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VOLUME III

STATISTICAL ANALYSES:

ESTIMATED PHYSICAL CHANGES DUE TO SONGS

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We are submitting a revised version of Volume III-1 entitled "Statistical Analyses: Estimated Physical Changes Due to SONGS". In this revised version we have included Upstream-Downstream and BACI analyses on the logarithm of irradiance as well as BACI analysis on temperature and seston. This revision of Volume III does not take full account of all reviewers' comments received so far. This will be done in the complete draft to be submitted on September 30, 1987. The treatment of results in 1.5 with low significance levels is unsatisfactory and will be revised in the September draft.

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STATISTICAL ANALYSES: ESTIMATED PHYSICAL CHANGES DUE TO SONGS

1.0 UPSTREAM-DOWNSTREAM ANALYSES

1.1 INTRODUCTION

Beginning in late 1983, a number of stations with instruments to record currents, irradiance and temperature were installed in the vicinity of SONGS, at the locations shown in Figure 1-1-1, to implement a plume-monitoring program for the MRC. This program was specifically designed for the difficult task of looking for statisticallysignificant physical changes attributable to the operation of SONGS, separating them from the coherent natural changes and random fluctuations that largely dominate the histories of physical variables off San Onofre.

Since the opportunities to make comparison measurements at times when SONGS was not operating would be limited to occasional shutdowns after 1983, the program was designed to compare measurements at times when a station was in the plume of SONGS Units 2 and 3 with those at times when the station was not in the plume, by a scheme called Upstream-Downstream analysis.

Here the term "plume" means the body of water discharged and entrained by the SONGS diffusers within some chosen span of time preceding the time of measurement. The boundaries of the plume are

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generally ill-defined, and it would certainly be very difficult, conceptually or practically, to determine with high accuracy that a given place is in or out of the plume at a given hour. For a feasible approximation, measurements were classified as in the plume (Plume) or out of the plume (Ambient) by applying a simple model for the behavior of the plume. The premises of this model are these: the advection of water in the plume is given by the current history recorded in the vicinity, with an added offshore velocity due to the original momentum of the discharge; the dispersion of water outward from the sides of the plume is given by Okubo's expression (1974) for the spreading of dyepatches in the sea. Using this model, the water at a station at a given hour is back-tracked by adding up displacements hour by hour until the back-trace crosses an operating diffuser line; the time elapsed since the most recent crossing is called the plume age of the water at the original place and time of a measurement. Measurements are classified as Plume or Ambient by whether the plume age is or is not less than a chosen cut-off age, which was taken as 10 hours in the analyses reported here. Details of this plume model are given below in 1.2.

Besides the plume model, these analyses also require a model for the nature of the SONGS effects and the natural effects that are to be separated from them. Consider two stations called N and S, one north of the diffusers and one south, and two sets of data, a set denoted by (0) from times when N was Ambient and S was Plume, and a set denoted by (1) from other times when N was Plume and S was Ambient.

a Sa Sa

 $N_{0} = \frac{1}{1} + A_{N} + \varepsilon$ $S_{0} = \frac{1}{1} + R_{S} + L + \varepsilon$ $N_{1}^{-2} = I + R_{N} + C + \varepsilon$ $S_{1} = I + A_{S} + L + C + \varepsilon$ Measurements of irradiance at the two stations and two sets of times are No-So= AN-Ps-L modelled linearly as:

(PN-ANKPS to)

 $N_0 = I + A_N + \epsilon$ $N_1 - S_1 = P_{N-A_S} - L$ $\mathbf{N_1} = \mathbf{I} + \mathbf{P_N} + \mathbf{C} + \mathbf{\epsilon} \left[\left(\frac{1}{2} - \frac{1}{2} \right) - \left($ $S_0 = I + P_S + L + \varepsilon$ $S_1 = I + A_S + L + C + \varepsilon$ in which $N_1 - S_0 = (P_1 - P_2) - (P_1 - P_2)$ (NI-SI- Wiele PN-AS=AN+PR

- •I is a constant irradiance,
- •A_N is the added irradiance due to SONGS at the north (PN + KS) (RN + KS)station when this station is Ambient,
- $\cdot A_s$ is the same, at the south station,
- $\ensuremath{^{\bullet P}}_N$ is the added irradiance due to SONGS at the north station when this station is Plume,
- ${}^{\bullet}\mathrm{P}_{S}$ is the same, at the south station,
- C is the natural difference between the times in the different sets (0) and (1), which may be due to the differences between currents at different times or to any other natural changes with time,
- •L is the mean natural difference of irradiance between the tow stations due to their different locations, and
- ε is a random fluctuation averaging to zero.

As the equations show, the natural time-difference C is taken to be the same at both stations, and the natural location-difference L is taken to be constant over time. Both kinds of natural difference are potentially much too large to leave out of the model; what the model must assume is that there are no natural differences between times

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(other than the fluctuations that average out) that are unequal at the two stations.

This is a system of four equations in seven unknowns, which cannot be solved for each of the unknowns. The partial solution that can be obtained by subtraction and averaging of the equations is:

 $\Delta \overline{\Delta} = \overline{\Delta}_{1} - \overline{\Delta}_{0} = (\overline{N_{1} - S_{1}}) - (\overline{N_{0} - S_{0}}) = (P_{N} - A_{N}) + (P_{S} - A_{S}),$

which is twice the average over the two stations of the SONGS-induced difference in irradiance between Plume and Ambient times. $LZ/2 = \int_{-\infty}^{\infty} \left(\left(c_{N} - A_{N} \right) + \left(c_{N} - c_{N} \right) \right) / 2$

This measure of SONGS' effects on irradiance is the best that can be obtained in the presence of large and unknown C and L, unless there also are enough data sets from times when SONGS was not operating, and with one station at a distance beyond the influence of SONGS, to provide four more equations (with one more unknown from the natural time difference between QN and OFF periods) so that the whole system can be solved to give P and A effects at the near station separately, instead of their difference. $F_{0} = T + M + \varepsilon$

Some analyses of this kind are described in 1.5 below. The necessary assumption that there are no time changes acting unequally on the two stations becomes weaker with distance, though, and it seems likely that these ON/OFF analyses with a distant station do in fact strain this assumption.

