marine review committee

RETURN TO REACTOR DOCKET
FILES

JOSEPH H. CONNELL, CHAIRMAN
University of California
BYRON J. MECHALAS
Southern California Edison Co.
JOSEPH A. MIHURSKY
University of Maryland

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Established by THE CALIFORNIA COASTAL ZONE CONSERVATION COMMISSION
to study the effects on the marine environment of the San Onofre Nuclear Generating Station

RETURN TO REACTOR DOCKET FILES

INTERIM REPORT OF THE MARINE REVIEW COMMITTEE
TO THE CALIFORNIA COASTAL COMMISSION
PART II: APPENDIX OF TECHNICAL EVIDENCE IN SUPPORT OF THE GENERAL SUMMARY

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RETURN TO REACTOR DOCKET FILES

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March 12, 1979

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INTRODUCTION

This volume comprises the Part II of the Interim Report of the Marine Review Committee to the California Coastal Commission of March 12, 1979. It contains the evidence gathered to date supporting the findings on the effects of SONGS Unit 1 and the predictions for Units 2 and 3.

The Findings and Predictions are numbered, and supportive evidence for these statements is given in identically numbered sections under the appropriate section of evidence.

The SONGS Units 1, 2 and 3 intake/discharge systems off San Onofre are described in the following Tables 1 to 3. The section on Physical/Chemical Oceanography includes a map which depicts the geographic area and locations of the cooling systems in operation and under construction. All coordinates are given in the MRC-defined Cartesian coordinate system which has as its origin the Unit 1 outfall.

The operational characteristics of the cooling systems are as follows: SONGS Unit 1 seawater withdrawal and discharge rates are 21.1 m^3/sec (5,840 gal/sec). The water intake flow rate is .72 m/sec (2.4 feet/sec). The time it takes for the cooling water to pass through the system is 15 minutes. It is heated to 19^o F above the temperature of the intake water. It has been estimated from dye tracer studies that the SONGS Unit 1 discharge water secondarily entrains mid- to bottom water at a rate of five times the discharge flow.

SONGS Units 2 and 3 diffusers are located offshore (see Table 1) in approximately 9 - 15 m (29 - 49 feet) of water located about 190 m (623 feet) and 400 m (1,312 feet) downcoast from the Unit 1 intake/discharge structures. Units 2 and 3 will each withdraw seawater at 52.3 m^3/sec (13,816 gal/sec). Discharged effluent which is heated to 19^o F above intake water temperatures is released at a rate of 3.96 m/sec (13 feet/sec) through two series of 63 diffuser ports spaced 12.2 m apart along two 768 m long pipes (see Tables for details).

The diffuser jets are pointed offshore (20° angle upwards and 7° angle outwards) from the line of the diffuser. This generates an offshore movement of discharged and secondarily entrained water. The time taken for the cooling water to pass through the system to the first diffuser port will be 22 minutes and 16 minutes for Units 2 and 3, respectively.

It has been estimated from laboratory-scaled tank model studies that Units 2 and 3 will each secondarily entrain about 10 times their water discharge volume.

Table 1. SONGS Units 1, 2 and 3 cooling structure locations given in the MRC coordinate system. Distance from shore and water depth are reported from mean-low-low water level (MLLW). The coordinates are centered on the discharge of Unit 1. The X coordinates are along a line parallel to the coast; - is upcoast, + is downcoast. The + Y coordinates are in the inshore direction, the - Y coordinates are in the offshore direction.

			X METERS	Y METERS	DISTANCE FROM SHORE (METERS)	WATER DEPTH (METERS)
UNIT 1	INTAKE		-6.4	-182.9	842.0	8.2
	OUTFALL		0.0	0.0	659.1	7.3
UNIT 2	INTAKE		195.0	-245.7	904.8	9.1
	DIFFUSER	START	185.9	-1037.9	1697.0	13.1
		END	185.9	-1793.8	2452.2	14.9
UNIT 3	INTAKE		393.8	-245.7	904.8	9.1
	DIFFUSER	START	402.9	-321.7	980.8	9.6
		END	402.9	-1077.6	1736.7	11.6

Table 2. Dimensions of SONGS Units 1, 2 and 3 water cooling systems dimensions. Pipe length is measured from the SONGS Unit 1 seawall. Units 2 and 3 discharge pipes carrying water offshore are of three different diameters; the number of diffuser ports connected to a discharge pipe of a specific diameter is noted in parenthesis.

		PORT HEIGHT FROM BOTTOM (METERS)	PORT INTERNAL DIMENSION (METERS)	VELOCITY CAP DIMENSION (METERS)	VELOCITY CAP SEPARATION FROM PORT (METERS)	PIPE INTERNAL DIAMETER (METERS)	PIPE INTERNAL SURFACE AREA (METERS^2)	PIPE LENGTH (METERS)
UNIT 1	INTAKE	3.2	5.5 x 6.4	9.1 x 10.6	1.2	3.66	11,257	979
	DISCHARGE	3.2	5.5 x 6.4	--	--	3.66	9,147	796
UNIT 2	INTAKE	2.9	8.53	12.2	2.1	5.49	17,972	1,042
	DIFFUSERS	2.2	.56 - .61	--	--	5.49 (25) 4.27 (19) 3.05 (19)	42,119	2,589
UNIT 3	INTAKE	2.9	8.53	12.2	2.1	5.49	17,972	1,042
	DIFFUSERS	2.2	.56 - .61	--	--	5.49 (25) 4.27 (19) 3.05 (19)	29,916	1,881

Table 3. Rates of water flow in the cooling system of SONGS.

		WATER WITHDRAWAL & DISCHARGE RATE (METERS^3/SEC)	SECONDARY WATER ENTRAINMENT (METERS^3/SEC)	WATER FLOW SPEED INTO INTAKE PORT (METERS/SEC)	WATER FLOW SPEED WITHIN PIPES (METERS/SEC)	WATER FLOW SPEED OUT OF DISCHARGE PORT (METERS/SEC)
UNIT 1	INTAKE	22.1	--	.72	1.98	--
	DISCHARGE	22.1	110.5	--	1.98	.59
UNIT 2	INTAKE	52.3	--	.51	2.21	--
	DIFFUSER	52.3	523.2	--	2.21	3.96
UNIT 3	INTAKE	52.3	--	.51	2.21	--
	DIFFUSER	52.3	523.2	--	2.21	3.96

PHYSICAL/CHEMICAL OCEANOGRAPHY

An intensive study of physical and chemical oceanographic conditions off San Onofre was carried out in September and October of 1976 and was reported in three volumes (MRC, 1977). Instruments for measuring currents and temperature have been maintained at two stations (Numbers 1 and 2) off San Onofre since 1976. These have produced reliable records covering an aggregate recording time of about a year, distributed around the seasons in two or three years. Five more stations (Numbers 3 through 7) went into operation in the autumn of 1978. Records covering one to three months of aggregate recording time from the new stations have been processed up to now.

The locations of all stations are shown in Map 1, and their coordinates are given in Table 1A (in this section). The depths of the instruments at each station are given in Table 1B (in his section) as depths below mean lower low water (MLLW), which is approximately 1 m below mean sea-level at San Onofre.

The statistics of currents and temperature in Tables 2 - 8 below are derived from all reliable records for the specified stations and time periods, which are available as print-outs from the MRC Library at Solana Beach.

Findings

(1) Longshore currents predominate at San Onofre. They are mainly a combination of tidal currents that reverse direction once or twice a day with more persistent drift currents that keep the same direction for three days or more.

Comparing stations 1.5 miles (2.5 km) apart at the same depth, the longshore currents are very similar at 2.5 miles (4 km) offshore but become increasingly less similar closer inshore.

(2) Near the surface at 2 km offshore, the long-term average of hourly mean longshore current speed is 8 cm/sec. The hourly mean speed is less than 5 cm/sec for about 50% of the time, and less than 1 cm/sec for 12% of the time. Stagnation periods, with speeds of less than 1 cm/sec lasting longer than 8 hours, may be expected to occur several times a year, but only one such period lasting longer than 14 hours has been observed at San Onofre.

At 4 km offshore near the surface, the average speed is 14 cm/sec, and speeds below 5 and 1 cm/sec occur only half as often as they do at 2 km offshore. No stagnation periods longer than 7 hours have been observed here.

Currents observed at a larger network in autumn, 1978 show the same increase of velocity with distance from shore. Hourly mean longshore velocity at 3 m depth was 4 - 7 cm/sec at stations about 1 km offshore, 8 - 11 cm/sec at 2 km offshore, and 13 - 15 cm/sec at 4 km offshore.

(3) The ocean temperature at San Onofre, as elsewhere, generally decreases with depth and is relatively uniform horizontally over distances of 1 or 2 km. In winter, the water is well-mixed near the surface, and the temperature is fairly uniform down to a depth of 10 m or more. The temperature in this winter-mixed layer varies from month to month, and from year to year, normally lying in the range of 13 - 16° C (55 - 61° F). In summer, the sun's heat produces a warmed surface layer a few meters thick, lying above a narrow zone of steeply decreasing temperature called the summer thermocline. Summer surface temperatures at San Onofre are normally in the range of 17 - 21° C (63 - 70° F), with temperatures at 10 m depth averaging two or three degrees Celsius lower.

(4) Intake water, drawn from an average depth of about 4 m, is generally a little warmer than the ambient water at the site of the diffuser jets, at an average depth of about 10 m.

Monthly means of this temperature difference have an average value of about 1.5° C (2.7° F), and the largest monthly mean difference yet recorded is 3.0° C (5.4° F).

(5) The summer thermocline at San Onofre is often much agitated by internal waves, with periods of 6 - 24 hours and amplitudes up to several meters. At depths greater than one or two meters below the surface, these waves often produce temperature variations up to 4° C over a few hours at any fixed point in the sea or on the bottom. Besides these fast variations, occasional upwellings of deep water, two or three times a year, can lower the ambient temperature by two or three degrees Celsius for a week or so.

(6) The distribution of chemical nutrients (ammonium, nitrite and nitrate) and phytoplankton (indicated by chlorophyll-a) show a normal pattern for coastal waters. Nutrients are consistently lower in near-surface waters than at deeper depths, except in late winter when the waters are well-mixed to a depth of 10 - 12 m. Phytoplankton are more abundant in summer than in winter, and are more abundant inshore than offshore. Phytoplankton blooms occur in early spring and also in summer during upwelling episodes. Longshore variations in nutrients and phytoplankton are minor, except for the higher values of chlorophyll-a observed inshore near Unit 1. These patterns reflect the facts that phytoplankton require both sunlight and nutrients, that they deplete the nutrients in surface waters, and that their growth depends on upward mixing of nutrients from deep water or from the bottom.

(7) Suspended particles, both of sediment and organic detritus, are most concentrated inshore near the bottom. Here the median value is about 30 mg/liter, with extreme values 10 times higher, while the median in offshore surface waters is about 2 mg/liter. Near-surface waters close to Unit 1 have about twice as much suspended load as water upcoast and downcoast at the same distance offshore.

(8) Wave energy is high enough to resuspend bottom sediments near the Unit 1 intake about half the time, averaged throughout the year. Ambient turbidity is observed to be greater in winter and spring, when waves are higher.

(9) Scattered observations of surface turbidity plumes from Unit 1 vary from very small up to a maximum length of 3.7 km downcurrent and a maximum width of 1.5 km. The area liable to be affected by turbidity plumes from Unit 1 is about 2 km^2, in a region extending 1 km up- and downcoast and .5 km on- and offshore from the outfall. The source of this turbidity is the ambient suspended material drawn in at the intake, or entrained by the discharge.

Light levels at 5 m depth in the sea are sometimes reduced by 40% or more out to beyond 200 m up- and downcoast from the Unit 1 outfall.

Predictions

(1) The local offshore current induced by entraining ambient water in the discharge jets will be both necessary and sufficient to prevent build-up of heat and effluents during stagnant periods inshore lasting eight hours or more. This induced current will have a velocity of about 9 cm/sec by itself, enough to overcome back-dispersion of the effluent, and will transport the discharge out to a region where ambient currents are likely to be stronger. The offshore flow at the end of the diffuser lines will be equivalent to a stream 5/8 mile (1 km) wide, 33 feet (10 m) deep, flowing out at 18 feet/minute (9 cm/sec).

(2) When the water flowing alongshore past the diffuser line out to 2.6 km (1.6 miles) from shore, has an average longshore velocity less than about 5 cm/sec for several hours together, most of this water will be entrained in the discharge and carried offshore beyond the end of the diffuser line,

taking with it the nearshore plankton and the suspended particulates that are stirred up nearshore by waves. A significant fraction of this water will reach a distance of 4.8 km (3 miles) or more from shore.

(3) If the temperature rise in the Plant is 20° F, the temperature difference between discharging water and the ambient water just above the jets will average about 23° F. Outside the region of initial dilution near the discharge jets, temperature changes produced by turning Units 2 and 3 on or off will not be larger than the rapid variations due to internal waves in summer.

(4) Unit 1 clearly transports water from near the bottom to near the surface, by entrainment in the discharge. Units 2 and 3 will do the same, with a volume transport about 10 times greater, and will also carry the entrained water offshore to a degree depending on the prevailing longshore currents. The result will be an increase of phytoplankton, suspended particle load and fallout of particulates in the longshore and offshore neighborhood of the diffuser lines.

(5) The mixture of discharged and entrained water from Units 2 and 3 will have a somewhat smaller suspended load per unit volume than that from Unit 1, because the entrained water comes from further offshore where the water has about half as much suspended matter as inshore water at the same distance off the bottom. The volume flow-rate of water, however, will be about 10 times greater. The probable net result is that all units together will inject about 3 - 6 times as much suspended matter into the surface layer as will Unit 1 alone. The area liable to be affected by this turbidity will be about 10 km^2, in an oval region extending about 2 km up- and downcoast and 1.5 km on- and offshore from the outer end of the diffuser line.

Supportive Evidence for Findings

(1) For current reversals and correlations between stations, see Tables 2 and 3.

(2) For long and short period hourly current speeds, see Tables 4, 5 and 6.

(3) For monthly mean temperature statistics, see Tables 7 and 8.

(4) For monthly mean temperature differences, see Table 9.

(5) Internal waves. Data from 1976 are shown and discussed in MRC (1977). Temperature variations due to internal waves are to be seen on the records from any subsurface thermometer in any summer month. Note the large seasonal changes in standard deviations in Table 7.

(6) Nutrients and phytoplankton. These observations are detailed in MRC (1977), and MEC (1978).

(7) Suspended particles. Measurements of suspended particles (seston) made in 1976 are given in MRC (1977).

(8) Wave energy. See Inman (1957), Institute of Marine Resources (1976), U.S. Army Corps of Engineers (1975).

(9) Turbidity plumes. See Intersea Research Corp. (1972, 1973), Marine Advisors, Inc. (1969). See MRC (1977) for observations of light levels.

Supportive Evidence for Predictions

(1 and 2)

The offshore velocity and transport are estimated by List and Koh (1974) from a tank model of the diffusers of Units 2 and 3.

Shallow-water dispersion observed in dye-patch experiments (see, for example, Okubo, 1971) can be roughly expressed by a dispersion velocity of the order of 1 cm/sec. An ambient current velocity somewhat greater than this is needed to carry away effluents from a continuous discharge faster than they can disperse back against the current.

The cross-section out to 2.6 km from shore, at the end of the diffuser line, is about 20,000 m^2. An average longshore flow velocity of 4.5 cm/sec through this cross-section is needed to supply the offshore transport of 900 m^3/sec estimated by List and Koh (1974).

The dye-photographs and isotherm maps of the tank model (List and Koh, 1974) show definite accumulations of discharged water at the seaward boundary of the tank for longshore current velocities of 5 cm/sec or less. This boundary is at a scaled distance of 2200 m seaward from the end of the diffuser line. Because of the boundary, the tank is an imperfect analogue of the ocean, but the discharged water that accumulated at the outer edge of the tank would certainly have travelled farther offshore in the absence of the boundary.

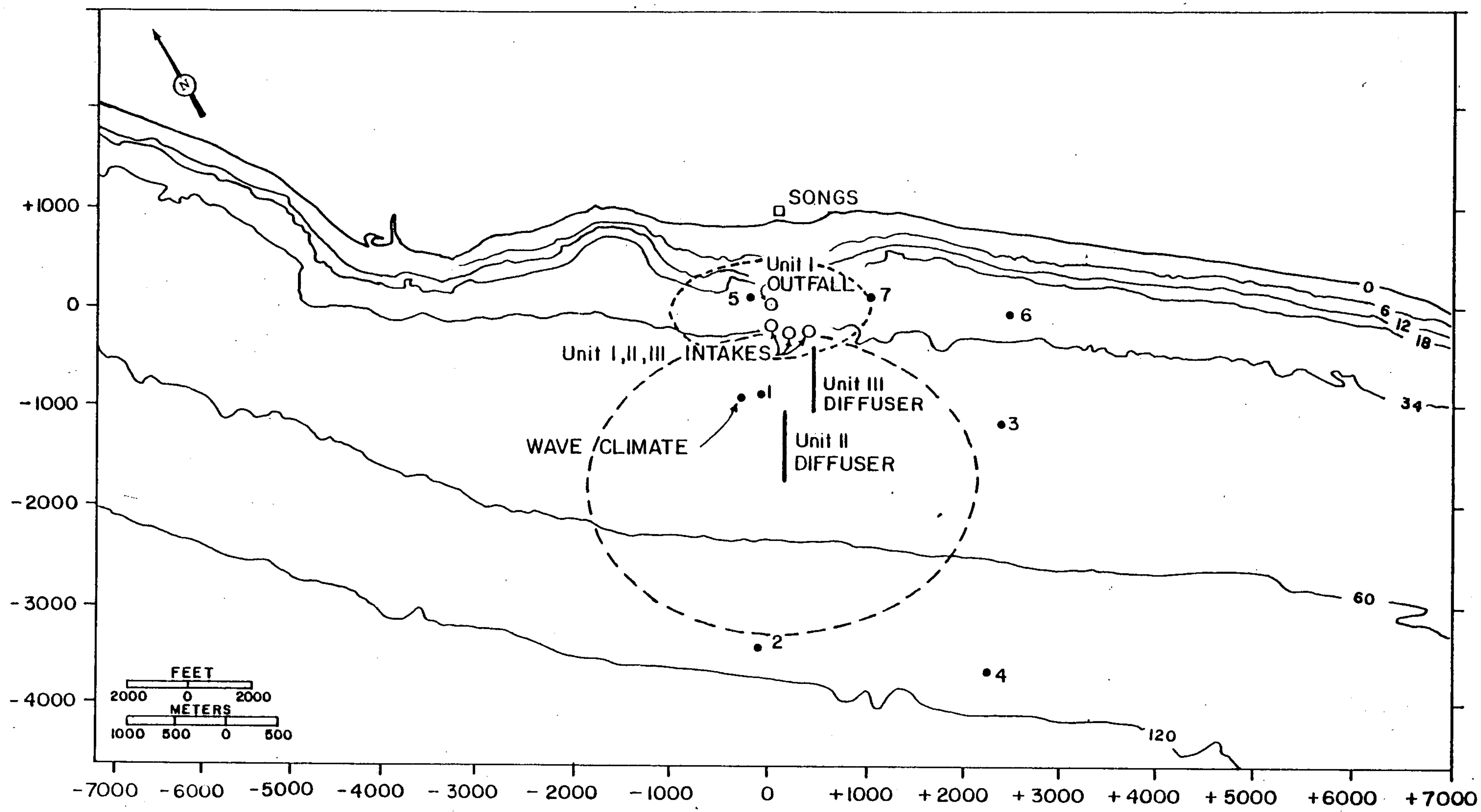
(3) The initial temperature difference at the jets will be the sum of the 20^{o} F rise in the Plant and the ambient difference (Table 9) of about 3^{o} F or less. Initial dilution will reduce this difference to 2.5^{o} F or less (List and Koh, 1974), which is less than the variations of 7^{o} F or so which may come from internal waves.

(4 and 5)

The discharge plus initial entrainment from Unit 1 is estimated to be less than 100 m^3/sec (MRC, 1977), while the discharge plus initial entrainment from all three units together is predicted to be about 1000 m^3/sec (List and Koh, 1974).

The values for ambient suspended load in inshore and offshore waters are generalized from data in MRC (1977).

The area affected by the plume from Units 2 and 3 is estimated from the dye-photographs of the tank model (List and Koh, 1974).



Map 1. Locations of intakes, outfalls, and current-measuring stations 1 - 7. MRC coordinates in meters are shown at margins. Depth contours are in feet below MLLW. Dashed lines around outfalls show the estimated regions liable to be affected by turbidity plumes.

Table 1A: Station coordinates in meters. These are in the MRC coordinate system which has its origin at the outfall of SONGS Unit 1 (792.5 m from shore), positive X directed to 123° T (downcoast), and positive Y directed to 033° T (onshore).

STATION NO.	X	Y	DISTANCE FROM SHORE AT MLLW
1	- 26	- 961	1620 m
2	92	-3451	4110 m
3	2408	-1196	1850 m
4	2295	-3634	4290 m
5	- 198	50	610 m
6	2445	82	580 m
7	978	184	480 m

Table 1B: Depths of current meters and thermometers in m below MLLW.

DEPTH	STATION NO.						
	1	2	3	4	5	6	7
3 m	X	X	X	X	X	X	X
9 m	X	X	X	X			
21 m		X		X			

Table 2. Frequency of time-intervals between reversals of hourly mean longshore currents (Stations 1 and 2, 1976 - 1978; instrument depths below MLLW).

	STATION 1		STATION 2	
TIME (HRS.)	3 m (%)	9 m (%)	3 m (%)	21 m (%)
< 12	32	38	16	20
12 - 24	24	29	11	17
24 - 36	7	7	4	6
36 - 48	10	10	4	8
48 - 60	4	3	3	3
60 - 72	4	3	4	7
72 - 84	2	2	9	6
84 - 96	4	3	10	3
> 96	13	5	39	30

Table 3. Correlation coefficients of hourly mean longshore velocities at pairs of stations 2.5 km apart longshore (Stations 1 - 6, Autumn, 1978).

STATIONS	DISTANCE FROM SHORE	CORRELATION COEFFICIENTS
5 and 6	0.6 km	+ .15
1 and 3	1.7 km	+ .75
2 and 4	4.2 km	+ .91

Table 4. Frequency of hourly mean current speeds (Stations 1 and 2, 1976 - 1978; instrument depths below MLLW).

	STATION 1		STATION 2	
SPEED (cm/sec)	3 m (%)	9 m (%)	3 m (%)	21 m (%)
0 - 1	12	15	6	10
1 - 3	19	26	10	16
3 - 5	15	19	9	13
5 - 7	12	14	8	12
7 - 9	9	9	7	10
9 - 11	8	7	7	8
11 - 13	5	4	7	7
15 - 19	7	2	10	8
19 - 23	4	1	9	4
23 - 27	2	0	5	3
27 - 31	1	0	5	1
> 31	1	0	10	2
MEAN SPEED (cm/sec)	7.8	5.1	14.3	8.9
STD. DEV.	± 7.5	± 4.5	± 11.6	± 7.9

Table 5. Number of occasions per year with N successive hourly mean longshore speeds (HMLS) less than given speed (Stations 1 and 2, 1976 - 1978); instrument depths below MLLW).

	STATION 1		STATION 2	
(HMLS) ≤ 1 cm/sec	3 m	9 m	3 m	21 m
$4 < N \le 8$ hr	31/yr	31/yr	7/yr	18/yr
$N > 8$ hr	6/yr	6/yr	0/yr	4/yr
Max. N	15 hrs	12 hrs	7 hrs	10 hrs
(HMLS) ≤ 3 cm/sec				
$4 < N \le 8$ hr	164/yr	196/yr	106/yr	150/yr
$N > 8$ hr	≥ 79/yr	≥ 95/yr	25/yr	≥ 55/yr
Max. N	15 hrs	15 hrs	14 hrs	15 hrs
(HMLS) ≤ 5 cm/sec				
$4 < N \le 8$ hr	237/yr	203/yr	138/yr	200/yr
$N > 8$ hr	177/yr	236/yr	93/yr	150/yr
Max. N	15 hrs	15 hrs	15 hrs	15 hrs

Table 6. Frequency of hourly mean current speeds in percent (Stations 1 - 7, Autumn, 1978; instrument depths below MLLW).

STATION NO.	5	7	6	1	3	2	4	1	3	2	4	2	4
DEPTH (m)	3	3	3	3	3	3	3	9	9	9	9	21	21
SPEED (cm/sec)													
0 - 1	11	30	16	7	10	6	7	12	14	7	12	13	11
1 - 3	16	19	23	16	19	9	14	21	22	9	22	20	22
3 - 5	15	17	17	11	17	10	11	18	18	9	15	14	18
5 - 7	15	13	15	9	12	10	8	15	15	8	10	13	16
7 - 9	12	7	11	10	10	9	6	12	11	9	8	11	11
9 - 11	10	5	7	8	9	8	5	7	8	7	6	8	9
11 - 13	6	3	3	7	6	5	4	6	5	6	4	6	6
13 - 15	5	2	3	6	5	7	3	3	3	6	5	5	3
15 - 19	6	3	3	8	6	10	7	3	3	16	6	7	3
19 - 23	2	1	1	6	3	9	10	2	1	10	5	1	1
23 - 27	1	--	--	3	1	7	8	--	--	7	3	1	1
27 - 31	1	--	--	2	--	5	5	--	--	3	3	1	1
> 31	--	--	1	7	2	5	12	1	-	3	1	--	--
MEAN SPEED (cm/sec)	7.2	4.4	5.8	11.4	7.6	12.8	14.4	6.3	5.5	12.6	8.1	6.7	6.1
STD. DEV.	5.8	4.6	6.6	10.7	7.1	10.2	12.4	5.8	4.3	9.2	7.8	5.7	5.1

- means < .5%

Table 7. Monthly mean temperatures ± standard deviations in ° C (Stations 1 and 2, 1976 - 1978; instrument depths below MLLW).

	STATION 1		STATION 2	
MONTH	3 m	9 m	3 m	21 m
O 76	--	17.7 ± 1.7	--	--
N 76	--	17.6 ± .5	--	--
D 76	--	17.3 ± .3	--	--
J 77	--	16.8 ± .2	--	--
F 77	15.7 ± .2	15.9 ± .2	15.9 ± .2	15.5 ± .3
M 77	13.5 ± .5	13.7 ± .2	13.4 ± .5	--
A 77	15.2 ± 1.6	14.7 ± 1.2	16.7 ± 1.0	13.2 ± 1.0
M 77	16.8 ± .9	16.1 ± 1.3	16.4 ± .7	13.2 ± 1.6
J 77	18.4 ± .9	15.5 ± 2.3	17.9 ± .7	12.2 ± 1.3
J 77	--	14.9 ± 1.6	--	12.4 ± .8
A 77	18.9 ± 1.9	--	--	14.8 ± 1.5
S 77	17.6 ± 1.4	--	17.6 ± 1.0	14.3 ± .8
O 77	17.8 ± .8	--	18.4 ± 1.1	15.1 ± 1.1
N 77	17.9 ± .8	--	17.9 ± .8	17.0 ± 1.2
D 77	16.8 ± 5	--	16.7 ± .3	15.3 ± 1.4
J 78	--	--	16.4 ± .4	13.3 ± .1
F 78	17.4 ± .1	--	15.6 ± .7	14.4 ± .2
M 78	--	--	16.4 ± .8	15.0 ± .8
A 78	17.4 ± .4	16.5 ± .6	15.9 ± 1.3	13.6 ± 1.7
M 78	17.7 ± 1.1	15.9 ± 1.7	16.6 ± .9	11.6 ± .4
J 78	17.1 ± 2.0	15.2 ± 2.0	15.7 ± 2.1	12.1 ± 1.0
J 78	17.9 ± 1.8	15.1 ± 1.4	17.5 ± 2.1	12.0 ± .7
A 78	19.9 ± 1.8	17.2 ± 2.2	20.1 ± 1.2	13.7 + 1.5
S 78	20.8 ± 1.1	19.9 ± 1.8	21.0 ± 1.0	17.4 ± 2.3
O 78	19.6 ± 1.6	18.4 ± 1.8	20.5 ± 1.2	15.5 ± 1.4
N 78	--	--	19.2 ± .6	17.2 ± .8

- denotes no data

Table 8. Monthly mean temperatures ± standard deviations in °C (Stations 1 - 7, Autumn, 1978; instrument depths below MLLW).

STATION NO.	DEPTH (m)	AUG. 78	SEPT. 78	OCT. 78	NOV. 78
5	3	20.0	20.3	19.6	18.2
7	3	19.9	20.4	19.0	18.4
6	3	19.9	21.3	18.9	18.2
1	3	19.9 ± 1.8	20.8 ± 1.1	19.6 ± 1.6	-- --
3	3	19.7	19.9	18.9	17.8
2	3	20.1 ± 1.2	21.0 ± 1.0	20.5 ± 1.2	19.2 ± .6
4	3	20.1	21.0	19.4	18.7
1	9	17.2 ± 2.2	19.9 ± 1.8	18.4 ± 1.8	-- --
3	9	17.5	20.9	17.9	17.6
2	9	17.7 ± 1.85	19.6 ± 1.77	19.4 ± 1.68	-- --
4	9	-- --	19.6	18.8	18.3
2	21	13.7 ± 1.5	17.4 ± 2.3	15.5 ± 1.4	17.2 ± .8
4	21	13.2	15.9	14.6	-- --

-- denotes no data

Table 9. Monthly mean temperature differences between screenwell and diffuser locations for Units 2 and 3 in °F.

MONTH	T: SCREENWELL, UNIT 1	T: STN. 1, 9 m BELOW MLLW	ΔT
Aug. 76	63.64°	59.45°	4.19°
Oct. 76	68.32	64.96	3.36
Nov. 76	66.25	64.40	1.85
Dec. 76	64.51	60.93	3.58
Feb. 77	61.32	60.53	0.79
Mar. 77	57.61	56.71	0.90
Apr. 77	60.48	58.42	2.06
May 77	62.92	60.89	2.03
June 77	62.29	60.04	2.25
July 77	64.11	58.68	5.43
Apr. 78	62.40	61.63	0.77
May 78	64.42	60.69	3.73
June 78	64.02	59.49	4.53
July 78	63.79	59.04	4.75
Aug. 78	66.05	62.99	3.06
Sep. 78	68.72	67.80	0.92
Oct. 78	69.75	65.26	4.49
			mean 2.86

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PLANKTON

This report concentrates mainly on the animals in the plankton (zooplankton). The macrozooplankton consists of three groups: (a) animals that spend their entire life in the plankton and reproduce there (the holoplankton); (b) the larvae of fish (the ichthyoplankton); and (c) the larvae of animals that live on the bottom (meroplankton). In this report, the macrozooplankton are treated as a whole except where the differences among the three groups become important. The microzooplankton are very young stages of holoplankton, some meroplankton, and other very small holoplanktonic organisms.

Findings

(1) The normal distribution of zooplankton and phytoplankton among upper, middle and bottom waters is disrupted around Unit 1. This effect can be detected out to 500 yards from the Plant, over an area approximately one-tenth of a square mile. The concentration of zooplankton in surface water in this area ranges up to 20 times greater than at other places along the coast at the same depth. This is caused by discharge water drawing to the surface dense concentrations of about half the species, which are normally found mainly near the bottom at this depth. By contrast, the density of a few species in the upper water is reduced, with one species decreased at times to as little as 1% of the density found at the same depth at other places along the coast. These are species normally found mainly near the surface and the discharge reduces their density there by dragging up bottom water that contains lower densities of the species.

(2) Unit 1 kills plankton drawn through its cooling system and possibly by entraining plankton in the discharge water. The mortality caused by the Plant results in the incursion

into adjacent water of plume water with a reduced density of living plankton. We calculate that under the slow current conditions that occur about half the year, this process is equivalent to killing, each day, about 1% of the plankton population in a zone 2.5 miles (4 km) wide and 12 miles (∿ 20 km) along the shore. Over an area of three square miles (∿ 8 km^2), it is equivalent to killing roughly 10% of the zooplankton population each day. This is about the level of natural mortality. The location of the affected zone varies with the direction and speed of the currents. (MRC is developing new methods of calculating Plant-induced mortality which will improve the evaluation of its significance.)

(3) We estimate that Unit 1 kills 100 - 170 billion microzooplankton, 2.5 - 4 billion macrozooplankton and 3.5 - 6 million ichthyoplankton individuals per day, which is equivalent to about 100 - 200 tons of total zooplankton biomass per year. The minimum values given are based on the assumption that no discharge entrainment mortality occurs, while the maximum values assume that 12% of the organisms entrained into the discharge plume are killed.

Implications

Unit 1 probably does not have a significant effect on the plankton community in the SONGS area. The observable change in vertical distribution is very localized. In spite of the fact that the Plant kills billions of plankton individuals per day, this mortality has no detectable effect upon the plankton density in the area. It appears that mixing with unaffected water very rapidly swamps the Plant's influence. Compensatory reproduction, survival and growth by the surrounding populations presumably also occurs, but more slowly than mixing.

Since the effects of Units 1, 2 and 3 are expected to be more extensive than those of Unit 1, a more detailed discussion of the implications of increased mortality for the different types of zooplankton, for other parts of the food web, and for the adult populations of fish and benthos is postponed to the following section on the Predictions.

Predictions

We face a special problem in predicting the effects of Units 2 and 3. We can estimate the amount and number of plankton taken into the new intakes, but we cannot be sure (a) to what extent the diffusers of Units 2 and 3 will move zooplankton offshore with the entrained water mass and (b) what the mortality will be of those that are entrained by the diffusers. Within the entrained water, organisms could be killed by turbulent stress, or, if they become disoriented by the extreme turbulence, by being eaten by fish and/or by being moved offshore into a potentially unsuitable environment.

In the predictions of mortality that follow, we provide a range of values. The minimum estimates assume zero mortality via discharge entrainment, the maximum estimates assume that all zooplankton entrained by Unit 2 and 3 discharge water will be killed.

(1) A group of zooplankton (which includes the larvae of some species of fish and of benthic animals as well as holoplankton) is confined almost exclusively to a 2.5 mile (4 km) wide band along the coast. The major effect of Units 1, 2 and 3 will be to cause mortality in this group on the order of 6 - 30 times greater than that caused by Unit 1 alone. We calculate that, under the slower current conditions that occur about half the year, this will be equivalent to killing, each day, about 1 - 10% of the zooplankton in an area of 30 square miles ($\sim 80\ \text{km}^2$).

Natural mortality rates for zooplankton are variable, but roughly 10% of those alive at any given time die within a day, so that the maximum estimated SONGS-induced mortality would be of the same order as natural mortality over 30 square miles. Although mixing (and presumably "compensation") will occur, the losses are large enough that we expect to see a reduction in plankton density in some area around the Plant. We are not yet able to give a reliable estimate of the area over which a reduction in density might be detectable. We do not expect to see the local extinction of any species.

The consequences are likely to be different for each of the three types of plankton:

(a) Holoplankton:

Of the three types, the holoplankton is likely to show least detectable change in density, for two reasons. First, they reproduce in the plankton and take a relatively short time to become sexually mature. They are, therefore, likely to show the greatest tendency to return to normal density levels through "compensation," i.e., as a result of increased survival, growth, and reproduction in the zone of reduced density. Second, all stages are planktonic and are, therefore, continuously physically mixed in the ocean, so local effects are least likely to persist or accumulate in this group.

(b) Ichthyoplankton:

The planktonic stages of fish do not reproduce, and they take a relatively long time to become sexually mature. The planktonic stages can compensate at reduced densities, therefore, only by surviving or growing at increased rates, not by reproducing. The planktonic stages are therefore expected to show a detectable reduction in density over a greater area than for the holoplankton. However, adult fish are highly mobile, and this will tend to "smear out" the effects of the Plant. The potential effects of these larval losses upon the yield of fish are discussed in the Fish section.

(c) Meroplankton:

The larvae of benthic species do not reproduce in the plankton and, as in the case of fish larvae, we expect to detect reductions in larval density over a greater area than for the holoplankton. In addition, the benthic stages of many species, which includes the adults, move very little or not at all. As a consequence, any reduction in larval density in the plankton is more likely to result in a persistent and locally detectable reduction in adult density in benthic species than in any other group. However, we do not yet know enough about the population dynamics to be able to predict if or how much adult density will be affected by reduced larval density (see Subtidal Sand Bottom Benthos section).

(2) The minimum and maximum estimates that follow again correspond, respectively, to the assumption of zero offshore transport and mortality or 100% transport and mortality of those zooplankton that are entrained by the discharges of Units 2 and 3. Roughly 14 - 150 billion macrozooplankton and 600 - 6,000 billion microzooplankton individuals will be killed, per day, by Units 1, 2 and 3. Of the macrozooplankton, between 20 and 340 million will be fish larvae.

These losses total 700 - 7,500 tons per year of zooplankton biomass that will be transported various distances offshore. The consequences of this movement of organic matter for fish production are discussed in the Fish section.

(3) During more than half the year, surface waters are low in nutrients. The discharge from Units 2 and 3 will draw up bottom water, which contains higher concentrations of nutrients. This could lead to the production each year of

roughly an additional 200,000 tons of phytoplankton biomass in the waters offshore of a 2 mile (∿ 3 km) band, and to a change in the types of phytoplankton present. In turn, this could alter both the total production of zooplankton in the area and the relative abundance of different species of zooplankton. We cannot yet estimate how likely or how extensive this effect on the zooplankton will be. In addition, phytoplankton from inshore areas of high concentration will be moved offshore, where concentration is lower. We estimate this will total about 38,000 tons per year. The consequences of these possible changes in the phytoplankton, for fish production, are discussed in the Fish section.

Implications

We believe that some mortality will result from entrainment in the discharge plume, but we cannot yet estimate how much; 100% mortality is probably an overestimate.

The detailed information on compensation and mixing in real plankton communities, which is needed to predict the degree of reduction in density, is simply not available. We believe Units 1, 2 and 3 probably will reduce the density of some plankton species in an area that may be detectable one or more miles along the coast and one or two miles offshore. We do not expect to detect reductions in density as far as 10 miles distant from the Plant. SONGS is unlikely to so reduce the density of any species that it will disappear from this local area. Given the large physically well-mixed ecosystem of which this area is but a small part, these effects are not likely to alter the local community in a substantial way. However, if other equivalent sources of man-induced mortality were to be constructed within 10 miles or so of SONGS, substantial effects on the inshore species might be expected.

The effects discussed above could be reduced by moving the intakes and diffusers offshore and by changing to a single-point discharge.

Supportive Evidence for Findings

The supportive evidence for the Findings and Predictions are presented in this section. Detailed calculations of total nutrients and plankton influenced by the system are presented after the Tables and Figures and just before the References.

(1) Increases in the density of phytoplankton (chlorophyll-a) and zooplankton in the surface waters near SONGS have been found throughout the year. The spatial extent of the changes in abundance was estimated by comparing the relative abundance against sampling positions with respect to the outfall. The relevant section of the 1977 Annual Report (Barnett and Sertic, 1977) reads: .

> "An increase in abundance of zooplankton has been shown to exist in the surface waters near the SONGS Unit 1 discharge in past investigations. The present study confirms this zooplankton increase and documents its horizontal and vertical extent, its persistence and its magnitude. A sufficient degree of replication was attained that permitted some characteristics of the abundance distributions near SONGS to stand out above the patchiness of the plankton. These characteristics are:
>
> A. The region over which this increase in abundance has been clearly observed extends no further than 500 m downcurrent from the discharge in the longshore direction and 250 m outward in the offshore direction.
>
> B. Elevated abundances occurred at mid-depth and some times near the bottom as well as at the surface.
>
> C. The increased abundances near the discharge are always present when the SONGS circulating pumps are operational, even during reactor shutdown when the discharge effluent is not heated. These effects disappear when the pumps are off.
>
> D. The kinds of plankton that show increased abundance are those that have relatively large abundances, under ambient (normal) conditions, in the layer of water within 2 m of the bottom.

E. Other types of plankton which have relatively higher abundances in surface waters (and very low abundances near the bottom) under ambient conditions, are found in lower abundances in surface waters near the discharge when the circulating pumps are operating.

These observations, taken together, point strongly to the conclusions that the major cause of increased surface abundances near the discharge point is the entrainment of bottom water. This water which contains higher concentrations of plankton is dragged to the surface by the discharge outflow and subsequently mixed with waters from the surface and mid-depth. Comparisons of the vertical distributions of plankton at the nearest stations up- and downcurrent from the outfall indicate that over half the organisms in the water column 25 m downcurrent from the discharge have been transported from the bottom water into surface and midwaters."

The types of plankton involved are shown in Table 1, which also shows that chlorophyll-a increases in concentration within 500 m of the Unit 1 outfall (Barnett and Sertic, 1977b). The increase in density in surface waters near SONGS of those species of plankton normally most concentrated near the bottom ranges seasonally from 1.3 - 21.3 times the ambient density. The decrease in density in surface waters of some species which normally are least concentrated near the bottom varies seasonally. The abundance of one of these species was reduced to between 1/28 and 1/100 of the ambient density (Barnett and Sertic, 1978).

(2) The estimation of the significance of the mortality caused by the Plant proceeds in two major steps. First, we estimate the number of plankton killed by the Plant and express this as a loss rate suffered by the population of plankton in some volume of water around the Plant. Secondly, we compare this loss rate with that suffered by natural populations. This latter estimate is taken as 10% per day; that is, of all the planktonic organisms alive in any given volume of the ocean in this area, some 10% are expected to die from natural causes within 24 hours.

We postpone the account of this procedure to the section supporting Prediction 1 below, since there we will examine significance for different types of plankton, an issue that is not relevant to Unit 1. The Unit 1-induced daily mortality was estimated to range from less than 0.1 - 0.9%, for various species, in an area of about 80 km^2 adjacent to the Plant (see Table 4).

(3) Estimated average losses induced by SONGS Unit 1 are given in Table 2. The minimum values are shown under Column A. The maximum values are from Column C and include a 12% diffuser entrainment loss (see next section). The microzooplankton average values are estimated from a representative date of low abundance (January 18, 1978) and are adjusted for times of higher abundances. The macrozooplankton values are estimated from representative dates of high and low abundance. The ichthyoplankton values are estimated from abundances averaged over four dates in spring and over four dates in fall. They were cross-checked against abundance values averaged over 18 dates throughout 1978 and differed by only 18%.

Supportive Evidence for Predictions

(1) SONGS Units 1, 2 and 3 combined are expected to affect different groups of plankton to different degrees. In particular, their major effect should be on those species that are confined almost entirely to an inshore band extending 3 - 4 km from shore (Table 3). These include some species whose entire life is spent in the plankton (holoplankton), those planktonic stages of benthic animals that live inshore (meroplankton) and some fish larvae. These species are expected to be the most affected because their populations are of a more limited extent than other nearshore species and because the discharge water from Units 2 and 3 will entrain large amounts of water from inshore and will sometimes transport them offshore beyond the 3 - 4 km boundary.

This section analyzes and evaluates the possible effects of mortality caused by Units 1, 2 and 3. It concentrates on the "inshore" group of species, which are expected to be most affected. There are six steps in the analysis:

(a) The patterns of abundance of different groups of plankton are established.

(b) We estimate the abundance of plankton in the SONGS region.

(c) We estimate the number of plankton killed by the Plant per day.

(d) We estimate the size of the population of plankton that is influenced by this mortality, and hence the percentage mortality occurring over a specified area.

(e) We estimate the natural mortality rate.

(f) We evaluate the SONGS-induced mortality in the light of the natural mortality rate and other features of plankton biology.

