FOR THE ROCK & ECOTONE HABITATS
FALL 1985 SURVEYS

	JUVENILE		SUB-ADULT		ADULT		TOTAL	
SPECIES	ABUN.	RANK	ABUN.	RANK	ABUN.	RANK	ABUN.	RANK
BLACKSMITH	8,261	1	283	2	289	1	8,833	1
WRASSE, rock	29	7	292	1	102	5	424	2
PERCH, black	65	4	132	5	214	2	411	3
SHEEPHEAD, Ca	155	2	165	4	74	7	394	4
GARIBALDI	7	8	102	6	108	3	217	5
CROAKER, black	3	10	169	3	8	15	180	6
SENORITA	128	3	14	12	32	9	175	7
HALFMOON			45	10	83	6	128	8
BASS, barred sand	42	6	59	7	23	10	125	9
BASS, kelp	57	5	54	8	10	14	121	10
OPALEYE			17	11	103	4	120	11
SARGO	5	9	46	9	51	8	101	12
PERCH, pile	1	12	8	14	18	12	27	13
SCORPIONFISH, Ca			10	13	15	13	24	14
SEAPERCH, rubberlip			1	16	19	11	21	15
SEAPERCH, rainbow					6	16	6	16
GOBY, bluebanded	2	11					2	17
GREENLING, painted			2	15			2	18
ROCKFISH, brown					2	17	2	19
SEAPERCH, white					1	18	1	20
TRIGGERFISH, finescale					1	19	1	21
Total Individuals	8,756		1,400		1,157		11,313	

TABLE 34

PENDLETON ARTIFICIAL REEF
JUVENILE -- ADULT FISH SURVEY
BIOMASS ABUNDANCE ESTIMATE FOR THE ROCK & ECOTONE HABITATS
FALL 1985 SURVEYS

	JUVENILE		SUB-ADULT		ADULT		TOTAL	
SPECIES	BIOM.	RANK	BIOM.	RANK	BIOM.	RANK	BIOM.	RANK
SHEEPHEAD, Ca	12.64	1	85.17	1	104.12	1	201.94	1
GARIBALDI	0.13	7	27.80	2	68.89	2	96.82	2
OPALEYE			4.65	11	52.01	3	56.66	3
PERCH, black	0.44	5	9.28	7	45.78	4	55.50	4
BLACKSMITH	10.27	2	8.88	8	26.02	5	45.16	5
BASS, barred sand	2.93	3	14.35	5	19.21	7	36.48	6
WRASSE, rock	0.31	6	15.07	4	18.16	8	33.54	7
HALFMOON			5.68	9	22.57	6	28.25	8
CROAKER, black	0.12	8	20.09	3	2.25	14	22.46	9
SARGO	0.06	10	5.45	10	15.97	9	21.48	10
BASS, kelp	2.54	4	10.73	6	6.88	12	20.15	11
SCORPIONFISH, Ca			3.72	12	12.81	11	16.53	12
SEAPERCH, rubberlip			0.43	14	13.86	10	14.28	13
PERCH, pile			1.19	13	6.50	13	7.69	14
SENORITA	0.09	9	0.37	15	2.15	15	2.61	15
SEAPERCH, rainbow					0.99	16	0.99	16
TRIGGERFISH, finescale					0.12	17	0.12	17
GREENLING, painted			0.11	16			0.11	18
Total Individuals	29.52		212.98		418.28		660.78	

TABLE 35

PENDLETON ARTIFICIAL REEF
JUVENILE -- ADULT FISH SURVEY
NUMERICAL ABUNDANCE ESTIMATE FOR CREST, SLOPE, ECOTONE AND ADJACENT SAND

FALL 1986 SURVEYS

	JUVENILE		SUB-ADULT		ADULT		TOTAL		
SPECIES	ABUN.	RANK	ABUN.	RANK	ABUN.	RANK	ABUN.	2*SE	RANK
BLACKSMITH	9832	1	2446	1	450	1	12727	6675	1
WRASSE, rock	5	8	519	3	206	3	730	189	2
SHEEPHEAD, Ca	344	2	165	6	39	6	548	30	3
MACKEREL, jack			523	2			523	1046	4
PERCH, black	89	4	244	4	128	4	461	183	5
SENORITA	328	3	45	11	16	11	389	70	6
SARGO			65	9	211	2	276	282	7
CROAKER, black			216	5			216	147	8
HALFMOON			77	8	77	5	154	131	9
GARIBALDI	5	7	106	7	36	7	147	37	10
BASS, barred sand	44	5	50	10	17	10	111	129	11
BASS, kelp	39	6	24	12	9	12	72	37	12
PERCH, pile			17	13	24	8	41	38	13
OPALEYE			8	14	19	9	27	8	14
SEAPERCH, rubberlip			4	16	5	13	9	9	15
SCORPIONFISH, Ca	1	10	3	17	2	14	6	4	16
GREENLING, painted			4	15			4	9	17
BONITO, Pacific	3	9					3	5	18
TRIGGERFISH, finescale					1	15	1	3	19
ROCKFISH, olive			1	18			1	1	20
Total individuals	10690		4516		1241		16447	6046	

TABLE 36

PENDLETON ARTIFICIAL REEF
JUVENILE -- ADULT FISH SURVEY
BIOMASS ABUNDANCE ESTIMATE FOR CREST, SLOPE, ECOTONE AND ADJACENT SAND

