NUTRIENTS AND PHYTOPLANKTON COMMUNITY COMPOSITION IN SOUTHERN CALIFORNIA COASTAL WATERS.[1]

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ABSTRACT

Analysis of portions of a phytoplankton data set collected in Santa Monica Bay from 1957 to 1972 suggested seasonal and distributional relationships between diatoms and dinoflagellates. Blooms of both groups overlapped and tended to be concentrated into a period from spring through summer. However, while diatom biomass was advected into the Bay from offshore, dinoflagellate blooms seemed to arise inshore near sources of anthropogenically derived nutrients.

Differences in abundance and community composition were explained on the basis of groups of environmental factors (parameter sets) favoring each group. Supplement of limiting factors (such as nitrogen) enhances total biomass, but differences in parameter sets may result in inshore-offshore distributional patterns. It was suggested that the relative abundance of ammonia-N may be a tag for the dinoflagellate parameter set.

RESUMEN

El análisis de porciones de la serie de datos de fitoplancton colectadas en la Bahía de Santa Mónica de 1957 a 1972 sugirió que existen relaciones estacionales y distribucionales entre diatomeas y dinoflagelados. Los florecimientos de los dos grupos son concurrentes y tendieron a concentrarse en el período de primavera a verano. Sin embargo, mientras la biomasa de diatomeas se desplazaba desde mar afuera hacia la Bahía, florecimientos de dinoflagelados parecían originarse en la zona costera cerca de concentraciones de nutrientes derivados antropogénicamente.

Las diferencias en la abundancia y en la composición de la comunidad se explicaron basándose en grupos de factores ambientales (series de parámetros) que favorecen a cada grupo. El suplemento de factores limitativos (como el nitrógeno) aumenta la biomasa total, pero diferencias en las series de parámetros pueden dar lugar a patrones distribucionales cerca de la costa y mar adentro. Se sugirió que la abundancia relativa de amoníaco-N puede ser un indicador para la serie de parámetros de dinoflagelados.

NUTRIENTS AND PHYTOPLANKTON COMMUNITY COMPOSITION IN SOUTHERN CALIFORNIA COASTAL WATERS

The abundance, distribution, and succession of phytoplankton in southern California coastal waters is regulated by interactive processes occurring both offshore—at and beyond the coastal shelf edge—and inshore, along the shelf (cf. Eppley et al. 1978, 1979 a, b). Whereas oceanic processes tend to influence large segments of the coastal system, and the effects of inshore processes are often more localized, both significantly influence the coastal phytoplankton (cf. Thomas 1972; SCCWRP 1973; MacIsaac et al. 1979). For example, a municipal waste-water outfall may, during periods of strong upwelling, be insignificant as a source of nutrients to surface waters. However, when upwelled nutrients are unavailable, the outfall can be a determinant of both numbers and types of phytoplankton present in a certain area. Locally fertilized areas, in turn, tend to concentrate planktonic and pelagic grazers and carnivores (Brewer et al. 1979).

In this paper I will examine some of the interactions between offshore- and inshore-derived nutrients as they relate to the regulation of phytoplankton numbers and community composition in coastal waters.

There is an imbalance between the amount of effort spent in relating macro- and mesoscale phenomena to changes in total phytoplankton biomass (as chlorophyll, or particulate C or N) and that spent in discerning the importance of small-scale events and the interactions between large- and small-scale events as they affect the abundance and types of phytoplankton in the coastal zone (Ryther and Officer 1979). Unfortunately, the costs and difficulties of studying the fine details of coastal phytoplankton dynamics often prohibit their consideration.

However, since the development of marine food webs is largely dependent upon these details (cf. Tont 1976; Lasker 1975), the value of the phytoplankton as a source of information about coastal ecosystems is seriously reduced if we fail to consider them. Thus, Ryther (1954) observed that changes in nutrient composition due to waste-water loading to Long Island bay waters altered phytoplankton community structure to the extent that diatoms, the principal food of the hardshell clam, were significantly reduced. The result of this alteration was expressed by the demise of the clam fishery in that area.

Thus, in terms of the food web, changes in total phytoplankton biomass explain little unless accompanied by information about the taxa that compose that biomass. Simply put, many food webs in coastal waters develop around localized phytoplankton communities, and these communities represent a response to interactions between numerous environmental conditions or parameter sets that favor the growth of certain taxa over others. For the time being these parameter sets must remain undefined. However, nitrogen, in various forms, appears to be a com-

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ponent of some these hypothetical sets. Thus, the form of nitrogen may serve as a "tag" for different parameter sets, thereby providing a means for understanding and predicting phytoplankton composition on the basis of a few measurements.

