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DETERMINATION OF LIMNOLOGICAL CHARACTERISTICS OF THE SAPANCA LAKE

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ABSTRACT: *The limnological characteristics of Sapanca Lake, located in the Marmara Region, have been investigated. From field surveys conducted in July, August, and September, 1989, it appears that there exists a phosphorus deficiency with respect to available nitrogenous compounds in the water column of the lake. Chlorophyll-a maxima in the lake were always observed below the thermocline, indicating a dynamic biological system in the lower layers to which at least 1 % of the surface light intensity penetrates. The nitrate concentration was found to be about 200 µg-N/l in the deep waters whereas o-phosphate concentrations were less than 2 µg-P/l at these depths. The total phosphorus concentration was in the range of 6-10 ppb in the water column, except for peak values detected at intermediate depths at which the population of phytoplankton was dense. Trophic State Indices (TSI) for the Sapanca Lake computed from chlorophyll-a, secchi disk transparency, and total phosphorus measurements performed in the epilimnion layer of the lake were found to range between 28 and 35, indicating oligotrophy.*

SAPANCA GÖLÜNÜN LİMNOLOJİK ÖZELLİKLERİNİN BELİRLENMESİ

ÖZET: *Marmara Bölgesinde bulunan Sapanca Gölü, limnolojik özelliklerinin belirlenmesi amacıyla araştırıldı. Temmuz, Ağustos ve Eylül 1989 da yapılan saha çalışmalarından, göldeki azot bileşiklerinin derişimi dikkate alındığında fosfat derişiminin düşük olduğu görülmektedir. Klorofil-a maksimumu daima termoklin tabakasının altında olduğu gözlendi. Bu da termoklin altındaki tabakada yüzey ışık şiddetinin % 1'e indiği derinliğe kadar dinamik bir biyolojik sistemin varlığını göstermektedir. Nitrat derişiminin 200 ppb'ye ulaştığı alt sularda orto-fosfat derişimi 2 ppb'nin altında bulunmuştur. Fitoplankton yoğunluğunun fazla olduğu ara tabaka hariç, toplam fosfat derişimi 6-10 ppb arasındadır. Epilimnion tabakasındaki klorofil-a, seki disk ve toplam fosfat değerleri kullanılarak Sapanca Gölü için Trofik State Indeks (TSI) değerleri hesap edildi. Bulunan 28-35 değerlerinden Sapanca Gölünün oligotrofik özellikte olduğu saptanmıştır.*

INTRODUCTION

Lake Sapanca, located in the Marmara Region (Figure 1), has a surface area of 46.8 km^2 and a volume of about 1.0x109 m^3. Its catchment area is about 250 km^2. No big river, but several streams with seasonally changing flow rates feed the lake, According to calculations of the water balance of the lake, a significant volume of ground water enters the lake from points at the lake bottom (1), whose locations have yet to be determined.

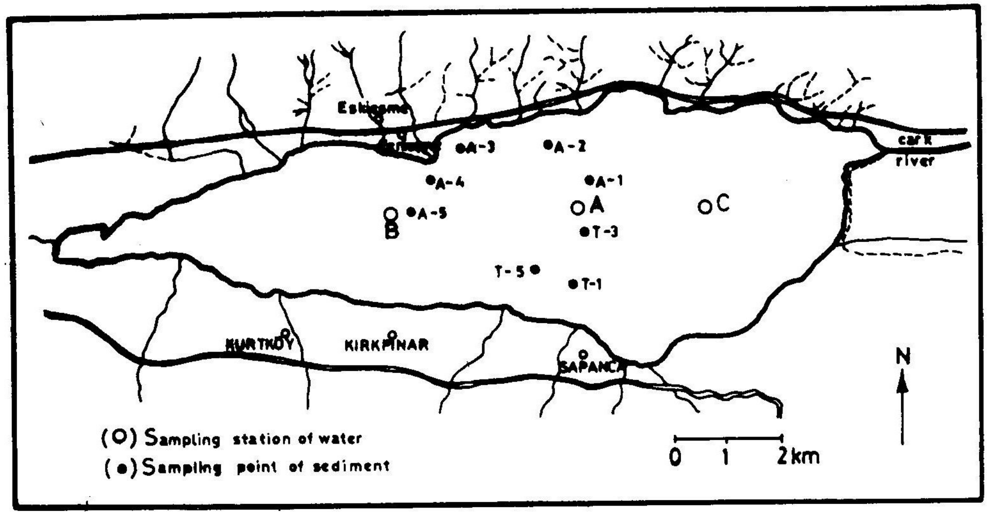

Figure 1. Sampling stations in the Sapanca Lake.

The Sapanca Lake having only low concentrations of both dissolved inorganic ions and organic carbon has been used for decades as a source of drinking and process water by the City of Adapazarı and several important industries in the İzmit area. The lake, due to its oligotrophic characteristics, does not support fishing.

There are few heavy industries around the lake, and therefore, the majority of pollutants entering the lake originate through surface run-off from domestic and agricultural sources. No sewerage or wastewater treatment systems have so far been established for the small towns in the drainage area of the lake.

Until recently, few studies have determined either the limnological characteristics or the pollution levels of the Sapanca Lake (1-3). From the limited studies it can be stated that the water quality of the lake is adequate for drinking, domestic, process and irrigation usage (1-3). However, examination of previous studies shows that biochemical parameters necessary for determining the quality of inland water sources and their beneficial uses have not been measured in the Sapanca Lake. For example, no data are available showing the spatial and temporal variations of such parameters as fluoride, iodide, boron, sulphate, some important toxic metals, dissolved and particulate organic carbon, pesticides, detergents, phenolic compounds, nutrient elements, primary production, etc. Further, detailed examination of the limited data pertaining to nutrients and trace metals indicated unreasonable distribution patterns due presumably to the inadequate sampling, storage and analytical methods followed.

