Calif. Mar. Res. Comm., CalCOFI Rept., 16: 84–94, 1972

SOME ASPECTS OF POLLUTION IN SAN DIEGO COUNTY LAGOONS

JOHN S. BRADSHAW
University of San Diego
San Diego, California

and

PETA J. MUDIE
Foundation for Ocean Research
Scripps Institution of Oceanography
La Jolla, California

INTRODUCTION

Water is considered polluted if it is not suitable for its intended use, whether that be a water supply, propagation of fish and wildlife, or recreation. Water pollution thus covers a diversity of events, such as oil spills, pesticide accumulation, heavy metal contamination and sewage discharge. Since the most serious pollutant in the lagoons of San Diego County appears to be sewage effluent, we shall confine ourselves to this topic.

Almost all of the coastal lagoons in San Diego County have a history of use as sewage disposals. Most of the effluent now entering the lagoons is secondarily treated, that is, the solids have been removed, and most of the organic matter has been oxidized. However, even after secondary treatment, the effluent still contains large quantities of nitrogen and phosphorus. The effluent adds a large nutrient load to the naturally nutrient-rich lagoon water, and results in a stimulation of excessive plant growth. Phytoplankton in some lagoons may be so prolific that the water turns pea green; other lagoons become covered with rafts of filamentous algae (*Enteromorpha spp.*). Following an algal bloom, the decomposition of plant material may result in the lowering of dissolved oxygen to such low concentrations that fish and other aquatic organisms can no longer survive; the death of these organisms further adds to the organic load and the oxygen deficiency. Other undesirable effects of this eutrophication process include the accumulation of sludge from the partially decomposed organic matter, the development of foul odors, and a lowering of the esthetic and recreational values of the lagoons.

Some of the features of this eutrophication process in the San Diego County lagoons have previously been described by Bradshaw (1968), Carpelan (1964, 1969), Gannon (1967), the California Department of Fish and Game (1951) and the California Department of Public Health (1951). The primary purpose of our study was to measure several chemical indicators of eutrophication (specifically, inorganic nitrogen and phosphorus) in lagoons receiving different amounts of nutrient-rich effluent, and to compare these nutrient levels with the background values of non-polluted lagoons in the same area. We also attempted to estimate the impact of sewage effluent disposal via the lagoons on the nutrient levels of the adjacent coastal waters. Our data was collected between August 22 and October 17, 1970; we have also drawn on the data of Gannon (1967), and on the records of the San Diego County Regional Water Quality Control Board. Our preliminary analyses are based on limited data, but we hope that the broad trends shown by them will spark more detailed and exacting studies in the future.

Description of the Lagoons

The distribution of the coastal lagoons in San Diego County is shown in Figure 1. These partially landlocked water bodies have resulted from the drowning of river mouths and the subsequent development of protective sand bars, a process thought to have begun approximately one million years b.p. Evidence from Indian kitchen middens indicates that all of these lagoons supported rich marine faunas from approximately 9,000 to 800 years ago (Miller, 1966).

Some aspects of the recent ecology and geology of these lagoons have been studied by Carpelan (1964, 1969), Miller (1966), Gannon (1967), Bradshaw (1968), Ford (1968), Damon (1969), Fairbanks (1969), and Mudie (1970). The most important factor affecting the lagoon ecosystems appears to be the size of the tidal prism, which is the volume of water exchanged by the tide. If the tidal prism is reduced below a critical volume (due to obstruction of the entrance channel, or to decrease of river inflow or lagoon volume), long-shore transported sand fills in the lagoon mouth, and tidal exchange ceases until the entrance barrier is breached by river flooding or by artificial means. If the lagoon remains closed for an extended period of time, the ecosystem changes from one characteristic of protected inshore ocean water to one dominated by brackish water (when the volume of fresh water inflow is high) or by hypersaline water (when the fresh water inflow is small).

The tidal prism of a lagoon is determined by the surface area, the height of the sill at the lagoon entrance, and the tidal range. Large lagoons (tidal prism $> 1 \times 10^7$ cu.ft.) generally remain open to the ocean (Inman and Frautschy, 1965), and, in Southern California, where river flows are relatively small, the salinity of the water in these open lagoons is similar to that of the ocean 33.5‰. At the other extreme, small lagoons normally remain closed and are connected with the ocean only during times of severe winter flooding. Fresh water predominates in these lagoons, the salinity generally being less than 5 parts per thousand (‰). Lagoons with tidal prisms in the "critical range" (defined empirically here as 1×10^7 to 1×10^5 cu.ft.) tend to remain open only a few months of the year but can be kept open artificially by annual small-scale dredging of the entrance channel. The salinity of the water in these variable lagoons is subject to great seasonal variation, the maximum range being approximately 10 to 65‰.

The pertinent characteristics of the San Diego County lagoons are summarized in Table 1. San Diego Bay, Mission Bay and Agua Hedionda Lagoon are open lagoons which support a high diversity of inshore marine fish and invertebrates, and a phytoplankton flora dominated by marine diatoms. Sewage effluent discharge rates in these lagoons are presently relatively low, the effluent constituting raw sewage contributed directly from watercraft. Up until 1962, however, large volumes of raw and primary sewage were discharged into San Diego Bay (1962 discharge rate was approximately 60×10^6 gals/day). Buena Vista is a closed lagoon with a limited brackish water fauna and flora. Prior to 1966, approximately 2×10^6 gals/day of secondary sewage effluent were discharged into this lagoon. In recent years, however, this discharge has stopped and at present only a small volume of irrigation runoff enters the lagoon from Buena Vista Creek.