(a) Patterns of Abundance

The "nearshore" plankton assemblage consists of those organisms which have the greatest portions of their total numbers generally restricted to within ∿ 7 km of shore. These are the species encountered in highest abundance off SONGS. From the results reported by Barnett and Sertic (1979) and Barnett, et al. (1979), the taxa of the nearshore plankton assemblage can be divided into three groups based on their density patterns. These groups are summarized in Table 3. The most important group for our purposes is that confined to within ∿ 3 km offshore. Numerically dominant taxa of zooplankton (holoplankton and meroplankton) and the larvae of queenfish, white croaker and anchovies are all members of the inshore group.

(b) Estimates of the Abundance of Plankton in the SONGS Region

Representative Species

These estimates refer only to the "inshore" and "variable" groups of plankton. We use five representative species to make the calculations: two holoplanktonic species, one meroplanktonic taxon, and one ichthyoplanktonic species from the "inshore group," and one holoplanktonic species from the "variable group." These are Acartia clausi, Oithona occulata, cypris larvae of barnacles, Seriphus politus, and Acartia tonsa, respectively. Acartia clausi and Oithona occulata (Figures 1 and 2) were chosen because they represent species which have a limited offshore range which is similar to the offshore extent of nearfield effects of the operations of Units 1, 2 and 3. Cypris larvae (the pre-settling stage) of barnacles were selected as a meroplankter with a limited offshore range (Figure 3). Acartia tonsa (Figure 4) was selected because it is a species of the nearshore assemblage of plankton which consistently has the highest numbers and is probably the greatest contributor to energy transfer through the planktonic system. Larvae of the queenfish, Seriphus politus (Figure 5) were chosen since they are one of the most abundant ichthyoplankton which spend all of their life history in the inner nearshore environment and are withdrawn by the intakes in large numbers relative to other larval fish.

Representative Dates

For the purposes of the analyses of holoplanktonic species and total macrozooplankton, data are presented from two cruises; one during which the concentrations of total macrozooplankton and the selected representative species were low (January 20, 1978) and one during which they were high (November 2, 1977). Cypris larvae were analyzed for one date only, November 2, 1977. Since larvae of Seriphus politus demonstrate a seasonal shift in pattern of inshore-offshore and depth density, we have analyzed a set of data from spring, 1978, a time when the higher concentrations generally were found between 1.7 and 3.2 km from shore, and in midwaters, and from summer, 1978, when the higher concentrations generally were found within 1.7 km from shore and near the bottom.

(c) Estimates of the Number of Plankton Killed Per Day By Units 1, 2 and 3

Losses to Units 1, 2 and 3 cooling operations were estimated for three sources; intake withdrawal, discharge entrainment and transport offshore. The plankton were assumed to be uniformly distributed in the longshore direction with the abundances shown in Figures 1 - 5. Inshore-offshore regions of influence were assigned for the intakes, the Unit 1 discharge and the Units 2 and 3 diffusers: 855 - 1035, 630 - 855, and 945 - 2790 m from shore, respectively.

The strata of water influenced by the sources of mortality are described in the appropriate following sections on intake withdrawal, discharge entrainment and offshore transport. The daily volume in each stratum is multiplied by the concentration in that stratum and the numbers from each stratum are then summed to give the total number of organisms involved in each source of mortality on a daily basis. The estimated maximum losses for each of these sources is presented in Tables 4 and 5 for Unit 1, for Units 2 and 3, and for Units 1, 2 and 3 together. Representative species losses for the cases resulting in maximum impact and other assumed cases are presented as the percentages of influenced population lost per day in Tables 6 and 7.

Intake Losses

One of the sources of plankton mortality caused directly by the operation of Units 1, 2 and 3 is intake withdrawal. Intake withdrawal rates were taken as 1.8×10^6 m^3 day^{-1} for Unit 1 and 9×10^6 m^3 day^{-1} for Units 2 and 3 together. It is estimated that the Unit 1 intake withdraws water from the water column in the following proportions:

Surface (surface - 1 m below surface) = 0%
Midwater (1 m below surface - 1 m above bottom) = 95%
Bottom (1 m above bottom - bottom) = 5%

These estimates are based on the proportion of mysids or ichthyoplankton from various depth strata that are found in the intake riser on two dates. These proportions were used in the present calculations of intake withdrawal of plankton. The numbers of plankton withdrawn were the average densities in the waters influenced by the intake times the volumes of water withdrawn. The proportion of plankton lost of those withdrawn have been shown to be sufficiently close to 100% (see Table 8) to justify the use of 100% for the present estimates of intake withdrawal losses.

Discharge Losses

The numbers of plankton undergoing discharge entrainment were calculated as the average longshore density for the nearfield influenced by the discharges, times a multiple (see below) of the discharge rate which reflected the amount of water entrained. The nearfield was taken for Unit 1 as up to 100 m inshore and 100 m offshore of the Unit 1 discharge and from surface to bottom. For Units 2 and 3, the nearfield was the lower two-thirds of the water column from about 1 - 2.8 km offshore. Based on our dye studies, the Unit 1 discharge entrains about five times as much water in the nearfield as it emits directly. Therefore, we have used an entrainment rate of 9×10^6 m^3 day^{-1} (= $5 \times 1.8 \times 10^6$ m^3 day^{-1}). According to List and Koh (1974), Units 2 and 3 diffusers will entrain in the nearfield ∿ 10 times the water emitted directly. Therefore, we have used a rate of 90×10^6 m^3 day^{-1} ($10 \times 9 \times 10^6$ m^3 day^{-1}) for Units 2 plus 3 discharge entrainment.

The proportion of plankton lost of those undergoing discharge entrainment is not precisely known at this time. We did not detect discharge entrainment mortality at Unit 1 on Acartia tonsa, a relatively robust copepod (Table 9). However, delayed mortalities of up to 12% of those entrained could have gone undetected because of the variability inherent in the experiment. Therefore, a discharge entrainment loss of 0% or 12% was used in the present estimates for Units 1, 2 and 3.

Transport Losses

The diffuser outflow of Units 2 and 3 are likely to have a much greater effect on plankton than the discharge outflow of Unit 1. As noted in the Physical/Chemical Oceanography section of this report, when the longshore current is less than about 5 cm sec^{-1} (0.1 knot) for several continuous hours (which could happen in any given week), a major portion of mid-depth to near bottom water flowing alongshore within 2 or 3 km from the shore will be entrained in the discharge and carried to the surface and offshore 1,500 - 3,000 m (1 - 2 miles) beyond the end of the diffuser line.

We presently cannot be sure (a) to what extent the diffusers of Units 2 and 3 will move zooplankton offshore with the entrained water mass and (b) what the mortality will be of those that are entrained in this water mass. Organisms which become disoriented by the extreme turbulence are more likely to be eaten by fish and/or be transported offshore into a potentially unsuitable environment. Once offshore, the inshore waters will be diluted by offshore waters (Figure 6).

Whether inner nearshore organisms will die in the outer nearshore region will depend upon the time they spend there, the degree of dilution of inner with outer waters, the change in predators, prey, and physical-chemical characteristics of the water (these last are expected to change to a lesser degree).

Evidence of increased mortality when an organisms is outside its habitat and its prey is diluted over that which normally occurs can be implied from selective feeding studies and critical period studies (e.g., Lasker, et al. 1970, Barnett 1974, Lasker 1975). Recent studies in the Atlantic Ocean have demonstrated directly, progressive degeneration of a planktonic assemblage in a continental shelf water mass separated from its source waters (Wiebe and Richardson, 1978), and biological instabilities (extraordinary predation) initiated in ambient waters by incursions of water not usually found in the area (Deibel, 1978).

In the present analyses we assume cases where there is no, half and total dilution with outer nearshore waters and 0%, 50% and 100% mortality of inner nearshore organisms when in the outer nearshore environment (Figure 6, and Tables 6 and 7).

(d) Size of Population That Suffers The Additional Mortality Imposed by SONGS

The water that has passed through SONGS or the ambient waters entrained have greatly reduced densities of living inshore zooplankton. These waters form part of the plume and dilute downstream populations of zooplankton. As one moves further from the Plant, the concentration of plume water decreases until it is immeasurably small very distant from the Plant.

This dilution acts essentially as an additional mortality factor, which would tend to reduce the local population density. The extent of the effect depends upon how far the plume spreads, the effect at any point decreasing the further the plume spreads. Clearly, any decision to designate some zone close to the Plant, as containing "the population of plankton affected by the Plant-induced mortality," is a somewhat arbitrary one. We have chosen to use the area within which the concentration of plume water is 3% or greater under "typical" oceanographic conditions (Table 4). The reason for this choice is that within this boundary, Plant-induced mortality, averaged over the whole zone, occurs at about the same rate as natural mortality (see below). Results based on the 1% boundary are also presented to provide an idea of the influence of scaling (Table 5).

A model of how the plume disperses (dispersion model of R. Davis, Scripps Institution of Oceanography) describes the degree of dilution of plume water with distance from the Plant under steady-state current conditions. The model is run in the following "typical" conditions:

(a) A long-term, mean longshore current of 3 cm sec^{-1}. This reflects a net longshore drift exclusive of tidal velocities and other dispersive water movements of shorter duration.

    (1) At least 12% of 6-hour average velocities were less than 3 cm sec^{-1}, for all current

measurements taken between August 4, 1976 and June 9, 1978 (calculations based on data from Table 4, Physical/Chemical Oceanography section).

(2) At least 62% of the 30-day moving averages of velocities were less than 3 cm sec^{-1} for all measurements of at least 30 days duration between April 20 and November 1, 1977.

(b) A sinusoidal tidal current of 7.5 cm sec^{-1}. Thus, tidal plus net current can range between 4.5 cm sec^{-1} in one longshore direction and 10.5 cm sec^{-1} in the opposite direction approximately every 12 hours.

(c) Diffusion proportional to $(time)^2$.

(d) Conditions maintained long enough for the plume to reach a "quasi-steady state."

The 3% dispersion boundary under the specified current regime includes an area ∿ 4 km wide, stretching ∿ 20 km along the coast. The 1% boundary includes an area ∿ 6 km wide, stretching ∿ 44 km along the coast.

To estimate the number of zooplankton in this area, the waters off SONGS were divided into a three-dimensional spatial array of volumes with sampling locations on the date in question[1]. Measured densities for each species of plankton were placed in the appropriate water parcels so that the parcels reflected the patterns of density as measured in the field. The three-dimensional spatial array was collapsed longshore into a two-dimensional flux plane so that each offshore-depth stratum contained

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[1] A two-dimensional array, vertical and inshore-offshore was used for _S. politus_.

at least 25 samples taken from locations spanning at least 20 km along the coast. The numbers of a species within the sampling grid was obtained by (1) multiplying the average concentrations in each offshore depth stratum by the area of the stratum and by the longshore length over which the spatial array was collapsed; and (2) summing over strata. Upper and lower 90% confidence bounds were determined for the total numbers found within the sampling grid on the basis of a stratified-random sampling equation (Cochran, 1963). If the longshore length of the sampling grid was narrower than the dispersion model bounds, the total numbers and the confidence bounds were extrapolated proportionally. If the offshore width or depth of the sampling grid was less than the dispersion model bounds, concentration values were placed in the unmeasured parcels in proportion to the values found on another survey taken within 1 - 3 days of the grid survey. During the second survey, offshore and depth positions were sampled more extensively on a single transect.

The total population sizes within those bounds are in Tables 4 and 5. The percentage daily loss rate is then computed by dividing the number killed per day by the Plant by this population size.

(e) Estimate of Natural Mortality Rate

SONGS-induced mortality is expressed as the fraction of additional animals that would die in the bounded area on the assumption that the population would otherwise be at a fixed density. For comparison, we need to express natural mortality also as a fraction dying per day. But we cannot measure natural mortality directly; furthermore, there is always an array of age classes present and animals in each class are dying continuously, being replaced continuously, and animals are being born continuously. We, therefore, need to make some assumptions to estimate mortality from the single type of data available to us--the fraction of the population in each age class at various times of the year. These assumptions are:

(1) Over the interval of interest the population does not change in density (number of dying = number of being born).

(2) The instantaneous death rate for any age class is constant throughout the sampling period.

(3) We can estimate this rate for the season by comparing the average number in each class throughout the season. This assumption also implicitly assumes that animals within an age interval that die are replaced by births and growth.

(4) The length of time spent in each age class does not vary throughout the year.

(5) The sampling gear used for each depth stratum are equally efficient in capturing organisms in question.

These assumptions will all be violated to some degree in real populations, but our estimate of natural mortality need be only approximate.

The parameter that is estimated by this procedure is in the instantaneous death rate per day, d, of a cohort of young as it passes through the life cycle. The fraction of those animals, alive at the start of a 24-hour period, which die within 24 hours, is then $D = 1 - e^{-d}$.

Seriphus politus (queenfish) was used as the representative or target species. Estimates of natural mortality of S. politus larvae were based on the annual estimates of total larvae in 0.5 mm length classes over the entire spawning season. Length was translated to age at length relationship shown in Figure 7. The annual estimates of total larvae were determined by summing the numbers of larvae in each length class in a flux plane (transect) 1 m wide (longshore length), from 0.4 - 6.3 km from shore (6 - 75 m depth contours), and from the surface to the bottom on biweekly surveys off San Onofre. This approach is similar to that used by Houde (1977) and Polgar (1977). The age frequency relationship is shown in Figure 8. If it is assumed that the mortality is constant for all larval age classes, the natural mortality rate (d) determined from these data is .12 day^{-1}, giving a finite daily mortality rate (D) of 11.4%. Since all age classes are assumed to die at the same rate, this is also the death rate of the population and is the same regardless of the age-distribution. If adjacent age classes are used for estimates (Fager, 1973), the resulting mortality rates are:

Age (Days)	Instantaneous Mortality Rate (day^{-1})	Finite Mortality Rate % Lost Per Day (1 - e^{-d} x 100)
11.4 - 25.1	.044	4.3
25.1 - 38.7	.121	11.4
38.7 - 52.3	.117	11.0
52.3 - 65.9	.077	7.4

It appears that the mortality rate does not vary greatly between age groups of the larval stages and that a 10% finite mortality rate would be a reasonable estimate. This rate is within the range found by others. Estimates of finite natural mortality rates of nearshore marine copepods from other studies range between 0 and ∿ 40% lost per day (Table 10). Estimates for freshwater copepods averaged from 8 - 10% (Cummins, et al., 1969) The finite mortalities of queenfish in our study compare favorably with those of Polgar (1977) for striped bass larvae (Table 10).

(f) Evaluation of SONGS-induced Mortality

Plankton and Ichthyoplankton

Over a zone of some 80 km^2, SONGS-induced mortality is about as large as natural mortality (10%). The additional mortality will tend to reduce the population density within the 80 km^2 zone, but two processes will tend to ameliorate this condition.

(1) Changes in current conditions and small scale dispersion will bring in ambient water, with a strong longshore current essentially flushing the local populations far along the coast.

(2) The residual population during periods of slower or oscillating longshore flow can respond to lowered density by increasing the birth rate, shortening generation time or experiencing reduced mortality from other causes. This is "compensation". Compensation probably occurs. For marine zooplankton and for marine fish, evidence is available only from laboratory studies; it is available for freshwater plankton and fish from field studies (e.g., Hoppenheit, 1975; Healy, 1978; Power and Gregoire, 1978). However, we do not know whether compensation can maintain the population density in the face of an additional 10% mortality.

Natural mortality rates of plankton are thought to to be highly variable (M.M. Mullin, Scripps Institution of Oceanography; N. Sonntag, University of British Columbia, personal communication). If Populations can recover from rather large variations in natural mortality rates on a short time scale, then they quite likely can recover from the additional mortality imposed by SONGS under most circumstances. The possible exception to this "recovery" argument occurs when SONGS mortality is imposed upon a population at or near the lowest extreme of its variation. The potential for recovery is then unknown. No direct evidence from the marine studies are available but for freshwater plankton, Cummins et al. (1969), show data which strongly suggest that the time-history of natural mortality over a year is extremely variable, ranging as much as from 0 in one week to .25 day^{-1} in a following week. However, a reduction in plankton density in some areas around the Plant is still expected to occur, both because the response to compensation may not be immediate or complete. The size of the area of reduced density will depend initially on the mixing processes of the ocean. The estimated losses are such that we expect to find reduced numbers of plankton of the inshore group several kilometers along the coast and a few kilometers offshore if the assumptions used in our calculations are correct.

Planktonic Stages of Benthic Organisms

The following discussion pertains to larvae of benthic species which are primarily confined to a narrow inshore zone 3 km or so wide.

There are two critical questions that must be answered to evaluate quantitatively SONGS influence on the benthic fauna via its effects on planktonic stages.

(1) What is the reduction in the number of organisms available for settling per unit time on the benthos, as a function of distance from the Plant? We could estimate the reduction in meroplankton available for settlement caused

by SONGS by estimating the degree to which it reduces the density of meroplankton, at various distances from the Plant, under specified current regimes, and by knowing the frequency of such regimes. Unfortunately, we cannot yet predict the local reduction in plankton density caused by the Plant.

(2) What is the minimum reduction in settlement rate that will reduce the average density or productivity of the benthic stages? More fully, how is settlement rate related to benthic density and productivity? In one such study off Southern California (Yoshioka, 1973) the recruitment of the ectoproct, Membranipora, was found to be proportional to the density of their larvae. No other information is available to the best of our knowledge.

While we cannot answer the first question quantitatively, we can make a qualitative statement. We expect that the settlement rate of inshore benthic species will be reduced within some distance, perhaps over several kilometers, from the Plant, both in the up- and downcoast directions. This expectation is based on (a) our prediction that holoplankton abundance will be reduced near the Plant, and (b) our estimate that benthic settlement near the Plant will show greater suppression than holoplankton density.

Point (b) is based on two features of meroplankton biology that are radically different from that of holoplankton:

(i) After a parcel of water passes through or near the Plant, the holoplanktonic organisms in it have a relatively small chance of passing through the vicinity of the Plant again. The surviving individuals and their offspring (even if they are inshore species) will move along the coast and only a small fraction will return. Thus, the effects on holoplankton tend to be well-mixed.

By contrast, if meroplankton density is reduced in some zone, let us say 500 m downcurrent from the Plant, during some period when currents are moving slowly, the loss of settlement during this period has a fixed spatial location. As similar currents occur again and again throughout the year, settlement to the same area will be reduced again and again. If settlement is continuous throughout the season, the Plant's effects continually operate on the same area and may be cumulative.

For example, more than half of the year, currents along the coast are slow enough (less than 5 cm sec^{-1} net flow per day; derived from the same data used in Table 4, Physical/Chemical Oceanography section) that virtually all meroplankton reaching SONGS will be killed in the cooling system or pushed beyond 3 km offshore. Water coming from upstream, or from offshore of 3 km, may therefore be largely depleted of meroplankton. Roughly 25% of the year this "shadow" is predicted to be upcoast of SONGS and roughly 25% of the year it will be downcoast. Such regimes are interrupted, of course, by intervals during which the current reverses and the "shadow" zone is bathed by normal settlement rates.

We do not know the extent of these "shadow" zones, but when slow unidirectional currents persist over a week or so, they could extend 20 or more km from SONGS, and within this zone, settlement might be reduced temporarily anywhere from 0 - 100%, depending on distance from the Plant and on the percentage killed in the diffuser plume.

(ii) Unlike the holoplankton, there are no reproductive stages of benthic species present in the plankton. A reduction in density therefore is not directly compensated for by reproduction. Consequently, mortality caused by the Plant will tend to have a greater suppressive effect on meroplankton density.

(2) Estimated average losses of total plankton losses induced by SONGS Units 2 and 3 and by Units 1, 2 and 3 together are given in Table 2. Specific loss estimate calculations are presented following the figures in this section. The representative dates from which the abundance data were obtained were previously described in the section entitled, "Supportive Evidence for Findings (3)."

For macrozooplankton and ichthyoplankton, the methods by which the losses were estimated were the same as those described for particular species in Part (c) of the section entitled, "Supportive Evidence for Predictions (1)," with one exception. The loss values obtained for A. tonsa in Table 4 were multiplied by the ratio of total macrozooplankton to A. tonsa in each area in question to arrive at total macrozooplankton losses. For example, on the representative date of low abundances, estimated daily losses for the Unit 1 intake were 742×10^6 *A. tonsa* (Table 4). On that date, *A. tonsa* represented 29% of the macrozooplankton in the area of the intake. Thus, total losses equal (742×10^6 *A. tonsa*) x $\left(\frac{100 \text{ total macrozooplankton}}{29\ \textit{A. tonsa}}\right)$ or 2537×10^6 macrozooplankton. On the representative date of high abundance, *A. tonsa* represented 28.5% of the total macrozooplankton in the area of the intake so intake losses of total macrozooplankton equaled (689×10^6 *A. tonsa*) x $\left(\frac{100 \text{ total macrozooplankton}}{28.5\ \textit{A. tonsa}}\right)$ or 2418×10^6 organisms. The average of these values, 2.5×10^9 organisms was presented as the estimate of Unit 1 intake losses in Table 2. The same method was used to obtain diffuser losses of total macrozooplankton. *A. tonsa* represented 24% and 9% of the total macrozooplankton over the diffusers during the dates of low and high abundance, respectively.

The approximate ratios of total fish larvae to *S. politus* were used to estimate ichthyoplankton losses. To check the larval calculations, the total larval abundance in midwater depths from the area of the intakes and diffusers was averaged over 19 dates spread throughout 1978. The daily intake withdrawal rate of $1.8 \times 10^6\ m^3\ day^{-1}$ multiplied by the average abundance in midwater of 2.3 total larvae m^{-3} gave 4.14×10^6 fish larvae per day or an 18% difference from the value of 3.5×10^6 obtained by the first method and shown in Table 2.

For microzooplankton estimates, no allowance was made for inshore-offshore or depth patterns. Throughout the nearshore area, the average abundance of larger microzooplankton was $2.2 \times 10^4\ m^{-3}$ and of smaller microzooplankton was $1.8 \times 10^4\ m^{-3}$. The estimated losses were taken as the product of the volumes involved in withdrawal and entrainment times abundances.

The conversion from numbers to biomass (wet weight) assumes the following factors:

Microzooplankton - equivalent volumes of about

4.6×10^{-4} mm^3 per larger microzooplanktonic organism,
3.3×10^{-5} mm^3 per smaller microzooplanktonic organism,
0.1 mm^3 per macrozooplanktonic organism,
1 mg per fish larva and a body density of 1 g cm^{-3} for all organisms.

The basic conversion equation was:

$$(\ ) \text{ organisms} \times (\ ) \text{ mm}^3 \text{ organism}^{-1} \times \frac{10^{-3}\text{cm}^3}{\text{mm}^3} \times 1\text{g cm}^{-3} =$$

( ) 10^{-3} grams of plankton biomass.

The estimated losses caused by Units 1, 2 and 3 ranged from six to about 35 times those estimated for Unit 1. The lower value represents a comparison between minimum loss estimates, i.e., only intake withdrawal (Table 2, Column A versus Column G).

The larger value is based on maximum estimated losses which include discharge entrainment and offshore transport mortality (Column C versus Column I).

(3) The surface waters of Southern California are low in nutrients relative to the deeper waters for over half of the year (Table 11). Estimates made from samples taken during these times of lower surface concentration over a three-year period show that the nitrate concentrations averaged about 3.1 μg-at N $liter^{-1}$ higher in the lower half of the water column over the diffusers than in the surface waters offshore of the diffusers. Assuming the Units 2 and 3 diffusers entrain 9×10^7 m^3 day^{-1}, the amount of nitrate transported offshore will be:

(3.1 μg-at N $liter^{-1}$) (10^3 liter m^{-3}) (9×10^7 m^3 day^{-1}) (182 day $year^{-1}$) = 5.1×10^{13} μg-at N $year^{-1}$.

Using the Redfield (1934) relationship of 106 gram-atoms of carbon per 16 gram-atoms of nitrogen in phytoplankton and the fact that there are 12 grams of carbon per gram-atom of carbon, the nitrate transported to the surface in excess of ambient nitrate concentrations represents 40.8 x 10^5 kg $year^{-1}$ of phytoplankton carbon. This in turn translates into 1.7 x 10^5 metric tons or 1.87 x 10^5 tons of phytoplankton biomass through the relationship that 1 mg phytoplankton carbon is equivalent to 42 mg phytoplankton biomass (Cushing, et al., 1958).

In addition to nutrient gradients, there are differences found between standing stocks of phytoplankton inshore and offshore, with the higher concentrations inshore. This higher standing stock will be transported offshore by the intake withdrawal and diffuser entrainment of Units 2 and 3. On the average, .77 μg of chlorophyll-a will be added over and above the offshore surface ambient levels for each liter of water transported offshore. A volume of 99 x 10^6 m^3 of water per day (9 x 10^6 m^3 from intake withdrawal and 90 x 10^6 m^3 from diffuser entrainment) will be transported offshore. Assuming that few of the involved phytoplankton are killed, the amount transported offshore in a year will be:

$(.77\ \mu g\ chl\text{-}a\ liter^{-1})\ (10^3\ liter\ m^{-3})\ (99 \times 10^6\ m^3\ day^{-1})$
$(365\ day\ yr^{-1}) = 2.8 \times 10^{13}\ \mu g\ chl\text{-}a\ yr^{-1}$.

Assuming a carbon:chlorophyll-a ratio of 30 to 1 (Strickland, 1969), 84 x 10^{13} μg C per year would be transported offshore. This carbon:chlorophyll-a ratio could be as high as 100 to 1 in a nutrient-limited situation. At 1 mg C = 42 mg wet weight of phytoplankton (Cushing, et al., 1958), the cooling system will transport 3.5 x 10^4 metric tons per year:

$(84 \times 10^{13}\ \mu g\ C\ yr^{-1})\ (10^{-3}\ mg\ \mu g^{-1})\ (42\ mg\ wet\ weight\ mg\ C^{-1})$
$(10^{-9}\ metric\ tons\ mg^{-1}) \simeq 3.5 \times 10^4$ metric tons of phytoplankton biomass per year. This is equivalent to 3.85 x 10^4 tons of phytoplankton biomass per year.

The paucity of nutrients in surface waters can give a competitive advantage to dinoflagellates or at least allow them to maintain their stocks against those of diatoms for the following reasons (Wyatt and Howard, 1973): (1) they can migrate vertically into zones of optimum levels of light and nutrients, and (2) they are relatively free from sinking losses. The upwelling of nutrients into nutrient-limited zones will cause an increased productivity of diatoms whose uptake kinetics of nutrients will produce a more rapid reproductive rate (Eppley, et al., 1969), thereby altering the character of the phytoplankton assemblage. A change in the phytoplankton asemblage can also alter the character of the herbivorous and omnivorous assemblage because some of those plankton have feeding preferences (Barnett, 1974; Lasker, et al., 1970). It is unknown at this time to what extent in time and space this alteration will take place because the factors needed to describe the spread of the nutrients and the lag phase between nutrient upwelling and phytoplankton production have not yet been determined.

Table 1. Types of plankton which did or did not show an increase in abundance within 500 meters of the outfall. From MRC Doc. 77-09 No. 2, Table 2-1, p. 2-33.

ORGANISM	PROBABILITY[1] OF NO EFFECT	EFFECT APPARENT QUALITATIVELY
Phytoplankton		
Chlorophyll-*a*	<.01	Yes
Microzooplankton		
Tintinnids	<.01	Yes
Copedpod nauplii	<.05	Yes
Cladocerans		
Evadne nordmanni	NT[2]	No
Evadne spinifera	NT	No
Penilia avirostris	>.20	No
Podon polyphemoides	>.20	No
Copepods		
Acartia clausi	<.01	Yes
Acartia tonsa	<.01	Yes
Corycaeus anglicus	>.10	No
Labidocera trispinosa	>.20	No
Oithona occulata	<.01	Yes
Oithona plumifera	<.01	Yes
Paracalanus parvus	<.01	Yes
Meroplankton		
Cypris larvae	<.01	Yes
Cyphonautes larvae	>.20	Yes[3]
Chaetognaths		
Sagitta euneritica	>.20	Yes[3]
Fish		
Unidentified eggs	NT	No

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[1] The probability of no effect was based on a Kendall Concordance Test (Kendall, 1962). Three longshore regions: 500 m or greater downcurrent of the outfall, within 500 m of the outfall, and 500 m or greater upcurrent of the outfall were used as the main classification with the null hypothesis of no difference between regions. The average percentage abundance in one depth stratum of all locations within a region was used as the observation. This observation directly reflects the average abundance. The row variable was each depth strata (surface, middepth, or bottom) of all cruises during which the circulating pumps of the plant cooling system were functioning.

[2] NT: Organism was not present in samples from enough cruises for testing.

[3] A discrepancy between statistical and graphic evaluation arose when the abundances at the extreme locations on the transects were higher than all values except those directly adjacent the outfall. The outfall effect was still apparent.

Table 2. Summary of estimated total plankton losses to SONGS cooling operations. Unit 1 entrainment losses in column B consist of 12% of the organisms secondarily entrained at the discharge. Units 2 and 3 entrainment losses in column E represent 100% of the organism secondarily entrained by the diffusers. Minimum estimated losses for Unit 1, Units 2 and 3 and Units 1, 2 and 3 are given in columns A, D and G, respectively. Maximum estimated losses are given in columns C, F and I. See text for discussion of maximum losses.

	A	B	C	D	E	F	G	H	I
	UNIT 1			UNITS 2 & 3			UNITS 1, 2 & 3		
	Intake Withdrawal	Discharge Entrainment	Total	Intake Withdrawal	Discharge Entrainment	Total	Intake Withdrawal	Discharge Entrainment	Total
Microzooplankton									
Numbers/day	108×10^9	65×10^9	173×10^9	540×10^9	5400×10^9	5940×10^9	648×10^9	5465×10^9	6113×10^9
Metric tons/year	10.7	6.2	16.8	52.6	526	579	63.1	532	595
Tons/year	11.7	6.8	18.5	57.9	579	637	69.4	585	655
Macrozooplankton									
Numbers/day	2.5×10^9	1.8×10^9	4.3×10^9	12×10^9	137×10^9	149×10^9	15×10^9	139×10^9	154×10^9
Metric tons/year	90	65	155	450	5000	5450	540	5065	5605
Tons/year	99	71	170	500	5500	6000	599	5571	6170
Ichthyoplankton									
Numbers/day	3.5×10^6	2.7×10^6	6.2×10^6	17.5×10^6	316×10^6	334×10^6	21×10^6	319×10^6	340×10^6
Metric tons/year	1.3	1.0	2.3	6.5	115	122	7.8	116	124
Tons/year	1.4	1.1	2.5	7.0	127	134	8.4	128	136

Table 3. Groups of the nearshore plankton off SONGS based on their inshore-offshore abundance patterns. (Adapted from MRC Doc. 79-01),

INNER NEARSHORE GROUP (∿ .5 to ∿ 3 km; region of intakes and diffusers)

Microzooplankton (Non-meroplanktonic)

Acartia spp nauplii, *Labidocera* spp nauplii

Macrozooplankton

Acartia clausi, *Oithona occulata*, *Podon polyphemoides*

Meroplankton

Cypris larvae, polychaete larvae, bivalve larvae

Ichthyoplankton

Atherinid larvae, *Ilypnus gilberti*, clinid A, *Hypsoblennius* spp, *Heterostichus rostratus*, *Leptogobius lepidus*, *Seriphus politus*, *Genyonemus lineatus*

OUTER NEARSHORE GROUP (∿ 3 to ∿ 7 km)

Macrozooplankton

Sagitta euneritica, *Oithona plumifera*, *Evadne nordmanni*, *Penilia avirostris*, *Paracalanus parvus*, *Corycaeus anglicus*

Ichthyoplankton*

Scorpaenid larvae, *Merluccius productus*, *Stenobrachius leucopsarus*

VARIABLE NEARSHORE GROUP (∿ .5 to ∿ 7 km)

Macrozooplankton

Evadne spinifera

Labidocera trispinosa

Acartia tonsa

Meroplankton

Cyphonautes larva

Gastropod veligers

Ichthyoplankton

Fish eggs, *Engraulis mordax*, clinid B, *Gobiesox rhessodon*, *Paralichthys californicus*, *Pleuronichthys* spp, *Typhlogobius californiensis*

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*These taxa probably have a large portion of their total numbers beyond 7 km offshore.

Table 4. Summary of estimated daily losses of representative plankton species and numbers of those species influenced by SONGS based, respectively, on daily loss rates and on a 3% dispersion boundary. This boundary extends about 20 km alongshore and 4 km offshore. All numbers except percentages are given in millions (i.e., multiply value by 10^6). See text section, Prediction (1) for further explanation.

	Intake Loss Unit 1	Discharge Loss Unit 1	Total Loss Unit 1	Intake Loss Units 2 & 3	Discharge Loss Units 2 & 3	Transport Loss Units 2 & 3	Total Loss Units 2 & 3	Total Loss Units 1, 2, 3	Number influenced Within 3% Dispersion Boundaries 90% Confidence Bounds			Daily Loss Rate (% Loss of Numbers Influenced)		
									Mean	Lower	Upper	Unit 1	Units 2 & 3	Units 1, 2, 3
Cypris larvae - "inshore" species of meroplankton														
Date of high abundance	37.1	23.2	60.3	185	134	819	1140	1200	9,270	7,600	10,900	0.7	12.3	12.9
Seriphus politus (Queenfish) "inshore" species of Ichthyoplankton														
Spring	.145	.099	.244	.726	2.06	10.5	13.3	13.5	157	N/A[1]	N/A	0.2	8.5	8.6
Summer	.466	.574	1.04	2.33	.365	0	2.70	3.74	123	N/A[1]	N/A	0.8	2.2	3.0
Acartia clausi - "inshore" species of plankton														
Date of high abundance	106	97.9	204	531	240	1460	2230	2430	25,100	17,300	33,100	0.8	8.9	9.7
Date of low abundance	110	76.5	186	549	157	642	1350	1530	21,100	17,700	24,500	0.9	6.4	7.3
Oithona occulata - "inshore bottom" species of plankton														
Date of high abundance	103	141	244	515	185	1170	1870	2110	28,300	0	60,300	0.9	6.6	7.4
Date of low abundance	3.18	3.73	6.91	15.9	5.77	29.2	50.9	57.8	962	543	1,380	0.7	5.3	6.0
Acartia tonsa - "variable" species of plankton														
Date of high abundance	689	562	1250	3440	5770	13300	22500	23800	527,000	416,000	637,000	0.2	4.3	4.5
Date of low abundance	742	458	1200	3710	3320	11600	18600	19800	414,000	352,000	476,000	0.3	4.5	4.8

[1] No estimates of confidence bounds based on longshore variability are available.

Table 5. Summary of estimated daily losses of representative plankton species and numbers of those species influenced by SONGS based, respectively, on daily loss rates and on a 1% dispersion boundary. This boundary extends about 44 km alongshore and 6 km offshore. All numbers except percentages are given in millions (i.e., multiply value by 10^6). See text section, Prediction (1) for further explanation.

	Intake Loss Unit 1	Discharge Loss Unit 1	Total Loss Unit 1	Intake Loss Units 2 & 3	Discharge Loss Units 2 & 3	Transport Loss Units 2 & 3	Total Loss Units 2 & 3	Total Loss Units 1, 2, 3	Number Influenced Within 1% Dispersion Boundaries 90% Confidence Bounds			Daily Loss Rate (% Loss of Numbers Influenced)		
									Mean	Lower	Upper	Unit 1	Units 2 & 3	Units 1,2,3
Cypris larvae - "inshore" species of meroplankton														
Date of high abundance	37.1	23.2	60.3	185	134	819	1140	1200	21,700	17,800	25,600	0.3	5.3	5.5
Seriphus politus (Queenfish) "inshore" species of ichthyoplankton														
Spring	.145	.099	.244	.726	2.06	10.5	13.3	13.5	499	N/A[1]	N/A	< 0.1	2.7	2.7
Summer	.466	.574	1.04	2.33	.365	0	2.70	3.74	441	N/A[1]	N/A	0.2	0.6	0.8
Acartia clausi - "inshore" species of plankton														
Date of high abundance	106	97.9	204	531	240	1460	2230	2430	58,800	40,400	77,500	0.3	3.8	4.1
Date of low abundance	110	76.5	186	549	157	642	1350	1530	65,300	54,500	76,000	0.3	2.1	2.3
Oithona occulata - "inshore bottom" species of plankton														
Date of high abundance	103	141	244	515	185	1170	1870	2110	66,300	0	141,000	0.4	2.8	3.2
Date of low abundance	3.18	3.73	6.91	15.9	5.77	29.2	50.9	57.8	2,560	1,470	3,650	0.3	2.0	2.3
Acartia tonsa - "variable" species of plankton														
Date of high abundance	689	562	1250	3440	5770	13300	22500	23800	2,550,000	2,010,000	3,080,000	< 0.1	0.9	0.9
Date of low abundance	742	458	1200	3710	3320	11600	18600	19800	1,400,000	1,180,000	1,620,000	0.1	1.3	1.4

[1] No estimates of confidence bounds based on longshore variability are available.

Table 6. Estimated total daily losses of plankton to SONGS cooling system based on various assumptions of losses in the inshore water that is transported offshore by the diffusers and the subsequent dilution of the inshore water by offshore ambient water. Losses are presented as the percentage of the total number of that organism found within the 3% or 1% plume (dispersion) boundaries that are lost per day. Estimates are for a representative date of high abundance.

Loss Conditions (% loss of those subjected to source)				Daily Loss on Date of High Abundance (% loss of population)				
Intake	Entrainment	Offshore Transport	Dilution	Cypris larvae	Seriphus politus	Oithona occulata	Acartia clausi	Acartia tonsa
			3% Plume Boundary					
100	0	0	None	2.4	0.6	2.2	2.5	0.8
100	0	0	Half	7.5	4.5	4.5	5.9	2.5
100	0	0	Full	12.5	8.4	6.9	9.2	4.3
100	0	50	None	7.8	5.4	4.6	6.1	4.3
100	0	50	Half	10.2	7.1	5.8	7.6	4.3
100	0	50	Full	12.5	8.4	6.9	9.2	4.3
100	0	100	None	12.5	8.4	6.9	9.2	4.3
100	0	100	Half	12.5	8.4	6.9	9.2	4.3
100	0	100	Full	12.5	8.4	6.9	9.2	4.3
100	12	0	None	4.1	1.9	3.3	3.9	2.0
100	12	0	Half	8.5	5.3	5.4	6.8	3.3
100	12	0	Full	12.9	8.6	7.4	9.7	4.5
100	12	50	None	8.8	6.2	5.5	7.0	4.5
100	12	50	Half	10.9	7.4	6.5	8.3	4.5
100	12	50	Full	12.9	8.6	7.4	9.7	4.5
100	12	100	None	12.9	8.6	7.4	9.7	4.5
100	12	100	Half	12.9	8.6	7.4	9.7	4.5
100	12	100	Full	12.9	8.6	7.4	9.7	4.5
			1% Plume Boundary					
100	0	0	None	1.0	0.2	0.9	1.1	0.2
100	0	0	Half	3.2	1.4	1.9	2.5	0.5
100	0	0	Full	5.4	2.6	2.9	3.9	0.9
100	0	50	None	3.3	1.7	2.0	2.6	0.9
100	0	50	Half	4.3	2.2	2.5	3.3	0.9
100	0	50	Full	5.4	2.6	2.9	3.9	0.9
100	0	100	None	5.4	2.6	2.9	3.9	0.9
100	0	100	Half	5.4	2.6	2.9	3.9	0.9
100	0	100	Full	5.4	2.6	2.9	3.9	0.9
100	12	0	None	1.8	0.6	1.4	1.7	0.4
100	12	0	Half	3.6	1.7	2.3	2.9	0.7
100	12	0	Full	5.5	2.7	3.2	4.1	0.9
100	12	50	None	3.8	2.0	2.3	3.0	0.9
100	12	50	Half	4.6	2.3	2.8	3.6	0.9
100	12	50	Full	5.5	2.7	3.2	4.1	0.9
100	12	100	None	5.5	2.7	3.2	4.1	0.9
100	12	100	Half	5.5	2.7	3.2	4.1	0.9
100	12	100	Full	5.5	2.7	3.2	4.1	0.9

Table 7. Estimated total daily losses of plankton to SONGS cooling system based on various assumptions of losses in the inshore water that is transported offshore by the diffusers and the subsequent dilution of the inshore water by offshore ambient water. Losses are presented as the percentage of the total number of that organism found within the 3% or 1% plume (dispersion) boundaries that are lost per day. Estimates are for a representative date of low abundance.

Loss Conditions (% loss of those subjected to source)				Daily Loss on Date of Low Abundance (% loss of population)			
Intake	Entrainment	Offshore Transport	Dilution	Seriphus politus	Oithona occulata	Acartia clausi	Acartia tonsa
				3% Plume Boundary			
100	0	0	None	2.3	2.0	3.1	1.1
100	0	0	Half	2.0	3.7	5.0	2.8
100	0	0	Full	1.8	5.6	6.8	4.6
100	0	50	None	2.3	4.2	5.9	4.1
100	0	50	Half	2.3	4.9	6.4	4.3
100	0	50	Full	1.8	5.6	6.8	4.6
100	0	100	None	2.3	5.6	6.8	4.6
100	0	100	Half	2.3	5.6	6.8	4.6
100	0	100	Full	1.8	5.6	6.8	4.6
100	12	0	None	3.0	3.0	4.2	2.0
100	12	0	Half	2.7	4.4	5.8	3.4
100	12	0	Full	2.3	6.0	7.3	4.8
100	12	50	None	3.0	4.9	6.7	4.6
100	12	50	Half	3.0	5.5	7.0	4.7
100	12	50	Full	2.3	6.0	7.3	4.8
100	12	100	None	3.0	6.0	7.3	4.8
100	12	100	Half	3.0	6.0	7.3	4.8
100	12	100	Full	2.3	6.0	7.3	4.8
				1% Plume Boundary			
100	0	0	None	0.6	0.7	1.0	0.3
100	0	0	Half	0.6	1.4	1.6	0.8
100	0	0	Full	0.5	2.1	2.2	1.4
100	0	50	None	0.6	1.6	1.9	1.2
100	0	50	Half	0.6	1.8	2.1	1.3
100	0	50	Full	0.5	2.1	2.2	1.4
100	0	100	None	0.6	2.1	2.2	1.4
100	0	100	Half	0.6	2.1	2.2	1.4
100	0	100	Full	0.5	2.1	2.2	1.4
100	12	0	None	0.8	1.1	1.4	0.6
100	12	0	Half	0.7	1.7	1.9	1.0
100	12	0	Full	0.6	2.3	2.3	1.4
100	12	50	None	0.8	1.8	2.2	1.4
100	12	50	Half	0.8	2.0	2.3	1.4
100	12	50	Full	0.6	2.3	2.3	1.4
100	12	100	None	0.8	2.3	2.3	1.4
100	12	100	Half	0.8	2.3	2.3	1.4
100	12	100	Full	0.6	2.3	2.3	1.4

Table 8. Estimated loss caused by intake withdrawal based on sampling the Unit 1 intake and discharge risers synoptically before and after heat treatment on December 1 and 5, 1978, respectively. Percent losses across cooling system equals:

$$\% \text{ Loss} = 100 - \left[\frac{\text{concentration in discharge riser}}{\text{concentration in intake riser}} \times 100\right]$$

Species	% Loss of Organisms Across Cooling System Before Heat Treatment	% Loss of Organisms Across Cooling System After Heat Treatment
Acartia tonsa	99	82
Paracalanus parvus	98	72
Penilia avirostris	98	91
Coryceaus anglicus	95	55

Table 9. Results of Delayed Mortality Study, August 10, 1978, with *Acartia tonsa* used as the test organism. Numbers given are percent mortality after four days *in situ* incubation. About 50 organisms were used in each container.

