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PRIMARY PRODUCTIVITY IN THE EASTERN HARBOUR OF ALEXANDRIA

PRIMARNA PROIZVDNJA U ISTOČNOJ LUCI ALEKSANDRIJE

Y. Halim,* A. A. Samaan** and H. H. Sultan**

**Department of Oceanography, Faculty of Science, Alexandria, Egypt*
***Institute of Oceanography and Fisheries, Alexandria, Egypt*

In the »Eastern Harbour« of Alexandria monthly measurements (September 1972 to August 1973) of primary production and phytoplankton sampling were performed.

The Secchi-disc visibility was very low and the calculated thickness of the euphotic layer ranged from 8.47 to 17.3 leters.

The vertical profiles show a decrease with depth in primary production and in all cases production is optimum at the depth of abouth 40—50% of incident light transmission.

The montlhy variations in the optimum production and the crop density at the corresponding depth folow the same trend.

The »production efficiency« of the phytoplankton was higher in the erly phase of the bloom than in the subsequent phases.

In the last few years the standing crop density does not follow previous seasonal trend as result of the increasing eutrophication.

The optimum production ranges from 120 to 676 mg $C/m^3/12$ hr, the gross daily production from 351.4 to 3025 mg C/m^2 and the year's production to 584 g C/m^2. This is a high level compared to the general values for the Mediterranean.

INTRODUCTION

The phytoplankton of Alexandria waters has been investigated by different authors over several year cycles (El-Maghraby & Halim, 1965; Dowidar & Aleem, 1967; Guerguess, 1969; Hassan, 1972; Halim *et al*, in this volume). The available observations cover the systematic composition of diatoms and dinoflagellates as well as the numerical variations of the standing crop in the Eastern Harbour and in the offshore waters. No observations on primary production are available however from this area, nor from any locality in the South East Mediterranean (Sournia, 1973). In the present work, results of measurements of the *in situ* primary production in the E. Harbour are discussed. Observations on the »incubated« production have also been carried out offshore along a section extending to the continental slope (H a l i m *et al,* in prep.).

MATERIAL AND METHODS

The »Eastern Harbour« of Alexandria is a large bay partly isolated from the open sea by a concrete breakwater with two wide outlets. Docks for fishing-boats are restricted to the north-western part of the harbour. The average surface salinity ranges from 37,5‰ to 38,5‰ The station worked hies mid-ways between the docks and the western outlet, in a moderately eutrophied zone. Its depth is about 8 m (Fig. 1).

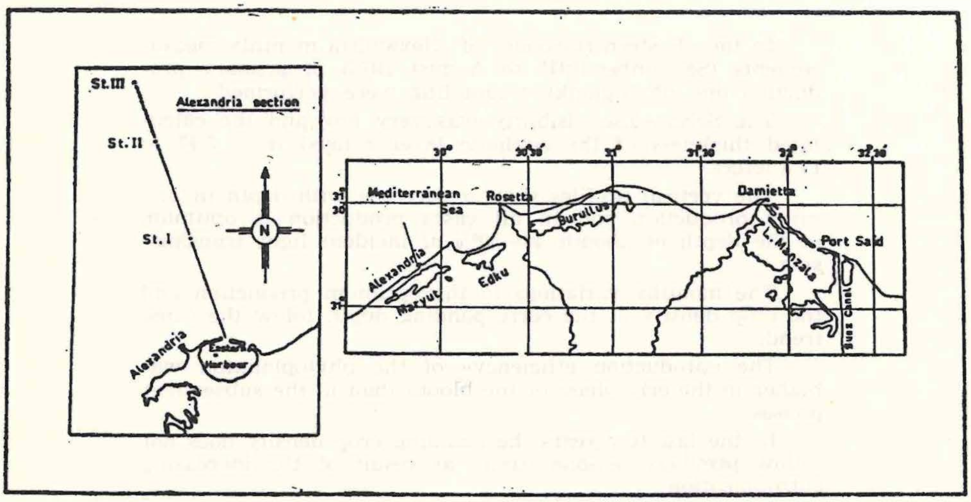

Fig. 1. Area of investigation

Phytoplankton sampling was carried out monthly, from September 1972, to August 1973, using a plastic Ruttner sampler of one litre, from 1, 2, 3 and 4 m depths and the samples counted under an inverted microscope, after sedimentation.

