Hydrobiologia vol. 43, 1—2 pag. 77—91, 1973.

Effects of Environmental Perturbations on Short-Term Phytoplankton Production off Lawson's Bay, A Tropical Coastal Embayment

by

D. V. SUBBA RAO*

Department of Zoology, Andhra University, Waltair, India

ABSTRACT

1. The phytoplankton cycle off Lawson's Bay, Waltair follows a bimodal pattern with a major peak during March-May; a minor peak during October-November months and with a low production during the summer months i.e., June-August.
2. During the summer months of 1957, 1958, 1960 and 1962 dumping of dredged spoil from the entrance channel of the harbour into the sea resulted in a natural enrichment of waters.
3. Following this enrichment, there was a qualitative and quantitative increase in the phytoplankters thus leading to the development of a bloom.
4. Only *Thalassiosira subtilis* and *Chaetoceros curvisetus* commonly bloomed during the four years.
5. The increase in gross production which varied from 3—13 fold and the high photosynthesis-respiration ratios 5.1 to 10.5 indicated that the bloom populations were in a healthy state.
6. The decrease of the populations to the initial levels suggests that some unknown factor, other than those investigated must have been operating.
7. Consequences of eutrophication of different origins on stimulation of phytoplankton production are briefly discussed.

INTRODUCTION

Effects of eutrophication are known to result in irreversible changes in the aquatic ecosystem through competitive exclusion of certain species and changes in trophodynamics. The coastal zone being a major contributor from the fishery point of view (RYTHER, 1969),

*Present address: Marine Ecology Lab., Bedford Institute of Oceanography, Dartmouth, N.S. Canada.

Received April 12, 1972

consequences of man-induced perturbations need be fully evaluated. While there is a growing concern for the protection of the coastal marine environment in the temperate and higher latitudes, there is little information on this aspect from the tropical waters. In the present study, owing to their close coupling with the environment, phytoplankters are chosen to understand their response and recovery to effects of eutrophication off Lawson's Bay, a tropical embayment from Bay of Bengal. Lawson's Bay is a coastal embayment situated at 17°44'N and 83°23'E on the east coast of India. Visakhapatnam harbour is about 7.5 km south of Lawson's Bay. Since 1957, to prevent silting near the harbour entrance channel, extensive dredging operations have been conducted by the harbour authorities. The spoil was dumped at times at a dumping ground located about 7 km south of Lawson's Bay. According to the port authorities the dumped spoil gets redistributed in about 6—7 months by the littoral currents.

Methods

Surface water and plankton samples were collected at a fixed station located on the 20 m line in Lawson's Bay during 1956 through 1962 (map Fig. 1). Water samples for chemical analyses were stored in polyethylene bottles. Known quantities of surface water were sampled with a bucket and filtered through a medium Epstein net made of fine bolting silk having 200 meshes per linear centimeter. To the cod end of the net a plastic collector was attached. The concentrated plankton sample was drawn into a wide mouthed Pyrex bottle and stoppered. The plankton was aportioned for the following analyses:

Numerical

Utermohl's inverted plankton microscope method (Steemann Nielsen, 1933) was used.

Total organic matter

Verduin's method (1951) of determining the loss of organic matter due to inceneration of dried plankton was used.

Plant pigments

Harvey's (1934) method of estimation of plant pigment was used. Plankton sample was filtered through a Whatman 47 filter paper and the filter was placed in a tube containing 90% acetone and stoppered and kept in a desiccator for 24 hrs in dark at room temperature. The