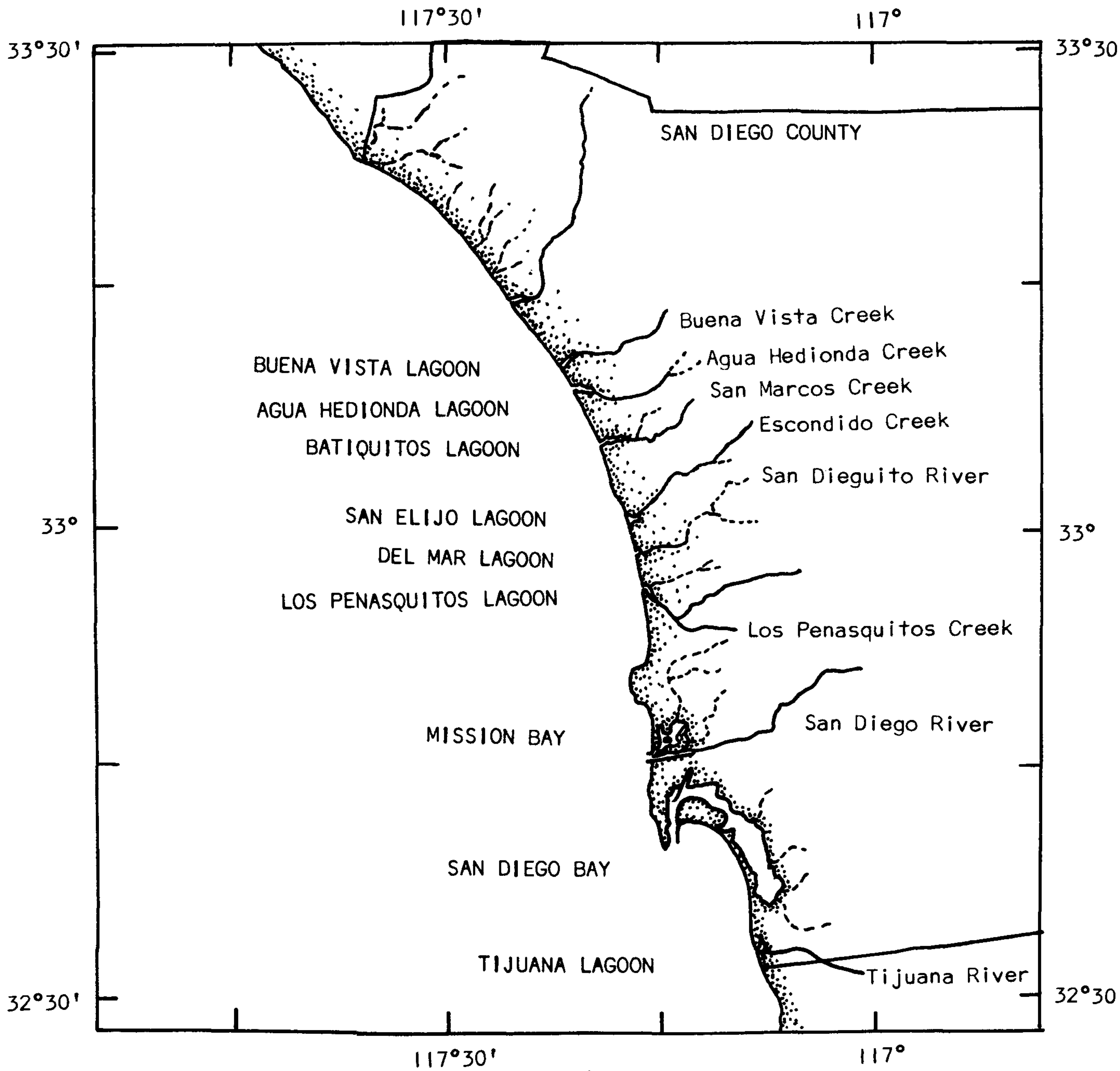

FIGURE 1. Distribution of the San Diego County lagoons sampled in this study.

Los Penasquitos, San Elijo, Batiquitos and Del Mar lagoons are variable lagoons. Prior to the inflow of significant volumes of sewage effluent (commencing between 1955 and 1960), these lagoons probably supported a limited euryhaline biota, with brackish water elements appearing temporarily during periods of fresh water accumulation. The biology of these variable lagoons has undoubtedly been altered by their history of secondary effluent discharge. At present, sewage enters the Los Penasquitos and Del Mar lagoons in ditches from treatment plants located within one mile of the lagoons. In contrast, the sewage entering San Elijo Lagoon originates as effluent discharged into the Escondido Creek approximately eleven miles upstream. The effluent entering Batiquitos Lagoon now comprises a relatively small volume of irrigation runoff and overflow from a sewage effluent storage dam. However, extensive sludge beds still exist in the lagoon from an earlier period of greater sewage discharge. Most of these polluted lagoons presently support an impoverished aquatic fauna comprising a few species of fish and large populations of Tubificidae, chironomids and ostracods. The phytoplankton is usually dominated by unicellular or colonial green algae, several species of which commonly number well over 100,000 cells/ml during bloom periods. Los Penasquitos Lagoon forms an exception to this general picture. This lagoon has been periodically opened by artificial means since 1966; tidal flushing for approximately nine months of each year has subsequently allowed the establishment of a moderately diverse marine biota.

Methods of Nutrient Analysis

Surface water samples were collected in 100 ml polyethylene bottles and were frozen within one to four hours after collection. Analyses for ammonia, nitrite, nitrate and orthophosphate on unfiltered samples were carried out with a Technicon AutoAnalyzer, using a modification of the techniques of Strickland and Parsons (1968), as described by Bradshaw and Spanis (1971).

Results of Nutrient Analyses

The horizontal distribution of nutrients in Mission Bay (Figure 2) and in San Elijo Lagoon (Figure 3) illustrate typical late-summer nutrient profiles of an unpolluted and heavily polluted lagoon, respectively.

Mission Bay is a tidally-flushed lagoon receiving an insignificant sewage input, and thus can be considered as representing the background nutrient levels of an open lagoon. The phosphate levels were generally low (0.3–1.2 μg-at P/l), although occasional higher values (up to 6 μg-at P/l were found. Nitrate and nitrite levels were also uniformly low (< 2.5 μg-at N/l). In contrast, ammonia values were relatively high and variable, with a total range of 17–720 μg-at N/l. The two extremely high ammonia values appear atypical and comparable values were found in no other lagoons.

Figures 3 and 4 show the distribution of nutrients in San Elijo Lagoon and in Escondido Creek below the entry point of the sewage effluent. This lagoon is open for only one to two months of each year following winter flooding. Between these major openings, the lagoon is usually closed except for sporadic short-term artificial openings (2–7 days duration).

Approximately 3×10^6 gals/day of secondary sewage effluent enters the creek from the City of Escondido, 14 miles inland; roughly two-thirds of this reaches the lagoon 11 miles downstream. Above the sewage outlet, the inorganic nutrient levels of the creek were low (NO_3-N, NO_2-N and PO_4-P values were < 1.5 μg-at/l; NH_3-N was 8 μg-at/l). The sewage entry was marked by a moderate increase in ammonia (25 μg-at N/l) and a dramatic rise in phosphate (700 μg-at P/l). The first 3.5 miles downstream from the sewage outlet were characterized by a decrease of approximately 50% in phosphate, and a relatively moderate increase in inorganic nitrogen levels. Between 3.5 and 5 miles downstream, however, ammonia and nitrite levels soared rapidly, reaching peak values of 8000 and 150 μg-at N/l, respectively. Phosphate and nitrate levels also increased to lesser peaks in this region.