Secchi-disc transparency was measured around mid-day. Relative light penetration was measured by means of a Selenium photo-cell connected to a sensitive microammeter, and surface water temperature by means of an ordinary thermometer. Total daily radiation was compiled from the records of the Meteorological Station of Alexandria.

Primary production measurements were carried out using the carbor-14 technique (S t e e m a n n N i e l s e n, 1952). The radioactive C^{14} solution was provided by the International Agency for C^{14} determinstion, Denmark. The ampoules used contained 1 ml of an aqueous solution of $NaHCO_3{}^{14}$ of activity 4 μci. Clear stoppered Jena glass bottles of about 160 ml were filled with the water samples and the contents of an ampoule injected near the bottom of the bottle by means of a polyethylene syringe. The ampoule is then rinsed twice with a small amount of the water sample taken from the upper half of the bottle and the rinsing water added. The bottles are then exposed *in situ* at the surface, at 1, 2, 3, 4 and 6 m., from 9 a.m. to 6 p.m. The samples collected from 1 m were exposed at the surface and at 1 m, and those collected from 4 m exposed respectively at 4 and 6 m. Samples taken from 2 and 3 m were exposed at the respective levels. After exposure, the bottles were well shaken and a definite volume of sach sample filtered through a Sartorius membrane filter (Göttigen, Germany) of diameter 35 mm and average pore

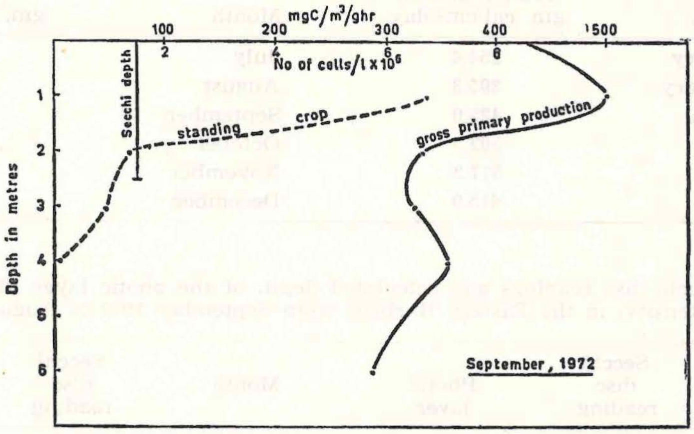

Fig. 2. Vertical profiles of gross primary production ($mg\ C/m^3/9$ hr) and of phytoplankton standing crop (No cells/$1x10^3$) in October, 1972

size 0.45 μ, using a Tracer-hab E 8 A precipitation apparatus. The membrane is washed twice with 2 c.c distilled water, then fixed on a Planchet type E7 brass ring and disc. The planchets are then left in a dessicator over silica gel and their activity measured later using a thin mica window Geiger tube, connected a scaler SA 250 and a timer. The background is substracted to get the actual activity of the sample.

The *in situ* primary production is expressed in $mgC/m^3/12$ hr., after applying the standard corrections (Steemann Nielsen, 1952 and 1965). The gross primary production below the square meter Σ_{gross}, is obtained by graphic integration. The results from the respective depths are plotted graphically and the area to the heft of the curve taken to represent photosynthesis below one square meter (Steemann Nielsen, 1958).

RESULTS

Light

The average daily radiation from the sun and sky at Alexandria in 1972 (Table 1) amounted to 435 $gm.cal/cm^2/day$. It remains below this average from October through March, the minimum, 200 $gm.cal/cm^2/day$ being in December and the maximum, 616, in June.