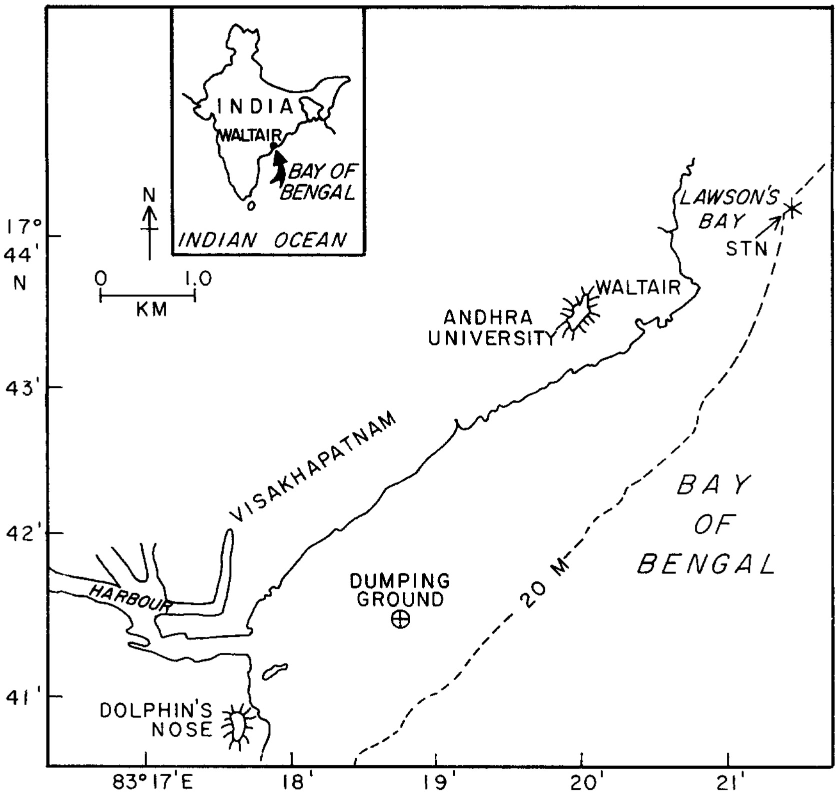

Fig. 1 Map showing Waltair coast and Lawson's Bay.

extract was filtered through Whatman 47 filter paper and the concentration of Harvey plant pigment units measured with a Lumetron photoelectric colorimeter.

Gross production

The dark and light bottle method of GRAN (1929) was used. Surface water was drawn into clean 275 ml Pyrex bottles, stoppered and incubated under natural light in a trough on the roof of the laboratory. Water in the trough was kept under circulation by overflow from an overhead water reservoir. The incubation was 6 h usually from 10 a.m. WINKLER's method was used to determine the oxygen content of the samples.

Water and mud samples were also collected in and around the dumping ground through the courtesy of the port authorities from dredgers "S. D. Vizagapatam" and "Visakha" or from a launch and the samples were stored in Polyethylene bottles. The following methods were employed for the chemical analyses:

a) *Water samples:*

1. Turbidity: Hellige's Turbidimeter was used.
2. Inorganic phosphate: DENIGE's method as modified by ROBINSON & THOMPSON (1948).
3. Silicates: DIENERT and WANDENBULCKE's method as modified by ROBINSON (1948).

b) *Mud samples:*

1. Interstitial and adsorbed phosphate: ROCHFORD's method (1951).
2. Manganese: PIPER's method (1947).
3. Total Iron: PIPER's method (1947).

Table 1: Results of chemical analyses of mud samples.

Sample No.	Colour	Lithology	Mg/gm sediment		µg/gm sediment	
			Manganese	Total Iron	Interstitial PO_4	Adsorbed PO_4
1	Grey	clayey sand	6.90	28.50	1.20	1.25
2	Reddish black	silt clay	12.50	8.00	1.70	1.38
3	Greyish black	clay	13.00	7.50	1.35	1.50
4	Greyish black	siltclay	10.45	8.40	0.90	1.68
5	Reddish grey	clay	19.50	5.80	1.50	1.70
6	Black	clay	22.00	27.00	1.38	4.20
7	Black	clay	15.50	10.00	1.72	3.25
8	Greyish black	silt clay	3.00	28.00	-	-
9	Black	clay	3.00	28.50	-	-
10	Black	sandy	2.30	25.00	-	-
11	Black	sandy	3.00	22.00	-	-
12	Reddish black	sandy	2.30	4.50	-	-

RESULTS

Table I shows that the interstitial phosphate ranged from 0.90 to 1.72 and adsorbed phosphate between 1.25 and 4.20 µg/gm sediment. The manganese content varied from 2.30 to 22.00 and total iron from 4.50 to 28.50 mg/gm desiment. In general, silt clay sediments had a higher concentration of these nutrients.

