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M E C BIOLOGICAL PROJECT  
SAN ONOFRE NUCLEAR GENERATING STATION  
MONITORING STUDIES ON  
ICHTHYOPLANKTON AND ZOOPLANKTON  
FINAL REPORT

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## EXECUTIVE SUMMARY

Marine Ecological Consultants (MEC) has conducted monitoring studies of the plankton community in the vicinity of the San Onofre Nuclear Generating Station (SONGS) on behalf of the Marine Review Committee (MRC) since 1976. The major thrust of these studies since 1979 has been to predict, and subsequently to measure, the effects of SONGS Units 2 and 3 on the plankton (studies prior to 1979 were largely directed toward measuring the effects of Unit 1). This report is MEC's Final Report to the Marine Review Committee describing the results of our Units 2 and 3 monitoring studies of ichthyoplankton, macrozooplankton, and phytoplankton.

SONGS Units 2 and 3 began commercial operations in 1983 and 1984, respectively. Units 2 and 3 account for 85 percent of the 7800 m<sup>3</sup>/min of cooling water used by the three SONGS units. Long diffusers discharge the cooling water 1 to 2.5 km offshore, where it is diluted six- to ten-fold by entrained ambient water. One of the concerns originally raised during the planning stages of Units 2 and 3 was that the use of so much cooling water (the amount withdrawn every day corresponds to the volume under one square kilometer in the vicinity of the intakes) could lead to large-scale reductions in the plankton, since cooling water withdrawal and discharge subjects plankton to death in the intake system, to entrainment and offshore translocation in the discharge plume, and to habitat alterations (which can be favorable--e.g., increased food or the creation of favorable physical conditions, or unfavorable--e.g., increased turbidity, altered physical conditions). This report addresses the original concern, and also considers the potential direct and indirect effects of SONGS operation. The report consists of five major text sections and a separate volume of supporting appendices.



MEC's study was designed to meet the objectives of the MRC's monitoring program. As part of the permitting process for SONGS, the MRC was charged with monitoring the effects of Units 2 and 3. This monitoring was to provide information that would enable the California Coastal Commission to evaluate the impacts of SONGS Units 2 and 3 operations. The goals of the MRC Units 2 and 3 monitoring studies were: 1) to predict the effects of Units 2 and 3 operations on the marine biota; 2) to measure the magnitude and extent of any such changes; and 3) to determine whether the operation of Units 2 and 3 caused those changes. The MRC defined a significant change as a 50 percent increase or reduction in abundance from what would be expected in the absence of SONGS. The sampling programs were designed to detect such a change if it occurred over an area of several square kilometers.

The planktonic communities near SONGS that the MRC monitored in order to meet these goals were the ichthyoplankton, the macrozooplankton, and the phytoplankton. MEC's monitoring studies sought to determine whether the operation of SONGS had caused a marked reduction in the abundance of ichthyoplankton, or marked changes in the abundances of macrozooplankton and phytoplankton, and whether SONGS operations caused changes in the distributions of the ichthyoplankton and macrozooplankton.

Ichthyoplankton was sampled at two locations: an Impact site about 1-3 km south of SONGS (to permit the detection of large-scale changes) and a Control area about 18 km south (to correspond with the MRC adult fish studies). Samples were collected with towed nets from the neuston, midwater, and epibenthos in four onshore/offshore blocks between the 6 and 45 m isobaths at each site (which permitted descriptions of changes in distribution) on 38 preoperational (1979 through 1981) and 27 operational (1984 through 1986) period surveys.

The macrozooplankton and phytoplankton were sampled at three onshore/offshore locations (the 8, 13, and 30 m isobaths) along an Impact transect off Unit 1, and along a Control transect about 12 km south. Pumped samples were collected from the surface, from one or two midwater strata, depending on water depth, and from the epibenthos at each location. This arrangement permitted descriptions of changes in spatial distributions. Thirty-two preoperational (1976 through 1981) and 23 operational (1983 through 1986) period surveys were taken.

The data were analyzed to detect changes in abundance (using the BACI--Before/After, Control/Impact--approach), and changes in spatial distribution (using MANOVA/ANOVA/Bonferroni pattern analyses). The BACI approach is described in detail in Section 3.7.1. The BACI approach tests whether the difference between abundances at the Impact and Control sites in the Before (preoperational) period was different, on average, from the difference between Impact and Control abundances in the After (operational) period. The primary test is a two-sample t-test of means. When the nature of the data did not permit the use of a t-test, the t-test was replaced by the Wilcoxon rank sum test, the autoregressive errors t-test, the binomial test, and regressions of SONGS versus Control data. These secondary tests were also used to provide insight into the data. Additional secondary tests consisted of BACI tests performed on two subsets of the After data, one containing surveys taken when the Impact site was influenced by the Units 2 and 3 diffuser plume ("Plume" surveys), and the other containing surveys taken when it was not (Non-plume"). These test results were used to aid in the interpretation of the results based on the full After data set.