FALL 1986 SURVEYS

	JUVENILE		SUB-ADULT		ADULT		TOTAL		
SPECIES	BIOM.	RANK	BIOM.	RANK	BIOM.	RANK	BIOM.	2*SE	RANK
SHEEPHEAD, Ca	31.22	1	81.26	1	50.03	1	162.51	26.91	1
BLACKSMITH	9.87	2	50.60	2	37.28	3	97.76	47.31	2
WRASSE, rock	0.05	9	33.98	4	35.85	4	69.88	15.95	3
SARGO			7.12	10	49.59	2	56.72	56.68	4
GARIBALDI	0.12	8	29.58	5	22.71	6	52.41	18.09	5
PERCH, black	0.60	6	18.80	7	25.05	5	44.45	15.60	6
MACKEREL, jack			34.59	3			34.59	69.17	7
BASS, barred sand	2.82	3	10.51	8	17.22	8	30.55	52.30	8
HALFMOON			9.97	9	19.07	7	29.05	26.33	9
CROAKER, black			21.91	6			21.91	14.97	10
BASS, kelp	1.90	4	4.82	11	7.44	11	14.16	14.93	11
OPALEYE			2.14	12	10.72	9	12.86	5.36	12
PERCH, pile			1.89	13	8.68	10	10.57	10.19	13
SEAPERCH, rubberlip			0.85	16	2.84	12	3.68	3.96	14
SCORPIONFISH, Ca			1.18	14	2.21	13	3.39	1.30	15
SENORITA	0.16	7	1.01	15	0.95	14	2.12	1.23	16
BONITO, Pacific	0.68	5					0.68	1.37	17
TRIGGERFISH, finescale					0.65	15	0.65	1.29	18
GREENLING, painted			0.21	17			0.21	0.43	19
ROCKFISH, olive			0.04	18			0.04	0.09	20
Total Individuals	47.43		310.46		290.30		648.19	266.59	

YOY-OJ FISHES AT PAR: ESTIMATED (RANK) NUMERICAL DENSITY, FOR EACH LIFE STAGE (AND POOLED LIFE STAGES) WITHIN A TAXON, ENCOUNTERED ON SURVEYS DURING FALL 1985-86. Taxa include each species encountered, plus total fishes (all species) and total fishes (minus blacksmith). Density estimates are weighted by the areal contribution of component strata (both years: Crest, Perimeter).

TABLE 37

PENDLETON ARTIFICIAL REEF
YOUNG OF YEAR -- OLDER JUVENILE FISH SURVEY
NUMERICAL DENSITY ESTIMATE (#s/1000 m**2) FOR ENTIRE REEF

FALL 1985 SURVEYS

	YOUNG OF YEAR			OLDER JUVENILE			TOTAL JUVENILE		
SPECIES	DENS.	2*SE	RANK	DENS.	2*SE	RANK	DENS.	2*SE	RANK
BLACKSMITH	8,082	4,324	1	172	196	1	8,253	4,347	1
SHEEPHEAD, Ca	32	5	4	125	14	2	156	17	2
WRASSE, rock	0	0	11	122	51	3	122	51	3
SENORITA	82	89	2	4	4	13	86	90	4
BASS, kelp				72	32	4	72	32	5
PERCH, black	63	13	3				63	13	6
GARIBALDI	16	9	5	43	25	5	59	19	7
HALFMOON				24	22	6	24	22	8
SCORPIONFISH, Ca	0	0	12	12	11	7	12	11	9
BASS, barred sand				11	3	8	11	3	10
GOBY, blackeye	2	1	7	9	3	9	11	4	11
SARGO	2	4	8	8	1	10	10	4	12
GOBY, bluebanded	10	16	6				10	16	13
PERCH, pile	0	1	9	8	15	11	8	15	14
GREENLING, painted				5	6	12	5	6	15
CROAKER, black				3	7	14	3	7	16
GOBY, zebra	0	0	10				0	0	17
HALIBUT, Ca				0	0	15	0	0	18
Total Individuals	8,289	4,426		618	158		8,907	4,402	
Tot. Ind. Minus Blacksmith	207	112		447	59		654	104	

TABLE 38

PENDLETON ARTIFICIAL REEF
YOUNG OF YEAR -- OLDER JUVENILE FISH SURVEY
NUMERICAL DENSITY ESTIMATE (#s/1000 m**2) FOR ENTIRE REEF

FALL 1986 SURVEYS

	YOUNG OF YEAR			OLDER JUVENILE			TOTAL JUVENILE		
SPECIES	DENS.	2*SE	RANK	DENS.	2*SE	RANK	DENS.	2*SE	RANK
BLACKSMITH	3,361	1,085	1	222	182	2	3,583	1,258	1
SHEEPHEAD, Ca	4	4	5	285	86	1	289	84	2
PERCH, black	102	53	2				102	53	3
WRASSE, rock				87	16	3	87	16	4
SENORITA	50	47	3	14	19	7	64	65	5
GARIBALDI	2	2	7	28	10	4	30	9	6
GOBY, blackeye	8	3	4	13	7	8	21	10	7
HALFMOON				20	13	5	20	13	8
BASS, kelp	1	2	8	16	17	6	17	19	9
CROAKER, black				12	17	9	12	17	10
BASS, barred sand				3	1	10	3	1	11
GOBY, bluebanded	2	2	6				2	2	12
GREENLING, painted				2	3	11	2	3	13
SARGO				1	2	13	1	2	15
PERCH, pile				1	2	13	1	2	15
SCORPIONFISH, Ca	0	0	9	0	0	15	0	0	16
HALIBUT, Ca				0	0	14	0	0	17
Total Individuals	3,529	1,167		705	151		4,234	1,307	
Tot. Ind. Minus Blacksmith	168	93		483	37		651	67	

TABLES 39-40

YOY-OJ FISHES AT PAR: ESTIMATED NUMERICAL ABUNDANCES, FOR YOY, OLDER JUVENILE (AND POOLED JUVENILE STAGES) ENCOUNTERED ON SURVEYS DURING FALL 1985-86. Taxa include each species encountered, plus total fishes (all species) and total fishes (minus blacksmith). Abundance estimates are weighted by the areal contribution of component strata (both years: Crest, Perimeter).