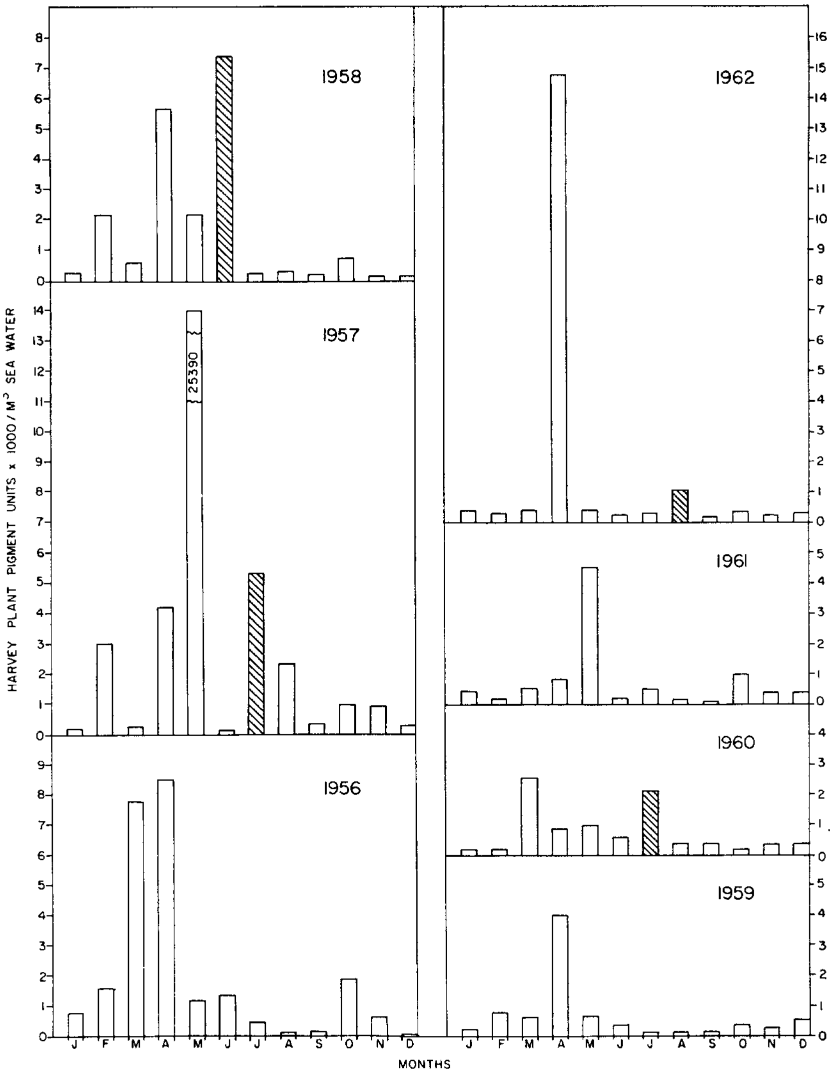

Fig. 2. Annual phytoplankton cycle off Lawson's Bay, Waltair. Hatched bars represent phytoplankton blooms during dredging operations.

Figure 2 shows that the annual phytoplankton cycle in Lawson's Bay waters followed a bimodal pattern with a major peak during March—May and a minor peak during October—November coinciding with the activity of the southwest and northeast monsoons respectively. The phytoplankton crop was low during the summer months i.e. June—August as noticed in 1956, 1959 and 1961. However, an additional phytoplankton bloom was noticed during the