The MANOVA/ANOVA/Bonferroni pattern analysis on each ichthyoplankton and macrozooplankton taxon compared the cross-shelf pattern of abundance ranks at the Impact site in the After period with a

composite pattern of ranks derived from the distributions at SONGS in the Before period and at Control in the Before and After periods. The pattern analysis is described in detail in Section 3.7.2.

Statistically-significant large-scale general reductions in plankton abundance near SONGS were not detected. However, statistically significant reductions in the relative abundances of total larvae (i.e., the sum of the developmental stages) were detected in the full operational data set for five of the 19 ichthyoplankton taxa tested (of the approximately 150 types identified during the SONGS studies). In addition, one or more developmental stages of six taxa (including four of the above five) declined significantly in relative abundance. In all, therefore, seven taxa (the gobies Clevelandia ios, Quietula y-cauda, and Ilypnus gilberti, the queenfish Seriphus politus, the kelp and seabasses Paralabrax spp., the jacksmelt Atherinopsis californiensis, and the northern anchovy Engraulis mordax) exhibited relative decreases in abundance, either of total larvae, or of various developmental stages, or both. One taxon, the California grunion, would have been shown to increase significantly had we done two-tailed tests rather than the lower-tail tests that were used. This means that for one of the 19 ichthyoplankton taxa analyzed, our a priori alternative hypothesis--that abundance could only decrease--was wrong. Two of the relative decreases in total larvae -- those for the shadow goby and cheekspot goby -- were due to smaller increases in abundance at SONGS than at Control. The relative decrease in jacksmelt larvae was due to a greater decrease at SONGS than at Control, and the relative decreases in the abundances of the arrow goby and the northern anchovy were due to decreased abundances at SONGS and increased abundances at Control.

A significant relative increase was detected in the full operational data set for one (barnacle larvae) of the sixteen

macrozooplankton taxa tested (of the twenty taxa and categories counted during the SONGS studies); there were no significant relative decreases in the full data set for the macrozooplankton. Two additional taxa (Evadne nordmanni and cyphonautes larvae) increased in relative abundance on plume dates. The phytoplankton standing crop, measured as chlorophyll-a concentration, showed no significant relative change.

None of the significant relative changes detected for the ichthyoplankton and macrozooplankton could be ascribed solely to the operation of SONGS Units 2 and 3. This was because except for the nearshore gobies, estimated losses due to intake withdrawal--the only SONGS mechanism known to operate--were too small to have accounted for the significant relative reductions detected, and could not have produced increases. Although estimated losses could have caused the changes in the abundance of gobies, alternative mechanism could be postulated. SONGS operations may, however, have contributed to the significant relative reductions that were detected among the ichthyoplankton, and to the three relative increases detected among the zooplankton taxa. SONGS mechanisms that were postulated as contributors to the ichthyoplankton decreases included intake withdrawal, secondary entrainment in the diffuser plume, and losses to predators attracted to the vicinity of the plume. We were unable to postulate the mechanism(s) that might have produced the relative increases among the macrozooplankton.

The pattern analysis detected statistically significant, but relatively minor, shifts in the distribution of total larvae of three ichthyoplankton taxa, and of one of the three life stages of an additional five taxa. The shifts were variable and generally occurred in areas of low larval abundance. These were not considered SONGS effects.

Total macrozooplankton and four macrozooplankton taxa (cyphonautes larvae and the copepods Acartia tonsa, Corycaeus anglicus, and Oithona plumifera) also displayed statistically significant shifts in distribution. These formed a relatively coherent pattern which was considered evidence of a SONGS effect, and from which a conceptual model of SONGS-induced circulation was derived. The major elements of this model are a shoreward flow of make-up water required to replace the water withdrawn at the intakes and entrained by the seaward-directed discharge plume. The shoreward motion of the make-up flow and the seaward motion of the plume are maintained whenever Units 2 and 3 operate. The model was derived from two principal elements of the macrozooplankton pattern analysis results. The first included the relative decreases in the mean ranks of abundance seaward of the Units 2 and 3 offshore cooling structures, which were interpreted as reflecting shoreward motion of the make-up water containing lower concentrations of the coastal macrozooplankton species, and relative increases in mean ranks of abundance in midwater and relative decreases in the epibenthos of the depth zone encompassing the Units 2 and 3 intakes and diffusers, interpreted as reflecting the combined effects of secondary entrainment and shoreward make-up flow. Since these various pattern shifts were redistributions within strata normally occupied by the taxa involved, and since they were unaccompanied by substantial relative decreases in abundance, they were considered only minor SONGS effects.