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Meanwhile it is most important to remember that the irradiance changes $\Delta\bar{\Delta}/2$ reported here are the estimated differences between Plume and Ambient times due to SONGS, averaged over both stations. These are not generally the same thing as the aggregate effect of SONGS over the whole period of observation, averaged over both stations. To relate the two requires further knowledge or assumptions about the separate P's and A's, and also about the effects of SONGS at the stations at times when neither station was in the plume.

Direct estimates of the aggregate SONGS effects at some stations are given by the BACI analyses reported in 2.0. These are derived by overall comparisons of long spans of time before and after SONGS began operation, so the results are only comparable with long-term averages of (P-A). A comparison of these BACI results with the overall Upstream-Downstream results from 1.6, leading to separate estimates for \overline{P} and \overline{A} , is given in the final section 3.0.

1.2 The Plume Model for Classifying Observations

The actual computations for classifying an observation made at the MRC coordinates (X, Y) and hour t as Plume or Ambient were done in the following steps by a program named PLUME.SAS.

The longshore coordinate X_W at t of water that left the diffusers n hours before t was computed as $\frac{1}{2} \frac{\chi(t)}{3}$

$$X_{W}(t,n) = X_{W0} + \sum_{k=0}^{n} -V_{t-k}\Delta t$$
,

Xwo

trn

where V is hourly mean longshore current (m/hr, with positive V directed toward negative X) derived from local records as described later on; $\Delta t = 1$ hour, and $X_{WO} = +350$ m, taken to be the MRC X-coordinate of both diffusers. For every hour t, X_W was computed for n = 0, 1, 2, ..., and for each n the results were tested against the condition

> $X_W 0 \leq X(l) \leq X_W |$ $X_W(n,t) < X(t) < X_W(n+1,t) \text{ for } X > 0$

or

$$X_W(n,t) > X(t) > X_W(n+1,t)$$
 for $X < 0$.

If the condition was satisfied for n (meaning that water discharged in the nth hour before t crossed the X-coordinate of the station in the hour t), the cross-shelf coordinates Y_{WL} and Y_{WU} at t of water discharged at t-n from the inshore (L) and offshore (U) ends of the

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operating diffusers were computed by the model

and
$$Y_{WL}(n,t) = Y_0 - \sigma + \sum_{k=0}^n (U_{t-n} + U_D) \Delta t$$

and $Y_{WU}(n,t) = Y_{WL} + 2\sigma + L$,

where Y_0 is the MRC Y-coordinate of the inshore end of the most inshore operating diffuser (that is, Unit 3 if only Unit 3 is operating and Unit 2 if both or only Unit 2 are operating); U is hourly mean longshore current derived from records in the same way as V (m/hr; positive Y and U are directed onshore); $U_D = -180$ m/hr, taken to be a constant additional offshore velocity imposed by the momentum of the discharge; $\Delta t = 1$ hour, as for X_W ; L is the length of one diffuser if only one is operating, or the combined length of the two if both are operating; and $\sigma = 10.8$ n^{3/2} (m) is the standard deviation of distance of particles dispersing in the sea over n hours from the ends of the diffusers, derived from a relation given by Okubo (1974), discussed below.

As we said, $Y_{WL}(n,t)$ and $Y_{WU}(n,t)$ were computed for the first n that satisfied the condition on X. These were then tested against the condition $Y_{WL}(n,t) > Y(t) > Y_{WU}(n,t)$ (all station Y's are negative). If this condition on Y is also satisfied, besides the condition on X, it means that the station at (X,Y) at hour t lies within the boundaries of the part of the model plume that left the diffusers within hour t-n. At the smallest value of n for which both conditions were satisfied, the hour t was assigned a plume age of n hours, and the computations were started over for the next hour (t + 1).

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When both conditions were not satisfied for $n = 0, 1, 2, 3, \ldots$, the computations were cut off at a specified n, and no plume age was assigned to t at that location. At the final stage of actually classifying measurements as Plume or Ambient, a further cut-off was applied. In the analyses reported here, measurements at X, Y, t with plume age n < 10 hours were classified as Plume, and those at x, y, t with $n \ge 10$ hours, or with no assigned value, were classified as Ambient.

To produce a series of representative hourly values of ambient V and U for these computations, with as few data gaps as possible, V_t and U_t were formed by averaging the means for hour t from the records of several current meters at 3 m depth. The locations used for these averages in different years were:

> 1984: UVT08, UVT09, UVT10, UVT11 1985: UVT01, UVT11, UVT12, UVT13 UVT14, UVT17, UVT18, UVT19 1986: UVT13, UVT14, UVT17, UVT18

These locations are shown on the station map Figure 1-1-1; they are symmetrically disposed about SONGS. The stations of choice would be UVT 13, 14, 17, and 18, as in 1986, bracketing SONGS but probably not much influenced by plume velocities; the closer stations were used by necessity in earlier years because these stations were not yet installed. All stations on the list for a given year that were operating in hour t were included in the average for that hour.

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The offshore velocity $U_D = -180 \text{ m/hr}$ or -5 cm/sec, chosen as a constant to represent the offshore momentum of the plume itself, was derived from inspection of dye-trajectories in a hydraulic scale-model of the SONGS diffusers (Koh, et al, 1974, Figures 6.3-6.7), with corroboration of its general magnitude from many field observations. The classification of hours as Plume or Ambient did not turn out to be very sensitive to moderate variations of U_D .