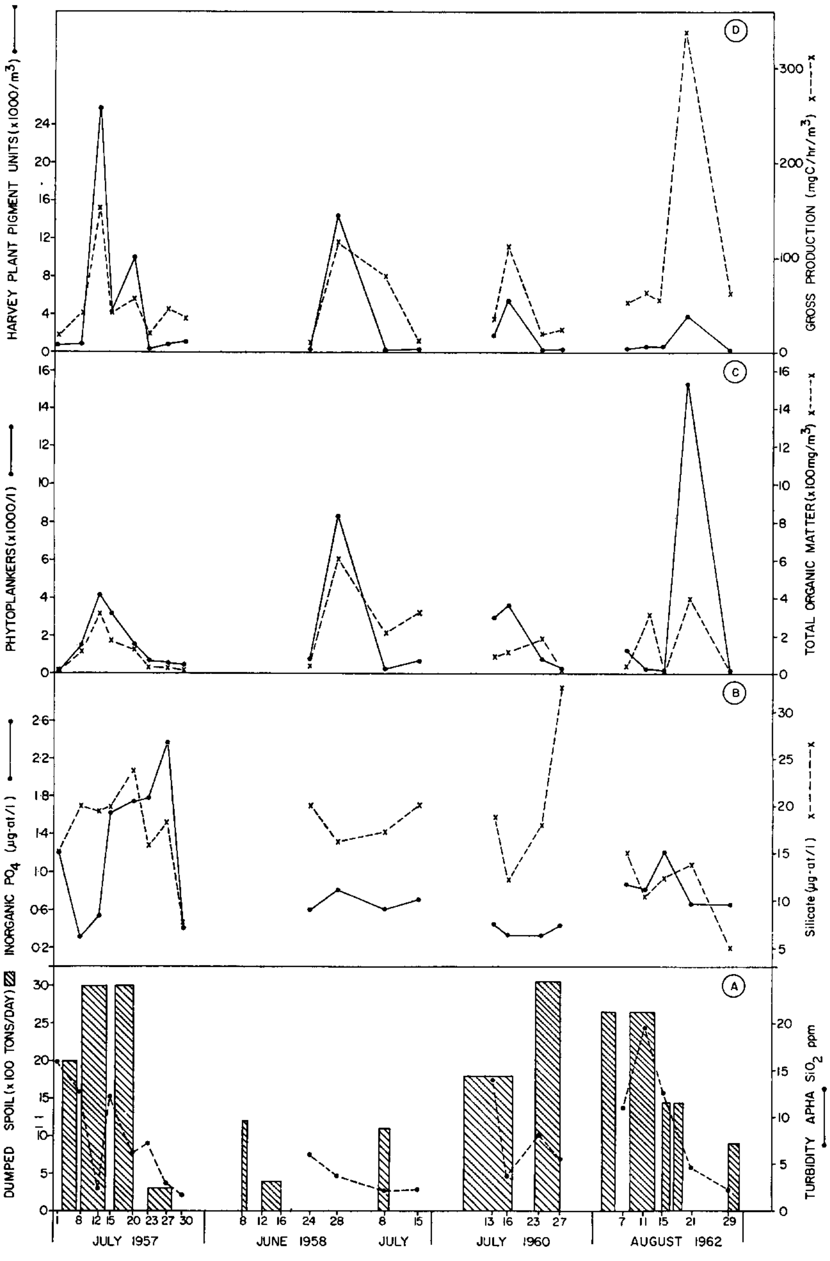

Fig. 3. Changes in turbidity, nutrients, phytoplankton standing crop and gross production following dredging operations.

summer months of 1957, 1958, 1960 and 1962. The following account shows that these summer blooms are associated with dredging operations.

Figure 3 shows details on the changes during these summer blooms. Different areas of the harbour were dredged and the quantity of spoil dumped into the sea varied from 300 to 3050 tons/day (Fig. 3A). In the wake of a northerly coastal current, the dumped spoil was transported into the Lawson's Bay causing extensive brownish red discolouration and an increase in the turbidity of the waters (Fig. 3A). The nutrient level of the water was high with a maximum of 2.36 μg at PO_4-P/L and 32.50 μg at SiO_2/L (Fig. 3B). A sudden increase in the standing crop of phytoplankton judged by cell numbers, total organic matter (Fig. 3C) and Harvey plant pigments (Fig. 3D) was noticed following the dredging operations. The gross production ranged from 9.20 to 152.05 mg C/hr/M^3 and a 3 to 13 fold increase in the gross production was noticed during the actual bloom. The photosynthesis-respiration ratios ranged from 0.4 to 10.5 and low values were observed on the pre and post bloom phytoplankton populations. The high P/R ratios of 10.4 (12 July 57), 7.4 (20 July 57); 10.4 (28 June 58; 10.5 (16 July 60); 5.1 (21 Aug 62) coincide with the sudden increases in gross production.

Table II shows differences in the magnitude of phytoplankton biomass between the Lawson's Bay station located 7 km north and

Table 2: Comparison of phytoplankton biomass between Lawson's Bay and off Pigeon Island.

	Harvey plant pigment units/M^3		
Date	Lawson's Bay	Date	Pigeon Island
12-7-1957	25632	14-7-1957	520
20-7-1957	10000	22-7-1957	196
28-6-1958	14516	2-7-1958	375
16-7-1960	5550	19-7-1960	355
21-8-1962	3850	18-8-1962	420
		25-8-1962	315

off Pigeon Island located 2 km south of the dumping ground. While the phytoplankton populations responded and developed into blooms in the Lawson's Bay area following eutrophication due to sediment transportation, the standing crop off Pigeon Island remained poor.

Table III shows the phytoplankton composition during the summer months for such years when dredging operations were carried out. For comparison, phytoplankton abundance for the month preceding dredging blooms was also given in Table III. A qualitative

TABLE III

Phytoplankton composition in the surface waters during summer months off Lawson's Bay, Waltair.