	Control Organisms	Entrained Organisms
Replicates	32, 38, 46, 36, 40	42, 28, 26, 42, 32
$\bar{X}$	38.4	34.0
95% Upper Bound	44.84	43.47
95% Lower Bound	31.96	24.53

The maximum possible percent undetectable loss in this experiment is calculated from the difference in lower 95% bound of the control mortality and highest 95% bound of the entrainment mortality rate.

Maximum undetectable loss = 43.47 - 31.96 = 11.51

= ∿ 12%

Description of Experiment

Entrained organisms in the plume immediately downcurrent of the Unit 1 discharge and "control" organisms from near the bottom upcurrent of the Unit 1 discharge were caught and placed in experimental containers. No organisms were captured when pure discharge waters were sampled so the entrained samples were free of organisms which had been transported through the cooling system. The experimental containers were plexiglass cylinders with 103-μ mesh on approximately 1/3 of the surface area. The containers were incubated *in situ* ∿3 km downcoast from SONGS at the same depth contour as the Unit 1 discharge. Four replicate containers were analyzed (without replacement) each day for mortality using vital staining techniques. The results presented above are for the fourth and final day of the experiment.

Table 10. Summary of finite natural mortality rates from other studies. Ranges include values attributed to different methods of calculations as well as variations in results.

Organism	Estimated Finite Mortality	Source
Acartia tonsa (copepod, copepodid stage)	.44	Heinle (1966)
Calanus helgolandicus (copepod, late copepodid stage)	.01 - .32	Mullin and Brooks (1970), Fager (1973)
Pseudocalanus elongatus (copepod)	0 - .40	N. Sonntag, Univ. of British Columbia (personal communication - CEPEX Large Volume Plastic Bag Experiments)
Roccus saxatilis (Striped bass larvae)	0.7 - .27	Polgar (1977)

Table 11. Frequency of occurrence of higher concentrations of nutrients near the bottom in the area of the Units 2 and 3 diffusers.

Month	Number of dates (cruises) during which nutrients were sampled in 1977 and 1978	Number of dates during which nitrate plus nitrite were found in higher concentrations near the bottom* in the area of the Units 2 and 3 diffusers
Jan	4	2
Feb	1	1
Mar	2	1
Apr	1	1
May	2	2
Jun	2	2
Jul	2	1
Aug	3	1
Sep	1	1
Oct	2	2
Nov	2	0
Dec	3	1
	25	15

*Concentrations equal to or greater than .5 μg-at N liter^{-1} higher in the bottom waters than in the surface waters.

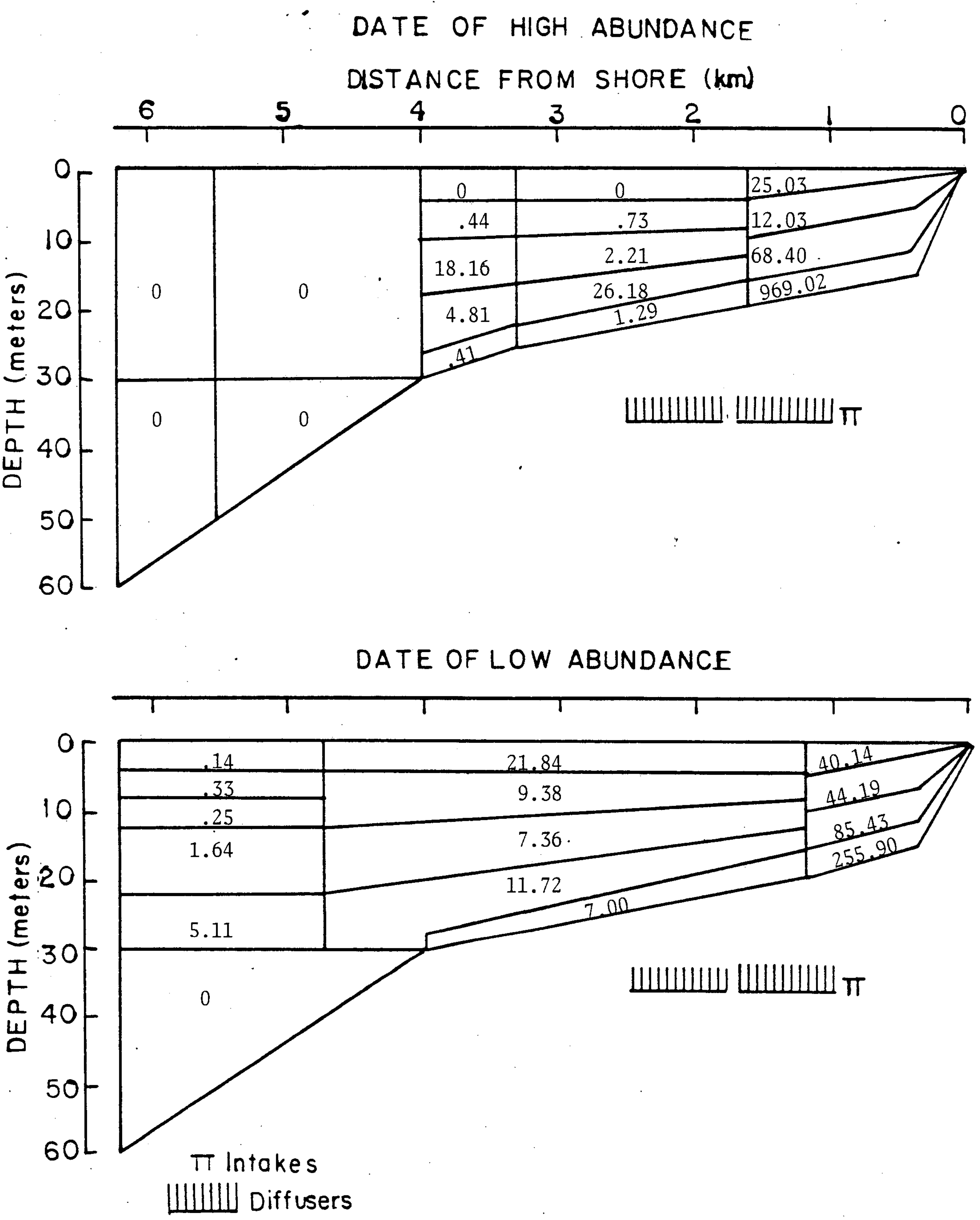

Figure 1. Mean concentrations (numbers m^{-3}) of *Acartia clausi* on November 2, 1977 (representative date of high abundance) and January 20, 1978 (representative dates of low abundance) used in the analysis of "SONGS Losses" in Tables 4 and 5. Inshore blocks are not drawn to depth scale. Concentrations shown in each stratum are the mean values of 25 replicates from locations 20 - 25.5 km in total longshore extent.

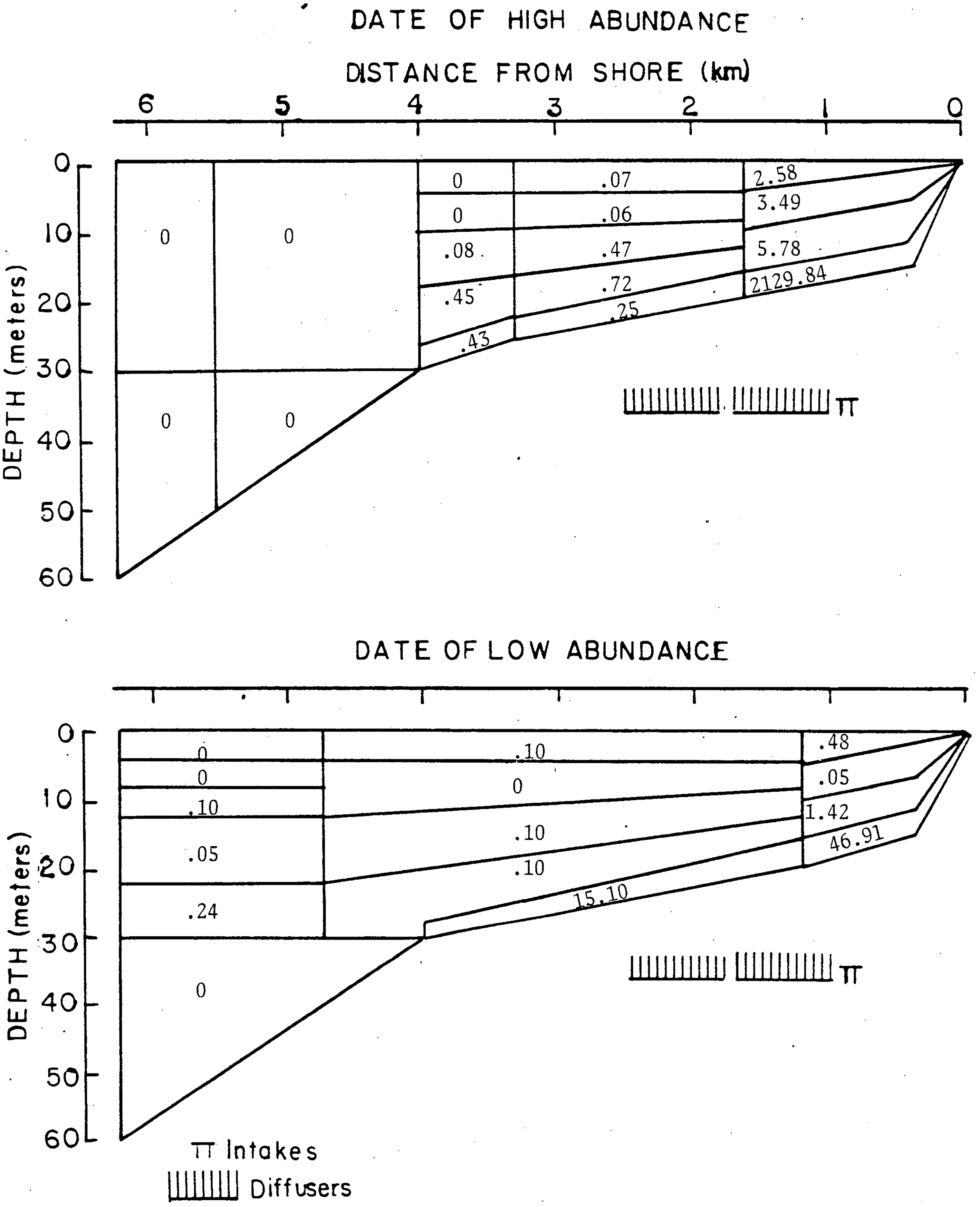

Figure 2. Mean concentrations (numbers m^{-3}) of Oithona occulata on November 2, 1977 (representative date of high abundance) and January 20, 1978 (representative date of low abundance) used in the analysis of "SONGS Losses" in Tables 4 and 5. Inshore blocks are not drawn to depth scale. Concentrations shown in each stratum are the mean values of 25 replicates from locations 20 - 25.5 km in total longshore extent.

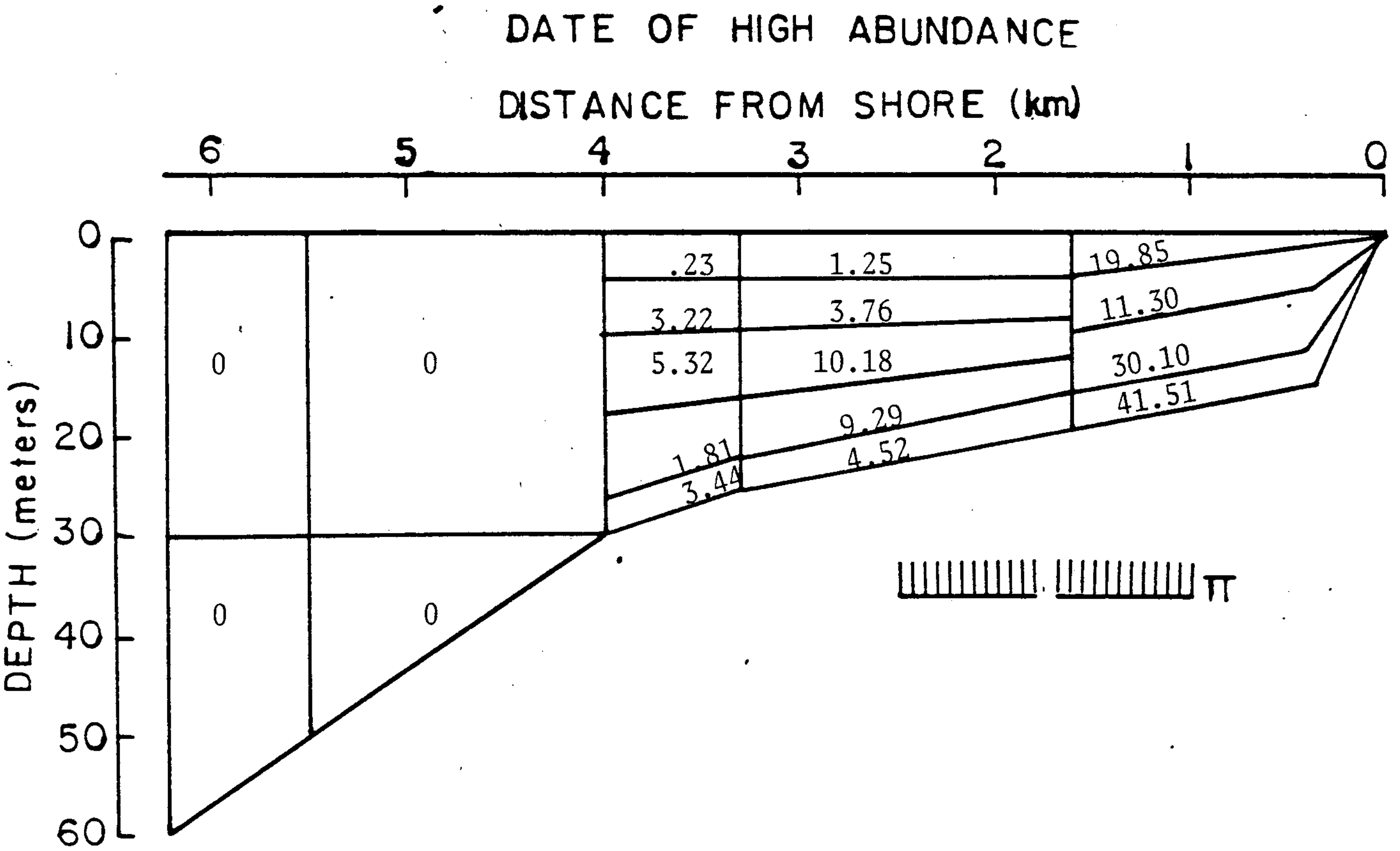

Figure 3. Mean concentrations (numbers/m^{-3}) of cypris larvae on November 2, 1977 (representative date of high plankton abundance) used in the analysis of "SONGS Losses" in Tables 4 and 5. Inshore blocks are not drawn to depth scale. Concentrations shown in each stratum are the mean values of 25 replicates from locations 20 - 25.5 km in total longshore extent.

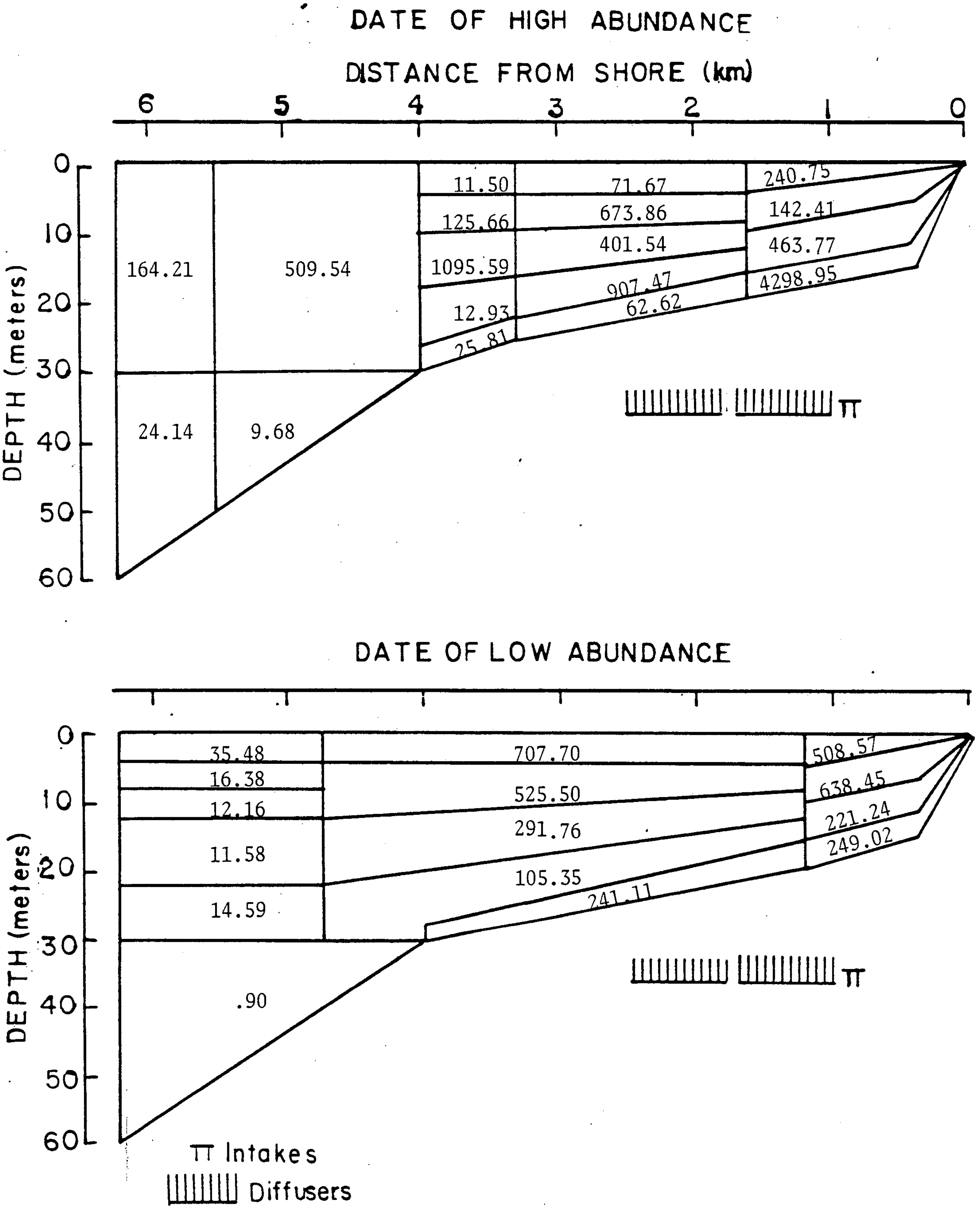

Figure 4. Mean concentrations (numbers m^{-3}) of <u>Acartia tonsa</u> on November 2, 1977 (representative date of high abundance) and January 20, 1978 (representative date of low abundance) used in the analysis of "SONGS Losses" in Tables 4 and 5. Inshore blocks are not drawn to depth scale. Concentrations shown in each stratum are the mean values of 25 replicates from locations 20 - 25.5 km in total longshore extent.

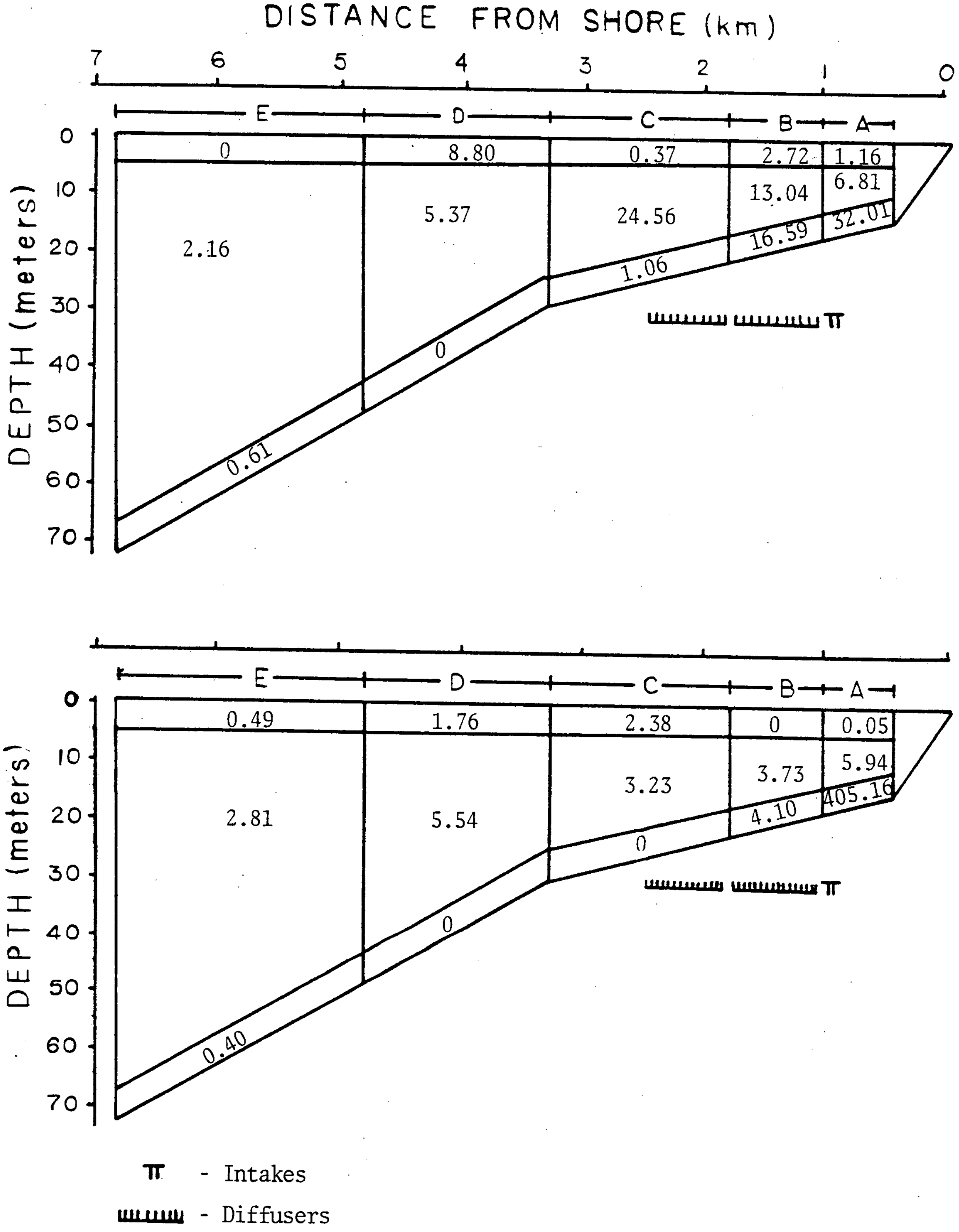

Figure 5. Mean concentrations (numbers/100 m^3) of Seriphus politus in the neustonic, midwater and epibenthic layers during four surveys in the Spring (Case 1) and in the Summer (Case 2) of 1978. Neustonic and epibenthic layers are vertically exaggerated relative to midwater layers. These data are used in the analysis of "SONGS Losses" in Tables 4 and 5.

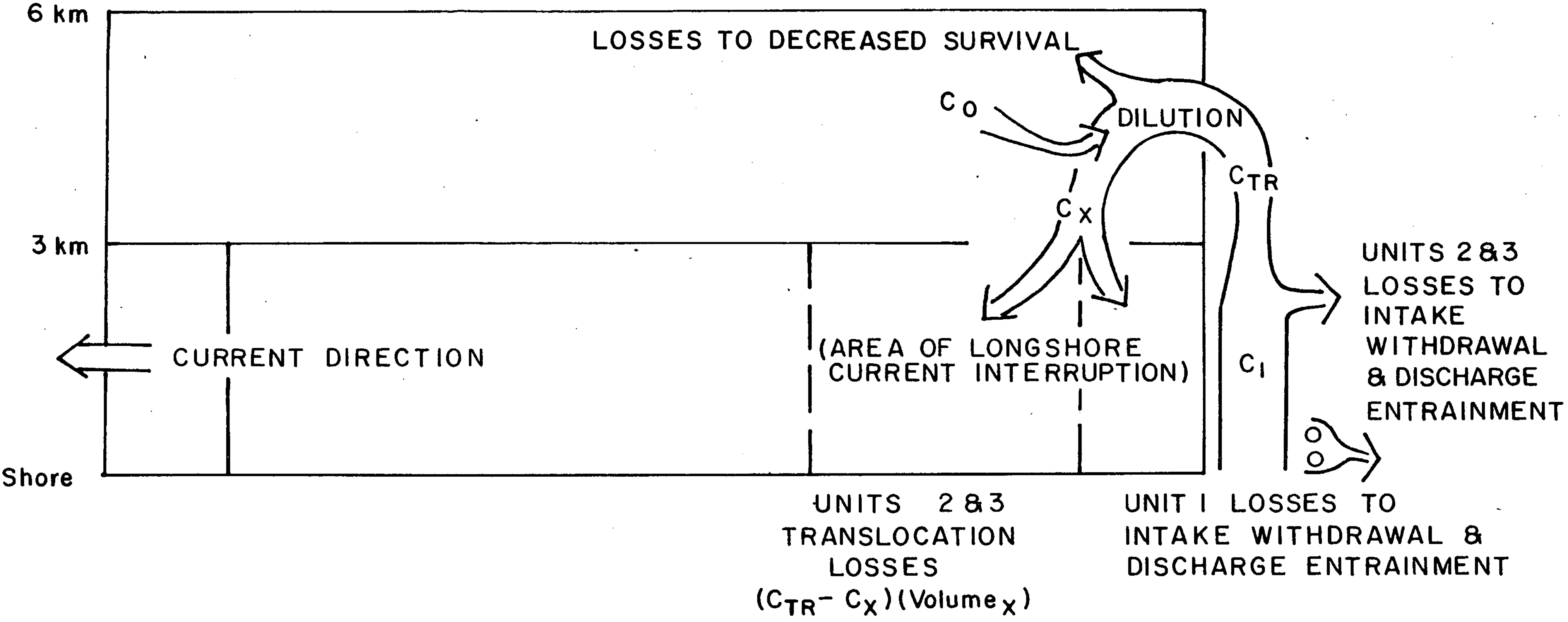

Figure 6. Diagram of sources of plankton losses to SONGS cooling operations during conditions of slower downcoast longshore flow. C_1 is the concentration affected by Units 2 and 3 intake withdrawal and discharge entrainment. C_{TR} is the concentration of plankton transported offshore and is subjected to various conditions of mortality rates and dilution by offshore waters (C_O = concentration offshore). C_X is then the concentration of the diluted mixture available to disperse back towards shore. Some of the offshore water must move onshore downcurrent of SONGS to replace the waters removed by the longshore flow which has resumed downcurrent after its interruption by SONGS. Transport (= translocation) losses are calculated by (C_{TR} - C_X) times the volume in which C_X returns toward shore.

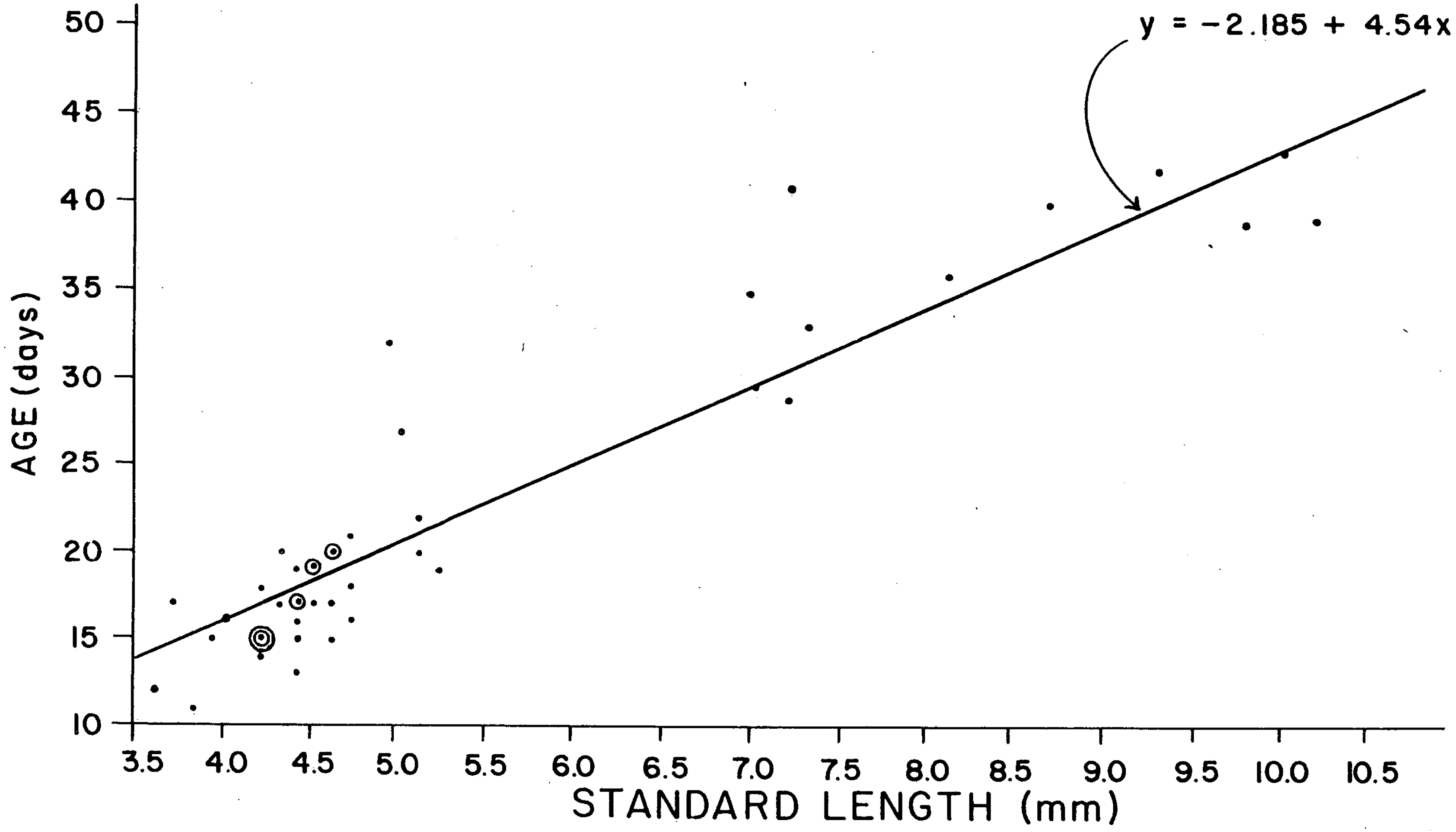

Figure 7. Age versus length for Seriphus politus larvae collected May 8 and May 23, 1978. Age determined from otoliths. Circles around points indicate multiple observations.

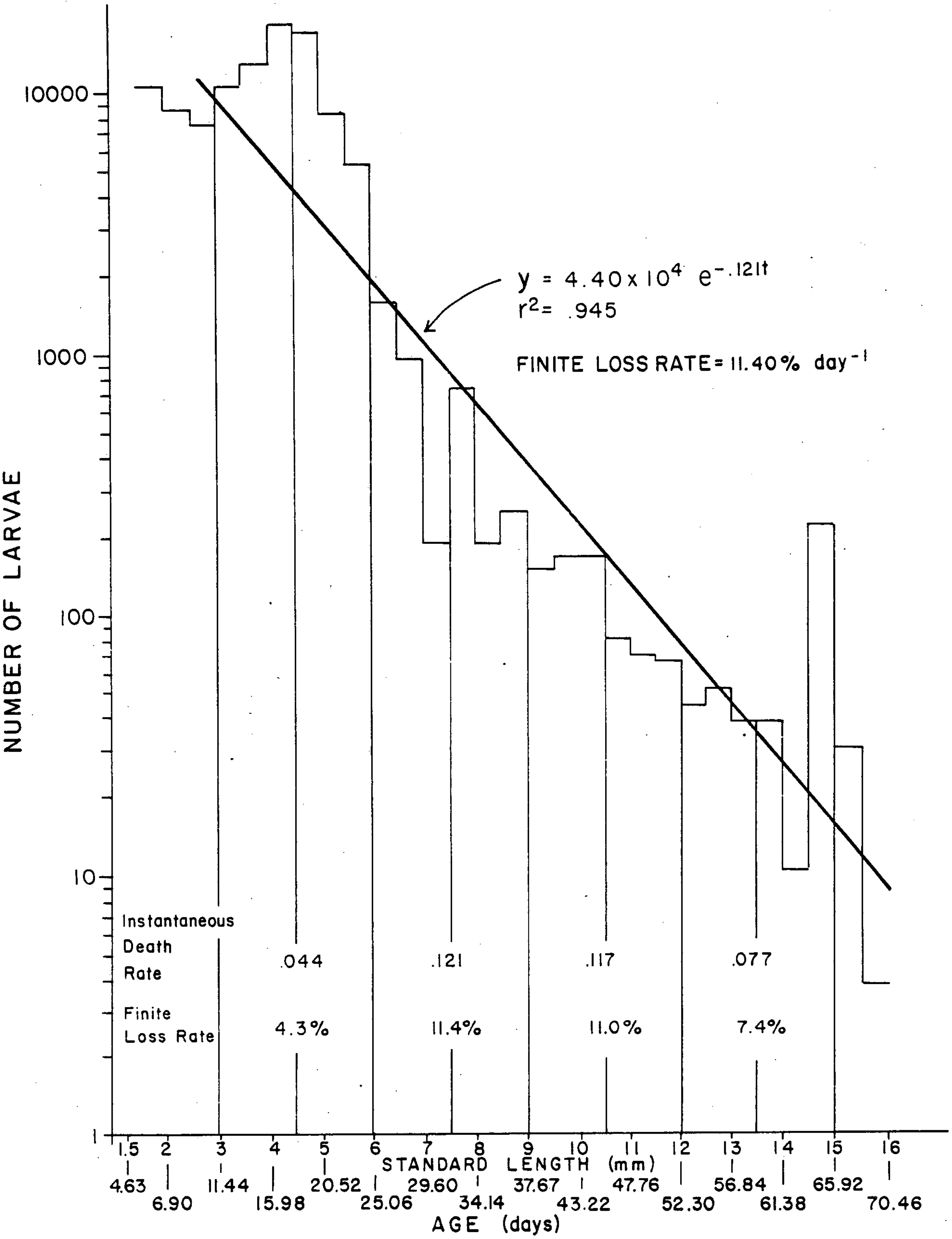

Figure 8. Length and age frequencies of Seriphus politus under a 1 m wide strip between 6 and 75 m 1 km south of SONGS. Data were pooled from April to August, 1978. The line represents mortality rate, assuming equal mortality through all classes. The data were also divided into 8 classes to calculate mortality between paired classes according to the method of Fager (1973). Standard length was converted to age using the regression equation from Figure 7.

LOSS ESTIMATE CALCULATIONS

Macrozooplankton

To estimate the total of macrozooplankton loss, values for *Acartia tonsa* (see Table 4 of this section) were used. These were multiplied by the ratio of the total number of organisms to the number of *A. tonsa* in the area (intake area or diffuser area) on that date (see Table A, Loss Estimate Calculations/Macrozooplankton). The total plankton lost were estimated as follows:

For SONGS Unit 1 intake withdrawal on a date of high abundance, total macrozooplankton organisms lost would be:

$$\frac{689 \text{ x } 10^6 \textit{ A. tonsa}}{\text{day}} \text{ x } \frac{100 \text{ total macrozooplankton organisms}}{28.5 \textit{ A. tonsa}} = \frac{2418 \text{ x } 10^6 \text{ total macrozooplankton organisms}}{\text{day}}$$

Similarly, for a date of low abundance, the number of organisms lost would be:

$$\frac{724 \text{ x } 10^6 \textit{ A. tonsa}}{\text{day}} \text{ x } \frac{100 \text{ organisms}}{29 \textit{ A. tonsa}} = 2537 \text{ x } 10^6 \frac{\text{organisms}}{\text{day}} .$$

For an average day, the number lost will be:

$$\frac{(2418 \text{ x } 10^6 + 2537 \text{ x } 10^6)}{2} \frac{\text{organisms}}{\text{day}} = 2478 \text{ x } 10^6 \frac{\text{organisms}}{\text{day}} .$$

Maximum losses to Unit 1 discharge entrainment (12% of those entrained) on a date of high abundance will be:

$$\frac{562 \text{ x } 10^6 \textit{ A. tonsa}}{\text{day}} \text{ x } \frac{100 \text{ organisms}}{28.5 \textit{ A. tonsa}} = 1972 \text{ x } 10^6 \frac{\text{organisms}}{\text{day}} .$$

on a day of low abundance:

$$\frac{458 \text{ x } 10^6 \textit{ A. tonsa}}{\text{day}} \text{ x } \frac{100 \text{ organisms}}{29 \textit{ A. tonsa}} = 1566 \text{ x } 10^6 \frac{\text{organisms}}{\text{day}}$$

Averaging these two values will give an average loss of:

$$\frac{[(1972 \times 10^6) + (1566 \times 10^6)]}{2} \, \frac{\text{organisms}}{\text{day}} = 1769 \times 10^6 \, \frac{\text{organisms}}{\text{day}}$$

Losses of all macrozooplankton are figured similarly for Units 2 and 3. On the date of high abundance, using values for *A. tonsa* from Table 4 and Table A, the loss to intake withdrawal will be:

$$\frac{3440 \times 10^6 \ \underline{\text{A.}} \ \underline{\text{tonsa}}}{\text{day}} \times \frac{100 \text{ organisms}}{28.5 \ \underline{\text{A.}} \ \text{tonsa}} = 12{,}070 \times 10^6 \, \frac{\text{organisms}}{\text{day}}$$

and on a date of low abundance:

$$\frac{3710 \times 10^6 \ \underline{\text{A.}} \ \underline{\text{tonsa}}}{\text{day}} \times \frac{100 \text{ organisms}}{29 \ \underline{\text{A.}} \ \underline{\text{tonsa}}} = \underline{12{,}793 \times 10^6} \, \frac{\text{organisms}}{\text{day}}$$

Average losses will be:

$$\frac{[(12{,}070 \times 10^6) + (12{,}793 \times 10^6)]}{2} \, \frac{\text{organisms}}{\text{day}} = 12{,}432 \times 10^6 \, \frac{\text{organisms}}{\text{day}}$$

Losses to Units 2 and 3 diffuser entrainment and offshore transport are, for a day of high abundance:

$$\frac{19070 \times 10^6 \ \underline{\text{A.}} \ \underline{\text{tonsa}}}{\text{day}} \times \frac{100 \text{ organisms}}{9 \ \underline{\text{A.}} \ \underline{\text{tonsa}}} = 211{,}889 \times 10^6 \, \frac{\text{organisms}}{\text{day}}$$

and for a day of low abundance:

$$\frac{14920 \times 10^6 \ \underline{\text{A.}} \ \underline{\text{tonsa}}}{\text{day}} \times \frac{100 \text{ organisms}}{24 \ \underline{\text{A.}} \ \underline{\text{tonsa}}} = 62{,}167 \times 10^6 \, \frac{\text{organisms}}{\text{day}}$$

On a yearly basis, the loss would be the average of the two dates:

$$\frac{[(211{,}889 \times 10^{6}) + (62{,}167 \times 10^{6})]}{2} \frac{\text{organisms}}{\text{day}} = 137{,}028 \times 10^{6} \frac{\text{organisms}}{\text{day}}$$

To get losses per year for Units 1, 2 and 3, the losses for Unit 1 are added to losses for Units 2 and 3 as shown in the table below.

To convert these numbers lost per day to tons lost per year, several calculations are made. First the numbers per day are multiplied by 365 days year^{-1} to get numbers lost per year. To then calculate the biomass, it is assumed that an average macrozooplankter is the size of a fourth copepodid stages *A. tonsa* which measures 0.1 cm by .03 cm by .03 cm or about $0.1 \times 10^{-3}\ \text{cm}^{3}$. Using a density of 1 gm cm^{-3}, the wet weight of one organism is 0.1 mg ($0.1 \times 10^{-3}\ \text{cm}^{3} \times 1\ \text{gm cm}^{-3} \times 10^{3}\ \text{mg gm}^{-1}$). Expressing this weight in metric tons (MT):

$$\frac{0.1\ \text{mg}}{\text{org}} \times \frac{10^{-3}\ \text{g}}{\text{mg}} \times \frac{10^{-3}\ \text{kg}}{\text{g}} \times \frac{10^{-3}\ \text{MT}}{\text{kg}} = \frac{0.1 \times 10^{-9}\ \text{MT}}{\text{organism}} = \frac{10^{-10}\ \text{MT}}{\text{organism}}$$

Metric tons are then changed to tons by multiplying by 1.1 tons MT^{-1}. To summarize these steps:

$$\frac{(\ \ )\ \text{organisms}}{\text{day}} \times \frac{365\ \text{days}}{\text{year}} \times \frac{10^{-10}\ \text{MT}}{\text{organism}} \times \frac{1.1\ \text{tons}}{\text{MT}} = \frac{(\ \ )\ \text{tons}}{\text{year}}$$

	Organisms Day^{-1}	Organisms Yr.^{-1}	Metric Tons Year^{-1}	Tons Year^{-1}
Unit 1 Intake	2478×10^{6}	90×10^{10}	90	99
Unit 1 Discharge	1769×10^{6}	$65. \times 10^{10}$	65	71
Unit 1 Total	4247×10^{6}	155×10^{10}	155	170
Units 2 and 3 Intakes	12432×10^{6}	454×10^{10}	454	500
Units 2 and 3 Discharge	137028×10^{6}	5000×10^{10}	5000	5500
Units 2 and 3 Total	149460×10^{6}	5454×10^{10}	5454	6000
Units 1, 2 and 3 Intakes	14910×10^{6}	544×10^{10}	544	599
Units 1, 2 and 3 Discharges	138797×10^{6}	5066×10^{10}	5066	5571
Units 1, 2 and 3 Total	153707×10^{6}	5610×10^{10}	5610	6170

Minimum estimated losses assume that 100% of the macrozooplankton withdrawn by the intakes are killed. These losses would be 2.5 x 10^9 organisms per day for Unit 1 and 15 x 10^9 organisms per day for Units 1, 2 and 3.

Maximum estimated losses assume that 12% are lost to entrainment turbulent stress and the remaining organisms entrained by the Units 2 and 3 diffusers are transported offshore where they all are diluted into offshore ambient water and die because of decreased survivorship. These losses total 4.3 x 10^9 organisms per day for Unit 1 and 154 x 10^9 organisms per day for Units 1, 2 and 3.

Table A. Percent of plankton represented by *Acartia tonsa*. Numbers are the percent of *A. tonsa* total plankton counted at each sampling location. Plankton counted represent about 75% of the total macrozooplankton in a sample. Therefore, 75% is multiplied by the mean percent of *A. tonsa* to obtain the fraction of the total macrozooplankton represented by *A. tonsa*.