(2.5×10-11m

very sensitive to moderate variations of U_D. G = (C, z) + U = 2.5 + 10.6 +

These representations of the effects of plume momentum and dispersion are certainly inexact, but they come from arguments that have nothing to do with the data points being classified. The chosen cut-off time of n < 10 hours is an arbitrary element, resulting from tuning the model in early trials, but the classifications are not strongly sensitive to small variations of the cut-off around 10 hours. At ages considerably larger than 10 hours, the condition on Y becomes easy to meet because of the growth of σ , and the conditions revert ultimately to a simpler criterion depending only on X and X_W .

6= (C1 2) 2 7 32

Actual plumes vary widely in dilution as well as location, and we should consider the effects of expressing plume influence as a dichotomy between present or absent. We can envisage an actual plume effect as P(g), depending on the fraction g of plume-water (perhaps weighted by age) at a time and place. If we could measure g, we would probably look for P by a linear regression, modelling P(g) by Bg and \overline{P} by Bg. The dichotomy essentially models P(g) by a step-function, 0 for g between 0 and 1-f_p, and Δ for g between 1-f_p and 1, f_p being the fraction of data points classified as Plume, and Δ the difference of means between classes; the dichotomy models \overline{P} by f_p Δ Δ An ideal dichotomy would give f_p = \overline{g} for any data set, and would be equivalent to a linear regression, giving b = Δ . The minimum requirement for an acceptable dichotomy is that it should give f_p non-decreasing with \overline{g} when applied to many data sets.

If the actual P(g) is reasonably linear, so as to be well-fitted by a linear regression model, Δ will be reasonably independent of variations in the fraction f_P resulting from the use of stringent or lax criteria for classifying a point as Plume. A search for bias in the estimates of \overline{P} given by a particular classification-scheme must be directed to interactions of the scheme with non-linearities in the actual effect.



1.3 Statistical Methods

The data sets of hourly irradiance values that are compared in these analyses show a high degree of autocorrelation; the departure from the mean of a value (or a difference) at a given hour is not independent of the departures in previous hours. When autocorrelation is present in the data, ordinary least-squares estimates are not efficient: even with large samples, the standard error is underestimated and the significance of an estimated difference is overestimated (the value of p is too small).

The method adopted to find proper p-levels for estimates drawn from these data sets was to recast the model of the SONGS-induced and natural effects discussed above in 1.1 into a linear regression model with autocorrelated errors, as follows: taking the data sets denoted by (0) and (1) in 1.1 together, the irradiance difference (N-S) for a given hour t is expressed as N-S = $\Delta(t) = B_0 + B_1W(t) + e(t)$, with

 $e(t) = A_1 e(t-1) + A_2 e(t-2) + A_3 e(t-3) + \varepsilon(t)$.

In this expression, B_0 and B_1 are constants, and W(t) is an indicator variable that takes on the value 0 for hours in the data set (0), when S is classified as Plume and N as Ambient, and takes on the value 1 for hours in the data set (1), when N is called Plume and S Ambient. The north-south differences in the error terms in 1.1 are written as e(t), a sum of previous error differences, each multiplied by a constant coefficient A_n for its lag of n hours, plus a final term $\varepsilon(t)$ representing independent normal errors.

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Apart from the treatment of error terms, this regression model is equivalent to the model 1.1, and the physical assumptions about the nature of SONGS-induced and natural changes are exactly the same. The average over all the hours with W=0 gives $B_0 = N_0 - S_0 = A_N - P_S - L$; the average over all the hours with W = 1 gives $B_0 + B_1 = N_1 - S_1 = P_N - A_S - L$; and the difference of the two averages gives $B_1 = (P_N - A_N) + (P_S - A_S) = \Delta \overline{\Delta}$ in the notation of 1.1. The natural current-effect or time-effect C is eliminated at the outset in this model by starting with the differences of paired observations at the north and south stations in the same hour.

The necessity, and the value, of the regression model comes from its ability to estimate each of the constants B_0 , B_1 , A_1 , A_2 , and A_3 in the presence of all the others, and to test each one separately for significant departure from zero.

The actual regression analyses were carried out by the SAS procedure PROC AUTOREG (SAS/ETS User's Guide, 1984, pp. 189-195), using the option of maximum-likelihood estimation strongly recommended by the Guide for data sets with many missing values. This SAS routine provides estimates of each constant, with its standard error, t-value, and p-value. The routine also provides, among other things, the total r^2 (the fraction of the variance of $\Delta(t)$ that is explained by the model), as a check that the model is actually suitable to the data sets.

As a preliminary to these analyses, the means and variances of hourly station differences in a number of data sets were computed for a

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succession of three-day periods extending over six weeks; these threeday means were examined for trends against time and against each other. No such trends were found in many trials, and we have assumed that all the data sets used in these analyses are stationary time-series, as is required for the valid use of a regression model with no secular term proportional to time. A large set of trial runs also showed that the coefficient A_3 was small and insignificant enough to be disregarded, and this term was dropped from the model. The important question of additivity in the data sets is treated in 1.6 below, and again in 2.1, in the discussion of BACI analyses.

As a final step, the residuals from the model were examined. There were occasional very large outliers, out to 9 standard deviations from zero, and a good number at 3 or 4 standard deviations, indicating that the residuals are not generally normal. We have taken no further steps to deal with these.

1.4 Results of Upstream-Downstream Analysis of Irradiance

Each of Figures 1-1-2 through 1-1-12 gives plots of four variables throughout a year at one station. The uppermost plot is simply the daily mean irradiance recorded at the station, in E/m^2 -day. The second plot gives an estimate every seventh day of $\Delta\bar{\Delta}/2$ at the station, from analysis of a period of 28 days centered around the day in E/m^2 -hr. The third and fourth plots give the fractions f_p of daylight hours (defined as hours with recorded I > .01 E/m^2 -hr) and of all hours that were classified as Plume by the model given in 1.2. This distinction is necessary in studying relations between f_p and $\Delta\bar{\Delta}/2$ because the plume of course does not affect irradiance in the absence of sunlight.