The Secchi-disc visibility in the Eastern Harbour ranged between 1.3 and 4.0 meters (Table 2). Maximum transparency was observed from December through March and was constantly around 4.0 meters. This period is proceded in September through November, and followed, in April—August, by periods of high turbidity, respectively 1.6 to 2.5 meters and 1.4 to 2.1 meters. The

Table 1. Average total daily radiation at Alexandria during 1972
(Compiled from the Meteorological Department)

Month	Total radiation gm. cal/cm²/day	Month	Total radiation gm. cal/cm²/day
January	254.4	July	605.1
February	395.3	August	544.8
March	425.0	September	470.8
April	502.5	October	365.8
May	577.2	November	261.0
June	615.9	December	200.0

Table 2. Secchi-disc readings and calculated depth of the photic layer (depth of 1% light intensity) in the Eastern Harbour from September 1972 to August 1973.

Month	Secchi disc reading	Photic layer	Month	Secchi disc reading	Photic layer
September	2.50	10.80	March	4.00	17.28
October	1.60	6.91	April	1.80	7.78
November	2.25	9.72	May	2.00	8.64
December	4.00	17.28	June	2.10	9.07
January	3.80	16.42	July	1.38	5.96
February	4.00	17.28	August	2.05	8.86

water turbidity was mainly due to the increased phytoplankton density (Halim *et al.*, in prep.) and/or to detritus stirred up from the bottom. The lowest value, recorded in July 1973, was accompanied by the dense blooming of the dinoflagellate *Alexandrium minutum* Halim. High turbidity during October was due to wind-induced turbulence. Simultaneous secchi-disc readings and photocell measurements in the E. Harbour indicate that the relative incident light at the depth of Secchi-disc disappearance is about 35%. Observations made in offshore waters on the continental shelf and slope (Halim *et al.*, in prep.) show the Secchi-disc to remain visible down to the depth of 27—25% light transmission.

The mean depth of 1% light intensity in the E. Harbour was found to be 4.32 times the Secchi-disc, while in offshore waters, the factors is smaller, 3.35 to 2.1 (Halim *et al*, in prep.). Assuming the depth of 1% light transmission to represent the lower limit of the photic layer (Jerlov, *in* Stemann-Nielsen and Jensen, 1957), the (calculated) thickness of this layer in the E. Harbour ranged from 8.47 to 17.3 meters, increasing offshore to 70.6—80 metres (Halim *et al*, in prep) (Table 2).

Vertical profiles

Autumn. The photosynthetic rate was lowered at the surface during October and Nocember due to partial inhibition by the still relatively high solar radiation (366 & 261 gm.cal/cm^2/day), but not in December (200 gm.cal/m^2/day). The optimum rate 300 mg C/m^3/9 h, is found at 0.65 metre in October (Fig. 3).

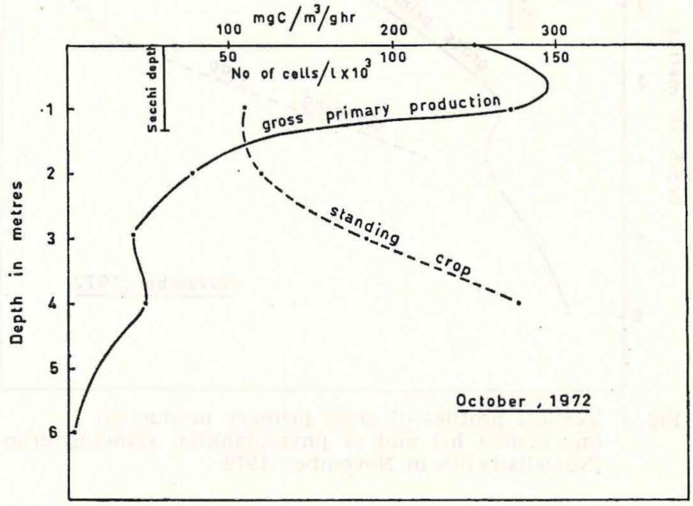

Fig. 3. Vertical profiles of gross primary production (mg C/m^3/9 hr) and of phytoplankton standing crop (No cells/1x10^3) in October, 1972