The aim of the present research has therefore been to determine the limnological characteristics of the Sapanca Lake by monitoring spatial and temporal variation in its basic physical and biochemical parameters and to investigate the distributions of the important major and trace metals in the surface sediments.

EXPERIMENTAL

Sampling: The locations of sampling points for water and sediment are shown in Figure 1. Water samples were collected from 0.5, 10, 15, 20, 25, 30, 40 and 45 meter depths, at two stations, A and B by using a horizontal-type Nansen bottle. The sediment samples were collected by a grab-type sampler in July and August, 1989. The samples for bioassay were collected by a horizontal water sampler at a depth of 3 m and where the light intensity was reduced to 1 % of surface value at station B. Chlorophyll-a samples were taken at depths of 0.5, 5, 10, 15, 20, 25 and 30 meters. The samples for biological analysis and measurements were collected at depths where surface irradiance at 400-700 nm was reduced to 75 %, 25 %, 10 % and 1 %. For the estimation of daily primary production the depths where the surface irradiance was reduced to 95 %, 50 % and 3 % were also determined. The vertical transmission of light at Station B and the light in the incubator was measured by a quanta meter (LICOR 185) in the spectral region 350-700 nm at intervals of one hour from true noon to sunset.

Sample Storage: The water samples for (nitrate+nitrite), ammonia and phosphate analyses were kept frozen until analysis time. Water samples for TOC analysis were acidified with 6 N HCl (2ml/l) and those for silicate analysis were refrigerated until processing. The samples for phytoplankton production, bioassay and chlorophyll measurements were transported to the laboratory in ice-boxes and the experiments were carried out immediately after collection of the samples. The chlorophyll samples were filtered and kept frozen until analysis. The sediment samples were kept frozen in precleaned plastic bags. The water samples for pH and for inorganic carbon (carbonate ion) were kept refrigerated and were then analysed as soon as possible.

Analytical Procedure: Phytoplankton algal production was estimated in samples from depths at which the irradiance was reduced to 75, 25, 10 and 1 % of the surface value. The 14C technique given by Nielsen (4) and modified by Gargas (5) was followed. Further details are given in the technical reports (6, 7).

Chlorophyll-a concentrations of water samples were measured by the standard acetone extraction method (8). 0.5-3.0 liters of water sample are filtered through Whatman GF/C filter papers. Filters were kept frozen until use. The chlorophyll and pheopigment concentrations were measured and calculated according to the procedure given in the Standard Methods (8).

The nutrients o-PO4, total-phosphorus, nitrate, ammonia and silicate were measured by the methods developed by Technicon (9, 10) and given in the Standard Methods (8). Details of the analytical methods used for the other parameters discussed here have been described elsewhere (7).

RESULTS AND DISCUSSION

Field surveys were performed in July at one station (St.A) and in August and September 1989, at two stations, St. A and B. The results of the parameters measured in the water column at both stations are presented in Table 1. Primary productivities and the trophic state indices calculated from chlorophyll-a, secchi disk transparency and total phosphorus data are displayed in Tables 2 and 3, respectively. The concentrations of the major and trace metals in the lake sediments are given in Table 4.

Table 1. The Distributions of the Basic Physicochemical Parameters Measured in the Sapanca Lake Water.

Depth (m)	Conduct. (uS/cm at 25°C)	pH	Total Org. Carbon (ppm)	Fluoride (ppm)	Chloride (ppm)	Sulphate (ppm)	Carbonate (ppm)	Si (ppm)	Tot.N[(a)] (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	K (ppm)
0.5	251-262 (256)[(b)]	8.12-8.54 (8.37)	2.05-2.45 (2.23)	0.13-0.16 (0.15)	5.7-6.0 (5.9)	17.6-18.0 (17.8)	117-118.3 (117.5)	0.84-0.93 (0.89)	0.45	37.1	7.0	6.1	1.49
5	255-256 (256)	8.46-8.57 (8.52)	1.91-2.39 (2.14)	0.14-0.15 (0.15)	5.9-6.0 (5.9)	17.6-17.7 (17.7)	117-118.2 (117.7)	0.84-0.92 (0.89)	-	37.1	7.0	6.0	1.48
10	253-267 (258)	8.18-8.58 (8.47)	2.15-2.18 (2.16)	0.15-0.19 (0.17)	5.9-6.2 (6.0)	17.7-17.8 (17.7)	112-117.5 (116.0)	0.84-1.40 (1.00)	0.43	38.3	6.9	6.0	1.49
20	282-289 (286)	7.68-8.00 (7.76)	2.41-4.35 (3.10)	0.13-0.17 (0.15)	5.6-6.1 (5.9)	17.0-18.0 (17.4)	131-144.4 (139.6)	1.44-1.79 (1.60)	0.43	40.3	6.9	6.0	1.53
25	288-289 (288)	7.63-7.80 (7.71)	2.30-4.00 (2.97)	0.13-0.15 (0.14)	5.6-5.9 (5.7)	17.0-17.6 (17.2)	-	1.54-1.90 (1.68)	0.27	-	-	-	-
30	283-289 (288)	7.56-7.74 (7.63)	1.91-2.30 (2.06)	0.14-0.15 (0.14)	5.6-6.1 (5.8)	16.8-17.7 (17.1)	-	1.60-1.96 (1.79)	0.23	40.7	6.9	6.0	1.50
40	286-289 (288)	7.35-7.67 (7.53)	1.91-2.06 (1.95)	0.14-0.15 (0.15)	5.5-7.6 (6.2)	16.3-17.4 (16.9)	- -	1.83-2.21 (1.98)	0.22	41.6	6.9	6.1	1.50
45	286-294 (290)	7.37-7.88 (7.50)	1.88-2.07 (1.97)	0.35	8.0	17.2	-	2.10	-	-	-	-	-

(a): Total-N=Organic nitrogen+Inorganic nitrogen

(b): The value in parenthesis represents the arithmetic mean of the measurements.

