MICROPLANKTON AND OTHER SESTON COMPONENTS IN COASTAL WATERS NEAR THE POINT LOMA (SAN DIEGO) SEWAGE OUTFALL

J.R. BEERS, F.M.H. REID AND G.L. STEWART
Institute of Marine Resources
University of California San Diego
La Jolla, CA 92093

ABSTRACT

A report of high phytoplankton abundance at the Point Loma (San Diego) sewage outfall in July 1970, presumably as the result of increased nutrient supply, prompted our study on two occasions (June 1972 and August 1973) of a series of sites extending approximately 8 km to both the north and south of the outfall in an attempt to detect any enhanced activity of the larger microplankton (mainly dinoflagellates, which could be heterotrophs, and microzooplankton) near the outfall. Standing stocks of nutrients, seston dry weight, adenosine triphosphate (ATP), chlorophyll *a*, and microplankton taxa and abundance (principally in the 35-μm mesh net fraction) were determined over the water column. A plume of ammonia, most pronounced at approximately 30-40 m, was found in June 1972 extending from the outfall to the north and northwest. At the stations north of the outfall, both the seston dry weight and ATP levels were higher in the depth interval coinciding with the enhanced ammonia levels than they were at the southern stations. The components of the microplankton studied did not show marked differences in abundance.

INTRODUCTION

Numerous coastal municipalities, including San Diego, continually discharge effluent from sewage treatment plants into the nearshore marine environment. Chemical substances in the discharges include material that may be utilized by heterotrophic and autotrophic organisms for their growth and reproduction. For example, the abundant ammonia that has been found in the effluents (Thomas 1972; Hendricks and Harding 1974) could provide an important nitrogen source for photosynthetic forms. If the magnitude of the input of nutrients from the outfalls relative to the level supplied from other sources, e.g. in situ regeneration and upwelling, is large, then it can be hypothesized that the regions around such effluents have the potential for supporting relatively high production which may be seen as large standing crops of organisms. Realizing this, however, would be dependent upon such factors as the nature of the circulation in the affected area; the absence of growth-suppressing materials such as heavy metals, organic pesticides, etc. in the discharge; and zooplankton grazing pressures that do not result in rapid cropping of new production. Nutrient and hydrographic studies of San Diego coastal waters (e.g. University of California, Institute of Marine Resources 1968), while showing periods of intense upwelling with relatively high nutrient levels within the euphotic zone, also show extensive periods when nutrient values are low and probably limiting to primary production. It is during these latter periods that outfall discharges would be most apt to have a demonstrable effect on populations of autotrophs.

Interest in the effects of outfall discharges into southern California waters on planktonic and benthonic populations is relatively long-standing (e.g. Resig 1959, 1960; Allan Hancock Foundation, University of Southern California 1965a, b). In more recent years there has been quickened concern with outfall areas due to the fear that discharges into the marine environment might be detrimental to the varied uses of coastal waters. The opportunities for observations on factors affecting biological production provided by the outfall sites stimulated studies of the plankton near southern California outfalls, including that at San Diego (i.e. the Point Loma outfall), by several members of the University of California's Institute of Marine Resources (e.g. University of California, Institute of Marine Resources 1972; Eppley et al. 1972; Thomas 1972). These studies considered primarily the photosynthetic populations within the euphotic zone and provided evidence that the areas directly adjacent to outfalls, including that at Point Loma, can be, at least at times, eutrophic compared to other coastal regions. Eppley et al. (1972) reported eutrophication at the San Diego outfall, evidenced by phytoplankton crops and productivity several times higher than that at a "control" site near the Scripps Canyon off La Jolla. In addition, their calculation of specific growth rates for the phytoplankton crop at the outfall showed similar rates to those at the control site, thus implying no strong inhibitory effects of the discharge.

The role of trophic levels above that of primary producers within the euphotic zone at the outfalls has received relatively little attention. The purpose of the present study was to identify and quantitatively describe the animal as well as the plant components of the microplankton populations (i.e. pelagic organisms other than bacteria that would normally *pass* approximately 200-μm mesh netting) directly at the San Diego outfall and at adjacent sites that would not be expected to have significant chemical enrichment from the sewage discharge. The work concentrated on the fraction of the microplankton that would be retained on 35-μm mesh netting. Amongst the dominant components of this population are the dinoflagellates, many species of which may be heterotrophic or even phagotrophic. Also prominent are ciliate protozoans which, because of their mode of reproduction and reproductive capacity, are in a position to affect food chain dynamics in a markedly different manner from metazoans. Most importantly, they have the ability to respond quickly to changes in their environment, and species successions can occur rapidly. The predominant micrometazoans are copepod developmental stages.

In contrast to some earlier studies, the total water column, to within a few meters of the bottom, was examined. If the populations resulting from higher primary production in the euphotic zone were not being utilized or removed by lateral transport, they could be settling and providing the basis for enhanced heterotrophic and/or phagotrophic activity below the compensation depth. Organic enrichment from the outfall could be utilized for heterotrophic production. Hence, when the discharge wastefield is effectively held below the euphotic zone by its density characteristics relative to the upper water, the potential for heterotrophic/phagotrophic production at some deeper level of the water column may be established.

In addition to microscope study of the microplankton, chemical or gravimetric estimates were made of other parameters of the microseston. The nutrient concentrations and hydrographic conditions were examined at each station.