Figure 1 shows the locations of 18 stations in Santa Monica Bay sampled weekly from 1957-72 by Hyperion Treatment Plant personnel using vertical net (#20 silk 10.6-cm aperture diameter) tows from about 15 m. Further details of sampling are given in SCCWRP (1973). The stations along lines 7, 3, and 2 are considered in this discussion and have been connected by dashes.

Figure 2 is a plot of weekly abundances (as sample volume, in ml) of diatoms at an offshore station (7C) and dinoflagellates at an inshore station (3C) during 1965, a year representative of average conditions in the Bay. Rapid increases in the biomass (which I will refer to as blooms) occurred in mid- to late winter, early spring, and during mid-summer. Bloom intensities increased to a maximum of 10 ml for diatoms and 8.5 ml for dinoflagellates, then decreased to late fall-early winter minima. Diatom blooms both offshore and inshore were characterized by dramatic but short-lived changes in biomass; dinoflagellate populations were more stable, sample volumes rarely falling below 0.1 ml from winter through late summer.

Figure 3a shows how mean monthly diatom abundances changed from offshore to inshore; Figure 3b provides the same analysis for dinoflagellates. The plots are for data collected at eight stations along lines 7, 3, and 2 (Figure 1). Diatom densities generally decreased inshore indicating that biomass is advected into the Bay from at or beyond the coastal shelf edge (Figure 4).

Figure 3b shows that dinoflagellate densities tended to increase inshore. There were three centers of maximum biomass: 1) at the mouth of Ballona Creek; 2) near the Chevron Oil Company refinery at El Segundo; and 3) in the vicinity of the 1-mile Hyperion outfall, which was operative twice weekly (discharging at 10 million gallons/day) throughout the 1960's (J. Nagano personal communication). It would appear that growth of dinoflagellates was initiated within the Bay, possibly from "seed beds," at these locations.

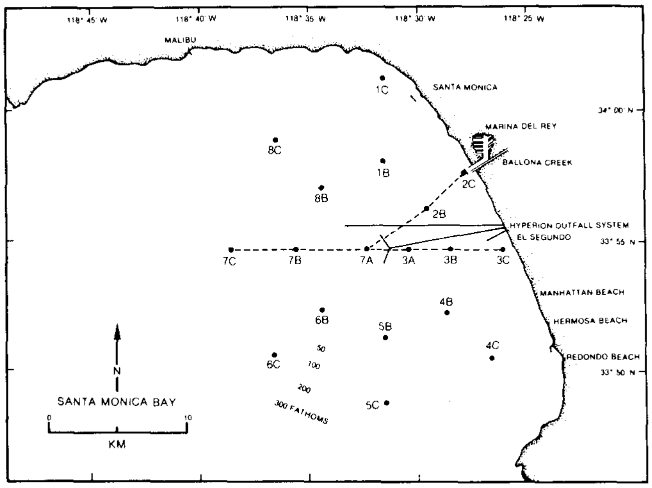

Figure 1. Stations sampled each week in Santa Monica Bay from 1957-72. Locations of 5- and 7-mile Hyperion outfalls are shown. Dashed lines connect stations considered in this discussion.

The Mann-Whitney U test (Downie and Heath 1971) was used to discern whether the apparent offshore-inshore distributional patterns in Santa Monica Bay phytoplankton communities were significant. The results, shown in Table 1, suggest that during 1963, a red tide year, dinoflagellates were more abundant inshore than offshore ($P<0.05$). In 1965, when data from months with highest and lowest biomass values were disregarded, U was again significant ($P<0.05$) for both dinoflagellates and diatoms. U, being a rank order statistic, was destabilized by data points representing extreme events such as blooms (July) and biomass minima (November, December). On the average, however, there are distributional differences between inshore and offshore communities.

It seems that two types of parameters regulate phytoplankton dynamics in Santa Monica Bay: 1) those that influence total abundance, and 2) those that influence community structure.