The production rate decreases rapidly in spite of the increase in the cell numbers. This can be attributed to the rapid reduction of incident light with depth, the Secchi depth being at a minimum this month, 1.6 m. The gross primary production below one square meter in October amounted to 839 mg C/m^2/day. The optimum production rate during November was at 0.9 m. It considerably decreased since October to 99 mg C/m^3/9 hr (Fig. 4). The vertical profile shows a gradual decrease down to 6 m. The phytoplankton crop attains its maximum density at 2 metres, decreasing again with depth. The gross primary production during this month, dropped to 351 mg C/m^2/day. The month of December (Fig. 5) showed a more or less constant production at all depths with but a slight increase to 156 mg C/m^3/9 hr at 3 and 4 m. Transparency is higher, as the Secchi-depth reached 4 meters. The phytoplankton density drops to a minimum at 3 m followed by a rise at 4 m due to the increased density of *Nitzschia closterium.* The gross primary production in December increased markedly, attaining 997 mg C/m^2/day, in parallel with the increased crop density since November (170$\times$10^3, for 95$\times$10^3 cell/L in November), and in spite of the lowered radiation intensity.

Winter. Surface inhibition was not observed during January and February, but it reappeared in March, with the increased solar radiation (254, 395 and 425 gm cal/cm^2/day in January, February and March, respectively). In January

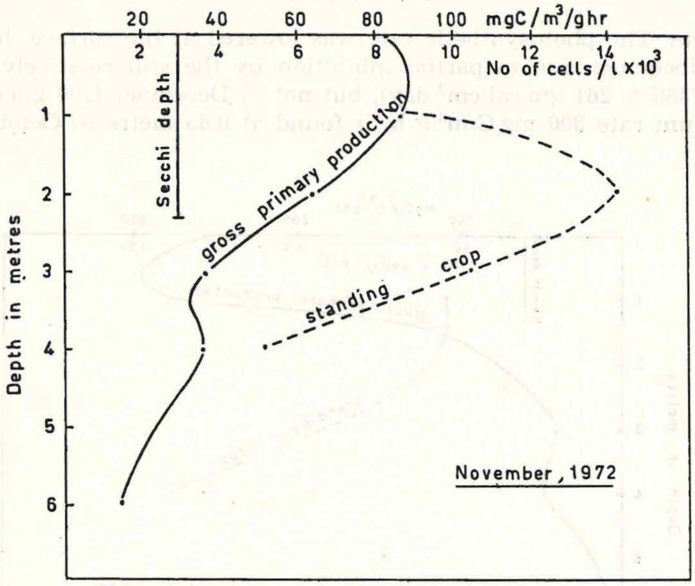

Fig. 4. Vertical profiles of gross primary production (mg C/m^3/9 hr) and of phytoplankton standing crop (No cells/1x10^3) in November, 1972

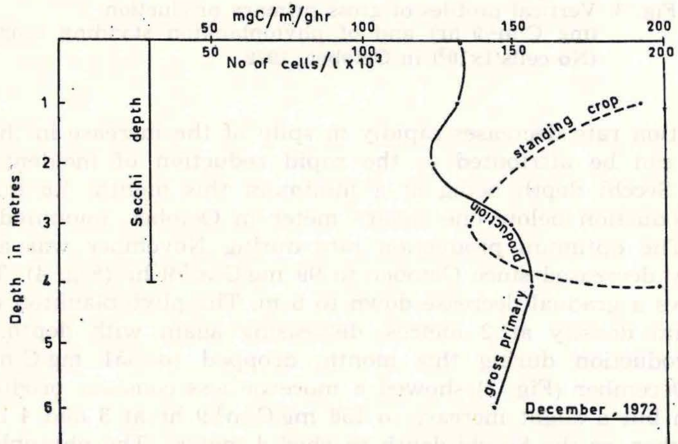

Fig. 5. Vertical profiles of gross primary production (mg C/m^3/9 hr) and of phytoplankton standing crop (No cells/1x10^3) in December, 1972