MATERIALS AND METHODS

Sampling was done from the R/V *Alexander Agassiz* at 10 sites within a grid extending 5 miles (8.1 km) to the NNW and SSE and 1.5 miles (2.4 km) seaward of the outfall (Figure 1) during the daylight hours of 23 and 24 June 1972. Stations 1-7 were repeated during the day of 10 August 1973. Stations 1-7 were in an approximately straight line following the contour of the water depth found at the outfall. Except for the two southerly sites off the mouth of San Diego Bay, the stations were approximately equidistant from shore. The numbering of the stations is in the order of sampling in June 1972. In August 1973 the stations were sampled from south to north, i.e. 7, 6, 5, 1, 2, 3, and 4.

Some earlier studies of the outfall plankton populations have employed control stations at greater distance from the outfall than our most distant site and often with different characteristics such as water column depth, euphotic depth, distance from shore, etc. (e.g. Eppley et al. 1972 used the Scripps Canyon off La Jolla). Studies of the benthic populations in the vicinity of Point Loma have indicated an assymetrical gradient of effects around the outfall. Chen et al. (1972 seen in Southern California Coastal Water Research Project [SCCWRP] 1973) found that stations to the north show a more marked effect than those to the south. In this study we have chosen to examine a series of similarly situated stations to both the north and south of the outfall, presuming that, dependent upon the circulation at the time of the observations, one direction would be downstream of the discharge whereas the other would be upstream. Considering the total water column, however, this can be complicated if the currents vary at different depths. Hendricks (SCCWRP 1973), in his modelling of the phytoplankton in outfall areas, points out that maximum response could occur at some distance (e.g. several km) from the discharge. Dependent upon the amount of shear, if any, between surface and subsurface currents, the discharge may be moving in one direction away from the outfall while enhanced phytoplankton crops could appear in the opposite direction.

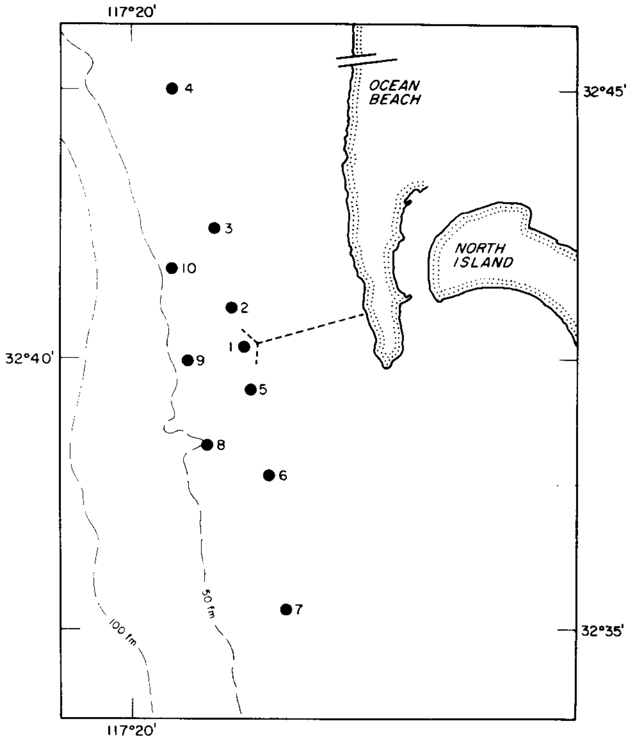

Figure 1. Location of sampling sites. Station 1 is at the terminus of the outfall.

A pumping system, incorporating a Flotec Inc. Rotalator Impeller Pump (Series R5S1), 1-inch (2.5-cm) I.D. Heliflex™ reinforced PVC hose, a voluming meter, and plankton concentrator (35-μm mesh netting), was used to obtain integrated samples over four standard depth intervals of surface–15 m, 15–30 m, 30–45 m, and 45 to within a meter or two of the bottom (60–70 m) at each station. The hose intake was moved through the water column at appproximately 1.5 m/minute.

A constant fraction of the pumped water was accumulated over each depth interval for analysis of chlorophyll *a* and phæophytin by the fluorometric method (Yentsch and Menzel 1963; Holm-Hansen et al. 1965), adenosine triphosphate (Holm-Hansen and Booth 1966), and total seston dry weight by a modification of the procedure of Banse et al. (1963) in which an ammonium formate solution, isotonic with seawater, was used to rinse the filters of salts. Sample volumes varied depending upon their content of total particulate matter. In June 1972 they averaged 500 ml for chlorophyll *a*, 376 ml for ATP, and 942 ml for seston dry weight; and in August 1973, 331 ml for chlorophyll *a*, 341 ml for ATP, and 549 ml for seston dry weight. The chlorophyll filters from the June 1972 sampling were inadvertently removed from the freezer for an unknown length of time, possibly as long as 48 hours, but were *not* exposed to light. Tests simulating the various possible conditions of this occurrence using water with the same approximate chlorophyll level indicated that a consistent loss of up to approximately ¼-⅓ of the chlorophyll could have resulted. Hence, the data are used only in supplementary discussion.

The pumped water also provided an unconcentrated (UNCONC) sample of the small microplankton for determination of the numerical abundance and biomass of taxa too small to be quantitatively retained on 35-μm mesh netting. These samples have been enumerated at selected sites only. The larger components of the microplankton were concentrated on 35-μm mesh netting (+35 CONC samples) from approximately 60-150 liters of pumped seawater. Fixation/preservation of both the UNCONC and +35 CONC samples was at 2% formaldehyde. Sodium borate and $SrCl_2$ were included in the fixative to aid in the preservation of calcareous and strontium-containing organisms, respectively. Analysis of the samples was by inverted microscope procedures described in Reid et al. (1970) and Beers and Stewart (1970).