Date of high abundance (November 2, 1977)

Units 1, 2, 3 Intake and Unit 1 Discharge Depth						Units 2 and 3 Diffuser Depth					
47	30	86	45	28	81	6	1	4	20	14	9
43	66	39	71	26	55	23	5	7	19	64	40
10	19	11	76	15	7	12	11	12	7	9	6
14	37	2	78	11	12	14	4	0	3	3	0

$\bar{X}$ % = 38%

(.75)(.38) = .285 = 28.5%

$\bar{X}$ % = 12%

(.75)(.12) = .09 = 9%

Date of low abundance (January 20, 1978)

Units 1, 2, 3 Intake and Unit 1 Discharge Depth					Units 2 and 3 Diffuser Depth				
8	1	32	4	53	69	37	2	28	21
22	57	49	9	37	37	75	15	8	16
8	52	88	54	40	61	40	37	3	4
27	52	91	36	58	70	34	48	10	34

$\bar{X}$ = 39%

(.75)(.39) = .2925 = 29%

$\bar{X}$ = 32%

(.75)(.32) = .24 = 24%

Larval Fish

Losses for all larval fish are calculated from estimated losses of *Seriphus politus* shown in Table 4 (see preceding Plankton section, Table and Figures). Spring (high abundance) and summer (low abundance) values are averaged.

In the area of the Unit 1 intake and discharge, *S. politus* represents 2.4% of the larval fish in the spring and 47.6% in the summer. The number of larvae lost per day to intake withdrawal is calculated as follows:

$$\text{Spring} \quad \frac{.145 \times 10^6 \ \textit{S. politus}}{\text{day}} \times \frac{100 \text{ total larvae}}{2.4 \ \textit{S. politus}} = \frac{6.04 \times 10^6 \text{ total larvae}}{\text{day}}$$

$$\text{Summer} \quad \frac{.466 \times 10^6 \ \textit{S. politus}}{\text{day}} \times \frac{100 \text{ total larvae}}{47.6 \ \textit{S. politus}} = \frac{0.98 \times 10^6 \text{ total larvae}}{\text{day}}$$

Averaging spring and summer values:

$$\frac{(6.04 \times 10^6) + (.98 \times 10^6)}{2} \ \frac{\text{larvae}}{\text{day}} = \frac{3.51 \times 10^6 \text{ larvae}}{\text{day}}$$

Losses to Unit 1 discharge assume that 12% of larvae entrained will be killed:

$$\text{Spring} \quad \frac{.099 \times 10^6 \ \textit{S. politus}}{\text{day}} \times \frac{100 \text{ total larvae}}{2.4 \ \textit{S. politus}} = \frac{4.13 \times 10^6 \text{ total larvae}}{\text{day}}$$

$$\frac{.574 \times 10^6 \ \textit{S. politus}}{\text{day}} \times \frac{100 \text{ total larvae}}{47.6 \ \textit{S. politus}} = \frac{1.21 \times 10^6 \text{ total larvae}}{\text{day}}$$

Averaging spring and summer values:

$$\frac{(4.13 \times 10^6) + (1.21 \times 10^6)}{2} \ \frac{\text{larvae}}{\text{day}} = \frac{2.67 \times 10^6 \text{ larvae}}{\text{day}}$$

The proportion of *S. politus* in the area of the Units 2 and 3 intakes are the same as above. Losses to these intakes are calculated same way:

$$\text{Spring}\quad \frac{.726 \times 10^{6}\ \underline{\text{S}}.\ \underline{\text{politus}}}{\text{day}} \times \frac{100 \text{ total larvae}}{2.4\ \underline{\text{S}}.\ \underline{\text{politus}}} = \frac{30 \times 10^{6} \text{ total larvae}}{\text{day}}$$

$$\text{Summer}\quad \frac{2.33 \times 10^{6}\ \underline{\text{S}}.\ \underline{\text{politus}}}{\text{day}} \times \frac{100 \text{ total larvae}}{47.6\ \underline{\text{S}}.\ \underline{\text{politus}}} = \frac{4.9 \times 10^{6} \text{ total larvae}}{\text{day}}$$

Averaging spring and summer values:

$$\frac{(30 \times 10^{6}) + (4.9 \times 10^{6})}{2} \frac{\text{larvae}}{\text{day}} = \frac{17.45 \times 10^{6} \text{ larvae}}{\text{day}}$$

In the area of the Unit 2 and 3 diffusers, S. politus represents 2% and 9.6% of total larvae in the spring and summer, respectively. Losses to entrainment and offshore transport are:

$$\frac{12.56 \times 10^{6}\ \underline{\text{S}}.\ \underline{\text{politus}}}{\text{day}} \times \frac{100 \text{ total larvae}}{2\ \underline{\text{S}}.\ \underline{\text{politus}}} = \frac{628 \times 10^{6} \text{ total larvae}}{\text{day}}$$

$$\frac{.365 \times 10^{6}\ \underline{\text{S}}.\ \underline{\text{politus}}}{\text{day}} \times \frac{100 \text{ total larvae}}{9.6\ \underline{\text{S}}.\ \underline{\text{politus}}} = \frac{3.8 \times 10^{6} \text{ total larvae}}{\text{day}}$$

Averaging these values:

$$\frac{(628 \times 10^{6}) + (3.8 \times 10^{6})}{2} \frac{\text{larvae}}{\text{day}} = \frac{316 \times 10^{6} \text{ larvae}}{\text{day}}$$

Losses for Units 1, 2 and 3 are the sums of the losses calculated above and are shown below. Conversion from larvae day^{-1} to larvae year^{-1} is then made. The next step is to convert the number of larvae to biomass in metric tons (MT) by first assuming a weight of 1 mg larvae^{-1} (based on weights of S. politus), then multiplying:

$$(\quad) \frac{\text{larvae}}{\text{year}} \times \frac{1 \text{ mg}}{\text{larvae}} \times \frac{10^{-3} \text{ g}}{\text{mg}} \times \frac{10^{-3} \text{ kg}}{\text{g}} \times \frac{10^{-3} \text{ MT}}{\text{kg}} = \frac{(\quad)\ 10^{-9} \text{ MT}}{\text{year}}$$

Metric tons are then changed to tons (1.1 tons = 1 MT).

	Larvae Day^{-1}	Larvae Year^{-1}	MT Year^{-1}	Tons Year^{-1}
Unit 1 Intake	3.5×10^6	1.3×10^9	1.3	1.4
Unit 1 Discharge	2.7×10^6	1.0×10^9	1.0	1.1
Unit 1 Total	6.2×10^6	2.3×10^9	2.3	2.5
Units 2 and 3 Intakes	17.5×10^6	6.3×10^9	6.3	7.0
Units 2 and 3 Discharges	316×10^6	115×10^9	115	127
Units 2 and 3 Total	334×10^6	122×10^9	122	134
Units 1, 2, and 3 Intakes	21×10^6	7.7×10^9	7.7	8.5
Units 1, 2, and 3 Discharges	319×10^6	116×10^9	116	128
Units 1, 2 and 3 Total	340×10^6	124×10^9	124	136

Minimum losses are based on intake withdrawal only and assume that all larvae withdrawn are lost. These estimates are 3.5×10^6 larvae day^{-1} for Unit 1 and 21×10^6 larvae day^{-1} for Units 1, 2 and 3.

Maximum losses include losses to discharge entrainment, for Unit 1 12% loss to turbulent stress is assumed, and loss to Unit 1 is 6.2×10^6 larvae day^{-1}. Maximum losses to Units 1, 2 and 3 assume that all larvae entrained by Units 2 and 3 die either due to turbulent stress or decreased survivorship when transported offshore. This loss is estimated at 340×10^6 larvae day^{-1}.

Larval Fish*

Larval fish losses are based on mean abundance (number m^{-3}) from 19 dates in 1978 in the area of both the intakes and diffusers. The dates are spaced at two to three week intervals. These abundances are then multiplied by the volume (m^3) of water involved in intake withdrawal or diffuser entrainment. For Unit 1, the mean abundance in the area of the intake is 2.3 fish larvae per m^3, and a volume of 1.8×10^6 m^3 day^{-1} is withdrawn. Therefore, assuming 100% mortality of withdrawn larvae, the loss will be 2.3 larvae $m^{-3} \times 1.8 \times 10^6$ m^3 $day^{-1} = 4.14 \times 10^6$ larvae day^{-1}. The discharge will entrain 9×10^6 m^3 day^{-1} and, assuming that 12% of those larvae entrained are killed by turbulence, the loss will be 2.3 larvae $m^{-3} \times 9 \times 10^6$ m^3 $day^{-1} \times .12 = 2.48 \times 10^6$ larvae day^{-1}. Units 2 and 3 intakes will withdraw 9×10^6 m^3 day^{-1} and, therefore, kill 2.3 larvae $m^{-3} \times 9 \times 10^6$ m^3 $day^{-1} = 20.7 \times 10^6$ larvae day^{-1}. The diffusers will entrain and transport offshore 90×10^6 m^3 day^{-1}, thus killing 3.1 larvae $m^{-3} \times 90 \times 10^6$ m^3 $day^{-1} = 279 \times 10^6$ larvae day^{-1}. Totalling the losses above and projecting them to a yearly loss (x 365 day $year^{-1}$) gives losses as shown below. The next step converts larvae $year^{-1}$ to metric tons (MT) per year, assuming a larvae to weigh 1 mg (based on weights of S. politus), the conversion is 1 mg $larvae^{-1}$ x 10^{-3} g $mg^{-1} \times 10^{-3}$ kg $g^{-1} \times 10^{-3}$ MT $kg^{-1} = 10^{-9}$ MT $larvae^{-1}$. Metric tons are then converted to tons (x 1.1 tons MT^{-1}).

Larval losses $day^{-1} \times 365$ days $year^{-1} \times 10^{-9}$ MT $larvae^{-1} \times 1.1$ ton MT^{-1} = number of tons lost per year (see next page):

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*These numbers differ from Table 2 (see preceding Plankton section, Tables and Figures) since they are based on total larvae for 19 dates rather than spring and summer.

	Larvae Day^{-1}	Larvae Year^{-1}	MT Year^{-1}	Tons Year^{-1}
Unit 1 Intake	4.14×10^6	1.5×10^9	1.5	1.65
Unit 1 Discharge	2.48×10^6	$.9 \times 10^9$	.9	.99
Unit 1 Total	6.62×10^6	2.4×10^9	2.4	2.64
Units 2 and 3 Intakes	20.7×10^6	7.6×10^9	7.6	8.36
Units 2 and 3 Discharge	279×10^6	102×10^9	102	112
Units 2 and 3 Total	300×10^6	110×10^9	110	121
Units 1, 2, and 3 Intakes	24.8×10^6	9×10^9	9	9.9
Units 1, 2 and 3 Discharge	282×10^6	103×10^9	103	113
Units 1, 2 and 3 Total	307×10^6	112×10^9	112	123

Minimum loss estimates are those from intake withdrawal only, and are 4.14×10^6 larvae day^{-1} for Unit 1 and 24.8×10^6 larvae day^{-1} for Units 1, 2 and 3.

Maximum loss estimates assume that, in addition to intake withdrawal losses, 12% of larvae entrained by Unit 1 discharge will be killed by turbulence and that all those entrained by Units 2 and 3 will be either killed immediately or transported offshore where they will be diluted by ambient waters or lost due to decreased survivorship. These maximum losses are 6.62×10^6 larvae day^{-1} for Unit 1 and 307×10^6 larvae day^{-1} for Units 1, 2 and 3.

Microzooplankton

Estimates of loss of microzooplankton to SONGS cooling operations were made from data in the area of the intakes and diffusers on a representative day of low abundance (January 18, 1978). On this day, copepod nauplii, early copepodites and meroplankton were counted, averaging 2.2×10^4 organisms m^{-3}. These organisms made up over half the samples, the rest of the sample consisting mainly of tintinnids and larvaceans and estimated to have an abundance of 1.8×10^4 organisms m^{-3}. The average abundance, therefore, was determined to be 4×10^4 organisms m^{-3}, during this time and double (8×10^4 organisms m^{-3}) for a period of higher abundance.

To convert numbers of organisms lost per day to biomass loss, volumes previously measured for individual types by methods of Beers and Stewart (1970) were used. These averaged 4.6×10^{-4} mm^3 for larger organisms and 3.3×10^{-5} mm^3 for smaller organisms. Multiplying these volumes by the abundances stated above:

$$\frac{4.6 \times 10^{-4}\ mm^3}{organism} \times \frac{2.2 \times 10^4\ organisms}{m^3} = \frac{10.12\ mm^3}{m^3} \text{ equivalent volume and}$$

$$\frac{3.3 \times 10^{-5}\ mm^3}{organism} \times \frac{1.8 \times 10^4\ organisms}{m^3} = \frac{.594\ mm^3}{m^3} \text{ equivalent volume.}$$

These are added together to get the average volume of microzooplankton, $(10.12 + .594)\ mm^3\ m^{-3} = 10.7\ mm^3\ m^{-3}$ for times of low abundance and double this ($21.4\ mm^3\ m^{-3}$) in times of high abundance. At a body density of 1 g cm^{-3}, the average biomasses are:

$$\frac{10.7\ mm^3}{m^3} \times \frac{10^{-3}\ cm^3}{mm^3} \times \frac{1\ g}{cm^3} = \frac{10.7 \times 10^{-3}\ g}{m^3}$$

and

$$\frac{21.4\ mm^3}{m^3} \times \frac{10^{-3}\ cm^3}{mm^3} \times \frac{1\ g}{cm^3} = \frac{21.4 \times 10^{-3}\ g}{m^3}$$

Losses are then figured for both numbers and biomass lost per day using the average of the high and low numbers.

$$\frac{[(4 \times 10^4) + (8 \times 10^4)]}{2} \; \frac{\text{organisms}}{\text{m}^3} = \frac{6 \times 10^4 \text{ organisms}}{\text{m}^3}$$

$$\frac{[(10.7 \times 10^{-3}) + (21.4 \times 10^{-3})]}{2} \; \frac{\text{g}}{\text{m}^3} = \frac{16.05 \times 10^{-3} \text{ g}}{\text{m}^3}$$

Losses to Unit 1 intake withdrawal are figured by multiplying the average values above by the volume withdrawn:

$$\frac{6 \times 10^4 \text{ organisms}}{\text{m}^3} \times \frac{1.8 \times 10^6 \text{ m}^3}{\text{day}} = \frac{108 \times 10^9 \text{ organisms}}{\text{day}} \text{ or}$$

$$\frac{16.05 \times 10^{-3} \text{ g}}{\text{m}^3} \times \frac{1.8 \times 10^6 \text{ m}^3}{\text{day}} = \frac{29 \times 10^3 \text{ g}}{\text{day}}$$

Losses to Unit 1 discharge entrainment assume that 12% of those organisms entrained are killed, and Unit 1 entrains five times the discharge volume.

$$\frac{6 \times 10^4 \text{ organisms}}{\text{m}^3} \times \frac{9 \times 10^6 \text{ m}^3}{\text{day}} \times .12 = \frac{65 \times 10^9 \text{ organisms}}{\text{day}} \text{ or}$$

$$\frac{16.05 \times 10^{-3} \text{ g}}{\text{m}^3} \times \frac{9 \times 10^6 \text{ m}^3}{\text{day}} \times .12 = \frac{17 \times 10^3 \text{ g}}{\text{day}}$$

Losses to Units 2 and 3 intake withdrawal are figured in the same way.

$$\frac{6 \times 10^4 \text{ organisms}}{\text{m}^3} \times \frac{9 \times 10^6 \text{ m}^3}{\text{day}} = \frac{540 \times 10^9 \text{ organisms}}{\text{day}} \text{ or}$$

$$\frac{16.05 \times 10^{-3} \text{ g}}{\text{m}^3} \times \frac{9 \times 10^6 \text{ m}^3}{\text{day}} = \frac{144 \times 10^3 \text{ g}}{\text{day}}$$

Losses to Units 2 and 3 discharge entrainment assume that those organisms not killed immediately are transported offshore and diluted or die in the offshore environment and that ten times the discharge volumes are entrained.

$$\frac{6 \times 10^{4} \text{ organisms}}{m^{3}} \times \frac{90 \times 10^{6} \ m^{3}}{\text{day}} = \frac{5400 \times 10^{9} \text{ organisms}}{\text{day}} \text{ or}$$

$$\frac{16.05 \times 10^{-3} \ g}{m^{3}} \times \frac{\times 10^{6} \ m^{3}}{\text{day}} = \frac{1440 \times 10^{3} \ g}{\text{day}}$$

Losses are then converted from g day^{-1} to tons year^{-1} by the following:

$$\frac{(\quad) \ g}{\text{day}} \times \frac{365 \text{ day}}{\text{year}} \times \frac{10^{-6} \text{ MT}}{g} \times \frac{1.1 \text{ tons}}{\text{MT}} = \frac{(\quad) \text{ tons}}{\text{year}}$$

where MT = metric ton.

	Grams Day^{-1}	Grams Year^{-1}	MT Year^{-1}	Tons Year^{-1}
Unit 1 Intake	29×10^{3}	10.6×10^{6}	10.7	11.7
Unit 1 Discharge	17×10^{3}	6.2×10^{6}	6.2	6.8
Unit 1 Total	46×10^{3}	16.8×10^{6}	16.8	18.5
Units 2 and 3 Intakes	144×10^{3}	52.6×10^{6}	52.6	57.9
Units 2 and 3 Discharge	1440×10^{3}	526×10^{6}	526	579
Units 2 and 3 Total	1584×10^{3}	579×10^{6}	579	637
Units 1, 2 and 3 Intakes	173×10^{3}	63.1×10^{6}	63.1	69.4
Units 1, 2 and 3 Discharge	1457×10^{3}	532×10^{6}	532	585
Units 1, 2 and 3 Total	1630×10^{3}	595×10^{6}	595	655

Minimum losses to intake withdrawal only are 108 x 10^9 organisms day^{-1} to Unit 1 and 648 x 10^9 organisms day^{-1} for Units 1, 2 and 3.

Maximum losses include losses to discharge entrainment, offshore transport and dilution. Losses are 173 x 10^9 organisms day^{-1} to Unit 1 and 6113 x 10^9 organisms day^{-1} to Units 1, 2 and 3.

Microzooplankton*

Estimates of abundance for a day of very high abundance (October 19, 1978) are 43×10^{4} organisms m^{-3}, with a volume of 147 $mm^{3}\ m^{-3}$ or at 1 g cm^{-3}, 147×10^{-3} g m^{-3}; i.e., $\left[\left(\frac{147\ mm^{3}}{m^{3}} \times \frac{10^{-3}\ cm^{3}}{mm^{3}} \times \frac{1\ g}{cm^{3}}\right)\right]$. Organism volumes were calculated as before and all categories summed. These numbers are averaged with those from a day of low abundance (January 18, 1978), 4×10^{4} organisms m^{-3} at 10.7×10^{-3} g m^{-3}.

$$\left[\frac{(43 \times 10^{4}) + (4 \times 10^{4})}{2}\right] \frac{\text{organisms}}{m^{3}} = \frac{23.5 \times 10^{4}\ \text{organisms}}{m^{3}} \text{ or}$$

$$\left[\frac{(147 \times 10^{-3}) + (10.7 \times 10^{-3})}{2}\right] \frac{g}{m^{3}} = \frac{78.9 \times 10^{-3}\ g}{m^{3}}$$

Multiplying these values by the volumes involved and assuming a 12% mortality for Unit 1 discharge entrainment, losses to Unit 1 intake withdrawal are:

$$\frac{23.5 \times 10^{4}\ \text{organisms}}{m^{3}} \times \frac{1.8 \times 10^{6}\ m^{3}}{\text{day}} = \frac{423 \times 10^{9}\ \text{organisms}}{\text{day}}$$

$$\frac{78.9 \times 10^{-3}\ g}{m^{3}} \times \frac{1.8 \times 10^{6}\ m^{3}}{\text{day}} = \frac{142 \times 10^{3}\ g}{\text{day}}$$

and to Unit 1 discharge entrainment assuming 12% mortality are:

$$\frac{23.5 \times 10^{4}\ \text{organisms}}{m^{3}} \times \frac{9 \times 10^{6}\ m^{3}}{\text{day}} \times .12 = \frac{254 \times 10^{9}\ \text{organisms}}{\text{day}}$$

$$\frac{78.9 \times 10^{-3}\ g}{m^{3}} \times \frac{9 \times 10^{6}\ m^{3}}{\text{day}} \times .12 = \frac{85 \times 10^{3}\ g}{\text{day}}\ .$$

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*Recalculations using data from a representative day of high abundance, previous calculations estimated this value.

Losses to Units 2 and 3 are calculated in a similar manner, but all organisms entrained by the discharges are assumed to die. Losses to intake withdrawal are:

$$\frac{23.5 \times 10^{4} \text{ organisms}}{\text{m}^{3}} \times \frac{9 \times 10^{6} \text{ m}^{3}}{\text{day}} = \frac{2115 \times 10^{9} \text{ organisms}}{\text{day}}$$

$$\frac{78.9 \times 10^{-3} \text{ g}}{\text{m}^{3}} \times \frac{9 \times 10^{6} \text{ m}^{3}}{\text{day}} = \frac{710 \times 10^{3} \text{ g}}{\text{day}}$$

and losses to discharge entrainment are:

$$\frac{23.5 \times 10^{4} \text{ organisms}}{\text{m}^{3}} \times \frac{90 \times 10^{6} \text{ m}^{3}}{\text{day}} = \frac{21150 \times 10^{9} \text{ organisms}}{\text{day}}$$

$$\frac{78.9 \times 10^{-3} \text{ g}}{\text{m}^{3}} \times \frac{90 \times 10^{6} \text{ m}^{3}}{\text{day}} = \frac{7101 \times 10^{3} \text{ g}}{\text{day}}$$

Totalling losses and converting to tons year^{-1} by $\frac{(\ \ ) \text{ g}}{\text{day}} \times \frac{365 \text{ day}}{\text{year}} \times \frac{10^{-6} \text{ MT}}{\text{g}} \times \frac{1.1 \text{ tons}}{\text{MT}} = \frac{(\ \ ) \text{ tons}}{\text{year}}$.

	Grams Day^{-1}	Grams Year^{-1}	MT Year^{-1}	Tons Year^{-1}
Unit 1 Intake	142×10^{3}	51.8×10^{6}	51.8	57.0
Unit 1 Discharge	85×10^{3}	31×10^{6}	31	34.1
Unit 1 Total	227×10^{3}	82.8×10^{6}	82.8	91.1
Units 2 and 3 Intakes	710×10^{3}	259×10^{6}	259	285
Units 2 and 3 Discharges	7101×10^{3}	2592×10^{6}	2592	2851
Units 2 and 3 Total	7811×10^{3}	2851×10^{6}	2851	3136

	Grams Day^{-1}	Grams $Year^{-1}$	MT $Year^{-1}$	Tons $Year^{-1}$
Units 1, 2 and 3 Intakes	852×10^3	311×10^6	311	342
Units 1, 2 and 3 Discharges	7186×10^3	2632×10^6	2623	2885
Units 1, 2 and 3 Totals	8038×10^3	2934×10^6	2934	3227

Minimum loss estimates to intake withdrawal only assume 100% mortality. These losses are 423×10^9 organisms day^{-1} to Unit 1 and 2538×10^9 organisms day^{-1} for Units 1, 2 and 3. Maximum loss estimates include losses to intake withdrawal and discharge entrainment and are 677×10^9 organisms day^{-1} for Unit 1 and $23,942 \times 10^9$ organisms day^{-1} for Units 1, 2 and 3.

NUTRIENT AND CHLOROPHYLL-A ADDITIONS TO SURFACE WATERS

Estimates from samples taken over a three-year period show nitrate concentrations average 3.1 μg-at N liter^{-1} higher in the lower half of the water column than the surface in the area of the diffusers (Table 11, this section on Plankton). This difference is seen for about half the year. The diffusers would entrain this water and transport it to offshore surface waters. The nitrate thus transported will be:

$$\frac{3.1\ \mu\text{g-at N}}{\text{liter}} \times \frac{10^3\ \text{liter}}{\text{m}^3} \times \frac{90 \times 10^6\ \text{m}^3}{\text{day}} \times \frac{182\ \text{day}}{\text{year}} = \frac{5.1 \times 10^{13}\ \mu\text{g-at N}}{\text{year}}$$

Using a carbon:nitrogen ratio for phytoplankton of 106:16 gram atoms (Redfield, 1934), this is $\frac{5.1 \times 10^{13}\ \mu\text{g-at N}}{\text{year}} \times \frac{106\ \text{g-at C}}{16\ \text{g-at N}} = \frac{3.4 \times 10^{14}\ \mu\text{g-at C}}{\text{year}}$.

There are 12 g of carbon per gram-atom of carbon (12 μg C:1 μg-at C), so this becomes:

$$\frac{3.4 \times 10^{14}\mu\text{g-at C}}{\text{year}} \times \frac{12\ \mu\text{g C}}{1\ \mu\text{g-at C}} = \frac{40.8 \times 10^{14}\ \mu\text{g C}}{\text{year}} \quad \text{or}$$

$$\frac{40.8 \times 10^{14}\ \mu\text{g C}}{\text{year}} \times \frac{10^{-6}\ \text{g}}{\mu\text{g}} \times \frac{10^{-3}\ \text{kg}}{\text{g}} \times \frac{10^{-3}\ \text{metric tons (MT)}}{\text{kg}} =$$

$$\frac{40.8 \times 10^{2}\ \text{MTC}}{\text{year}}$$

One mg phytoplankton carbon is equivalent to 42 mg phytoplankton biomass (Cushing, et al., 1958), so this becomes:

$$\frac{40.8 \times 10^{2}\ \text{MTC}}{\text{year}} \times \frac{42\ \text{mg biomass}}{1\ \text{mg C}} = \frac{1.7 \times 10^{5}\ \text{MT}}{\text{year}} \text{ of phytoplankton biomass}$$

$$\frac{1.7 \times 10^{5}\ \text{MTC}}{\text{year}} \times \frac{1.1\ \text{tons}}{\text{MT}} = \frac{1.87 \times 10^{5}\ \text{tons}}{\text{year}} \text{ of phyto-}$$

plankton biomass.

Differences are found in standing stock between inshore and offshore, with the higher measurements inshore. This higher standing stock will be transported offshore by the intake withdrawal and diffuser entrainment of Units 2 and 3. On the average, .77 μg of chlorophyll-a will be added to the offshore surface environment for each liter of water transported offshore. 99×10^6 m^3 of water per day will be transported (9×10^6 m^3 from intake withdrawal and 90×10^6 m^3 from diffuser entrainment) offshore. Assuming that few phytoplankton are killed, the amount transported offshore in a year will be:

$$\frac{.77\ \mu\text{g chl-}\underline{a}}{\text{liter}} \times \frac{10^3\ \text{liter}}{m^3} \times \frac{99 \times 10^6\ m^3}{\text{day}} \times \frac{365\ \text{day}}{\text{year}} = \frac{27823 \times 10^9\ \mu\text{g chl-}\underline{a}}{\text{year}} \quad \text{or}$$

$$\frac{2.8 \times 10^{13}\ \mu\text{g chl-}\underline{a}}{\text{year}}.$$

Assuming a carbon:chlorophyll-a ratio of 30:1 (Strickland, 1960),

$$\frac{2.8 \times 10^{13}\ \mu\text{g chl-}\underline{a}}{\text{year}} \times \frac{30\ \text{g C}}{1\ \text{g chl-}\underline{a}} = \frac{84 \times 10^{13}\ \mu\text{g C}}{\text{year}}$$

would be transported offshore. This C:chlorophyll-a ratio could be as high as 100:1 in a nutrient limited situation. At 1 mg C = 42 mg wet weight of phytoplankton (Cushing, et al., 1958), the cooling system will transport offshore:

$$\frac{84 \times 10^{13}\ \mu\text{g C}}{\text{year}} \times \frac{10^{-3}\ \text{mg}}{\mu\text{g}} \times \frac{42\ \text{mg wet wt}}{\text{mg C}} \times \frac{10^{-9}\ \text{MT}}{\text{mg}} \simeq \frac{3.5 \times 10^4\ \text{MT}}{\text{year}} \text{ of}$$

phytoplankton biomass. This is equivalent to:

$$\frac{3.5 \times 10^4\ \text{metric tons}}{\text{year}} \times \frac{1.1\ \text{tons}}{1\ \text{metric ton}} = \frac{3.85 \times 10^4\ \text{tons}}{\text{year}}$$

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MYSIDS

Mysids are small shrimps (less than 1 inch long) that remain just above the bottom during the day, often in dense aggregations. Some of them move higher into the water column at night. They are an important source of food for fish, particularly queenfish.

Findings

(1) SONGS Unit 1 kills mysids withdrawn through its cooling system and possibly by entrainment in the discharge water. The mortality caused by the Plant results in the incursion into adjacent waters of plume water with a reduced density of living mysids. We calculate that, under the slow current conditions that occur about half the year, this process is equivalent to killing, each day, about 10% of the mysid population in an area of 0.6 square miles (1 km^2). This is about the level of natural mortality.

(2) There is evidence that the density of mysids is lower, in a zone extending about 200 yards from the Plant, than it is at the same depth at sampling stations roughly two miles (3.2 km) from the Plant. The cause of this reduction is not known; it could be withdrawal losses, but it is also associated with the area of coarsened sediments (see Subtidal Sand Bottom Benthos section).[1]

(3) The density of mysids at about 200 yards downcurrent from the Plant is greater than it is closer to or further away from the Plant, at the same depth. Possible causes of the increase include a high concentration of organic matter from the discharge

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[1] See Figure 5-4, Section 5.0 (Subtidal Sand Bottom Benthos), Annual Report to the California Coastal Commission, September, 1977 - August, 1978, Updated Estimated Effects of SONGS Unit 1 on Marine Organisms. MRC Doc. 78-01, August, 1978.

of Unit 1 and a more suitable bottom type (see Subtidal Sand Bottom Benthos section). It is possible that the reduction and increase in mysid density approximately balance out to give a total density in the area similar to what it would be in the absence of SONGS. Sampling has not been intensive enough to resolve this question.

(4) We calculate that Unit 1 kills more than 20 million mysids per day through intake withdrawal, which is equivalent to 16 tons per year.

Implications

The observable effects of Unit 1 on mysid density are very localized.

Since the effects of Units 1, 2 and 3 are expected to be more extensive than those of Unit 1, a more detailed discussion of the implications of increased mortality for the mysids and for other parts of the food web is postponed to the section on Predictions.

Predictions

(1) The mysids as a group are most highly concentrated in a zone within 2.5 miles (4 km) of the shore, and most of the mysids found throughout the inshore area belong to species that show this restricted distribution. In predicting the effects on these mysids, we face the same uncertainty concerning discharge entrainment as we did in discussing the zooplankton: we do not know what fraction of the mysids entrained by the discharges of Units 2 and 3 will be moved offshore or what fraction will be killed as a result of such entrainment. Units 1, 2 and 3 could cause greatly increased mortality in the inshore mysid species if (in addition to the increased losses caused by withdrawal) large numbers that are expected to be entrained

into the discharge plume are killed as a result. Mortality would be on the order of 40 times greater than that caused by Unit 1 alone if discharge entrainment causes 100% mortality. If discharge entrainment causes no deaths, mortality caused by Units 1, 2 and 3 will be about five times greater than that caused by Unit 1 alone. We calculate that, under the slower current conditions that occur about half of the year, the estimated maximum losses will be equivalent to killing, each day, about 6% of the population in an area of 30 square miles (48.3 km^2). Mixing (and some compensation) will occur; nevertheless, the maximum estimated additional mortality is roughly the same as the natural mortality and may be great enough to cause a reduction in mysid density in some area around the Plant. If the minimum estimated mortality were to occur, it would be equivalent to killing, each day, about 1% of the mysids over an area of 30 square miles (48.3 km^2), or about 6% over 4 square miles (6.4 km^2).

We are not yet able to give a reliable estimate of the area over which a reduction in density might be detectable. However, since mysids are more sedentary than zooplankton, and take at least twice as long to mature as most zooplankton, we believe reduction in mysid density will be detectable over a greater area than for zooplankton.

(2) We calculate that each day SONGS Units 1, 2 and 3 will kill between 120 million and 1 billion mysids, which is equivalent to 100 800 tons per year. The consequences of this for fish production are discussed in the Fish section.

Implications

These are similar to the implications for zooplankton. We expect some detectable local reduction in density, possibly over an area a few miles (4.8 km) along the coast and about one or two miles (1.6 or 3.2 km) offshore, but probably not as far as ten miles (16 km) along the coast. More information about discharge entrainment losses and population dynamics is needed to be more specific.

The effects noted above could be reduced by moving the intakes and diffusers offshore and by having a single-point discharge.

Supportive Evidence for Findings

(1) The evidence for this finding is presented in the section supporting Prediction 1, since it is an integral part of that analysis.

(2 and 3)
Comparisons of samples taken with and without Unit operating show that there is a significant reduction in the density of mysids within 200 m of the discharge site and an increase just beyond that distance (Figure 1).
Also, sampling showed a trend of descreasing mysid density within 300 m of the Unit 1 intake (Figure 2).

(4) Total mysid losses to SONGS Unit 1 cooling operations were extrapolated from the losses for M. elongata shown in Table 2, knowing the fraction of total mysids that M. elongata represented. The basis for the estimate of M. elongata losses is presented in the section of supporting evidence and analyses for Prediction 1.
Unit 1 was estimated to have killed about 10×10^6 M. elongata per day in the summer when this species comprised 25% of the total mysids. Therefore, $\sim 40 \times 10^6$ mysids were lost per day (specific calculations are shown in appended section after figures). Winter losses were estimated at about $.7 \times 10^6$ M. elongata per day with this species making up 98% of the total in the area of the intake. Therefore, during times of low

abundance $\sim .7 \times 10^6$ total mysids were lost. Assuming half the year mysid abundances are high and the other half of the year low, the average total mysid loss per day was bout 20×10^6 organisms. It was assumed the average biomass of a mysid was represented by immature M. elongata which weigh about 2 mg. Thus, by the following conversion.

$$(20 \times 10^6 \text{ mysids/day}) \left(\frac{2 \text{ mg mysid biomass}}{\text{mysid}}\right) \left(\frac{365 \text{ days}}{\text{year}}\right) \left(\frac{10^{-9} \text{ metric tons}}{\text{mg}}\right)$$

$\left(\frac{1.1 \text{ tons}}{\text{metric ton}}\right)$, the yearly loss of total mysid biomass was estimated to be about 16 tons.

Supportive Evidence for Predictions

(1) This section analyzes and evaluates the possible effects of mortality caused by Units 1, 2 and 3. It concentrates on the "inshore" group of species, which are expected to be most affected. There are six steps in the analysis.

- (a) The distribution of different groups of mysids is established.
- (b) We estimate the fraction of mysids passing near the Plant that is acted upon by the Plant.
- (c) We estimate the number of mysids killed by the Plant per 24 hours.
- (d) We estimate the size of the population of mysids that is influenced by this mortality, and hence the percentage mortality occurring over a specified area.
- (e) We estimate the natural mortality rate.
- (f) We evaluate the SONGS-induced mortality in the light of the natural mortality rate and other features of mysid biology.

Methods utilized in the six steps are described in detail in the plankton section on Supporting Evidence for Prediction 1. Descriptions herein will be restricted to variances from the plankton approach.

(a) Pattern of Mysid Species

The assemblage of mysids off SONGS consists of two groups.

The first group is restricted to the inshore waters within 3 - 4 km of shore while the second group appears at ∿ 3 km and extends further offshore. These extents are illustrated in Figures 3 and 4 for winter through spring and for summer, respectively. The most abundant species in the SONGS nearshore area are members of the inshore group. We have selected Metamysidopsis elongata, the most consistently abundant member of the inshore group, as the representative species for further analyses of mysid interaction with SONGS cooling operations.

(b) Estimates of the Fraction of Mysids Passing Near the Plant that is Acted Upon by the Plant

Mysids are sampled during the day when they are all near the bottom and more efficiently (in terms of logistics) captured. A portion of the mysids migrate up into the water column at night and only then are subject to Plant operations (only the Unit 1 discharge can act on the mysids during the day). The most complete inshore-offshore sets of summer (July 14, 1978) and winter (January 19, 1979) abundance data are used to describe the inshore-offshore patterns of M. elongata (Figure 5). Other data sets reflect similar patterns. Data from vertically stratified night samples from the same seasons were used to provide the basis for estimating the portions of those mysids which occurred in the water column at night. At night the vertical arrangements were as follows:

Vertical Stratum (m)	% of Total *M. elongata* in different vertical strata of Water Column	
	Summer (Aug 25-25, 1977)	Winter (Dec 21, 1978)
0-3	16.9	5
3-5	11.9	
5-7.25	26.9	7
7.25-8.5 (Bottom)	44.2	88

Note that a higher proportion of individuals of this species were found above the bottom stratum in summer and thus, were then more susceptible to Plant activity. The extrapolated night abundance patterns are shown in Figure 6. Further methods and calculations used to estimate the numbers of *M. elongata* involved per day in intake withdrawal, discharge entrainment, and offshore transport are the same as those described for plankton in the section on Supportive Evidence for Predictions (1), part (c), and will not be repeated here.

(c) Estimates of the Numbers of Mysids Killed by the Plant per Day

For purposes of calculating intake mortality, it is assumed that 100% of the mysids withdrawn by the intakes are killed (Table 1). This assumption is based on (1) data from a single night (December 21, 1978, the third week after heat treatment in an 11 week cycle) when mysid concentrations were measured in triplicate in the intake riser and the discharge riser, and (2) on laboratory heat stress experiments. Discharge entrainment losses due to turbulent stress are assumed to be negligible (0% of the organisms entrained).

No estimates are available and it is thought that mysids are more robust than macrozooplankton (although this may be countered by the argument that turbulent shears arising from entrainment will probably be more intense on mysids which are larger). We presently cannot be sure (a) to what extent the diffusers of Units 2 and 3 will move mysids offshore with the entrained water mass and (b) what the mortality will be of those that are transported. Since the mysid species we are concerned with are those which are confined almost entirely to the inshore band, offshore transport by the Units 2 and 3 diffusers, should it occur, may have considerable influence on the total mysid losses.

A case can be made for offshore transport. The flow velocity of ∿ 4 m/sec^{-1} leaving the diffuser jets should cause considerable turbulence throughout the lower two-thirds of the water column above the jet openings. This turbulence should be sufficient to disorient mysids in the area so they cannot resist being transported with the upward and offshore movement of the entrained waters. Evidence from sampling near the Unit 1 discharge indicated mysid patterns are disrupted by discharge entrainment (Figure 7). It is estimated that the offshore current at the ends of the diffusers during periods of low ambient current will have an intensity of about 9 cm/sec^{-1} and be roughly 1 km wide and 10 m deep (February 2, 1979 Memorandum to MRC from J. List and R.C.Y. Koh, California Institute of Technology). To escape this flow, mysids must swim downward or inshore since the longshore extent is so wide. Inshore-offshore flows are generally not of this intensity or persistence in the SONGS area. It is questionable whether the disoriented mysids in the upper 10 m of the water column would direct their swimming against this flow when they are away from the bottom since they appear to use the bottom for orientation. Thus the mysids would have to retain or recover sufficient orientation to escape downward. If they do, they will enter the water mass in the lower half of the water column which, during slower longshore current conditions, is being drawn toward the diffuser jets to be subsequently entrained. It is possible therefore, that many, if not, all of the mysids will not overcome entrainment and will be displaced offshore of their habitat.

The portion of mysids which die in the offshore environment will depend upon the length of time they spend out there, how quickly their source waters are diluted by offshore waters and the predator-prey composition of the water mixtures. Most mysids live near the bottom during the day. But the bottom offshore of 4 km is deeper, contains a different assemblage of organisms (potential predators and prey and mysid competitors) and will have a detrital component different than that which occurs inshore (see Subtidal Sand Bottom Benthos section). It has been demonstrated (Wiebe and Richardson, 1978) that the original assemblage of organisms found in a disenfranchised mass of water that has been separated from its source declines with the time that the water mass has been separated from its parent source.

Due to our uncertainty in matters of offshore transport and mortality, 0, 50 and 100% offshore transport losses are assigned for conditions of no, half and total dilution with offshore waters in the present assessment. The estimated numbers of mysids killed per day from the causes described above are shown in Table 2.

Minimum estimates assume only intake withdrawal losses; maximum estimates assume 100% mortality of mysids transported offshore or 50% mortality with full dilution of plume water by ambient water in the offshore region.

(d) The Size of the Mysid Population Influenced by the SONGS Mortality

The extent of the population of mysids influenced by the Plant was taken to be the same as that used for plankton. Namely, the waters contained within the dispersion bounds in which the ratio of SONGS discharge water to ambient water is 3 to 97 (3% bounds) and 1 to 99 (1% bounds). The manner in which the bounds were determined is fully described in the Plankton section, Supportive Evidence for Predictions (1), part (d). The 3% dispersion boundary was estimated to be 20 km longshore and 4.0 km offshore giving a total area of about 80 km^2 within which the influenced populations of 6×10^9 and 1.3×10^9 *M. elongata* are found in summer and winter, respectively (Table 2). Similarly, the 1% bounds are 4 km longshore by 6.2 km offshore, approximating a 270 km^2 area. Estimates of the total *M. elongata* found in these areas are 14×10^9 organisms in summer and 3×10^9 in winter (Table 2).

(e) Estimates of Natural Mortality Rates

The natural mortality rate of mysids is estimated for *M. elongata* by comparing series of field samples collected at fixed intervals of time. The method of calculation is as follows:

$$d = 1/t\,[\log_e (A + 1) - \log_e (N + 1)]$$

where d = instantaneous natural mortality rate (Units: day^{-1})

t = length of time between samplings

A = abundance (number m^{-2}) of adults at the end of the period, t

N = the abundance of all ages considered at the start of the period.

The value of d derived from this equation will be negative, indicating that the numbers decrease with time (although d is usually presented as a positive number with the knowledge that it causes decreases in numbers of organisms).

The relationship derives from the integrated form of the exponential equation:

$$N_t = N_o e^{rt},$$

where $N_t = A$

$N_o = N$ (as noted above)

and r refers in the present circumstances only to the death rate, d. The approach assumes that all mysids included in the original density estimate reach maturity by the end of the period, t; and mysids smaller (hence, younger) than those included in the original estimate do not mature by time, t. It also assumes that the mortality rate is constant with age and that the adults sampled at time t are representative of of the remnants of the mysids originally included in N. Mysids included in the estimates of N are restricted to those with uropods .44 mm or longer, and .33 mm in maximum width or wider. Animals smaller than this appear not to be sampled quantitatively by the gear which utilizes .33 mm mesh. The period assigned "t" was 28 or 29 days. This was obtained as follows: Mysid (M. elongata) growth studies in field cages conducted during the fall of 1978 when the water was 17° C indicate that mean development times from released brood to maturity for males and females were 41 and 50 days, respectively. The representative overall mean development time for males and females was taken as of 46 days. Based on published information on mysid incubation periods and development rates (Clutter, 1978 modified work statement to

MRC) development times are about 83% of those given above during June - August when the water is warmer (this is the time of the year from which data is available for good estimates of N and A; see below). Therefore, estimated development time modified for temperature is 46 (.83) $\simeq$ 38 days. Since mysids included in the estimates of N, the number of mysids at the start of a period, were .44 mm or longer, the duration of the earlier uncaptured stages must be subtracted from the temperature-modified development time. This duration was estimated to be 9 days, leaving 29 days as the temperature-modified development time of mysids included in N. Samples 28 and 29 days apart covering the full inshore-offshore extent of *M. elongata* with sufficient replications (n = 4 to 20) were available from three periods. The periods, estimates of N, A and d, are shown in Table 3. Estimates of natural mortality d range from 0.01 to 0.14.