BACI tests of chlorophyll data from all stations and from a station that was expected to experience the maximum influence of SONGS operations yielded no statistically significant indications of an effect of SONGS operation.

The fate of planktonic organisms withdrawn at the Units 2 and 3 intakes is addressed in Section 5. Measured through-plant losses were

85-100% when the intake conduit fouling community was well established, and lower, but still substantial, when the fouling community was reduced following heat treatment. There was no significant through-plant gain or loss of dissolved, particulate, or total organic carbon. A relatively large (150%) and significant through-plant increase of inorganic seston occurred which was only partially attributable to inputs from the biofouling community.

Estimates of the average annual losses of ichthyoplankton and macrozooplankton to Units 2 and 3 withdrawal are also presented in Section 5 and are compared with the original MRC projections of losses. Loss estimates are presented for average 1981-1986 withdrawal volumes, for withdrawal at 75% of capacity (closely approximating the actual level of operation during the 1983-1986 operational monitoring period), and for continuous full-power operation (100%). Operation at the 75% level was considered the most realistic estimate of future Units 2 and 3 operations and was used in the comparisons. The final estimated losses of species of sport and commercial fishery value tended to be higher than the original projections. Estimated losses of fodder fish, in contrast, tended to be much lower than the original projections. This reflected the lower abundances of sport and commercial species, and higher abundance of fodder species, in 1978--the basis for the original projections--than were found in most later years. Estimated losses of total macrozooplankton were nearly one and one-half to two times higher than the originally-projected losses, whereas estimated losses for individual taxa ranged from as low as about one-half to as high as about three and one-half times the earlier projections. Macrozooplankton losses were estimated to be equivalent to natural mortality under a nearshore area of ocean of about 4.8 km<sup>2</sup>.

In summary, no large-scale reductions in the abundance in the SONGS area were detected. However, statistically significant smaller-scale changes in relative abundance and cross-shelf patterns of both ichthyoplankton and macrozooplankton were detected, demonstrating that the program design was sufficiently robust to identify large-scale changes had they occurred. Of those that found, the changes in the relative abundances of 7 ichthyoplankton taxa, and changes in the patterns of total macrozooplankton, could be plausibly linked with operations of the SONGS Units 2 and 3 macrozooplankton taxa, and changes in the discharge plume were found, the changes in the relative abundances of 7 ichthyoplankton taxa, and changes in the patterns of total macrozooplankton could be plausibly linked with operations of the SONGS Units 2 and 3 cooling systems as a contributing factor. It was shown that intake withdrawal and secondary entrainment in the discharge plume were unlikely to have fully accounted for the significant changes in cross-shelf abundance that were detected; other mechanisms must have contributed as well. MEC concluded that the effects detected were of relatively minor importance during the 1983-1986 operational monitoring period for the following reasons: (1) no general large-scale reduction of plankton abundance was detected; (2) although there were suggestions of relatively uniform patterns of change within some subsets of the ichthyoplankton and macrozooplankton, there was no evidence of an overall uniform pattern of change in the plankton community; (3) in many cases where significant changes were detected, plausible alternative explanations for those changes could be postulated; and (4) for the ichthyoplankton, significant test results tended to reflect changes in the more numerous younger larvae. Synopses of biological information, including details of our research protocols, details of our research, and details of our research, are available in the SONGS Environmental Monitoring Report.

## 1.0 INTRODUCTION

### 1.1 Overview

The San Onofre Nuclear Generating Station, located on the coast of southern California (Figure 1-1), consists of three units, each powered by a pressurized water reactor. Unit 1, rated at 456 megawatts, began operation in 1968. Units 2 and 3, each rated at 1180 megawatts, began operation in 1983 and 1984, respectively.

All three units use seawater for once-through condenser cooling. The cooling water intakes are located approximately 0.9 km offshore, in about 9 m of water (Figure 1-2). The maximum cooling water flow of the three units is 7,800 m<sup>3</sup>/min (11.2 million m<sup>3</sup>, or 3 billion gallons, per day). Note that this volume of water roughly corresponds to the volume contained under 1 km<sup>2</sup> of a water column 9 m deep (9 million m<sup>3</sup>). Cooling water passes through the Unit 1 system approximately 15 minutes, and takes 25 to 30 minutes to pass through Units 2 and 3. The cooling water for Unit 1 is discharged at approximately 2 m/sec from a single large port located in 8 m of water approximately 0.8 km from shore. Units 2 and 3, however, use long, multiple-port diffuser pipes; water is discharged at approximately 4 m/sec. The Unit 2 diffuser discharges in 12 to 15 m of water 1.8 to 2.6 km offshore, and Unit 3 discharges in 10 to 12 m of water 1.1 to 1.9 km offshore. Figure 1-3 shows the history of Units 2 and 3 cooling water flow through 1986. The cooling water is raised approximately 12°C above ambient during normal operations. The discharged water is diluted approximately six to ten-fold with ambient water that is entrained in the discharge jets. The volume entrained per day roughly corresponds to the water under 9 km<sup>2</sup> (i.e., a square 3 km on each side) of a water column 10 m deep.