Since nitrogen is believed to be one of the substances that most limit the growth of phytoplankton in coastal waters (Ryther and Dunstan 1971; SCCWRP 1973; Thomas 1972), it is reasonable that changes in nitrogen concentration, particularly inorganic-N, will result in changes in total biomass or numbers (Eppley et al. 1979 a, b). Some examples of nitrogen sources to coastal waters, presented in Table 2, show that upwelled nitrate provides most of the nitrogen along the coast (SCCWRP 1973). However, significant upwelled nitrate inputs occur only during a few months of the year in most places. Municipal effluents, discharged at 60 m, represent a potentially continuous nutrient source (Schafer 1978), but it is not known how often 60-m outfall discharges reach the surface (Eppley et al. 1977; Hendricks 1975), especially considering that initial dilution reduces the nitrogen in the waste field by about 200 times within 100 seconds of

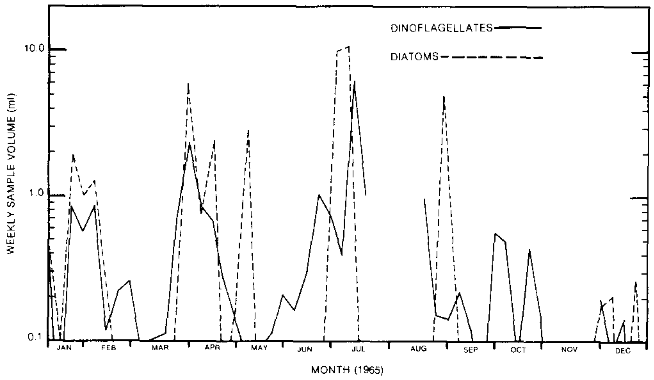

Figure 2. Weekly sample volumes of dinoflagellates (solid line) from an offshore station (7C) and diatoms (dashed line) from an inshore station (3C) in Santa Monica Bay during 1965.

