GRADIENT ANALYSIS OF PHYTOPLANKTON PRODUCTIVITY AND CHEMICAL PARAMETERS IN POLLUTED AND OTHER NEARSHORE HABITATS

John Victor Rowney

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

GRADIENT ANALYSIS OF PHYTOPLANKTON PRODUCTIVITY AND CHEMICAL PARAMETERS IN POLLUTED AND OTHER NEARSHORE HABITATS

by

John Victor Rowney

Thesis Advisor: E. D. Traganza

March 1973

Approved for public release; distribution unlimited.

Gradient Analysis of Phytoplankton Productivity
and
Chemical Parameters in Polluted and Other Nearshore Habitats

by

John Victor Rowney
Lieutenant, United States Navy
B.S., United States Naval Academy, 1967

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

ABSTRACT

Measurements of primary productivity, chlorophyll standing crop, and nutrient concentrations were made along a gradient of five nearshore habitats, a seaward transect, and a longshore transect to determine environmental relationships. The effects of municipal sewer outfalls, type of shoreline, and degree of exposure to high winter seas were found to be dramatic. The behavior of nutrient ratios suggest their use as pollution tracers in certain circumstances. The ratios of productivity to chlorophyll demonstrated physiological regimes among the phytoplankton in the sampling area. Comparison of data with carbon monoxide and methane concentrations provided a possible correlation between phytoplankton productivity and carbon monoxide production.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I wish to thank my advisor, Professor Eugene D. Traganza, Department of Oceanography, for his assistance and advice during the preparation of this thesis. His careful analysis, critical evaluation, and support were much appreciated. I also thank Dr. Malvern Gilmartin and Mr. Tom Bowhay of Hopkins Marine Station for their help in the productivity methodology and for use of their geiger counter. Appreciation goes to Professor Stevens P. Tucker, Department of Oceanography, and to Mr. Kenneth Graham, Department of Research Administration, for their assistance in the chlorophyll determinations. I am also indebted to LCDR Gaylord Paulson who took the time to show me the intricacies of the Auto analyzer despite a deadline to meet on his own thesis.

A special thanks must be expressed to the NPS boat crew, of the First Lieutenant's Division. Their tireless help and cheerful support, despite adverse weather conditions in potentially hazardous waters, was instrumental in the completion of the sampling phase.

Finally, I would like to thank Professor Eugene C. Haderlie, Department of Oceanography, for his critical and constructive evaluation of the final manuscript.

I. INTRODUCTION

This study was designed to test the hypothesis that measureable relationships exist between primary productivity, standing crop, and the chemical environment(nutrients, carbon monoxide, and methane) of sublittoral [1] phytoplankton communities. The data is presented as a gradient analysis of a variety of nearshore habitats characterized by large stands of macroalgae including Macrocystis and Nereocystis. The gradient analysis is a study of a series of biological and chemical parameters which vary along an environmental gradient to determine which factors, if any, are limiting. The study was carried out in late fall to midwinter, a poorly documented season in the literature, but during which numerous and noticeable oceanic and atmospheric effects on the phytoplankton community took place.

Part of the impetus for this thesis came from a desire (from the Naval Research Laboratory) to examine relationships, if any, between primary productivity and carbon monoxide and methane concentrations in an oceanic environment. Therefore, sampling was carried out simultaneously with James T. Welch and the data analysed together (see Welch, 1973, and this report).

Although much work has been done in recent years measuring and surveying the primary productivity of the world's oceans, most studies have been confined to relatively deep water, especially in coastal areas, and accomplished in the spring and late summer, the times of upwelling and phytoplankton blooms. Little work has been done less than 1000 meters from shore in the sublittoral environment. In Monterey Bay, Cowles (1972)

---

[1] beyond the intertidal, but with waves and turbulence still influencing the entire vertical range of depth.

has studied the sublittoral nearshore, but only in a transect from one nearshore location to deep water in the spring season.

II. MATERIALS AND METHODS

A. STATIONS

Sea water samples for the measurement of primary productivity, chlorophyll, and nutrients were taken at five nearshore stations representing a variety of habitats (Figure 1). Data were taken during a ten week period from 10 October to 15 December, 1972, in Monterey Bay, California. The study began in the local "Oceanic Period",[2] characterized by calm seas and warm sea surface temperature. A sharp drop in temperature and an influx of clear, oceanic surface water (Figure 2) marked the onset of the "Davidson Current Period".[3] Heavy rainfall and high seas accompanied the passage of storms during the fifth, sixth, and ninth weeks.

Five nearshore stations represent a gradient from a protected (bay) environment to an exposed (oceanic coast) environment. A seaward transect from two of these stations illustrate a gradient to open water and the effect of kelp beds on productivity. A longshore transect was designed to examine a sewer outfall and the gradient of productivity in a large kelp bed. Local depth and diurnal surveys were made in order to obtain maximum results when sampling. A station in deep water was made in order to provide an oceanic deep water index for this season.

1. Nearshore Stations

Station 1 was the center of an extensive kelp bed at Del Monte

---

[2] a period of variable winds and calm seas when cool, saline surface water (previously upwelled) sinks and is replaced by warm oceanic water (Welch, 1967).

[3] a period when Davidson Current develops, flowing north along the California coast; net transport is on-shore due to the Coriolis effect (Welch, 1967)

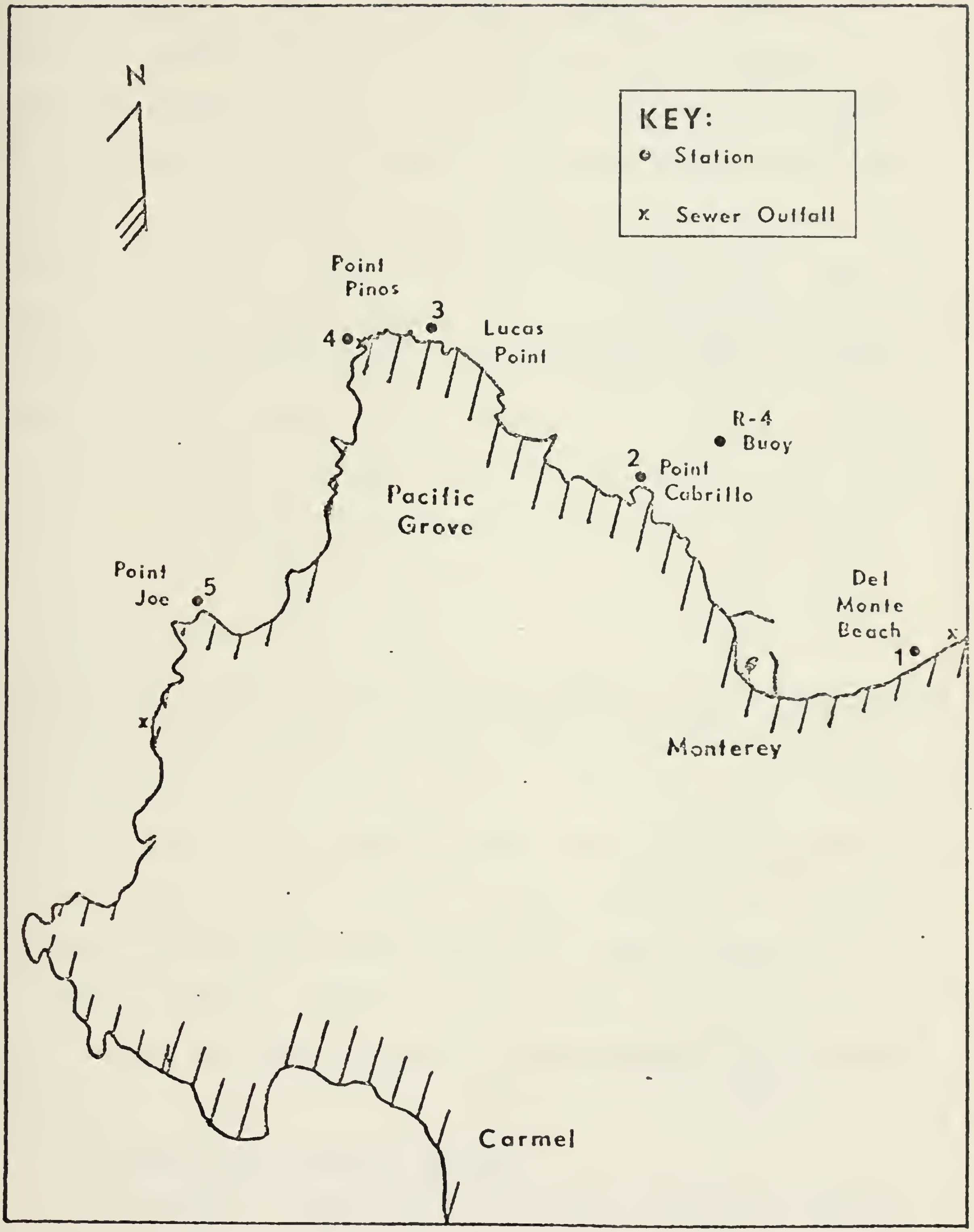

Figure 1. Chart of the Monterey Peninsula showing nearshore stations.

beach, adjacent to the Postgraduate School beach laboratory and about 200 yards offshore. Water depth was about eight meters over a sandy bottom. In general, the area was relatively calm, less affected by the stormy seas further along the coast. A sewer outfall which was pumping effluent directly into the kelp bed was located near the eastern edge. Station 2 was located in a kelp bed off Point Cabrillo, adjacent to the Hopkins Marine Station. Here the bottom and shore was rocky. Depth was about 10 meters 100 yards offshore. The area was subjected to some heavy swell from the north and northwest during the study. Station 3 was located in the kelp bed between Point Pinos and Lucas Point (denoted "Point Pinos North" hereafter). Samples were taken from the approximate center of the kelp bed about 300 yards from the rocky shoreline and in about 14 meters of water. This area received very heavy swell most of the time, as did the following two stations. Station 4 was a kelp bed just south of the main rock outcropping of Point Pinos. This station (denoted "Point Pinos South" hereafter) was about 300 yards offshore in about 15 meters of water and was the first "oceanic influence" station. It had a sewer outfall in the rocks about 200 yards from the kelp bed. Point Joe, Station 5, was the furthest from the influence from the bay. Sampling took place in the kelp bed center which was in about 15 meters of water and 300 yards offshore. Besides receiving heavy swell, the turbulence of the area was increased by large eddies formed between the kelp bed and the shore.

2. Seaward and Longshore Transects

Transects were made from the kelp beds at Del Monte beach and Point Cabrillo to the bell buoy adjacent to Point Cabrillo. The buoy is in open water of about 40 meters depth. In each transect, samples were taken in the center of the kelp, and at equidistant intervals from the

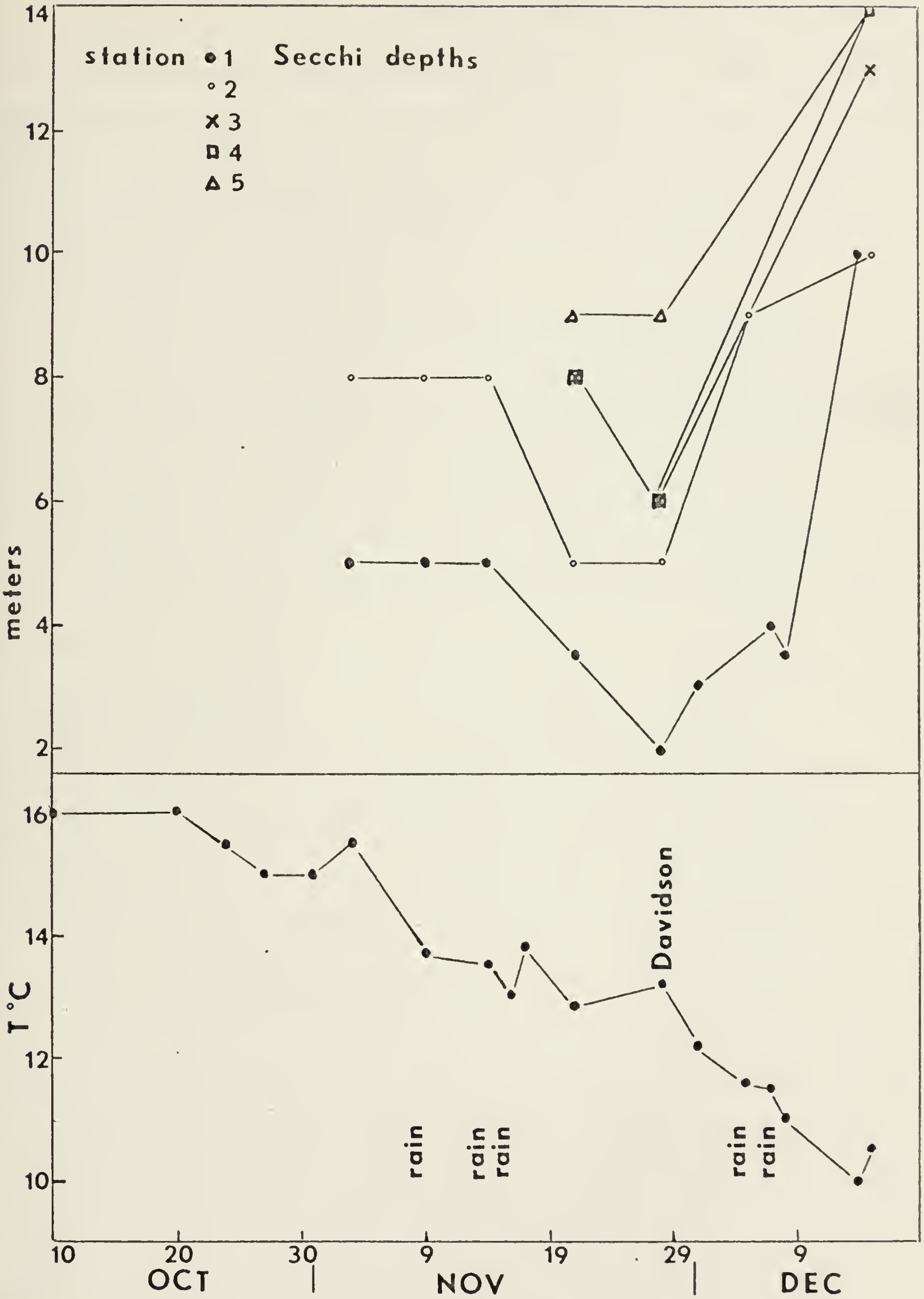

Figure 2. Environmental conditions during the sampling period. Periods of rain and Davidson current intrusion are noted.

edge of the kelp to the buoy. Another transect was made across the expanse of the Del Monte beach kelp bed (Figure 3). Six locations approximately 400 yards apart were selected for sampling: at the east edge, at the sewer outfall, adjacent to the Water Pollution Facility pumphouse, adjacent to the NPS beach laboratory, adjacent to La Playa apartments, and at the west (harbor) edge.

3. Diurnal and Depth Surveys; Deep Ocean Reference Stations

A diurnal time series survey was taken at Monterey harbor wharf #2, near the west end of the Del Monte beach kelp bed. Samples were taken every two hours for 24 hours. Two depth surveys each were taken at Del Monte kelp bed and Point Cabrillo kelp bed. Two deep stations were taken in the Monterey canyon at 36°44'N, 122°7'W and 36°44'N, 122°5'W, aboard R/V Acania.