	1957		1958		1960		1962	
	June	July	May	June	June	July	July	August
Stephanopyxis palmeriana		211	125		7	8	8	
Skeletonema costatum					250	412		
Thalassiosira subtilis	4	472		2532	13	52	40	3000
Coscinodiscus centralis	10	6	70	16	7	12		59
C. marginatus	12					12	5	
C. lineatus		25		290		14	3	
Planktoniella sol					2	4		
Asteromphalus wyvillei				1				
Lauderia borealis			128				3	
Schroderella delicatula			4					1
Gunardia flaccida		17						1
Rhizosolenia stolterfothii		1	4	132	10	1		
R. hebetata					1			
R. setigera				68	2	218	16	11
R. robusta							8	3
R. imbricata		12		24				
R. styliformis	1	45		32		6	23	18
R. crassispina		29	70		7	15		
R. alata		39	125	14		2		4
Bacteriastrum delicatulum		1					19	5
B. hyalinum		26				8	7	
B. varians		29						1
B. comosum						1		
Chaetoceros coarctatus								1
C. peruvianus							13	10
C. lorenzianus		85		34				2
C. messanensis		75						
C. curvisetus		22		32		250	30	24
C. compressus		175	1250	128	23	25	32	38
C. diversus							13	14
Eucampia zodiacus		9				1		
Streptotheca indica		9				12	7	4
Bellorochea malleus	5						3	
Ditylum sol	1	22	126	296	3	2		
Lithodesmium undulatum					3	12		

	1957		1958		1960		1962	
	June	July	May	June	June	July	July	August
Triceratium sp.	5							2
Biddulphia sinensis		29	66	1	2		2	
B. mobiliensis	12		4	64	13	55	3	
B. heteroceros			63	4		2	6	4
Hemidiscus hardmannianus			4	4	100	22		
Thalassionema nitzschioides			362	424			33	49
Thalassiothrix frauenfeldii	1	24	63	16	10	15		8
Asterionella japonica			254	34			3	2
Gyrosigma sp.								1
Pleurosigma elongatum			63				3	
P. normanii							3	14
P. aestuarii	5	2						2
Bacillaria paradoxa	4	5			20	6		12
Nitzschia seriata		35	258	208	13	100		2
N. sp.			53					
Amphora sp.			4	2				4
Tropidoneis sp.						1		
Navicula sp.		24	52			750		1
Other diatoms		2	63	16	3	1	8	
Dipsolapsis lenticula					5			17
Dinophysis caudata	1	12		2	7	4	2	1
D. miles							2	10
Amphisolenia spinulosa							3	
Ornithocercus magnificus								1
O. steini							2	2
Gymnodinium sp.	4					50		1
Noctiluca scintillans						94		27
Pyrophacus horologicum					2	1		
Peridinium oceanicum	1	14		1	15	6	10	30
P. depressum	3	14	4	4	3	6		1
P. sp.			63	6	1		25	4
Ceratium candelabrum								
C. furca			2	25			8	2
C. fusus							5	2
C. tripos			16			2	3	1
C. breve	4		32	6			3	
C. vultur var. *sumatranum*						1		1
Goniodoma polyedra						1		
Pyrocystis sp.						2	7	
Other dinoflagellates		2	3	26	5	1	3	
Total number of species	16	31	28	30	26	40	36	42
Total phytoplankton organisms/L.	78	1473	3341	4442	539	2207	364	3396

and quantitative increase in the phytoplankters resulted in the dredging blooms. Only *Thalassiosira subtilis* and *Chaetoceros curvisetus* commonly bloomed during the four years. Other species that mainly constituted the blooms during the different years are as follows:

1957: *Stephanopyxis palmeriana*, *Coscinodiscus lineatus*, *Rhizosolenia styliformis*, *R. crassispina*, *R. alata*, *Bacteriastrum hyalinum*, *B. varians*, *Chaetoceros lorenzianus*, *C. messanensis*, *C. compressus*, *Ditylum sol*, *Biddulphia sinensis*, *Thalassiothrix frauenfeldii*, *Nitzschia seriata*, and *Navicula* sp.

1958: *Coscinodiscus lineatus*, *Rhizosolenia stolterfothii*, *R. setigera*, *R. imbricata*, *R. styliformis*, *Chaetoceros lorenzianus*, *Ditylum sol*, *Biddulphia mobiliensis*, *Thalassionema nitzschioides*, *Nitzschia seriata* and *Ceratium furca*.