Since $\Delta\bar{\Delta}/2$ is an average over many daylight hours, it can be approximately converted to E/m^2 -day for comparison with the plot of mean daily irradiance simply by multiplying $\Delta\bar{\Delta}/2$ by 10, which is about the average number of daylight hours (as defined here) per day in the data sets.

Recall that $\Delta \overline{\Delta}/2$ plotted for a station is actually the average of P-A over the station and a counterpart on the other side of the diffuser lines. Whenever possible, the counterpart station was chosen to be at the same water depth and distance from the diffusers as the station it matched. Other stations were used as counterparts when it was necessary to fill data gaps, in the following orders of preference: in 1984, PS1 was the counterpart of choice for all the stations in SOK, with L45 as a

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STATION	COUNT	ERPART		
	1	2	3	
SOKU45 and SOKD45	PL45	PN	PIN	
SOKU35	PN	PIN	PL45	
SOKD35	PIN	PN	PL45	

second choice; in 1985 and 1986, counterparts were chosen by the table below.

The locations of all these are shown in Figure 1.

The plots of $\Delta\overline{\lambda}/2$ in Figures 2 through 12 show a nearly continuous history of negative P-A, a reduction of irradiance in Plume hours relative to Ambient hours at all four stations in SOK and their counterparts. This effect is on the order of -0.06 E/m^2 -hr, sometimes two or three times larger, and is mostly found at a significance-level of $p \leq .05$. Here it is worth reiterating that the model which leads to these results eliminates any consistent natural changes C due to correlation of irradiance with current-direction, say, so that the effect (P-A) must be attributed to something that lies between the station and its counterpart. This point is discussed further in 1.6.

1.5 Upstream-Downstream-On-Off Analyses

During 1984 and 1985 there were five periods of 15 to 35 days in which both of SONGS Units 2 and 3 were out of operation, to the extent that no heat was generated and the pumping rate for both units together was half or less of the rate for full operation. There were no such periods in 1986.

By comparing data from these OFF periods with data from adjacent periods of full operation, and using a distant station for the north station, we can set up a model like that in 1.1 to give a fully soluble system of eight equations in six unknowns. Denoting the data sets from OFF periods by primes, these equations are:

$N_0 = I + \varepsilon$	$N_0' = I + T + \varepsilon$
$N_1 = I + C + \varepsilon$	$N_1' = I + C + T + \varepsilon$
$S_0 = I + P_S + L + \varepsilon$	$S_0' = I + L + T + \varepsilon$
$S_1 = I + A_S + L + C + \varepsilon$	$S_{1}' = I + L + C + T + \epsilon$

The unprimed equations are those of 1.1, with P_N and A_N set equal to zero because the north station is distant from SONGS. All the notation is the same as in 1.1, except that a new constant T appears in the primed equations, expressing a natural difference between the ON and OFF periods which is taken to be the same at both stations. These equations give $P_S = (S_0 - S_0') - (N_0 - N_0')$ and $A_S = (S_1 - S_1') - (N_1 - N_1')$, even if we relax the assumption that the natural current-effect C is the same at both stations.

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The equivalent model used in the statistical analyses to deal with autocorrelated errors is a recasting of this model like that described in 1.3, now using three indicator variables to distinguish among the eight data sets. That is,

 $\Delta(t) = N-S = b_0 + b_1F + b_2G + b_3H + e(T)$,

in which F, G, and H are indicator variables taking on the values zero or one according to the following table.

					F	G	H
	SONGS	OFF,	S	AMBIENT	Q	0	0
	SONGS	OFF,	S	PLUME	1	0	0
	SONGS	ON,	S	AMBIENT	0	1	0
•	SONGS	ON,	S	PLUME	0	0	1

In this form of the model, $-b_2$ is the estimate of A_S , the mean SONGS effect on the south station in hours when it is classified as Ambient; $-b_3$ is the estimate of P_S , the mean SONGS effect on the south station in hours when it is classified as Plume. If the assumption that the natural change T is the same at both stations does not hold, then $-b_2$ estimates $A_S + (T_N - T_S)$ and $-b_3$ estimates $P_S + (T_N - T_S)$; that is, the same unknown error is added to the estimates of A_S and P_S . The discussion of statistical methods in 1.3 applies equally to this model and its application, since the only difference between the models is in the number of indicator variables.

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The available OFF periods were:

JAN	13-FEB	11,	1984	,	30 days;
JUN	16-JUN	30,	1984	,	15 days;
OCT	28-DEC	1,	1984	,	35 days;
JAN	26-MAR	1,	1985	,	35 days;
NOV	16-DEC	1,	1985	,	15 days;

Corresponding ON data sets were formed by bracketing each OFF period of days with about half as many ON days or more from immediately before and after. So far as data were available, comparisons were made for each of the five periods; for each of the stations SOKD45, SOKD35, SOKU45, and SOKU35, each at two levels, on the bottom and 2 m above botton; and using each of the stations SMK45, PMRN, PMRS, and BK55 at the corresponding level for the control station (which need not actually be north of SONGS or the other station).