TABLE 39

PENDLETON ARTIFICIAL REEF
YOUNG OF YEAR -- OLDER JUVENILE FISH SURVEY
NUMERICAL ABUNDANCE ESTIMATE FOR ENTIRE REEF

FALL 1985 SURVEYS

	YOUNG OF YEAR			OLDER JUVENILE			TOTAL JUVENILE		
SPECIES	ABUN.	2*SE	RANK	ABUN.	2*SE	RANK	ABUN.	2*SE	RANK
BLACKSMITH	72,912	39,015	1	1,548	1,767	1	74,461	39,218	1
SHEEPHEAD, Ca	285	43	4	1,124	125	2	1,409	149	2
WRASSE, rock	1	1	11	1,102	462	3	1,103	461	3
SENORITA	744	804	2	34	34	13	777	811	4
BASS, kelp				647	288	4	647	288	5
PERCH, black	566	119	3				566	119	6
GARIBALDI	146	83	5	388	223	5	535	175	7
HALFMOON				220	198	6	220	198	8
SCORPIONFISH, Ca	1	1	12	109	95	7	109	95	9
BASS, barred sand				101	24	8	101	24	10
GOBY, blackeye	17	7	7	84	27	9	101	34	11
SARGO	16	32	8	72	7	10	88	39	12
GOBY, bluebanded	88	140	6				88	140	13
PERCH, pile	3	6	9	68	136	11	71	133	14
GREENLING, painted				48	56	12	48	56	15
CROAKER, black				31	62	14	31	62	16
GOBY, zebra	2	2	10				2	2	17
HALIBUT, Ca				0	1	15	0	1	18
Total Individuals	74,780	39,935		5,577	1,423		80,358	39,713	
Tot. Ind. Minus Blacksmith	1,868	1,013		4,029	531		5,897	942	

TABLE 40

PENDLETON ARTIFICIAL REEF
YOUNG OF YEAR -- OLDER JUVENILE FISH SURVEY
NUMERICAL ABUNDANCE ESTIMATE FOR ENTIRE REEF

FALL 1986 SURVEYS

	YOUNG OF YEAR			OLDER JUVENILE			TOTAL JUVENILE		
SPECIES	ABUN.	2*SE	RANK	ABUN.	2*SE	RANK	ABUN.	2*SE	RANK
BLACKSMITH	30,327	9,786	1	2,002	1,645	2	32,329	11,349	1
SHEEPHEAD, Ca	33	33	5	2,575	780	1	2,607	762	2
PERCH, black	916	479	2				916	479	3
WRASSE, rock				788	144	3	788	144	4
SENORITA	449	421	3	128	171	7	577	587	5
GARIBALDI	15	15	7	252	91	4	267	80	6
GOBY, blackeye	72	25	4	121	63	8	193	87	7
HALFMOON				183	118	5	183	118	8
BASS, kelp	10	21	8	144	156	6	155	172	9
CROAKER, black				108	152	9	108	152	10
BASS, barred sand				23	8	10	23	8	11
GOBY, bluebanded	20	21	6				20	21	12
GREENLING, painted				16	31	11	16	31	13
SARGO				10	21	13	10	21	15
PERCH, pile				10	21	13	10	21	15
SCORPIONFISH, Ca	1	2	9	1	1	15	1	1	16
HALIBUT, Ca				1	1	14	1	1	17
Total Individuals	31,842	10,531		6,361	1,363		38,203	11,789	
Tot. Ind. Minus Blacksmith	1,515	835		4,359	331		5,874	602	

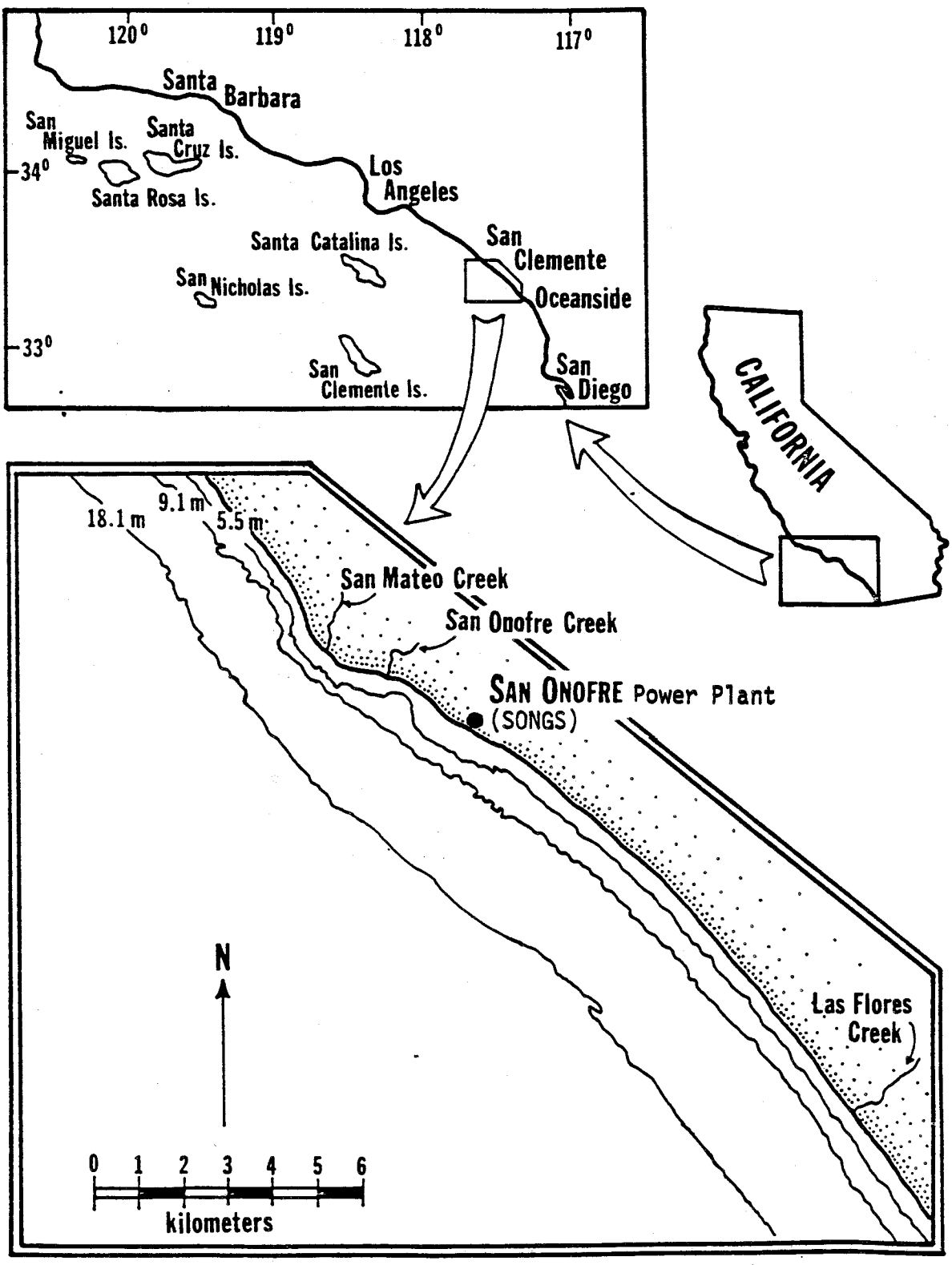
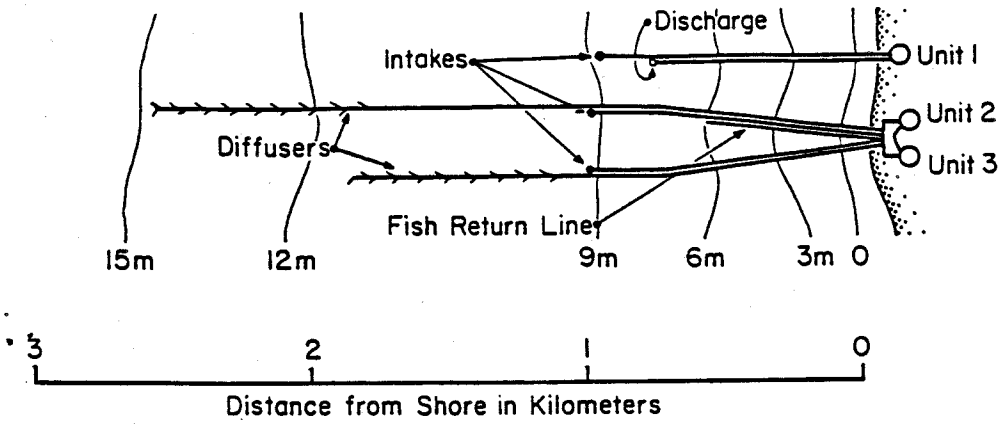


