

**INTERIM TECHNICAL REPORT
TO THE
CALIFORNIA COASTAL COMMISSION**

4. Plankton

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April 1, 1988

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SUMMARY

The study of plankton in the vicinity of SONGS addressed three basic questions: Are standing stocks of zooplankton and phytoplankton changed in the vicinity of the Plant? Are nearshore zooplankton moved offshore by the discharge waters? What is the average annual loss of zooplankton to intake withdrawal? The results of the study can be summarized as follows:

Abundance Changes

There is no evidence that a severe reduction in total numbers of zooplankton has occurred in the vicinity of the plant. The once-predicted decline of 50% did not occur. In fact, while there was evidence of a decrease in one relatively uncommon species of cladoceran, a number of taxa, mostly larvae of benthic invertebrates, increased in the vicinity of the Plant.

While the occurrence of these changes at the Impact site in the After periods suggests that SONGS is responsible, the mechanism by which the operation of the Plant results in these changes is not known. It is possible that adult populations of the benthic invertebrates associated with the diffuser system may be the source of the increased numbers of larvae near the Plant.

There was no increase in phytoplankton (as measured by the chlorophyll-a content of seawater) near the Plant in the After period.

Distributional Changes

One potential effect of concern was the offshore displacement of nearshore larvae. There is little evidence that such movement, which occurs as discharge water is moved offshore, is sufficient to cause a significant change in the cross-shelf distribution of most species. Evidence of significant offshore shifts was seen in two taxa, both larvae of benthic invertebrates. In both of these cases, the movement offshore probably did not extend further than several hundred meters beyond the end of the diffuser lines and did not displace the plankters into an area where they do not normally occur.

Intake Loss

Incorporating 10 years of density estimates, we estimate that the Plant withdraws an average of approximately 12 trillion zooplankters (of the sizes we sampled) per year. This is equivalent to approximately 1,000 US tons of zooplankton per year. We estimate that an additional 350 US tons of smaller microzooplankton are also withdrawn. These estimates are based on the average pumping rate that has occurred during the operational period.

I. INTRODUCTION

Speculation on the potential depletion of plankton in the vicinity of the power plant was given at the Permit hearings of 1973, and concern for the plankton was expressly stated in the Permit establishing the MRC. In response to the mandate of the Permit, the MRC began its study of zooplankton and phytoplankton in 1976. Marine Ecological Consultants, Inc. (MEC) was awarded the contract to conduct the study, which was completed in 1987.

The first phase of the program was designed to determine the effects of the operation of Unit 1. The intent was to use this information to predict the effects of the two new units. This phase of the study ran from 1976 to 1979.

During this period, the cross-shelf distributions and abundances of various zooplankton taxa were determined. Both holoplanktonic and meroplanktonic taxa were enumerated. This information was necessary to estimate the amount of the zooplankton withdrawn into the Plant and to determine if specific taxa were distributed as to be at greater risk of either withdrawal into the Plant or movement offshore in water entrained by the Plant's discharge. In addition, the chlorophyll content of seawater (a measure of phytoplankton abundance) was determined at all sampling locations.

The results of this early study which pertain to Unit 1 alone are presented elsewhere (Barnett and Sertic, 1979). However, information gained during the Unit 1 study has also been used in the second major phase of the Plankton program, assessing the impact of the operation of Units 2 and 3. This phase of the program began in 1979.

Although the studies of Unit 1 did not indicate a significant adverse effect on zooplankton (Barnett and Sertic, 1979), the much greater volume of water both withdrawn and entrained by Units 2 and 3 led MRC contractors to predict that the zooplankton community might indeed be adversely affected. They also predicted that entrainment of bottom water by the diffusers would result in an increase in phytoplankton productivity. The subsequent study of Units 2 and 3, the subject of this report, addressed the questions:

(1) During the period of operation, did standing stocks of zooplankton and phytoplankton change at a site near the Plant (the Impact site) relative to those at a Control site located beyond the influence of the Plant?

(2) Are nearshore zooplankton, particularly those which are found predominantly in the area corresponding to the location of the Unit 2 and 3 diffuser lines, moved offshore by the discharged water from the diffuser?

(3) What amount of zooplankton is killed annually by intake withdrawal?