There were enough data to run 55 of all these combinations. Of these runs, 28 gave no estimates of either P_S or A_S with p < .33, and in general were not considered further. The OFF period 16-30 June, 1984, for which only SMK45 was available as a control, gave significant large positive estimates of A_S : +.18 E/m^2 -hr (p = .015) at SOKD45; +.23 (p = .015) at SOKD45; +.23 (p=.016) at SOKD35, + .11 (p=.10) at SOKU45, all at the level 0 m off bottom. The corresponding estimates at 2 m above the bottom were definitely not significant: -.04 (p = .52) at SOKD45, + .19 (p = .38) at SOKD35, and +'.10 (p = .71) at SOKU45. The irradiance records for June and July of 1984 (see VI-3) show two large individual

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peaks of irradiance within the OFF period occurring at both levels at SMK45; at the stations in SOK these peaks were less strong at 2 m above bottom and weak or absent at the bottom. The estimated positive A_S appears to be due to a relative suppression of irradiance at SOK in a special subset of the OFF days, rather than an enhancement at SOK in ON days; on these grounds, it is easier to accept this effect as a $(T_N - T_S)$ arising from the failure of an assumption than to take it as an effect of SONGS on the SOK stations when SONGS is operating and the stations are not in the plume.

All the other estimates of A_S with p < .33 averaged to + .024 E/m^2 hr; 13 were positive and six negative. Estimates of P_S with p < .33 averaged -.032 E/m^2 -hr; 7 were negative and 1 positive. Taking only the estimates with p < .10, the estimates of A_S averaged +.037 (6 positive, 3 negative) and the estimates of P_S averaged -.049 (6, all negative).

Only five runs gave estimates of both P_s and A_s from the same data sets with one having p < .10 and the other having p > .33. The results from these (with p-levels in parentheses) are:

^P s	A _S	
014 (.32)	024 (.09)	
014 (.19)	019 (.08)	gri fili Anna a Anna An
035 (.04)	027 (.13)	
039 (.09)	071 (.18)	P
080 (.10)	044 (.21)	

The first three of these pairs are from the same location and period (SOKU 45 at the bottom, Jan.-Feb. '84) with different controls (SMK, PMRS, BK, in order). The other two are from other and different places and periods, with BK as the common control.

In contrast to the Upstream-Downstream analyses of close stationpairs in 1.2, which produced a three-year month-by-month calendar of consistently negative estimates for P-A, mostly significant at the level p < .05, the Upstream-Downstream-On-Off analyses do not lead to any conclusive results unless one refuses to discount the results of June-July 1984. <u>1.6</u> <u>Overall</u> <u>Upstream-Downstream</u> <u>Analyses</u> <u>of</u> <u>Irradiance</u> <u>and</u> <u>the</u> <u>Logarithm</u> <u>of</u> <u>Irradiance</u>

The results given in 1.4 above show smoothed histories of (P-A) at four stations in SOK. In this section, the data for each station in the separate years 1985 and 1986 are combined to estimate the average for the station and year. These analyses have been carried out for the irradiance I, and also for its natural logarithm lnI. To show the reason for this, and to interpret the results, we must consider the assumptions of the model in 1.1 more closely, from the point of view of the additivity of the data sets.

It was noted in 1.1 that the model must assume that natural changes between times in state (0) and times in state (1) are the same at both stations. That is, the mean natural difference between stations, after averaging out random fluctuations, must be constant over time, and the same for both states. This assumption is certainly not true in general for any variable that may be studied. To use the linear or additive model on a particular data set, this assumption must be validated by statistical testing of the data set, with or without the support of physical arguments about how the data is expected to behave.

The problem is most simply illustrated by considering a Before-After-Control-Impact study (see 2.0 below) to detect and estimate a powerplant effect on the abundance of some organism, though the principles are the same for the more complex Upstream-Downstream

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studies. Briefly, if the mean natural difference of abundance between Impact and Control locations, as observed Before the powerplant starts up, is indeed constant over time, then a change in this difference After the powerplant starts can be attributed to the powerplant. But it is possible or even likely that natural changes will increase or decrease abundance in proportion to the existing local abundance, rather than simply adding or subtracting the same number of individuals at each place. If this were so, and the additive model were used, natural changes could masquerade as powerplant effects: the means Before abundance at the Impact location, for example, might be twice that at the Control; an improvement in natural conditions might double both mean abundances in the After period, so that the difference would also be doubled; if there were no actual powerplant effect, the additive model would still indicate a positive powerplant effect equal to the original difference, simply because it is the wrong model for describing changes in abundance.

The right model for this example would be exactly equivalent to applying the additive model to the logarithm of abundance; the natural difference of the logarithms would be constant over time. This is an example of transforming the observed variable to additivity, to make the linear model applicable to the data. In general, the right model is not known in advance even if it can be surmised, and a common procedure is to test the variable and some one-to-one transformations (such as the logarithm and various powers of the variable) for additivity. A full discussion of transformations and additivity tests is given by Stewart-Oaten (1986).

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The material available for testing, without assuming any model or mechanism for powerplant effects, is the set of Before observations at Impact and Control stations. The Tukey test between station values is likely to be the same After as Before, even if both station values change considerably in the meantime, by seeing whether the difference of station values is correlated with their sum in the absence of the powerplant. This is done by a linear regression of the differences on the sums, and a test for significant departure of the regression coefficient from zero. This cannot prove the additivity of any variable or transformation, of course, but it can reject an assumption of additivity, or else leave it stronger because a search for evidence against it has turned up little or none.

In the Upstream-Downstream studies, there is no set of observations free of any powerplant influence, like the Before data in a BACI study, and data sets cannot be screened in advance for additivity as they can in BACI studies. However, the validity of results with respect to additivity can be examined in retrospect by seeing whether the results depend strongly on the transformation that is used. When the differences among stations and states are fairly small relative to the station values, logarithmic and power-law models become approximately additive, and the choice of transformation becomes less important as a source of error. As we will see below, the Upstream-Downstream results for whole years give essentially the same relative changes in irradiance whether the analyses are carried out on I or lnI, and there is no reason to believe that these results are seriously

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biased by failure of additivity. (The results of Tukey tests on irradiance data for BACI analyses are given and discussed below in 2.0).