(f) Evaluation of SONGS-Induced Mortality with Respect to Natural Mortality and Other Features of Mysid Biology

The maximum SONGS-induced mortality was estimated at 6.8% of the influenced population lost per day in an 80 km^2 area off SONGS. The estimates of natural mortality rates ranged from .01 - .14, with a mean of .07 day^{-1}. The mean is equivalent to finite mortality, D, of .07 (or 7% per day). Finite mortality is related to instantaneous mortality, d, in the following manner:

$$D = 1 - e^{-d}$$

Thus, the range of estimated SONGS-induced mortality rate (Table 2) is of the same magnitude as the estimated natural mortality rates of .01 - .14. We do not, at this time, know whether the addition of a SONGS-induced mortality to natural mortality of the same magnitude will have a significant biological effect on the mysid population off SONGS. We do expect, however, that the SONGS-induced mortality for mysids is more likely to affect their populations than similar rates found for plankton (see Plankton section, Supportive Evidence for Predictions (1)). This is because mysid generation times (and, therefore, time needed to compensate) are longer, about twice that of plankton. Additionally, since mysids move less than zooplankton the effects are expected to be more local. The SONGS-induced mortality rate is based on the assumption that the SONGS losses are rapidly spread throughout the population bounded in the ∿ 80 km^2 area. This may not occur if only a portion of the mysids are subject to major physical mixing (by advection and diffusion) at night when they move above the bottom layer. Limited dispersal also implies limited immigration from the regions lying outside of the 80 km^2 area. Thus, greater depletions in mysid abundances can potentially occur within a few kilometers of SONGS, rather than smaller depletions over a much wider area.

(2) Total mysid losses to SONGS Units 2 and 3 cooling operations were extrapolated from the losses for M. elongata shown in Table 2, knowing the fraction of total mysids that M. elongata represented.

The methods of calculation used were the same as those shown to support estimates of Unit 1 losses in Supportive Evidence for Findings (4). Specific calculations are shown in the appended section after the figures. The only additional information employed was that in the area of the diffusers, M. elongata represented 20% of the total mysids in summer and 83% of the total mysids in winter. Due to our uncertainty about the diffuser entrainment losses, minimum and maximum values are estimated (Table 4). The lower value

(Table 4, Column D) represents losses to intake withdrawal only; the higher value (Table 4, Column F) assumes 100% mortality of organisms entrained by diffuser outflow. The losses of Unit 1 estimated in Supportive Evidence for Findings (4) were added to those calculated for Units 2 and 3 to give totals for Units 1, 2 and 3 of from 120 - ∿ 1000 million mysids per day. These values are approximately equivalent to 96 - 800 tons per year.

Table 1. Estimates of percent loss from Unit 1 intake withdrawal.

A. Through-Plant losses not including heat effects

Results from Riser-Discharge date (three replicates),

December 21, 1978.

Counts: (all mysids, all species and stages, in equivalent replicates).

	Riser				Discharge			
	Intact	Damaged	Total	% Intact	Intact	Damaged	Total	% Intact
$\overline{X}$	116	37	152	76.3	42	89	131	32.1

Discharge abundance = 9.79 mysids/m^3
Riser abundance = 14.05 mysids/m^3

Calculations:

$$100 \left[1 - \frac{\text{Discharge abundance (fraction intact)}}{\text{Riser abundance (fraction intact)}} \right] = \% \text{ loss}$$

$$100 \left[1 - \frac{9.79\ (.32)}{14.05\ (.76)} \right] = 71\% \text{ loss}$$

B. Heat losses

Laboratory experiments indicate that at least 50% of the mysids will undergo delayed mortality due to heat stress when subjected to water 27° C for 8 minutes (time of passage from condenser to discharge). This temperature is reached by through-Plant cooling waters during all but about 3 months in winter. Therefore, of the 29% estimated above as surviving plant mechanical stress, 50% or more will die from heat stress, leaving 15% of mysids withdrawn surviving intake withdrawal effects. Since through-Plant cooling water temperatures are greater than 27° C most of the year, more than 50% of the mysids are expected to die from heat stress. In addition those undergoing mechanical stress and heat stress are more likely to die than those undergoing only heat stress. Therefore, we are assuming 100% loss to those mysids withdrawn by the intakes.

Table 2. Summary of estimated daily losses, numbers influenced by SONGS and daily loss rate of *Metamysidopsis elongata* with varying conditions of offshore dilution and offshore transport losses. All values except percentages are in millions (i.e., multiply value by 10^6). Single numbers to the left of brackets apply to all rows (cases). Daily loss rates for the 1% dispersion boundary (extending about 44 km alongshore and 6 km offshore) and the 3% dispersion boundary (extending about 20 km alongshore and 4 km offshore) are shown.

DAILY LOSSES

	Intake Unit 1	Discharge Unit 1	Total Unit 1	Intake Units 2 & 3	Discharge Units 2 & 3	(% Loss: Offshore Dilution)	Translocation Units 2 & 3	Total Units 2 & 3	Total Units 1, 2, 3
Summer	9.85	0	9.85	49.2	0	(0 :None)	0	49.2	59.1
						(0 :Half)	175	224	234
						(0 :Full)	350	399	409
						(50 :None)	175	224	234
						(50 :Half)	263	312	322
						(50 :Full)	350	399	409
						(100:None)	350	399	409
						(100:Half)	350	399	409
						(100:Full)	350	399	409
Winter	.684	0	.684	3.42	0	(0 :None)	0	3.42	4.10
						(0 :Half)	10.6	14.0	14.7
						(0 :Full)	21.2	24.6	25.3
						(50 :None)	10.6	14.0	14.7
						(50 :Half)	15.9	19.3	20.0
						(50 :Full)	21.2	24.6	25.3
						(100:None)	21.2	24.6	25.3
						(100:Half)	21.2	24.6	25.3
						(100:Full)	21.2	24.6	25.3

1% Dispersion Boundary

	Number Influenced	Daily Loss Rate % Loss of Number Influenced Unit 1	Units 2 & 3	Units 1, 2, 3
Summer	14100	< 0.1	0.3	0.4
			1.6	1.7
			2.8	2.9
			1.6	1.7
			2.2	2.3
			2.8	2.9
			2.8	2.9
			2.8	2.9
			2.8	2.9
Winter	3140	< 0.1	0.1	0.1
			0.4	0.5
			0.8	0.8
			0.4	0.5
			0.6	0.6
			0.8	0.8
			0.8	0.8
			0.8	0.8
			0.8	0.8

3% Dispersion Boundary

	Number Influenced	Daily Loss Rate % Loss of Number Influenced Unit 1	Units 2 & 3	Units 1, 2, 3
Summer	6030	< 0.2	0.8	1.0
			3.7	3.9
			6.6	6.8
			3.7	3.9
			5.2	5.3
			6.6	6.8
			6.6	6.8
			6.6	6.8
			6.6	6.8
Winter	1340	< 0.1	0.3	0.3
			1.0	1.1
			1.8	1.9
			1.0	1.1
			1.4	1.5
			1.8	1.9
			1.8	1.9
			1.8	1.9
			1.8	1.9

Table 3. Estimated rates of natural mortality for *M. elongata* on three dates in summer. d = instantaneous mortality (day^{-1}), A = adults, N = 0.44 mm long (adults).

Period	d	N (number m^{-2})	A (number m^{-2})	Replicates	Source of Samples (MRC Grid Ref.)
Aug. 3 - 31, 1977 (28 days)	0.14	454.26	8.76	4	Unit 2 & 3 Line x: + 300 y: + 400 to -1700
June 16 - July 14, 1978	0.01	47.15	75.25	20	Unit 2 & 3 Line x: + 300 y: + 250 to -1750 Ref. Line x: + 3250 y: + 250 to -1750
July 14 - Aug. 10, 1978 (28 days)	0.05	151.7	33.25	20	Unit 2 & 3 Line x: + 300 y: + 250 to -1750 Ref. Line x: -3250 y: + 250 to -1750

Table 4. Summary of estimated total mysid losses to SONGS cooling operations. Unit 1 entrainment losses to turbulent shear in column B are assumed to be negligible. Units 2 and 3 entrainment losses in column E represent 100% of the organism secondarily entrained by the diffusers. Minimum estimated losses for Unit 1, Units 2 and 3 and Units 1, 2 and 3 are given in columns A, D and G, respectively. Maximum estimated losses are given in columns C, F and I. See text for discussion of potential losses due to diffuser entrainment.

	A	B	C	D	E	F	G	H	I
	UNIT 1			UNITS 2 & 3			UNITS 1, 2 & 3		
	Intake Withdrawal	Discharge Entrainment	Total	Intake Withdrawal	Discharge Entrainment	Total	Intake Withdrawal	Discharge Entrainment	Total
Mysids									
Numbers/day	20×10^6	0	20×10^6	100×10^6	888×10^6	988×10^6	120×10^6	888×10^6	1008×10^6
Metric tons/year	14.6	0	14.6	73	648	721	87.6	648	736
Tons/year	16	0	16	80	713	793	96	713	809

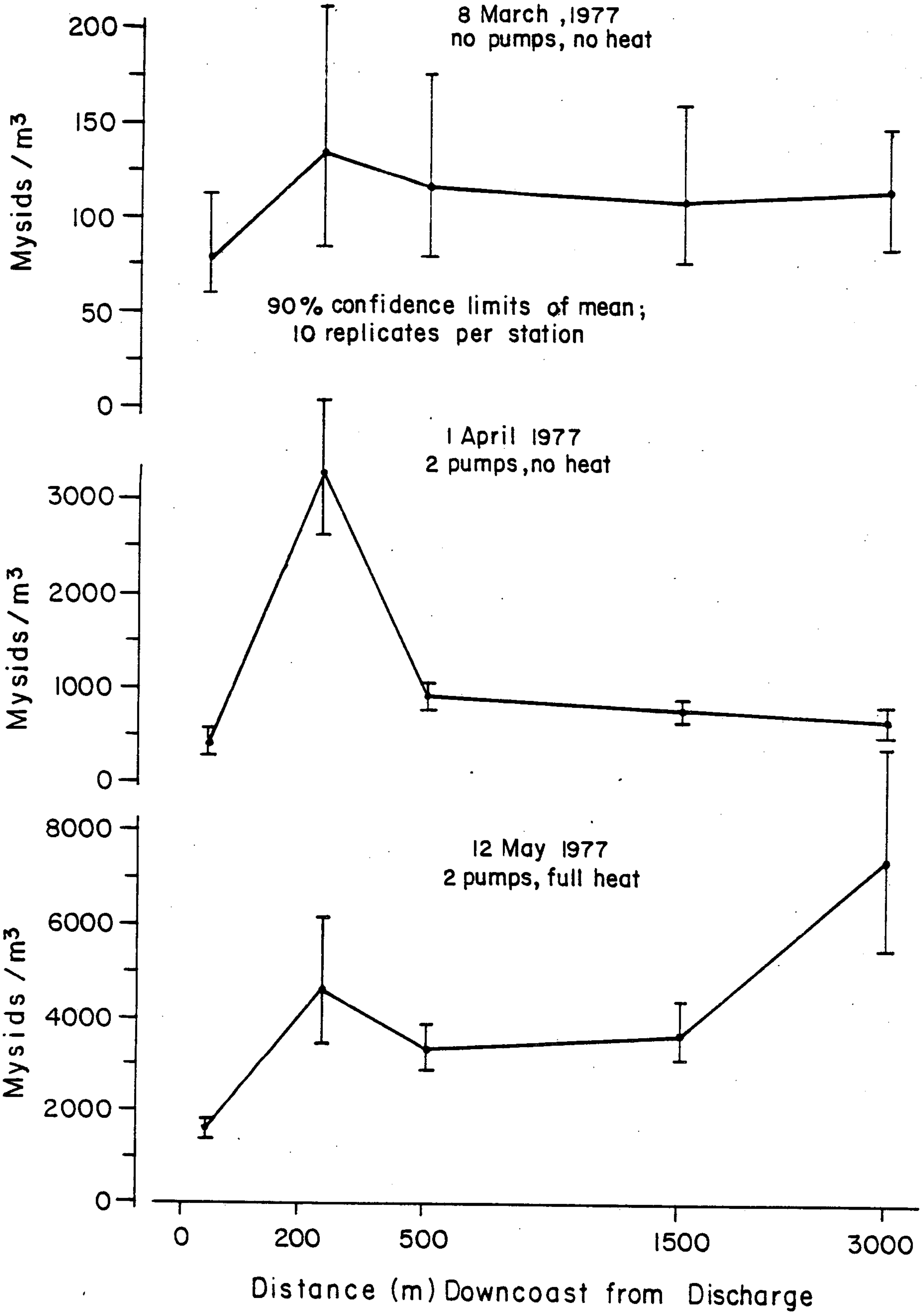


Figure 1. Abundance of mysids at five locations downcoast from Unit 1 discharge, representing three phases of SONGS operation: non-operation, pumps only, and full operation. Each point based on ten 50 m tows, with epibenthic sampler in daytime. (From Figure 3-9, September, 1977, Annual Report to MRC.)

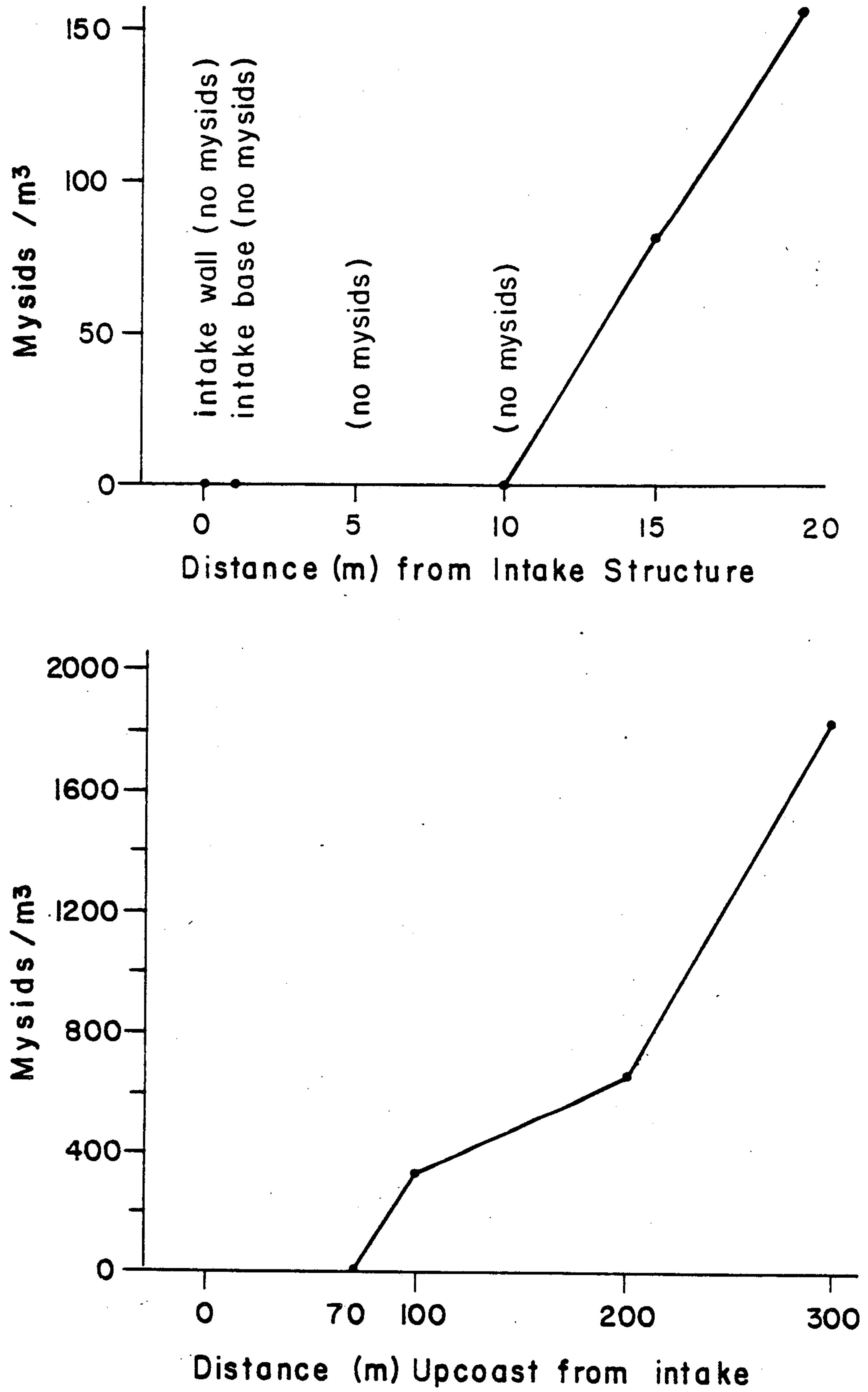


Figure 2. Trends in mysid density near Unit 1 intake. Upper graph data from sampling with diver net, November 17, 1975. Lower graph data from sampling with epibenthic net based on one replicate, May 12, 1976. (From Figure 3-11, September, 1977, Annual Report to MRC.)

Figure 3. Zonation of nearshore mysids, January - April, 1978. Zones of at least 90% occurrence are shown. Data from Auriga net samples taken on five dates between January and April are used as replicates.

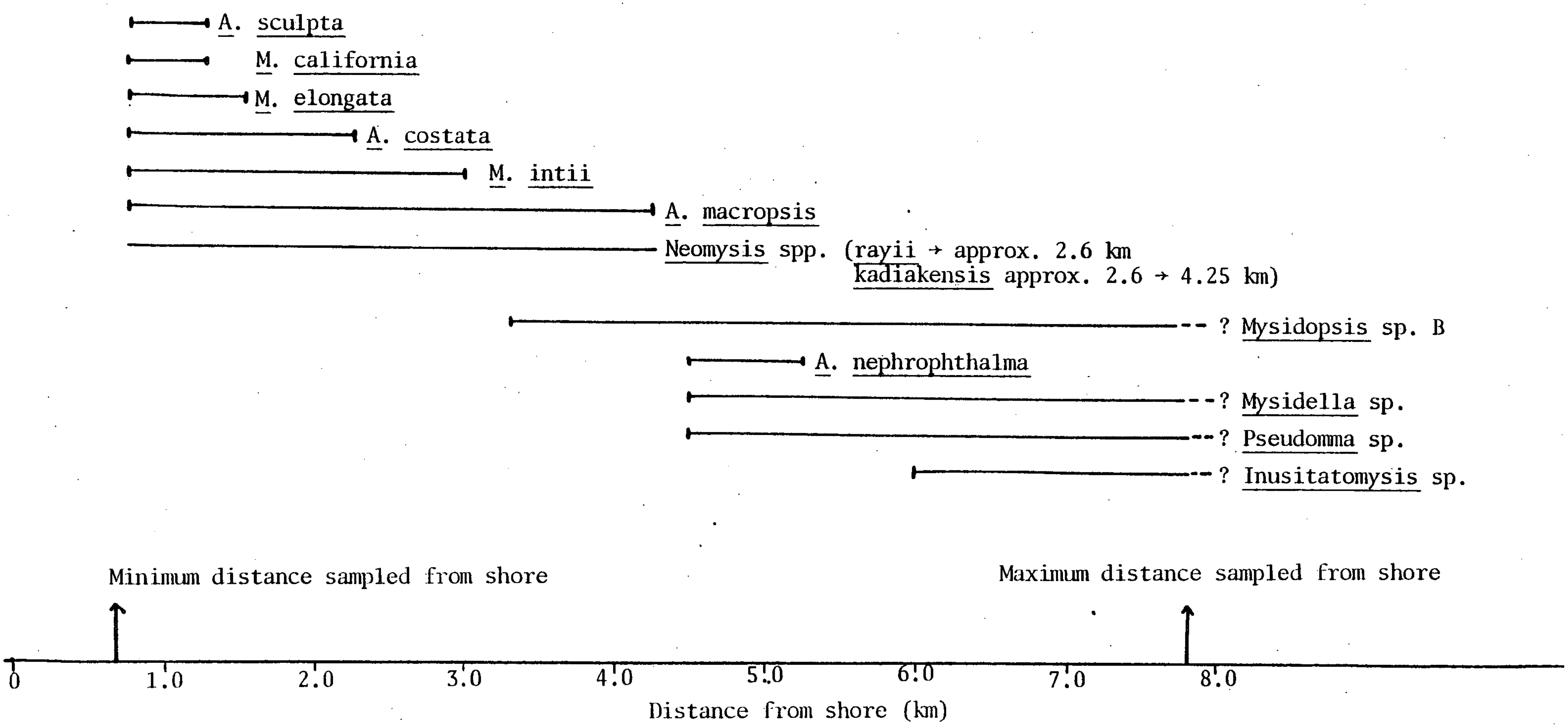
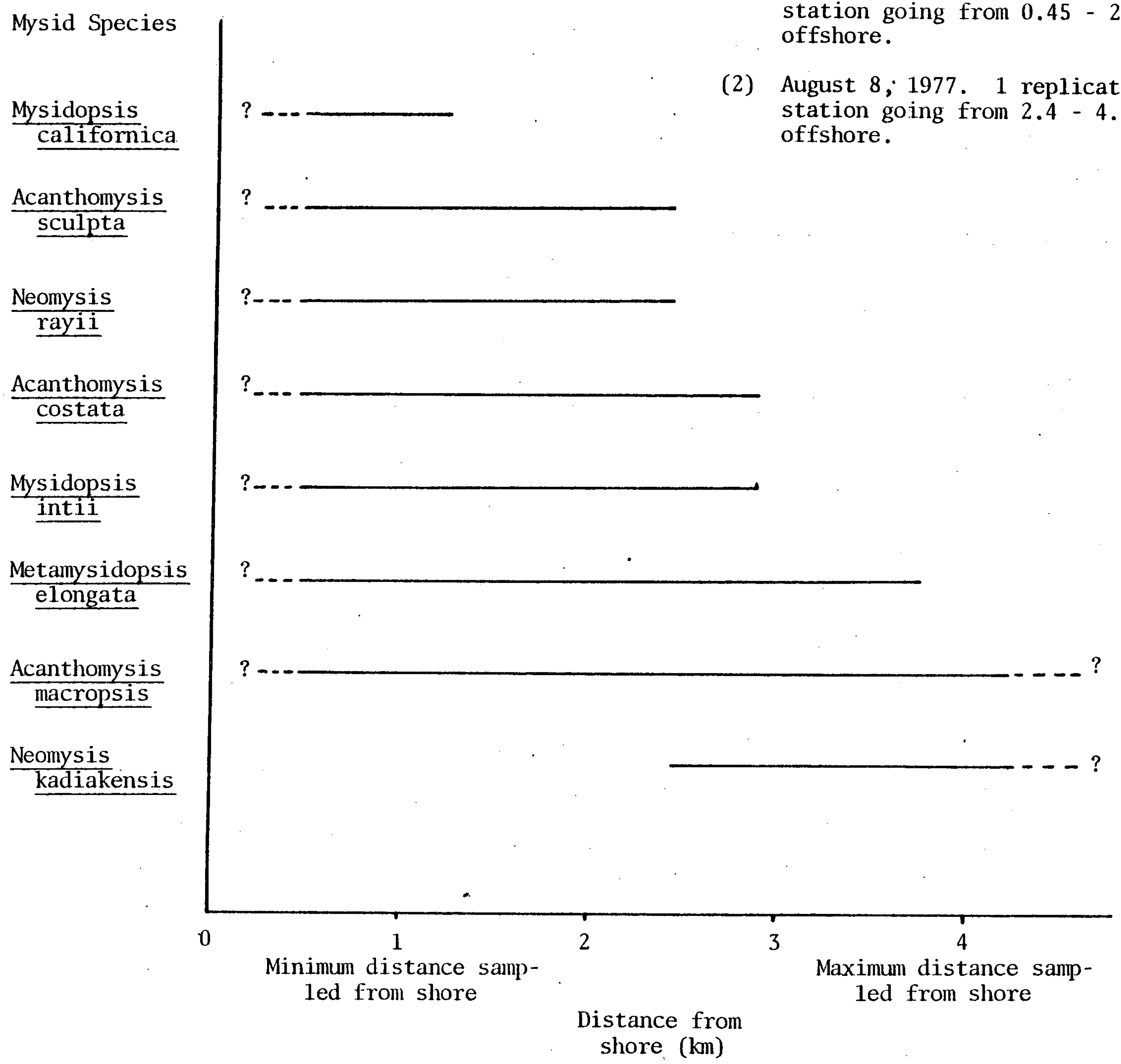


Figure 4. Zonation of nearshore mysids in August, 1978. Zones of occurrence are shown. Data are based on epibenthic sled transects from the following two dates: (1) August 3, 1977. 4 replicates/station going from 0.45 - 2.45 km offshore.

(2) August 8, 1977. 1 replicate/station going from 2.4 - 4.25 km offshore.



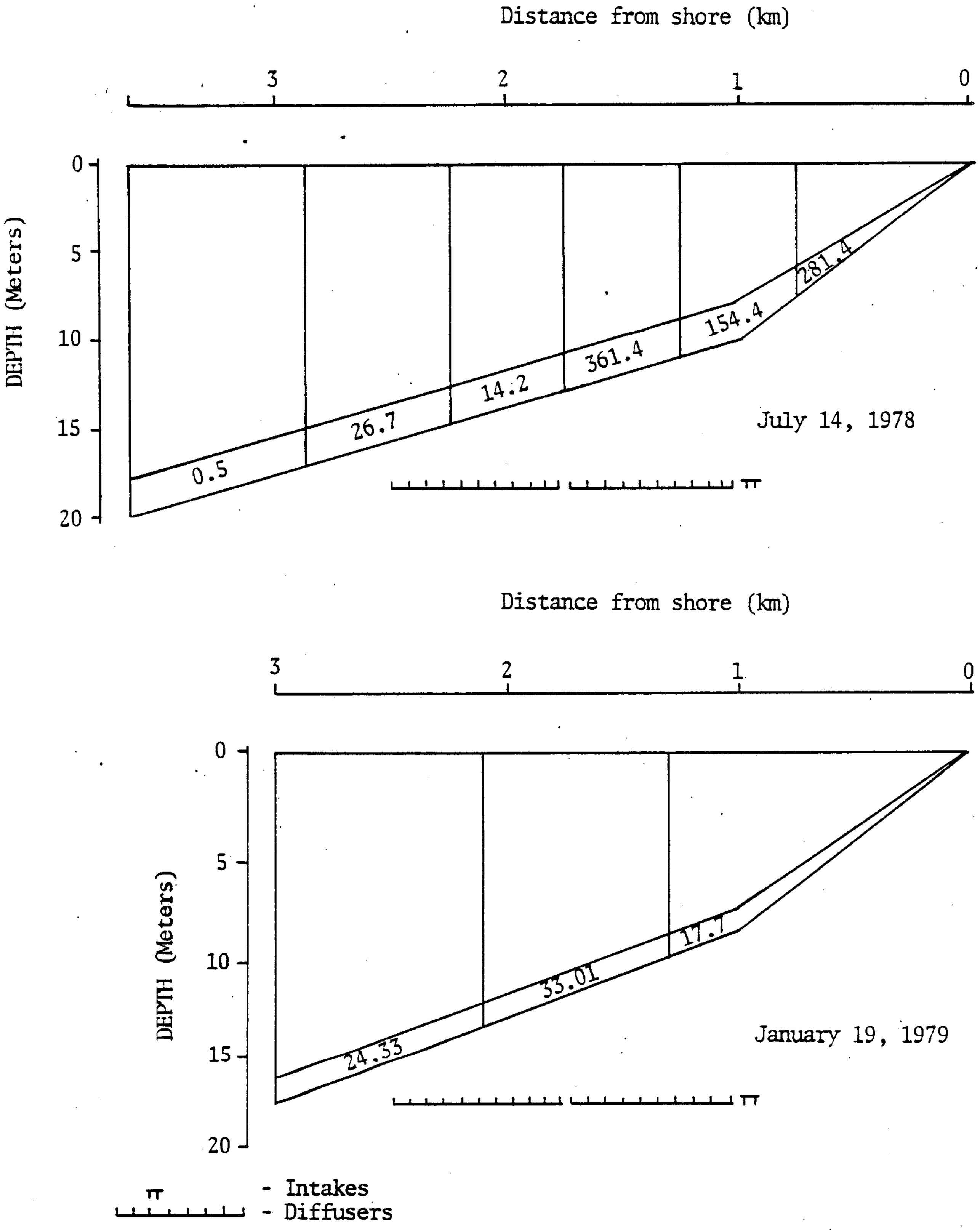


Figure 5. Daytime abundances (numbers/m^2) of *Metamysidopsis elongata* on representative dates in summer (top) and winter (bottom). Since all *M. elongata* are found in the bottom meter, the values also represent numbers/m^3 in the layer within 1 m of the bottom. Epibenthic layers are vertically exaggerated relative to the midwater layer. Summer values are based on 10 replicates and winter values on four replicates.

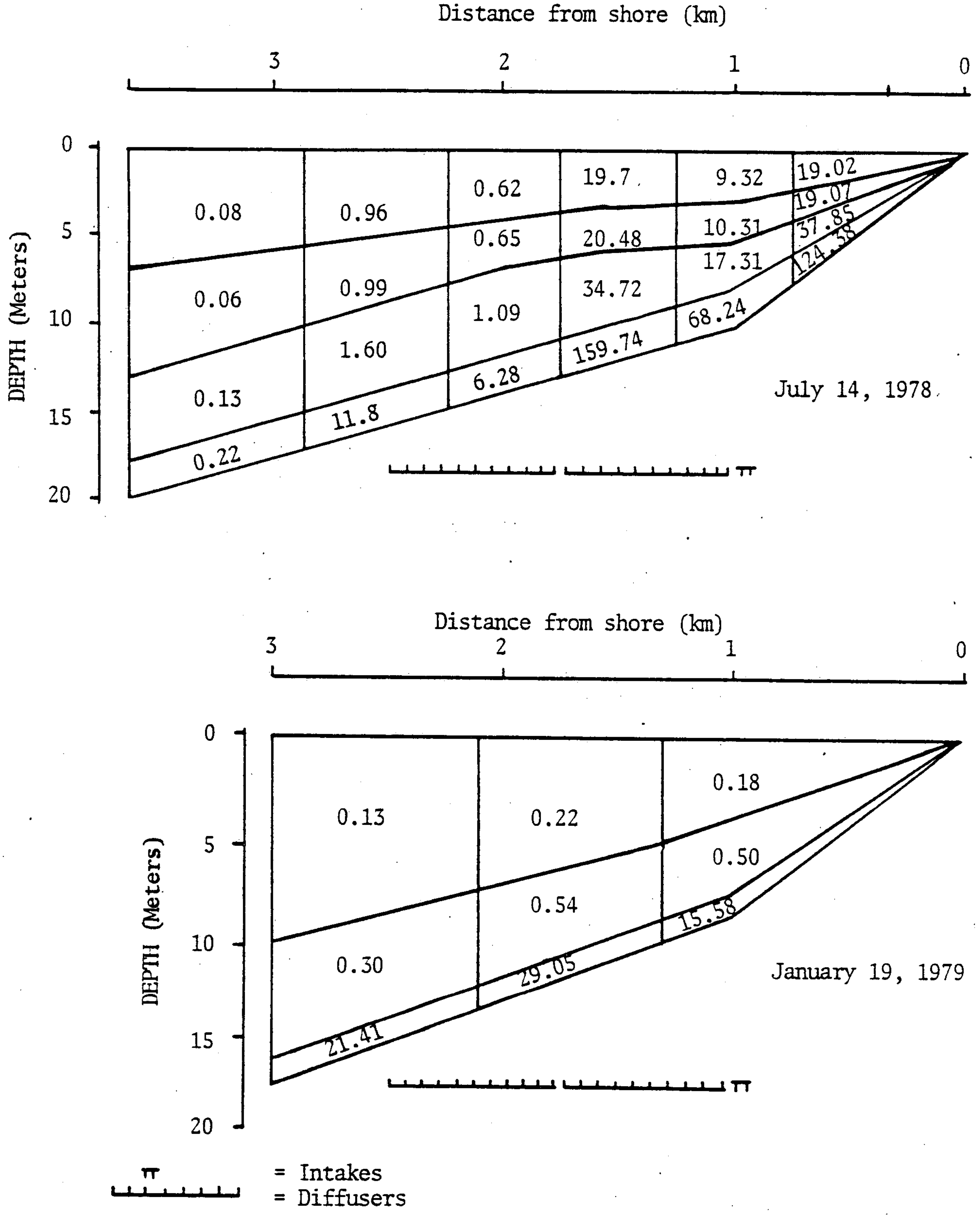


Figure 6. Estimated nighttime abundances (numbers/m^3) of Metamysidopsis elongata in the vertical strata of the water column during representative dates in the summer (top - July 14, 1978) and winter (bottom - January 19, 1979). Epibenthic layers are vertically exaggerated relative to midwater layers. To obtain the values on a m^2 basis as shown in Figure 5, the concentrations within each stratum must be multiplied by the depth of that stratum and summed over all strata; e.g., for the inshore block during winter (.18 org m^{-3} x 5.5 m) + (.50 org m^{-3} x 2.25 m) + (15.58 org m^{-3} x 1 m) = 17.7 organisms m^{-2}.

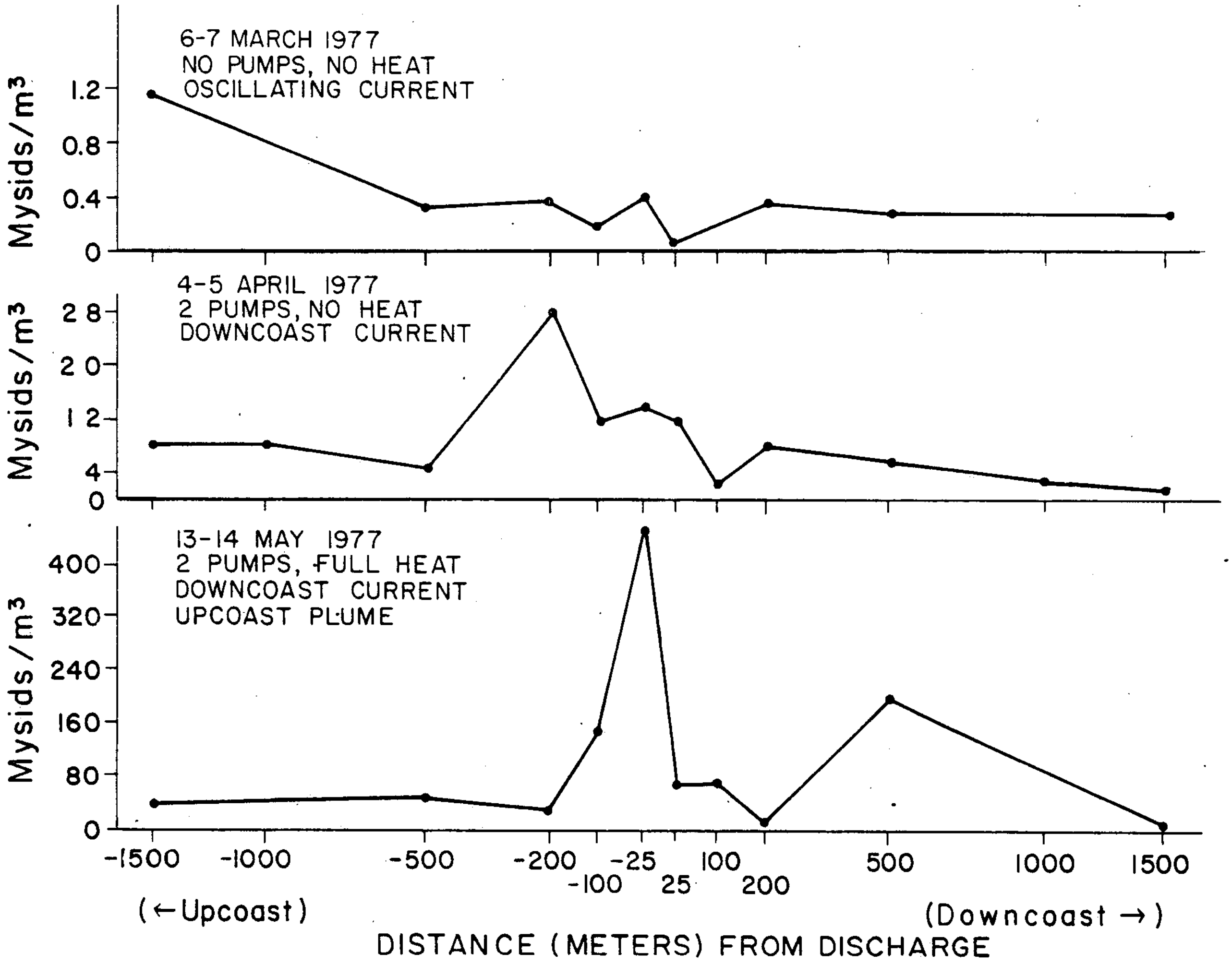


Figure 7. Abundance of total mysids at 2 m below the surface at 9 - 12 locations upcoast and downcoast from Unit 1 discharge representing three phases of SONGS operation; non-operation, pumps only and full operation. Points are based on the mean of ten samples each taken at night with the plankton pump. Surface current directions according to the inshore MRC current meter are shown for all cases. However, the current meter direction may not always be indicative of the plume direction as is seen in the third case when the plume as measured by temperature was upcoast while the current meter indicated a downcoast direction.

LOSS ESTIMATE CALCULATION FOR MYSIDS

Mysid losses to the SONGS cooling operations are estimated from losses of *Metamysidopsis elongata* in Table 4. The numbers of *M. elongata* are multiplied by the ratio or abundance of all mysids to *M. elongata* in the area of the intakes and Units 2 and 3 diffusers.

To estimate losses to Unit 1 withdrawal, summer and winter values are calculated for total mysids, then averaged to obtain losses per day.

$$\text{Summer} \quad \frac{10 \times 10^6 \ \textit{M. elongata}}{\text{day}} \times \frac{100 \text{ mysids}}{25 \ \textit{M. elongata}} = 40 \times 10^6 \text{ mysids/day}$$

$$\text{Winter} \quad \frac{.7 \times 10^6 \ \textit{M. elongata}}{\text{day}} \times \frac{100 \text{ mysids}}{98 \ \textit{M. elongata}} = .7 \times 10^6 \text{ mysids/day}$$

$$\frac{(40 \times 10^6) + (.7 \times 10^6)}{2} \ \frac{\text{mysids}}{\text{day}} = 20 \times 10^6 \text{ mysids/day}$$

Losses to Units 2 and 3 intakes are calculated in the same manner:

$$\text{Summer} \quad \frac{49.2 \times 10^6 \ \textit{M. elongata}}{\text{day}} \times \frac{100 \text{ mysids}}{25 \ \textit{M. elongata}} = 197 \times 10^6 \text{ mysids/day}$$

$$\text{Winter} \quad \frac{3.42 \times 10^6 \ \textit{M. elongata}}{\text{day}} \times \frac{100 \text{ mysids}}{98 \ \textit{M. elongata}} = 3.49 \times 10^6 \text{ mysids/day}$$

$$\frac{(197 \times 10^6) + (3.49 \times 10^6)}{2} \ \frac{\text{mysids}}{\text{day}} = 100 \times 10^6 \text{ mysids/day}$$

Mysid losses to Units 2 and 3 diffusers will be to entrainment and offshore transport, and are also calculated by the same method.

Summer $\frac{350 \times 10^6 \text{ \underline{M}. \underline{elongata}}}{\text{day}} \times \frac{100 \text{ mysids}}{20 \text{ \underline{M}. \underline{elongata}}} = 1750 \times 10^6$ mysids/day

Winter $\frac{21.2 \times 10^6 \text{ \underline{M}. \underline{elongata}}}{\text{day}} \times \frac{100 \text{ mysids}}{83 \text{ \underline{M}. \underline{elongata}}} = 25.5 \times 10^6$ mysids/day

$$\frac{(1750 \times 10^6) + (25.5 \times 10^6)}{2} \frac{\text{mysids}}{\text{day}} = 888 \times 10^6 \text{ mysids/day}$$

These losses are then totalled and put on a yearly basis (x 365 days/year). Then they are converted to biomass on the basis of 2 mg/mysid or

$$\frac{2 \text{ mg}}{\text{mysid}} \times \frac{10^{-3} \text{ g}}{\text{year}} \times \frac{10^{-3} \text{kg}}{\text{g}} \times \frac{10^{-3} \text{ metric tons}}{\text{kg}} = 2 \times 10^{-9} \text{ metric tons/mysids}$$

Metric tons are then converted to tons (1.1 tons/metric ton) as shown below:

$$(\quad) \frac{\text{mysids}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{2 \times 10^{-9} \text{ metric tons}}{\text{mysid}} \times \frac{1.1 \text{ tons}}{\text{metric tons}} = (\quad) \frac{\text{tons}}{\text{year}}$$

	Mysids/Day	Mysids/Year	MT*/Year	Tons/Year
Unit 1 Intake	20×10^6	7.3×10^9	14.6	16
Units 2 and 3 Intakes	100×10^6	36.5×10^9	73	80
Units 2 and 3 Discharge	888×10^6	324×10^9	648	713
Units 2 and 3 Total	988×10^6	361×10^9	722	794
Units 1, 2 and 3 Intakes	120×10^6	43.8×10^9	87.6	96
Units 1, 2 and 3 Discharge	888×10^6	324×10^9	648	713
Units 1, 2 and 3 Total	1008×10^6	368×10^9	736	810

Minimum estimates of loss assume that the only loss is to intake withdrawal and that 100% of those mysids withdrawn are killed. This loss would be 20×10^6 mysids/day for Unit 1 and 120×10^6 mysids/day for Units 1, 2 and 3.

*Metric tons

Maximum estimates of loss assume that, in addition to intake withdrawal losses, the Units 2 and 3 diffusers will transport offshore all entrained mysids where they will be diluted to ambient waters and lost due to decreased survivorship. Maximum loss will be 20 x 10^6 mysids/day to Unit 1 and 1008 x 10^6 mysids/day to Units 1, 2 and 3.

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Weibe, P.H. and P.L. Richardson, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. A Multidisciplinary Time-Series Study of Gulf Stream Cold Core Rings. Paper presented at the twenty-first Annual Meeting of ASLO, Victoria, British Columbia, June, 1978.

SUBTIDAL SAND BOTTOM BENTHOS

The assemblage of animals and plants living in and on the sandy bottom subtidally represents a community distinct from that on rocky substrates. It occupies more than half of the area of bottom off San Onofre and consumes a large portion of the energy flowing through the nearshore ecosystem. It provides the main food for a large proportion of the benthic commercial and sport fish of the area.

Findings

(1) Within about 200 m of the intake and outfall of Unit 1, in a total area of about 0.2 km^2 (49 acres), the sediment texture is more coarse, due to the addition of shells of fouling organisms discharged during normal operations or during the backflushing at heat treatments. Suspended inorganic and organic particulates are 2 - 3 times higher in this zone.

(2) Within this zone, as compared to further away from Unit 1, the abundance and diversity of sedentary invertebrates are reduced, for all species combined. This is probably due to the more coarse texture of the sediments. Many of the species are different from those in areas further away from Unit 1. The total weight of animals is no different, however.

(3) Within this general pattern, different sorts of animals have different distributions. Mobile crustaceans are more scarce near the intake than the outfall or other stations, probably because they are sucked into the intake more readily. Other species are more common near the intake and outfall than further away.

(4) The abundance and diversity of organisms increase with depth. Concomitantly with increasing distance offshore, the sediment texture becomes less coarse, organic carbon content increases, as does sediment stability. Water column turbidity and amount

of large particulate detritus decreases.

Predictions

(1) Around the intakes of Units 2 and 3, the sediments will be made more coarse. The total area around all three intakes that will be affected will be about .41 km^2 (101 acres), at least twice as great as around Unit 1 alone. The sedentary animal community in this area will have lower abundances and diversity than further away at the same depths.