B. SAMPLING TECHNIQUES

A 40 foot boat was used for a total of 22 cruises to the inshore stations. Although analyses could not be performed aboard, the boat size made it easier to get close to shore. Heavy seas during the fifth, sixth, and ninth weels did make it impossible to collect samples at Point Pinos and Point Joe. Water samples were collected from each station in a two liter, opaque, PVC Van Dorn bottle with hand lines for lowering and tripping. Subsamples were then dispensed into three 125 ml Pyrex bottles for productivity, one 500 ml Pyrex bottle for chlorophyll, and one five ml plastic Technicon Autoanalyzer cup for nutrient analysis. All bottles were put in a dark plastic bag of seawater for the remainder of the cruise and transportation to the lab. Sea surface temperatures and a Secchi disc reading were taken at most stations. All samples were taken between 0800 and 1000 local time and within two meters of the surface.

Figure 3. Del Monte beach kelp bed. Stations sampled during the longshore transect are indicated by an "X"; the sewer outfall is the second station from the right.

C. TOOLS USED IN THE GRADIENT ANALYSIS

1. Productivity Measurements

Food-chain ecology of the sea has attracted a great deal of interest in recent years. Researchers have been striving to accurately measure primary productivity, the basis of life in the sea. They have tried to relate phytoplankton standing crop or biomass, nutrient concentrations, and chlorophyll concentrations to primary productivity but with the possible exception of nutrients, have not had a great deal of success due to interfering processes (Ryther, 1956). Initially, primary productivity was measured by the relative production of oxygen in light versus dark bottles, but incubation periods are long and the ratio of CO_2 (assimilated) to O_2 (produced) while close to unity is variable (Ryther, 1956). On the other hand, the uptake of CO_2 is equivalent, mole for mole, to carbon production and represents the most direct approach to primary productivity measurements. The method of radioactive carbon fixation was first described by Steemann-Nielsen (1952). A known activity of radioactive carbon (C^{14}) is added to a phytoplankton culture and incubated at appropriate light levels. The radioactivity of the C^{14} assimilated by the plants is measured on a geiger counter. Steemann-Nielsen claimed the C^{14} method measured gross production (total carbon produced) while later researchers claimed the method to yield net production (carbon produced less carbon used in respiration) (Ryther, 1956). The general consensus is to regard the results as somewhere between gross and net production, longer term experiments favoring a net value (Riley and Skirrow, 1965). Artificial light may be used instead of *in situ* or natural illumination to determine "relative productivity" (Jitts, 1961).

Other modifications to Steemann-Nielsen's (1952) carbon-14 method for measuring primary productivity have been used. The method

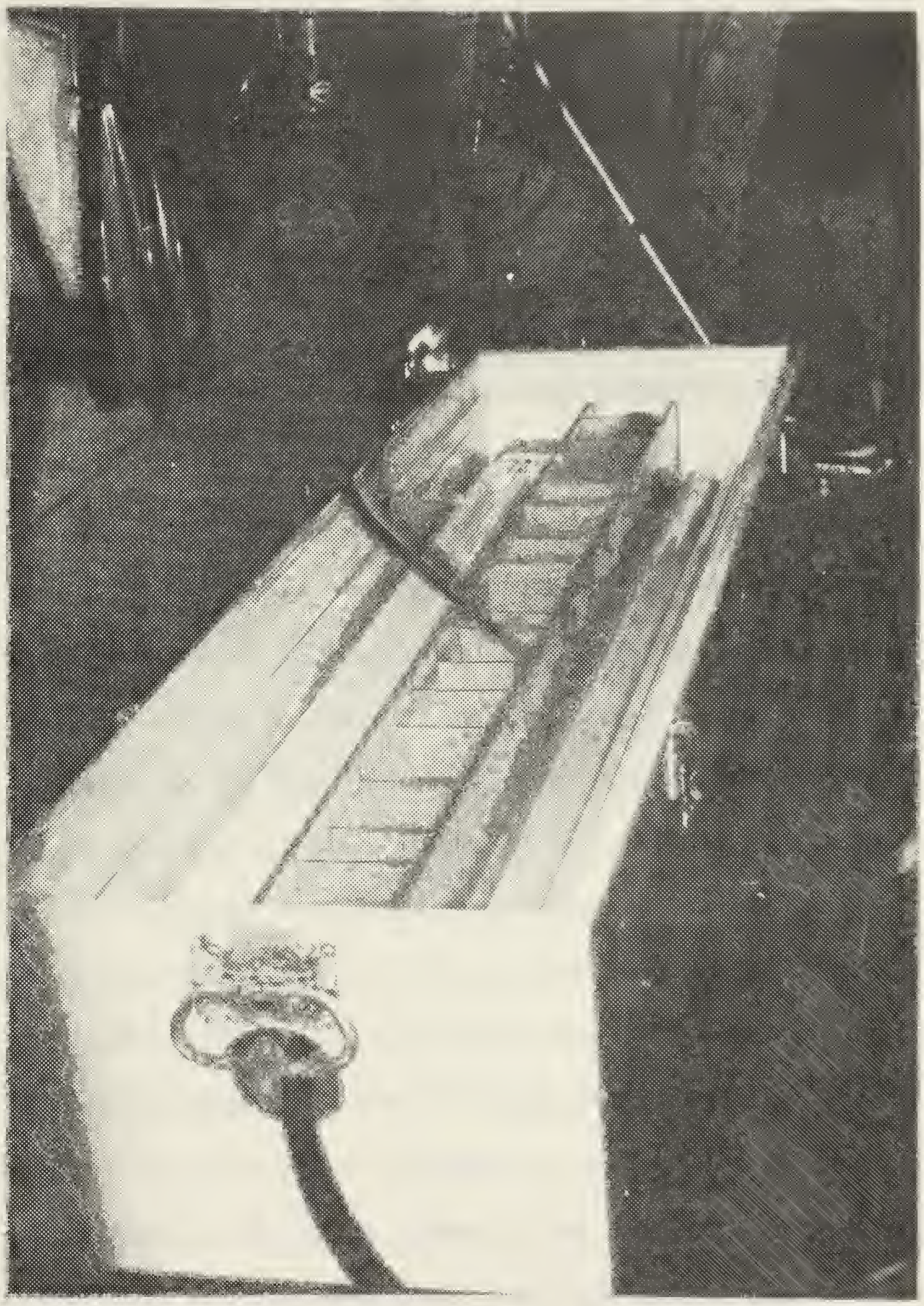

Figure 4. Incubation box (after Doty, 1959). Sea water coolant enters the box from tubing above.

employed here was based on that of Stickland and Parsons (1968) and used a fluorescent light incubator (Doty and Oguri, 1959) as shown in Figure 4. Two light and one dark bottle from each station were inoculated with one ml of $NaC^{14}O_3$ from glass ampoules containing about five microcuries of radioactivity. The bottles were incubated under fluorescent light ("cool white" bulbs, about 0.06 langley per minute) for three to four hours. Taylor and Hughes (1967) have shown that carbon uptake is linear over the first two to eight hours. Use of a short incubation period also eliminated the loss of C^{14} by respiratory oxidation (Harvey, 1955) and "bottle effects" such as bacterial growth on walls. The bottles were cooled in the incubator by filtered sea water which was pumped from the sea just off of Del Monte beach. The incubator cooling was always within $+2^{\circ}C$ of sea surface temperature. In the depth analyses, neutral density filters were used to reduce incubator light to approximately that which was present <u>in situ</u> (McAllister and Strickland, 1961). After incubation the bottles were filtered through 0.45 micrometer Millipore HA-type filters under 0.5 atmosphere vacuum. Bottles of 125 ml capacity were used due to high filtering times encountered with 250 ml bottles of the particulate laden nearshore water. The method is independent of volume filtered. Filters holding the radioactive phytoplankton were rinsed with a few ml of filtered sea water, sucked dry, and mounted on copper planchettes with rubber cement. The above procedures were carried out aboard ship for the deep water stations only. The filters were dried in a dessicator for 24 hours and transferred to airtight jars containing silica gel and soda lime to insure dry, carbon dioxide-free storage. The radioactivity of each sample was counted within one week of collection. Samples can be stored for several weeks in this manner without physical loss of radioactivity (Strickland and Parsons, 1968).

The mounted filters were counted on a Nuclear Chicago Scalar geiger counter (model 161A) equipped with a model D47 gas flow chamber and a "micromill" window. Light bottle counts were held to 5000 counts or three minutes, whichever came first. Dark bottles were counted two to three minutes. It was also necessary to determine the total amount of activity in the C^{14} ampoules. The first batch used was pre-calibrated at the factory. The second batch was calibrated on a Nuclear Chicago liquid scintillation counter in the method of Jitts and Scott (1961). This method has proven to be much more accurate than the barium carbonate precipitation method described in Strickland and Parsons (1968). Errors inherent in extrapolating to "zero" thickness are eliminated. Primary productivity is then given by the formula:

$$\text{mg C m}^{-3}\ \text{hr}^{-1} = \frac{(R_S - R_B) \times W \times 1.05}{R \times N}$$

where: R_S = light bottle count in counts per minute (CPM),

R_B = dark bottle count in CPM,

R = total absolute activity of an ampoule in CPM,

W = weight of carbonate carbon in the water in mg C/m^3,

N = number of hours incubated, and

1.05 = an isotope discrimination factor.

In this study W was assumed to be constant at 24000 mg C/m^3. Periodic checks in various locations showed this to be valid within 1%. The discrimination factor accounts for the difference in behavior of the C^{14} isotope from the C^{12} isotope found in nature (Strickland and Parsons, 1968). In the calculations, dark bottle counts were subtracted from light bottle counts. The dark bottle acts as a control representing a combination of non-photosynthetic fixation of carbon and absorption of C^{14} by particulate matter and detritus (Taylor and Hughes, 1967).

2. Nutrient Measurements

In sea areas where nutrient cycles and phytoplankton have been studied, it is clear that certain minor inorganic constituents of sea water are required for growth and reproduction. Due to the low concentrations of these nutrients in sea water, phytoplankton production may become limited by their depletion (Raymont, 1963). Study of the nutrient environment, therefore, may give significant insight to variations in primary productivity and the "fertility" of the seas.

Upon reaching the laboratory after collection, the five ml nutrient samples were frozen in a dark freezer until enough samples were collected to warrant automated analysis (Steven, Brooks and Moore, 1970, and Corcoran and Alexander, 1963). Samples were analyzed on a Technicon Autoanalyzer II with concentrations reported in microgram-atoms per liter (µg-at/l) of nitrate (NO_3^-), nitrite (NO_2^-), phosphate (principally $HPO_4^=$), and silicate ($H_4SiO_4 \rightleftarrows H^+ + H_3SiO_4^-$). Overall, the sensitivity, reproducibility, and accuracy of this system for sea water nutrient analysis have been found to be very satisfactory. The last batch of phosphate samples run (representing 9 November - 15 December collections) are somewhat suspect due to erratic behavior of the phototube.

3. Chlorophyll and Acid Factor Measurements

A 500 ml water sample was used to make an estimate of standing crop of phytoplankton by measurement of chlorophyll _a_. Grazing pressure was estimated by calculation of the chlorophyll _a_ to phaeophytin _a_ fluorescence ratio. Using chlorophyll _a_ as an index of standing crop is valid as long as the species composition remains relatively stable between stations and over the time period of collection (Cowles, 1972). Chlorophyll degradation products, such as phaeophytin, are often found in areas of zooplankton activity. These compounds fluoresce strongly at the same

wavelength of maximum fluorescence of the chlorophylls. Undegraded chlorophyll a can be determined by measuring the decrease in fluorescence (occuring at 665 nm) which takes place when the pigment extract is treated with dilute acid to convert it to phaeophytin a. The ratio of the unacidified fluorescence to the acidified fluorescence, or the "acid factor", is a measure of zooplankton grazing pressure under ideal conditions. An acid factor of close to one, indicative of a very high phaeopigment concentration, has been found below the photic zone and in the vicinity of large populations of zooplankton. Ratios above 1.7 indicate high concentrations of undegraded chlorophyll. The exact value will depend on the relative amounts of chlorophyll a, b, and c present (Holm-Hansen, et. al., 1965, Yentsch and Menzel, 1963).

In this study, the experimental method of Strickland and Parsons (1968) was used to determine chlorophyll a and acid factor. Each 500 ml water sample was filtered in the laboratory within an hour of collection through a Whatman GF/C glass fiber filter under 1/3 atmosphere vacuum. Samples from the deep water station were processed aboard ship. One ml of magnesium carbonate suspension was added to the final small volume of each sample passing through the filter. The filter containing the sample was folded in half and frozen in the dark until fluorometric determination. A time study, in which three replicate samples were stored for five days, three weeks, and two months respectively, showed no degradation of pigment with this procedure. The filters were removed from the freezer, ground in a tissue grinder, and centrifuged. The fluorescence of the supernatant liquid extract was measured on a Turner Model 111 fluorometer. Two drops of dilute HCl were then added, and, after five minutes, the fluorescence was measured again. The acid factor was then calculated.

The fluorometer was calibrated by measuring the chlorophyll extinction of one sample on a Beckman spectrophotometer and calculating concentration with the equation of Strickland and Parsons (1968):

$$\text{mg Chlorophyll } \underline{a}/\text{m}^3 = \frac{11.6E_{6650} - 1.31E_{6450} - 0.14E_{6300}}{V}$$

where: E = extinction value at the specified wavelength

V = volume of sea water filtered in liters.

4. Nitrogen/Phosphorous Calculation

From the nutrient data, nitrate to phosphate ratios (N:P), or phytoplankton "assimilation ratios", were calculated to estimate chemical interrelationships in the sea water (Riley and Skirrow, 1965).

5. Productivity/Chlorophyll Calculation

Productivity to chlorophyll (Pc) ratios were calculated as an index of physiological or population changes within the groups of phytoplankton and habitats studied (Riley and Skirrow, 1965).

6. Carbon monoxide/ Methane/ Productivity Comparison

Carbon monoxide and methane concentrations were compared to productivity data to determine if any interrelationships exist. See Welch (1973) for methods of measurement.

III. RESULTS

A. DEPTH AND DIURNAL STUDIES

Maximum daily production rates were desired for this study. It was assumed that the bulk of the phytoplankton population would be in the upper two meters of water owing to the reduction of natural light in the winter and the turbidity of inshore waters (Taylor and Hughes, 1967). According to Riley and Skirrow (1965), photosynthesis in phytoplankton occurs at its maximum rate in the late morning hours. Separate experiments confirmed these assumptions. Depth studies taken on different days at Del Monte beach and Point Cabrillo confirmed maximum production to take place from one-half to two meters in depth (Appendix A, Cruises 4, 13, and 18). A twenty-four hour study (Figure 5) showed the greatest increase in production to occur in late morning with a maximum at 1330 local time. A similar phenomenon has been noted by other researchers in other waters (Doty and Oguri, 1957, McAllister, 1963, and Lorenzen, 1963).

At the deep water stations in the Monterey submarine canyon (Figure 6), productivity and standing crop at the surface was comparable to the values obtained at Point Pinos and Point Joe. The values decreased rapidly with depth to a low at 46 meters, the depth at which only 1% of the surface light was available as determined by Secchi disc. As expected the acid factor indicated heavily degraded chlorophyll at this level. Figure 7 shows "reactive" nitrate and silicate both increasing to deep water maximums while high values of "reactive" phosphate and nitrite remain in the surface layer. Acid factors were roughly on the same order as the inshore stations.