2 II. METHODS

2.1 A. Sampling Locations

The basic sampling design consisted of sampling along two transects extending offshore (Fig. 1). One transect, the Impact site, was located 500 m north of the Unit 2 and 3 diffuser lines. This location was chosen because (1) it was close to the diffuser lines and therefore in the area of the greatest potential impact, (2) it was away from the area immediately south of the diffuser lines where construction

activity in the early portion of the Before period made sampling difficult, and (3) because it had been the Impact site of the Unit 1 studies, it allowed a continuity of the data collected and allowed the use of the early samples in the analysis of effects of Units 2 and 3. The Control transect was located 12 km south of the diffuser lines. Early plume modelling studies indicated that this was beyond any expected influence of the discharge plume.

It should be noted that the longshore current flow past SONGS can move in either an upcoast or downcoast direction. Therefore, since the discharge plume is moved by the longshore current, fixing the location of the Impact site on one side of the diffusers means that the discharge plume may not be present on all sampling dates. However, as will be discussed, the samples are representative of average conditions at the chosen distance from the diffusers. *And, the presence of the*

plume can be factored...

On each transect three stations, located on the 8 m, 13 m, and 30 m isobaths, were sampled. These depth contours correspond to (1) the depth of the intake structures, (2) the midpoint of the diffuser lines, and (3) the point at which the faunal break between inshore and more oceanic plankton occurs. On some surveys a fourth location was sampled, the 18 m contour. This location corresponded to approximately 500 m offshore of the seaward end of the Unit 2 diffuser. Because this station was not sampled frequently during the Before period, data from this location were not used in the final analysis of SONGS' effects. Likewise, some samples were taken at the 100 m isobath. However, these data were not used in the analysis because the sampling location was at a distance beyond any potential influence of the Plant's discharge.

At each station three depth strata were sampled: the bottom 1 m of water column (epibenthos), the top 2-3 m of the water column (surface), and the mid-water between. The midwater was sampled at two depths (except for the 8 m station where the sample was taken at a depth of 4 m) on each survey. At the 13 m isobath samples were taken at 4 m and 8 m depths. At the 30 m station samples were taken at 8 m and 20 m depths. See Barnett, 1987 for further details.

A single estimate of the mean density of zooplankton in a meter-wide strip of the water column extending from the shoreline to the 30 meter depth contour was obtained in the following manner: The cross-shelf wedge was divided into three blocks (A, B and C), whose dimensions and offshore locations are given in Appendices A and B. The estimated density of a species within a stratum in each block was multiplied by the volume of water in the stratum. The resulting abundances were added across all block/stratum combinations. The mean cross-density was obtained by dividing the combined block/stratum abundances by the total volume of the cross-shelf wedge.

Sampling these various depths and distances offshore allowed us to sample all areas likely to be influenced by the operation of SONGS. Furthermore, the three blocks spanned all or nearly all of the offshore distribution of those species most likely to be at risk from SONGS, those species largely restricted to nearshore areas.

Water samples from each sampling location were analyzed for chlorophyll-a concentration. This measure was used as an index of the abundance of phytoplankton. A cross-shelf average was obtained as above.

2, 2 B. Sampling Techniques

All zooplankton samples were collected with a plankton pump. At each depth at each sampling location replicate samples of 1 cubic meter were drawn through 0.202 mm mesh netting. The same pumping rate ($1 \text{ m}^3/\text{min}$) was used at all locations. The material from the replicate samples was pooled and subsampled for analysis. Water samples analyzed for chlorophyll-a concentration were collected by either plankton pump or Van Dorn bottles. Further details concerning the field sampling and laboratory preparation of the samples are described in Barnett, 1987.

2, 3 C. Sampling Schedule

The dates on which zooplankton samples were collected are presented in Appendix C. The 32 preoperational (Before) samples were collected over a five year period from August 25, 1976 to November 5, 1981. The operating conditions of the three units at SONGS during this period are presented in Appendices C and D. Neither Units 2 nor 3 generated power during the Before period although some water was circulated through Unit 2 during a period of low level testing of the circulating pumps. Table 3 presents the operating conditions of Units 2 and 3 combined on the sampling dates. Note that no power was generated on any of the dates, and that the average number of pumps running on the preoperational sampling dates was 0.17 (the maximum number possible is 8). The average daily number of pumps running in Units 2 and 3 throughout the Before period was 0.28.