The creek below this area is inaccessible for sampling, but the nutrient values at stations 10 and 11 miles downstream indicated a marked decrease in ammonia and nitrite, a lowering of phosphate, and a rise in nitrate along this stretch. Approximately 12 miles downstream from the sewage outlet, the creek enters the shallow upper reaches of San Elijo Lagoon. Within the lagoon, ammonia and nitrite levels remained

TABLE 1

Summary of Lagoon Characteristics

	Type of Lagoon	Effluent Discharge Rate (cu. ft. $\times 10^3$/day)	Type of Effluent	Lagoon Volume at MHHW (cu. ft. $\times 10^6$)	Tidal Prism (cu. ft. $\times 10^6$)	Salinity Range °/°°	Nutrient Concentration Factor[3]
Mission Bay	Open	<0.134	Untreated	1,260	456	32–35	0.147×10^{-6}
Agua Hedionda	Open	<0.134	Untreated	81	30	32–35	2.23×10^{-6}
San Diego Bay	Open	33.4	Untreated	15,000	3,000	32–35	5.63×10^{-6}
Los Peñasquitos	Variable[1]	133.7	Secondary	2.8	0.7	15–40	9.55×10^{-2}
Buena Vista	Closed	0.669	Irrigation	28.7	0[2]	2–5	0.64×10^{-2}
Batiquitos	Variable	3.1	Secondary & irrigation	17.4	0.3[2]	4–27	4.6×10^{-2}
San Elijo	Variable	267.4	Secondary	69.9	0.6[2]	2–14	91.5×10^{-2}
Del Mar	Variable	26.7	Secondary	5.5	0.2[2]	5–55	1.27

[1] Normally kept open artificially and thus treated as open lagoon for calculation of nutrient concentration factor.
[2] Normally closed and thus tidal prism is effectively zero.
[3] Patio of concentration of pollutant in lagoon to concentration of pollutant in sewage (see text for details).

uniformly low. However, nitrate reached a maximum peak of 325 μg-at N/l near the creek entrance, and phosphate increased to a minor peak of 200 μg-at P/l in the upper reaches of the lagoon. In contrast, at the lagoon entrance, all nutrient levels were low (< 5 μg-at/l), suggesting that the broad shallow lagoon acts as an effective nutrient filter.

In order to compare the nutrient levels of the various types of lagoons in a meaningful way, it was necessary to relate the effluent discharge rate for each lagoon to the physical factors (tidal prism, lagoon volume etc.) of each lagoon. A highly simplified mathematical model of lagoon effluent dilution was constructed (see Appendix for details) and from this model, the ratio of pollutant concentration in a lagoon (C_L) to pollutant concentration in the effluent (C_E) was calculated. We have called this ratio the "nutrient concentration factor."

For open lagoons, a steady state condition between effluent influx and tidal removal was assumed, and the nutrient concentration factor was calculated from the

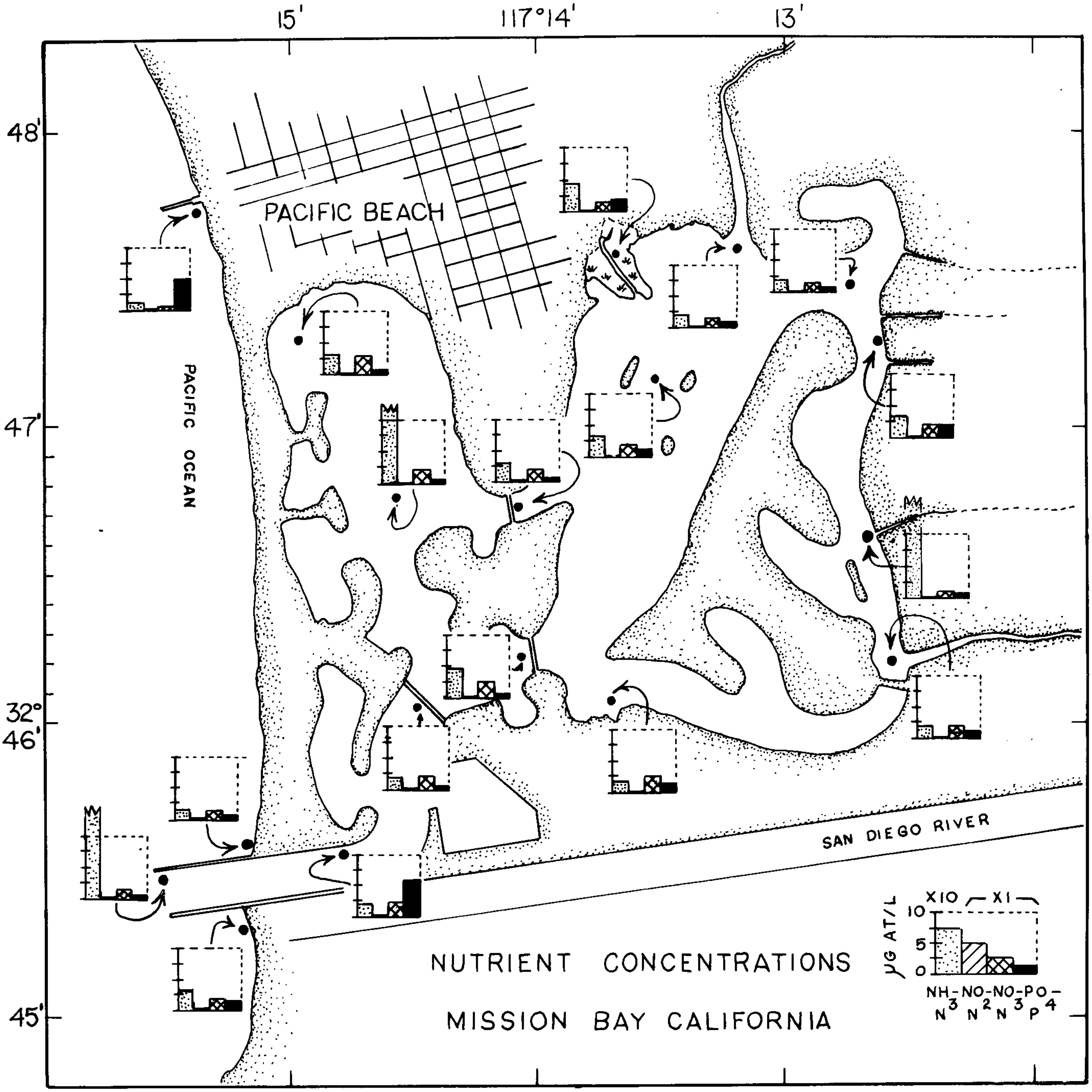

FIGURE 2. Distribution of orthophosphate-phosphorus and inorganic nitrogen from surface water of Mission Bay, October 17, 1970. Samples were collected between 1100 and 1300 hours. Serrated column on histogram indicates "off-scale" value.

equation $\frac{C_L}{C_E} = \frac{R_E}{2T}$, where R_E is the rate of effluent discharge and T is the tidal prism. For a closed lagoon, the assumption was made that flood water flushes the lagoon of accumulated nutrients once a year, and that the concentration of pollutant in the lagoon water at the time of closing was very small relative to that in the incoming effluent. The nutrient concentration factor was then calculated as $\frac{C_L}{C_E} = \frac{R_E \times N}{V_L}$, where N is the number of days after closing, and V_L is the volume of the lagoon. It was assumed that evaporation from the closed lagoon was balanced by effluent inflow, an assumption that is supported by casual observations.