(2) Around the offshore diffusers of Units 2 and 3, the sediments will also be made more coarse over an area of about 0.68 km^2 (168 acres). The sedentary animal community will be affected to a lesser degree than around the intakes.

(3) Loss of meroplankton larvae, as indicated in the Plankton section, may produce a lowered abundance of the settled stages of some species in the inshore sandy subtidal community.

(4) We do not yet have enough information to predict the extent of the loss of habitat, the loss and redistribution of detritus food or the changes in phytoplankton and algae living in and on the sediments which are utilized as food. Also, the effect that loss of larvae has on the adult benthic population is not known for any species in the sandy subtidal benthos. Due to these uncertainties, it is not possible to predict, at this time, the overall effects that will be caused by SONGS Units 1, 2 and 3 on this community.

Implications

Although it is not yet possible to present a balance sheet of gains and losses, it seems quite likely that the present design of the Units 2 and 3 diffusers will cause some deleterious effects to species restricted to within 1.5 miles of the coastline. We surmise that if the diffusers were changed to single-point discharges further offshore, the possibility of harm to the San Onofre Kelp bed and the predicted transport offshore of larvae and detritus food would be prevented. At the same time, the increased productivity of phytoplankton from upwelling would still occur offshore.

Supportive Evidence for Findings

(1) For sediment characteristics in relation to SONGS Unit 1 activity see:
Diener and Parr (1977) - Text (Section 4.4); Tables 4-7 and 4-9; Figures 4-2 and 4-4.
Parr and Diener (1978) - Text (Section 5.2.1); Tables 5-5, 5-6; Figures 5-1.
For discussion and data of suspended inorganic and organic particulate values from sediment traps see:
Parr and Diener (1978) - Text (Section 5.2.1); Figure 5-3.

(2) For abundance, diversity and biomass (weight) relationship to SONGS Unit 1 see:
Parr and Diener (1978) - Text (Section 5.2.2); Figures 5-6 and 5-9.

(3) For distribution patterns of different groups of organisms and of specific key species in relation to SONGS Unit 1 see:
Parr and Diener (1978) - Text (Section 5.2.2); Tables 5-9 and 5-11; Figures 5-11, 5-13, 5-15, 5-16, 5-17 and 5-18.
For abundance data of crustaceans at the intake in relation to other areas see:
Figure 1 (this section).

(4) For sediment characteristics of sediment texture, organic carbon, and detritus in relation to depth see:
Parr and Diener (1978) - Text (Section 5.2.5); Table 5-5; Figures 5-4 and 5-5.

Turbid water (reduced light transmission) is a natural part of the nearshore environment. Water clarity is affected by a variety of natural factors including wave energies, currents, bottom composition and slope, organic and inorganic debris, land-runoff and plankton blooms. Water clarity in the nearshore area of San Onofre generally increases with distance offshore (Table 1 and Figure 2 of this section) and decreases with depth. Turbidity in the nearshore area and development of turbidity plumes tend to be seasonal, with low turbidity in summer and fall and higher turbidity in winter and spring. The seasonality of turbidity plumes is related to the seasonality of wave energy patterns (Marine Advisors, Inc., 1969; Intersea Research Corporation, 1973).

For abundance, diversity, and biomass (weight) in relation to depth at SONGS see:

Parr and Diener (1978) - Text (Section 5.2.5); Tables 5-9 and 5-10; Figures 5-6, 5-9, 5-24 and 5-25.

Supportive Evidence for Predictions

(1) Increases in sediment coarseness in the vicinity of the intake and outfall structures after heat treatment have been measured and observed visually. See Diener and Parr (1977), Figures 4-2, 4-3, and 4-4; Parr and Diener (1978), Figure 5-1, Tables 5-5, 5-6 and 5-12.

The areal extent and the duration of this effect varies depending upon time between heat treatments, duration of shutdown periods with pumping and the patterns of currents and wave energies that redistribute particles following their initial discharge at the intake and outfall. Generally, we did not observe increases in shell fragments (coarseness) more than 200 m away from the intake or outfall structures.

However, these larger sediments are buried within weeks by finer sediments and are, therefore, not quantitatively measured after a period of time by our surface sediment samples (8 cm deep). That coarse sediments are transported more than 200 m away is indicated by layers of shell fragments found by digging below the surface sediments and by the large volumes of shell fragments exposed in the vicinity of the intake/outfall by pier construction for SONGS Unit 2 200 m downcoast. We have not, as yet, observed this for the second pier which was constructed later for Unit 3. The estimated area of sediment modification is an area equal to 125,600 m^2 or 31 acres around the Unit 1 outfall (Parr and Diener, 1978). To obtain the total area for both the intake and outfall of Unit 1, the two circles of modified sediments around the structures adjusted for the overlap results in an impacted Unit 1 area of 202,000 m^2 or 50 acres (intake/outfall: 251,200 m^2, area overlapped: 49,200 m^2).

Because Units 2 and 3 have 3.2 times greater intake pipe area than the Unit 1 intake and also greater volumes of water withdrawn, we estimate a possible 50% increase in the area where sediments will be modified around the intake structures (particularly with prolonged operation). However, if the smaller mesh screens in the new Units are effective in collecting significantly greater amounts of shell material sloughed off during and following heat treatment, then the extent of this effect could be diminished or accumulated more slowly. Thus, based upon a 245 m radius extent, we estimate added new impact from Units 2 and 3 intakes to be .11 and .09 km^2 (27 and 22 acres), respectively.

Sediment modification around the diffuser lines is more difficult to estimate. There are two effects:

(a) Discharge of fouling organisms and suspended particulates sucked in at the intakes and

(b) The possible erosion of fine sediments near the diffuser ports due to wave resuspension of bottom sediments and removal from the area via secondary entrainment. Because of the stronger longshore currents at the diffuser depths and the greater depth of water (takes particulates a longer time to fall out of the water column), the effects along the diffuser may be similar to the Unit 1 outfall even though there is a strong onshore-offshore orientation to the discharge. As a best estimate, if sediment modification effects are limited to within 200 m of the diffuser lines, then the areal impact of the Unit 2 diffuser operation is estimated to be .43 km^2 or 106 acres. This estimate is based upon the diffuser length (763 m) times the estimated width of impact (400 m) plus the two circular end areas (.125 km^2). The total areal extent of sediment modification near the Unit 3 diffuser lines is estimated to be the same as for Unit 2. However, the area estimated for Unit 2 overlaps areas expected to be impacted by Unit 3. Thus, the new area of benthos to be impacted by the operations of the Unit 3 diffusers equals .25 km^2 or 62 acres. Total impacts predicted for sediment modification taking into account overlap of effects are shown in Figure 3 (in this section). Total area of impact is approximately 1.1 km^2 or 272 acres.

For the basis of predicted lower diversity and abundance from sediment modification see:

Diener and Parr (1977) - Text (Section 4.4); Tables 4-5, 4-6, 4-7, 4-8 and 4-9; Figures 4-2, 4-3 and 4-4.

Parr and Diener (1978) - Text (Sections 5.2.1 and 5.2.2); Tables 5-1, 5-2, 5-9 and 5-11; Figures 5-1, 5-2, 5-6, 5-7, 5-8a, 5-8b, 5-9, 5-10a, 5-10b, 5-11, 5-13, 5-14, 5-15, 5-17 and 5-18.

(2) For the basis of predicting a lesser effect at SONGS Units 2 and 3 diffuser depths than at depth of intakes see:
Parr and Diener (1978) - Text (Section 5.2.4) p. 5-17, last paragraph.

(3) See Plankton section in this report - Discussion of meroplankton.

Table 1. Concentrations of suspended inorganic particulates at the surface averaged from 1964 - 1973.

Distance offshore (m)	mg/liter
305	5.74
405	5.38
1027	2.14
1634	1.01

*From Intersea Research Corporation, August, 1973. Semiannual Report of San Onofre Oceanographic and Biological Monitoring Program - July, 1972 - January, 1973.

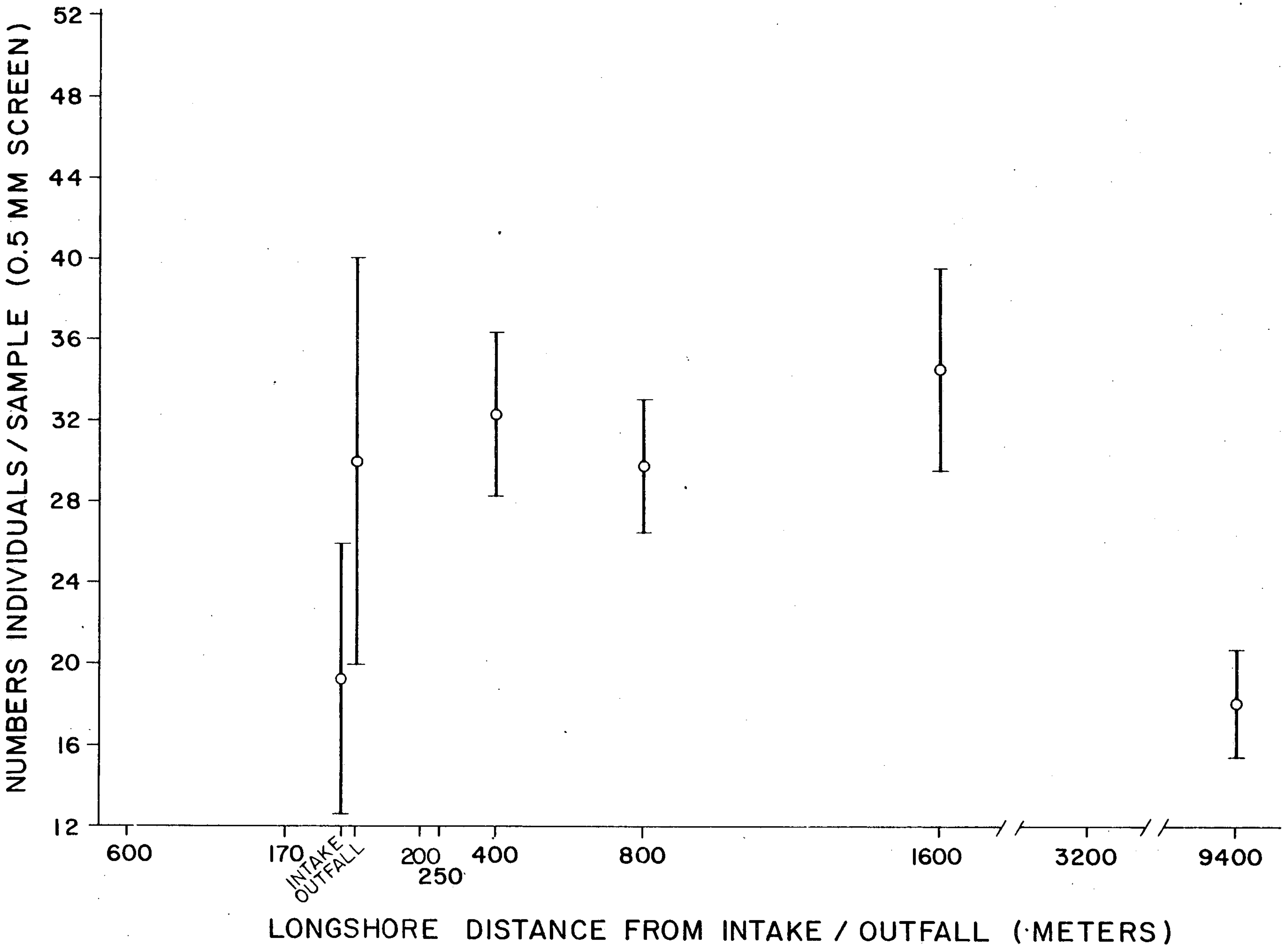
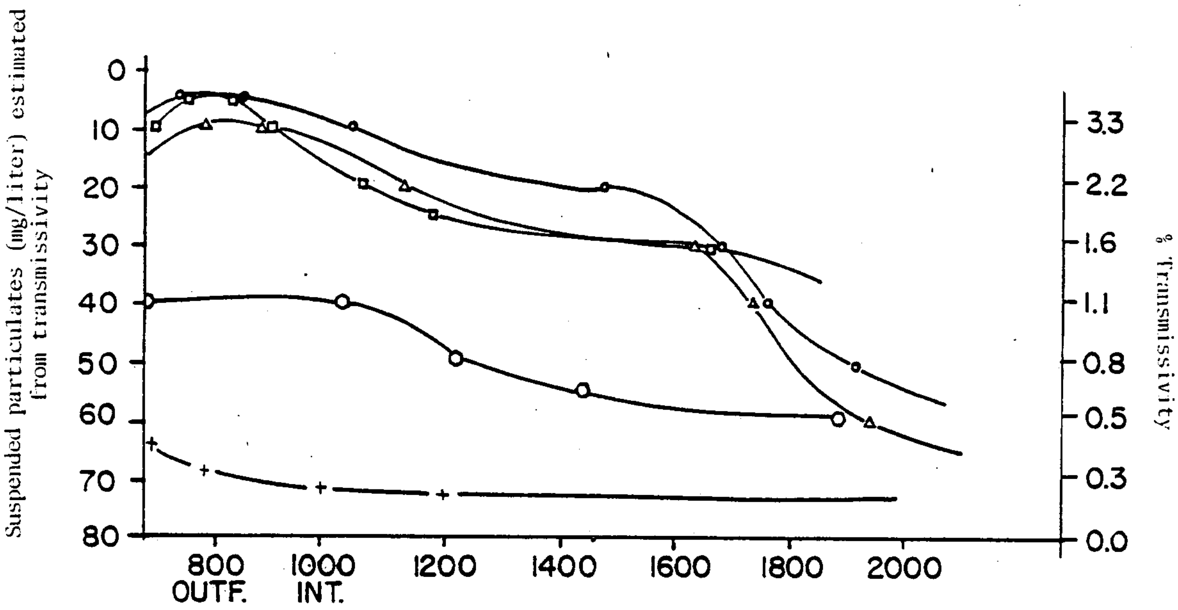


Figure 1. Five survey average of crustacean abundance at SONGS Unit 1 depth.

Figure 2. Transmissivity data from San Onofre, 1976 (before pier construction).*



*Plotted from data presented in: Southern California Edison, 1976. Environmental Technical Specifications, Annual Operating Report, Vol. 1, Oceanographic Data Summary, 1976.

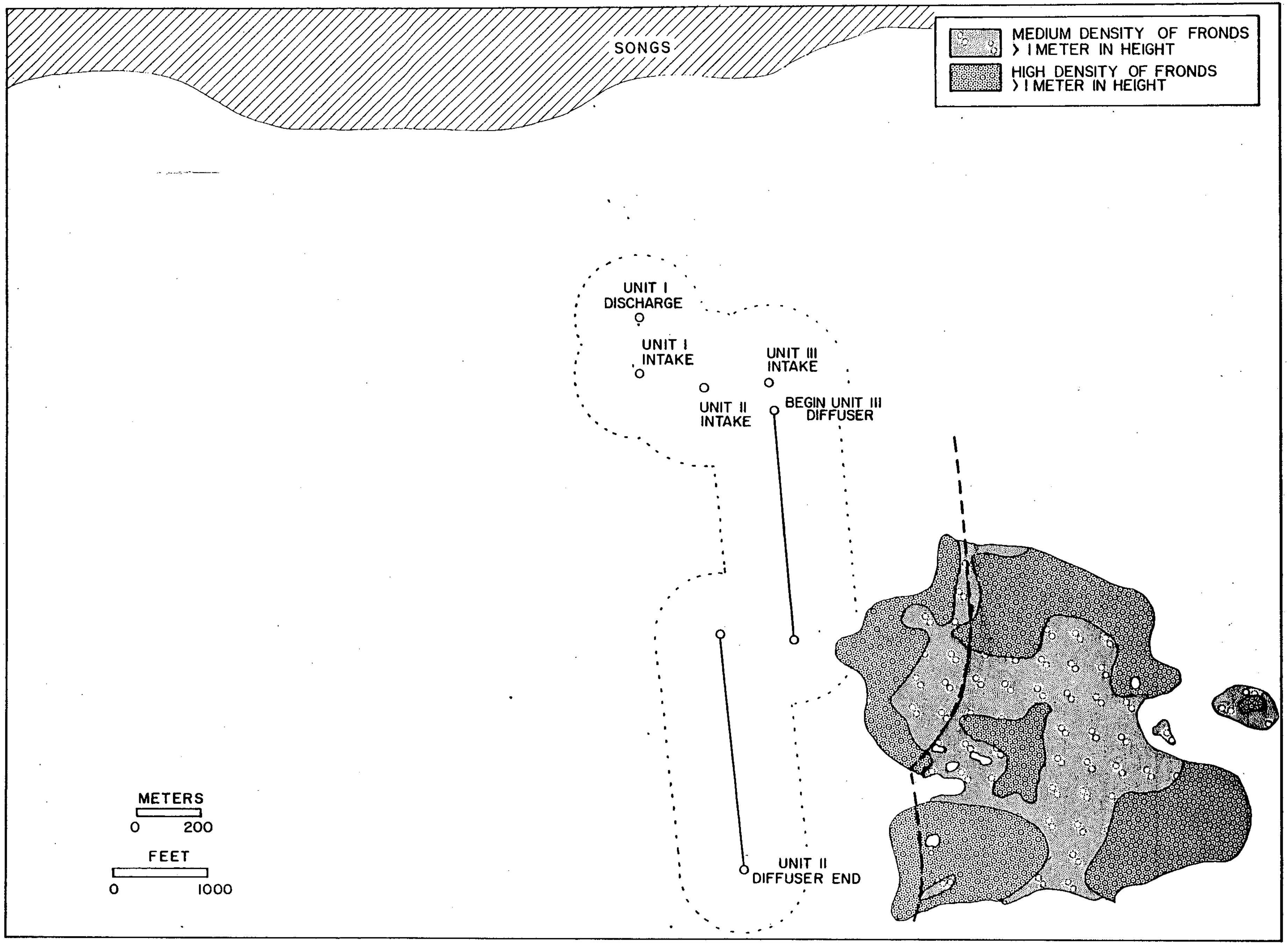


Figure 3. Sediment modification at SONGS.

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FISH

SONGS Unit 1 affects local species of fishes by drawing their eggs, larvae, juveniles and adults into the cooling system where some or all are killed. Units 2 and 3 have a new fish return system which is designed to transport the fish back to the ocean with as little harm as possible. Larvae and eggs will still be entrained. They will also be secondarily entrained in the diffuser plume and may be lost to shear stress, increased predation and transport offshore beyond their normal habitat.

Another way that SONGS could affect fish is to change the distribution and/or abundance of their food and predators.

Findings

(1) MRC studies estimate that, on the average, about 520,000 juvenile and adult fish weighing a total of 18,000 kg (20 tons) are killed over a full year's operation of Unit 1. Most are very small (average weight less than two ounces) and more are caught between January and May than during the rest of the year.

(2) Three-quarters of these are queenfish, a fodder-fish eaten by sport and commercial fish. In one summer, the numbers killed represented about 3% of the queenfish living along 44 km (27 miles) of coastline near SONGS.

(3) Although the total abundance of queenfish within 0.5 km (one-third mile) of SONGS is no less than that found up to 6 km (3.5 miles) away, the proportion of juveniles is much lower and the proportion of adult males is much higher near SONGS. This is because greater numbers of juveniles are sucked in and killed than adults and, among adults, more females than males are sucked in and killed.

(4) The species composition and relative abundance of midwater fishes near the Unit 1 intake are not different (in a statis-

tical sense) from those found elsewhere within 6 km (3.5 miles) of SONGS. However, a greater number of benthic species, mainly commercially unimportant types, have been recorded within 0.5 km (one-third mile) of SONGS than elsewhere, perhaps attracted by the new habitats created by the structures, by increased temperature or food, or by all of these factors.

(5) It is estimated that between 3.5 and 6 million fish larvae are killed per day by Unit 1. The lower value assumes no entrainment mortality due to discharge turbulence, the higher value assumes 12% of those entrained are killed.

Predictions

(1) Although Units 2 and 3 have been designed to reduce the intake of juvenile and adult fish, more fish will certainly be killed when all three units are in operation than at present. Since the area of each of the intake structures of Units 2 and 3 is about twice that of Unit 1 (and larger "reefs" attract greater numbers of fish), the numbers of juvenile and adult fish sucked in could increase to five times that at present. During the summer months, Units 2 and 3 would suck in about 13% of the queenfish living along 44 km (27 miles) of shoreline near SONGS. This five-fold increase would obtain if the mitigating measures (improved velocity cap and the fish return system) designed for Units 2 and 3 prove totally unsuccessful. If the mitigating measures are partially effective, the numbers of fish sucked in would increase less than five-fold.

(2) The magnitude of the combined Units 1, 2 and 3 kills of juvenile and adult fish thus greatly depends on the effectiveness of the improved velocity cap and the fish return system. Neither of these design changes has been tested at full scale or under field conditions; in particular, the possibility that fish will suffer damage while passing down the long,

narrow return conduit has never been tested. Some damage will occur, and for the smaller individuals that represent most of the fish entrained, the incidence of damage will probably be very high. In this event, only small numbers of the fish that are sucked in could be expected to survive, even if they are returned to the ocean. Of the small fish returned to the ocean, a fraction will fall prey to sport and commercial fish and some that die will be assimilated by bacteria and invertebrates, thence to become food for forage fish, economically important species, or scavengers. We cannot as yet quantify these processes and predict their net effect on the sport and commercial fish catch.

(3) The modified age distribution and mean size of queenfish near the Plant (i.e., proportionately fewer juveniles and more males) will occur over a larger area than at present.

(4) The size of the area over which a greater number of benthic fish species could be expected to occur will increase.

(5) The large, warm discharge plume of Units 2 and 3 will probably not be extensive enough to affect the longshore movements of migratory fishes.

(6) If the San Onofre Kelp bed is destroyed, the abundance of at least one species of fish will be greatly reduced near SONGS.

(7) Because of our uncertainty concerning mortality of fish larvae entrained in the discharge plumes, we give two values for estimated loss: between 20 and 340 million fish larvae will be killed per day by Units 1, 2 and 3. This is equivalent to 8,000 - 124,000 kg (8 - 136 tons) of larvae per year.

(8) Each year, assuming maximum transport of zooplankton, about 8,000 tons of food for fodder-fish will be shifted from within 1.5 miles of shore to 3.5 miles or more offshore. Some of this food will be converted into fodder-fish in the plume area, and hence into sport and commercial fish. A fraction will fall to the bottom and will be assimilated by bacteria

and invertebrates. Again, some fraction of this production will reach the sport and commercial fish production via bottom-feeding fish, though some will be diverted en route. We expect that most of the energy that is cycled into fish will be maintained within the same group of species, since most sport and commercial species have broad depth distributions.

(9) The annual production of an additional 200,000 tons of phytoplankton, due to diffuser entrainment of bottom waters, would lead to an increase in the production of sport and commercial fish.

Implications

We are not yet able to estimate the potential gains and losses to sport and commercial fish production that will arise from the various effects of Units 1, 2 and 3. There is uncertainty about the extent to which the new fish return system will reduce fish mortality, about discharge entrainment losses of fish larvae, and about the capacity of San Onofre fish populations to endure and compensate for the added mortality of larval, juvenile and adult fish. We do not yet know the extent to which these losses, and those caused by reduced zooplankton density and the transport of plankton offshore, will be balanced by increased fish production from increased offshore phytoplankton production. Very preliminary calculations have suggested that a net loss of fish production will occur. However, we are not yet confident in these calculations, and need more detailed quantitative information. The calculations do show, however, that the problem is sufficiently serious that it must be studied in detail in order to predict and then determine the actual effects of Units 2 and 3.

Supportive Evidence for Findings

(1) Tables 1 and 2. Also see Tetra Tech, 1977b, pp. 15 - 17, Figures 2-2 - 2-13.

(2) Tables 2 and 4. Queenfish are a known food item of a number of sport and commercial fishes, including California barracuda, California halibut, kelp bass, and California scorpionfish (Limbaugh, 1955; Young, 1963; Quast, 1968; Frey, 1971; Feder, et al., 1974).

During May - August, 1978, an estimated 286,000 juvenile and adult queenfish were killed by intake entrainment at SONGS Unit 1.

The estimated mean abundance of juvenile and adult queenfish in a 44 km (27 mile) longshore reference area during May - August, 1978, was 11 million fish, with 90% confidence bounds of about 4 - 37 million fish (Table 5). (A 44 km [27 mile] reference area is used to enable comparisons of these density estimates with those reported for larval queenfish in the Plankton section.) Queenfish stock density estimates were calculated using the following steps:

(a) Lampara net surveys of queenfish were made at 5 - 20 m depths near the Unit 1 intake and at three other longshore areas ranging from 3 km south to 6 km north of Unit 1. These areas are 1 km wide; the onshore/offshore extent of the main transect area (1 - 2 km north of SONGS) is 3 km.

(b) The weighted (by time) mean lampara net catch-per-net-haul of queenfish in each depth stratum (Table 5) was multiplied by a lampara net catch-efficiency density correction factor (cf) determined empirically for each depth (Table 6) to estimate true queenfish abundance in the net, so that catch-per-net-haul x cf = abundance in the net.

(c) The upper and lower 90% bounds on these weighted mean density estimates were calculated by combining the upper and lower extremes of the catch-per-net-haul and catch-efficiency estimates. For example, lower bounds were calculated using the lower bound of catch-per-net-haul and the smaller catch-efficiency multiplier (higher efficiency bound).

(d) Abundance was then corrected by the ratio of the total sampling area (m^2) within the specified depth stratum to the net area (4,400 m^2) to obtain an estimate of the total number of queenfish within the specified depth stratum:

$$\text{Abundance} \times \left(\begin{array}{c}\text{Total area within}\\ \text{specified depth}\\ \text{stratum}\end{array} / \text{lampara net area}\right) = \text{number of fish in depth stratum,}$$

where lampara net area = 4,400 ± 75 m^2 (n = 33 sets).

(e) The numbers of fish in all depth strata were summed to obtain an estimate of total queenfish density, both by day and at night, within a 3 km area that is 1 km wide.

(f) The day and night density estimates for 1 km longshore were then averaged to provide the best single mean estimate of total numbers of queenfish within a 1 km longshore area. The estimate per km was then extrapolated to 44 km longshore.

(3) Kruskal-Wallis One-Way Analysis of Variance shows no significant differences in queenfish catch-per-net-haul values at 5 - 11 m depths for longshore reference areas and within 0.5 km of SONGS (by day) or among longshore

reference areas at night (Table 7). The sex ratio (Figure 1) and size-composition (Table 8) of queenfish, however, is markedly different within 0.5 km of the SONGS Unit 1 intake than in three reference areas up to 6 km distant. The sex ratio and size-composition of queenfish in intake entrainment samples is also unique (Figure 1, Table 8).

(4) The Canberra-Metric Index of Dissimilarity (Clifford and Stephenson, 1975: 58 - 60) shows no difference in the relative abundance of fishes in 5 - 11 m of water during daylight hours near Unit 1 and at other longshore areas. Fish were collected by lampara net during May, 1978, and June - October, 1978; during these two time periods, index values varied only slightly from 0.57 - 0.73 and from 0.59 - 0.81, respectively (Tables 9 and 10).

Table 11 and Figure 2. The present data suggest that the assemblage of benthic fishes within 0.5 km of the Unit 1 intake structure is more diverse (species-rich) than elsewhere within 6 km of the Plant. However, the apparent differences illustrated by Figure 2 are not statistically significant by Kolmogorov-Smirnov Two-Sample Test ($p > 0.1$).

Shrode (1978) and Ehrlich, et al. (1978) have shown with behavioral experiments that many nearshore Southern California fishes will selectively position themselves in slightly warmer water such as a power plant effluent.

The attractiveness of artificial reef structures to fish in Southern California is well-documented (Carlisle, et al., 1964; Turner, et al., 1969).

(5) See Plankton section.

Supportive Evidence for Predictions

(1) See 1978 MRC Interim Report, p. 6; also, 1978 MRC Annual Report, pp. 6-1 - 6-9.

See Downs and Meddock (1974). The area of the rectangular velocity cap atop the SONGS Unit 1 intake structure is 928 feet^2, whereas the areas of the circular caps atop the proposed Units 2 and 3 intakes are each 1,885 feet^2. We expect that a "reef" that is twice the area will attract about twice the number of fish, including midwater-feeding species (e.g., queenfish) that aggregate in the intake current stream lines near the velocity cap. If so, it is likely that twice the number will lose their orientation during periods of swell turbulence and be sucked in. Since the SONGS Unit 1 intake presently kills an estimated 2.6% of the queenfish stocks in a 44 km longshore area during May - August, the Units 1, 2 and 3 intakes together will kill about 5 x 2.6% = 13% of these stocks if the mitigating measures are ineffective.

Through design changes in the intake structure, SCE has predicted a slower intake velocity (1.7 fps) for Units 2 and 3 than presently occurs at Unit 1 (2.6 fps). Laboratory tests of a scaled-down prototype of the Units 2 and 3 fish return system have led to predictions that it will be 70 - 80% effective in safely returning intake withdrawn fish to the area (Schuler, 1974). Also see Downs and Meddock (1974).

(2) See 1978 MRC Interim Report, p. 6, and 1978 MRC Annual Report, pp. 6-1 - 6-9. The effectiveness of the fish return system will be significantly reduced if fish are injured during transit. Our studies of queenfish and walleye surfperch, plus qualitative observations on other small species, indicate that smaller individual fish are more susceptible to stress and mechanical damage

(i.e., loss of protective mucus and scales). Injured, weakened, or disoriented fish are very susceptible to predation. Laboratory tests with queenfish have shown that greater than 25 - 50% scale loss per se is fatal for this species.

Those fish (initially sucked into the Units 2 and 3 offshore intake structures) that are diverted into the fish return system will be returned to the sea in a four-foot (I.D.) conduit and discharged shoreward of the intakes in 19 feet of water (Downs and Meddock, 1974). Many species of carnivorous fish occur in the shallow nearshore waters at San Onofre (Tetra Tech, 1977c). These include both piscivorous species and relatively large benthic fishes that feed on epifaunal and infaunal macroinvertebrates. The opportunistic feeding behavior of carnivorous fishes is generally recognized (Weatherley, 1972: 129 - 134; Larkin, 1978).

(3) See Figure 1 and Table 8. The observed change in sex ratio and size-composition of queenfish within 0.5 km of the SONGS Unit 1 intake structure reflects the selective removal of juveniles and adult females by Unit 1 intake entrainment. Since both the Unit 2 and 3 intake structures will be located less than 0.5 km south of the Unit 1 intake structure, their effects will be additive to those of Unit 1.

(4) See Table 11 and Figure 2. Greater fish species richness and increased species diversity have also been found at the King Harbor Marina, Redondo Beach (Stephens, 1978).

The addition of the Units 2 and 3 intake and diffuser line structures will pose a greater reef-type attraction for some fish species. Additional organic enrichment of sediments caused by the settling of organic detritus from the Unit 1 outfall and Units 2 and 3 diffuser lines will further promote the local abundance of the tube-building polychaete, *Diopatra* (Diener and Parr, 1977). This will, in turn, attract greater numbers of epibenthic grazing fishes such as sargo and spotfin croaker, the abundances of both of which have been noted to be greater near San Onofre than elsewhere in Southern California (Tetra Tech, 1977a).

(5) Depth distributions are broad for most nearshore fishes (Limbaugh, 1955; Turner, et al., 1969; Fitch and Lavenberg, 1971, 1975; Feder, et al., 1974) as well as for pelagic species (Fitch, 1969; Mais, 1974) in Southern California.

(6) The kelp clingfish (*Rimicola muscarum*) and (especially juvenile) kelp perch (*Brachyistius frenatus*) are virtually endemic to the giant kelp (*Macrocystis*) habitat in Southern California (Limbaugh, 1955; Feder, et al., 1974; J. Coyer, personal communication).

(7) A total of 124 billion fish larvae will be killed each year by intake and discharge entrainment of SONGS Units 1, 2 and 3 (see Plankton section).

(8) As a result of intake and discharge entrainment by SONGS Units 2 and 3, 859 tons of microzooplankton, 6,050 tons of macrozooplankton, 134 tons of ichthyoplankton, and 793 tons of mysids will be translocated annually (see Plankton, Mysids, and Physical/Chemical Oceanography sections).
Most species of nearshore sport and commercial fishes in Southern California have broad depth distributions (Limbaugh, 1955; Fitch and Lavenberg, 1971, 1975; Feder, et al., 1974) that extend seaward and shoreward of the SONGS Units 2 and 3 diffuser line depths.

(9) See Plankton section.

Table 1. Comparison of total fish numbers and total fish biomass killed at SONGS Unit 1 during the 5 months of peak impingement (March through July) in 1976, 1977, and 1978. Twelve month projected fish mortality both in total fish numbers and biomass is also shown.

Period	Total No. Fish Impinged	Total Fish Biomass Impinged	Projected 12-mo. Total No. Fish Impinged (March - February)	Projected 12-mo. Biomass Impinged (March - February)
March - July 1976	266,600	10,610	506,540	20,159
March - July 1977	155,900	5,850	296,210	11,115
March - July 1978	394,900	12,030	750,310	22,857
			$\overline{x}$ = 517,700 fish	$\overline{x}$ = 18,043 kg

Table 2. Fish Impingement Data (all species) for SONGS Unit 1, June 1977 - May 1978.

Month	Number Samples	Estimated Number Fish Impinged Each Month	Estimated Biomass Impinged Each Month (kg)
		$\hat{N}$	$\hat{N}$
June 1977	10	16,400	920
July 1977	10	48,000	1,710
Aug 1977	13	14,400	430
Sept 1977	3[1]	7,200	430
Oct 1977	10	18,700	420
Nov 1977	8	29,300	1,340
Dec 1977	11	32,300	570
Jan 1978	4	78,400	3,080
Feb 1978	9	86,300	3,290
Mar 1978	9	67,800	3,230
Apr 1978	5[1]	54,700	1,660
May 1978	9	165,200	3,650
TOTAL	102 Normal Flow + 7 Heat Treatments	618,700	20,730
90% Confidence Intervals on Annual Total		321,500 - 1,243,500	12,440 - 36,910

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[1] Limited number of sample collections due to plant shut-down.

Table 3. Comparisons of percent[1] composition of walleye surfperch and queenfish (numbers and biomass) in SONGS Unit 1 intake withdrawal samples collected during the peak impingement season (March - July) of 1976, 1977, and 1978. Percent composition during an entire year (June 1977 - May 1978) is also given.

Period	March '76 to July '76	March '77 to July '77	March '78 to July '78	June '77 to May '78
Total Numbers of Fish Impinged	266,600	155,900	394,900	618,100
% Walleye Surfperch	9.2	9.0	6.2	10.8
% Queenfish	74.4	73.4	75.6	72.2
% Summation	83.6	82.4	81.8	83.0
Total Biomass Impinged (kg)	10,610	5,850	12,030	20,600
% Walleye Surfperch	7.4	7.6	4.2	12.0
% Queenfish	50.8	52.2	48.0	46.7
% Summation	58.2	59.8	52.2	58.7

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[1] Percent composition estimated from 24-hr (Normal Flow) samples.

Table 4. Queenfish as the percent of total juvenile-adult fish individuals killed by Unit 1 intake entrainment.

	1976	1977	1978
January	no data	offline	65
February	no data	83	72
March	70	47	70
April	76	80	85
May	92	71	81
June	94	79	69
July	40	90	73
August	83	63	92
September	75	62	88
October	77	78	offline
November	offline	57	data under analysis
December	offline	64	data under analysis
AVERAGE	76%	70%	77%

Table 5. Estimated abundance of juvenile and adult queenfish in a 44 km (27 mile) longshore reference area during the period of May - August, 1978, as determined from lampara net CPUE values during day and night at all depths. Values in parentheses are 90% confidence bounds on the respective mean.

DEPTH STRATUM (m)	$\bar{x}$ Catch-Per-Net-Haul (CPUE) May to Mid-June	Mid-June to August	(May-August)	x density correction factor	= abundance in net	x DEPTH STRATUM AREA (m^2) divided by NET AREA[1]	= Total Number Queenfish per Depth Stratum	Total No. Queenfish per longshore km by day and night	Mean No. Queenfish per longshore km (Day, Night Average)	Total Number Queenfish in 44 longshore km
Day										
5-8	1094 (627,1561)	359 (159,811)	508 (268,874)	4.7 (3.6,6.6)	2,388 (963,5767)	$\frac{3.125x10^5}{4.4x10^3}$	$1.70x10^5$ ($6.84x10^4$,$4.10x10^5$)			
>8-11	457 (176,1186)	331 (74,1461)	303 (90,1086)	4.7 (3.6,6.6)	1,424 (323,7170)	$\frac{4.375x10^5}{4.4x10^3}$	$1.42x10^5$ ($3.21x10^4$,$7.13x10^5$)	$3.12x10^5$ ($1.0x10^5$,$1.12x10^6$)		
11-14	0	0	0	0	0					
>14-20	0	0	0	0	0					
Night										
5-8	269 (174,416)	120 (85,169)	141 (95,209)	3.1 (2.7,3.7)	437 (256,774)	$\frac{3.125x10^5}{4.4x10^3}$	$3.10x10^4$ ($1.82x10^4$,$5.5x10^4$)		$2.5x10^5$ ($8.8x10^4$,$8.4x10^5$)	$11 x10^6$ ($3.9x10^6$,$3.7x10^7$)
>8-11	153 (96,241)	59 (35,102)	75 (46,123)	3.1 (2.7,3.7)	233 (125,456)	$\frac{4.375x10^5}{4.4x10^3}$	$2.31x10^4$ ($1.24x10^4$,$4.53x10^4$)			
11-14	132 (60,291)	48 (29,77)	64 (33,126)	4.8 (3.9,6.4)	307 (127,805)	$\frac{10.625x10^5}{4.4x10^3}$	$7.41x10^4$ ($3.07x10^4$,$1.94x10^5$)			
>14-20	24 (11,50)	105 (28,378)	60 (17,204)	4.8 (3.9,6.4)	288 (67,1306)	$\frac{8.75x10^5}{4.4x10^3}$	$5.73x10^4$ ($1.33x10^4$,$2.6x10^5$)	$1.86x10^5$ ($7.46x10^4$,$5.54x10^5$)		

[1] NET AREA = 4,400 ± 75 m^2 (n = 33 sets)

Table 6. Lampara Net Catch-efficiencies (%) Under Different Conditions with Correction Factors for the Conversion of Queenfish CPUE to Estimates of Density. Correction Factors are Given for Mean Percent Recapture and for the Confidence Interval Extremes ($\bar{x}$ ± 90%).

Time and Depth of Net Set	$\bar{x}$ % Recapture ± 90% C.I.	No. of Test Sets	Density Correction Factor $\bar{x}$	-90%	+90%
Day, 8, 12, and 16 meters	21.3 ± 6.2	49	4.7	6.6	3.6
Night, 12 and 16 meters	20.7 ± 5.0	29	4.8	6.4	3.9
Night, 8 meters	32.0 ± 5.2	18	3.1	3.7	2.7

Table 7. Lampara net catch-per-net-haul (CPUE) for queenfish in the NEAR and various longshore reference areas, by day and at night.[1]

		May to Mid-June 1978		Mid-June through August 1978	
Area and Depth Stratum	Day or Night	$\bar{X}$ CPUE[3]	No. net-hauls	$\bar{X}$ CPUE	No. net-hauls
SOUTH, 5-11 m	Day	1006	11	227	6
NEAR, 5-11 m	Day	1688	11	1571	5
MAIN, 5-11 m	Day	2338	14	934	6
MAIN, 11-14 m	Day[2]		9		7
MAIN, 14-20 m	Day[2]		9		7
NORTH, 5-11 m	Day	1347	12	250	6
All Areas, 5-11 m, Day		1420	48	410	23
SOUTH, 5-11 m	Night	236	10	101	5
MAIN, 5-11 m	Night	245	10	76	5
MAIN, 11-14 m	Night	132	10	48	5
MAIN, 14-20 m	Night	24	11	37[4]	4
NORTH, 5-11 m	Night	141	9	118	5
All Areas, 5-11 m, Night		201	29	94	15

[1] No NEAR collections made at night because of buoys and construction hazards.

[2] No queenfish collected in this area.

[3] Kruskal-Wallis 1-way ANOVA indicates no significant differences in CPUE values for each of the 5-11 m longshore areas at day ($X^2_3 = 0.48$, $p > 0.1$) and night ($X^2_2 = 2.34$, $p > 0.1$).

[4] Excludes one net-haul with unusually high numbers of queenfish.

Table 8. Mean Body Lengths[1] of Immature, Male, Female, and Total Queenfish Inplant and in the Four Longshore Areas.[2]

May - August 1978

	Inplant	NEAR	SOUTH	MAIN	NORTH
Immatures	91 ± 0.2	86 ± 0.4	85 ± 0.4	88 ± 0.2	90 ± 0.2
Males	118 ± 0.4	131 ± 0.3	129 ± 0.8	123 ± 0.3	123 ± 0.7
Females	132 ± 0.3	146 ± 0.8	142 ± 1.1	137 ± 0.4	144 ± 0.9
All Fish	103 ± 0.2	126 ± 0.4	111 ± 0.8	109 ± 0.3	108 ± 0.5

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[1] Ninety percent confidence intervals of mean values (in mm) are noted.

[2] All field collections made using standard lampara net-hauls.

Table 9. The Results of Two Different Types of Comparisons[1] of Shallow Water (5-11 m) Fish Associations Sampled by Lampara Net in Four Areas During Day and Night.[2]

May 1978

	CZEKANOWSKI Similarity Index	CANBERRA-METRIC[3] Dissimilarity Index
Day		
South vs. Near	0.63	0.73
South vs. Main	0.64	0.68
South vs. North	0.66	0.66
Near vs. Main	0.62	0.68
Near vs. North	0.65	0.68
Main vs. North	0.64	0.72
Night		
South vs. Main	0.63	0.65
South vs. North	0.63	0.72
Main vs. North	0.69	0.57

[1] Mean index values based on the catches made during 7 boat-trips; northern anchovies (*Engraulis mordax*) are ubiquitous and atherinids also have been excluded because field identifications are impractical. Each pairwise comparison is based on collections made within 8 hr of one another.

[2] No Near Area samples were collected at night due to buoys and construction hazards.

[3] Raw data transformed to log (x+1) form prior to analysis.

Table 10. The Results of Two Different Types of Comparisons[1] of Shallow Water (5-11 m) Fish Associations Sampled by Lampara Net in Four Areas During Day and Night.[2]

June - October 1978

	CZEKANOWSKI Similarity Index	CANBERRA-METRIC[3] Dissimilarity Index
Day		
South vs. Near	0.58	0.67
South vs. Main	0.55	0.81
South vs. North	0.58	0.74
Near vs. Main	0.52	0.74
Near vs. North	0.48	0.77
Main vs. North	0.49	0.81
Night		
South vs. Main	0.63	0.66
South vs. North	0.70	0.59
Main vs. North	0.58	0.72

[1] Mean index values based on the catches made during 7 boat-trips; northern anchovies (*Engraulis mordax*) are ubiquitous and atherinids also have been excluded because field identifications are impractical. Each pairwise comparison is based on collections made within 8 hr of one another.

[2] No nearfield samples were collected at night due to buoys and construction hazards.

[3] Raw data transformed to log (x+1) form prior to analysis.

Table 11. Comparisons of lists of fish species unique[1] to the NEAR area and the other 3 longshore reference areas. Collections made by lampara net at 5-11 m (day only) during May - December 1978.