(Table 3 and Fig. 6), the optimum photosynthetic rate, 178 mg C/m^3/9 hr, is at the surface, rapidly decreasing with depth. The phytoplankton was irregular in vertical distribution with two intermediate maxima. The average crop value, however, is low and of the same order as in December. The gross primary

Table 3. Optimum gross primary production, its depth ($A_{opt.}$) phytoplankton (cells/L) at the corresponding depth and average water temperature.

Month	A_{opt},mg C (m^3) 12 hr	Depth m	Cells/L x 10^3	Average water temperature, °C
September, 1972	669	1.00	6691	27.5
October	394	0.65	56	23.0
November	120	0.90	81	16.0
December	208	4.00	198	15.5
January, 1973	249	surf.	217	16.3
February	206	surf.	160	13.1
March	204	2.40	848	17.8
April	583	2.00	1839	22.3
May	617	2.00	15898	25.0
June	539	2.00	2872	26.6
July	617	1.00	6201	28.5
August	676	1.00	6926	26.9

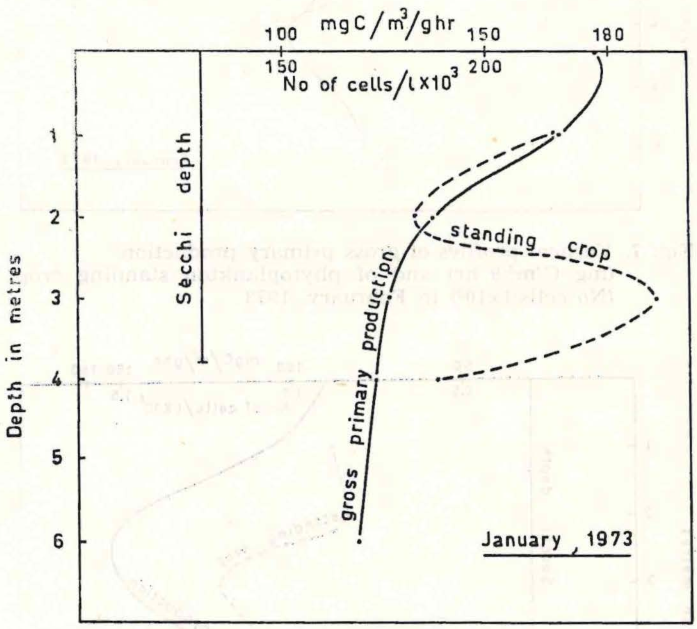

Fig. 6. Vertical profiles of gross primary production (mg $C/m^3/9$ hr) and of phytoplankton standing crop (No cells/1x10^3) in January, 1973

production below one square meter, during January amounted to 961 mg C/m^2/day. In February (Fig. 7) the optimum photosynthetic rate was still at the surface (156 mg $C/m^3/9$ hr), decreasing gradually to 6 m. The standing crop variations were more or less parallel. The gross primary production below one square meter was of 871 mg C/m^2/day. By March (Fig. 8) the depth of optimum production (153 mg $C/m^3/9$ hr) is increased to 2.4 meter. The phytoplankton density follows more or less the same profile. The gross primary production below one square meter during this month amounted to 946 mg C/m^2/day.