The results of the yearly analyses are given in Table 1. For each location and year, the left side of the table lists $\Delta\bar{\Delta}(I)$, which is (P-A), and the relative irradiance change $\Delta(I)/I_{s1}$, in which I_{s1} is the mean of irradiance at the SOK station when its counterpart was in the plume. The right side of this table lists $\Delta\bar{\Delta}(\ln I)$ and the relative irradiance change $\Delta I/I = \exp(\Delta\bar{\Delta}(\ln I)) - 1$, in which I can be taken as the geometric mean of natural irradiance at either station, in the absence of powerplant effects. The significance levels of all the $\Delta\Delta$'s are p < .00001 except where larger values are noted in the table; all p's above .05 come from runs with 100 or fewer error degrees of freedom (the 35-foot stations in 1985).

The mean irradiance I_{s1} is not the same thing as the mean I defined here, and will be larger than I if mean A_s is positive. Keeping this in mind, we can see from the table that the relative irradiance changes (P-A)/I estimated from $\Delta\bar{\Delta}(I)$ and $\Delta\bar{\Delta}(\ln I)$ for the different locations and years are in total agreement as to sign and substantial agreement as to magnitude. Neither I not lnI may be strictly additive (see 2.0 below), but the irradiance differences dealt with here are small enough so that this does not matter.

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2.0 BEFORE-AFTER-CONTROL-IMPACT STUDIES

2.1 INTRODUCTION

A homogeneous set of hourly irradiance recordings at 0 and 2 meters above the bottom has been maintained, with some gaps, since mid-1981, at three stations in SOK and one in SMK which were kept clear of kelp canopy. These records provide material for Before-After-Control-Impact (BACI) studies like those carried out on abundances of organisms by MRC's biological programs.

The physical model for BACI studies on a variable Y is as follows, denoting Impact and Control locations by subscript I and C, and Before and After times by subscript B and A:

$Y_{CB} = Y + \varepsilon$	Northeast
$Y_{IB} = Y + L + \varepsilon$	
$Y_{CA} = Y + T + \varepsilon$	the t
$Y_{IA} = Y + L + T + E + \varepsilon$	n anna an Anna Anna Anna Anna Anna Anna

in which Y is the natural mean at Control, L is the natural difference due to location, T is the natural change between Before and After time, and E is the powerplant effect. For the mean Before and After station differences, this model gives $\overline{\Delta}_{B} = (\overline{Y_{I}} - \overline{Y_{C}})_{B} = L$ and $\overline{\Delta}_{A} = (\overline{Y_{I}} - \overline{Y_{C}})_{A} = L +$ E, so that $\Delta \overline{\Delta} = \overline{\Delta}_{A} - \overline{\Delta}_{B} = E$. The corresponding regression model for statistical analysis is

$$\Delta(t) = C_{0} + C_{1}W(t) + e(t) , \text{ with}$$

e(t) = D₁e(t-1) + D₂e(t-2) + ... + ε ,

in which the C's and D's are constants and W is an indicator variable set at 0 for t in the Before period and 1 for t in the After period. The coefficient C_1 determined by the SAS procedure PROC AUTOREG estimates the powerplant effect E, and the maximum-likelihood test for the significance of its departure from zero gives the significancelevel for this estimate.

Evidently, the physical model for BACI has the same form as the model for Upstream-Downstream analysis discussed above in 1.1. It is the same model, in fact, used now to estimate the aggregate powerplant effect E over the whole After period, instead of estimating the differential effect (P-A) for particular time spans. The regression model is also identical to that discussed in 1.3. The structure of assumptions about the constancy of the natural mean station difference is the same for BACI as for Upstream-Downstream analysis, and the need for additivity testing and perhaps for transformation of the variable applies equally to BACI, as discussed in 1.6. Tukey tests for additivity were carried out on the Before data sets.

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2.2 BACI Results for Irradiance and the Logarithm of Irradiance

The irradiance records analyzed by BACI are those from three stations in the San Onofre Kelp, SOKU45, SOKD45, and SOKD35, at 0 and 2 m above bottom, with records from the corresponding times and heights above bottom at station SMK45, in the San Mateo Kelp 5 km upcoast, used as controls for all the SOK records. A fourth station in SOK, SOKU35, was not treated by BACI because the site was not kept clear of kelp canopy, which could lead to large confounding effects on irradiance. The Before period included all data up through the end of 1982, comprising about a year and a half of recording; the After period included all data from the beginning of 1983 through the end of 1986. The variables treated were daily integrated irradicance I (Einsteins/m²-day) and its natural logarithm lnI.

Table 2-1 shows the following for each station and height: the maximum-likelihood estimate of the powerplant effect E on irradiance by PROG AUTOREG; the standard error of E and its p-level; and the p-level P_{NA} of a Tukey test for departure from additivity of the Before data set. Table 2-2 shows the same for logarithm irradiance.

The results in the table give no compelling reason to believe that the BACI analyses have detected a real powerplant effect on irradiance at any location. The only $\Delta\bar{\Delta}$'s of high significance are for lnI at SOKD45, which is obviously non-additive at the bottom and probably so at 2 m above; irradiance itself is most probably additive at SOKD45, but

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the $\Delta \overline{\Delta}$'s for irradiance here have very low significance. In general, this table shows nothing like the high consistency of signs and magnitudes between locations and between the variables I and lnI that is seen in the table of Upstream-Downstream results. Much of the inconsistency may be due to failures of additivity, which are probably more important in the BACI analyses than in the Upstream-Downstream analyses because the Before-After change in general irradiance levels was much greater than the average Upstream-Downstream difference.

