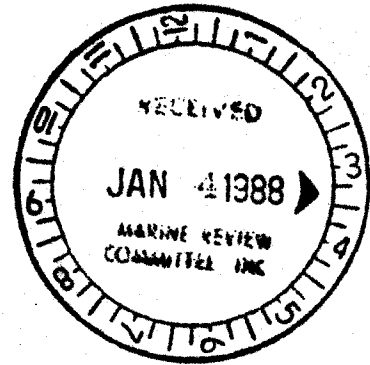


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**THE EFFECTS OF OPERATIONS OF THE  
SAN ONOFRE NUCLEAR GENERATING STATION  
ON FISH**

**FINAL REPORT  
(Vol. 1 of 2)**

**Prepared for the  
Marine Review Committee  
of the  
California Coastal Commission**



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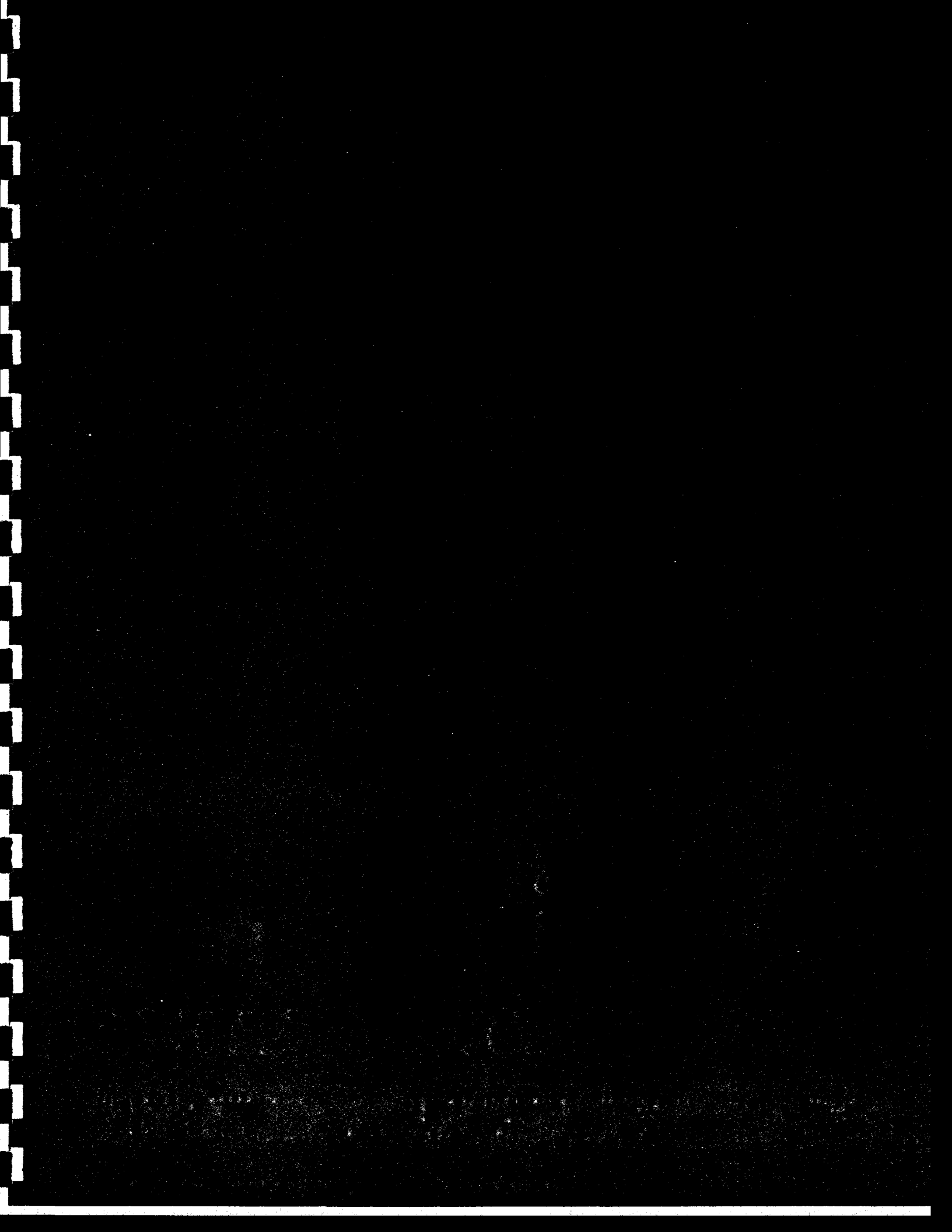
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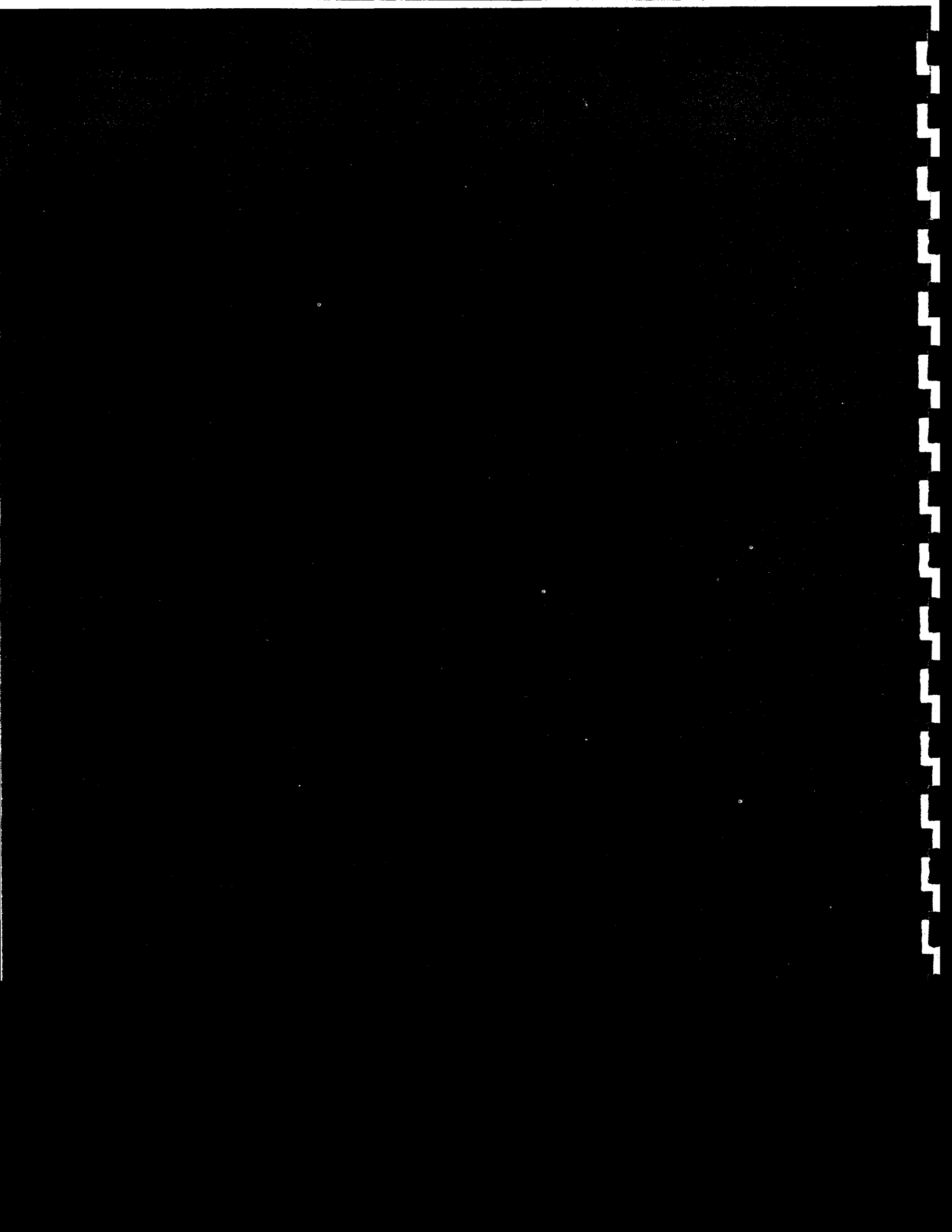
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## EXECUTIVE SUMMARY

### CHAPTERS ONE THROUGH FOUR

- Chapter 1: SONGS' Local Impact on Fishes  
Based on Net Monitoring Studies
- Chapter 2: An Evaluation of the Entrapment and Mortality  
of Fishes at SONGS Units 1, 2, and 3
- Chapter 3: An Evaluation of Fishes at San Onofre  
and San Mateo Kelp Beds
- Chapter 4: An Evaluation of Fishes at Pendleton  
Artificial Reef

## 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 interim period of June 1982-April 1984, operational sampling began in May 1984 and continued until December 1986.

x 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.

We used benthic trawls fished under the average, downcoast-setting diffuser plumes (from  $\leq 1$ -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). *where in relation to diffusers?*

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 entrapped 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:

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

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 simillimus).

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 rates 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 reseedling 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. # 3?

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) 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<sup>2</sup> 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

Strength determined from SOK?

}  
does he know this?  
IF THIS IS TRUE, WHAT ABOUT MITIGATION? (1) (2)?

XX ?