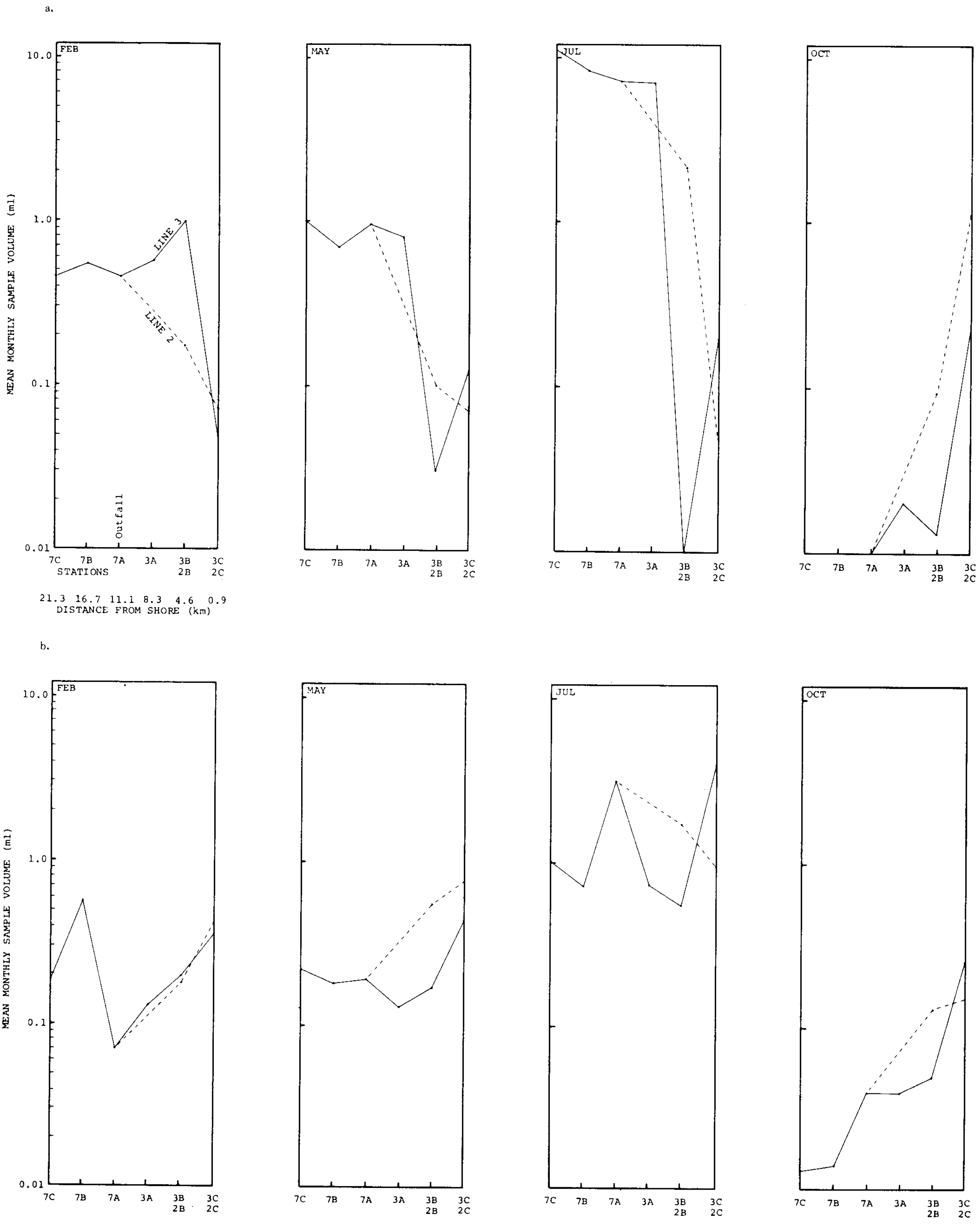

Figure 3. a) Mean monthly diatom abundance (as ml of diatoms per sample) at stations along lines 7, 3, and 2 in Santa Monica Bay in certain months, 1965. b) Same as in a) but for dinoflagellates. Station locations, outfall location (5-mile), and distance from shore are shown. The figures give representative seasonal patterns.

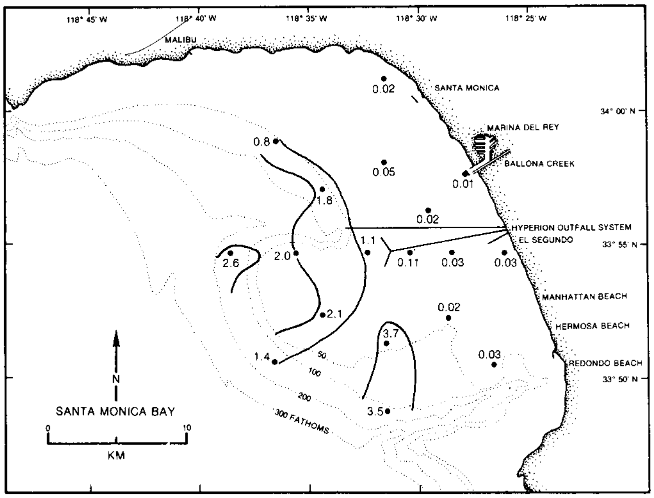

Figure 4. The distribution of diatoms (as mean sample volume in ml) in Santa Monica Bay, May 1965.

discharge (Table 3) and the presence of well developed thermal stratification may confine the remaining N below the surface for several days (Hendricks 1975). The effects of these discharges upon near-surface phytoplankton are uncertain at best (SCCWRP 1973; MacIsaac et al. 1979), but Figure 3 suggests that the 60-m effluents represent only a periodic nutrient source for the phytoplankton.

Inshore, nitrogen is supplied through tidal exchange with harbors, rainfall runoff from shore, and shallow-water discharges at industrial outfalls. Table 2 shows that most inshore nitrogen sources provide ammonia-N, a form more easily utilized by phytoplankton than nitrate (Soeder and Stengel 1974; Samuels 1979). Though inputs from runoff vary seasonally, sources such as shallow outfalls add nutrients on a fairly continuous basis. Unlike upwelling and the 60-m municipal effluents, inshore sources deliver most of their nutrients directly to the euphotic zone. This difference between inshore and offshore nutrient sources is very likely important to coastal phytoplankton as nutrient uptake kinetics, and hence community structure may be altered due to the change in the availability, the consistency of delivery, and the form of nitrogen present in inshore waters. For instance, following initial dilution, only 6.1 of the 1228.6 μg-atoms/liter ammonia-N discharged from the Hyperion 5-mile outfall remains in the waste-water plume (Table 3). This ammonia-N may not be available to the phytoplankton for several days during which time it is further diluted prior to surfacing. The Chevron Oil Co. outfall at El Segundo, on the other hand, continuously discharges on the average of 2050μg atoms/liter of ammonia-N into the euphotic zone. The data presented in Figure 3b, as well as those of others (Eppley et al. 1979 b; R. Eppley personal communication) suggest that the Chevron Oil Co. discharge supports a relatively constant enhancement of dinoflagellate biomass.

TABLE 1

Mann-Whitney U Values for Differences between Inshore (Station 3C) and Offshore (Station 7C) Populations of Diatoms and Dinoflagellates.[1]

	1963	1965
Diatoms		
Annual	†49.5	*41
[2]Extremes removed	*16.5	**17
Dinoflagellates		
Annual	**38.5	†47
[3]Extremes removed	----	*21

[1] The U test gives 2 values; the values reported here are the lower of the 2 values from which significance was then determined (cf. Downie and Heath 1971).