Taxa identified in the +35 CONC samples were those that would be expected to be quantitatively retained on 35-μm mesh netting and that could be identified at magnifications of 100-200X. Non-thecate dinoflagellates were not included because of possible damage to these delicate forms during net concentration. In general, one subsample of the greatest volume that could be settled without being too dense for good counting was studied from each sample. The unconcentrated sample volume represented in each +35 CONC subsample varied but was generally at least a liter.

In the Results section that follows, the measure of variability routinely given is one standard deviation. When stations to the north and south of the outfall are compared and there is no overlap of a parameter's mean ± one standard deviation they will be considered "dissimilar." They will be identified as "different" if there is no overlap of the means ± two standard deviations. In addition, a non-parametric statistic, the Mann-Whitney rank test (see Tate and Clelland 1957), having no assumptions as to the normalcy of the data, was used to detect differences between stations. Because of the limited number of sites being compared, the test provides an indication of difference only to the 0.10-probability level.

In order to characterize the environment of the microplankton, hydrographic (temperature and salinity) and nutrient chemistry measures (nitrate and nitrite-N, ammonia-N, and phosphate-P by methods outlined in Strickland and Parsons 1972) were made on Nansen reversing water bottle samples from every 10 m (surface to 60 or 70 m) over the total water column depth.

RESULTS

Hydrography

Temperature profiles for the two studies are shown in Figure 2. Average surface temperature was 20.1 (±0.3)°C in June 1972 and 18.6 (±0.2)°C in August 1973. At 10 m, average levels were: June 1972, 15.8 (±2.1)°C; August 1973, 13.1 (±1.0)°C. The relatively large standard deviation of the June 1972 data results mainly from Station 2 where the upper 10 m appeared to be isothermal. The average drop in the upper 10 m was 4.2°C ($\Delta\delta_t$, − 0.9) in June 1972 and 5.5°C ($\Delta\delta_t$, − 1.2) in August 1973. Expendable bathythermograph casts taken at selected stations in August 1973 showed the drop could be over a relatively few meters, with the temperatures in the upper part of the depth interval being approximately uniform. A further temperature decrease in the depth interval from 10-20 m averaged 2.9 (±1.6)°C ($\Delta\delta_t$, − 0.6) in June 1972 and 1.5 (±0.9)°C ($\Delta\delta_t$, − 0.3) in August 1973. Decreases in deeper intervals of the water column were relatively small.

Direct measurement of submarine light conditions was not made, but Secchi disc lowerings were done at a few stations on each cruise. Readings ranged from approximately 3.5–5 m, suggesting the photosynthetic compensation depth may have been no deeper than about 15 m (i.e. 3X Secchi depth).

Nutrient Chemistry

Inorganic nitrogen (ammonia-N and nitrate + nitrite-N) and phosphorus concentrations were determined at all stations in June 1972, but only ammonia, as a tracer of the outfall effluent, was quantified for the August 1973 samples. A plume with high concentrations of ammonia (maximum, 6.2 μg-atoms NH_3—N/l at 40 m, Station 1) originating at the outfall and extending to the north and northwest (Station 10, 1.39 μg-atoms NH_3—N/l at 40 m) was seen in June 1972 (Figure 3). The August 1973 samples showed no similarly enhanced levels of ammonia

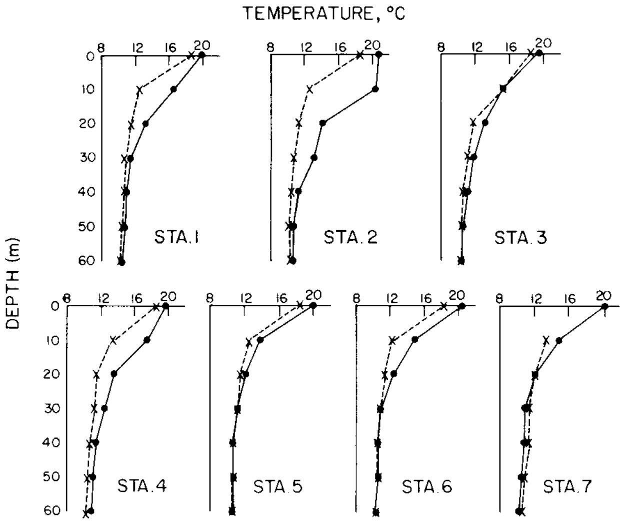

Figure 2. Temperature profiles. ● = June 1972; x = August 1973.

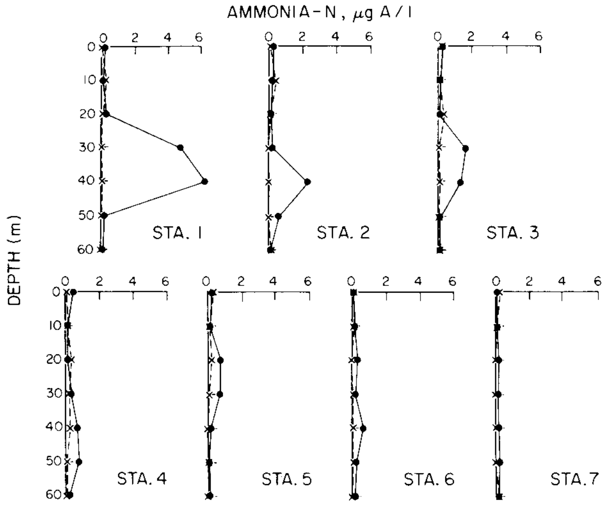

Figure 3. The vertical distribution of ammonia-nitrogen. ● = June 1972; x = August 1973.