The mean value and range of phosphate for each San Diego County lagoon and for the nearshore coastal water is shown in Figure 5. A positive correlation is apparent between the mean phosphate values and the nutrient concentration factor. The phosphate levels of those open lagoons which have relatively large tidal prisms and volumes are clustered around a

TABLE 2

Summary of Nitrite and Nitrate Data

Lagoons	Number of stations	NO_2-N (μg-at/l)	NO_3-N (μg-at/l)
Mission Bay	11	0.10– 0.22, $\overline{X}$ = 0.15	1.4– 2.9, $\overline{X}$ = 1.9
Agua Hedionda	6	0.05– 0.07, $\overline{X}$ = 0.05	0.5–31.0, $\overline{X}$ = 0.7
San Diego Bay	12	0.10– 0.50, $\overline{X}$ = 0.21	0.7– 2.0, $\overline{X}$ = 1.5
Los Peñasquitos	5	0.07– 1.40, $\overline{X}$ = 0.30	0.2–21.5, $\overline{X}$ = 2.5
Buena Vista	5	0.05– 0.10, $\overline{X}$ = 0.05	0.5– 0.6, $\overline{X}$ = 0.5
Batiquitos	5	0.10–10.0 , $\overline{X}$ = 2.8	0.6–26.0, $\overline{X}$ = 1.3
San Elijo	6	0.01– 0.05, $\overline{X}$ = 0.03	0.1–1.0(–325), $\overline{X}$ = 0.36
Del Mar	3	0.70– 0.85, $\overline{X}$ = 0.80	0.7– 1.7, $\overline{X}$ = 1.2
Beaches	13	0.05– 0.30, $\overline{X}$ = 0.15	0.5– 2.2, $\overline{X}$ = 1.0

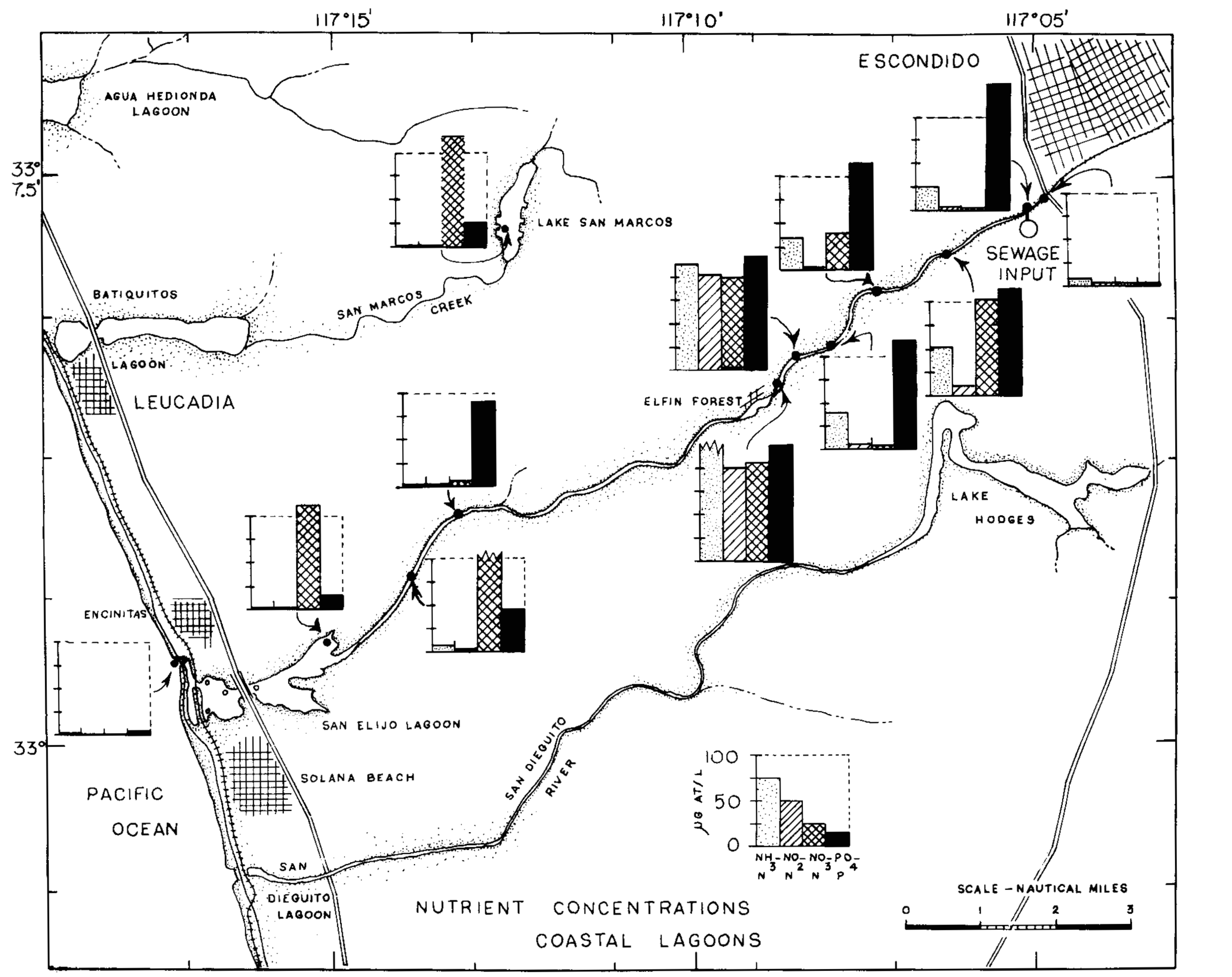

FIGURE 3. Distribution of orthophosphate-phosphorus and inorganic nitrogen from surface water of San Elijo Lagoon and Escondido Creek, August 23, 1970. Samples were collected between 1530 and 1900 hours. Serrated column on histogram indicates "off-scale" value.

mean value of 1 μg-at P/l. These values are similar to those found in the nearshore ocean water just off the local beaches. In contrast, the mean value for Los Penasquitos, an open lagoon with a small tidal prism, and relatively large effluent discharge rate, is approximately forty times greater than the mean of the other open lagoons. The mean phosphate values for the closed lagoons show a general increase with increasing nutrient concentration factor.

Figure 6 summarizes our data for ammonia levels in the lagoons and nearshore waters. The mean values show a much higher degree of scatter than those of phosphorus and we could find no obvious correlation with effluent dilution or effluent volume.