Anions, cations and total organic carbon: The concentrations of major anions and c
in the lake water were generally low (Table 1). The levels of chloride and sulphate
ranging between 5.7-6.2 and 17.0-17.7 ppm respectively, varied little with depth. N
and Mg ion concentrations were almost constant in the water column of the lake. The
es of calcium, the major cation in the lake water, varied between 37-41 ppm with th
wer concentration in the surface water. Considering its necessity for the prevention of
decay, the fluoride concentration was found to be relatively low. The total organic c
concentration generaly ranged between 1.9-2.5 pm, but reached a peak value of 4.35 a
25 m (Table 1) which originated from the accumulation of dissolved and particulate
nic matter of algal origin at the upper zone of the thermocline.

Table 2. Daily Primary Production in Sapanca Lake (mg C m-2 day-1).

Month	Station: A	Station: B
23 August, 1989	264	259
25 September, 1989	294	321

Table 3. Trophic State Index and its Associated Parameters (From Ref. 12)

TSI	Secchi Disk(m)	Surface t-Phosphorus (mg/m^3)	Surface chl-a (mg/m^3)
0	64.0	0.75	0.04
10	32.0	1.5	0.12
20	16.0	3.0	0.34
30	8.0	6.0	0.94
40	4.0	12.0	2.6
50	2.0	24.0	6.4
60	1.0	48.0	20.0
70	0.5	96.0	56.0
80	0.25	192.0	154.0
90	0.12	384.0	427.0
100	0.062	768.0	1183.0

Table 4. Monthly Variations in Trophic State Indices Calculated from Secchi Disk Transparency, Chlorophyll-a and t-P for the Sapanca Lake in 1989.

Month	Parameter and Measured Value			TSI	
		St.A	St.B	St.A	St.B
July 6,1989	SDD(m)	5.0	-	36	-
July 6,1989	Chll-a(mg/m^3)	0.48	-	23	-
August 23,1989	SDD(m)	9.0	7.5	28	31
August 23,1989	Chll-a(mg/m^3)	0.24	0.79	16	28
August 23,1989	t-P(ppb)	6.9	8.5	32	35
Sept. 23, 1989	SDD(m)	7.5	7.0	31	32
Sept. 23, 1989	Chll-a (mg/m^3)	0.85	1.05	29	31
Sept. 23, 1989	t-P (ppb)	7.0	7.0	32	32

Conductivity: The values of conductivity normalized to 25°C, showing the level of total dissolved ions, ranged between 250 to 260 µS/cm in the surface and from 285 to 290 µS/cm in the deep waters of the lake. From the measured concentrations of the major anions and cations in the water column of the lake, it can be concluded that the difference of about 30 µS/cm in conductivity between the surface and bottom waters resulted from differences in the concentrations of calcium, bicarbonate and silicate ions.

pH: Not unexpectedly the pH variation in the water column of the Sapanca Lake was in harmony with the biological productivity profiles and water temperatures. In the surface waters of the Sapanca Lake, the pH ranged from 8.2 to 8.5, depending upon environmental factors. In deep waters of the lake pH values were found to decrease to 7.4-7.7 due to CO_2 released by the biochemical oxidation of the organic matter sinking from the photic zone.

Temperature: Figure 2 shows that the surface water temperature in the lake reached a peak value of 26.7 °C in August. In the deeper layers (below 30 meters), the water temperature remained constant at 7.8-8.0 °C during the July-September period. The thermocline lay between 10-20 m and the temperature dropped from 22-24 °C at 10 meters to about 10 °C at 20 m. The temperature distribution in the lake was also measured by DSI (1) between 1986 and 1988. From the temperature data of both studies, it appears that the deep waters of the lake show an annual variation of ±1°C in summer which might result from the interannual temperature fluctuations in the water column.

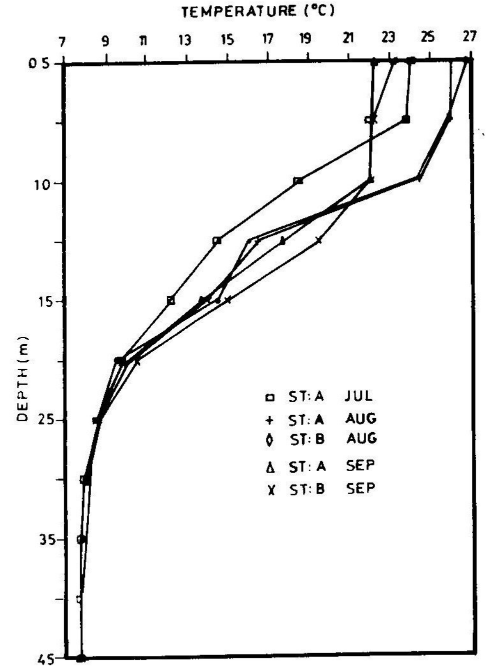

Figure 2. Temperature profiles measured in Sapanca Lake.

Dissolved oxygen: The concentration of dissolved oxygen (DO) in the Sapanca Lake varied with both depth and time. The DO concentration was almost at its saturation level in the first 10 meters of the surface water, at 10-15 meters it exceeded the saturation level due to algal photosynthesis at these depths. Below the thermocline at about 20 meters, DO values decreased steadily with increasing depth (Figure 3). As expected, the DO concentrations measured monthly in the deep waters (below 30 meters) of the lake showed a decreasing trend from July to September 1989. The DO value of about 7.5 ppm measured on July 6, decreased to 6 in August and 1.7 ppm on September 25, 1989. In two previous lake studies (2, 3), relatively high DO concentrations were measured in the deep layers, ranging from 3.2 to 4 ppm in October. In the DSI study (1) performed between 1986-1988, the DO concentration below the 30 meter water depth was found to decrease from 3.6 ppm in late summer to 1.2 ppm in Autumn. These measurements coincide with those of the present study. The drastic temporal DO decrease observed in the lower layers of the lake is due to the decay of organic matter originating from primary production proceeding above and in the thermocline (but in the photic zone) coupled to the inhibition of oxygen diffusion by the intense density stratification.