	NEAR	MAIN	SOUTH	NORTH
Total number different spp.	37	30	30	29

10* species unique[1] to NEAR area	
big skate	Raja binoculata
starry skate	Raja stellulata
Calif. butterfly ray	Gymnura marmorata
speckled sanddab	Citharichthys stigmaeus
spotted turbot	Pleuronichthys ritteri
kelp bass	Paralabrax clathratus
Pacific moonfish	Vomer declivifrons
black croaker	Cheilotrema saturnum
rubberlip surfperch	Rhacochilus toxotes
plainfin midshipman	Porichthys notatus

*7/10 spp unique[1] to NEAR area are epibenthic foragers

13** species not found in NEAR area (but in at least one of 3 other areas)	
thornback	Platyrhinoidis triseriata
Calif. lizardfish	Synodus lucioceps
diamond turbot	Hypsopsetta guttulata
Pacific mackerel	Scomber japonicus
barred surfperch	Amphistichus argenteus
pile surfperch	Damalichthys vacca
black surfperch	Embiotoca jacksoni
dwarf surfperch	Micrometrus minimus
rockfish sp.	Sebastes sp.
spiny dogfish	Squalus acanthias
common thresher	Alopias vulpinus
leopard shark	Triakis semifasciata
horn shark	Heterodontus francisci

**6/13 spp unique[1] to other longshore areas are epibenthic foragers

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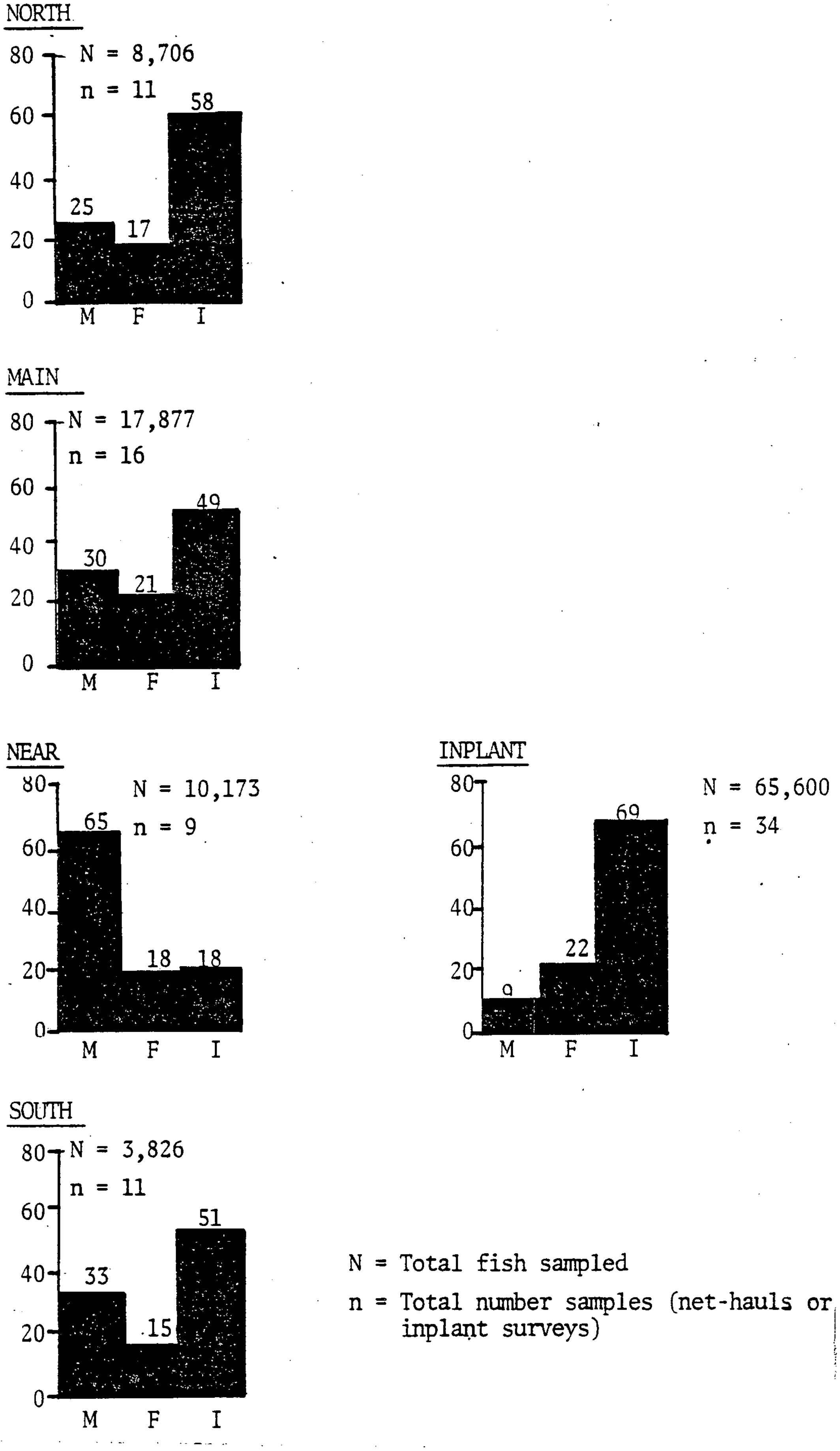
[1] Relative differences between areas which reflect sampling effort and the times of year sampled; does not imply absolute differences in species composition.



N = Total fish sampled

n = Total number samples (net-hauls or inplant surveys)

Figure 1. Percent composition of Male, Female and Immature Seriphus politus in samples from the shallow (5 - 11 m) longshore study areas adjacent to SONGS compared to the mean percentage composition of 24-hour inplant samples over the period of May - August, 1978. Numbers over columns are actual percentages.

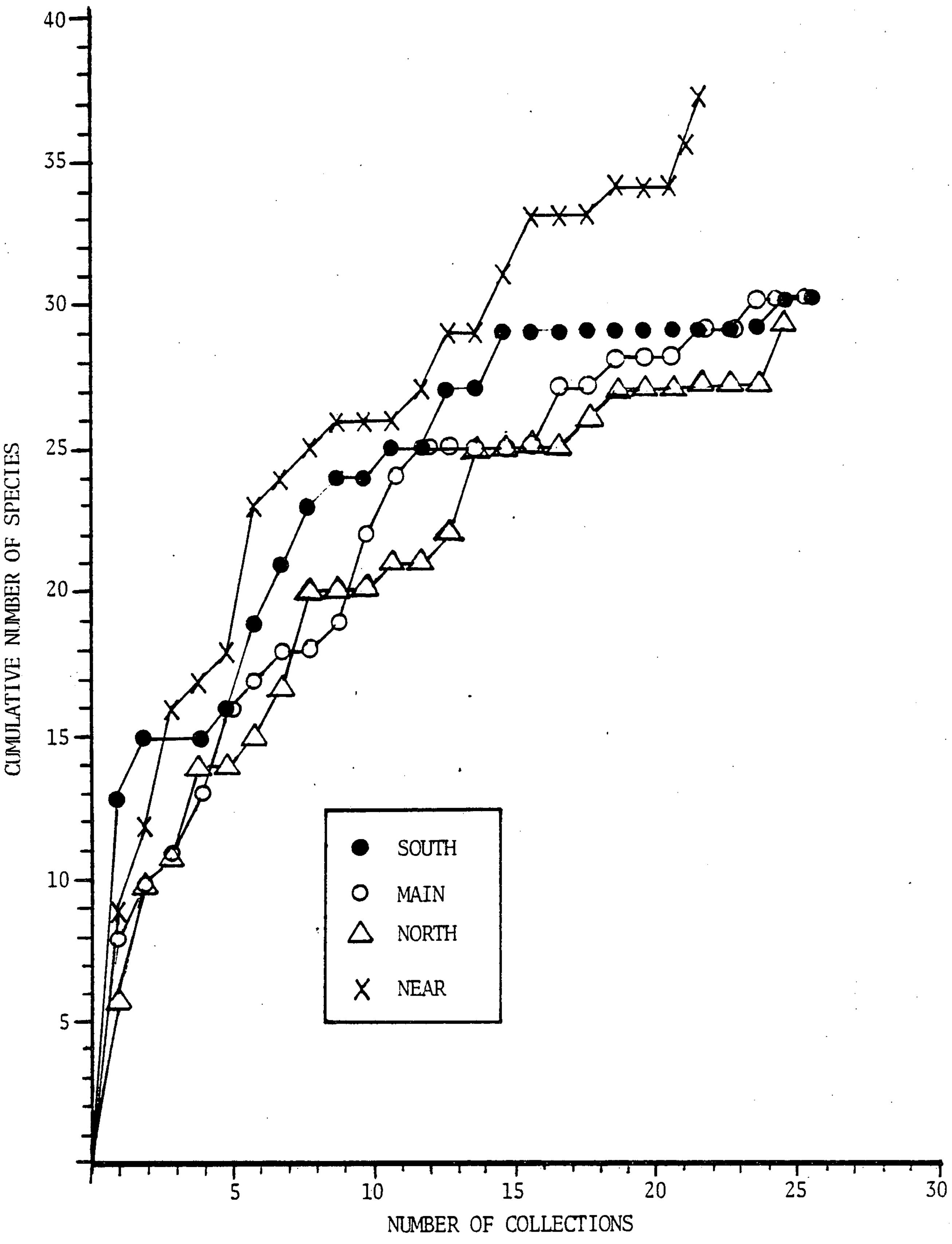


Figure 2. Cumulative number of fish species present in lampara net collections made in the period from May - December, 1978, by day at 5 - 11 m depths in the NEAR area (0.5 km radius of SONGS Unit 1 intake structure) and at three longshore reference areas (SOUTH, 2 - 3 km south of Unit 1; MAIN, 1 - 2 km north of Unit 1; and NORTH, 5 - 6 km north of Unit 1).

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EXPERIMENTAL HARD SUBSTRATES

There are many species that live on subtidal hard substrates. We have concentrated our studies on the sessile invertebrates that make up a large proportion of the species that colonize cobbles, the most common hard substrates near SONGS. To reduce variability between substrates and so increase the probability of detecting the effects of proximity to SONGS, we used identical panels placed at various distances from the Plant.

Findings

(1) The "inshore" community near Unit 1 is quite different from the "offshore" community living at the depths of the diffusers of Units 2 and 3. The inshore species live in an environment that is frequently turbid while the offshore species live in less turbid conditions.

(2) Many inshore species survive and grow well under the higher rates of turbidity and sedimentation generated by the discharge plume of Unit 1. Offshore species that settle inshore do not persist there, probably because they are smothered by sediment. This process happens faster nearer the Plant where turbidity is greater.

Prediction

Units 2 and 3 will sometimes cause increased turbidity in their vicinity offshore. Even if such turbidity plumes occur only sporadically, each one will add sediment that is deleterious to offshore species less tolerant of such effects. This will lead to a loss of species that are tolerant of sedimentation. This could lead to a 30% reduction in the numbers of species in an area near the Plant. We are not yet able to predict the extent of this effect, which will be determined by the dispersal pattern of the plume.

Implications

Since the changes predicted are due to the way the proposed Units 2 and 3 increase the turbidity offshore, they could be prevented by shifting the intakes and diffusers further offshore and by raising them above the substrate.

Supportive Evidence for Findings

(1) Of the 169 species which colonized panels in the San Onofre area, 23 colonized only at inshore stations, 68 colonized only at offshore stations, and 78 colonized in both places. Of these 78, some settled much more often at inshore stations and seldom survived very long at offshore stations, while many others were more common offshore and survived only for a short time at inshore stations. Thus, there are two communities - an inshore community and an offshore one. To illustrate this, we can look at species which either settle or grow fast enough to become the most abundant species on a panel (i.e., cover the greatest area). These we call "dominant" species. The percentage of panels on which a species becomes dominant is a measure of its relative frequency. By looking at the percentages on six-month old panels only, we can see which of the species remain or become dominant after six months. Table 1 shows these percentages at inshore and offshore sites. Some species became dominant only at nearshore sites and others only offshore, but three species were recorded as being dominant at some times in both places. Of these three, Alcyonidium dominated more of the panels after six months in both places. The other two species, Jassa and Obelia, remained abundant in only one of the two areas after six months.

Many offshore species (Tubulipora, Hippothoa and many rarer species) recruit to nearshore panels and never survive for more than a few months. They are often dead after five weeks.

The animals are often covered by a layer of fine sediment with no visible damage to their skeletons. It seems probable they die as a result of increased siltation in the nearshore sites.

(2) Three common onshore species (Tubularia, Jassa, and Eupomatus) recruit to panels offshore, but only in small numbers. Even when free space is abundant (> 50%) they do not grow to cover much of the panels. All are eliminated within a few months.

Our observations therefore indicate that offshore species die inshore, most likely as a result of the turbidity of the water and the consequent silting of nearshore hard surfaces. The nearshore sites examined are from 50 - 1600 m from the SONGS Unit 1 outfall. On sites nearer the outfall, the rate at which sessile animals colonize surfaces is greater. This is not just an increase in the numbers of one or a few species: the numbers of species which colonize is greater, too.

To show this, we measured the number of animals and the number of species on panels exposed for five weeks in five different months. These mean numbers of animals or species at each station along a transect from the outfall was ranked relative to other stations and the rankings obtained in different months were compared. Statistical analysis showed that there was significant agreement between these rankings, and there was a significant trend of greater numbers of individuals and species toward the Plant for both transects. The average rankings along each transect are shown in Table 2. These averages suggest that the maximum recruitment of animals occurs at 100 m from the Plant.
After six months, Tubularia becomes a dominant species at all nearshore stations. Figure 1 suggests that this dominance develops sooner near the discharge. With time,

Tubularia also replaces Obelia as a dominant species at even the most distant stations.

We do not know that "offshore" species would survive over a longer period at inshore sites if the Plant was absent, since we do not know whether the Plant has an effect at 1600 m distance. Information as to how far away the Plant increases turbidity at this distance is needed. However, we know that the Plant increases the biological difference between onshore and offshore.

Supportive Evidence for Prediction

We base our prediction on the idea that Units 2 and 3 will have effects which are comparable to Unit 1. For example, Unit 1 leads to increased recruitment near the outfall and we therefore predict that Units 2 and 3 will tend to increase recruitment around the outfall. We predict that the effect of Units 2 and 3 in the vicinity of the discharge will be increased turbidity and sedimentation, increased recruitment, increased abundance of inshore species resistant to turbidity, and the progressive elimination from surfaces of offshore species sensitive to turbidity. As a worst case, this could result in the elimination of most or all of the 68 exclusively offshore species from the rocky bottoms near the outfall, and their replacement by the 23 exclusively inshore species so that there might be a 30% reduction in the number (from 78 [spp common to both areas] + 68 to 78 + 23) of species in the area. It is presently impossible for us to predict the distance at which such an effect might occur.

Table 1. Percentage of observations where panels were dominated by each species. A species was considered "dominant" if it was the most abundant species on a panel. Observations of 30 nearshore and offshore panels were made at five different times, the last observations being after six months immersion.

	NEARSHORE PANELS		OFFSHORE PANELS	
SPECIES	AVERAGE OVER ALL TIMES	AFTER SIX MONTHS	AVERAGE OVER ALL TIMES	AFTER SIX MONTHS
Tubularia crocea	45	70	--	--
Jassa falcata	25	3	5	--
Eupomatus gracilis	3	7	--	--
Alcyonidium parasiticum	6	20	9	26
Obelia dichotoma	21	--	47	11
Folliculinidae	--	--	5	--
Tubulipora tuba	--	--	18	30
Hippothoa hyalina	--	--	1	--
Thalamoporella californica	--	--	1	3
Clytia edwardsi	--	--	4	--
Eudendrium tenellum	--	--	1	3
Leucosolenia eleanor	--	--	3	14
Parasmittina sp.	--	--	1	3
Balanus trigonus	--	--	5	6

Table 2. Effect of SONGS outfall: average rankings of sites on three variables and the concordance of the rankings on which the averages are based.

DISTANCE FROM OUTFALL	TOTAL NUMBER OF COLONIZING ANIMALS	TOTAL NUMBER OF SPECIES COLONIZING	% COVER OF *OBELIA*
North Transect (6 sites)			
50	2	1	6
100	1	2	5
200	3	3	4
400	4	5	3
800	5	4	2
1600	6	6	1
CONCORDANCE BETWEEN RANKINGS (KENDALL'S COEFFICIENTS)	0.51*	0.52*	0.51*
South Transect (4 sites)			
50	2	1.5	3
100	1	1.5	4
800	3	3	2
1600	4	4	1
CONCORDANCE BETWEEN RANKINGS	0.94*	0.66*	0.79

* = $p < 0.05$

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BIOASSAY OF PLUME EFFECTS

As the heated effluent of Units 2 and 3 spreads downcoast, it may affect organisms that live in the surface canopy of the San Onofre Kelp bed. To discover the effect of such a discharge plume, we used bags of sea mussels as a "bioassay," hanging them just below the water surface at varying distances from the Unit 1 discharge. The growth of the mussels was measured after one, two and four months, both when the Plant was operating normally and when it was not operating. In addition, we measured the settlement of hard benthos animals onto artificial surfaces and into the clumps of mussels at these same sites.

Findings

The discharge plume of Unit 1 has the following direct effects on organisms, some of which occur whether the plume is heated or not:

(1) When the Plant was operating, growth of mussels within a distance of about 400 m from the discharge was less after two and four months than it was at distant sites. During periods when the Plant was not operating, the pumps circulated water 60% - 80% of the time. Then the growth of mussels was depressed to lesser distances (100 - 200 m) from the Plant.

(2) Settlement of young stages of barnacles was greater within 25 m of the discharge than further away. Settlement of mussels, scallops and clams was greater out to about 200 m away. In contrast, two species of shrimps settled more at stations located 800 - 3200 m from the discharge than elsewhere.

Predictions

(1) During periods when the discharge plume of Units 2 and 3 is carried over the San Onofre Kelp bed, growth and

settlement of some organisms living in the surface canopy will probably be reduced.

(2) A settlement on the kelp fronds of young stages of some species will probably be increased.

Implications

These studies indicate that the discharge plume of Units 2 and 3 could have direct effects on organisms living in the surface canopy of kelp. The extent of such effects depends on the season of the year, upon how often and for how long kelp fronds will be bathed by the plume, and upon the concentrations of larvae, turbidity, chlorine, etc., in the plume at those times.

Supportive Evidence for Findings

(1) Lower growth of mussels which were suspended near the discharge is apparent in Figures 1 - 4. The distances to which growth was significantly lower than that observed 1600 m from the discharge are shown in Table 1.

(2) The abundance of barnacles on spar bouys located 25 m from the discharge was always greater than that on buoys at more distant sites. To document this pattern, barnacles which settled on the shells of mussels during a growth experiment (May 18 - September 22, 1977) were counted. There were from 0 - 5 barnacles at all locations except at the discharge. There were 1,755 barnacles at 25 m from the discharge site.

The settlement of mussels, kelp scallops, and clams generally was greater within 50 - 200 m of the discharge than at more distant sites (Figures 5 - 9). However, in some cases, there was very little settlement in the immediate vicinity of the discharge (e.g., Figure 7).

Shrimp generally settled in greater numbers from about 800 m - 3200 m than elsewhere (Figures 10 - 13).

Supportive Evidence for Predictions

(1) See Supportive Evidence for Findings (1).
(2) See Supportive Evidence for Findings (2).

Table 1. Differences in growth of mussels (in cm) between each of the longshore stations compared to that at stations 1600 m from the Unit 1 discharge in the same longshore direction. P - values (i.e., the probabilities that such difference could occur by chance alone) are listed next to each growth difference.

EXPERIMENT	TWO MONTHS PLANT OFF 12/27/76 - 2/25/77		FOUR MONTHS PLANT OFF 12/27/76 - 4/22/77		TWO MONTHS PLANT ON 5/18/77 - 7/25/77		FOUR MONTHS PLANT ON 5/18/77 - 9/21/77	
DIRECTION DISTANCE	North	South	North	South	North	South	North	South
25	.07-p>.90	.39-p<.001	.12-p>.40	.57-p<.01	.29-p<.001	.22-p<.001	.34-p<.02	.27-p<.10
50	.07-p>.90	.24-p<.001	.23-p>.20	.52-p<.01	.12-p<.05	.17-p<.01	.31-p<.05	.38-p<.01
100	.03-p>.90	.13-p<.02	.21-p>.70	.58-p<.01	.09-p<.10	.25-p<.001	--	.04-p>.90
200	.04-p>.90	0.0-p >.90	.03-p>.90	.54-p<.01	.12-p<.10	.06-p<.40	.35-p<.05	.30-p<.05
400	.04-p>.90	0.07-p>.90	.11-p>.50	.26-p<.20	.02-p>.90	.14-p<.05	.32-p<.05	.05-p>.90
800	--	--	--	.23-p<.20	--	.10-p<.10	--	.08-p>.90

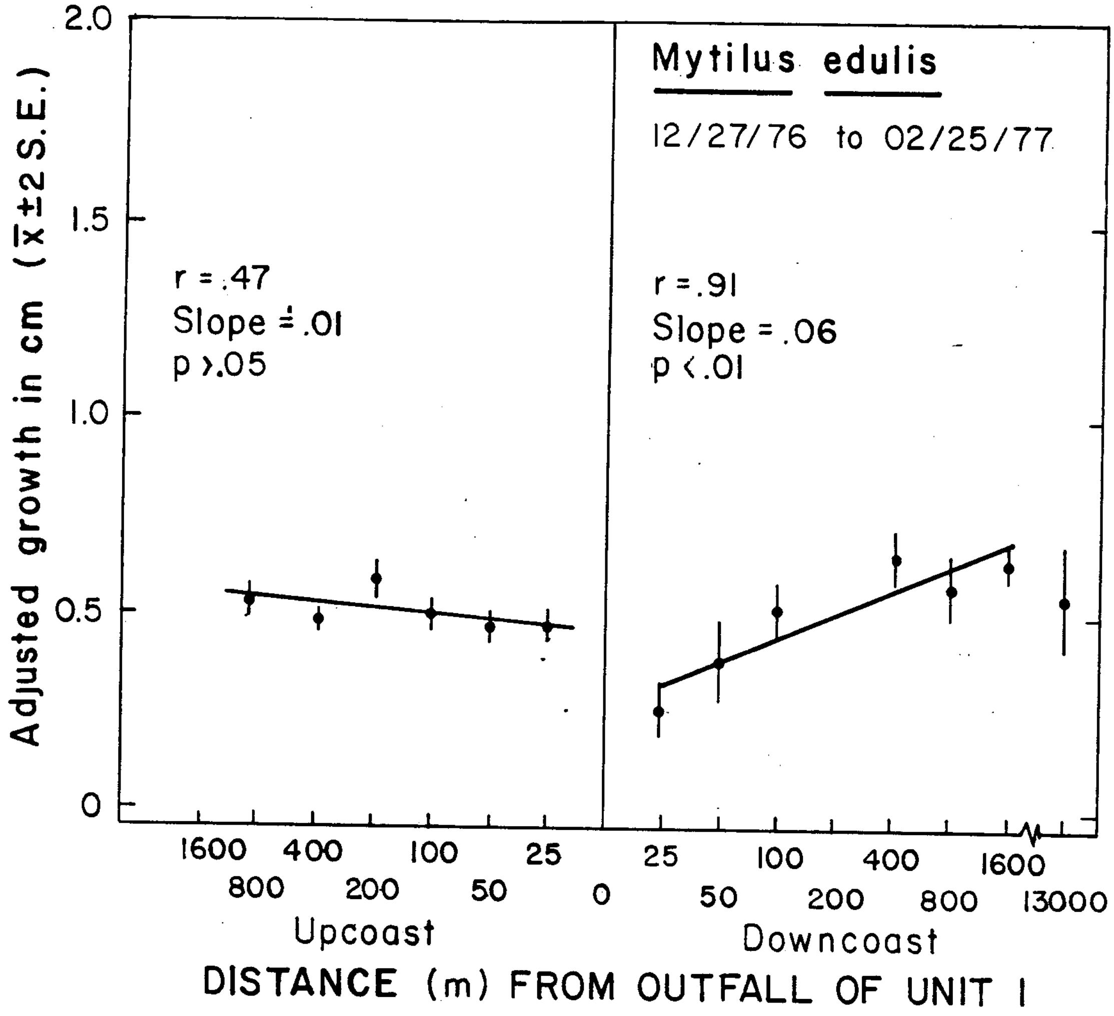

Figure 1. Effect of the discharge of SONGS Unit 1 on the growth of mussels suspended 1 m below the surface from December 27, 1976 - February 25, 1977. During this period the Plant was not operating but the pumps were circulating water 60 - 80% of the time. Each point represents the average growth of approximately 30 mussels in a single clump, except for the point plotted at 13,000 m downcoast, which represents growth averaged over nine clumps. Bars represent two standard errors.

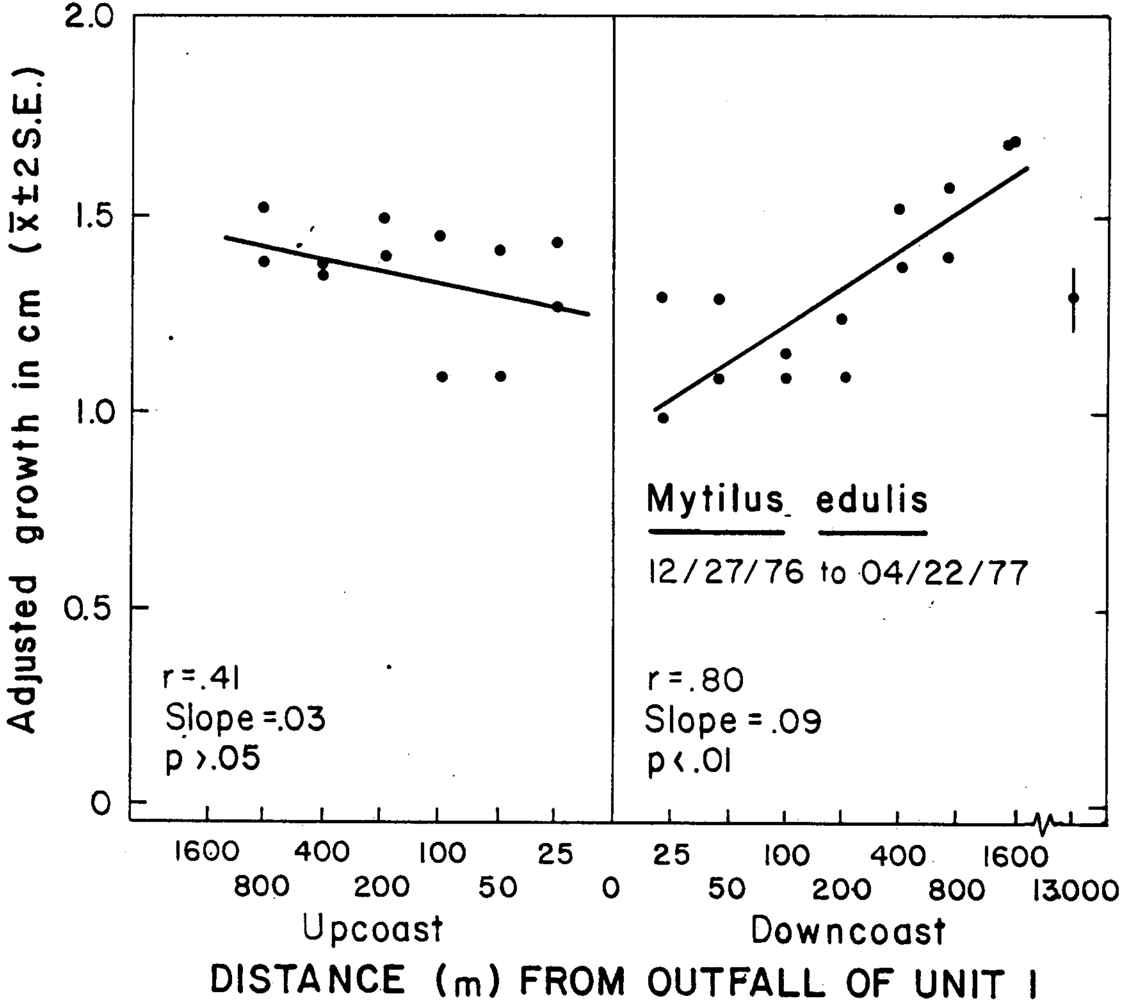

Figure 2. Effect of the discharge of SONGS Unit 1 on the growth of mussels suspended 1 m below the surface from December 27, 1976 - April 22, 1977. During this period the Plant was not operating but the pumps were circulating water 60 - 80% of the time. Each point represents the average growth of approximately 30 mussels in a single clump, except for the point plotted at 13,000 m downcoast, which represents growth averaged over 15 clumps. Bars represent two standard errors.

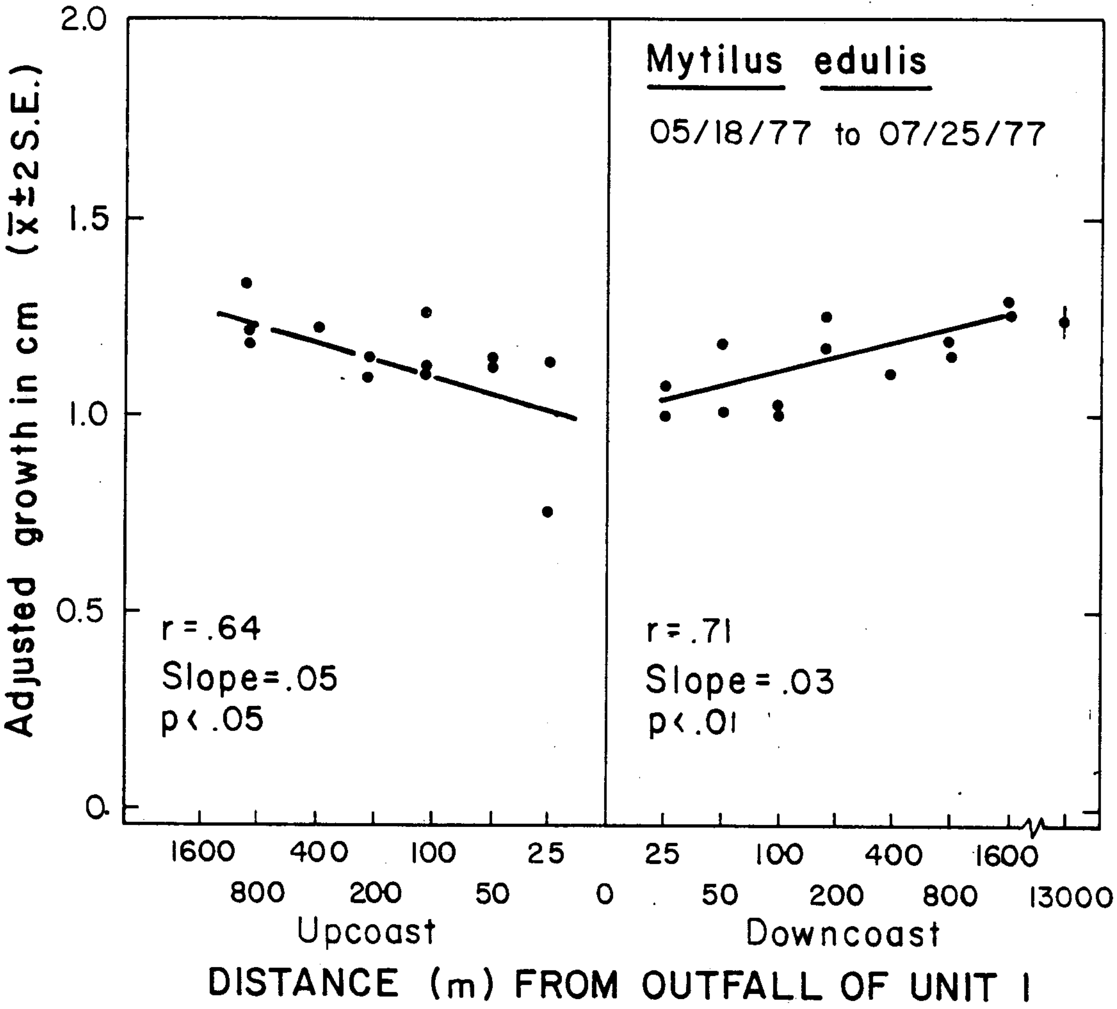

Figure 3. Effect of the discharge of SONGS Unit 1 on the growth of mussels suspended 1 m below the surface from May 18 - July 25, 1977. The Plant was operating throughout this period. Each point represents the average growth of approximately 30 mussels in a single clump, except for the point plotted to 13,000 m downcoast, which represents growth averaged over 21 clumps. Bars represent two standard errors.

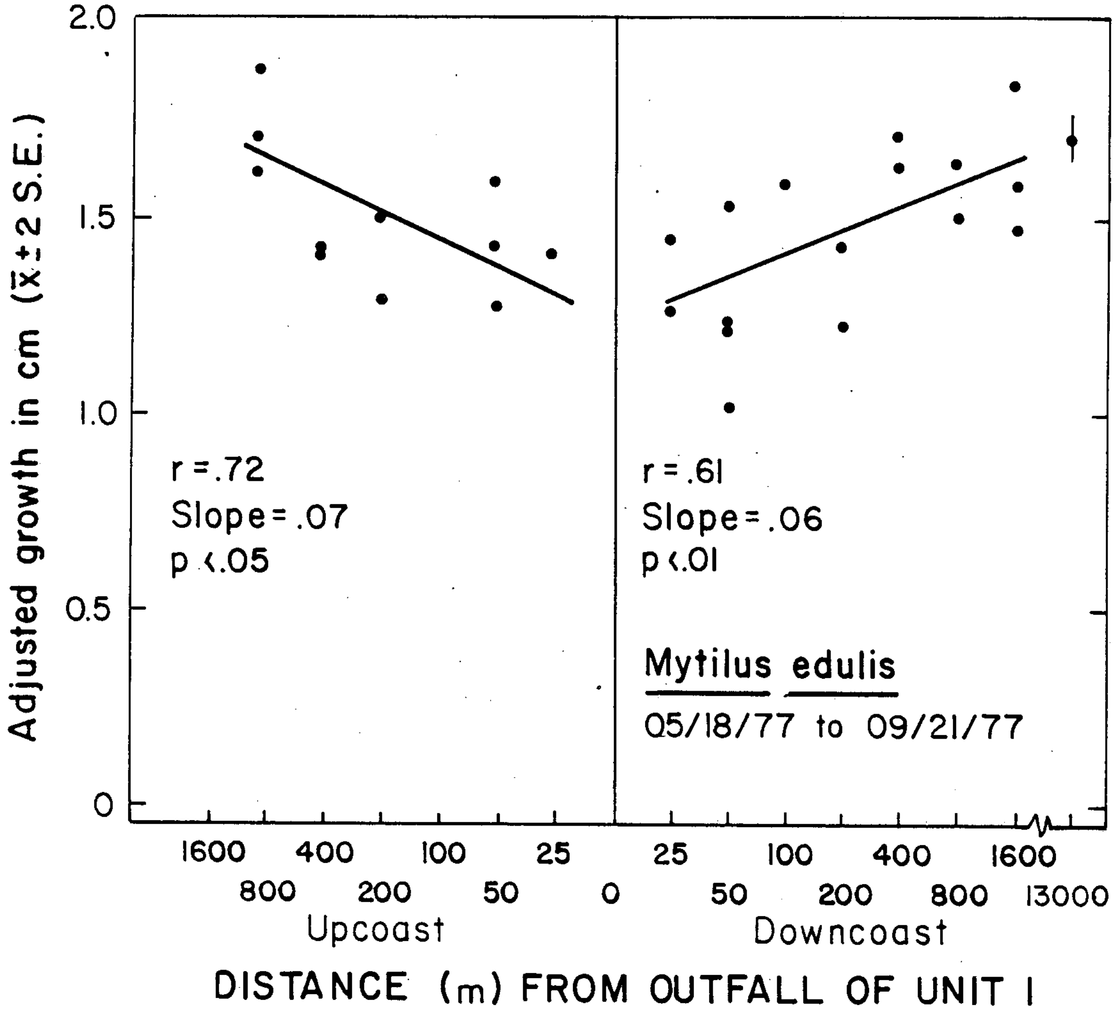

Figure 4. Effect of the discharge of SONGS Unit 1 on the growth of mussels suspended 1 m below the surface from May 18 - September 21, 1977. The Plant was operating throughout this period. Each point represents the average growth of approximately 30 mussels in a single clump, except for the point plotted at 13,000 m downcoast which represents growth averaged over 19 clumps. Bars represent two standard errors.

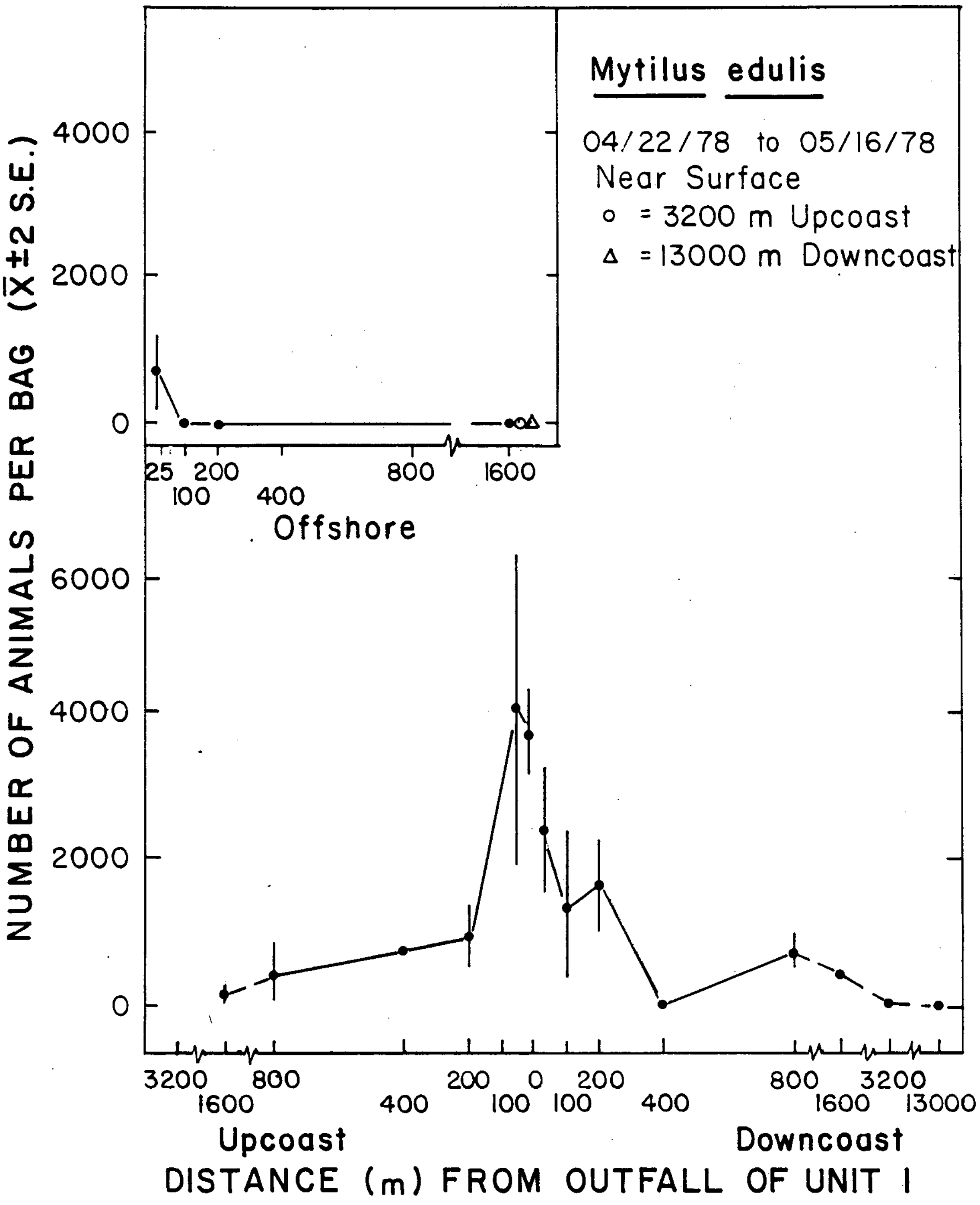

Figure 5. Effect of the discharge of SONGS Unit 1 on the settlement and/or survival of the mussel, *Mytilus edulis* (Spring, 1978 - one month Plant On). On April 22, 1978 nylon bags containing plastic ropes were suspended 1 m below the surface at each station in the experimental grid. On May 16, 1978 the bags were collected and the mussels which were attached within the bags were counted. Key: ○ = 3200 m upcoast; △ = 13,000 m downcoast.

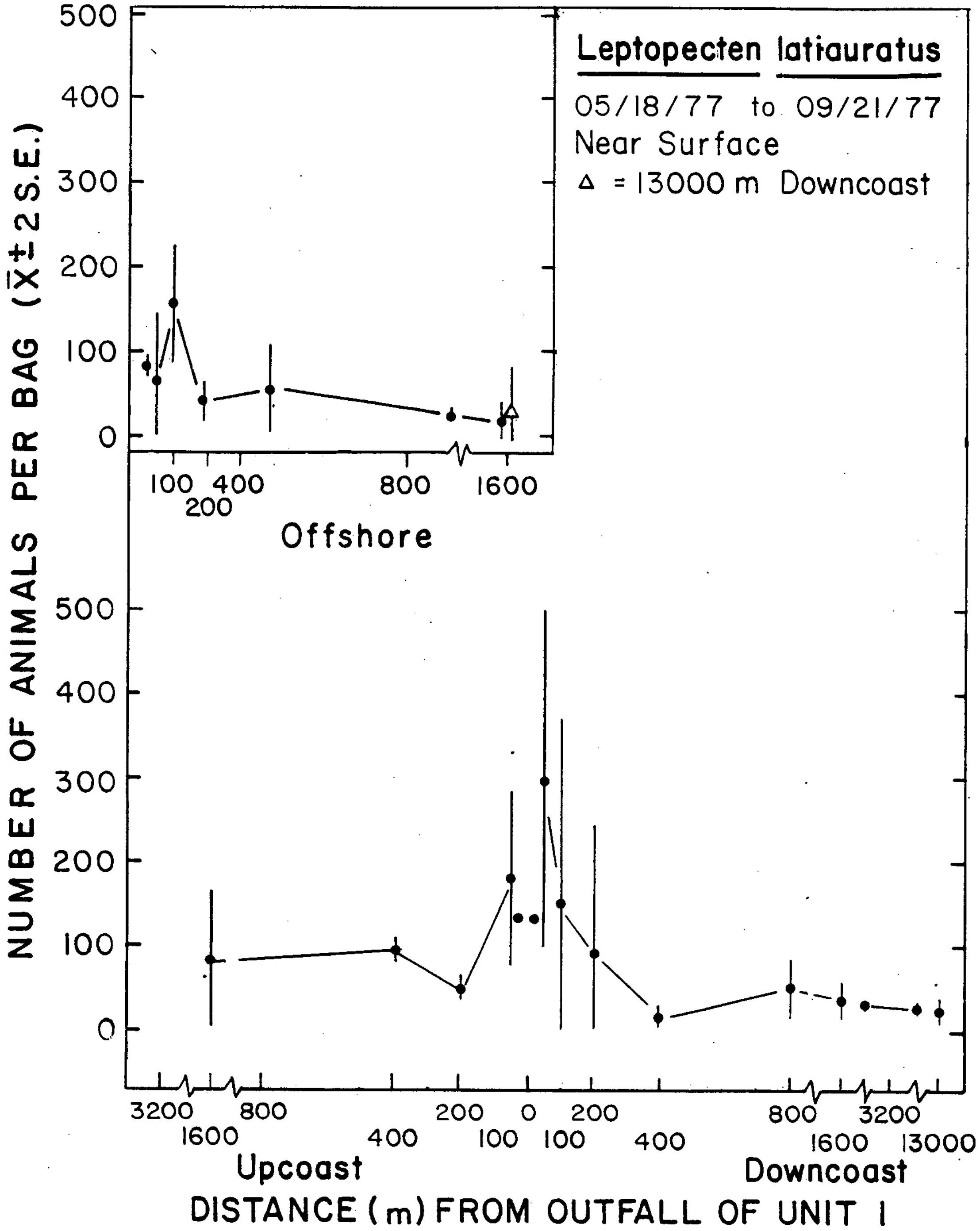

Figure 6. Effect of the discharge of SONGS Unit 1 on the settlement and/or survival of the kelp scallop, Leptopecten latiauratus (Summer, 1977 - four months Plant On). On May 18, 1977 nylon bags containing mussels were suspended 1 m below the surface at each station in the experimental grid. On September 21, 1977 the bags were collected and the scallops attached to the bags were counted. Key: Δ = 13,000 m downcoast.