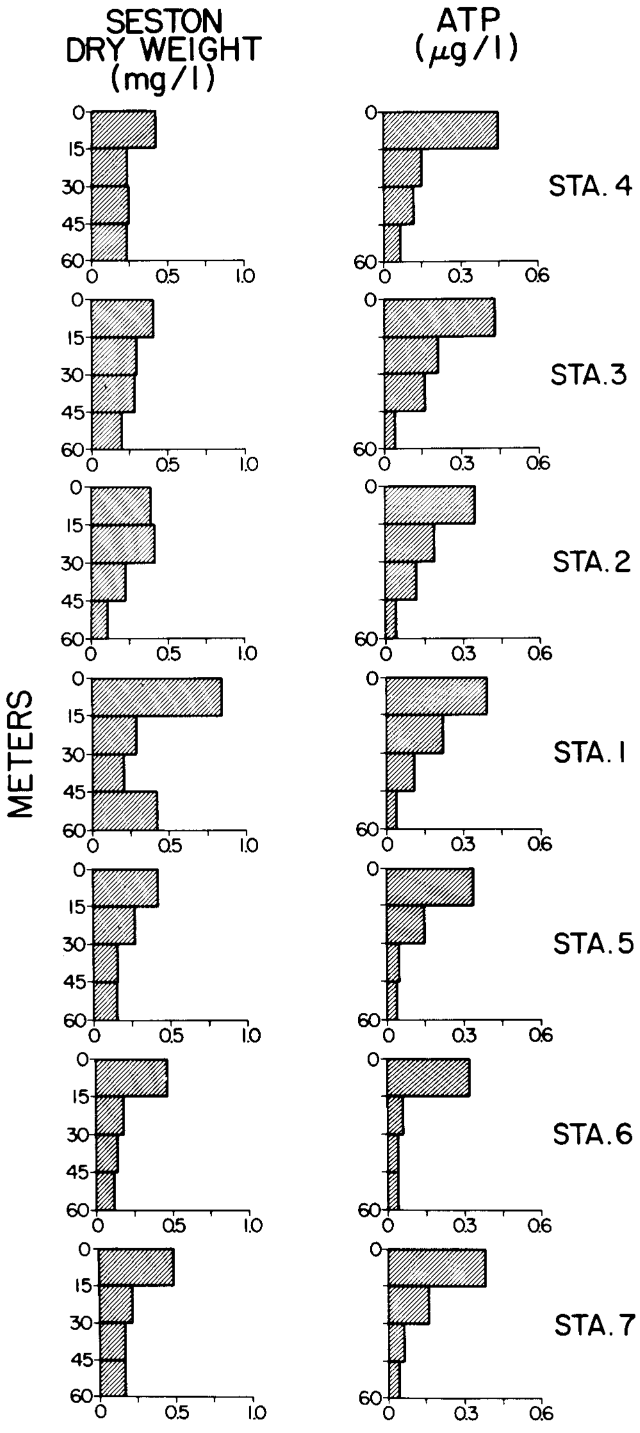

Figure 4. Seston dry weight and ATP abundance; June 1972 (stations are given, top to bottom, as they occur north to south).

to either the north or the south (Figure 3).

Levels of nitrate + nitrite-N (June 1972) were often undetectable or at concentrations less than 0.2 µg-atoms/liter in the surface down through the 20-m samples at the outfall and sites to the north, whereas the 20-m samples at stations to the south were within the nitrocline (Stations 5-7, 20 m; average 3.72 µg-atoms $NO_3 + NO_2 - N$/liter). Phosphate, alhtough often low in the upper waters, was generally present at detectable levels (Stations 1-7, surface: 0.07±0.05µg-atoms PO_4-P/liter; 10 m: 0.17±0.7 µg-atoms PO_4-P/liter). As seen in the nitrate + nitrite-N data, at 20 m the southern stations (Stations 5-7) had comparably higher phosphate (0.77 ±0.18 µg-atoms PO_4-P/liter) than those (Stations 2-4) to the north (0.30 ±0.10 µg-atoms PO_4-P/liter).