Fig. 1. Chart of the Los Angeles-San Diego region showing the location of the San Onofre Nuclear Generating Station (SONGS)

(a)



(b)

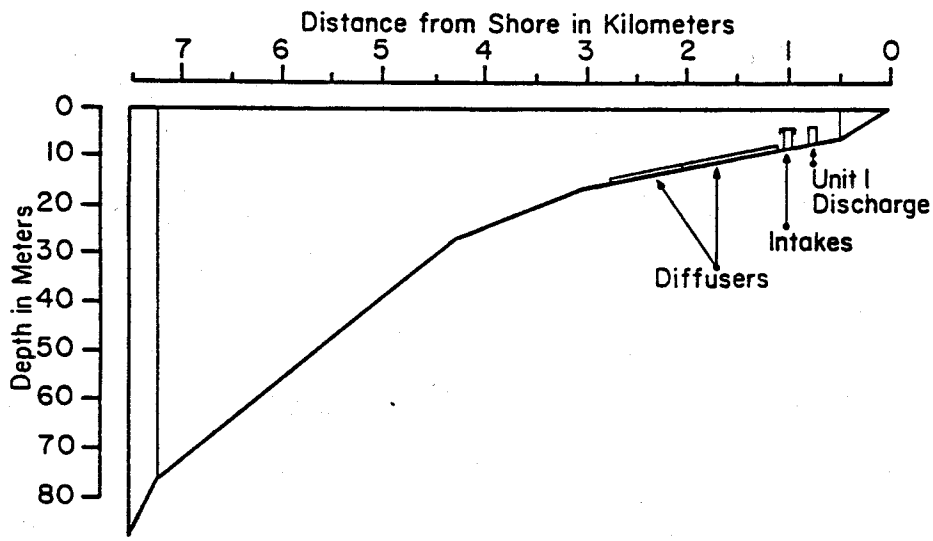


Fig. 2. Aerial (a) and cross-shelf (b) views of the San Onofre Nuclear Generating Station (SONGS) and its offshore intake and discharge structures. (Note that the distance scales differ for the two diagrams.)