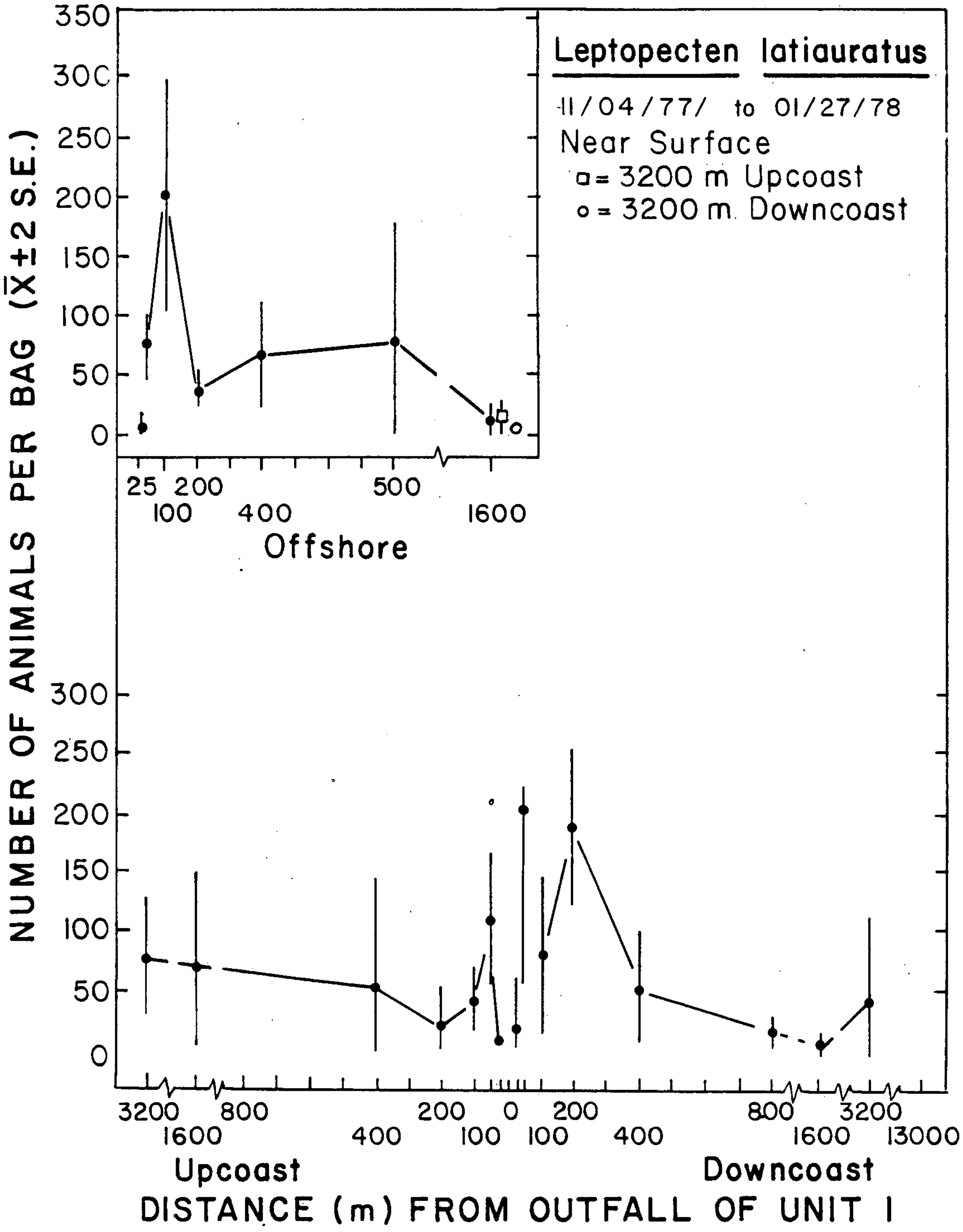

Figure 7. Effect of the discharge of SONGS Unit 1 on the settlement and/or survival of the kelp scallop, Leptopecten latiauratus (Winter, 1977 - 1978 - three months Plant On). On November 4, 1977 nylon bags containing mussels were suspended 1 m below the surface at each station in the experimental grid. On January 27, 1978 the bags were collected and the scallops attached to the bags were counted. Key: □ = 3200 m upcoast; ○ = 3200 m downcoast.

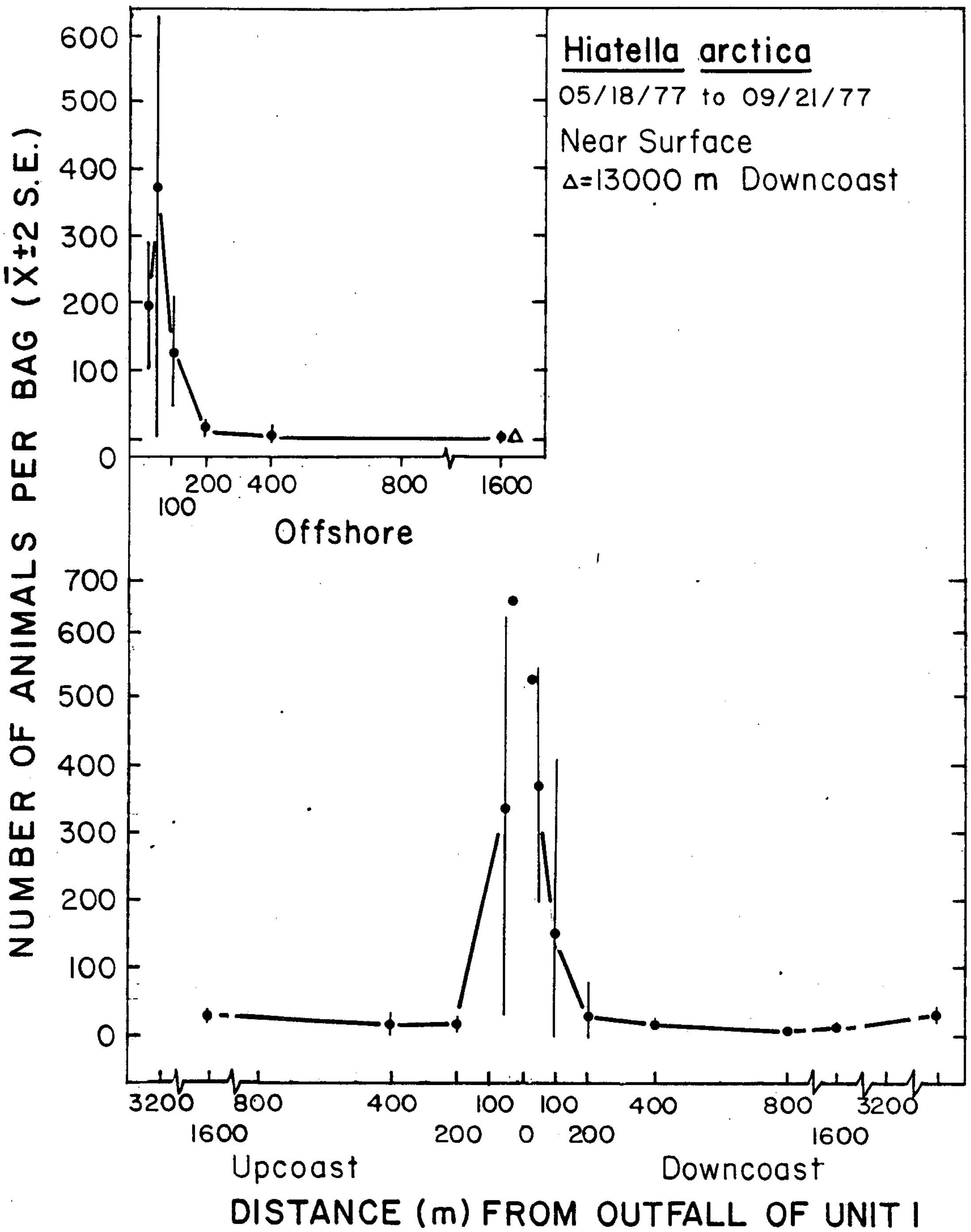

Figure 8. Effect of the discharge of SONGS Unit 1 on the settlement and/or survival of the clam, Hiatella arctica (Summer, 1977, four months, Plant On). On May 18, 1977 nylon bags containing mussels were suspended 1 m below the surface at each station in the experimental grid. On September 21, 1977 the bags were collected and the clams attached to the bags were counted. Key: △ = 13,000 m downcoast.

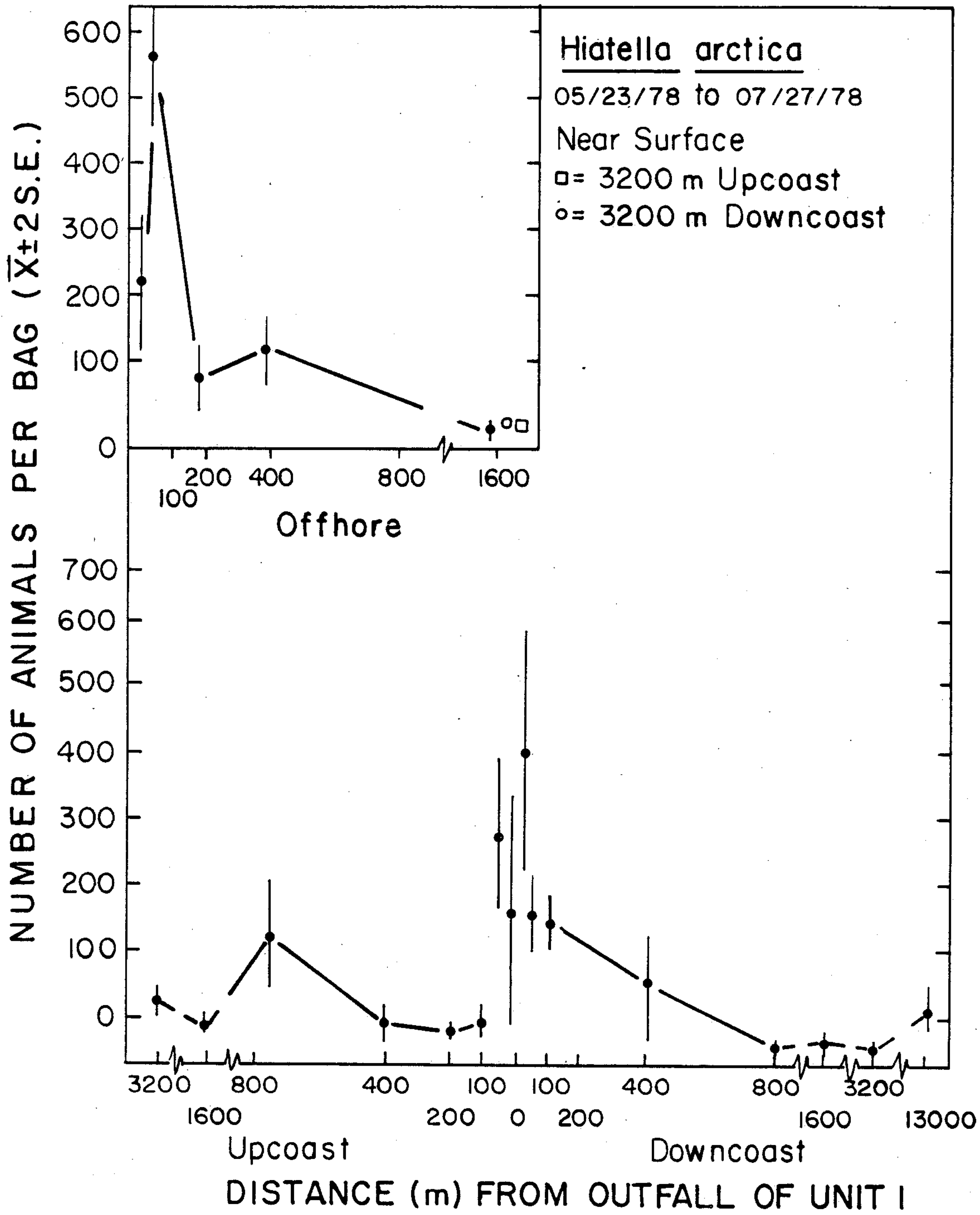

Figure 9. Effect of the discharge of SONGS Unit 1 on the settlement and/or survival of the clam, Hiatella arctica (Summer, 1978 - two months Plant On). On May 23, 1978 nylon bags containing plastic ropes were suspended 1 m below the surface at each station in the experimental grid. On July 27, 1978 the bags were collected and the clams attached to the bags were counted. Key: □ = 3200 m upcoast; ○ = 3200 m downcoast.

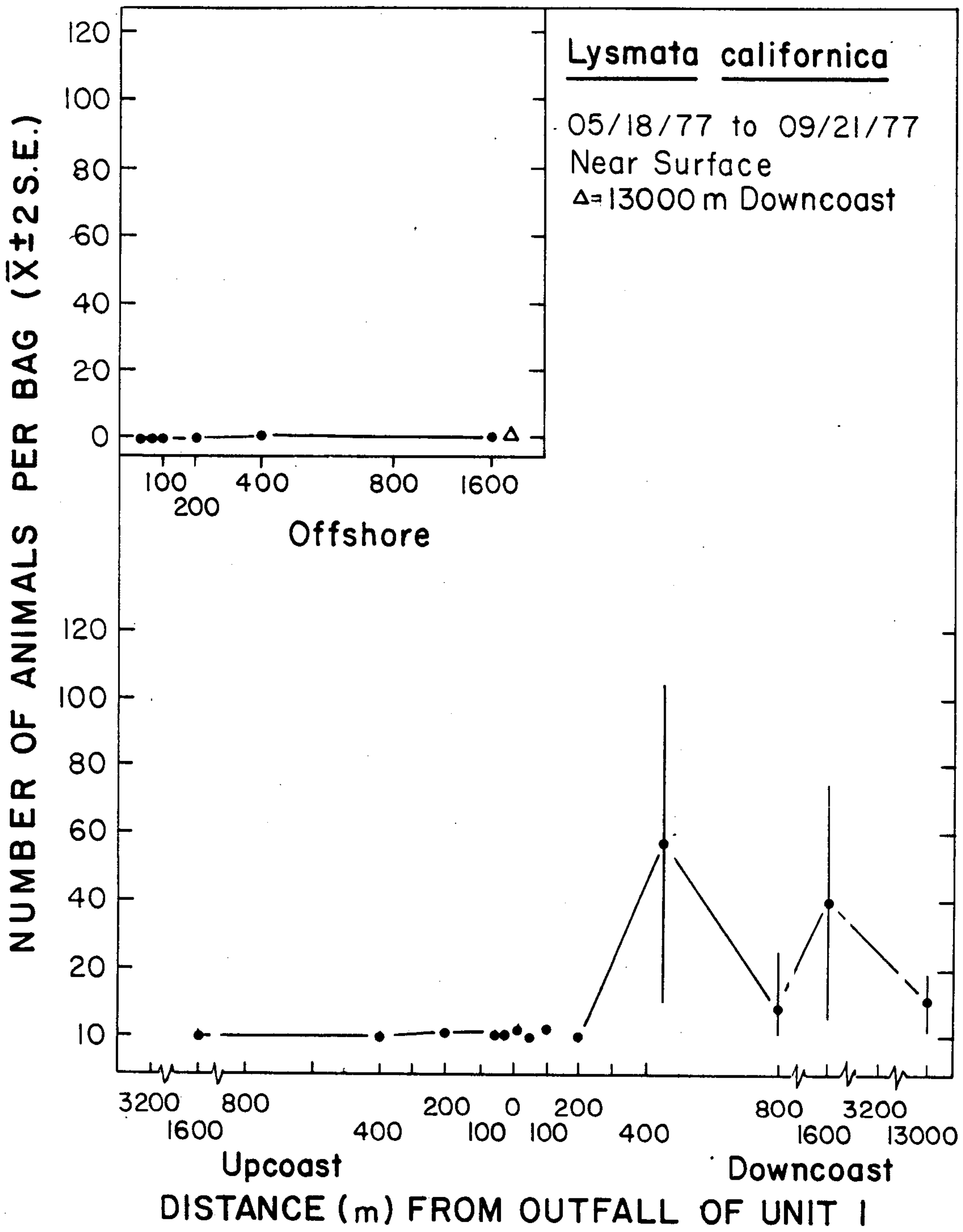

Figure 10. Effect of the discharge of SONGS Unit 1 on the settlement and/or survival of the shrimp, Lysmata californica (Summer, 1977 - four months Plant On). On May 18, 1977 nylon bags containing mussels were suspended 1 m below the surface at each station in the experimental grid. On September 21, 1977 the bags were collected and the associated shrimp were counted. Key: Δ = 13,000 m downcoast.

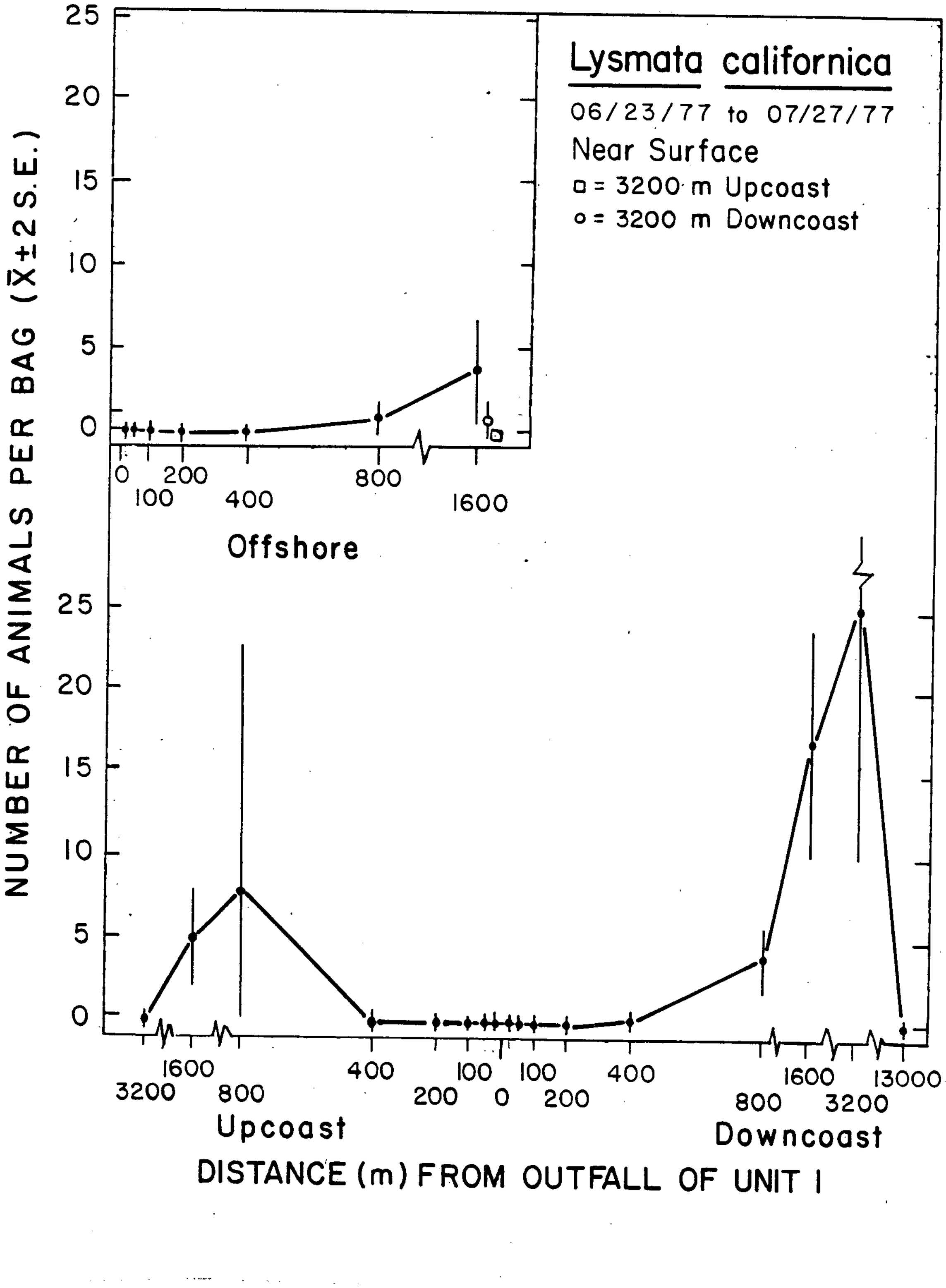

Figure 11. Effect of the outfall of SONGS Unit 1 on the settlement and/or mortality of the shrimp, Lysmata californica (Summer, 1978 - one month Plant On). On June 23, 1978 nylon bags containing plastic ropes were suspended 1 m below the surface at each station in the experimental grid. On July 27, 1978 the bags were retrieved and the shrimp counted. Key: □ = 3200 m upcoast and 1600 m offshore; ○ = 3200 m downcoast and 1600 m offshore.

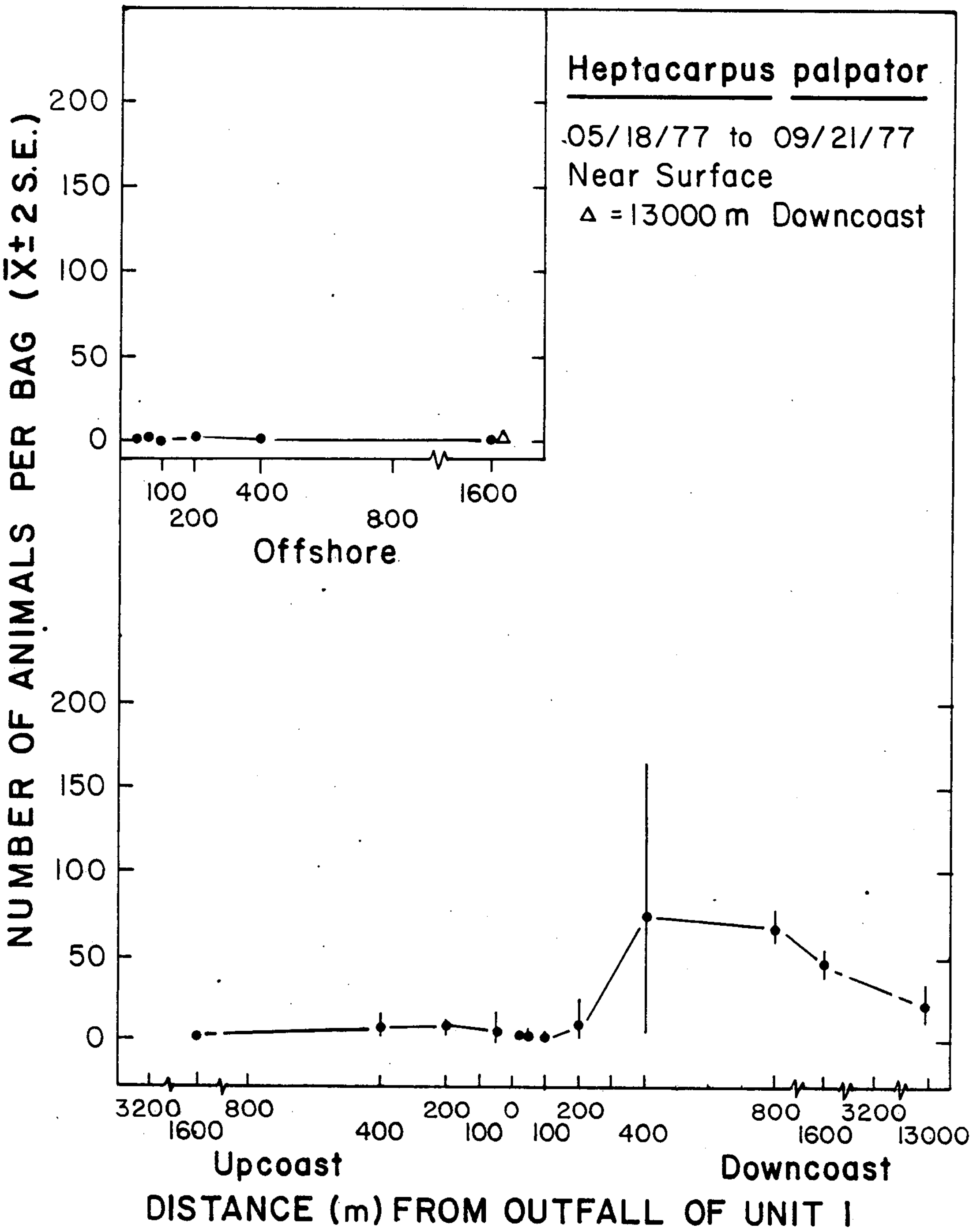

Figure 12. Effect of the discharge of SONGS Unit 1 on the settlement and/or survival of the shrimp, Heptacarpus palpator (Summer, 1977 - four months Plant On). On May 18, 1977 nylon bags containing mussels were suspended 1 m below the surface at each station in the experimental grid. On September 21, 1977 the bags were collected and the associated shrimp counted. Key △ = 13,000 m downcoast.

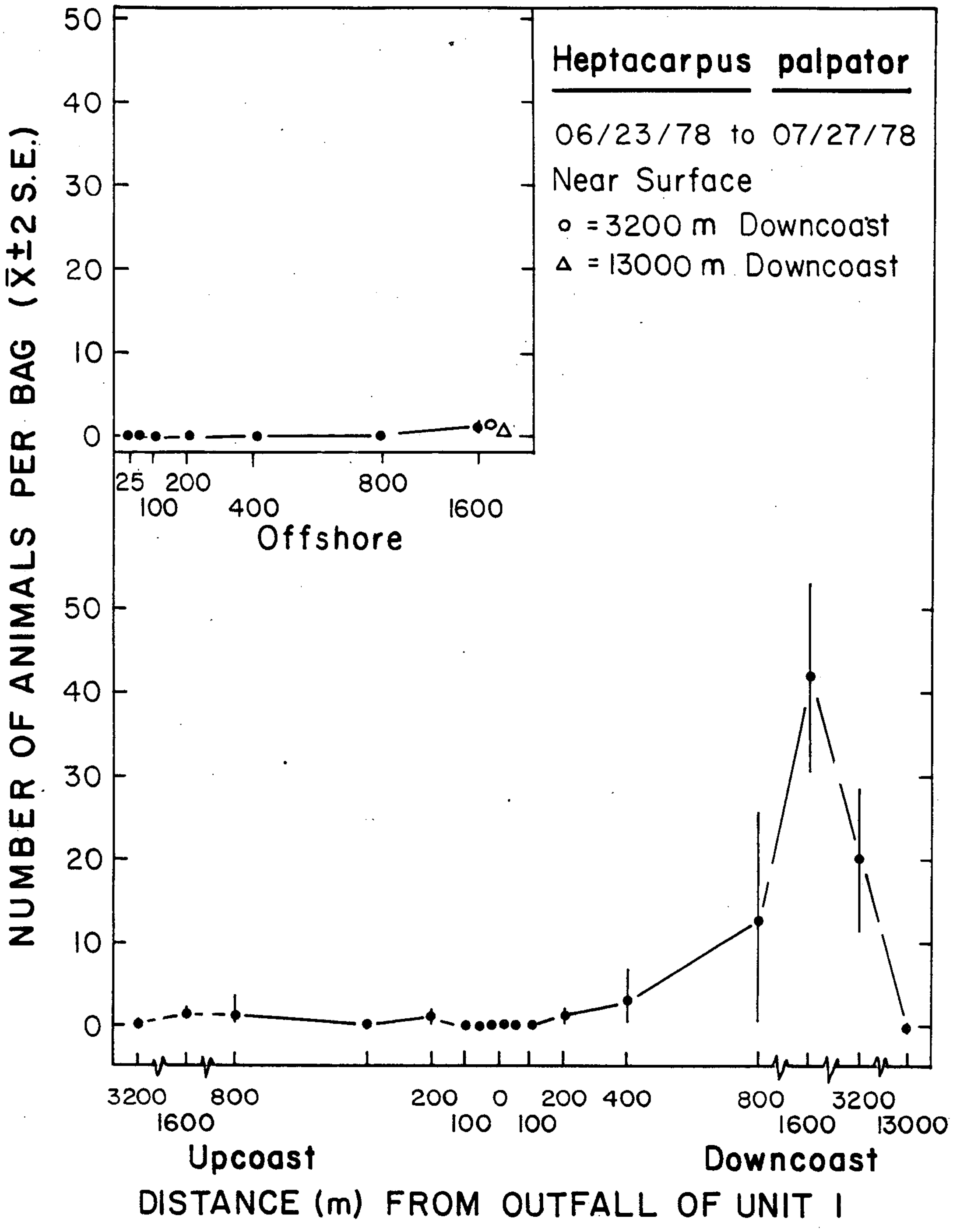

Figure 13. Effect of the discharge of SONGS Unit 1 on the settlement and/or survival of the shrimp, Heptacarpus palpator (Summer, 1978 - one month Plant On). On June 23, 1978 nylon bags containing plastic ropes were suspended 1 m below the surface at each station in the experimental grid. On July 27, 1978 the bags were collected and the associated shrimp counted. Key: ○ = 3200 m upcoast; △ = 13000 m downcoast.

KELP

Findings

(1) Survival and growth of young marine plants is dependent upon adequate quantity and quality of light. When the discharge plume of Unit 1 is turbid, it usually prevents young kelp plants placed 50 m away from surviving and growing. Only in the autumn when the plume is least turbid did young kelp plants survive near Unit 1 and even then they grew slower than elsewhere at the same depth.

(2) Other species of algae settled less and are less abundant on the bottom within 50 m of the Unit 1 discharge.

(3) Kelp beds have fluctuated in size since records began. A major decline occurred in 1957 - 58; it was associated with, but may not have been directly caused by, high water temperatures. Another possible cause of this kelp decline or death may have been low nutrients. Excess grazing and settlement of animals whose weight could sink the plants also can cause declines in abundance of kelp.

(4) The discharge plume of Unit 1 may have prevented one small bed nearby from recovering after the 1957 - 58 decline. However, appropriate observations were not made following the die-off and subsequent construction of Unit 1 so that it is likely that we will never be able to establish why the bed did not recover.

(5) The San Onofre Kelp bed did not reappear after the 1957 - 58 decline until 1972. Between 1974 and 1978, it has fluctuated in size between 90,000 and 500,000 m^2 of canopy. In December, 1978, it was nearly as large as any time since the early 1950's. The upcoast-offshore segment of the bed has been the most persistent portion.

(6) The branches (fronds) of kelp break off and become and important source of food (detritus) for many animals. In December, 1978, San Onofre Kelp bed produced an estimated 9,000 kg (wet weight) of detritus per day, equivalent to about 18 g wet weight/m^2/day.

(7) Kelp beds represent not only a source of food but also a place to live for many other species. Over 760 species of animals (invertebrates and fish) and over 120 species of plants have been found in kelp beds in Southern California. At least two fish, the kelp perch and the kelp clingfish, are almost never found outside of kelp plants. In the San Onofre Kelp bed alone, we have recorded 164 species of animals and 16 species of plants. This is certainly an underestimate. In all three beds (San Onofre Kelp, San Mateo Kelp, and Barn Kelp) in the vicinity, we have recorded 384 species of animals and 36 species of plants.

(8) Surveys of kelp areas in the Southern California Bight (south of Point Conception) show that most of the kelp is either north of Ventura or in the extreme south near San Diego. Thus, San Onofre is in a region where there is little kelp. Of the total kelp area in the southern half of the Bight (south of Palos Verdes), the San Onofre Kelp bed comprises about 3%. Along the 27 miles (44 km) of coast centered at SONGS, the San Onofre Kelp bed comprises about 30% of the kelp area.

Predictions

(1) At certain times, particularly from winter through early summer, the discharge plume of Units 2 and 3 may add turbidity to the water column to an extent that could prevent recruitment of young kelp plants in part or all of the San Onofre Kelp bed. Whether such occurrences will completely

suppress recruitment in all or part of the San Onofre Kelp bed cannot yet be estimated. The portion most likely to be deleteriously affected is the upcoast-offshore quarter of the San Onofre Kelp bed, which represents the major portion that survived the die-off of 1976.

(2) If the operation of Units 2 and 3 reduce the size of the San Onofre Kelp bed, it will thereby reduce the number of available habitats for many animal species. Some populations may be reduced to such a low level that they cannot persist.

(3) Similarly, reduction of the San Onofre Kelp bed will reduce the production of organic matter at San Onofre. Thus, energy available to higher trophic levels (e.g., benthic invertebrates and fish) will be reduced.

(4) Artificial upwelling of nutrients to surface waters caused by the diffusers of Units 2 and 3 may enhance growth of adult kelp. However, added surface nutrients may also cause phytoplankton growth. This may further reduce light available to microscopic and juvenile kelp on the bottom, thereby further reducing probability of successful recruitment. Neither effect is expected to be of major significance.

Implications

The major effect of the present design of Units 2 and 3 will be to increase the turbidity in the vicinity of the San Onofre Kelp bed. Whether this deleterious effect would partly be offset by the beneficial effect of nutrients from local upwelling is unknown at present. If the intakes and diffusers were shifted further offshore, this would mitigate the harmful effects. However, we cannot yet predict the degree of damage that Units 2 and 3 will cause.

Supportive Evidence for Findings

(1) Production of *Macrosystis* sporophytes (the conspicuous life stage) from microscopic gametophytes outplanted to a station 50 m north of the Unit 1 discharge (50 N) occurred only during the Fall of 1977 and 1978. (1977 data in Deysher and Medler, 1978.) During these periods sporophytes were also produced from outplanted gametophytes at all the inshore (6 m depth) controls. During the spring and summer outplants, however, no sporophytes were produced from gametophytes at 50 N, but were produced at both inshore controls (4.5 km upcoast and 11 km downcoast of the Unit 1 discharge) and at the deeper San Onofre Kelp station. The turbidity plume from Unit 1, therefore, is apparently more pronounced during the spring and summer months when natural recruitment of *Macrocystis* is usually highest.

A plot of sporophyte length at 42 days after outplant is correlated ($r=0.72$) with the concurrent light intensity during the outplant period (Figure 1).

Juvenile kelp plants (initially 0.5 m in length) from the San Onofre Kelp bed were transplanted to sites 50 m north of the Unit 1 discharge, 4.5 km upcoast of the Unit 1 discharge (inshore of San Mateo Kelp at a depth equal to the Unit 1 discharge site), and in the downcoast portion of the San Onofre Kelp bed. Over the period of observations (November and December, 1978), plants at the discharge site grew significantly less ($p<<0.01$) than those at control sites. San Onofre Kelp and upcoast control plants grew 8.4 and 7.1% per day respectively, while discharge plants grew only 2.9% per day.

(2) Outplant substrates at 50 N were almost barren of attached algae other than *Macrosystis* while substrates placed concurrently at the inshore controls (4.5 km upcoast and 11 km

downcoast) had a greater coverage of algal sporelings. For example, after 117 days, artificial substrates on the bottom at the upcoast control site approached 50% red algal sporeling coverage while corresponding substrates at 50 N had 1 - 2% coverage. This phenomenon occurred in each of five outplant experiments conducted from December, 1977 - September, 1978.

(3) Data is contained in two historical overviews of kelp distribution in the San Onofre region: Deysher (1978), and Marine Biological Consultants (1978).

Jackson (1977) discusses the co-occurrence of elevated temperatures and low nutrients in the water column above the thermocline in nearshore Southern California waters during the summer months. It is apparent that one or both of these factors is important in causing the frequently observed summer decline in Macrosystis populations; however, it is not clear how these factors interact.

The effects of kelp grazing by both fish and invertebrates have been well documented (e.g., North, 1971). Mortality of kelp due to heavy settlement of the scallop Leptopecten has been observed by Ron Mc Peak of Kelco Company (unpublished data). He noted that 10% of the kelp in a 49-acre portion of the bed off Point Loma was killed by Leptopecten settlement and subsequent frond sinking.

(4) Aerial photos from the early 1950's show that much of the area along an approximately 6 - 7 m depth contour between San Mateo Point and the Unit 1 discharge was covered with kelp canopy (Deysher, 1978). Recent surveys (ECOsystems Management surveys of June, 1978, September, 1978, and December, 1978) suggest that there is very little kelp in this region at present, even though suitable substrate exists.

Recent diver observations (in November, 1978) showed that while very few algae existed on a reef 500 m north of the discharge, a reef of similar structure and depth 11 km downcoast harbored many algae including kelp.

(5) Estimates of kelp canopy coverage prior to December, 1977 were reported by Barilotti (1978) and Marine Biological Consultants (1978). More recent estimates, 1977 - 1979, have been made by ECOsystems Management using side-scan sonar. The estimate of 500,000 m^2 is from a rough area measurement of the December, 1978 ECOsystems Management survey.

(6) Production estimate is as follows:

- Macrocystis density at San Onofre Kelp bed - 0.11 adults/ m^2 (from June, 1978 Transect data)
- Canopy area = 500,000 m^2 (ECOsystems Management)
- x # fronds/plant @ SOK = 17.7 (Barilotti, unpublished data)
- $\overline{x}$ frond loss rate = 0.167 frond/plant/day (Barilotti, unpublished data)
- $\overline{x}$ frond wet wright = 1 kg/frond (Gerrard, 1976)

Standing Stock =

$$\frac{17.7\ \text{fronds}}{\text{plant}} \times \frac{1\ \text{kg}}{\text{frond}} \times \frac{0.11\ \text{plants}}{\text{m}^2} \times 500{,}000\ \text{m} = 973{,}500\ \text{kg}$$

Detrital Production =

$$\frac{0.167\ \text{fronds lost}}{\text{plant/day}} \times \frac{0.11\ \text{plants}}{\text{m}^2} \times 500{,}000\ \text{m}^2 \times \frac{1\ \text{kg}}{\text{frond}} = \frac{9{,}166\ \text{kg}}{\text{day}}$$

(7) These species numbers for Southern California kelp beds have been obtained from species lists in North (1971). Abundances for Barn, San Mateo, and San Onofre Kelp beds are from Richard Osman (unpublished data).

(8) Estimates of the extent of kelp canopies in Southern California are given in Science Applications (1978). These are from aerial photographs and tend to underestimate actual coverage, but give good relative results.

Supportive Evidence for Predictions

(1) Predictions are based on estimates of changes in turbidity following operation of Units 2 and 3 (see Physical/Chemical Oceangraphy section) and Finding (1).

(2) Based on Finding (7).

(3) Based on Finding (6).

(4) Based on Finding (3) - also see Jackson (1977).

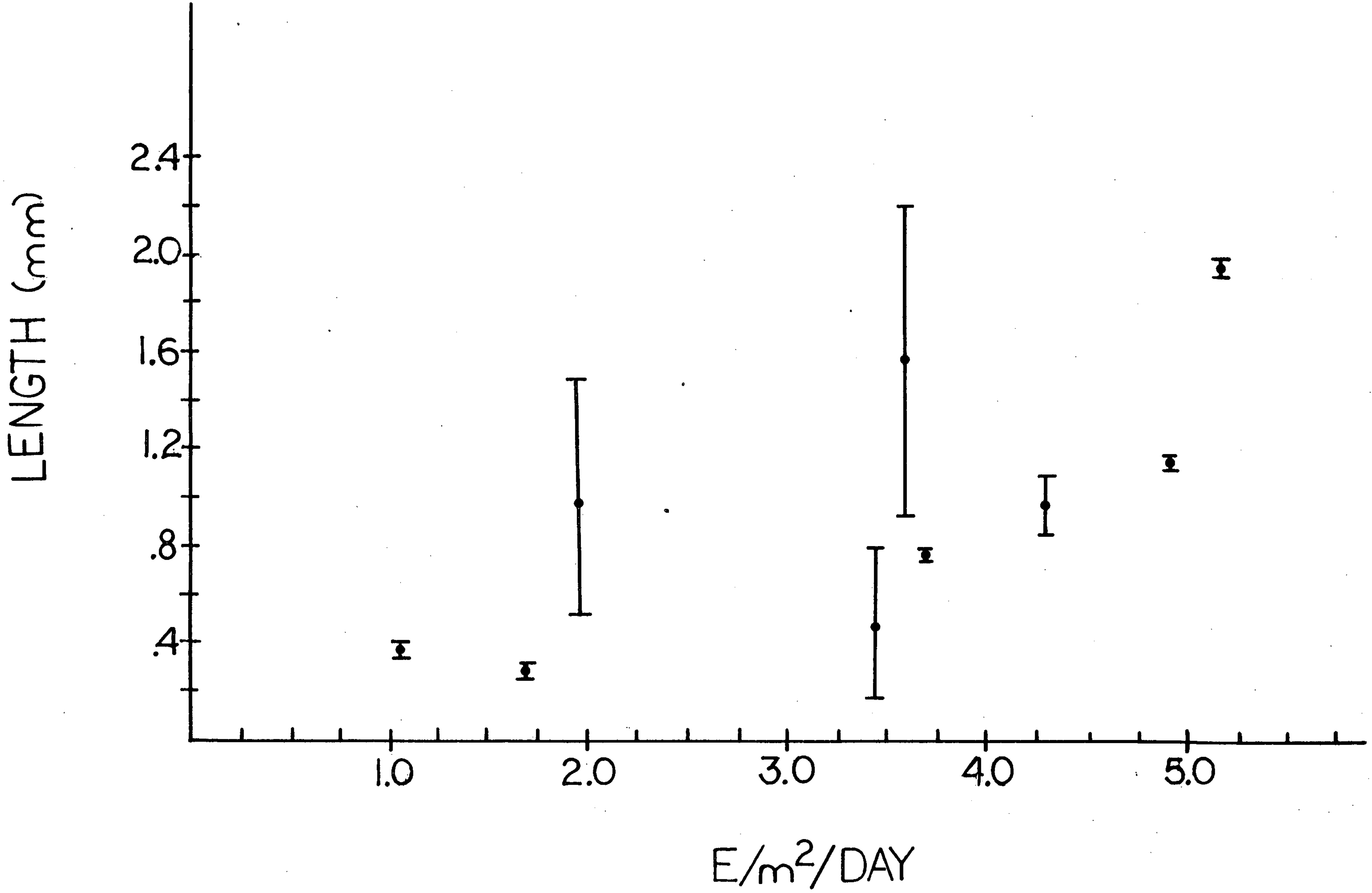

Figure 1. Sporophyte length (mm), ± 1.96 standard error, 42 days after initiation of gametophyte outplant plotted against the average quantum irradiance ($E/m^2/sec$) during this outplant period.

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