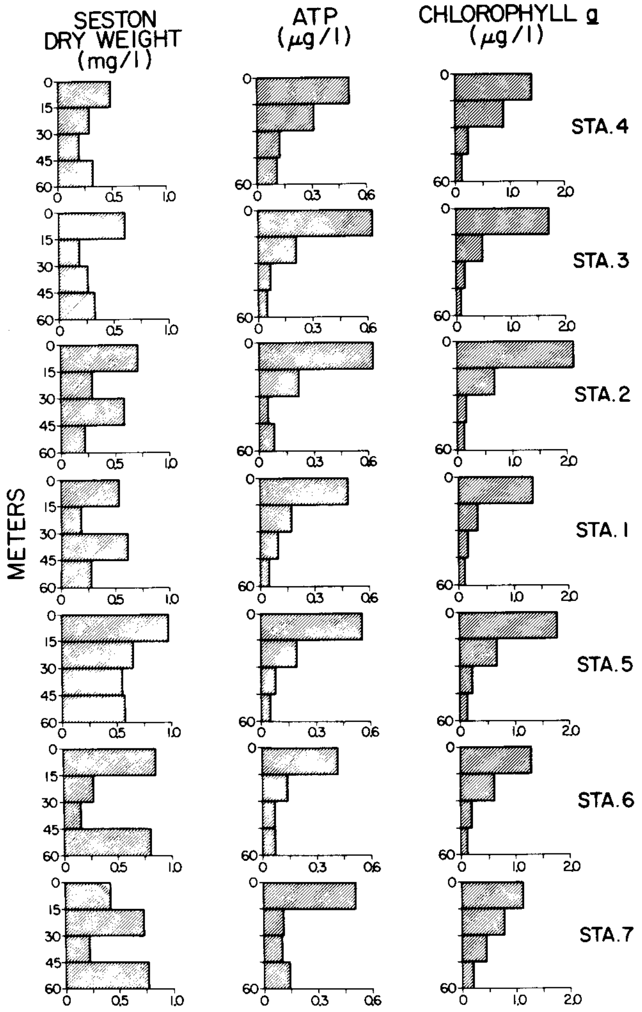

Figure 5. Seston dry weight, ATP, and chlorophyll a abundance; August 1973 (stations are given, top to bottom, as they occur north to south).

Measures of Seston Components

Depth profiles of the total seston dry weight, chlorophyll *a*, and ATP at Stations 1-7 are shown in Figures 4 and 5 for the June 1972 and August 1973 studies, respectively. Values integrated over the water column are given in Table 1.

TABLE 1

Average Levels[1] of Microseston Dry Weight, Adenosine Triphosphate, and Chlorophyll *a* over the 60 m Water Columns of Stations 1-7.

	23-24 June 1972			10 August 1973		
Station	Micro-seston	Chl *a*[2]	ATP	Micro-seston	Chl *a*	ATP
1.......	440	0.25	0.19	410	0.49	0.20
2.......	280	0.28	0.18	450	0.77	0.25
3.......	300	0.26	0.21	350	0.61	0.24
4.......	280	0.27	0.20	330	0.67	0.27
5.......	250	0.25	0.15	700	0.71	0.22
6.......	230	0.18	0.12	530	0.54	0.18
7.......	270	0.21	0.16	540	0.63	0.22

1. in µg/liter
2. see under Materials and Methods

The dry weight of the seston provides a measure of the total combined living and detrital materials. In June 1972 the greatest average abundance of seston over the whole water column was found at the outfall site, primarily the result of levels approximately twice the average for all stations in the 0-15 m and 45-60 m depth intervals. Although the outfall discharge is of dissolved and not suspended (sludge) materials (personal communication), its flow could result in some disturbance of the sediments. Stations to the north of the outfall showed slightly higher average levels (0-60 m, 286 ±8 µg dry weight seston/liter) than those to the south (0-60 m, 249 ±19 µg/liter). Seston abundance within the various depth intervals at the stations to the north and south was similar (i.e. within ± one standard deviation) except for 30-45 m, where the plume of ammonia was observed. Stations to the north were uniformly higher (247 ±31 µg dry weight seston/liter) than those to the south (157 ±15 µg/liter). The difference was also shown by the Mann-Whitney rank test. In August 1973 a difference in total seston within the bottom depth interval (45-60 m) was seen, with stations to the south being higher (723 ±122 µg dry weight seston/liter) than those to the north (294 ±91 µg/liter).

ATP provides an index of the abundance of all living organisms including autotrophs, heterotrophs, and phagotrophs in the seston (Holm-Hansen and Booth 1966). Its distribution pattern during the June 1972 study was similar to that determined for the total seston dry weight, which also includes detritus. The average ATP level over the 60-m water column was lower at southern stations (0.14 ±0.02 µg/liter) than northern stations (0.20 ±0.02 µg/liter), principally because of the 30-45 m depth interval in which ATP levels to the north were approximately twice as high (Stations 2-4, 0.13 ±0.02 µg/liter) as those to the south (Stations 5-7, 0.05 ±0.01 µg/liter). This interval includes the depths at which the ammonia plume originating from the outfall was detected. In August 1973 no differences were observed between stations in either direction from the outfall, including the 45-60 m depth interval in which high abundance of total seston was found south of the outfall.

Chlorophyll *a* provides an index of the phytoplankton standing crop. Reliable determinations are available only from the August 1973 cruise. No differences for any depth interval were seen between stations situated to the north or south of the outfall. The average level for the upper 15 m of the 7 stations was 1.50 (±0.35) µg chl *a*/liter, dropping to 0.64 (±0.18) µg chl *a*/liter at 15-30 m. In June 1972 the average chlorophyl *a* levels determined from Stations 1-7 were: 0-15 m, 0.45 (±0.07) µg/liter and 15-30 m, 0.31 (±0.10) µg/liter. Although the absolute levels are probably low by ¼ to ⅓ because of the accidental thawing of the filters, our examination of the effects of the thawing suggests that any relative differences would be retained. Similar to the August 1973 results, stations to the north and south of the outfall were not different at any depth.

The Microplankton

Total Population

Total microplankton was studied at the outfall (Station 1) and the extreme northern site (Station 4). In addition, samples from the most southern location (Station 7) were studied in August 1973. The station at the outfall was chosen for comparison with the more distant sites since the evidence of eutrophication reported by Eppley et al. (1972) was directly over the outfall.