Power plants that use once-through condenser cooling can affect the aquatic biota in ways that can be detrimental and beneficial. The withdrawal of planktonic organisms and the larvae of fish and benthic species in the cooling water results in the death of a large proportion of those organisms (Barnett et al., 1982, for Unit 2 and 3 losses and a review of Unit 1), thus removing them from the system and reducing their populations. Their carcasses, and the carcasses of invertebrates that live in the intake conduits and feed upon the material in the withdrawn water, are discharged into the environment, and may serve as an additional food source for the surrounding animals. Discharged material and animals entrained from the nearshore zone may be transported to the faster longshore currents farther offshore, and thus be lost to the inner nearshore zone. Sediments may be altered as a result of the transport of water high in suspended matter from inshore to farther offshore by the discharge currents. Predator/prey interactions may be altered as a result of changes in the abundances of predators or their prey. Discharges of the biocides, metals, and radionuclides that are present in low concentrations in the effluent may contribute to any net reductions in abundance; however, evaluations of such potential contributions are outside this scope of the SONGS study.

One of the original concerns that was raised when Units 2 and 3 were being planned was that the use of so much cooling water--the amount under one square kilometer every day--and the entrainment in the discharge of water representing an average of about eight times that volume could have cumulative effects that would lead to large-scale reductions in the aquatic biota, possibly extending several kilometers from SONGS. An alternative view was that the longshore currents, eddy

diffusivity, and cross-shelf circulation would be sufficiently strong to rapidly dilute the effects of SONGS to below detectable levels.

In 1974, as part of the permitting process for the San Onofre Nuclear Generating Station Units 2 and 3, the California Coastal Zone Conservation Commission (now the California Coastal Commission) issued Permit No. 183-73. The permit formed the Marine Review Committee (MRC), an independent committee whose members were drawn from academia, environmental groups, and Southern California Edison (SCE). One of the charges to the MRC was to monitor the effects of Units 2 and 3, placing emphasis "... on the plankton and larval forms that are the basis of the ocean's food chain and thus of the ocean's sport and commercial fisheries ...". The purpose of the MRC study was to obtain information that the Commission could use to decide whether or not changes in the cooling system should be required in order to prevent or reduce any adverse effects of Units 2 and 3.

The goals of the MRC studies were to detect significant changes in the marine biota, to determine the magnitude and extent of those changes, and to determine whether the operation of SONGS Units 2 and 3 caused the changes. In designing the program, the MRC (1983) defined a significant change to be a 50% reduction or increase between observed abundances and the abundances that would have been observed had SONGS not been operational. The sampling program was designed in a way that would permit the detection of such a change if it occurred over an area of several square kilometers, representing a very large zone in which biological communities are severely affected. To achieve that goal the MRC had to decide how to study the complex marine environment in a manageable but meaningful way.

Two fundamentally different approaches to impact monitoring have been considered by the MRC. The first is a sequential approach. The available effort is first devoted to determining whether there are detectable and significant net changes among the populations in the receiving water species assemblages, and whether those changes can be attributed to the effects of the potential disturbance being studied. If a net effect can not be determined, then future monitoring may be curtailed or eliminated. If a net effect can be detected, then, depending upon how important the effect is judged to be, appropriate isolating studies can be conducted to determine the specific source(s) of the observed change and the mechanism(s) by which the change is effected. Note that it is possible that the sum of the positive effects and the negative effects can result in a zero net sum. Thus, a drawback to this approach is that there could be effects, but they might not be identified or measured.

The second approach is to design each of the monitoring elements, possibly in conjunction with controlled laboratory and field experiments, in such a way as to make that element relate specifically to a particular source of, and/or mechanism for, potential effects. Negative results allow one to remove that source or mechanism from continued scrutiny. Positive results permit a more rapid determination of effects and potential mitigations. This approach is costly at a facility such as SONGS, at which a variety of mechanisms can cause changes in many different marine populations. Furthermore, it may or may not be possible to integrate the results of the various elements arithmetically, since some effects may interact synergistically to cause an impact far different from their arithmetic sum. These could include opposing effects that cancel each other. For these reasons,