The means and ranges of nitrite and nitrate are shown in Table 2. It is evident that, with the exception of one station in San Elijo (where nitrate = 325 μg-at N/l), the nitrate and nitrite values were generally low in both polluted and unpolluted waters, and showed no marked correlation with effluent discharges.

DISCUSSION

On the basis of the results of our preliminary study, we tentatively suggest that two important generalizations can be made concerning the values of inorganic nutrients found in the lagoons of San Diego County. Firstly, orthophosphate appears to be a relatively good

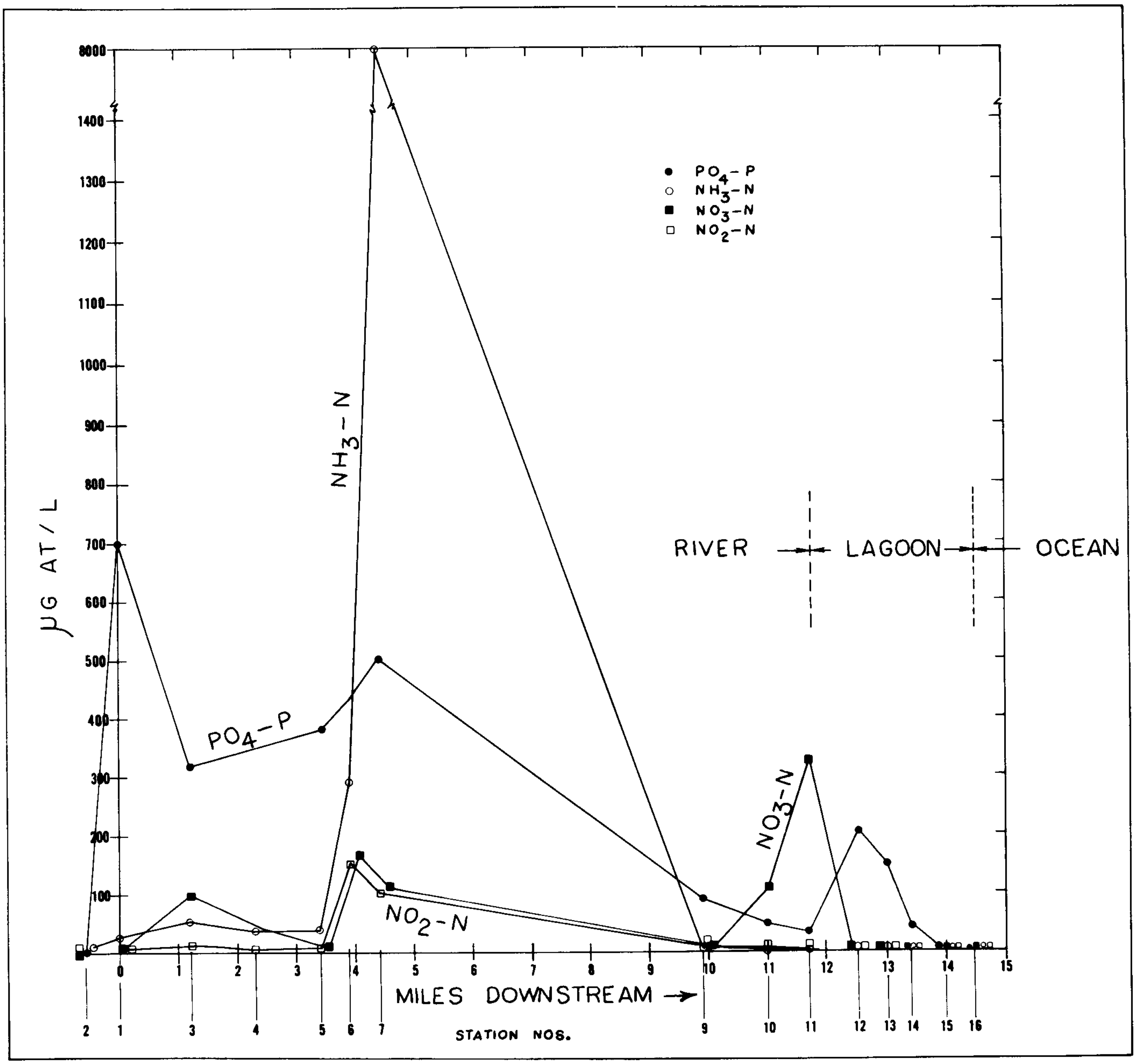

FIGURE 4. Distribution of data shown in Figure 3, plotted against distance downstream from point of effluent discharge.