[2] Extreme months for 1963 diatoms were offshore biomass minima during January and February; extreme months for 1965 were offshore biomass minima in September and October.

[3] Extreme months for 1965 dinoflagellates were inshore July biomass maximum and offshore minima in November and December.

†U not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$.

TABLE 2

Some Nitrogen Sources along the Southern California Coastal Shelf.

Source	Predominant form	Average concentration μg-atoms/liter	Annual mass emission (metric tons/year)	Constancy
[1]Upwelling (7,500 km)	NO_3–N	14.3	180,000	3 months/year (April-June)
[2]Municipal outfalls	NH_3–N	28,200	41,200	?
[1]Surface runoff	Total N	----	2,500	rainy season
[3]Chevron Oil. Co.	NH_3–N	2,050	235	continuous
[4]Long Beach Harbor	NH_3–N	7.48	----	4-month period (December-March)

Sources:
1. Southern California Coastal Water Research Project 1973.
2. Schafer 1978.
3. State Regional Water Quality Control Board, Los Angeles.
4. Environmental Quality Analysts and Marine Biological Consultants 1977.

TABLE 3

Examples of the Effects of Initial Dilution (200 Times) on Effluents from Major Outfalls.[1]

Location of Discharge	Ammonia-N μg-atoms/liter	Diluted NH_3–N μg-atoms/liter	Mass emission[2] (metric tons/year)	Diluted emission (metric tons/year)
Hyperion:				
5-mile	1,228.6	6.1	7,590	38.0
7-mile	18,500.0	92.5	1,650	8.3
JWPCP	2,785.7	13.9	18,000	90.0
Orange County	2,571.4	12.9	9,830	49.2
Point Loma	1,700.0	8.5	3,810	19.1
Oxnard	1,464.3	7.3	317	1.6

[1] About 0.5% of emission remains in the waste field. Diluted NH_3-N is probably dispersed to the extent that under most conditions noticeable phytoplankton biomass enhancements do not occur directly above outfalls.

[2] Source: Schafer 1978.

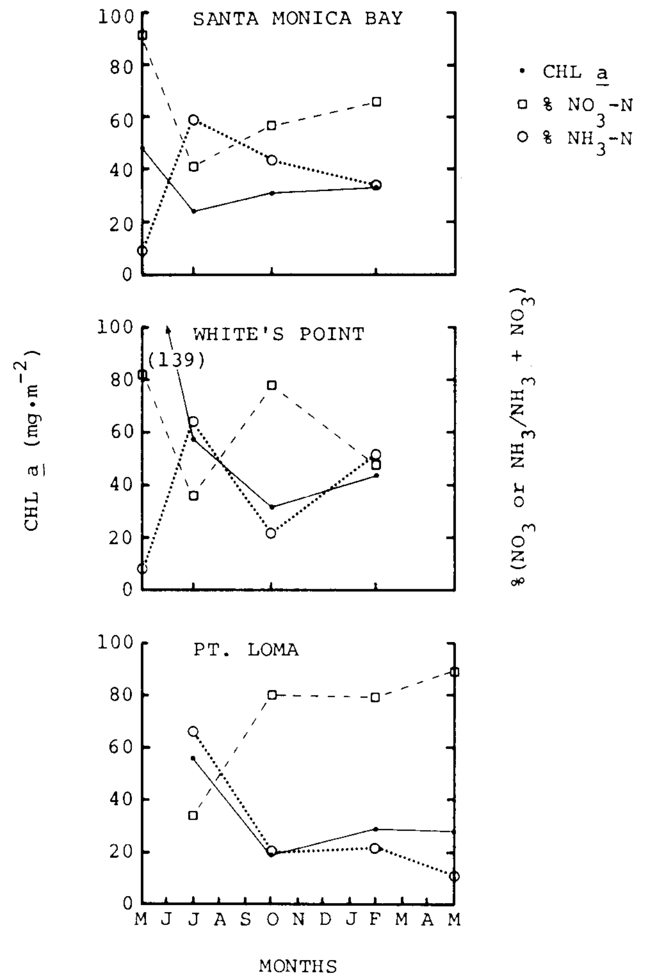

Figure 5. Euphotic-depth integrated chlorophyll concentration, % NH_3–N and % NO_3 during cruises from May 1971-May 1972 to stations adjacent to municpal outfalls at (top) Santa Monica Bay (Hyperion 5-mile outfall), (middle) White's Point (JWPCP outfall), and (bottom) Point Loma (San Diego County outfall). Values represent medians for all stations around each outfall.