Light: Penetration of solar light into the Sapanca Lake water is depicted in Figure 4. The depths to which at least 1 % of the surface incident light penetrated extended down to 18-20 meters. The light measurements performed by DSI (1) in 1986-1988 coincide with the results of 1989. The measurements of both studies clearly indicate that the light intensity below 25 meters was almost nil, less than 0.1 % of the surface value.

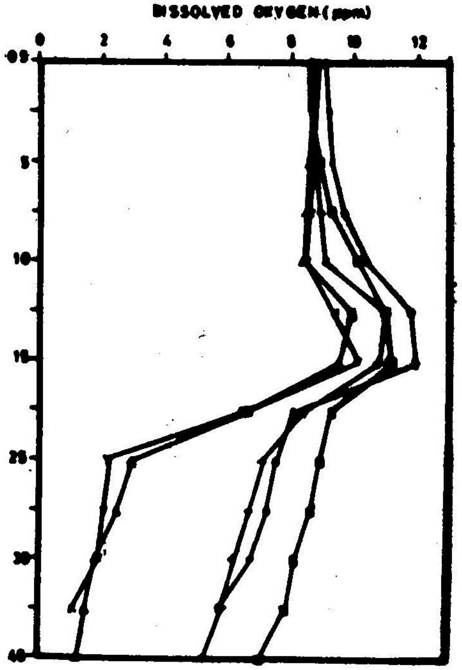

Figure 3. Variation of dissolved oxygen profiles in Sapanca Lake.

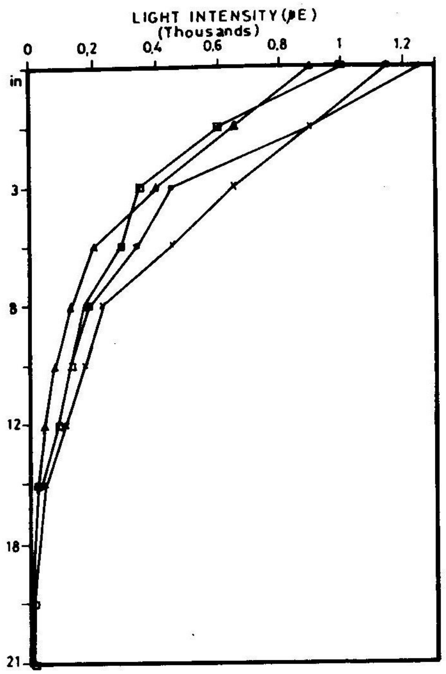

Figure 4. Light intensity profiles in Sapanca Lake.

Chlorophyll and pheophytin: There are two different standard spectrophotometric techniques for determining chlorophyll-a but one for pheophytin-a (8), Chlorophyll-b can only be determined by the trichromatic method (8). Chlorophyll-a concentrations calculated from measurements at three different wavelengths represent the total chlorophyll-a content of the sample, since pheophytin-a, which is the degradation product of chlorophyll-a in phytoplankton digested by zooplankton (11), absorbs light in the same region of the spectrum as chlorophyll-a (8). The concentrations of chlorophyll-a determined using two methods, chlorophyll-b and pheophytin-a are depicted in Figure 5. The chlorophyll-a profiles illustrated in Figure 5 indicate relatively high production and accumulation of phytoplankton below the thermocline. The highest total chlorophyll-a concentrations, ranging from 10 to 28 ppb, were always detected at 20-25 meters depth. However, when the active chlorophyll-a and pheophytin-a concentrations are compared at such depths, it is evident that the major fraction of total chlorophyll-a concentration was in the form of pheophytin-a. The levels and depths of total chlorophyll-a maxima recorded in the summer of 1989 were coincident with those measured in the summer of 1983 by TÜBİTAK (2).

It could easily have been concluded that photosynthetic production was not expected to take place below 25 meter from the surface of the lake since the measured light intensity below 25 meters depth was always less than 0.1 % of the surface value (Figure 4). However, at 25 and 30 meters depth, the total chlorophyll-a concentrations were found to be relatively high, even to give maxima at 25 meters in August and September 1989.