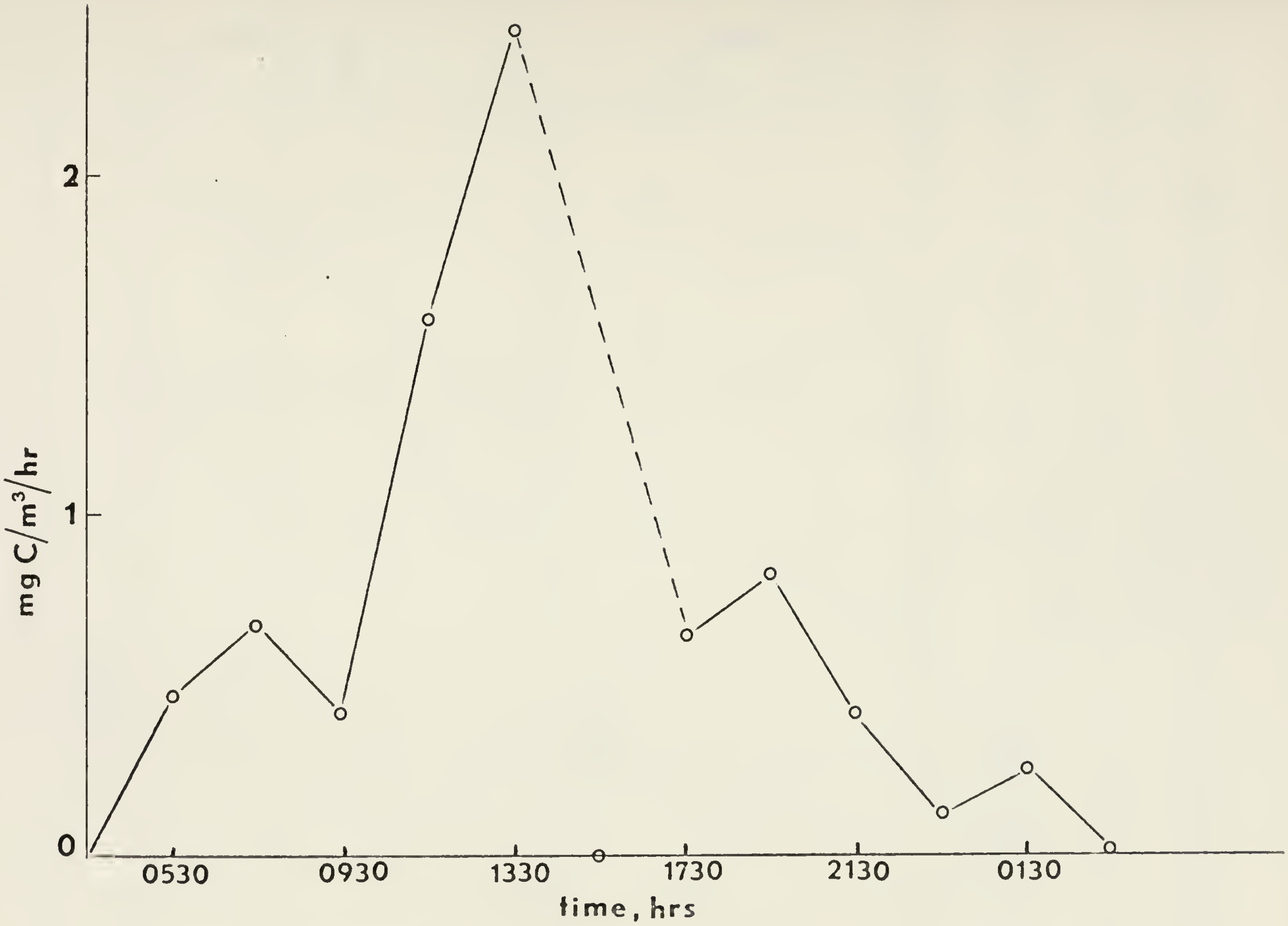

Figure 5. Diurnal productivity survey at Monterey Harbor. The low value at 1530 hours was probably due to absorption of C^{14} by particulate matter.

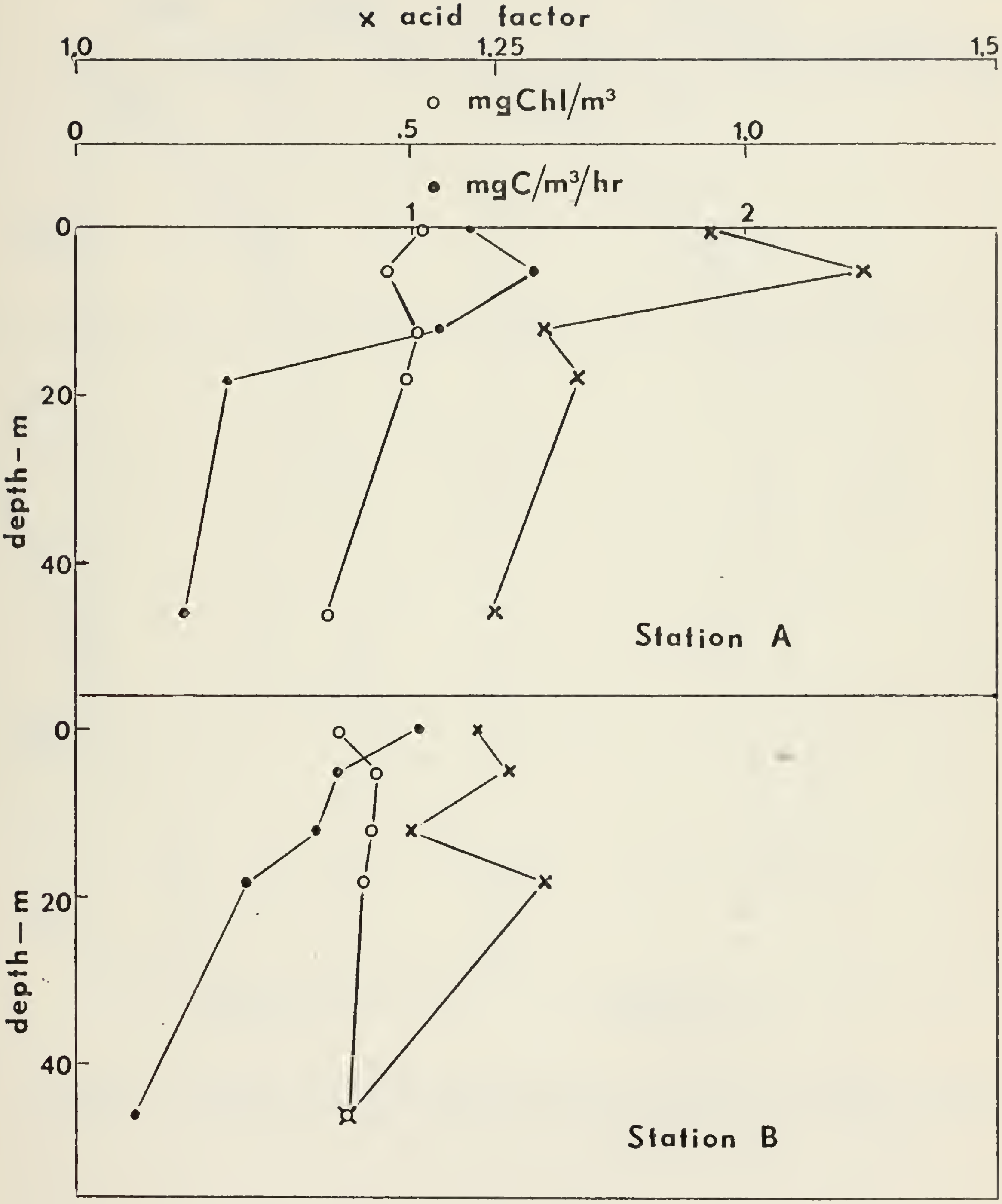

Figure 6. Productivity and chlorophyll (Chl) relations at the deep water station. Station A is at 36° 44' N, 122° 07' W; Station B is at 36° 44' N, 122° 05' W.

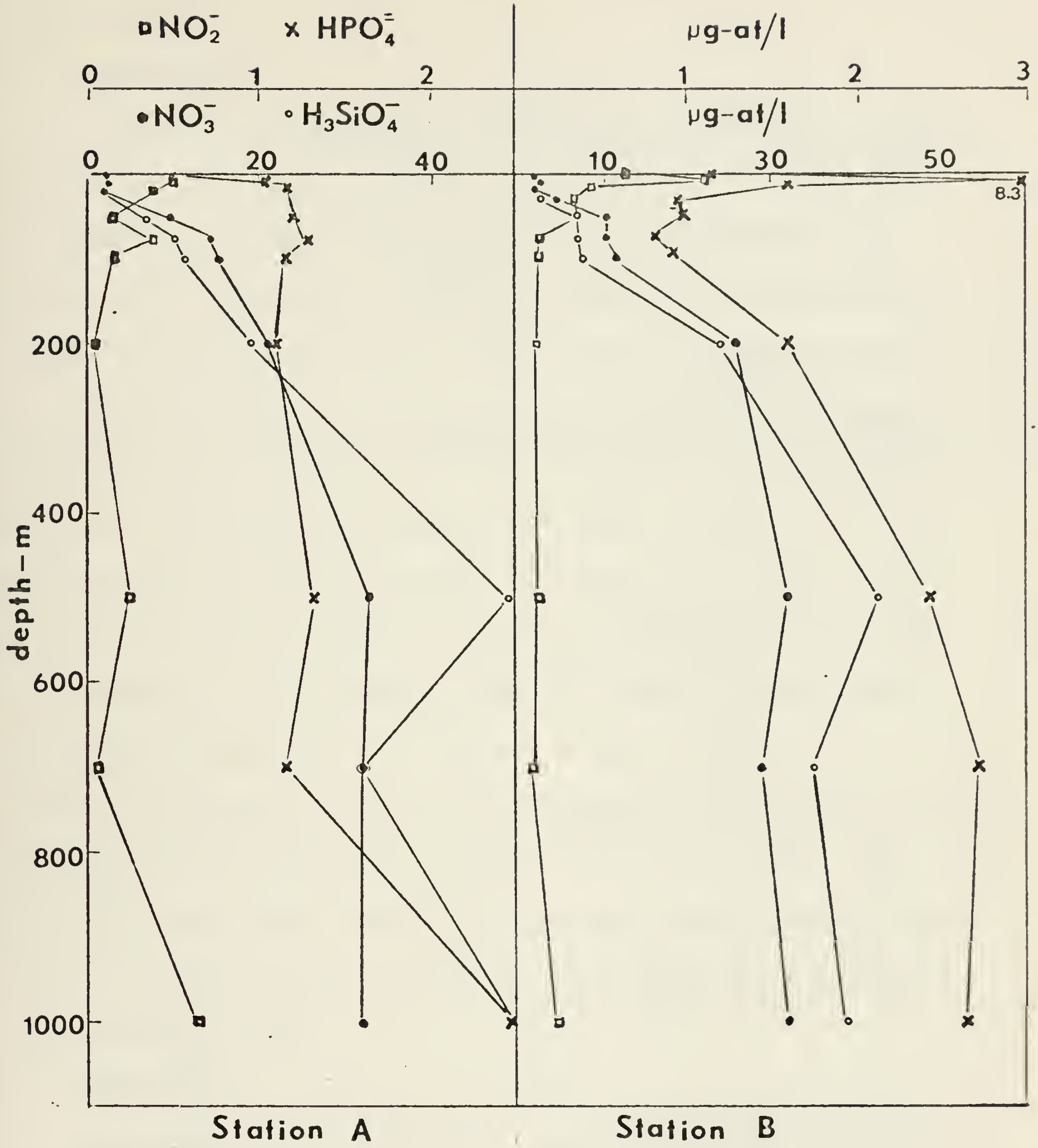

Figure 7. Nutrient concentrations at the deep water station. Station A is at 36° 44'N, 122° 07' W; Station B is at 36° 44'N, 122° 05' W.

B. GRADIENT ANALYSIS

1. Productivity

The gradient of productivity between the five nearshore stations for each week data was obtained, is presented in Table I. In addition, Figure 8 shows average values of all productivity measurements taken during the study. Productivity generally decreased toward the most exposed station, i.e., from Del Monte to Point Joe. The seaward transect shown in Figure 9, represents an average of two runs from Del Monte to the buoy and two runs from Point Cabrillo to the buoy. Runs were made on different days. Productivity increased from Point Cabrillo to the buoy, but decreased from Del Monte to the buoy. In each case, however, productivity was lower inside the kelp bed (mostly *Macrocystis*) than at the edge just outside it. The longshore transects across the width of the Del Monte kelp bed are presented in Figures 11 and 12. The first run showed maximum productivity from the beach laboratory to the harbor. On this day, the "boil" from the sewer outfall could not be found. The second run also showed high productivity from the laboratory to the harbor. The "boil" was sampled and found to be low in productivity, but increase was rapid towards the west.

2. Chlorophyll

Chlorophyll, like productivity, generally decreased from Del Monte to Point Joe along the nearshore gradient as shown in Figure 8 and Table I. Little change was noticed in the seaward transect from either Del Monte or Point Cabrillo to the buoy (Figure 9). Figure 11 shows chlorophyll to be variable in the first run of the longshore transect; when the "boil" was sampled (Figure 12), a very high chlorophyll standing crop was evident.