Unit 1 was operating during the Before period and the average daily number of pumps and percent power generated throughout this period were 1.4 (2 is the

maximum possible) and 48.8%. The average number of pumps and power generated on the Before sampling dates were 1.46 and 51.0% (Appendix ~~A~~).

D

The 23 operational (After) samples were taken over a three year period from August 18, 1983 to September 11, 1986 (Appendix C). Throughout this period Units 2 and 3 circulated water. Unit 2 was generating power by July, 1983 and Unit 3 began generating power in September of that year. Throughout the period over which samples were taken, the average number of pumps and average power generated by the combined units were 6.1 and 56.4%, respectively. The number of pumps and power averaged over the specific dates the samples were taken are 6.6 and 70.4%. Unit 1 was also operating during this period. The average daily number of pumps and power generated during the period was 1.1 and 25.6%, and on the sampling dates they were 1.27 and 31.3%.

The projected number of operational samples was determined by a power analysis using the sample variance found in the preoperational samples. We set as our goal having an 80% chance of detecting a 50% reduction in abundance of several of the most abundant zooplankters. After collecting three-quarters of the projected operational samples, analysis indicated that our ability to detect adverse effects would not be significantly aided by further sampling and sampling ceased.

From February, 1977 on, the direction and velocity of the longshore current were measured at SONGS. On 13 of the 32 Before sampling dates, the current flowed downcoast (and the Impact site was "upstream" of the diffusers). On 10 of the 32 dates the current direction was upcoast and the Impact site was "downstream" of the diffusers (current records are not available for the other nine dates). In the After period, there was a downcoast current on 10 of 23 sampling dates and an

upcoast current on 11 dates (no records are available for two dates). Throughout the entire study period the longshore current moved downcoast approximately 61% of the time (ECOSystems Management, 1988).

2.4 D. Intake Loss Sampling

There were no special sampling techniques used to estimate intake loss of zooplankton. Sampling within the intake structure was too difficult and had some attendant risk to both sampler and SONGS. Therefore, the samples taken at the 8 m station (the depth of the intake structures) during the monitoring surveys were used for intake loss estimation. Samples from both the Impact and the Control transects were used. Data from both sites were used because use of only Impact samples would bias the estimate because of the incorporation of whatever Plant effects may be present. For example, if plankton were reduced downstream of the intake, samples taken at that location would underestimate the abundances withdrawn. By like token, use of only Control samples would overestimate plankton loss because the impact (reduction in this example) averaged over all current conditions would not be incorporated into the estimate. Furthermore, since the objective was to determine an average yearly loss, using samples from both locations allowed a better estimate of the average abundance within a particular year by increasing the sample size. Details of the estimation procedure are described in the Results section below.

In addition to the surveys listed in Appendix C, data from six other cross-shelf surveys taken between January, 1982 and July, 1983 were incorporated into this estimate. Other additional data used in this estimation come from six surveys from 1985 to 1986 on which intake samples only were collected.

3 III. RESULTS

3.1 A. The Zooplankton Community

The average cross-shelf density (per m^3) of the 21 zooplankton taxa enumerated during the study at both the Control and Impact areas during each of the Before and After periods are presented in Appendix E. Standard errors of the means and the percentage of the total zooplankton each taxon represents at each location/period combination are also presented. Table 1 ranks the taxa by this percentage for both areas during both sampling periods.

The cross-shelf distribution patterns of the zooplankton taxa are presented in Appendix F. The mean density (per m^3) found in each block/stratum combination is presented.

A general description of the community and the natural history of the component taxa is presented elsewhere (Barnett, 1987).

Test on

3.2. 1. BACIP tests on abundance

3.2.1 a. Notes on the presentation of the test results

The BACIP test procedure was used to detect abundance changes in zooplankton (see Interim Technical Report Vol 2, for a discussion of the rationale and design of the Before-After-Control-Impact-Paired test procedure). Note that the BACIP test results presented in this report are those based on the log transformation (of a number of equally appropriate log transformations) which gave the lowest alpha, or most significant result. We recognize that selecting in this

manner may overestimate the occurrence of significant test results. However, by following this procedure we feel that all potentially affected species will receive further consideration.