The lack of significant results in the BACI analyses could be caused by an increase in the error variability of the BACI model due to plume effects. To see this, when the south station is in the plume, the irradiance level drops compared to when it is not in the plume. Therefore, the north minus south station irradiance differences used in BACI also change when the plume is over the south station relative to when the plume is not over the south station. These differences in irradiance levels are not included in the mean part of the BACI model, as they are in the plume model, these differences go into the error variance.

Depending on the different error variances at different locations, BACI analyses could detect powerplant effects of either sign from about 0.4 to 0.7 E/m^2 -day at the level of two standard errors, as long as the data do not overthrow a hypothesis of additivity. The upshot of the analyses is that no such effects have been detected at this level. The estimated effects are various, from -.37 to +.51 in I, and from -.13 to +.41 in lnI.

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2.3 BACI Results for Temperature and Seston Flux

The irradiance recordings described above in 2.2 were accompanied by hourly temperature recordings at the same locations. BACI analyses were carried out on daily means of temperature from these records, with the same periods of time, locations, and methods as described above for I and lnI. Also open-tube seston traps were set out at these same locations from 1977 onward; these traps were left out for periods ranging from a few days to three weeks, generally about two weeks, and the average height of accumulated seston in two or three traps at each location, divided by the number of days in the deployment, was given the name of seston flux, denoted by F . Since the dates of deployment and retrieval varied somewhat among stations, the data on seston flux were recast for BACI analyses into a set of equivalent successive two-week deployments, the same for all locations. The variable in the BACI analyses of seston flux F is the two-week mean rate of accumulation in mm/day; the periods and methods are the same as for I , lnI , and temperature T.

The results of BACI analyses and Tukey tests for non-additivity on T and F are given in Tables 2-3 and 2-4, which give $\Delta\overline{\Delta}$'s with their standard errors and p-levels, plus the p-levels of the Tukey tests, in the same form as Tables 2-1 and 2-2 for I and lnI.

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These tables show evidence, worth noting but not conclusive, of a SONGSinduced increase of temperature by about 0.4°C at 2 m above the bottom at the upcoast stations in SOK. Other than this, there are no powerplant effects on T or F of even marginal significance derived from data sets that can be presumed to be additive.

3.0 COMPARISON OF UPSTREAM-DOWNSTREAM AND BACI RESULTS

The Upstream-Downstream analyses of I and lnI for individual locations and years in 1.6 gave highly significant and consistent estimates of average (P-A), the difference between immediate SONGS effects in daylight hours when the station was in the model plume, and the effects in daylight hours when the station was not in the plume but its counterpart station was. The BACI analyses in 2.2 gave estimates of the overall effects of SONGS at the same locations, averaged over all the time when SONGS was operating. The BACI estimates are much less consistent among themselves; they are of low or marginal significance, or open to doubt because of probable non-additivity, or both. Nonetheless, these BACI estimates may be put together with average (P-A) to get very rough estimates of P and A separately.

In the language of 1.1 and 2.1, the overall powerplant effect found by BACI is $E = Af_A + Pf_P + M(1-f_A - f_P)$, in which A and P are the mean SONGS effects in daylight hours when the station is in the states called Ambient and Plume, and f_A and f_P are the relative frequencies of those hours. The new quantity M is the mean SONGS effect for daylight hours in a middle state in which neither the north nor the south staton was called Plume in the Upstream-Downstream analyses; data from these hours were not used in the analyses. There were so few hours with both stations called Plume that they are disregarded here.

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This equation can be combined with the difference D = (P-A), found by the Upstream-Downstream analyses, to say something about P and A separately, if we make some assumptions about the unknown M. We will do this only in a very general way, taking round averages from all location for lnI, which lets us combine different depths and avoids conversion of hourly to daily irradiance.

The adopted round averages are D = -.28 for lnl, and $f_A = f_P = .25$. These reduce the equations to P + A + 2M = 4E, and P - A = -.28. The overall value of E for lnl from the BACI studies is not well-determined. There is no good evidence that it differs from zero, and we will cut through the grave uncertainties of combining estimates with different significance-levels and different chances of error from non-additivity by taking E = 0 as the middling overall estimate, with E = +.07 and E = -.07 as illustrative bracketing values that are fully consistent with the BACI data.

The SONGS effect in the middling M state, with neither station in the model plume, can reasonably be presumed to lie between A and P. The middle state occurs most often when longshore current is weak and the plume goes offshore between the stations. These are the times when entrainment is least and the make-up flow is weakest, so M-effects due to the make-up flow should not be stronger than similar A-effects. On the other side, M-effects due to the presence of old plume water should not be stronger than p-effects due to newer plume water.

With these presumptions, we solve the equations for the three cases M = A, M = (P+A)/2, and M = P. The results are shown in the table below.

		M = A	M = (P+A)/2	M = P
¥.,				
E =07:	A	0	+.07	+.14
	P	28	21	14
E = 0 :	A	+.07	+.14	+.21
	Р	21	14	07
E = +07:	A	+.14	+.21	+.28
	P	14	07	0

These ranges of assumptions about E and M give results running the gamut from A = 0 to P = 0, within which A is always positive and P is always negative. A more negative E would have SONGS reducing irradiance in all daylight hours, on the average, and a more positive E would have SONGS increasing irradiance in all daylight hours. The lefthand column of the table, with M = A, is probably the most reasonable since it presumes that SONGS effects on a station not in the plume are generally about the same whether the opposite station is in the plume or not. Given the fairly well-established values for (P-A) f_A , and f_P , and the absence of good evidence for a strong, overall SONGS effect E , it seems most likely that P is negative, that A is positive, and that A is probably less in magnitude than P.