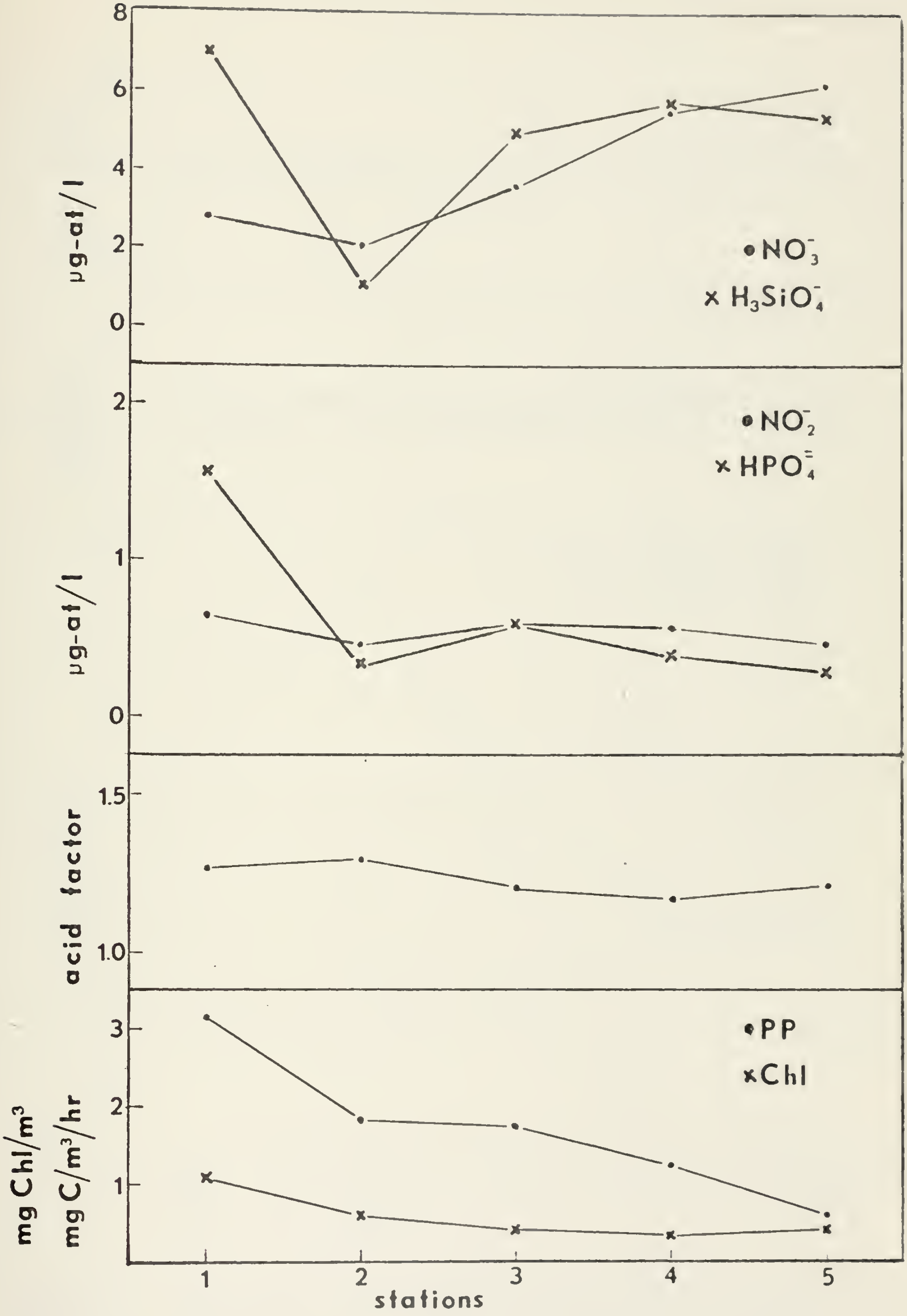

Figure 8. Average productivity (PP), chlorophyll (Chl) and nutrient data on the nearshore gradient. Data plotted from Station 1 (Del Monte) to Station 5 (Point Joe).

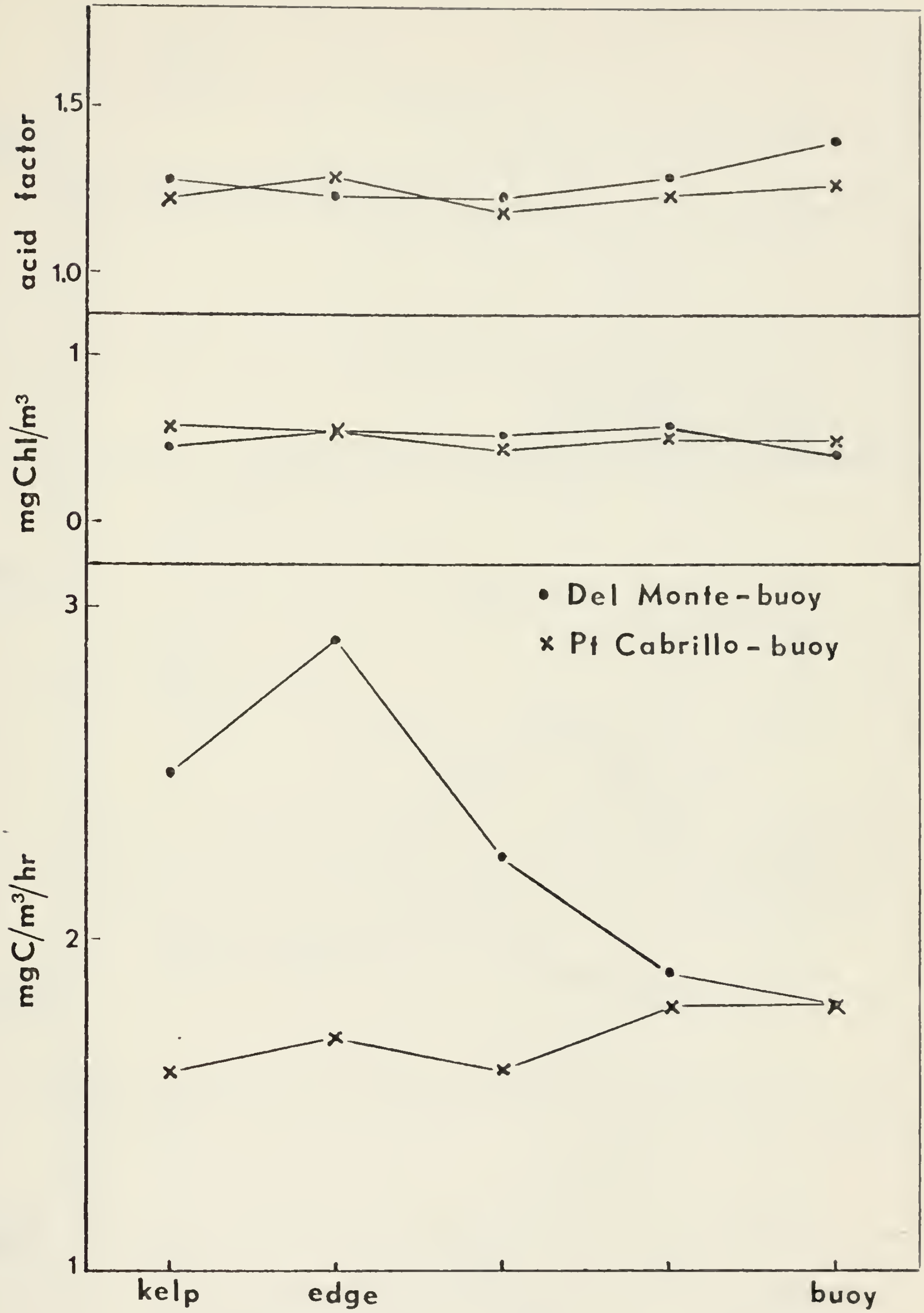

Figure 9. Average productivity & chlorophyll relations on the seaward transect. Samples were taken at the respective kelp bed center, kelp bed edge, and from there at equidistant intervals to the buoy.

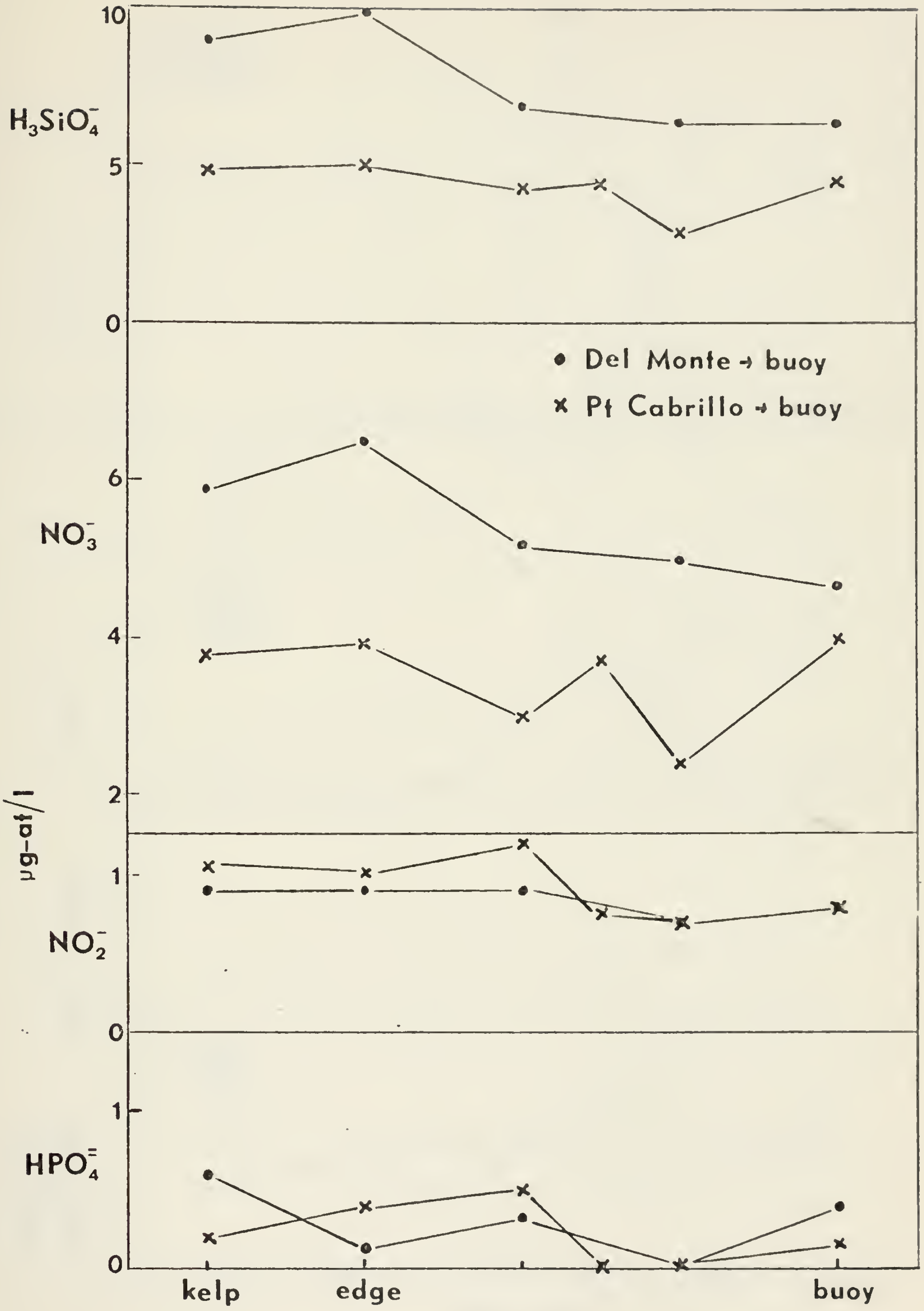

Figure 10. Average nutrient concentrations of the seaward transect. Samples were taken at the respective kelp bed center, kelp bed edge, and from there at equidistant intervals to the buoy.

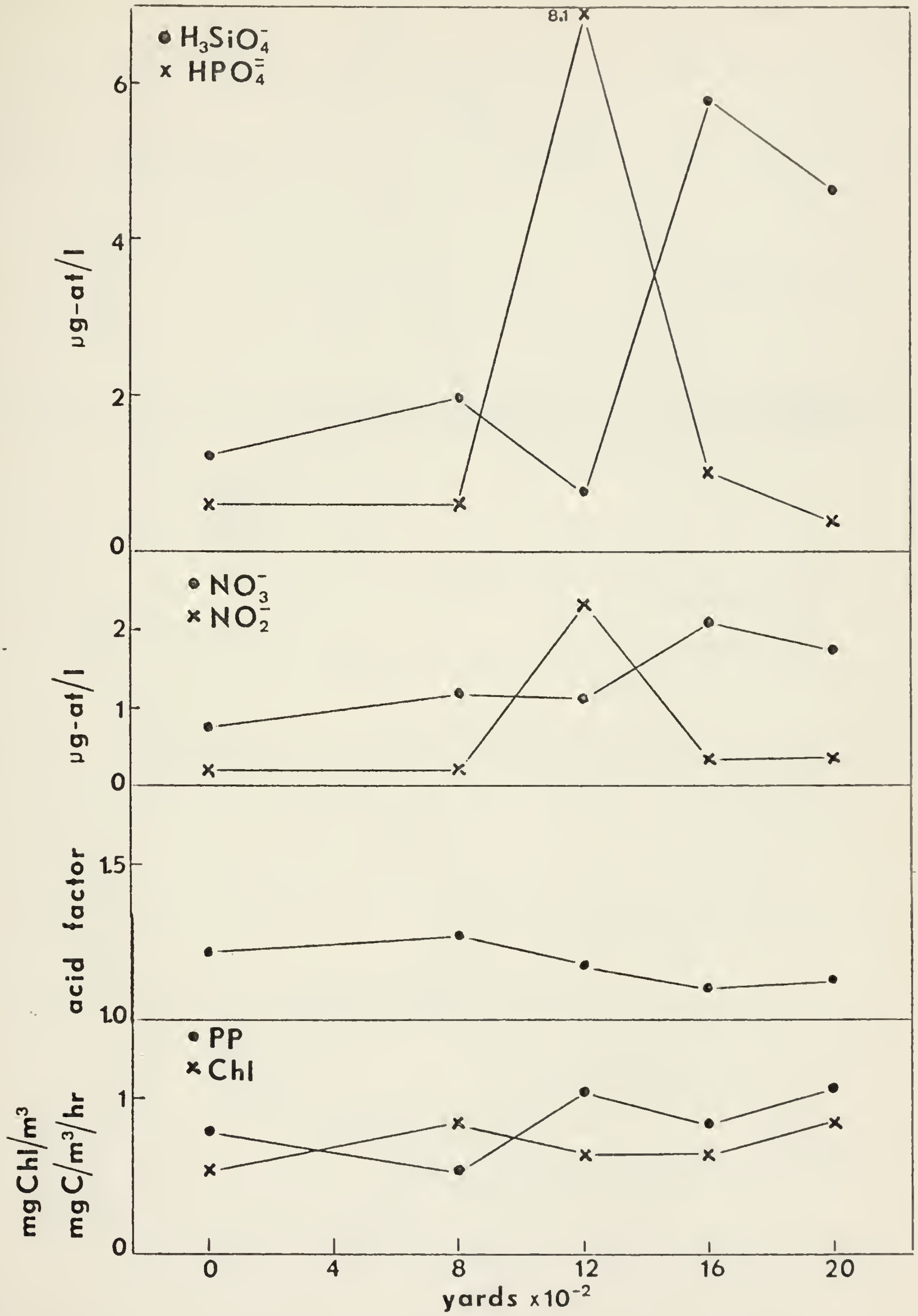

Figure 11. Productivity, chlorophyll, and nutrient data on the first longshore transect. Zero is the eastern edge of the kelp bed at Del Monte beach.