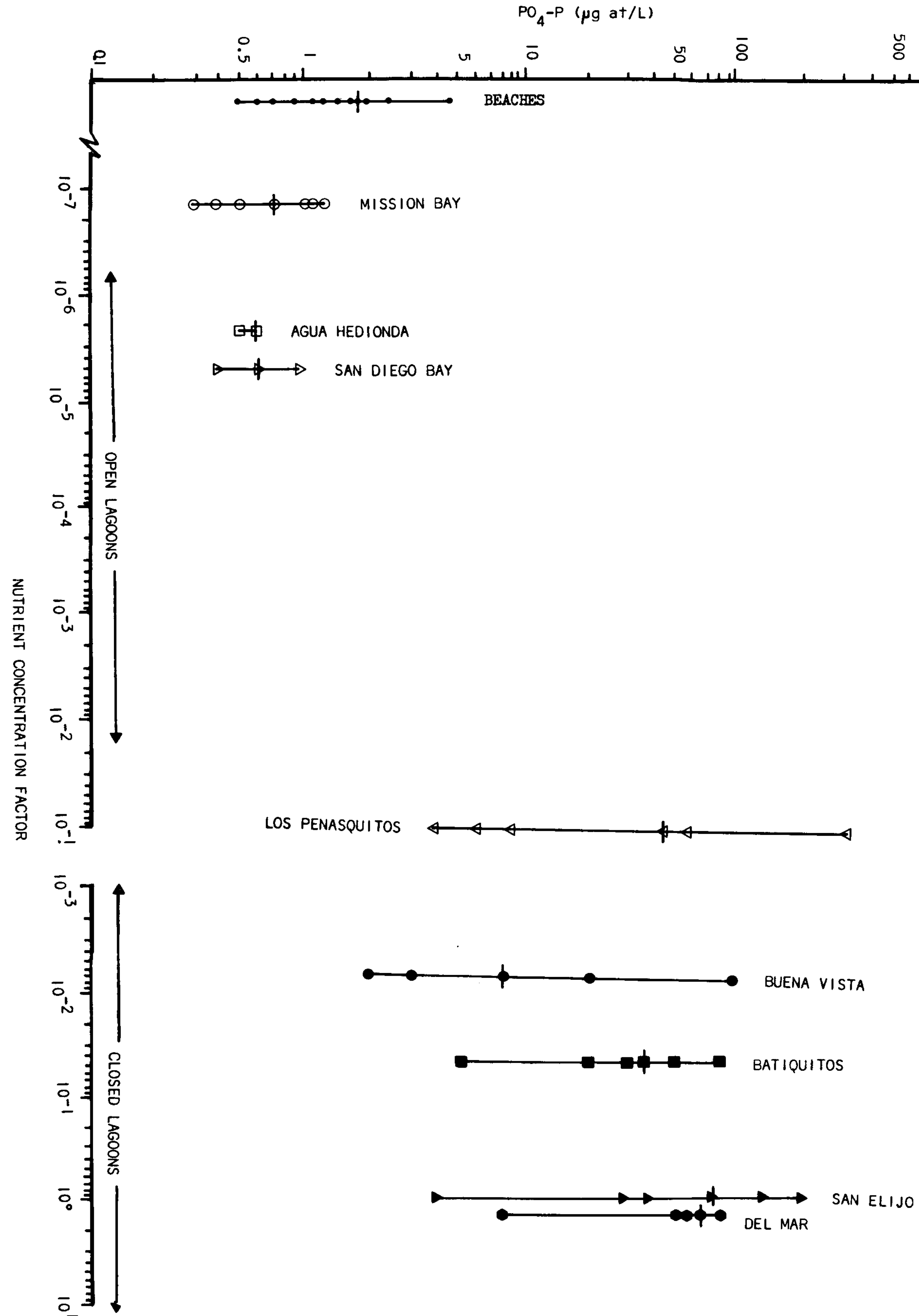

FIGURE 5. Summation of orthophosphate-phosphorus data from San Diego County lagoons and nearshore waters, Fall, 1970. Horizontal lines indicate mean values. Number of stations at each locality is shown in table 2.

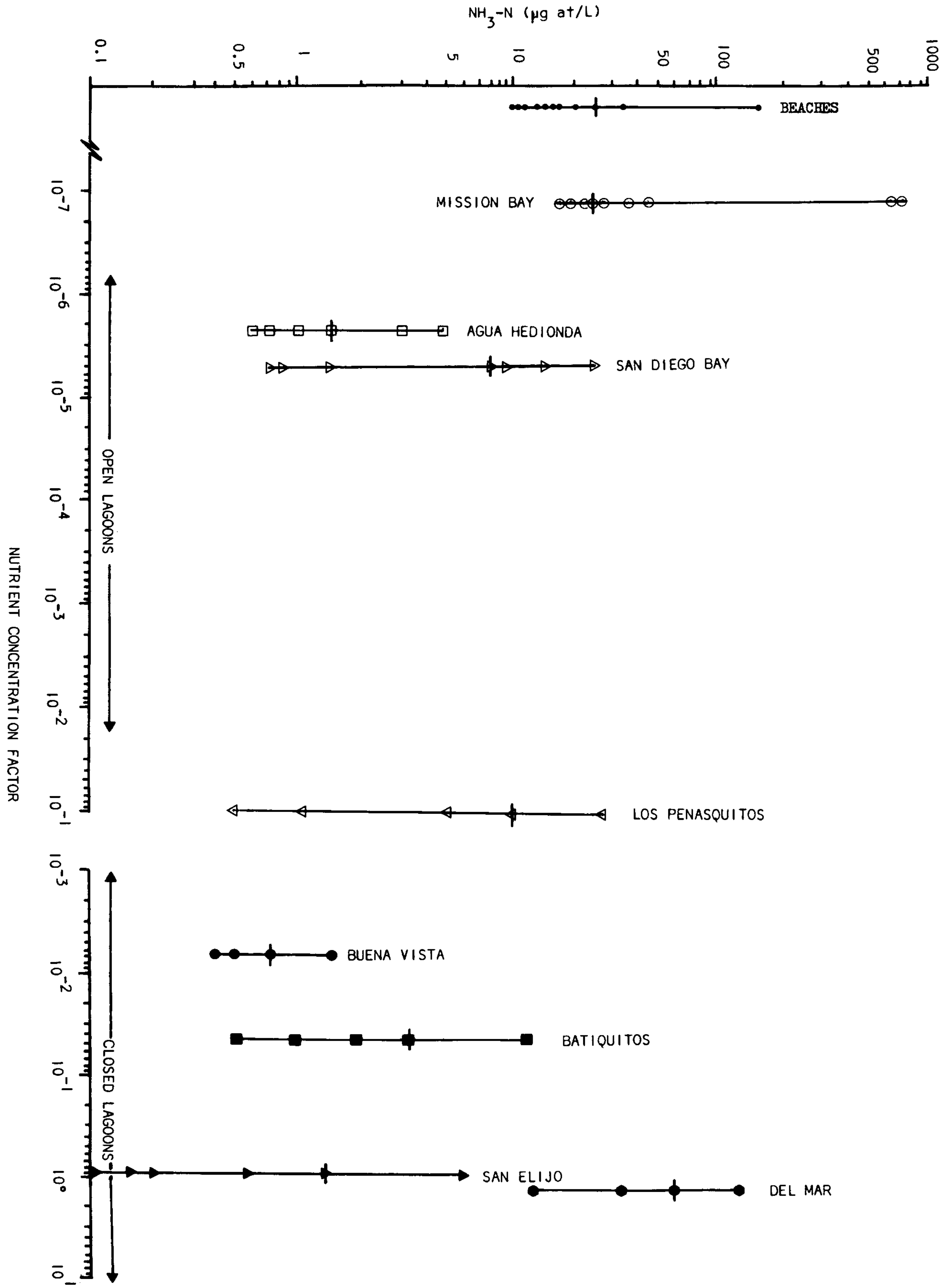

FIGURE 6. Summation of ammonia-nitrogen data from San Diego County lagoons and nearshore waters, Fall, 1970. Horizontal lines indicate mean values. Number of stations from each locality is shown in table 2.

indicator of nutrient enrichment in these coastal lagoons. This nutrient is relatively easy to measure and is far less subject to atmospheric contamination or loss than ammonia. In the lagoon ecosystems, orthophosphate appears to remain in excess of phytoplankton demands and thus seems less subject to sporadic depletion with algal blooms than does inorganic nitrogen. This observation is supported by the work of Ryther and Dunstan (1971) and Ketchum (1969) in the estuaries on the east coast of the United States. Although absorbed phosphate may be released from the lagoon muds when the overlying water is anaerobic (Mortimer, 1941), this is probably not an important factor in our shallow lagoon waters which are usually moderately or well oxygenated, and in which nighttime periods of oxygen depletion are usually brief (Carpelan 1969). To provide a complete picture of the phosphate budget in the lagoon ecosystem, it would be necessary to measure dissolved organic and particulate phosphate in addition to orthophosphate, both in the water and in the sediments. However, our data suggests that inorganic phosphate measurements of the water alone can serve as a useful estimate of excess nutrient loading.