The organic carbon content of the microplankton, subdivided into major taxonomic groups, is given in Table 2. Marked differences in the average microplankton carbon over the total water column were not seen between stations on either cruise. In June 1972 average carbon abundance (0-60 m) was slightly more than 20 μg/liter. Levels at the same depth interval but at different stations did not differ markedly. In August 1973 microplankton carbon was only about half as high in the upper 15 m at Station 7 as it was at Stations 1 and 4. However, levels in the other depth intervals were generally 2-4 times higher at Station 7, so averaged over the entire water column values were similar: Station 1, 31.8 μg C/liter, Station 4, 36.5 μg C/liter; and Station 7, 25.9 μg C/liter. The differences at Station 7 relative to the other two sites do not result from any one taxon but are general over most of the major groups. Of the total microplankton carbon, animal components accounted for <10% in the upper interval, increasing with depth to approximately 25%.

The diatom (i.e. pennate and centric) carbon in the depth interval of the ammonia plume at the outfall site in June 1972 was only ¼ that at the same depth of Station 4, and at 15-30 m it was only slightly greater than 50% of that seen at the site away from the outfall. The magnitude of these differences was as large or larger than any others seen between stations for all taxonomic groups on this cruise (but not larger than many seen in August 1973). It can be tentatively suggested that this may have resulted as an effect of the outfall discharge.

The factor, 286 × ATP concentration has been suggested as providing an estimate of the carbon content of the total living matter (Holm-Hansen 1973). Using this calculation and comparing it with the carbon abundance of microplankton determined from direct microscopy, it can be seen that it is in the upper depth interval that the organisms in the microplankton size range make their greatest contribution to the total biomass and that the fraction for which they account decreases with depth. The ratio of microplankton carbon, determined from microscopy, to ATP averaged 176:1 (range 108-233:1) for the 0-15 m depth interval at the five stations where total microplankton was studied on the two cruises. This dropped with depth to 64:1 (range 38-98:1) for the 45-60 m depth interval. If the calculation is valid, and assuming the remaining "living" carbon is bacterial, populations of such microbes would comprise fractions of the total microplankton biomass ranging from approximately 38% (0-15 m) to almost 80% (45-60 m).

TABLE 2

Organic Carbon Content* of the Major Taxonomic Groups of the Microplankton.

	Pennate diatoms	Centric diatoms	Thecate dinoflagellates	Non-thecate dinoflagellates	Coccolithophorids	"Monads and flagellates"	Protozoa	Micrometazoa
23-24 June 1972								
Station 1								
Surf-15m	0.30	0.43	15.	4.3	20.	13.	1.8	2.5
15-30m	0.54	0.37	1.9	0.90	5.7	4.6	0.77	2.9
30-45m.......	0.21	0.15	0.61	0.75	1.8	1.6	0.41	1.2
45-60m.......	0.15	0.12	0.34	0.55	0.56	1.3	0.47	0.37
Station 4								
Surf-15m	0.45	0.47	13.	5.1	19.	13.	1.1	2.3
15-30m.......	0.93	0.69	1.7	1.5	4.6	7.7	0.49	2.0
30-45m.......	0.59	0.86	0.84	0.87	2.6	2.3	0.64	1.7
45-60m.......	0.21	0.10	0.58	0.86	0.38	1.0	0.24	0.71
10 August 1973								
Station 1								
Surf-15m	1.8	2.9	4.7	20.	13.	69.	3.6	2.9
15-30m.......	0.12	0.92	0.31	2.5	1.4	3.3	0.72	1.9
30-45m.......	0.14	0.30	0.09	0.93	0.27	1.4	0.30	0.84
45-60m.......	0.06	0.26	0.70	0.60	0.50	2.0	0.34	0.54
Station 4								
Surf-15m	2.5	2.3	6.5	16.	10.	81.	4.0	3.5
15-30m.......	0.55	0.95	0.72	1.6	3.7	8.0	1.7	3.4
30-45m.......	0.39	0.48	0.48	0.87	1.0	4.2	0.59	2.0
45-60m.......	0.14	0.35	0.08	0.90	0.61	2.1	0.30	0.51
Station 7								
Surf-15m	0.68	1.1	6.2	5.1	5.9	36.	ND†	1.9
15-30m.......	0.23	2.5	2.2	4.4	7.7	15.	ND	2.3
30-45m.......	0.13	0.68	0.53	1.6	1.1	7.0	ND	1.8
45-60m.......	0.21	0.21	0.16	2.3	0.26	2.6	ND	0.7

* in μg C/liter
† not determined.

+35 CONC Phytoplankton Taxa

Thecate dinoflagellates generally dominated the +35 CONC phytoplankton in both numbers and biomass. It is probable that an important fraction of these may be heterotrophic, at least at times, but their identification as such is not possible from our preserved samples. The Mann-Whitney rank test indicated some differences in populations of the large dinoflagellates between stations north and south of the outfall. In June 1972 there was evidence of both relatively high numbers and carbon in the 15-30 m depth interval north of the outfall and of high numbers, but not carbon, at 30-45 m. The ammonia plume and high levels of other seston components were seen in the latter depth interval. For the August 1973 samples, the rank test indicated that stations to the south had greater numbers of thecate dinoflagellates and that carbon was higher in all depth intervals below the upper one. Results of the rank test for carbon distribution were clearly influenced by the relatively large species, *Peridinium depressum* Bailey, which was often present but in small numbers. No differences in the diversity (Shannon and Weaver 1949) of the +35 CONC dinoflagellate populations were seen for any depth interval.