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TABLE 1

Results of Upstream-Downstream Analyses for Irradiance and Logarithm Irradiance, Years 1985 and 1986

AT BOTTOM

SOKD45 85 - .071 - .299 - .462 - .370 86 - .044 - .287 - .406 - .334 SOKU45 85 - .033 - .214 - .213 - .192 86 - .024 - .254 - .246 - .218 SOKU35 85 - .003 (.86)* - .018 - .133 (.217) - .125	Station	Year	Station	ΔI (E/m²-Hr)	ΔΙ/Ī _s	Δ ln I	AI/I
SOKU45 85 - .033 - .214 - .213 - .192 86 - .024 - .254 - .246 - .218 SOKU35 85 - .003 (.86)* - .018 - .133 (.217) - .125	SOKD45	85 86	SOKD45	071 044	299 287	462 406	370 334
SOKU35 85003 (.86)*018133 (.217)12	SOKU45	85 86	SOKU45	033 024	214 254	213 246	192 218
86036285345292	SOKU35	85 86	SOKU35	003 (.86 036)*018 285	133 (.217) 345)125 292
SOKD35 85 026 (.067) 096 061 (.449) 059 86 046 254 380 316	SOKD35	85 86	SOKD35	026 (.06) 046	7)096 254	061 (.449) 380	059 316

AT 2 M ABOVE BOTTOM

Station	Year	ΔI (E/m²-Hr)	∆I/Ī _s	∆ ln I	AI/I
SOKD45	85	113	273	378	315
	86	045	189	316	271
SOKU45	85	082	281	378	315
	86	020 (.001)	113	220	197
SOKU35	85	035 (.009)	142	197 (.014)	179
	86	079	347	381	317
SOKD35	85	139	241	330	281
	86	.091	303	368	308

*Number between the parentheses represents the p-level.

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TABLE 2-1

BACI Results for Irradiance

Station	Height (m)	Powerplant effect I E/m²-day	p BACI test	P _{NA} Additivity test
SOKD45	0	+ .063 <u>+</u> .186	.74	.72
SOKD45	2	+ .244 <u>+</u> .290	.40	.86
SOKU45	0	221 <u>+</u> .241	.36	.13
SOKU45	· 2	365 <u>+</u> .319	.25	.07
SOKD35	0	+ .063 <u>+</u> .230	.79	.0001
SOKD35	2	+ .513 <u>+</u> .362	.16	.45

TABLE	2-2
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Station	Height (m)	Powerplant effect I E/m²-day	P BACI test	P _{NA} Additivity test
SOKD45	0	+ .413 <u>+</u> .178	.02	.0001
SOKD45	2	+ .336 <u>+</u> .133	.01	.16
SOKU45	0	+ .169 <u>+</u> .255	.51	.0001
SOKU45	2	002 <u>+</u> .188	. 99	.70
SOKD35	0	126 <u>+</u> .154	.41	.11
SOKD35	2	+ .120 <u>+</u> .173	. 48	.03

BACI Results for Logarithm Irradiance

TABLE 2-3

BACI	Results	for	Temperature
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Station	Height (m)	Powerplant effect (C°)	P BACI test	P _{NA} Addivity test
SOKD45	0	+ .425 <u>+</u> .279	.13	.11
SOKD45	2	+ .431 <u>+</u> .259	.10	.65
SOKU45	0	+ .076 <u>+</u> .207	.71	.42
SOKU45	2	+ .039 <u>+</u> .349	.91	.37
SOKD35	0	081 <u>+</u> .303	.79	.05
SOKD35	2	+ .456 + .349	.19	.63
SOKU35	0	NO DATA		•
SOKU35	2	NO DATA		

TABLE 2-4

BACI Results for Seston

Station	Height (m)	Powerplant effect (mm/day)	P BACI test	P _{NA} Addivity test
SOKD45	0	- 1.22 <u>+</u> 1.42	. 39	.0001
SOKD45	2	- 0.246 <u>+</u> 0.197	.22	.007
SOKU45	0	+ 1.95 + 1.52	.20	.0003
SOKU45	2	- 0.118 <u>+</u> .181	.52	.05
SOKD35	0	- 0.15 <u>+</u> 1.21	.90	.33
SOKD35	2	+ 0.017 <u>+</u> 0.210	.93	.688
SOKU35	0	- 3.01 <u>+</u> 1.69	.08	.003
SOKU35	2	+.398 <u>+</u> .247	.12	.06



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<u>Figure 1-2-1.</u>

Results of Upstream-Downstream analysis at SOKD35 for the year 1984.



<u>Figure 1-2-2</u>.

Results of Upstream-Downstream analysis - at SOKD35 for the year 1985.



<u>Figure 1-2-3</u>.

Results of Upstream-Downstream analysis at SOKD35 for the year 1986.



 Results of Upstream-Downstream analysis at SOKU35 for the year 1985.



Figure 1-2-5. Results of Upstream-Downstream analysis at SOKU35 for the year 1986.



<u>Figure 1-2-6</u>.

Results of Upstream-Downstream analysis at SOKD45 for the year 1984.



<u>Figure 1-2-7</u>.

Results of Upstream-Downstream analysis at SOKD45 for the year 1985.



<u>Figure 1-2-8</u>.

Results of Upstream-Downstream analysis at SOKD45 for the year 1986.





Figure 1-2-9.

Results of Upstream-Downstream analysis at SOKU45 for the year 1984.



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<u>Figure 1-2-11</u>.

Results of Upstream-Downstream analysis at SOKU45 for the year 1986.

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T = TRENCH OL NOTRENCH G = GRID or NOGRID W = WATER or NO WATER N= NUTRIENT or NONUTRIENT TGWN= TIGIWINjorTI"'IGI''IWI''II Then TGWN= TRENCH NOGRID WATER NUTRIENT ? for example TRENCH NOGRID WATER NUTRIENT MODEL # = TGWN' - note MSE same Mecens TGWN/BON ; Gives all possible interaction contrasts 24.23

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