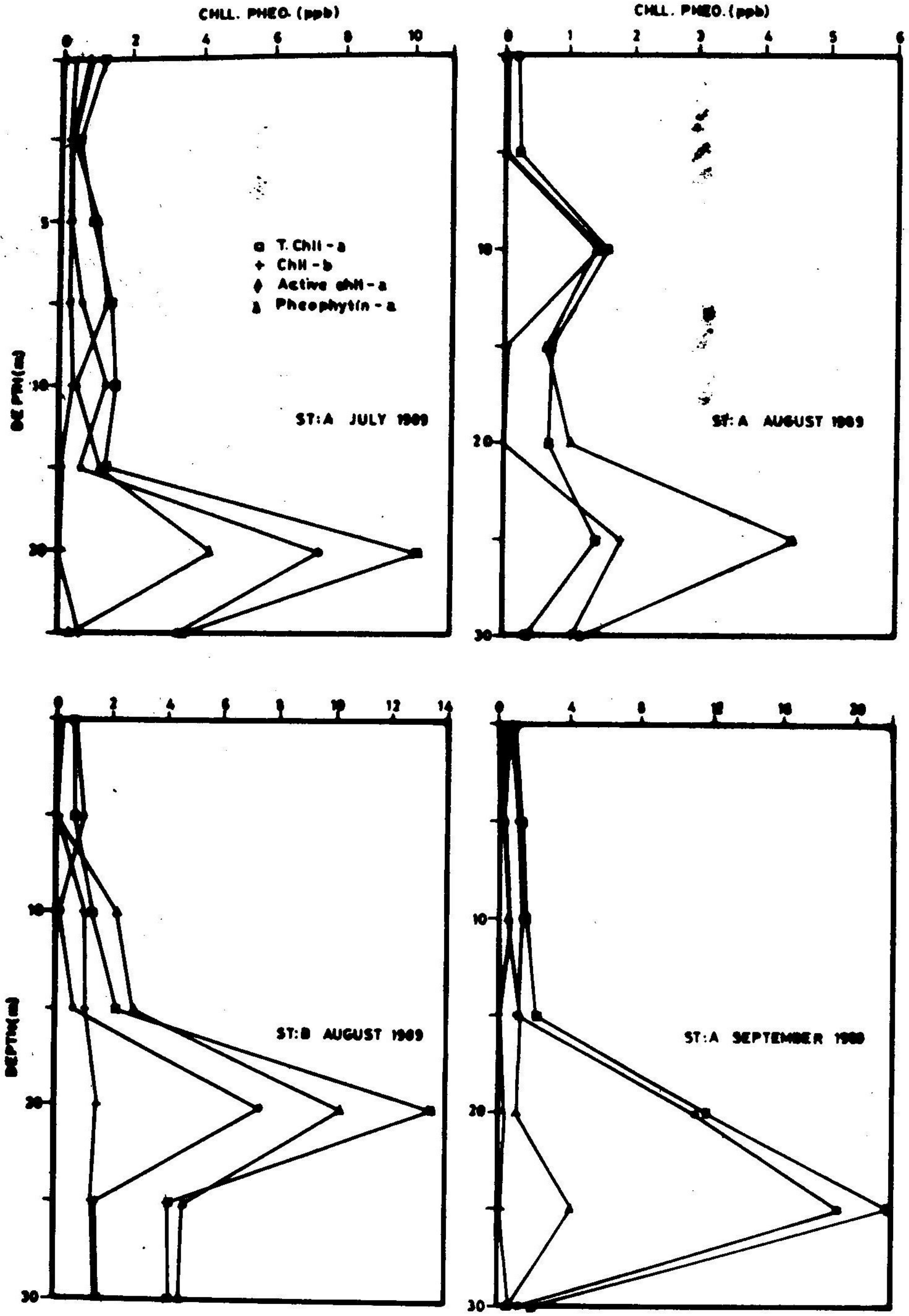

Figure 5. Vertical distributions of chlorophyll and pheophytin-a in Sapanca Lake.

From the literature reviewed, it has been realized that there are two basic biochemical processes which result in chlorophyll-a maxima below the depth of 1 % surface light intensity: First, various groups (16, 17) have observed deep chlorophyll maxima (DCM) in water bodies when the mixed layer (epilimnion) has been depleted of nutrients for sufficient time (as in the Sapanca Lake) that it has become clear enough to permit phytoplankton growth in the pycnocline. Neglecting transient phenomena, e.g. settling algal cells, one usually finds shade-adapted plants growing at irradiances near to or below 1 % of the surface value, but above the 0.1 % level. Hence, the growth controlling nutrient gradient (nutricline) appears below the DCM instead of showing a gradual increase from the top of the pycnocline downward. Secondly, it has been found that, under a variety of conditions algal carbon: chlorophyll-a ratios vary between 10-250 (17). High algal-C: chll-a ratios in algal cells have regularly been observed in well-illuminated, nutrient depleted surface water, whereas the lower ratios have been observed under the opposite conditions at the base of the euphotic zone, resulting in DCM at depth. Systematic decreases in algal-C: chll-a ratio with depth have been documented in oceanic and coastal waters.

One therefore synthesizes the simultaneous measurements of chlorophyll-a, primary productivity, nutrients and light intensity profiles in Sapanca Lake as follows: In the Sapanca Lake, the 0.1 % depth was generally above 25 m, the DCM observed at 25 m was therefore, a manifestation of increased cell chlorophyll, rather than of high biomass resulting from growth in the DCM. If algal-C: chll-a ratio at depths below 20 m has been as high as in the upper layers we would have observed significant increases in t-P concentrations similar to those determined in the chll-a concentrations. Below 20 m depth, increases in t-P concentrations were insignificant whereas the chll-a concentration amounted to 5-10 times the upper layer values, depending on the sampling location and time. In other words, increase in the phosphate-associated organic matter (biomass) was not as high as in chlorophyll-a observed at 25 m.

In conclusion, the DCM at 20 meters were not only the result of increase in the algal biomass concentration but also of the relative decrease in algal-C: chll-a ratios with respect to values in the upper layers. However, the DCM observed at 25 m, at which irradiance was less than 0.1 % of its surface value, very probably resulted from the low algal-C: chll-a ratios in the algal cells, indicating a relatively low algal biomass concentration at 25 m with respect to chll-a maxima and biomass concentration at 15-20 meters.

As can be seen from Figure 5 pheophytin-a profiles generally almost coincide with the chlorophyll-a profiles and predict that there might exist relatively dense zooplankton populations below the thermocline. The chl-a/chl-b ratios obtained from trichromatic measurements showed significant variations with depth and time due to relatively dense populations of phytoplankton having chlorophyll-b pigments at certain water depths. The detection of high pheophytin values at 25 m, which were coincident with the DCM, could result from: (a) sinking of a fraction of non-living algae from the upper layer, (b) excretion of algae by the zooplankton existing at 20-25 meters depth.