The numbers of diatoms counted in the subsamples of the +35 CONC samples studied were generally very small, resulting in wide limits of confidence on the data.

+35 CONC Microzooplankton Taxa

The ciliate protozoan fraction of the 35-μm mesh concentrated samples is dominated by tintinnids. All nearshore tintinnids, with the exception of some individuals of a few species having lorica diameters considerably less than 35 μm, principally of *Tintinnopsis* spp., would be expected to be retained by the netting. Tintinnid abundance was highest within the upper depth interval (surface-15 m) studied, averaging 25.5 ±14.4/liter at the seven stations of the June 1972 cruise and 118.0 ±56.5/liter during the August 1973 study. No dissimilarities between stations to the north or south of the outfall were observed in either tintinnid numerical abundance or carbon for any depth interval of the total water column population except at 15-30 m in June 1972 when stations to the south averaged higher than those to the north. The Mann-Whitney rank test also pointed out this difference for which we have no ecological explanation.

Actinopod sarcodinians, organisms capable of engulfing food particles including small phytoplankton and detritus, were relatively numerous. Radiolarian actinopods averaged 15.4 individuals/liter over the 60-m water column in June 1972 and 25.2/liter in August 1973. The only dissimilar distributions of radiolarians north and south of the outfall were a greater abundance in the 0-15 m samples to the south in June 1972 and to the north in the same depth interval in August 1973. Only the latter was also shown by the rank test. Acantharians, another group of actinopods, showed no differences in abundance at or within sites to the north or south of the outfall on either cruise. Average acantharian abundance (0-60 m) was slightly greater than that of radiolarians in August 1973, being 32.8 individuals/liter, but in June 1972, with an average 9.7 specimens/liter, was lower than that of radiolarians. Greatest acantharian abundance was in the upper depth interval, with a marked decrease in the lower parts of the water column.

The only metazoan microzooplankton group seen in sufficient numbers to give generally reasonable levels of confidence in the data was the naupliar copepods. In June 1972 dissimilar abundance of these developmental stages was found in the 30-45 m depth interval. Stations to the north of the outfall where the ammonia plume and higher seston and ATP levels were evident averaged 18.5 ±5.1 individuals/liter compared to 7.2 ±2.7/liter to the south. This difference was also detectable with the Mann-Whitney rank test. No additional differences were observed between sites north and south of the outfall in either the 1972 or 1973 study.

DISCUSSION

Eppley et al. (1972) considered the timing of their study in June-July 1970 as "propitious" for detecting eutrophication at outfalls. Natural occurrences, such as upwelling, which can also lead to enhanced productivity and greater standing crops, were not important at the time, thus allowing the sewage effluent-induced enhancement to stand out against a background of generally low crops. On both of our cruises, drops in temperature within the upper 10 m of 4-6°C indicated that colder water which might have been expected to be relatively nutrient-rich was reaching into the euphotic zone which Secchi disc readings had suggested was 10-15 m deep. Nutrient determinations, nevertheless (studied in June 1972 only), consistently showed low concentrations of inorganic nitrogen and phosphorous within the euphotic zone, although at stations to the south of the outfall the upper part of the nutricline may have been near the compensation depth. However, if the photosynthetic populations were utilizing the nutrients as fast as they became available, no enhanced levels would be seen. In the study of Eppley et al. (1972), inorganic phosphorus and nitrogen concentrations were uniformly low at both outfall and control stations suggesting nutrient availability was limiting to further production.

The standing crops of phytoplankton, as evidenced by chlorophyll *a* levels, could not be considered very high and thus potentially masking to outfall eutrophication. Even considering the possible loss of chlorophyll in the June 1972 samples at 50% or greater (see Materials and Methods), the values for both cruises were similar to those seen by Eppley et al. (1972) at their control sites off La Jolla and did not begin to approach the high levels they observed at the outfall. Their three sets of data from the control station showed an average chlorophyll *a* level of 0.9 μg/liter over the euphotic zone (average depth, 37 m), whereas at the Point Loma outfall the average level in the euphotic zone (average depth, 21 m) was almost 8 μg/liter. During a 5-month period of approximately weekly observations by the Food Chain Research Group (FCRG) in 1967 at sites 1.4 and 4.6 km offshore of La Jolla, the chlorophyll level through the euphotic zone averaged 1.07 (±0.86) and 0.65 (±0.56) μg/liter, respectively (University of California, Institute of Marine Resources 1968). The positions of our outfall stations in terms of water column depth and distance from shore fall intermediate between these two sites.

Direct measurement of primary production was not undertaken during either cruise. The nature of our sampling program with stations being occupied throughout daylight hours would have necessitated productivity incubations starting at various times of the day or else being held for differing lengths of time before starting incubations. Both conditions are undesirable, resulting in problems with interpretation of the data (see discussion in Thomas 1972).

Several other studies of the Point Loma area have also not found higher phytoplankton crops at the outfall. Included is a cruise in June 1971 by the FCRG (Anonymous 1971; Reid 1972). Thomas (1972), who conducted a series of approximately quarterly studies of various southern California outfalls from May 1971-May 1972, saw evidence of eutrophication at Point Loma in only one (June-July 1971) out of four studies. At that time the chlorophyll level through a 15-m euphotic depth at eight sites within a mile of the outfall ranged from 2.7-5.4 μg/liter whereas a site 5 miles (8.1 km) to the north showed 0.8 μg/liter, and other stations off Camp Pendleton (30 miles [48 km] to the north) taken as controls were 0.4-0.8 μg chl *a*/liter.