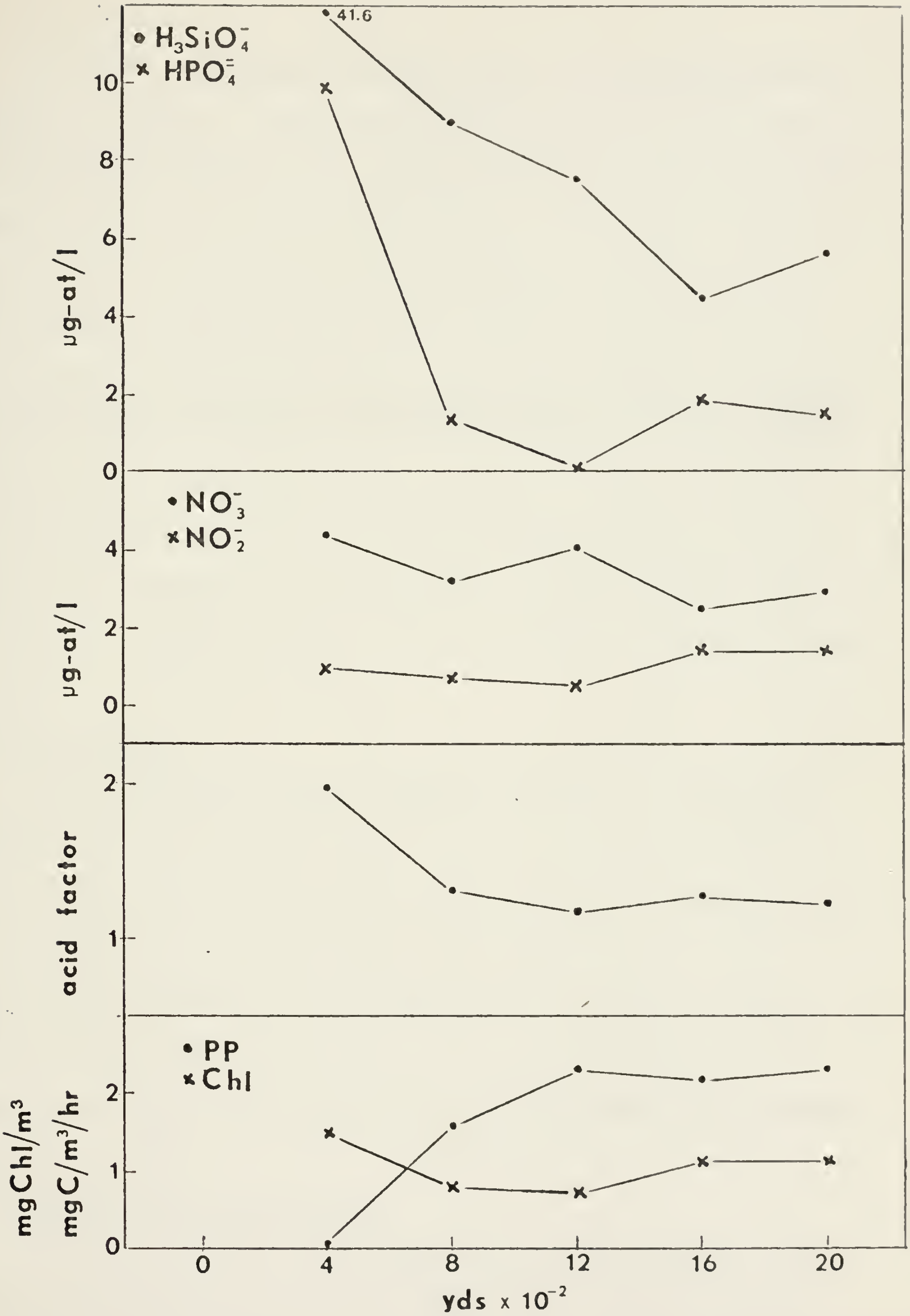

Figure 12. Productivity, chlorophyll, and nutrient data on the second longshore transect. Zero is at the eastern edge of the kelp bed at Del Monte beach. 400 is the sewer outfall.

3. Nutrients

Nutrient concentrations for each week in the nearshore gradient are presented in Table I. The average value plot (Figure 8) shows phosphates decreasing toward Point Joe, nitrates increasing toward Point Joe, and silicate highs at both ends of the gradient. The seaward transect (Figure 10) shows most nutrients decreasing towards open water at the buoy. Concentrations generally increased slightly at the edge of the kelp over those in the kelp bed center in both areas. The day the "boil" at the sewer outfall could not be found in the longshore transect (Figure 11), high silicate and phosphate concentrations were noted west of its supposed location. When the boil was sampled, very high concentrations of silicate and phosphates were found (Figure 12); these decreased with distance from the outfall. Nitrite, however, increased with distance from the outfall.

4. Acid Factor

In the nearshore gradient (Figure 8 and Table I), acid factor was not very definitive but generally was highest at Station 2 off Point Cabrillo. Acid factors in the seaward transect generally increased once out of the respective kelp beds (Figure 9). In the first run of the longshore transect (Figure 11), acid factors indicated higher grazing pressures towards the west (harbor) end. The second run showed a very high acid factor at the sewer boil, with diminishing values again towards the harbor (Figure 12).

5. Nitrogen/Phosphorous Ratios

In Figure 13, nitrate to phosphate ratios are plotted on the nearshore station gradient for four of five weeks. In these diagrams, the N:P ratio increases from Del Monte, Station 1, to Point Joe, Station 5. In the seventh week analysis, undetectable phosphate concentrations were suspect and therefore not considered.

TABLE I

Productivity, chlorophyll and nutrient data on the nearshore gradient. Productivity given in mg C $m^{-3}hr^{-1}$; chlorophyll given in mg/m^3; and nutrients given in ug-at/l. Station 1 is Del Monte; Station 2 is Point Cabrillo; Station 3 is Point Pinos North; Station 4 is Point Pinos South; Station 5 is Point Joe. Symbols are: PP(productivity), CHL(chlorophyll), AF(acid factor), N3(nitrate), S(silicate), P(phosphate), N2(nitrite).

Week	Station	PP	CHL	AF	N3	S	P	N2
3	1	11.4			.85	5.05	1.64	.28
	2	3.08			0.0	2.75	0	.20
	3	1.79			.38	2.60	.54	.39
	5	.37			4.72	2.55	.32	.42
4	1	6.80	3.39	1.4	0	8.15	.86	.14
	2	5.12	.72	1.49	0	2.15	.17	.22
	3	3.05			.15	3.85	.55	.28
	4	2.08			2.90	4.40	.65	.46
	5	.37			8.42	7.00	.48	.27
7	1	1.89	.65	1.17	3.08	8.05	0	.20
	2	.99	.56	1.46	3.48	4.95	0	.28
	3	.95	.42	1.17	4.08	4.35	0	.27
	4	.67	.32	1.13	4.78	3.90	.10	.25
	5	.12	.48	1.21	5.10	4.05	.22	.37
8	1	1.36	.56	1.15	6.31	12.4	1.37	.61
	2	2.83	.58	1.20	5.22	7.80	1.08	.76
	3	1.59	.51	1.23	7.10	7.45	.83	.72
	4	1.02	.36	1.20	8.52	8.00	.80	.74
	5	1.07	.39	1.20	7.47	7.50	.50	.59
10	1	3.02			5.75	9.55	1.19	1.21
	2	1.70			5.80	7.40	.40	1.35
	3	1.31			6.25	6.90	1.08	1.37
	4	1.30			5.72	6.70	.07	.87
	5	1.15			5.18	5.70	0	.75

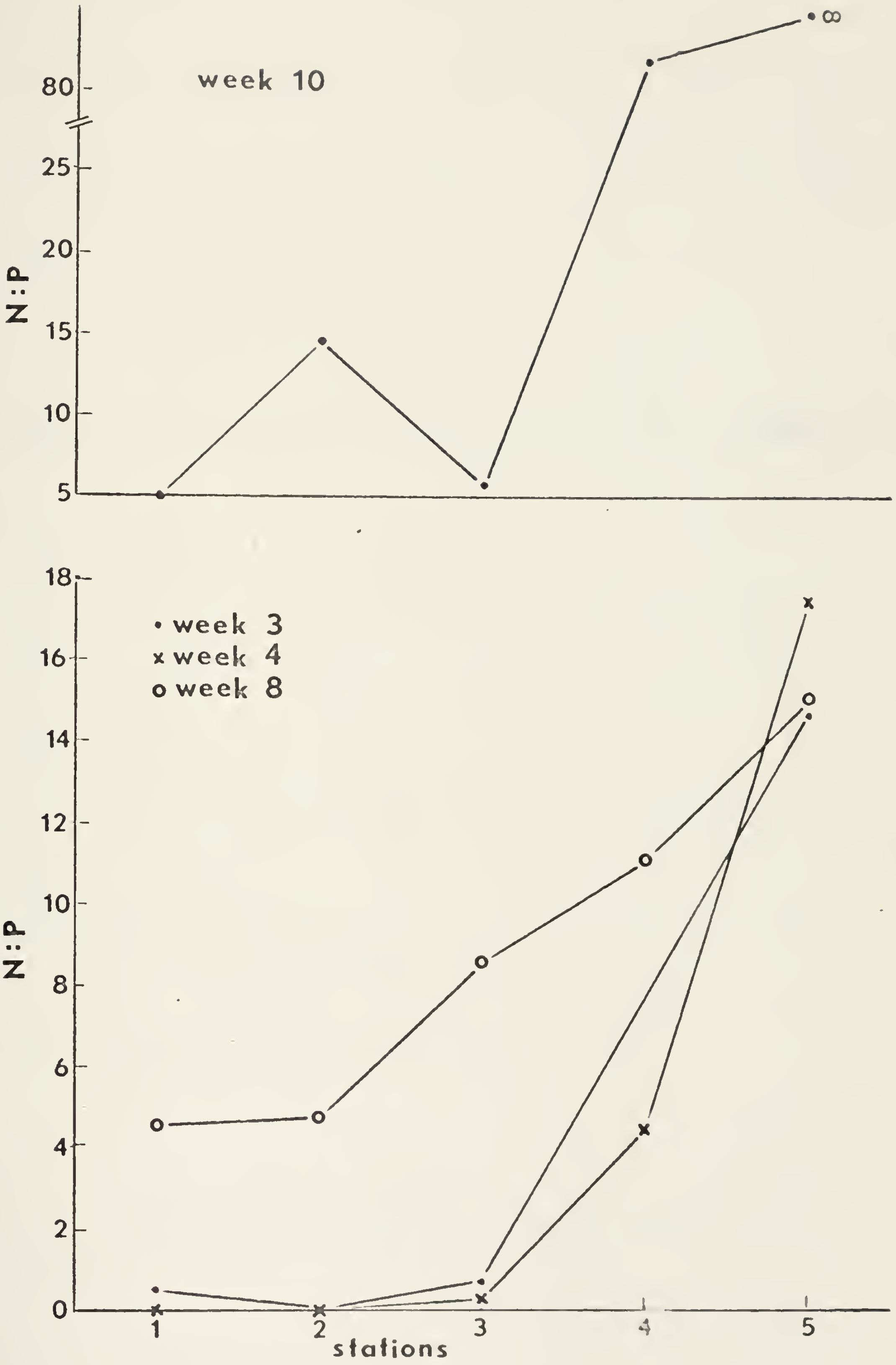

Figure 13. Nitrogen/phosphorous ratios on the nearshore gradient. Data plotted from Station 1 (Del Monte) to Station 5 (Point Joe).

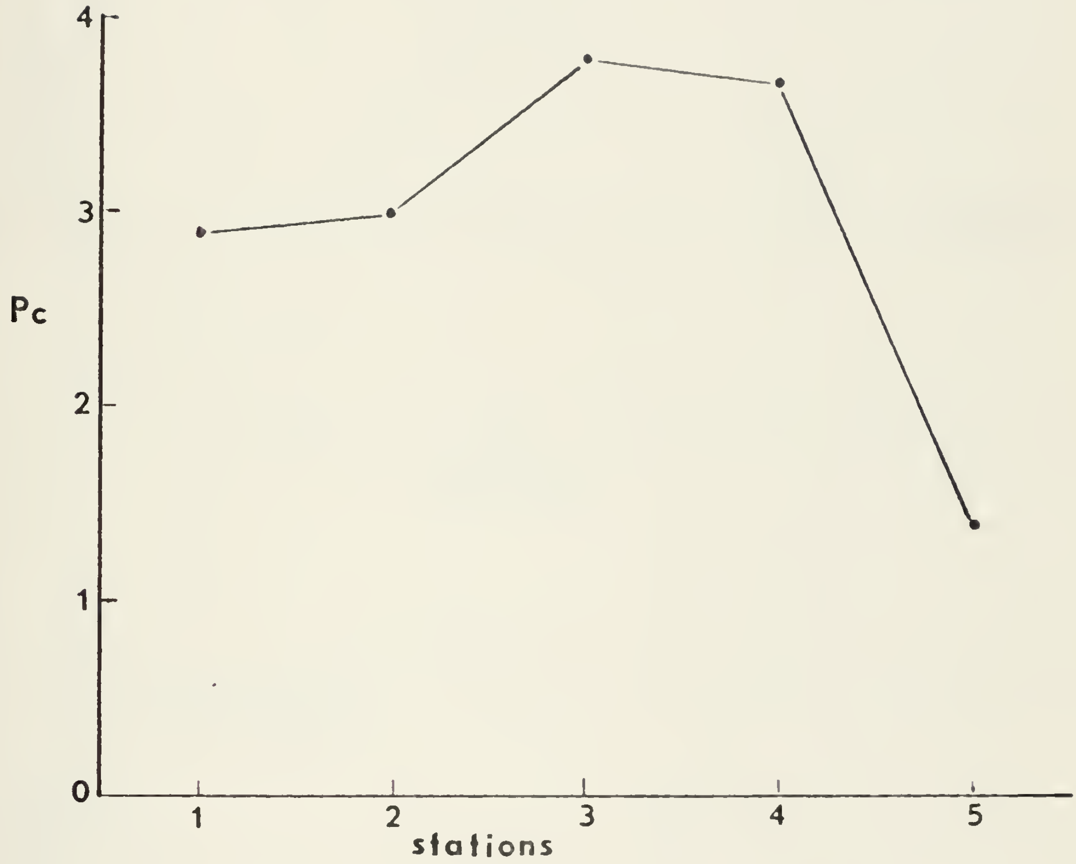

Figure 14. Productivity/chlorophyll (Pc) ratios on the nearshore gradient. Data plotted from Station 1 (Del Monte) to Station 5 (Point Joe).