Distributions of nutrients: Concentrations of the nutrient elements, nitrogen and phosphorus (in the forms of nitrate, nitrite, dissolved ammonia and ortho-phosphate) were found to be very low in the productive zone of the lake water (Figure 6 and 7). No (nitrite+nitrate) exceeding 2 ppb, was measured in the first 25 meters below the surface. Fugure 6 clearly shows that, in the deep waters of the lake, the nitrate concentration increased with depth to a value of about 200 ppb either in consequence of the mineralization of organic matter resulting from the primary production in the photic zone and subsequent digestion of phytoplankton by zooplanton or because of the mortality in the upper productive layers. The dissolved ammonia concentration was always less than 5 ppb (NH_3-N), the detection limit of the method followed. At intermediate water depths at which the chlorophyll-a and total dissolved organic carbon concentrations reached their maxima, some ammonia was detected at a level of 6-7 ppb. In one of the previous lake studies (1), the concentration of total inorganic nitrogen, (NO_3+NO_2+NH_3)-N, was found to vary seasonally between 0.05-0.4 ppm in the surface waters and 0.15-0.4 ppm in the bottom waters of the lake in the summer-autumn months. For example, total inorganic nitrogen concentrations of the deep waters increased 0.5 ppm in 3 months, from about 0.1 ppm in July, 1988, to 0.6 pm in September, 1988 (1). In oligotrophic lakes, such increases and high ammonia values are unlikely, particularly in dry summer months. We know that the determination of ammonia at ppb level is pretty difficult, due to contamination of water samples during sampling, storage and analysis. This could be the principal reason for remarkable differance between the nitrogen data obtained by DSI (1) and the present study since we always measured very low ammonia concentration in the lake water.

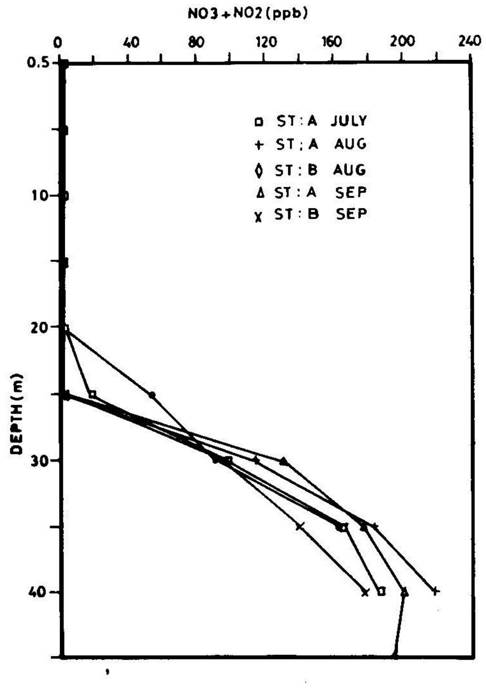

Figure 6. NO_3+NO_2 profiles

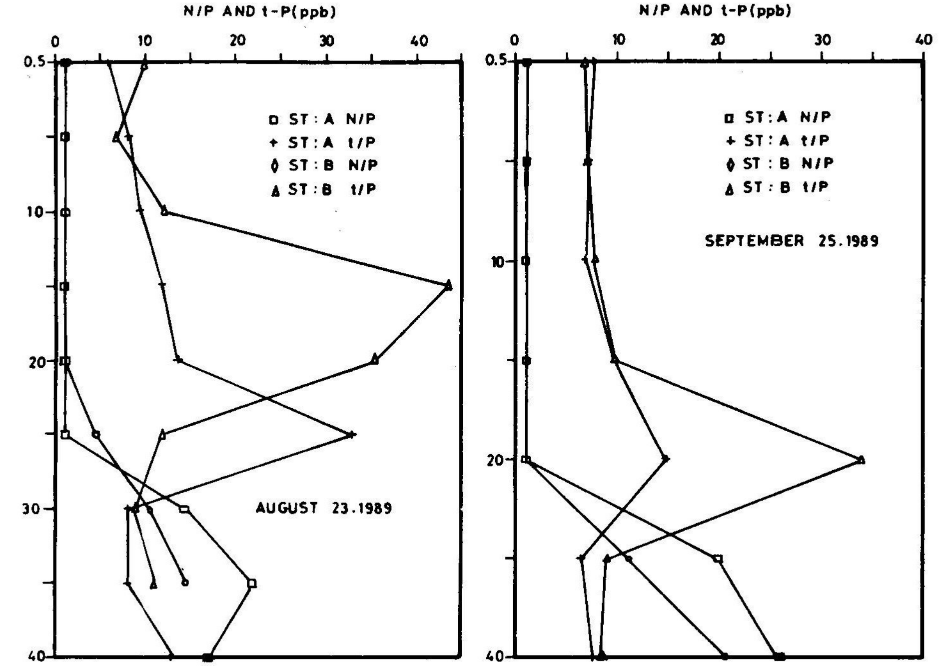

Figure 7. Vertical distributions of total-phosphorus and of (NO_3+NO_2)-N/(t-P) ratios.

The ortho-phosphate concentrations were less than 2 ppb in the water column of the lake while the (nitrate+nitrite) levels increased steadily in the deep water (Figure 6). The total phosphorus concentration was found to be in the range of 6-12 ppb (Figure 7), with the exception of some maxima recorded at those water depths at which chlorophyll-a and TOC (total organic carbon) maxima were determined. The deficiency of o-phosphate in the deep waters of the Sapanca Lake revealed that the major fraction of phosphate dissolved in the lower layer sedimented as a result of chemical reaction and adsorption onto particulate matter in the hypolimnion. The (NO3+NO2)/(t-P) ratio in the deep waters (below 25 m) increased with depth, from a N/P ratio of 1-4.5 at 25 m to a ratio of 21-26 at 40 meters depth. When the total nitrogen (organic-N + inorganic-N)/(t-P) ratio is calculated from the t-N and t-P concentrations given in Table 1, it is seen that the N/P ratio is about 60 in the surface waters and drops to 30 in the bottom waters of the lake. The significant difference in the N/P ratios of the two layers is probably caused by the excess dissolved organic nitrogen of humic origin together with the relatively low mineralization rate in the surface waters. The low (inorganic-N/organic-N) and high (t-N)/(t-P) ratios observed in the surface waters of the lake indicate that a significant percentage of the dissolved organic nitrogen is not available in photosynthesis through the mineralization reaction and some proportion of the phosphate probably sinks down to the lower layers. It should be remembered that measured t-N concentrations could be higher than the real values since the open digestion procedure followed might have permitted the contamination of the sample by ammonia absorption from the air in the laboratory.