An increase in primary crop and secondary stocks sufficient to be detected over background would depend upon the water movement, both lateral transport and vertical displacement, in the area. The general knowledge of circulation in the Southern California Bight has been summarized by Jones (1971). Much of his discussion is of the relatively long-term components (i.e. those measureable on a scale of weeks and months) such as current systems. For surface circulation to 100 m in waters directly adjacent to the coast, a generally southeasterly flow is seen much of the year. Hendricks and Harding (1974) also reported southerly currents both at the surface and in subthermocline waters (39 m) in May 1972, when they followed drogues set out at the Point Loma outfall for two days. Current flow, at least at subthermocline depths, in the opposite direction was indicated in the present study by the ammonia plume which was seen to the NNW of the outfall. Data of Thomas (1972) on ammonia around the Point Loma outfall also indicated northward currents at least at times (e.g. Outfall Cruise 2, June-July 1971).

Superimposed on the long-term flow patterns are shorter term variations. Gaul and Stewart (1960), working in nearshore areas off San Diego, concluded that short-term movements of waters below the thermocline (usually 10-15 m) were primarily tidal, whereas wind was principally responsible for short-term variations in the upper waters. Their study of surface circulation off Point Loma, including the area of the outfall, showed a generally clockwise movement with net *tidal* drift for a 25-hour cycle varying between approximately 1,220 and 3,050 m depending upon the type of tide.

Other parameters of short-term period of possible consequence to our results include internal waves and internal tides of time periods measurable in minutes and hours, respectively. Internal waves, for example, could affect the vertical position of the ammonia plume. Lafond (1963), making observations at a site about 12 km north of the sewage outfall, found over a week in summer that the most common internal waves were of 5.6 feet (1.7 m) with a periodicity of 7.3 minutes. Kamykowski (1974) showed, by computer modelling, the significant effect that the semidiurnal tides along the southern California coast could have on the distributions of various motile and non-motile microplankters. Analysis of the nature of water movements during the present study was beyond the scope of the work. It is clear, however, that as the result of physical phenomena outfall materials or the organisms utilizing them may be dispersed too rapidly to have a discernible effect in terms of crop elevation.

Failure to observe enhanced crops at the outfall would also result if the effluent contained a limiting factor. Thomas (1972) performed some bioassays with outfall surface and sub-thermocline waters using three common local algal species, and, although some inhibition was observed, there was no consistency as to which of the three species tested was inhibited.

Still another possible explanation for the lack of evidence of enhanced productivity and primary crops is that the effluent enrichment did not reach the euphotic zone. The effluent from the outfall diffuser system, although mixing with the surrounding seawater, is at a relatively low density and will rise. At the same time, it may be subject to turbulent mixing and can be dispersed laterally by currents. The dispersed effluent would cease to rise at a depth at which its density and that of the surrounding waters are the same. This depth would be dependent upon the salinity and/or temperature structure of the water column. If at a depth below the euphotic zone (i.e. 15 m) and, hence, the usual level of the strongest part of any thermocline, salinity could be the important determining factor. A salinity minimum at intermediate depths is characteristic of the area and was seen at the stations studied in June 1972 at depths of 20-40 m. Salinity at its minimum was 33.51 ppt (average, Stations 1-7), whereas at the surface and bottom (i.e. 60 m) average salinities were 33.68 and 33.66 ppt, respectively. It is possible that vertically migrating phytoplankton could utilize the effluent ammonia at intermediate depths (see discussion in Hendricks and Harding 1974), but their subsequent dispersion may be too rapid to be seen as enhanced standing crops. It can also be noted that depending upon the physical characteristics of the effluent and surrounding waters, the effluent materials might be maintained in a thin layer, and their detection by the relatively widely spaced water bottle sampling used here, as well as by Eppley et al. (1972)

and Thomas (1972), is subject to a degree of chance.

During the June 1972 cruise, at least, the outfall plume of enriched water was detectable as a recognizable entity, principally by its content of ammonia. Although only inorganic materials were measured, it can be suggested that dissolved organic materials may also have been higher in the plume. In addition to the evidence we saw of higher-than-average abundance of total seston and elevated ATP in the depth interval that included the plume, Carlucci (personal communication) found enhanced vitamin levels, principally B_{12}, in the same waters. Dissolved vitamins are known to be the products of both phytoplankton (e.g. Carlucci and Bowes 1970) and bacteria (e.g. Haines and Guillard 1974). Further, Carlucci and Shimp (1977) reported an approximate order-of-magnitude greater growth of low-nutrient bacteria at the 40-m depth of Station 1, where high ammonia levels were found, relative to 20- and 60-m samples. Thus, even though discernible effects of outfall eutrophication may not be apparent in the photosynthetic populations of the euphotic zone, there may be increased biological activity centered on the nutrient plume. Its magnitude, the number of trophic levels represented, and the discernible extent would depend upon the length of time the integrity of the effluent is maintained.

Although a number of studies have been undertaken in recent years to look for signs of eutrophication at the Point Loma outfall, the total is still relatively small. However, the results are sufficient to suggest that discernible evidence of outfall eutrophication may be unusual and of a very transitory nature. To obtain a more accurate evaluation of the importance of outfall eutrophication effects on biological production in San Diego coastal waters would, as strongly suggested by Hendricks (1975), require a monitoring program with a much more frequent and regular periodicity than the extremely sporadic and short-term observations characterizing the efforts to date.

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