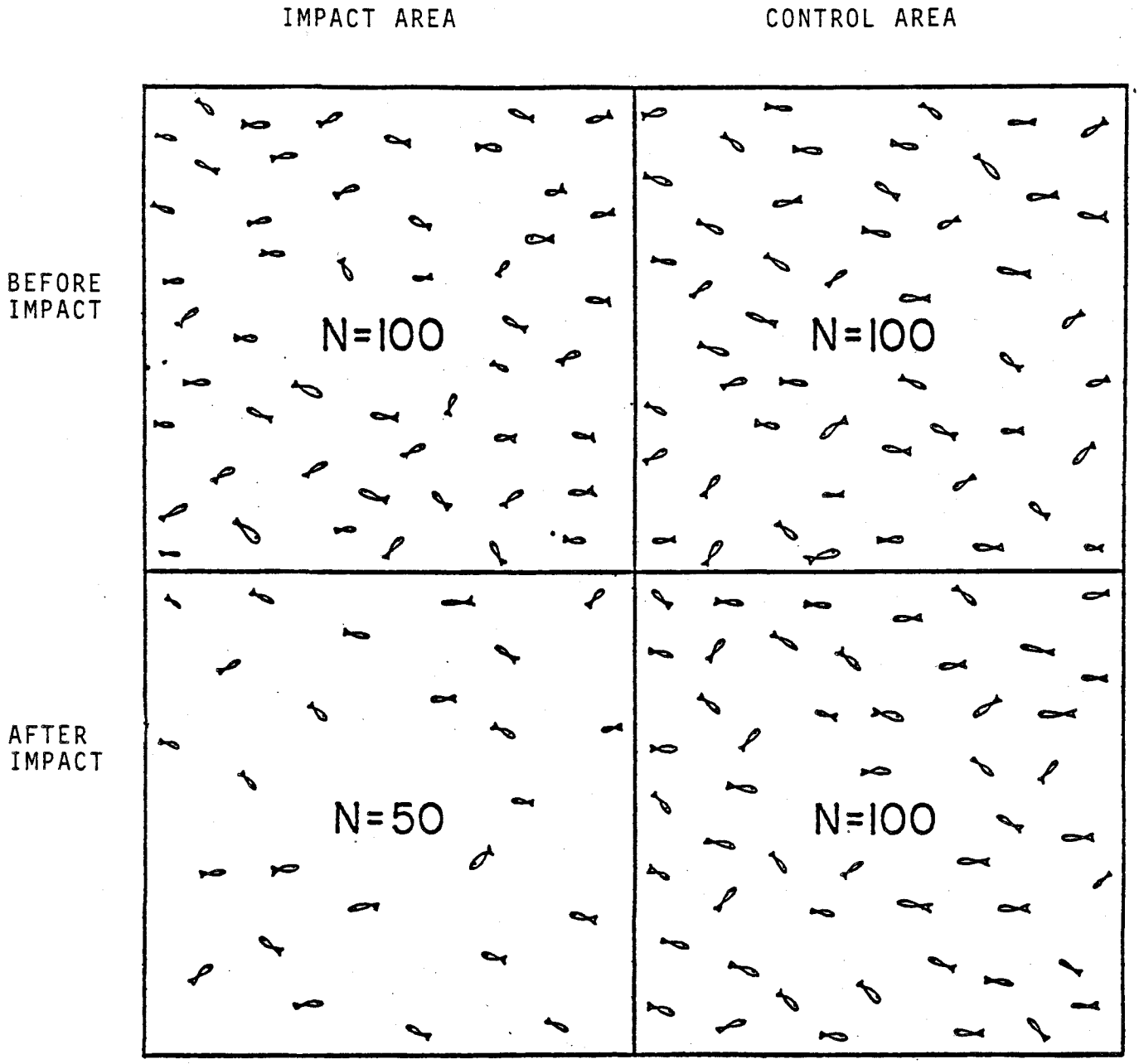


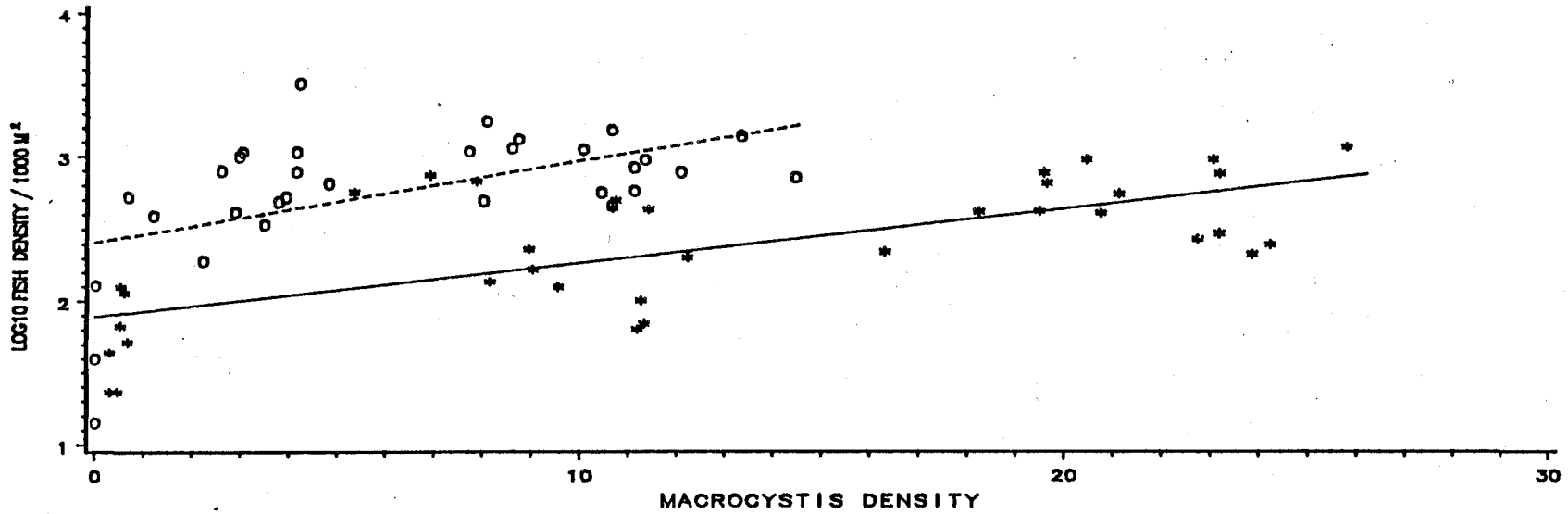
Fig. 3. BACI (Before-After/Control-Impact) model for SONGS fish monitoring

FIGURE 4

KELP BED FISHES: SCATTERPLOT OF THE RELATION BETWEEN THE (A) NUMERICAL AND (B) BIOMASS DENSITIES OF FISHES VERSUS THE DENSITY OF GIANT KELP AT SAN ONOFRE KELP BED DURING FALL 1985 AND FALL 1986. Fish densities represent the sum of all post-recruit stages of 14 major species.