It is also important to note that the reported estimate of percent relative change is based on the geometric means associated with the log transformation used in the BACIP test procedure, and not on the arithmetic means of the abundances observed at the various locations and periods. We therefore present the geometric means in the discussion of the results for each taxon (below). The arithmetic means are presented in Appendix E.

We calculate the percent relative change in the following manner:

The difference between preoperational and operational deltas, symbolically $\Delta\Delta$, based on log transformations, is equal to

$$(\log(t*s*U) - \log(t*k*U)) - (\log(U) - \log(k*U)).$$

U is abundance at SONGS in the Before period. k is the multiplier relating Control abundance to Impact abundance (location effect). If Impact and Control were of equal abundance in the preoperational period, k would have been 1. t is the multiplier due to changes in time, from preoperational to operational periods. t is the same for both Impact and Control. s is the multiplier due to SONGS operation and only affects Impact. If there was a 50% decline s would equal 0.5. In the preceding equation, U and factors k and t cancel out.

Thus,

$$\Delta\Delta = \log(s).$$

Back-calculating s from the $\Delta\Delta$, the relative percent change is given by

$$(\text{antilog}(\Delta\Delta)-1) \times 100.$$

In many cases, the estimate of percent relative change is not precise. Because zero abundances occur at times, a small constant is added to the log transformation. Estimates of percent relative change can be sensitive to the constant chosen, particularly in those species whose survey-by-survey data have a high proportion of zeros at either Impact or Control location. We will present the range of percent changes associated with the transformations which pass the assumption tests of the BACIP procedure. Also note the asymmetry in the reported percent increases and decreases. While a doubling is a 100% increase, a halving is a 50% decrease. Increases can exceed 100%, but decreases cannot. (Percent changes are translated into "factors" or "folds" in Appendix G).

Note that for the species discussed below, detailed BACIP test results, a figure of the survey-by-survey deltas, and either a figure or a listing of the survey-by-survey sampling data are presented in Appendix H.

3.2.2 b. Taxa tested for changes in abundance

3.2.2.1 *Holoplankton*

The BACIP test on abundance was conducted on all taxa enumerated except for two, the copepods *Eucalanus californicus* and *Rhincalanus nasutus*, which were

collected on only three Before surveys. Table 2 lists the 14 taxa of holoplankton tested. The combined taxon Total holoplankton was also tested. The significant ($p < 0.1$) test results are summarized in Table 3. We also present an estimate of the size of the relative abundance change for these same taxa. Under these criteria of reporting, one species obtained an alpha level of less than .05 (the cladoceran *Evadne spinifera*) and one obtained an alpha level between .05 and .10 (*Evadne nordmanni*).

Evadne spinifera

The BACIP results indicate that the abundance of this cladoceran decreased in the Impact area since the onset of Plant operation. This relatively uncommon species was the only taxon in which a significant decrease was detected. It accounted for 0.86% (at Control) and 0.34% (at Impact) of the zooplankton during the Before period and 0.30% (at Control) and 0.14% (at Impact) during the After period. The geometric mean abundances, percent relative change, and alpha level of the test were:

	Impact	Control	% change	P
Before	5.12	7.12		
After	0.98	4.10	-45 to -66	0.02

This species was the only taxon whose deltas exhibited a significant trend with time in the After period. The trend indicates that the relative decrease observed at Impact became larger with time in the After period (see Appendix H for a figure of the survey-by-survey deltas).

Evadne nordmanni

This cladoceran increased in abundance in the Impact area. It accounted for 1.12% (at Impact) and 1.87% (at Control) of the zooplankton during the Before period and 1.90% (at Impact) and 3.86% (at Control) during the After period. The geometric mean abundances, percent relative change and alpha level of the test (Mann-Whitney U) were:

	Impact	Control	% change	P
Before	12.82	16.45		
After	20.24	15.39	68	0.058

3.1.2.2 *Meroplankton*

All taxa enumerated were tested with the BACIP procedure (Table 2). The combined taxon, Total meroplankton, was also tested. A significant ($p < 0.05$) result was obtained for Total meroplankton (see Table 3 for summary of results). Other results ($0.05 < P < 0.10$) were obtained for Cirriped nauplii (a larval stage of barnacles), Cyphonautes larvae (bryozoan larvae), Unidentified meroplankton, ~~and Total meroplankton.~~ All demonstrated relative increases at the Impact site during the After period. The taxa are discussed below in order of their abundance.