1960: *Skeletonema costatum*, *Rhizosolenia setigera*, *Chaetoceros compressus*, *Biddulphia mobiliensis*, *Nitzschia seriata*, *Navicula sp.*, *Gymnodimium sp.*, and *Noctiluca scintillans*.

1962: *Coscinodiscus centralis*, *Chaetoceros compressus*, *Peridinium oceanicum* and *Peridinium* sp.

Discussion

The temporal and spatial occurrence of the phytoplankton blooms during the present study suggest their association with the dredging operations for the following reasons:

1) Limitation of the blooms only to the north in the wake of the sediment transport and their absence off the Pigeon Island located 2 km. south of the dumping ground.

2) Absence of the blooms during 1956, 1959, 1961 when dredging operations were not carried out. During the blooms, the magnitude of the standing crop is high as indicated by the microscopic examination and the plant pigment units. Although it is not possible to determine the contribution of the phaeophytins to the quantity of plant pigments, the populations during the blooms appear to be in a healthy state as evident from the gross production and photosynthesis: respiration ratios. Gross production values during the dredging blooms were higher than those summarized by Strickland (1960), Raghu Prasad & Nair (1963) from the inshore waters in the Gulf of Mannar, India and Subba Rao (1969) on *Asterionella japonica* bloom off Waltair. However, higher gross production values were reported on a dinoflagellate bloom (16,500 mg C/day/M^3) off Sapelo Island, Georgia by Ragotzkie & Pomeroy (1957) and on a phytoplankton bloom (19,600 mg C/day/M^3) on the west coast of New Zealand by Cassie & Cassie (1960). Further, these dredging blooms gave high ratios (10—13) of photosynthesis: respiration which are characteristic of log phase culture populations (Humphrey & Subba Rao 1967; Subba Rao unpublished) and natural populations (Eppley & Sloan 1965; Subba Rao 1969; Platt & Subba Rao 1970a, 1970b). The fact that gross production and photosynthesis:

respiration ratios increase rapidly, attain a peak and decline to the initial level suggests some nutrient is limiting further growth of the populations. Unfortunately nitrogen compounds in the sea water were not analysed but inorganic phosphate and silicate concentrations show that they were not exhausted. The interstitial and adsorbed phosphate concentrations are poor when compared to the values (interstitial 6 μg/gm sediment; adsorbed 2—20 μg/gm sediment) reported from the estuarine sediments of Kakinada Bay some 150 km south of Waltair (SHENOI 1960) or with the ranges (interstitial 9—33 μg/gm sediment; adsorbed 3—46 μg/gm sediment) from the inshore muds of the Malabar Coast (SESHAPPA & JAYARAMAN 1956). MOORE (1930, 1931), STEPHENSEN (1949) and HENDY (1951) showed that the bottom muds act as reservoirs of phosphate and that when agitated through turbulence release this nutrient into the overlying waters. Manganese and iron are also known to promote rapid phytoplankton growth (KETCHUM 1954). Manganese content of the dredged mud samples favourably compare with the values reported for the near shore sediments off Visakhapatnam (SUBBA RAO 1960). The high concentration of manganese and iron in these sediments is traced to the rocks in the drainage basins comprising of black cotton soils and laterite soils derived from Deccan traps, of various rivers emptying their waters and sediment load into the Bay (SUBBA RAO 1962). Table IV (RAO 1964) shows that during August 1962 despite a heavy phytoplankton growth, nitrate, inorganic phosphate, iron, copper and manganese concentrations increased and this can be attributed to the release of these nutrients through dredging operations.

Besides mineral nutrients, it is possible that the sediments release growth promoting organic substances such as vitamin B_{12} (BURKHOLDER & BURKHOLDER, 1958); biogenic organic compounds and chelators (JOHNSTON, 1963, 1964; BARBER & RYTHER, 1969) or humic acids (PRAKASH, 1970). Unpublished results on cultures of *Thalassiosira nordenskioldii* and *Skeletonema costatum* isolated from Nova Scotian shelf waters showed that addition of humic acids resulted in an increase in the cell numbers, photosynthetic pigments and carbon uptake. These observations are pertinent to the blooming of *Thalassiosira subtilis* during 1957, 1958, 1960, 1962 and *Skeletonema costatum* in 1960 off Lawson's Bay, Waltair.