Figure 5 was plotted from data reported by SCCWRP (1973). Water samples were collected from within the euphotic zone and analyzed for nutrient and chlorophyll content at stations above and adjacent to municipal waste-water outfalls in Santa Monica Bay (Hyperion 5-mile outfall), White's Point (JWPCP-Los Angeles County outfall), and off Point Loma (San Diego County outfall). The stations at each location were visited four times between May 1971 and May 1972. The data from each station were depth integrated, and the median value for each parameter was reported for each location. In Figure 5, phytoplankton biomass as chlorophyll *a* is plotted against time. The assumptions inherent in using chlorophyll *a* as an indication of biomass are discussed elsewhere (Eppley 1972; Kleppel 1979). If N is limiting, fluctuations in biomass should follow changes in nitrogen availability. In an attempt to determine whether the phytoplankton responded more to one form of N than another, median NH_3-N and NO_3-N values were plotted as the ratio of each form to their sum (NH_3-N/NH_3-N + NO_3-N and NO_3/NH_3−N+NO_3−N). In Santa Monica Bay (Figure 5a), the phytoplankton responded consistently to relative abundance of nitrate. Using the relative preference index (McCarthy et al. 1977), Eppley et al. (1979b) observed an increase in NO_3-N preference by diatoms during upwelling relative to inshore populations not exposed to upwelling. Since Santa Monica Bay in the vicinity of the outfall is both dominated by diatoms and adjacent to the Santa Monica Canyon, it would appear that local phytoplankton responded to upwelled nitrate more so than to ammonia-N.

At White's Point (Figure 5b), the biomass responded to nitrate when it was very abundant but switched to ammonia when nitrate was less abundant. Since sewage effluent is a principal source of ammonia, the JWPCP effluent may represent the nutrient source for phytoplankton in this area. However, the amount of ammonia reaching the surface did not appear to increase the biomass greatly relative to other areas. That is, while ammonia may be the more important form of nitrogen in these waters, it did not seem to be present at the surface in high enough concentrations to enhance production beyond background levels. The implications to community structure – whether diatom or dinoflagellate dominated – are presently unknown. Point Loma (Figure 5c) chlorophyll *a* followed the relative abundance of ammonia-N, again suggesting an anthropogenic or inshore influence upon the phytoplankton.

Although nitrogen loading is associated with changes in total phytoplankton biomass, it is apparent that the form and availability of the nitrogen (in relation to other parameters) may determine the structure of the planktonic community. This latter aspect of coastal phytoplankton dynamics is most important, as food web development hinges upon the composition of the planktonic community. For instance, the survival of first-feeding northern anchovies is partially dependent upon the juxtaposition of the larvae and a well-structured chlorophyll maximum composed largely of *Gymnodinium splendens* and other dinoflagelllates, which are the principal foods of the larvae (Lasker and Zweifel 1978).

In Santa Monica Bay, dinoflagellates appear to respond to a set of parameters characterized by inshore conditions (Figure 3b). The preponderance of ammonia sources in these waters suggests that ammonia may be a "tag" for the dinoflagellate parameter set. Conversely, diatoms respond to parameters characteristic of offshore waters, identifiable by changes in the relative abundance of nitrate. Similarly, Estrada and Blasco (1979) reported that dinoflagellates in the Baja upwelling system become dominant in the presence of low salinity, nutrient-rich water, supplied during periods of reduced upwelling, whereas diatoms are enhanced in the presence of high salinity, upwelled waters. The implications are that dinoflagellates are enhanced in the presence of waters derived inshore, and in this case, salinity is a "tag" for identifying associations of phytoplankton with various parcels of water.

Further work is needed to better define the dinoflagellate and diatom parameter sets in coastal waters. Recent studies in estuaries and coastal systems have revealed the importance of the often ignored interactions between phytoplankton community structure and the availability of silica, a macronutrient for diatoms, which is relatively unimportant for most dinoflagellates (Samuels 1979; Ryther and Officer 1979; L. Haury personal communication). In addition, the problems of heterotrophy are not well understood. Organic forms of carbon and nitrogen are more abundant inshore than offshore and are suspected of being utilized facultatively by several taxa of phytoplankton (Wheeler et al. 1977; B. Abbott personal communication).

The implications of identifying the factors regulating phytoplankton community structure are exciting with respect to understanding, and perhaps even manipulating, coastal food webs.

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