In contrast to inorganic phosphorus, the various forms of inorganic nitrogen measured by us did not show a clear-cut relationship to sewage effluent volume or dilution during the time of study. The uniformly low nitrate and nitrite levels suggest that these ions are limiting nutrients and are rapidly depleted by phytoplankton. A similar conclusion for the coastal waters of the United States east coast was reported by Ryther and Dunstan (1971). We have some evidence that a dramatic inorganic nitrogen depletion may occur within a distance of a few thousand feet when the effluent enters a shallow, sluggish-moving stretch of lagoon or creek water. For example, in San Elijo, nitrate fell from a maximum value of 325 to 1 µg-at N/l between stations 11 and 12; in the Del Mar Lagoon, nitrate dropped from 200 to 4.4 µg-at N/l within a distance of approximately 1000 feet of the broad shallow creek that conveys the effluent from the sewage oxidation pond to the lagoon. In general ammonia levels also showed a rapid decrease downstream of the effluent entry point, but sporadic high

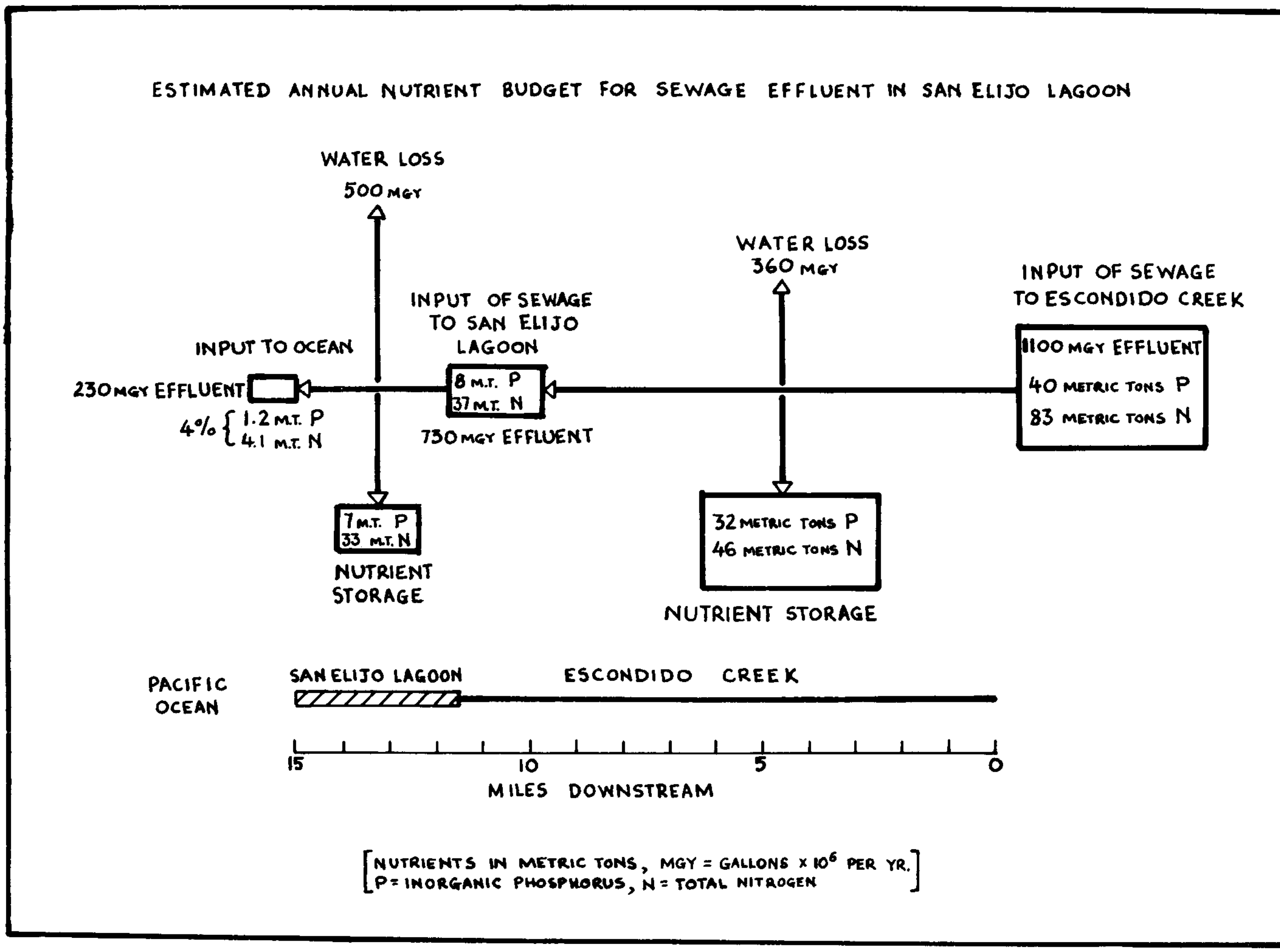

FIGURE 7. Estimated annual budget for sewage nutrients in Escondido Creek and San Elijo Lagoon.

values in both the polluted lagoons and the relatively unpolluted nearshore and open lagoon waters suggest that the factors governing ammonia uptake and regeneration are highly complicated.

The second generalization that we wish to make is that the broad, shallow lagoons in North San Diego County act as nutrient filters and thus normally prevent all but a fraction of the original effluent nutrient load from reaching the nearshore waters. Using data from Gannon (1967) and the WQCB records for Escondido Creek from 1964 to 1970, we have calculated a rough annual nutrient budget for orthophosphate-phosphorus and total nitrogen for San Elijo Lagoon (Figure 7).

Using an average daily effluent discharge rate of 3×10^6 gallons, a mean total nitrogen value of 20 mg N/l and a mean inorganic PO_4 concentration of 29 mg PO_4/1, we estimated an annual nutrient input into Escondido Creek of 83 metric tons of nitrogen and 40 metric tons of inorganic phosphorus. Approximately 10 miles downstream, one mile before the creek enters the lagoon, the average N and PO_4 concentrations were 13.8 and 8.9 mg/l, respectively, indicating that approximately 80% of the phosphate and 56% of the nitrogen were removed in the creek. (The creek flow at this station is approximately two-thirds that at the point of effluent entry.)

Although there is considerable horizontal and seasonal variation in nutrient levels within the lagoon, a reasonable average nutrient value would be 4.0 mg/l PO_4 and 4.8 mg/l N. This means that approximately 80% of the phosphorus and 90% of the nitrogen entering the lagoon from the creek is trapped in the four mile stretch of shallow lagoon channels and mudflats. Using an annual evaporation rate for the lagoon of 500×10^6 gallons (based on data from Lake Hodges, ten miles from the lagoon), and a creek inflow rate of 730×10^6 gallons/year, we estimate that 230 $\times 10^6$ gallons of effluent finally enter the ocean each year. This would contribute an annual load of approximately 1.2 metric tons of inorganic phosphorus and 4.1 metric tons of nitrogen, a mere $\pm$ 4% of the original sewage load. Compared with an estimated daily discharge rate of 90 metric tons of nitrogen and 30 metric tons of phosphorus into the New York bight (Ryther and Dunstan, 1971), this appears to be an insignificant contribution to the nearshore waters.