Spring. Solar radiation is increasing in intensity, finally reaching the year's maximum, 616 gm cal/m^2/day, in June. The surface inhibition remains well marked from April through June and the optimum rate is always at 2 m depth. Except for April, the maximum phytoplankton density is at the same

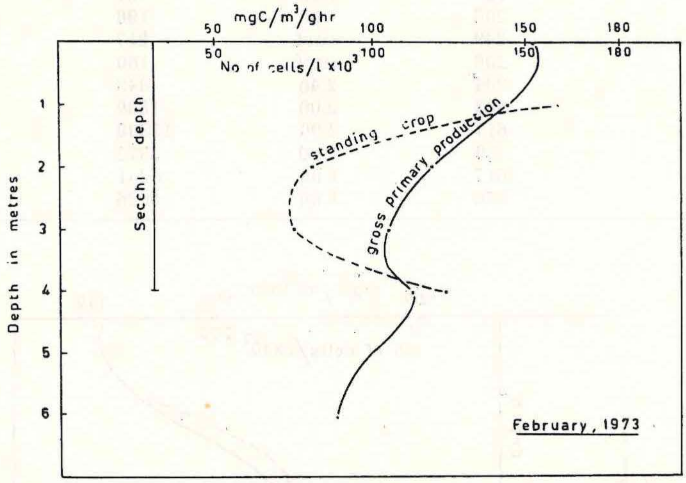

Fig. 7. Vertical profiles of gross primary production (mg C/m^3/9 hr) and of phytoplankton standing crop (No cells/1x10^3) in February, 1973

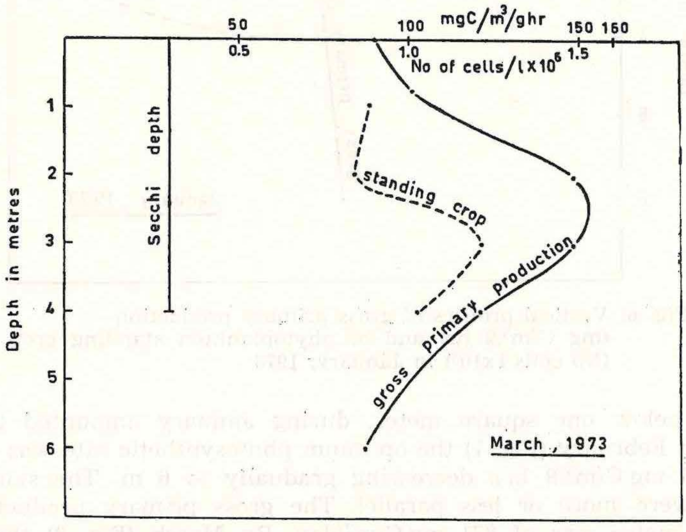

Fig. 8. Vertical profiles of gross primary production (mg C/m^3/9 hr) and of phytoplankton standing crop (No cells/1x10^6) in March, 1973

depth, and the two profiles are similar in shape. The crop density is considerably increased and May shows the year's maximum, with about 15 million cells/L, of which more than 90% were *Skeletonema costatum.* Following the rise in both solar radiation intensity and phytoplankton density, the optimum photosynthetic rate increased to about three fold its March value (respectively 438, 464 and 405 mg $C/m^3/9$ hr in April, May and June). The gross production below the square meter is also increased in about the same proportion, from 946 in March to 2559 mg C/m^2/day in April (Figs. 9 to 11).

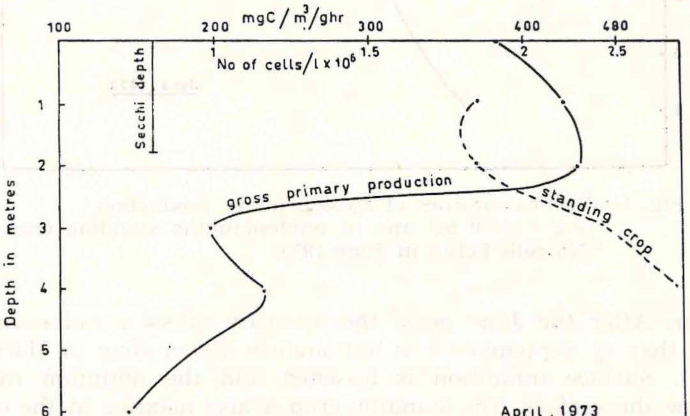

Fig. 9. Seasonal profiles of gross primary production ($mg\ C/m^3/9$ hr) and of phytoplankton standing crop (No cells/$1x10^6$) in April, 1973