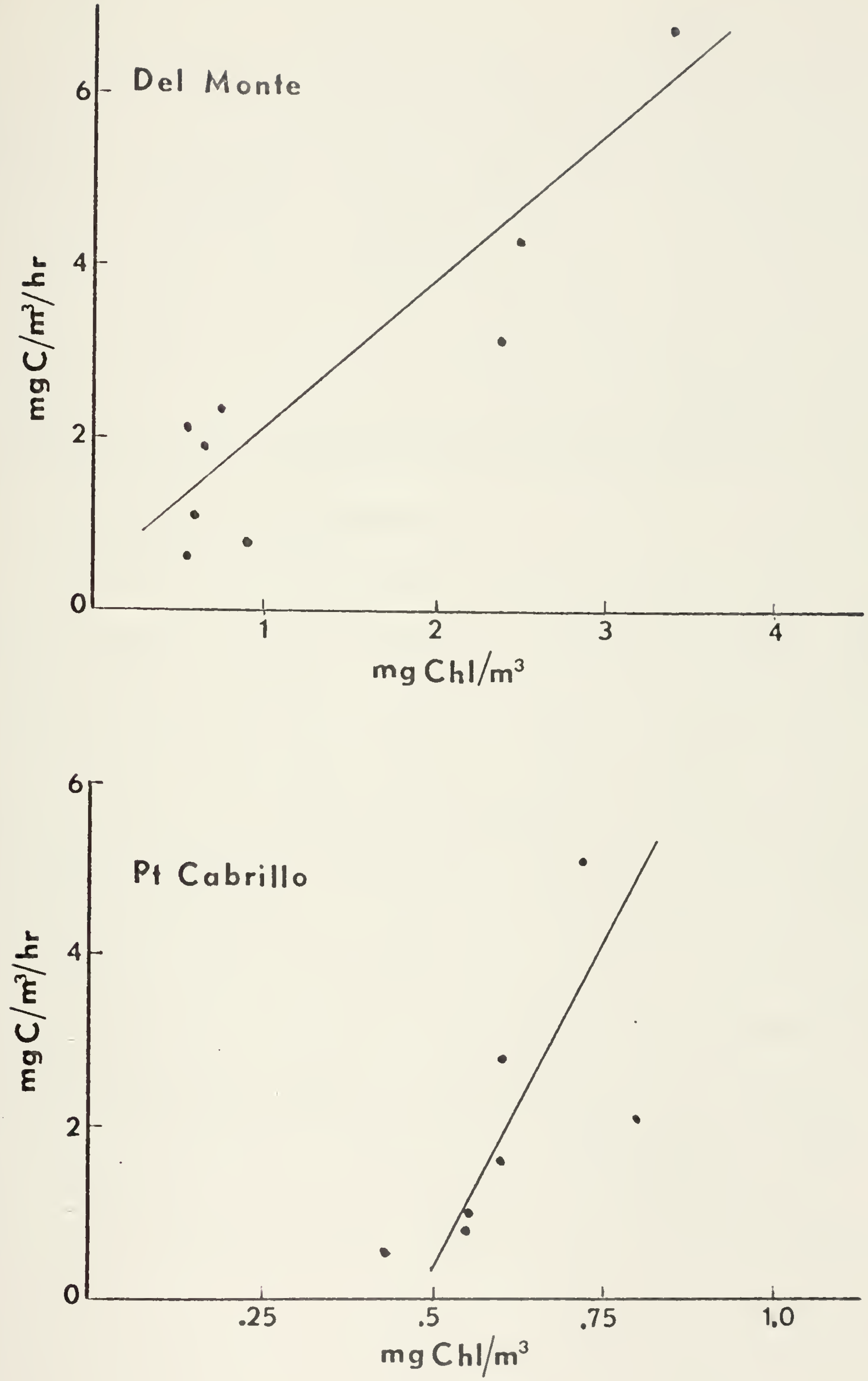

Figure 15. Productivity versus chlorophyll at Del Monte and Point Cabrillo.

6. Productivity/Chlorophyll Ratios

In Figure 14, average productivity to chlorophyll (Pc) ratios are plotted along the nearshore gradient for the two weeks that data was obtained for all areas (weeks seven and eight). Del Monte and Point Cabrillo (1 and 2) seem to represent similar conditions, as do the stations at Point Pinos (3 and 4). Point Joe (5) is by itself with a very low Pc ratio. When productivity was plotted against chlorophyll for Del Monte and Point Cabrillo (the two stations with the most chlorophyll data), definite but different relationships were obtained (Figure 15).

7. Carbon Monoxide and Methane

Carbon monoxide and methane data are from Welch (1973). Carbon monoxide, methane and depth relations are plotted in Figure 16. This figure represents conditions at one of the deep water stations studied. Both CO and CH_4 increased with depth to 15 meters, then CO abruptly decreased with depth to 100 meters with methane still increasing slightly. Both decreased from there to 1000 meters. In the nearshore gradient (Figure 17), average values of methane behaved very much like silicate (Figure 8) with a source at Del Monte and Point Joe. Carbon monoxide fluctuated but generally increased toward Point Joe. The sewer outfall showed strikingly high values for both CO and CH_4 in the longshore transect (second run) as shown in Figure 18. Concentrations decreased with distance from the boil, but both began a rise toward the harbor.

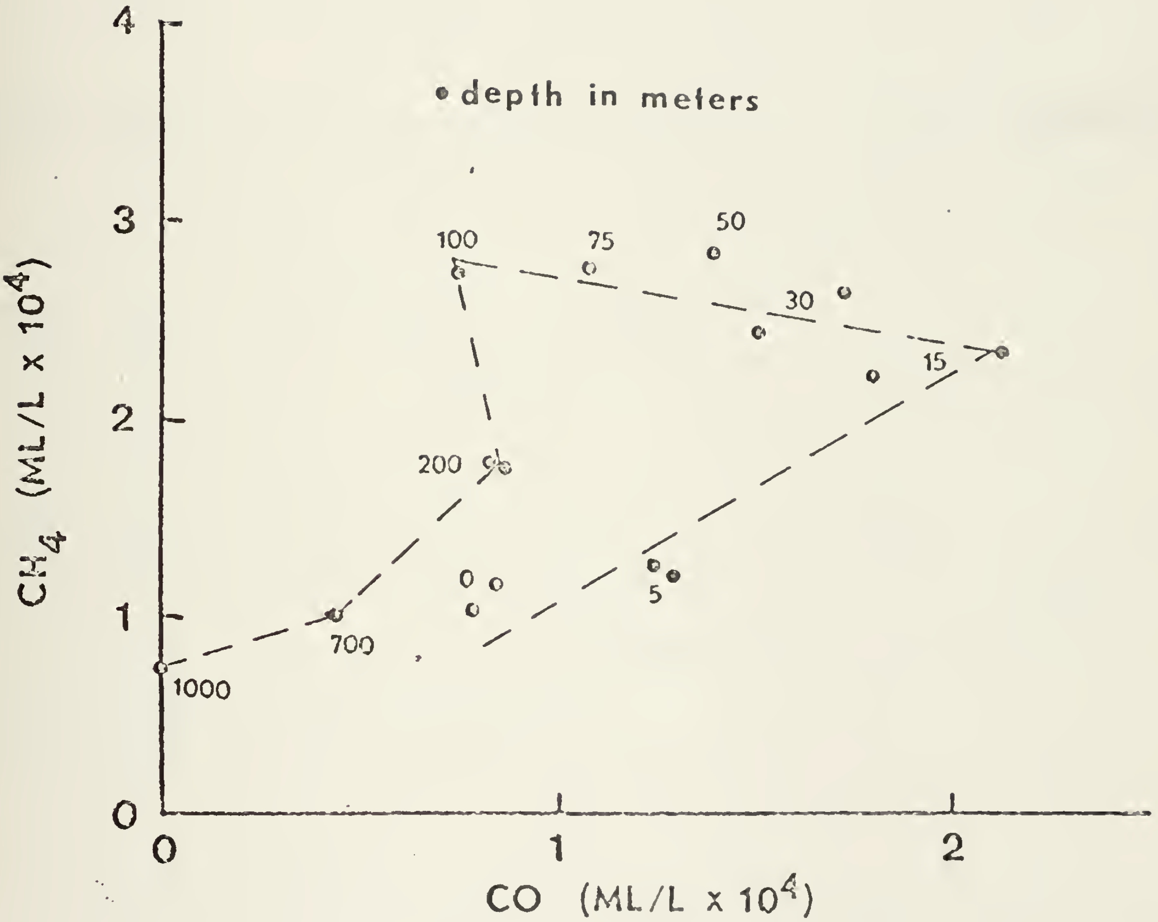

Figure 16. Carbon monoxide versus methane at deep station B.

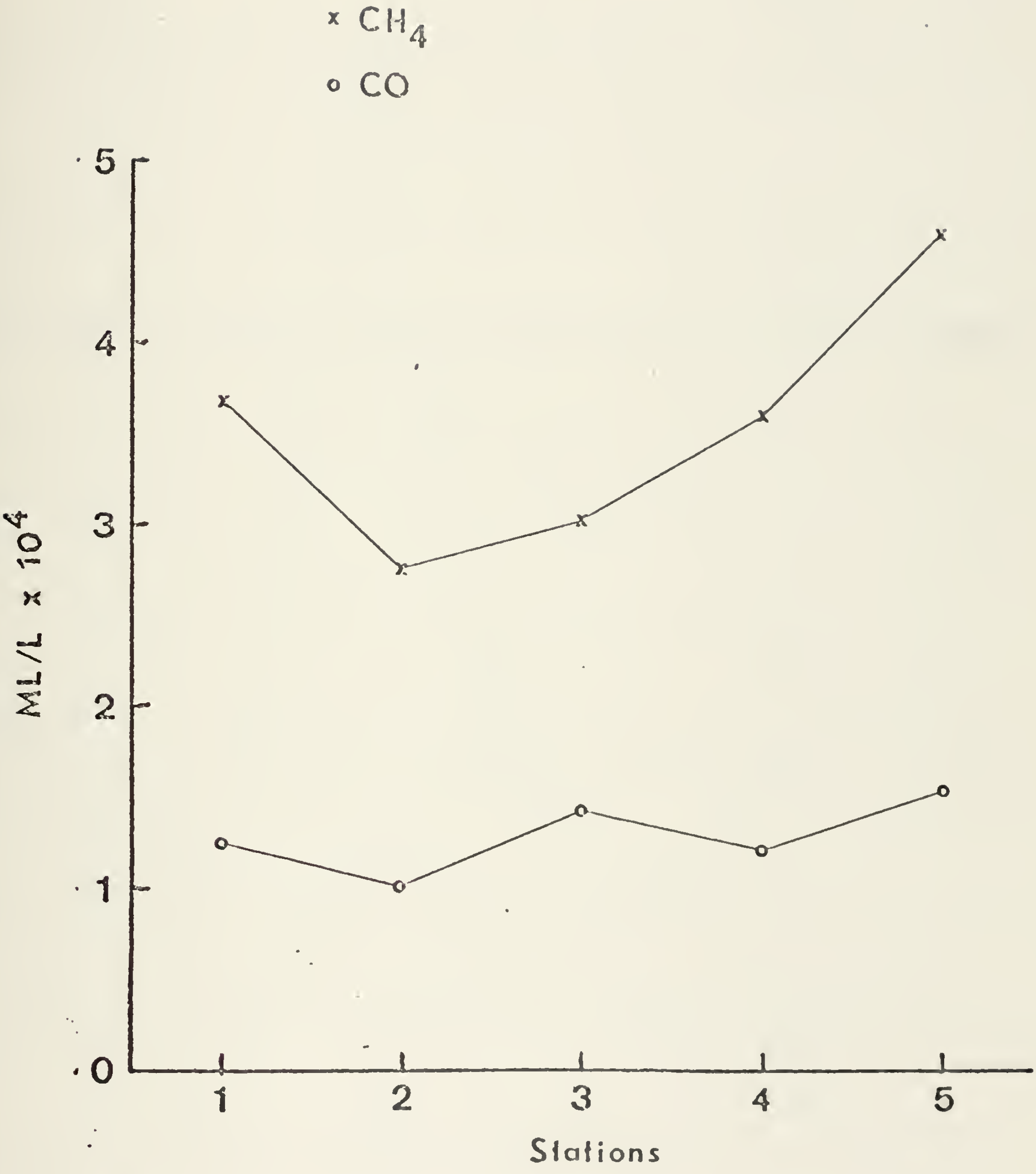

Figure 17. Carbon monoxide and methane on the nearshore gradient. Data plotted from Station 1 (Del Monte) to Station 5 (Point Joe).

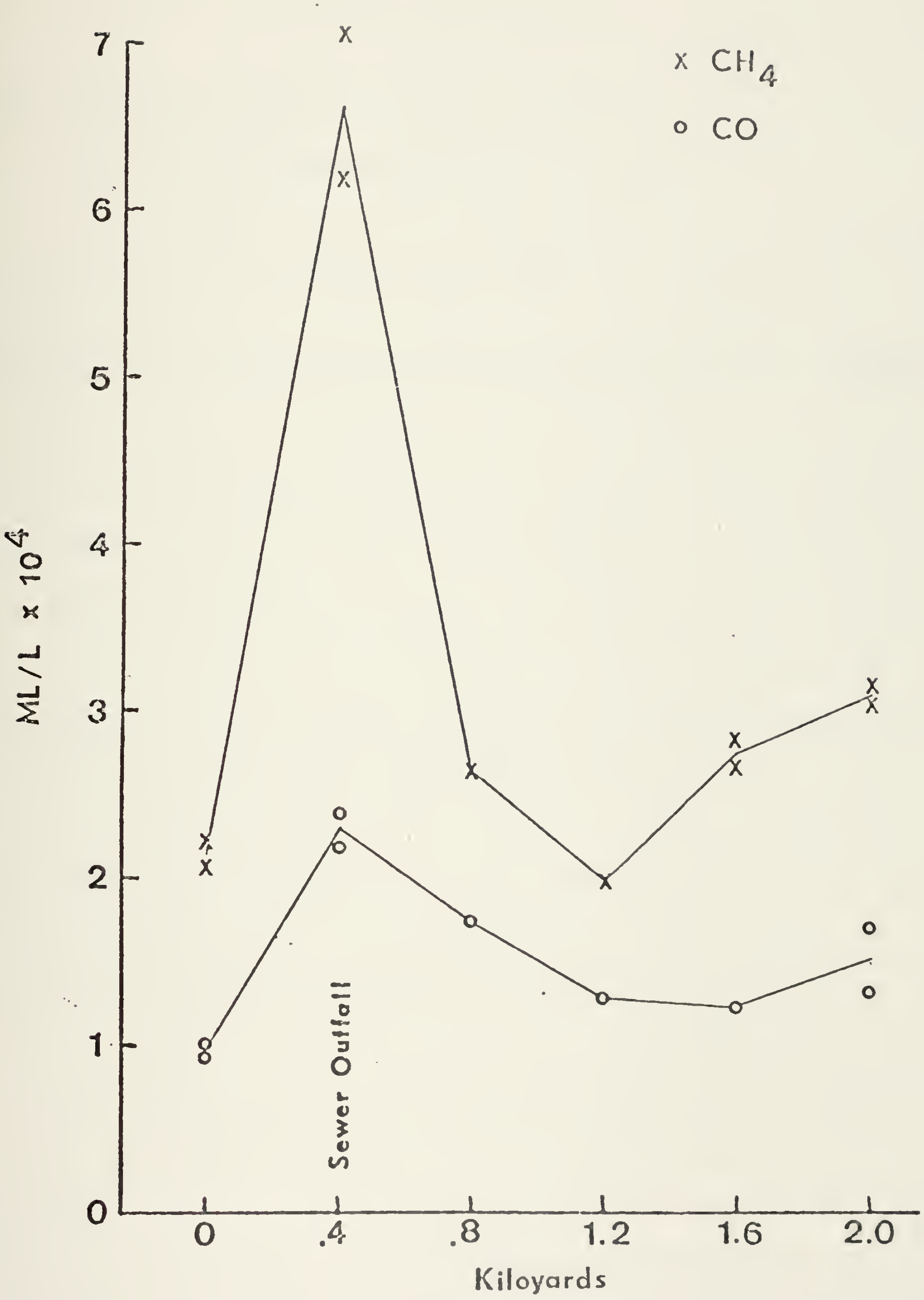

Figure 18. Carbon monoxide and methane on the second longshore transect. Zero is the eastern edge of the Del Monte beach kelp bed.

IV. DISCUSSION

A. PRODUCTIVITY, CHLOROPHYLL, AND NUTRIENTS

1. Nearshore Gradient: Del Monte to Point Joe

The high productivity and chlorophyll standing crop encountered at Del Monte and the decrease seaward was due to a combination of factors. Dunstan and Mengal (1971) have shown that "seawater diluted with secondary-treated sewage effluent provides excellent enrichment" for the maintenance of natural phytoplankton communities. At Del Monte Beach, municipal sewage effluent was present and this, combined with a relatively protected and stable environment, allowed the phytoplankton to proliferate at rates uncommon to the season. Out of the influence of the effluent and into more turbulent waters, productivity and standing crop fell gradually to the outermost station as shown in Figure 8 and Table I. Deep station productivity was on the same order as that of Point Joe.