In conclusion, it can be stated that the present rates of effluent discharge in the lagoons of San Diego County make little impact on the nearshore ocean water. However, the trapping of nutrients within the lagoons has an obviously deleterious effect on the estuarine biota, which is compounded in the variable lagoons by the stresses imposed by great salinity fluctuations.

APPENDIX

We extend our sincere thanks to Tanya M. Atwater, John D. Mudie, John M. Parks and Walter R. Schmitt, all of Scripps Institution of Oceanography, for their elucidation of the mathematics of effluent dilution.

The "nutrient concentration factor" used in this report was derived in the following way:

C_L, C_E and C_T are the concentrations of a pollutant in lagoon, effluent and tidal prism. V_L is the volume of water in the lagoon. R_E, 2T and R_e are the daily rates of water added or removed from the lagoon by effluent, tide and evaporation.

The amount of pollutant at time t will be

$$(C_LV_L)_t = (C_LV_L)_{t_1} + \int_{t_1}^{t}(C_ER_E + 2C_TT)dt - \int_{t_1}^{t} C_L(2T + R_E - R_e)dt$$

where it is assumed that the only additions to the lagoon are by the effluent and the tides, and the only removal is by outflow at the lagoon entrance and evaporation. Mixing is assumed to be perfect so that all water in the lagoon and flowing out of the lagoon has a concentration of C_L.

Steady State Situation. Tides are assumed to remove as much pollutant as is being added by the effluent, so that the amount of pollutant in the lagoon is constant, i.e. $(C_LV_L)_t = (C_LV_L)_{t_1}$.

Thus $\int_{t_1}^{t} C_ER_Edt + \int_{t_1}^{t} 2C_TTdt = \int_{t_1}^{t} C_L(2T + R_E - R_e)dt$, and differentiating with respect to t gives $C_ER_E + 2C_TT = C_L(2T + R_E - R_e)$. Assuming that the concentration in the incoming tide, C_T, is small compared to C_L, and that the rate of effluent addition, R_E, and evaporation rate, R_e, are small compared to the tidal prism, T,

$$\text{then } C_ER_E = C_L2T, \text{ and } \frac{C_L}{C_E} = \frac{R_E}{2T}.$$

This is the pollutant concentration ratio used to calculate the "nutrient concentration factor" for open lagoons.

Non-steady State Situation. Here the lagoon mouth closes at time t_1 and thereafter all pollutant added by the effluent remains in the lagoon. There is no tidal prism, i.e. T = 0. Evaporation is assumed to balance water added by effluent, i.e. $R_E = R_e$, and the concentration of pollutant in the lagoon when the mouth closes is assumed to be small, so that $(C_L)_{t_1} = 0$.

Thus $(C_LV_L)_t = \int_{t_1}^{t} C_ER_E\,dt$.

and at time t = N days after t_1, then $C_LV_L = C_ER_EN$,

$$\text{and } \frac{C_1}{C_E} = \frac{R_EN}{V_L}.$$

This is the pollutant concentration ratio used to calculate the "nutrient concentration factor" for closed lagoons, taking N = 240 for San Elijo, and N = 263 for the other closed lagoons.

REFERENCES

Bradshaw, J. S. 1968. *The Biological and Ecological Relationships in the Los Penasquitos Lagoon and Salt Marsh Area of the Torrey Pines State Park.* Contract No. 4-05094-033. Report prepared for the California Division of Beaches and Parks.

Bradshaw, J. S. and C. W. Spanis. 1971. Use of automated and continuous flow analysis in an educational program on pollution of coastal lagoons. Technicon Symposia, Volume 5, New York.

California Department of Fish and Game 1951. *San Diego Bay Water Pollution Survey.* Project No. 52-9-1. Report prepared for the San Diego Regional Water Pollution Control Board.

California Department of Public Health. 1951. *A Survey of Pollution and Nuisance Problems in San Diego Bay.* Code No. 52-9-1. Report prepared for the San Diego Regional Water Pollution Control Board.

Carpelan, L. H. 1964. Effects of salinity on algal distribution. *Ecology 45:* 70–77.

Carpelan, L. H. 1969. Physical Characteristics of Southern California coastal lagoons. In *Lagunas Costeras, Un Simposio.* Mem. Simp. Intern. Lagunas Costeras, UNAM-UNESCO, 1967, Mexico, D.F., pp. 319–334.

Damon, D. M. 1969. *Population Dynamics of Coenobiodiscus and Other Plankton with Respect to Nutrient Cycling in San Diego Bay*, 1967–68. M.S. Thesis, San Diego State College, pp. 135.

Fairbanks, D. A. 1969. *Environmental Factors Affecting Phytoplankton Populations in Mission Bay.* M.S. Thesis, San Diego State College, pp. 120.

Ford, R. S. 1968. *Marine Organisms of South San Diego Bay and the Ecological Effects of Power Station Cooling Water Discharge.* Report prepared for the San Diego Gas and Electric Company, San Diego.

Gannon, R. J. 1967. *The Eutrophication of San Elijo Lagoon, San Diego County, 1966–67.* Report prepared for the San Diego Regional W.Q.C.B. (No. 9) by Environmental Engineering Lab, Inc., 61 pp.

Inman, D. L. and J. D. Frautschy. 1965. Littoral Processes and the development of shorelines. *Proceedings of the Santa Barbara Specialty Conference on Coastal Engineering*, Santa Barbara, California, October, 1965, pp. 511–536.

Ketchum, B. H. 1969. Eutrophication of estuaries. In *Eutrophication: Causes, Consequence and Correctives.* N.A.S., Washington, D.C., pp. 197–209.

Miller, J. N. 1966. *The Present and the Past Molluscan Faunas and Environments of Four Southern California Coastal Lagoons.* M.S. Thesis, University of California at Los Angeles, 275 pp.

Mortimer, C. H. 1941. The exchange of dissolved substances between mud and water in lakes. *Journal Ecology 29:* 280–329.

Mudie, P. J. 1970. *A Survey of the Coastal Wetland Vegetation of San Diego Bay.* Contract No. W26D25-51. Report prepared for the California Department of Fish and Game, 79 pp.

Ryther, J. H. and W. M. Dunstan. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. *Science 171:* 1008–1013.

Strickland, J. D. H. and T. R. Parsons. 1968. *A Practical Handbook of Seawater Analysis. Fisheries Research Board of Canada Bull. 167.* 311 pp.