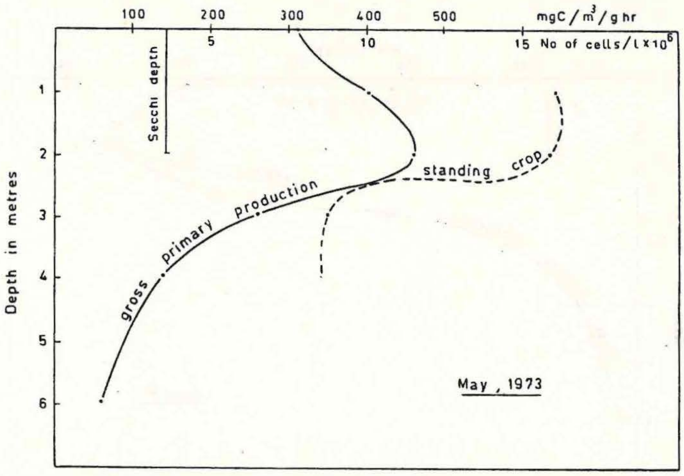

Fig. 10. Vertical profiles of gross primary production ($mg\ C/m^3/9$ hr) and of phytoplankton standing crop (No cells/$1x10^6$) in May, 1973

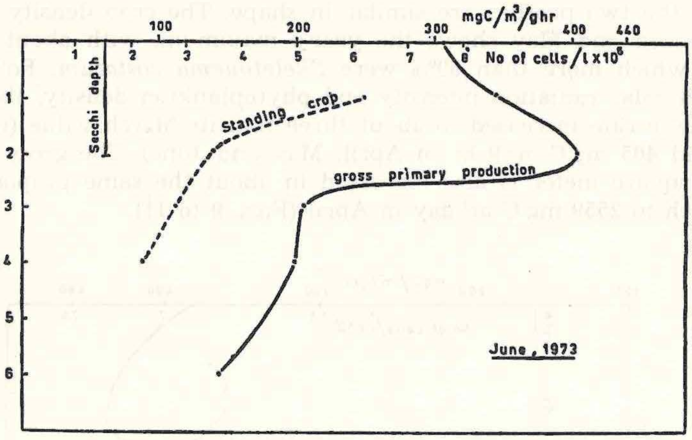

Fig. 11. Vertical profiles of gross primary production (mg $C/m^3/9$ hr) and of phytoplankton standing crop (No cells/$1x10^6$) in June 1973

Summer. After the June peak, the intensity of solar radiation is on the decrease so that by September it is but slightly higher than in March (470 gm cal/cm^2/day). Surface inhibition is lessened and the optimum rate is now at 1 m below the surface. The standing crop is also maxima at the corresponding depth. Its density is comparatively high, 5—6 million cells/L, representing the second blooming season of the year. The dinoflagellate *Alexandrium minutum* was dominant in July, and the diatom *Skeletonema costatum* in August. Although the crop density in July—August (1973) and September (1972) is less than half that of May, the optimum photosynthetic rate is slightly higher, 464 to 508 mg $C/m^3/9$ hr. (Figs. 2, 11—13).

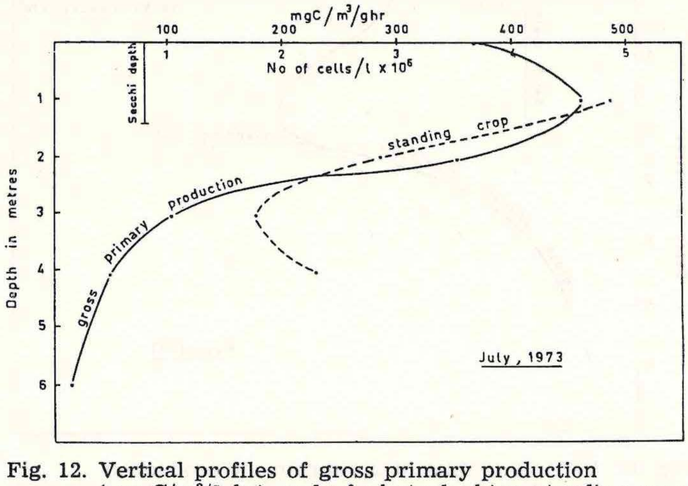

Fig. 12. Vertical profiles of gross primary production (mg $C/m^3/9$ hr) and of phytoplankton standing crop (No cells/$1x10^6$) in July, 1973