Total meroplankton

When all meroplankters are combined, the test result indicates an increase in the Impact area. Meroplankton accounted for 6.3% of the zooplankton when averaged over both sites and periods.

The geometric mean abundances, percent relative change, and alpha level of the test were:

	Impact	Control	% change	P
Before	150.9	195.7		
After	313.2	241.8	64	0.029

Unidentified meroplankton

This taxon is composed of the larval stages of unidentified benthic invertebrates of many taxa. The test result indicates an increase at the Impact site in the After period. During the Before period this taxon accounted for 1.75% (at Impact) and 2.45% (at Control) of the zooplankton, and during the After period it accounted for 6.19% (at Impact) and 3.47% (at Control). The geometric mean abundances, percent relative change, and alpha level of the test were:

	Impact	Control	% change	P
Before	52.54	71.98		
After	164.30	134.10	+ 68	0.07

Cyphonautes larvae

The BACIP results for this combined taxon (the larvae of unidentified bryozoans) indicate an increase in the Impact area. This taxon accounted for 1.89% (at Impact) and 2.85% (at Control) of the zooplankton in the Before period and 2.83% and 2.19% in the After period. The geometric mean abundances, percent relative change, and alpha level of the test (Mann-Whitney U) were:

	Impact	Control	% change	P
Before	60.64	70.19		
After	83.68	70.26	+ 38	0.093

Cirriped nauplii

This taxon, composed of the naupliar stage of unidentified barnacle larvae, increased in abundance in the Impact area. It accounted for 0.69% (at Impact) and 0.46% (at Control) of the zooplankton during the Before period and 0.24% (at Impact) and 0.16% (at Control) during the After period. The geometric mean abundances, percent relative change, and alpha level of the test were:

	Impact	Control	% change	P
Before	10.05	9.86		
After	5.57	2.34	69 to 134	0.054

3.2.3 2. BACIP test using current direction

The preceding BACIP analyses test whether, averaged over all current conditions, the abundance of zooplankton has changed at the Impact site relative to Control. To test whether these results were biased against detecting Plant effects compared to samples taken only when the prevailing longshore current direction places the Impact site "downstream" of the diffusers, we sorted the surveys in both Before and After periods by current direction and performed BACIP tests on the two sets of surveys.

The results are summarized in Appendix I. Because sample sizes are decreased when sorted by current direction, the power of the test is lessened and changes in the alpha levels of the test are not particularly informative. More telling, if consideration of current direction was critical to the detection of Plant effects, are differences in the indicated direction (increase or decrease) of the abundance change. As can be seen, the direction of the indicated abundance change obtained on dates when the longshore current flowed upcoast ("plume" dates), are the same

do disagree →

as obtained when data from all sampling dates are used. These results corroborate the results of the BACIP analyses using all survey dates.

3.2.4
3. Test of hypothesis of 50% decline

One of the goals of the MRC's zooplankton program was to be able to detect 50% reductions in the abundance of plankton in the vicinity of SONGS. When we do not detect a significant effect on a taxon, we can ask: Can we confidently say (at an alpha level of 0.10) that a 50% reduction did not occur? To answer this question we test the null hypothesis of the specified percent reduction (eg. 50% or greater) against the alternative hypothesis of a smaller reduction (or increase). We do so by reducing the Before abundance values found at SONGS by the specified percentage and testing against the After abundance values. (This is akin to the standard statistical procedure of testing a null hypothesis $u = c$ when c does not equal zero, by subtracting c from each sample value.) Had a 50% (or more) decline occurred in the After period, we would fail to reject the null hypothesis. On the other hand, rejection of the null hypothesis demonstrates that the change observed in the BACIP comparison was indeed not a 50% (or greater) reduction (at an alpha level of $P=0.1$). The results of these tests are presented in Appendix J.