Bioassay study: Nitrogen and phosphorus are the most important nutrients limiting algal growth in natural water bodies. In addition, diatoms need silicate for the formation of shell. In order to control eutrophication effectively, the relation between algal growth and nutrients must be thoroughly investigated. Bioassays carried out in September 1989, to determine the nutrient element limiting primary production in the lake showed no increase in algal production ((biomass) in nutrient-enriched samples compared to the unspiked control sample. Bioassays indicated that either the concentrations of phytoplankton were not high enough to consume the nutrients added to the samples or, more probably that other nutrient element(s) (e.g. essential metals) were needed to increase phytoplankton production, together with nitrate and phosphate in the surface water in September.

Primary Production: Vertical variation of phytoplankton production (mg C m-3 day-1) in the lake water, measured by the 14C technique, in August and September, 1989, is depicted in Figure 8. As can be seen from the figure, production ranged between 3 and 35 mg C m-3 day-1. The algal production rate was found to be generally higher in the surface layers. This mainly resulted from the continuous regeneration (recycling) of nutrients consumed by algae and the upward diffusion of nutrients released at the thermocline depth by wind induced vertical mixing. However, the greater rates still observed at 4-6 m in September strongly indicates the atmospheric input of nutrients through occasional precipitation and dry fall out. To assess the rate of nutrient input into the lake through the atmosphere in this urbanized area long-term air sampling and analyses are needed.

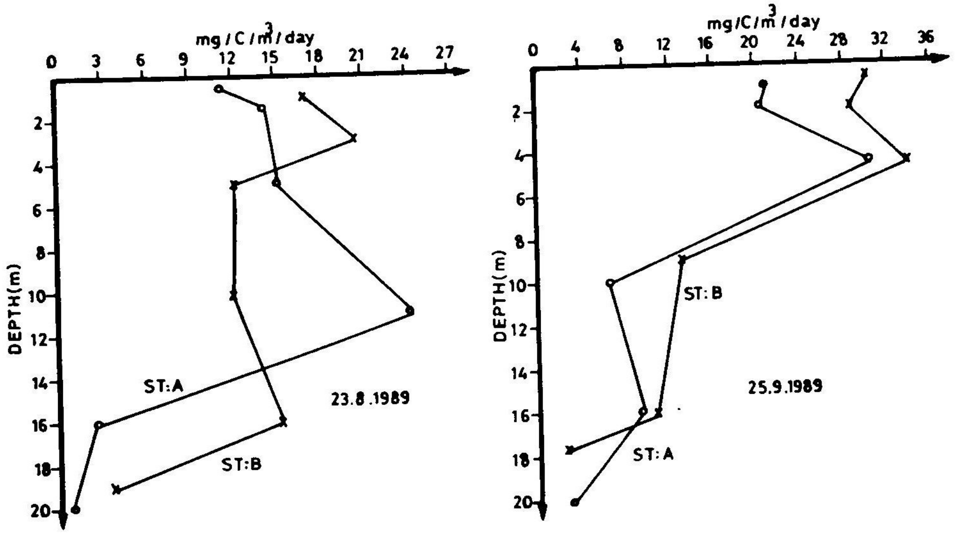

Figure 8. The rate of primary productivity with depth in Sapanca Lake.

As can be seen from Table 2, the rate of total algal production in the photic zone was a little higher in September than in August; no important spatial differences indicating local pollution or nutrient inputs from streams were observed.

Estimation of Trophic State Index: One needs a simple index of lake quality that: (a) is not lake specific; (b) is useful for decision making, prioritization, and public awareness; and (c) is objective, independent of other variables and easily measured (12, 13).

The ideal trophic state index has been developed by Carlson (12) using the relationship between algae biomass and Secchi Disk (SD) transparency. The equations are as follows:

$$TSI\ (SD) = 60-14.427 \times \ln(SD) \tag{1}$$
$$TSI\ (chl\text{-}a) = 30.6+9.81 \times \ln(chl\text{-}a) \tag{2}$$
$$TSI\ (t\text{-}P) = 4.15+14.427 \times \ln(t\text{-}P) \tag{3}$$

The assumptions inherent in these equations have been reviewed recently (7), whilst the complete scale and its associated parameters are shown in Table 3.

The TSI values for Sapanca Lake have been calculated using Equations 6, 7 and 8, from Secchi disk transparencies, chlorophyll-a concentrations (corrected for pheophytin-a) and total phosphate levels. The results are shown in Table 4.

It should be emphasized that the number generated is only an INDEX of the trophic status of a lake and does not define the trophic status (12, 13). In other words, chlorophyll-a and t-P are not considered as the basis of a more broadly defined concept. The best indicator of trophic status may vary both from lake to lake and also seasonally, so the best index to use should be chosen on pragmatic grounds.

SD transparency might be expected to give erroneous values of TSI in lakes containing high amounts of nonalgal particulate matter, in highly colored lakes and in extremely clear lakes. Chlorophyll-a values are apparently free from interference, especially if the values are corrected for pheophytin. It may be that the TSI number derived from chlorophyll gives the best estimates of algal biomass in most lakes and that priority should be given to its use as a trophic state indicator (12, 13). Accurate index values from total phosphorus depend on the assumptions that phosphorus is the major limiting factor for algal growth and that the concentrations of all algal forms of phosphorus present are a function of algal biomass (12).

As shown in Table 4, TSIs for the Sapanca Lake ranged from 16 to 36 during the July-September period. The TSI values computed from the data at Station A were found to be generally less than those at Station B. No significant fluctuations in TSI were observed in August and September, except for the TSI value based on chlorophyll-a at Station A in August.

Multidimensional observations conducted by limnologists in different lakes up to 1980 and TSI values calculated from chlorophyll-a, secchi disk transparency and total phosphorus measurements have shown that TSI values of less than 45 indicate oligotrophy and values greater than 50 indicate eutrophy (13). From this conclusion and the TSI values shown in Table 4, it is evident that the Sapanca is an oligotrophic lake.