FIGURE 4

(A) NUMERIC DENSITY



(B) BIOMASS DENSITY

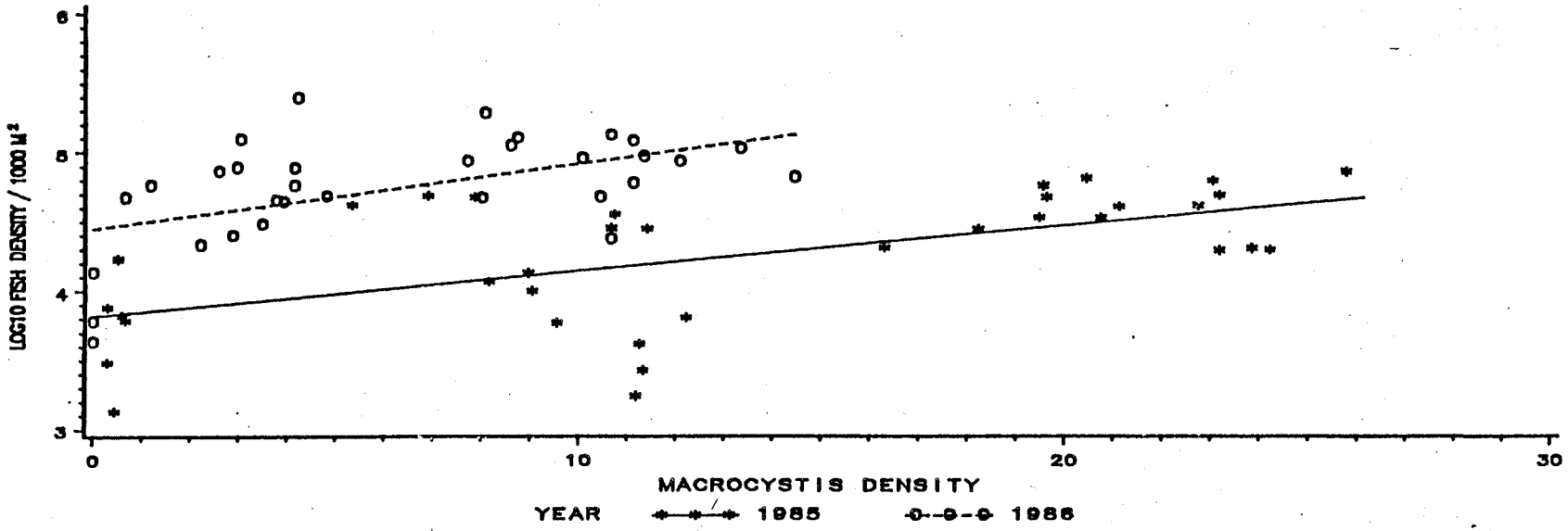


FIGURE 5

PAR FISHES: PLOT OF MEAN NUMERICAL DENSITY VERSUS DISTANCE FROM THE PAR MODULES FOR EACH OF FOUR MAJOR SPECIES AND FOR TOTAL FISHES IN DECEMBER 1985. Sample sizes are numbers of fish tallied. Juvenile-adult life stages are pooled in all cases. Densities at 0 - 3 m distance are estimated based on December 1985 "Ecotone" transects. Densities at successive distances are based on the following segments of the December 1985 "radial" transects (first 10 m: 4 - 12 m, second 10 m: 13 - 22 m, third 10 m: 23 - 32 m, last 45 m: 33 - 78 m). See Appendix Q, Tables 2, 3, Figs. 1,2 for details.