The high average inorganic nutrient values indicate that Del Monte beach is a phosphate and silicate source (see section 3, below). Nitrates and silicates are replenished at Point Pinos and Point Joe by turbulent upwelling of bottom water in the shallow nearshore. The low values of nitrate and silicate found at the surface of the deep station will be replenished in an analogous manner with the spring upwelling of water. High concentrations of nitrite, sometimes a product of phytoplankton as well as from bacterial reduction of nitrate and nitrification of ammonia, are often found in highly productive areas (Raymont, 1963, and Riley and Skirrow, 1965). In Figure 8, the highest values a nitrite were found inshore, at Del Monte and Point Cabrillo, the areas of highest production.

In contrast to the effect of the sewer outfall at Del Monte, the outfall at Point Pinos had little success stimulating productivity. In fact, it was noticed that the Del Monte outfall is surrounded by healthy kelp while the Point Pinos outfall is devoid of any visible life for about 200 yards. It was surmised that either the Point Pinos effluent was very toxic or that any nutrients there were dispersed quickly by turbulence. It was later found that the Point Pinos sewage is chlorinated to excess while the Del Monte effluent is only lightly chlorinated every three to four days.

2. Seaward Transect: From Del Monte and Point Cabrillo

As previously discussed, productivity increased from open water to the Del Monte kelp bed and decreased from open water to the Point Cabrillo kelp bed. The latter result is probably more typical of uninfluenced kelp beds (i.e., without a sewer outfall) and agrees with the findings of Cowles (1972). In his study of the Point Cabrillo transect, he attributes the lower level of productivity inshore to cell damage due to physical contact with the rocky shore, high bacterial activity, and photodegradation of chlorophyll. The Del Monte phenomenon is apparently due to the enrichening influence of the sewer outfall in a less turbulent or violent environment (sandy beach) which more than compensates for other nearshore hazards to phytoplankton. The fact that the plankton productivity was higher just outside either kelp bed than inside them may be explained by the presence of the kelp itself. The huge biomass of benthic algae is probably in direct competition with the phytoplankton for available nutrients. Those phytoplankton in the bed may simply not have as many nutrients available to them as those just outside. This is borne out to a certain extent in Figure 10, which shows a decrease in silicates, nitrates, and, in one case, phosphates, but more data needs to be taken.

Furthermore, the mass of benthic algae may have a shading effect in the bed preventing phytoplankton there from utilizing available light, which is low in the winter.

3. Longshore Transect: Del Monte Beach

Stevenson (1964) has noted in a current survey of Del Monte Beach that a southwesterly longshore current may develop when a north or northeasterly wind is blowing. It is surmised that these conditions were in effect when the first Del Monte transect was made. Since the outfall "boil" could not be found, it was probably being pumped under reduced pressure. The discharge, indicated by diluted, but still high, phosphates and silicates, was detected southwest of the outfall where the current had moved it. The next time the transect was sampled, the phosphate and silicate source at the Del Monte outfall was confirmed and concentration decreased with distance along the beach. The concentrations of phosphate and silicate at the outfall boil were approximately ten and eight times their respective average values at the most oceanic nearshore station studied (Point Joe). Moreover, the outfall was fifteen and thirteen times the surface concentrations at the deep station with respect to phosphate and silicate.

Productivity was very low, near zero, at the outfall which may have been due to the low salinity or toxic material in the effluent. Dunstan and Mengal (1971) found in a laboratory experiment that sewage: seawater mixtures in excess of 20:80 were inhibiting to marine diatoms with normal seawater salinity requirements. Once out of the immediate vicinity of the outfall, however, productivity increased greatly. High production adjacent to the beach laboratory indicated this to be about the optimum distance from the outfall. Nitrite increased with productivity hinting again that it might be a growth product. The high phytoplankton

standing crop at the outfall contained nearly pure chlorophyll as indicated by the very high acid factor (see below).

B. ACID FACTOR

In the nearshore gradient, the high acid factors indicated the least grazed chlorophyll at Del Monte and Point Cabrillo. However, the range of values showed that a large herbivore population might have been present. As Cowles (1972) points out, low acid factor in the nearshore may also be the result of processes other than grazing, e.g., bleaching of chlorophyll after cell damage in waves or on rocky shores. In fact, in the nearshore, grazing may be the least important factor in evaluating high phaeophytin concentrations. The seaward transect indicated that the lowest acid factors (highest degraded chlorophyll) were indeed the furthest inshore, at or near the kelp beds. This again, could be due to heavy grazing and/or physical cell damage. The longshore transect indicated the Del Monte sewer outfall to be just as inhibiting to zooplankton as to phytoplankton. Acid factor was very high suggesting that the chlorophyll present was not being grazed. Grazing pressure did increase, however, with the distance from the outfall boil.

C. NITROGEN/PHOSPHOROUS RATIOS

In most oceanic waters of the world, the ratio of nitrogen to phosphorous (also called the phytoplankton "assimilation ratio") has been reported to be on the order of 15 or 16 to 1 for both oceanic seawater and uptake by phytoplankton (Riley and Skirrow, 1965). This ratio is somewhat variable, especially in the coastal areas, and has been reported from 5:1 to 24:1. The nearshore gradient, from Del Monte to Point Joe, in four of five weeks showed a remarkably similar trend from low to high N:P ratio. In three of five weeks, the values at Point Joe, from 14.5:1

to 17.5:1 were similar to Riley and Skirrow's figgure. It seems that in this area, the assimilation ratio could be used as a "pollution tracer" with respect to the sewer outfall at Del Monte. The deep station reflected Riley and Skirrow's figure only at a depth of 100-200 meters due to upper layer depletion of nitrate. It is suspected that during the spring upwelling the ratios will become more typical of oceanic water.

D. PRODUCTIVITY/CHLOROPHYLL RATIOS

Pc ratios, that is, the ratios of primary productivity to chlorophyll concentration, have been shown to be a good index of comparative plant physiology (e.g., the effect of nutrient deficiencies) and species composition changes (Riley and Skirrow, 1965). High Pc ratios indicate a healthy or efficient state in a given population or characterize efficiency differences in different species. In Figure 14, Del Monte and Point Cabrillo seem to be on the same physiological level as do the two Point Pinos stations with a higher ratio. The much lower Pc ratio at Point Joe (Station 5) may reflect the low phosphate concentrations or some other physiological deficiency. There was a different genus of kelp at Point Joe, Nereocystis, which may indicate some environmental change. On the other hand, the different levels may be due to changes of the species composition of phytoplankton populations living on bay coast as opposed to oceanic coast. The deep water stations gave Pc values of 2.9 and 2.8 which indicate conditions or populations similar to those between Point Pinos and Point Joe. Figure 15 shows a definite proportionality between productivity and chlorophyll concentration suggesting most all the chlorophyll is contained in living plant cells (Steele and Baird, 1961).

E. CARBON MONOXIDE, METHANE, AND PRODUCTIVITY RELATIONSHIPS

Comparisons between carbon monoxide, methane, and productivity at the deep stations and at the outer nearshore stations, Point Pinos and Point Joe, are interesting. Comparing Figures 6 and 16, it is evident that there was a CO source in the upper 15 meters were productivity was productivity was highest. Below 15 meters, where productivity decreased, CO decreased rapidly also. It is theorized that certain bacteria which utilize CO reduced its concentration in the deeper water (Welch, 1973). In the nearshore gradient (Figure 17), a rise in CO occured between Point Pinos and Point Joe. In previous discussion, it was seen that the productivity and standing crop between these last two stations were very close to the deep station values. Moreover, Pc ratios showed like physiological conditions or populations in the area between Point Pinos and Point Joe and at the deep sations. Hence, the similar phytoplankton populations in the ares between Point Pinos and Point Joe and at the deep stations both showed a strong correlation with carbon monoxide production. Much more work needs to be done, however, to show a causal relationship.

Very little, if any, correlation was seen between primary production and CO and CH_4 concentrations in the longshore transect (Figures 12 and 18). This is probably due to large perturbations caused by the sewer outfall which effectively masks any correlations.

F. ENVIRONMENTAL EFFECTS

The period of study was characterized by a series of miniature blooms which are not uncommon in midwinter in shallow water (Doty, 1961). Small-scale, short-term vertical turbulence caused by storms periodically add nutrient-rich bottom water to surface layers in sublittoral areas, but nutrients are quickly depleted in the new mixed layer and are not renewed

until the next storm. In addition, rain and land runoff may lower salinities, prohibiting phytoplankton from frequenting the uppermost layers where they can best utilize the limited light available.

Figure 19 shows a time study of productivity for the five nearshore stations. Primary productivity was high during early weeks but was cut down drastically during the first heavy rains (Figure 2). Periods following the rain during the fifth, sixth, and ninth weeks showed productivity minimums. The reduction of light and the lowering of temperature with the onset of winter also limited the maximum value of the observed "mini-blooms" (Raymont, 1963). Nutrient renewal by turbulence was very evident at the outer nearshore stations (Point Pinos and Point Joe), but there also could have been nutrients added by land runoff. In fact, this factor could have varied from station to station.

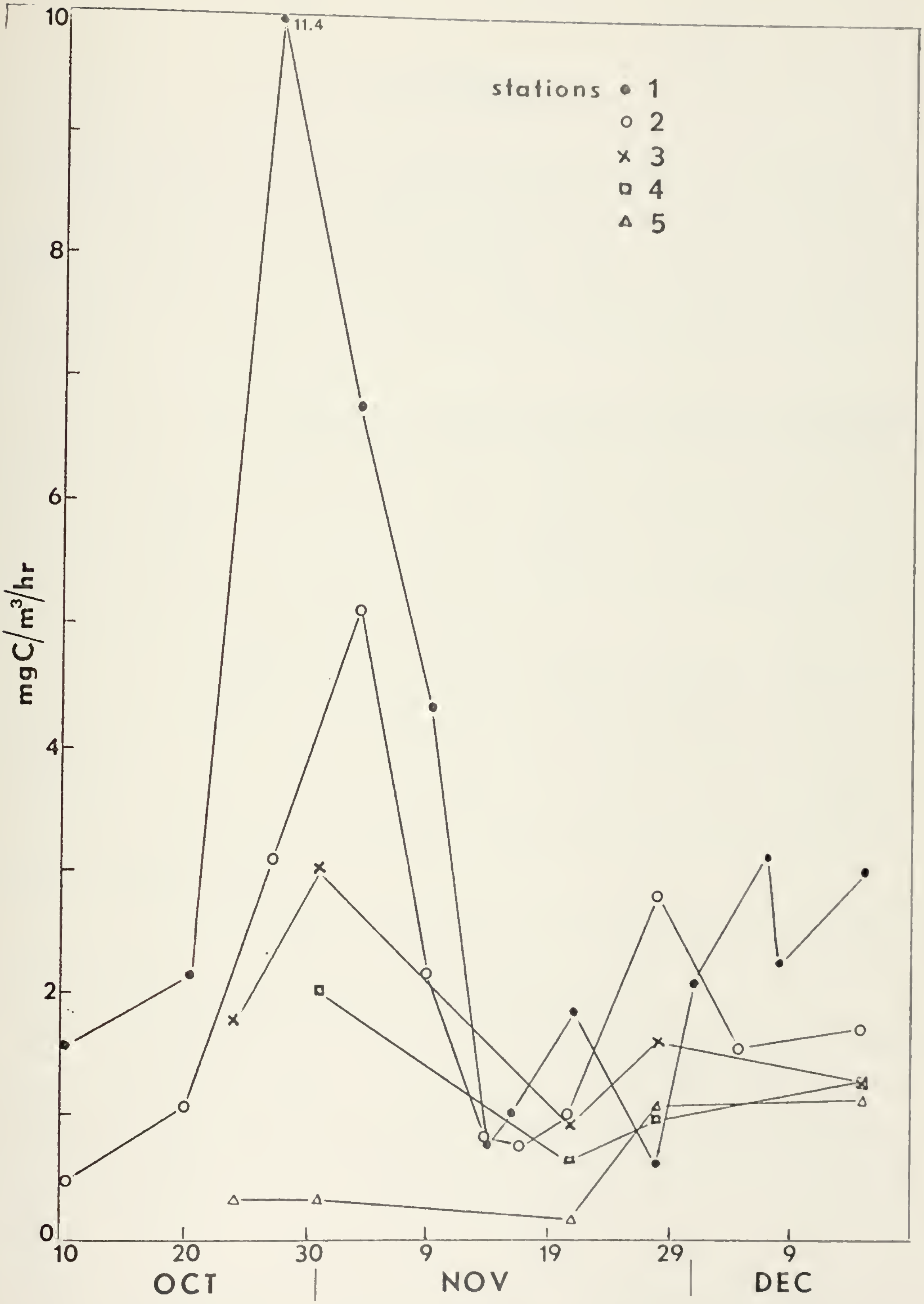

Figure 19. Time study of the productivity at the nearshore stations during the sampling period.

V. SUMMARY

As a result of this study, the following conclusions were made.

1. The value of the "gradient analysis" in revealing relations between biological and chemical parameters is seen, and it is recognized as a useful tool for monitoring and prognosticating the state of the environment. In particular:

    a. Primary productivity and standing crop in the sublittoral zone decrease significantly from Del Monte beach around the coast to Point Joe. A nutrient-rich and non-toxic sewer outfall at Del Monte beach and the gradient from a calm, sandy, bay environment to an exposed, rocky, oceanic coast are responsible for this trend.

    b. The ideal growth conditions at Del Monte also reverse a trend for productivity to increase from the nearshore to an open water environment.

    c. Nitrogen to phosphorous ratios are pollutions tracers for certain sewer outfalls.

    d. Productivity to chlorophyll ratios indicate unique phytoplankton habitats or populations in the area studied.

2. Two different municipal sewer outfalls have profoundly different effects on the environment. In just meeting the "letter of the law", the Del Monte outfall enhances an already productive area. The Point Pinos outfall, by adding toxicants beyond that required, creates a local abiotic area.

3. A correlation is seen between carbon monoxide production and primary productivity at the deep water stations and the nearshore oceanic coast stations.