3.3
B. Phytoplankton

A significant ($p < 0.1$) relative change between Impact and Control in the average cross-shelf concentration of the chlorophyll was not observed. See Appendix H for detailed results of the BACIP test.

3.4

C. Distributional Changes

One of the predicted effects of the operation of SONGS on the zooplankton community was an offshore movement of nearshore individuals by the seaward flow of water entrained by the Plant's discharge. Examination of the distributional patterns of the zooplankton taxa (Appendix B) indicates that most of the taxa enumerated are found across the cross-shelf transect. However, several taxa appear to be somewhat restricted to the areas corresponding to the offshore location of the diffusers (A and B blocks), and these taxa are the ones expected to be at greatest risk to offshore movement. Specifically, the copepods *Acartia clausi* and *Oithonna oculata*, Cypris larvae, and the cladocerans *Evadne nordmanni* and *Podon polyphemoides*, appeared to be found predominantly in the A and B blocks in the Before period. *Oithonna oculata* was the taxon which had the most restrictive nearshore distribution in the Before period with most individuals found in A block. The expected action of the discharge was to move plankton from A to B Block and from AB Block to C block.

We tested for distributional shifts by comparing the proportions of the cross-shelf abundances found in the offshore blocks at both Control and Impact in both the Before and After periods.

The test procedure is as follows: On each survey the abundances in A and B block are combined. These data and the abundance in C block are then transformed (log transformations). The C abundance value is then subtracted from the AB abundance value. The resulting difference from the Control line is then subtracted from the corresponding difference from the Impact line. These final differences (or deltas) from the Before surveys are compared to those from the

After surveys using the BACIP procedure.

The same taxa tested for changes in abundance were tested for changes in cross-shelf distribution. Two taxa demonstrated a change: Total Zooplankton ($p=0.036$) and Cypris larvae ($p=0.05$). Both of these taxa displayed a greater relative proportion in the nearshore AB block at the Impact site than at the Control site during the After period.

The percentages of Total Zooplankton in the AB blocks were:

	Control	Impact
Before	59.1	51.1
After	50.5	56.6

The percentages of Cypris larvae in the AB block were:

	Control	Impact
Before	62.0	78.0
After	78.5	84.6

Please note that the percentages shown here (and below) are those of the abundances summed over all surveys. The test, however, was performed on survey-by-survey distribution data as described above.

A second analysis, using the same procedure, was performed testing for shifts between A and B block. Again, the same taxa were tested and two displayed significant changes in the relative proportions found in A and B block, Cypris larvae ($p = 0.008$) and Unid. meroplankton ($p = 0.041$). Both of these taxa demonstrated an increase in the relative proportion found in B block on the Impact transect in the After period.

The percentage of Cypris larvae found in B block was:

	Control	Impact
Before	68.7	48.8
After	38.0	72.3

The percentage of unidentified meroplankton found in B block was:

	Control	Impact
Before	85.4	74.6
After	76.8	77.0

3.5 D. Estimation of Intake Loss

The average annual loss to intake withdrawal was calculated by averaging the density of plankton in the water column at or near the intake depth over several years and then multiplying this number by the volume of water withdrawn under specific operating conditions and periods.

In general, plankton abundances have strong seasonal patterns. In the face of such seasonality, the estimate of the yearly average would be influenced by the relative number of samples taken during periods of low and high abundance. To avoid this potential bias, the year was divided into two seasons, fall-winter (September-February) and spring-summer (March-August), and two seasonal averages determined for each year. These seasonal averages were then averaged to give the average "intake density" for that year. Table 4 presents the seasonal average intake densities of Total Zooplankton for the years 1976 through 1986 (except 1981 when too few samples were taken).

The average annual density was obtained by averaging over all years. This density was then multiplied by the volume of water withdrawn to arrive at the average annual intake loss. In making this estimate we have assumed that there will be no large seasonal difference in the long-term pumping rates of the new units. During the After period the average daily pumping rates for the two seasons were 70% (fall-winter) and 83% (spring-summer). If these seasonal differences in pumping rates continue, and if spring-summer plankton abundances continue to be, on average, greater than fall-winter, the procedure followed underestimates the loss by approximately 5%.