A distinction could be made between the consequences of eutrophication when the sources of enrichment have different origins. During the dredging operations where the source is autochthonous material, in spite of the blooms there does not seem to be a build up of phytoplankton biomass and this does not cause any excessive biological oxygen demand in the environment. Through rapid turnover

Table 4: Average concentrations of nutrients in the surface coastal waters off Waltair during 1962.

		July	August
NO_2-N	+	0.062	0.019
NO_3-N	+	2.80	6.40
Inorg. PO_4	+	0.50	0.79
Diss. Org. PO_4	+	2.47	1.29
Parti. PO_4	+	0.05	0.06
Total PO_4	+	3.02	2.14
Diss. Org-N	+	0.10	0.18
Parti-N	+	0.78	1.00
Iron	*	48.20	104.00
Copper	*	8.80	11.00
Manganese	*	8.80	13.00
Cobalt	*	0.38	0.32

+ µg at/L

* µg/L

and competitive exclusion, microflagellates are known to dominate when the enrichment is caused by allochthonous material such as the commercial fertilizer ammonium phosphate in Visakhapatnam harbour (SUBBA RAO, 1971). However, this does not seem to be the case when the enrichment involves autochthonous material as in the dredging operations or during upwelling of nutrient rich bottom waters.

In conclusion this report shows that off Waltair a high level of phytoplankton growth can be sustained through rapid turnover of natural nutrients without supplementing from an artificial source thus corroborating the view that marine productivity can be stimulated through raising nutrient rich sea water from depth to surface (ISAACS & SCHMITT, 1969). Artificially upwelled waters in the Carribean supported 27 times faster growth of selected plant life and PINCHOT (1970) suggested the possibility of using the numerous coral atolls in the Pacific and Indian Ocean as containers of nutrient rich waters for marine farming.

ACKNOWELDGEMENTS

I am grateful to PROFESSOR P. N. GANAPATI, Zoology Department, Andhra University for guidance and interest in this study. I am indebted to DR. TREVOR PLATT, Bedford Institute, Dartmouth, N.S., Canada and to DR. H. H. SELIGER, Johns Hopkins University for constructive criticism of the manuscript. My thanks are due to Mr. D. V. RAMANA MURTY, Visakhapatnam port for information on dredging operations and to DR. K. KAMESWARA RAO, Geochemist, Andhra University for help in chemical analyses. This work was supported by the Council of Scientific and Industrial Research (1957) and National Institute of Sciences of India, New Delhi (1960—1963).

REFERENCES

BARBER, R. T. & RYTHER, J. H. - 1969 - Organic chelator: Factors affecting primary production in the Cromwell current upwelling. *J. Exp. Mar. Biol. Ecol. 3*: 191—199.

BURKHOLDER, P. & BURKHOLDER, L. M. - 1958 - Studies on B vitamins in relation to productivity of the Bahia Fosforescente, Puerto Rico. *Bull. Mar. Sci. Gulf and Caribb.* 8: 201—223.

CASSIE, R. M. & CASSIE, V. - 1960 - Primary production in a New Zealand West Coast phytoplankton bloom. *N.Z.J. Sci.* 3: 173—199.

EPPLEY, R. W. & SLOAN, P. R. - 1965 - Carbon balance experiments with marine phytoplankton. *J. Fisheries Res. Board Can.* 22: 1083—1097.

GRAN, H. H. - 1929 - Investigation of the production of plankton outside the Romsdalsfjord 1926—1927. Rappt. Proces-verbaux Reunious, Conseil Perm. Intern. Exploration Mer. 56: 1—112.

HARVEY, H. W. - 1934 - Measurement of phytoplankton populations. *J. Mar. Biol. Ass. U.K.* 19: 253—276.

HENDY, N. I. - 1951 - Littoral diatoms of Chichester Harbour with special reference to fouling. *J. Roy. Mic. Soc.* 71: 1—86.

HUMPHREY, G. F. & SUBBA RAO, D. V. - 1967 - Photosynthetic rate of the marine diatom *Cylindrotheca closterium*. *Aust. J. Mar. Freshwat. Res.* 18: 123—127.

ISAACS, J. D. & SCHMITT, W. R. - 1969 - Stimulation of marime productivity with waste heat and mechanical power. *J. Cons. Int. Explor. Mer.* 33: 20—29.

JOHNSTON, R. - 1963 - Sea water, the natural medium of phytoplankton. I. General features. *J. Mar. Biol. Ass. U.K.* 43: 427—456.

JOHNSTON, R. - 1964 - Sea water, the natural medium of phytoplankton. II. Trace metals and chelation and general discussion. *J. Mar. Biol. Ass. U.K.* 44: 87—109.