APPENDIX A - CRUISE DATA

Symbol	Meaning
CRU	cruise number
Z	depth in meters of sample
T	sea surface temperature in °C
LOC	location
---	transect
Se	Secchi depth in meters
PP	productivity in mgC $m^{-3} hr^{-1}$
Cl	chlorophyll in mg/m^3
C/P	acid factor
N3	nitrate in ug-at/l
S	silicate in ug-at/l
P	phosphate in ug-at/l
N2	nitrite in ug-at/l
DM	Del Monte
PC	Pt. Cabrillo
PN	Pt. Pinos North
PS	Pt. Pinos South
PJ	Pt. Joe
CC	buoy adjacent to Pt. Cabrillo
HAR	Monterey harbor

Week of study	Cruise number applicable
1	1,2
2	3,4
3	5,6
4	7,8
5	10
6	11, 12, 13
7	14
8	15, 16
9	17, 18, 19
10	20, 21

CRU	DATE	LOC	TIME	Z	T	Se		PP	Cl	C/P		N3	S	P	N2	
0	7/26	HAR	1130	2	18			1.57				1.25	3.60	1.10	.15	
			1330		19.5			2.43				1.02	5.25	.21	.12	
			1530		19			0				1.38	3.15	.40	.10	
			1730		17.8			.64				.65	2.95	.14	0	
			1930		17.5			.84				.02	4.75	.21	0	
			2130		17.2			.42				.08	2.60	.38	0	
			2330		16.5			.13				.32	1.70	.34	.02	
			0130		16.7			.27				.65	2.20	.78	.05	
			0330		16.9			0				.85	3.65	.54	.10	
			0530		16.5			.48				.82	6.35	.39	.12	
			0730		16.6			.68				.65	2.80	.20	.08	
			0930		16.9			.41				0	2.75	.15	0	
1	10/10	PC		1	16			.44				.58	2.35	.56	.27	
		DH						1.59				.80	2.90	.93	.33	
2	10/13	CC		5	16			2.25								
								1.71								
								3.19								

CRU	DATE	LOC		Z	T	Se		PP	C1	C/P		N3	S	P	N2	
3	10/19	CC		0				1.67								
				5				.40								
				15				0								
				30				.08								
4	10/20	PC		1	16			1.14				1.55	1.90	.39	.40	
				3				.30				3.00	3.3	.5	.51	
				5				.27				3.65	4.05	1.34	.66	
		DH		1				2.15				.03	3.65	.51	.26	
				3				.88				.53	3.5	.74	.26	
				5				.71				1.22	1.45	.74	.86	
5	10/24	MH		1	15.5			1.79				.38	2.6	.54	.39	
				3				0								
		PJ		1				.37				4.72	2.55	.32	.42	
				3				.48				5.52	5.45	.64	.54	

CRU	DATE	LOC		Z	T	Se		PP	Cl	C/P		N3	S	P	N2	
6	10/27	FC		½	15			3.08				0	2.75	0	.20	
				2				1.72				.50	3.2	.23	.29	
		DH		½				11.4				.85	5.05	1.64	.28	
				2				6.37				.80	4.95	1.8	.23	
7	10/31	MI		1	15			3.05				.15	3.85	.55	.28	
		IS						2.08				2.9	4.4	.65	.46	
		FJ						.37				-8.42	7.0	.48	.27	
8	11/3	FC		½	15.5	8		5.12	.72	1.49		0	2.15	.17	.22	
		DM				5		6.80	3.39	1.40		0	8.15	.86	.14	

CRU	DATE	LOC		Z	T	Se		PP	Cl	C/P	Z	N3	S	P	N2	
9	11/7	DEEP		0		17		1.17	.52	1.38	0	2.15	2.65	.46	.49	
		36-44N		5				1.36	.47	1.47	5	2.42	3.10	1.08	.48	
		122-7W		12				1.09	.51	1.28	15	1.98	2.55	1.19	.29	
				18				.46	.49	1.30	30					
				46				.33	.38	1.25	50	9.95	7.0	1.2	.14	
											75	14.4	10.8	1.3	.39	
											100	15.3	11.6	1.16	.16	
											200	20.9	18.7	1.08	.02	
											500	33.4	49.8	1.31	.23	
											700	31.9	32.0	1.17	.05	
											1000	31.8	49.4	2.68	.64	
		DEEP		0		17		1.12	.40	1.24	0	2.52	2.65	1.16	.66	
		36-44N		5				.79	.45	1.26	5	3.08	2.75	8.36	1.17	
		122-5W		12				.72	.44	1.20	15	2.25	2.75	1.62	.46	
				18				.50	.43	1.28	30	5.3	3.35	.98	.34	
				46				.18	.41	1.16	50	10.7	7.55	1.0	.36	
											75	10.5	7.45	.82	.16	
											100	11.7	8.3	.93	.15	
											200	26.4	24.5	1.63	.12	
											500	31.1	42.7	2.44	.13	
											700	29.1	35.0	2.72	.10	
											1000	32.6	39.0	2.67	.23	

CRU	DATE	LOC		Z	T	Se		PP	Cl	C/P		N3	S	P	N2	
10	11/9	PC		½	13.7	8		2.15	.80	1.23		0	3.8	.03	.11	
		DM				5		4.34	1.25	1.36		3.25	10.0	1.26	.39	
11	11/14	PC		½	13.5	8		.84	.55	1.28		2.65	2.75	.76	.52	
		DM				5		.78	.88	1.25		3.3	7.65	.84	.37	
12	11/16	DM	east	½	13			.81	.54	1.22		.75	1.25	.56	.17	
			↓					.55	.88	1.26		1.22	2.0	.57	.18	
								1.03	.61	1.18		1.18	.1	3.04	2.32	
								.82	.66	1.11		2.05	5.75	.93	.34	
			west					1.09	.84	1.14		1.75	4.65	.4	.36	
13	11/17	PC		0	13.8			.56	.47	1.15		1.52	1.5	.36	.29	
				2				.73	.43	1.18		1.45	1.35	.26	.26	
				5				.54	.41	1.16		1.4	1.6	.26	.29	

CRU	DATE	LOC		Z	T	Se		PP	C1	C/P		N3	S	P	N2	
14	11/21	PJ		1	12.8	9		.12	.48	1.21		5.1	4.05	.22	.37	
		PS				6		.67	.32	1.13		4.78	3.9	.10	.27	
		PN				8		.95	.42	1.17		4.08	4.35	0	.27	
		PC				5		.99	.56	1.46		3.48	4.95	0	.28	
		DH				3.5		1.89	.65	1.17		3.08	8.05	0	.20	
15	11/28	PJ		1	13.2	9		1.07	.39	1.2		7.47	7.5	.5	.59	
		PS				6		1.02	.36	1.2		8.52	8.0	.8	.74	
		PH				6		1.59	.51	1.23		7.1	7.45	.83	.72	
		PC				5		2.83	.58	1.2		5.22	7.8	1.08	.76	
		DM				2		.61	.56	1.15		6.68	15.4	2.74	.59	
16	12/1	DM		½	12.2	3		2.11	.58	1.28		5.95	9.4	0	.62	
		↓				5.5		2.85	.61	1.24		3.18	11.6	0	.72	
		↓		1		11		2.75	.61	1.24		4.24	4.3	0	.51	
		↓				12		2.66	.67	1.29		4.08	4.7	0	.42	
		CC				13		2.09	.53	1.4		3.78	4.3	0	.38	

CRU	DATE	LOC		Z	T	Se		PP	C1	C/P		N3	S	P	N2
17	12/5	PC		1	11.6	9		1.55	.59	1.22		1.95	2.45	0	.77
		↓				10		1.61	.58	1.28		2.38	3.1	0	.47
		↓				11		1.45	.45	1.19		3.02	4.35	.5	1.19
		↓				11		1.71	.53	1.24		2.38	2.9	0	.67
		CC				13		1.82	.48	1.26		1.3	.95	0	.81
18	12/7	DM		0	11.5	4		1.85	1.03	1.25		2.02	4.25	3.09	.98
				1.5				3.15	1.24	1.38		1.85	2.95	2.25	1.18
				2.5				2.02	.82			2.2	3.2	.82	1.12
19	12/8	DM	west	½	11.0	3.5		2.29	1.15	1.22		2.87	5.7	1.54	1.4
			↓			3.5		2.19	1.09	1.29		2.5	4.5	1.84	1.42
			↓			4.5		2.28	.74	1.18		4.0	7.65	0	.5
			↓			5		1.57	.79	1.31		3.22	8.95	1.34	.7
			east			3.5		.05	1.45	1.97		4.4	41.6	9.96	.95

CRU	DATE	LOC		Z	T	Se		PP	C1	C/P		N3	S	P	N2	
20	12/14	CC		1	10	11.5		1.6				5.72	8.6	.8	1.25	
		↓				13		1.26				6.0	8.2	0	.95	
						12		1.72				6.2	9.1	.64	1.26	
						11.5		3.13				4.85	8.4	.27	1.09	
		DM				10		3.02				5.75	9.55	1.19	1.21	
21	12/15	PJ		1	10.5	14		1.15				5.18	5.7	0	.75	
		PS				14		1.3				5.72	6.7	.07	.87	
		PN				13		1.31				6.25	6.9	1.08	1.37	
		PC				10		1.7				5.8	7.4	.4	1.35	
		↓				11.5		1.95				5.4	6.85	.8	1.44	
						13		1.25				3.68	4.4	0	.75	
		CC				14		1.13				6.8	8.1	.28	.76	
22	1/12	CC		1	13.5			2.57								
		↓						1.93								
								1.82								
		PC						1.57								

REFERENCES

Corcoran, E.F., and Alexander, J.E., "Nutrient, Chlorophyll, and Primary Production Studies in the Florida Current," Bulletin of Marine Science of the Gulf and Caribbean, v. 13 (4), p. 527-541, Dec 1963.

Cowles, T.J., Nearshore Variations in Phytoplankton Productivity, Standing Crop, and Community Composition, Hopkins Marine Station of Stanford University, 1972.

Doty, M.S. and Oguri, M., "Evidence for a Photosynthetic Daily Periodicity," Limnology and Oceanography, v. 2 (1), p. 37-40, 1957.

Doty, M.S., and Oguri, M., "The Carbon-Fourteen Technique for Determining Primary Plankton Productivity," Publ. Staz. Zool. Napoli, v.31, p. 70-94, 1959.

Doty, M.S. (ed.), Primary Productivity Measurement, Marine and Freshwater, proceedings of the conference held at University of Hawaii, Honolulu, Hawaii, 21 Aug. - 6 Sept. 1961.

Dunstan, W.M., and Menzel, D.W., "Continuous Cultures of Natural Populations of Phytoplankton in Dilute, Treated Sewage Effluent," Limnology and Oceanography, v. 16 (4), p. 623-632. 1971.

Harvey, H.W., The Chemistry and Fertility of Sea Waters, University Press, 1955.

Holm-Hansen, O., Lorenzen, C.J., Holmes, R.W., and Strickland, J.D.H., "Fluorometric Determination of Chlorophyll," J. Coun. perm. int. Explor. Mer, v. 30 (1), p. 3-15, 1965.

Jitts, H.R., and Scott, B.D., "The Determination of Zero-Thickness Activity in Geiger Counting of C^{14} Solutions Used in Marine Productivity Studies," Limnology and Oceanography, v. 6 (2), p. 116-123, 1961.

Lorenzen, C.J., "Diurnal Variation in Photosynthetic Activity of Natural Phytoplankton Populations," Limnology and Oceanography, v. 8 (1), p. 56-62, 1963.

McAllister, C.D., and Strickland, J.D.H., "Light Attenuators for Use in Phytoplankton Photosynthesis Studies," Limnology and Oceanography, v. 6 (2), p. 226-228, 1961.

McAllister, C.D.,"Measurements of Diurnal Variation in Productivity at Ocean Station 'P'," Limnology and Oceanography, v. 8 (2), p. 289-292, 1963.

Paulson, G.O., A Study of Nutrient Variations in the Surface and Mixed Layer of Monterey Bay Using Automatic Analysis Techniques, M.S. Thesis, Naval Postgraduate School, 1972.

Raymont, John E.G., Plankton and Productivity in the Oceans, The MacMillan Company, 1963.

Riley, J.P., and Skirrow, G., (eds.), Chemical Oceanography, Academic Press, 1965.

Ryther, John H., "The Measurement of Primary Production," Limnology and Oceanography, v. 1 (2), p. 72-84, 1956.

Steele, J. H., and Baird, I. E., "Relations Between Primary Production, Chlorophyll and Particulate Carbon," Limnology and Oceanography, v. 6 (1), p. 68-77, 1961.

Steemann-Nielsen, E., "The Use of Radioactive Carbon (C^{14}) for Measuring Organic Production in the Sea," J. Coun. perm. int. Explor. Mer, v. 18 (2), p. 117-140, 1952.

Steven, D.M., Brooks, A.L., and Moore, E.A., Primary and Secondary Production in the Tropical Atlantic, Bermuda Biological Station, Dec. 1970.

Stevenson, C.D., A Study of Currents in Southern Monterey Bay, M.S. Thesis, Naval Postgraduate School, 1964.

Strickland, J.D.H., and Parsons, T.R., A Practical Handbook of Seawater Analysis, Fisheries Research Board of Canada, 1968.

Taylor, W.R., and Hughes, J.E., Primary Productivity in the Chesapeake Bay During the Summer of 1964, Chesapeake Bay Institute - The Johns Hopkins University, Apr. 1967.

Welch, J.T., Gradient Analysis of Carbon Monoxide and Methane Concentrations in Nearshore Habitats, M.S. Thesis, Naval Postgraduate School, 1973.

Welch, R.H., A Study of the Stratification of Phytoplankton at Selected Locations in Monterey Bay, California, M.S. Thesis, Naval Postgraduate School, 1967.

Yentsch, C.S. and Menzel, D.W., "A Method for the Determination of Phytoplankton Chlorophyll and Phaeophytin by Fluorescence," Deep-Sea Research, v. 10, p. 221-231, 1963.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Assoc Professor E.D. Traganza, Code 58tg (thesis advisor) Department of Oceanography Naval Postgraduate School Monterey, California 93940	7
4.	LT John V. Rowney, USN 1208 Awalt Drive Mountain View, California 94040	1
5.	Department of Oceanography Naval Postgraduate School Monterey, California 93940	3
6.	Oceanographer of the Navy The Madison Building 732 N. Washington Street Alexandria, Virginia 22314	1
7.	Dr. Ned A. Ostenso Code 4800 Office of Naval Research Arlington, Virginia 22217	1

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

RIGINATING ACTIVITY *(Corporate author)*

Naval Postgraduate School
Monterey, California 93940

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3 EPORT TITLE

Gradient Analysis of Phytoplankton Productivity and Chemical Parameters in Polluted and Other Nearshore Habitats

4 ESCRIPTIVE NOTES *(Type of report and, inclusive dates)*

Master's Thesis; March 1973

5 AUTHOR(S) *(First name, middle initial, last name)*

John Victor Rowney

6 EPORT DATE
March 1973

7a. TOTAL NO. OF PAGES
65

7b. NO. OF REFS
25

CONTRACT OR GRANT NO.

PROJECT NO.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Naval Postgraduate School
Monterey, California 93940

ABSTRACT

Measurements of primary productivity, chlorophyll standing crop, and nutrient concentrations were made along a gradient of five nearshore habitats, a seaward transect, and a longshore transect to determine environmental relationships. The effects of municipal sewer outfalls, type of shoreline, and degree of exposure to high winter seas were found to be dramatic. The behavior of nutrient ratios suggest their use as pollution tracers in certain circumstances. The ratios of productivity to chlorophyll demonstrated physiological regimes among the phytoplankton in the sampling area. Comparison of data with carbon monoxide and methane concentrations provided a possible correlation between phytoplankton productivity and carbon monoxide production.

4. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
primary productivity						
plankton						
pollution						
nearshore						
nutrients						
chlorophyll						
sewage						
effluent						
carbon monoxide						
methane						
sublittoral						
zooplankton						
grazing pressure						
acid factor						

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

Thesis 143252
R823 Rowney
c.1 Gradient analysis of phytoplankton productivity and chemical parameters in polluted and other nearshore habitats.