FIGURE 5

PENDLETON ARTIFICIAL REEF

JUVENILE–ADULT FISHES

DECEMBER 1985

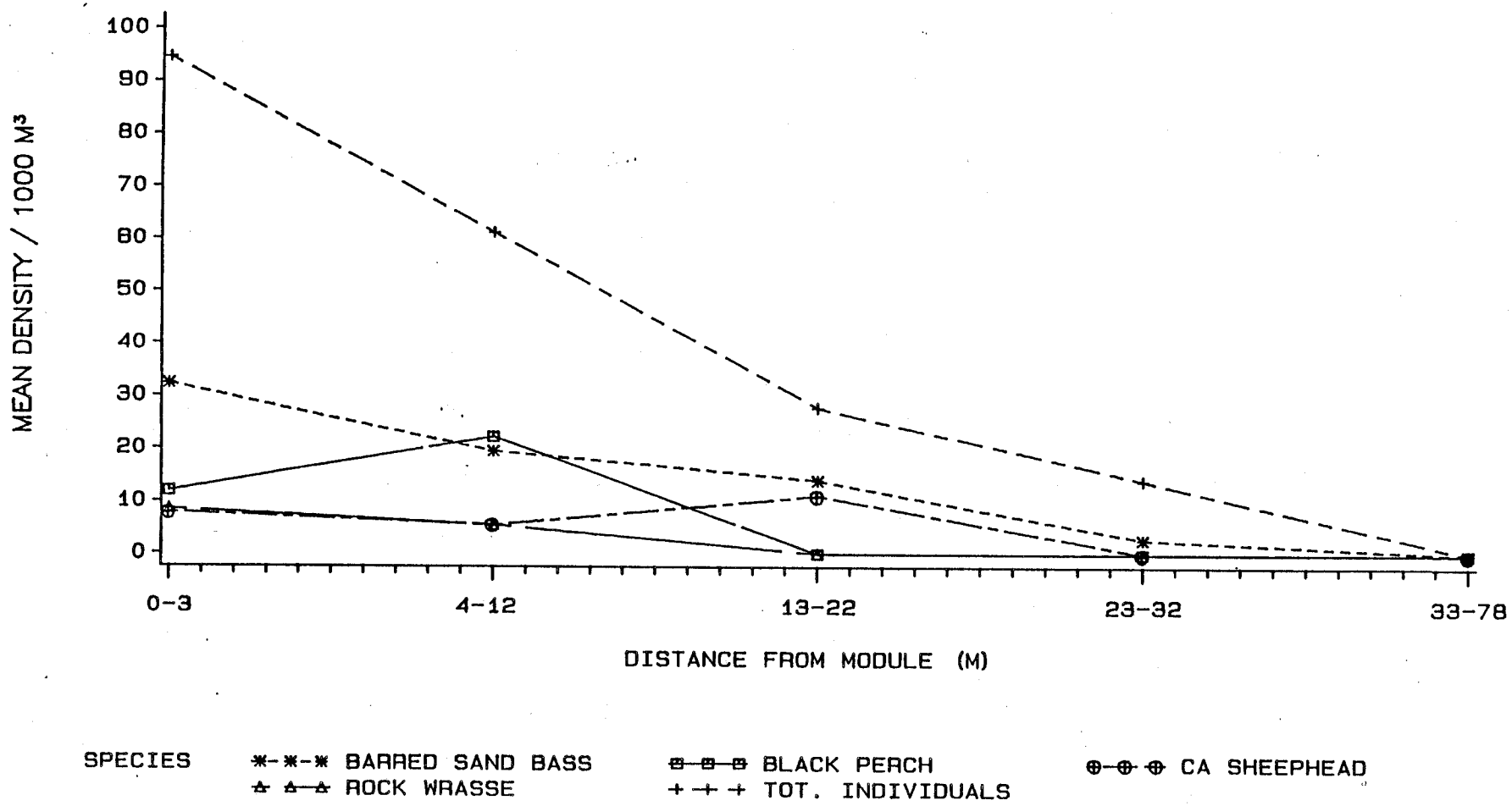


FIGURE 6

PAR FISHES: PLOT OF MEAN BODY WEIGHT PER FISH INDIVIDUAL VERSUS MICROHABITAT ATOP, AND DISTANCE FROM, THE PAR MODULES IN **DECEMBER 1985**. Sample sizes are numbers of fish tallied. All (juvenile-adult) life stages are pooled. Densities at 0 -3 m distance are estimated based on December 1985 "Ecotone" transects. Densities at successive distances are based on the following segments of the December 1985 "radial" transects (first 10 m: 4 - 12 m, second 10 m: 13 - 22 m, third 10 m: 23 - 32 m, last 45 m: 33 - 78 m). See Appendix Q, Tables 2, 3; Figs. 1, 2 for details.