Major and trace metals in the sediments of Sapanca Lake: The distributions of metal concentrations in surface sediments collected by a grab-type sampler from the points shown in Figure 1 are presented in Table 5. The reference sediment sample (SD-N-1/2) supplied from the International Atomic Energy Agency, Monaco, was analysed to check the reliability of the analytical procedure. The certificated metal concentrations in the reference sample are also included in the table. In general, no regional differences in trace metal concentrations, indicative of local metal pollution were observed. However, the sediments from the sampling points T-5 and A-4, which were relatively close to the land and under the direct influence of two streams, generally had relatively low metal concentrations. The highest lead concentration in the sediment was measured at point T-1.

Table 5. Concentrations of Major and Trace Elements in the Sapanca Lake Sediments

Element	Station Number*								Ref. sedim.	Ref.[a] sedim.	Reference[b] sedimenent
	T-1	T-3	T-5	A-1	A-2	A-3	A-4	A-5			
Al (%)	7.7	8.3	6.1	9.7	9.1	8.3	5.7	8.8	3.65	3.75	3.58-3.85
Fe (%)	4.7	4.7	3.8	4.8	4.9	4.3	3.3	4.4	3.51	3.64	3.53-3.78
Mn (ppm)	1107	1150	592	1007	901	705	900	1100	735	777	728-801
Ni (ppm)	92	120	67	126	86	62	59	87	30	31	27-34
Co (ppm)	26.5	25.5	18.5	22.5	21.0	15.5	15.0	18.5	10.7	12.1	11.2-12.7
Pb (ppm)	36.5	28.5	24.5	26.5	20.5	20.5	20.0	25.5	111.0	120.0	112-132
Cu (ppm)	53.0	53.0	40.0	53.0	47.0	40.0	36.5	48.0	75.0	72.2	68.1-75.2
Zn (ppm)	105	104	86	105	103	92	74	98	451	439	423-452

(a): Certificated concentrations, (b): confidence interval

*: Refer to Figure 1 for sampling locations

CONCLUSIONS

Trophic State Indices of around 30 computed from these surveys testify to the oligotrophic character of the lake. Despite the oligotrophy, dissolved oxygen concentrations of abou 7 ppm measured in the deep waters in July declined dramatically to 1.5 ppm in September.

Chlorophyll-a, nutrient and productivity measurements indicated that there exists a shade adapted phytoplankton production below the thermocline, extending down to 25 meters. The high values of chlorophyll-a measured below 20 m, at which depth the solar light possesses less than 1 % of its surface intensity resulted from low algal-C: chll-a ratios rathe than intense algal production.

Inorganic nitrogen ion concentrations, ortho-and total phosphate levels, and N/P ratios in-

licated the water column of the lake to be phosphate deficient and one predicts that the la-e might be very sensitive to a long term phosphate loading.

At present, the relatively low concentrations of inorganic ions suggest the continuous use f the lake for drinking and process water to be safe though no search has been made for race organic and inorganic contaminants. The level of fluoride ions was below that reconended for healthy teeth in children.

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REFERENCES

1. Seminar on Water Quality Observations, Control and Case Studies: The Sapanca Lake nd its Drainage Area, *228-300, DSİ Publication, May 1989 (in Turkish).*

2. The Sapanca Lake Pollution Study, *Technical Report, State Water Works Publ., 135, nkara, 1984 (in Turkish).*

3. Yiğit, V., Müftügil, N., A Study on the Sapanca Lake Water Pollution and Nutrient tatus, *Technical Report, TÜBİTAK-MRI, Food and Nutrient Dept., Publ., No: 78, June 984 (in Turkish).*

4. Nielsen, S., The Use of Radioactive (14-C) for Measuring Organic Production in the ea, *Royal Danish School of Pharmacy, Copenhagen, 1952.*

5. Gargas, E., User's Manual for Estimating the Daily Phytoplankton Production Measued in Incubators, *Contribution from the Water Quality Institute, No: 2, 1976.*

6. Morkoç, E., Tuğrul, S., Determination of Primary Production and Limiting Nutrients n the Bay of İzmit, *TÜBİTAK-MRC Chem. Eng. Dep. Publ. No: 232, 1989.*

7. Tuğrul, S., Morkoç, E., Determination of Limnological Characteristics of Sapanca Lae, *TÜBİTAK-MRC Chem. Eng. Dep. Publ. No: 234, 1989.*

8. Standard Methods for the Examination of Water and Waste Water, *APHA-AWWA-VPCP Publ., 16 th ed, 1985.*

9. Industrial Methods No: 253-80E and 100-70 W/B, *Technicon Industrial System, 1978.*

10. Nitrate and Nitrite in Water and Seawater, *Technicon Industrial Method No: 158-1W, June, 1977.*

11. Riley, J.P., Skirrow, G., Chemical Oceanography, *Academic Pres, 2, 1975.*

12. Carlson, R.E., A Trophic State Index for Lakes, Limnol and Oceanog., *22, 361-369 977.*

13. Porcella, D.B., Peterson, S.A., Larsen, D.P., Index to Evaluate Lake Restoration, J. f the Env. Eng. Div., *106, 1151-1169, 1980.*

14. Lorenzen, M.W., The Use of Chlorophyll-Secchi Disk Relationship, Limnol. and Ocean., *25, 371-372, 1980.*

15. Megard, R.O., Settles, J.C., Boyer, H.A., Combs, W.S. Jr., Limnol. and Ocean., *25, 373-377, 1980.*

16. Banse, K., Clouds, Deep Chlorophyll Maxima and the Nutrient Supply of Stratified Water Bodies, Journal of Plankton Research, *9, 1031-1036, 1987.*

17. Longhurst, A.R., Harrisson, W.G., The Biological Pump: Profiles of Plankton and Consumption in the Upper Ocean, Progress in Ocean., *23, 47-123, 1989.*