KETCHUM, B. H. - 1954 - Mineral nutrition of phytoplankton. *Ann. Rev. Plant Physiol.* 5: 55—74.

MOORE, H. B. - 1930 - The muds of the Clyde Sea area. I. Phosphate and nitrogen contents. *J. Mar. Biol. Ass. U.K.* 16: 595—607.

MOORE, H. B. - 1931 - The muds of Clyde Sea area. III. Chemical and physical conditions, rate and nature of sedimentation and fauna. *J. Mar. Biol. Ass. U.K.* 17: 325—358.

PINCHOT, G. B. - 1970 - Marine farming. *Scientific American.* 223: 15—21.

PIPER, C. S. - 1947 - Soil and plant analysis. University of Adelaide Press. Adelaide. p. 368.

PLATT, T. & SUBBA RAO, D. V. - 1970a - Primary production measurements on a natural plankton bloom. *J. Fish. Res. Board Can.* 27: 887—899.

PLATT, T. & SUBBA RAO, D. V. - 1970b - Energy flow and species diversity in a marine phytoplankton bloom. *Nature* 227: 1059—1060.

PRAKASH, A. - 1971 - Terrigenous organic matter and coastal phytoplankton fertility. In J. D. COSTLOW, JR. (ed), International symposium on the fertility of the sea. Sao Paulo, Brazil, Dec. 1969. pp 351—368. Gordon & Breach Science Publ. London, New York.

RAGHUPRASAD, R. & NAIR, P. V. R. - 1963 - Studies on the organic production. I. Gulf of Mannar. *J. Mar. Biol. Ass. Inida* 5: 1—26.

RAGOTZKIE, R. A. & POMEROY, L. R. - 1957 - Life history of a dinoflagellate bloom. *Limnol. Oceanogr.* 1: 62—69.

RAO, V. CH. - 1964 - Chemical oceanographic studies in the Bay of Bengal. Ph. D. Thesis. Andhra University, Waltair, India. p. 238.

ROBINSON, R. J. - 1948 - The determination of silicate in sea water. *J. Mar. Res.* 7: 49—55.

ROBINSON, R. J. & THOMPSON, T. G. - 1948 - The determination of phosphate in sea water. *J. Mar. Res.* 7: 33—39.

ROCHFORD, D. J. - 1951 - Studies on Australian estuarine hydrology. I. Introductory and comparative features. *Aust. J. Mar. Freshwat. Res.* 2: 1—116.

RYTHER, J. H. - 1969 - Photosynthesis and fish production in the sea. *Science* 166: 72—76.

SESHAPPA, G. & JAYARAMAN, R. - 1956 - Observations on the composition of bottom muds in relation to the phosphorus cycle in the inshore waters of the Malabar Coast. *Proc. Ind. Acad. Sci.* 43B: 288—301.

SHENOI, R. - 1960 - Distribution of phosphates in the sediments of the Kakinada Bay. *Proc. Ind. Acad. Sci.* 51B: 195—203.

STEEMANN NIELSEN, E. - 1933 - Über quantitative untersuchung von marinem plankton mit utermöhls umgekehrten mikroskop. *J. Cons. Int. Explor. Mer.* 8: 201—210.

STEPHENSON, W. - 1949 - Certain aspects of agitation upon the release of phosphate from mud. *J. Mar. Biol. Ass. U.K.* 28: 371—380.

STRICKLAND, J. D. H. - 1960 - Measuring production of marine phytoplankton. *Bull. Fish. Res. Board Can.* 122: 172.

SUBBA RAO, M. - 1960 - Organic matter in marine sediments off the east coast of India. *Bull. Am. Assoc. Petrol. Geologists.* 44: 1705—1712.

SUBBA RAO, M. - 1962 - Manganese in the shelf sediments of east coast of India. *Proc. Ind. Acad. Sci.* 56A: 274—284.

SUBBA RAO, D. V. - 1969 - *Asterionella japonica* bloom and discoloration off Waltair, Bay of Bengal. *Limnol. Oceanogr.* 14: 632—634.

SUBBA RAO, D. V. - 1971 - Effects of ammonium phosphate dumping on phytoplankton in Visakhapatnam harbour, Bay of Bengal. *Environmental Letters* 2: 65—73.
VERDUIN, J. - 1951 - Comparison of spring diatom crops of Western Lake Erie in 1949—1950. *Ecology* 32: 622—668.