FIGURE 6

PENDLETON ARTIFICIAL REEF

JUVENILE–ADULT FISHES

DECEMBER 1985

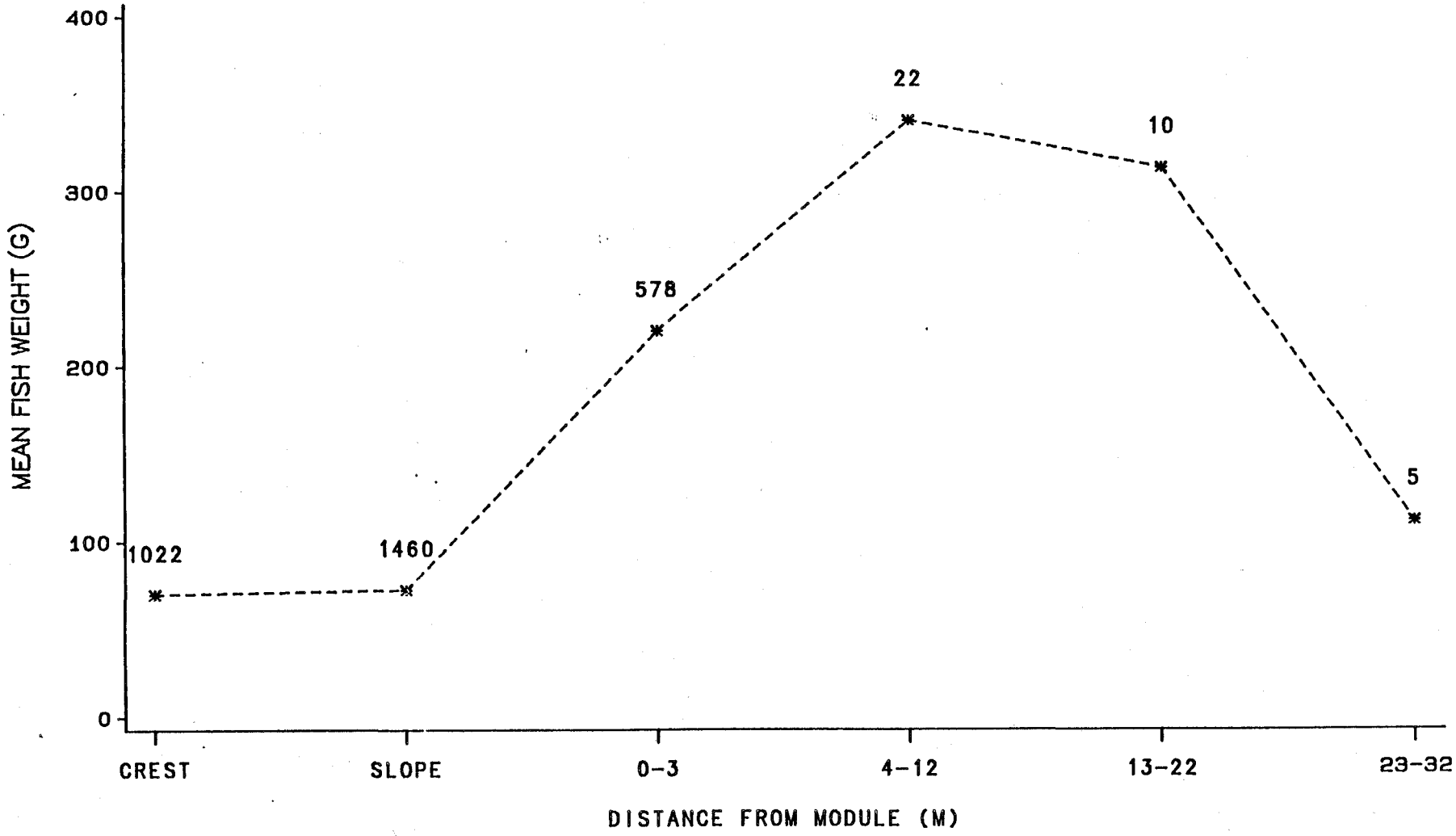


FIGURE 7

PAR FISHES: PLOT OF MEAN NUMERICAL DENSITY VERSUS DISTANCE FROM THE PAR MODULES FOR EACH OF FOUR MAJOR SPECIES AND FOR TOTAL FISHES IN **FALL 1986**. Sample sizes are numbers of fish tallied. Juvenile-adult life stages are pooled in all cases. Densities at 0 - 3 m distance are estimated based on "Ecotone" transects for all three (November 1986-January 1987) surveys. Densities at successive distances are based on the following segments of the November 1986-January 1987 "radial" transects (first 5 m: 4 - 8 m, second 5 m: 9 - 13 m, second 10 m: 14 - 23 m, last 10 m: 24 - 33 m). See Appendix Q, Tables 2, 3; Figs. 1, 2 for details.

FIGURE 7

PENDLETON ARTIFICIAL REEF

JUVENILE–ADULT FISHES

NOVEMBER 1986 – JANUARY 1987

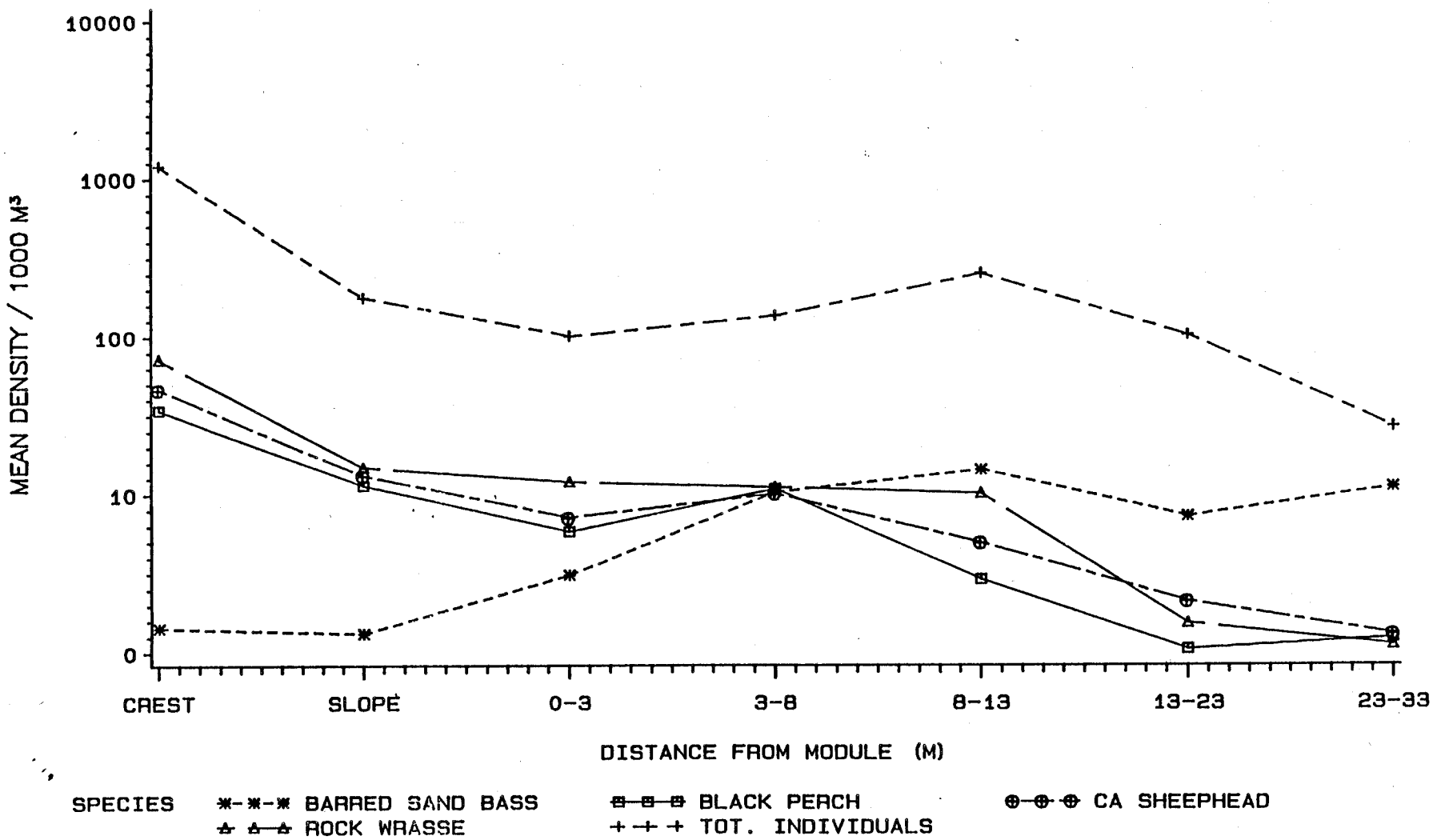


FIGURE 8

PAR FISHES: PLOT OF MEAN BODY WEIGHT PER FISH INDIVIDUAL VERSUS MICROHABITAT ATOP, AND DISTANCE FROM, THE PAR MODULES IN FALL 1986. Sample sizes are numbers of fish tallied. All (juvenile-adult) life stages are pooled. Densities at 0 - 3 m distance are estimated based on "Ecotone" transects for all three November 1986-January 1987) surveys. Densities at successive distances are based on the following segments of the November 1986-January 1987 "radial" transects (first 5 m: 4 - 8 m, second 5 m: 9 - 13 m, second 10 m: 14 - 23 m, last 10 m: 24 - 33 m). See Appendix Q, Tables 2, 3; Figs. 1, 2 for details.

FIGURE 8

PENDLETON ARTIFICIAL REEF

JUVENILE–ADULT FISHES

NOVEMBER 1986 – JANUARY 1987