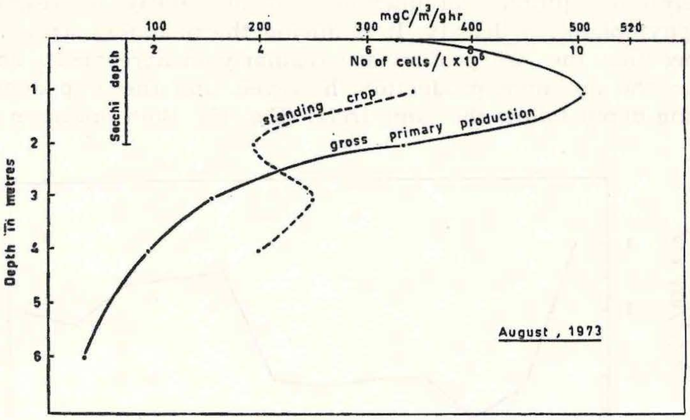

Fig. 13. Vertical profiles of gross primary production ($mg\ C/m^3/9\ hr$) and of phytoplankton standing crop (No cells/$1x10^6$) in August, 1973

The monthly variations of the gross primary production recorded in the present investigations is shown in Table 4.

Table 4. Monthly variations of gross primary production ($mg\ C/m^2/day$)

Month	$mg\ C/m^2/day$	Month	$mg\ C/m^2/day$
September, 1972	3025	March, 1973	946
October	839	April	2559
November	351	May	2476
December	997	June	2423
January, 1973	961	July	1831
February	871	August	1975

DISCUSSION

As a rule, the vertical profiles show a decrease in primary production with depth, but surface inhibition is observed, except in winter. The depth of optimum photosynthetic rate follows the cycle of incident solar radiation. From about 0.4 m in early spring, it increases to 2—2.4 m at the beginning of the summer. In July—August it is nearer to the surface than in June, as the intensity of solar radiation is decreased. In all cases production is optimum at the depth of about 40—50% of incident light transmission.

The empirical relation given by Harvey (1957) for Plymouth waters between K, the extinction coefficient, and D, the Secchi depth $K = \frac{1.7}{D}$, does not hold for this shallow eutrophied station. In the E. Harbour, the constant is nearer to unity, $K = \frac{1.06}{D}$.

The depth of optimum production does not always correspond to the maximum phytoplankton density. It is during the blooming season from May to September that the two profiles are regularly in agreement. The monthly variations in the optimum production, however, and the crop density at the corresponding depth follow the same trend (Fig. 15). Both optimum production

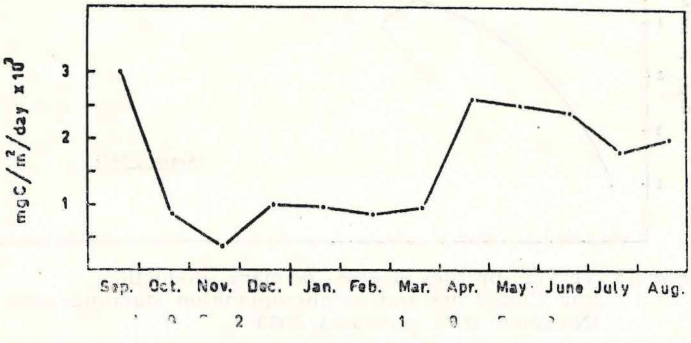

Fig. 14. Seasonal fluctuations of gross primary production (mg C/m²/day x 10³) during 1972—73

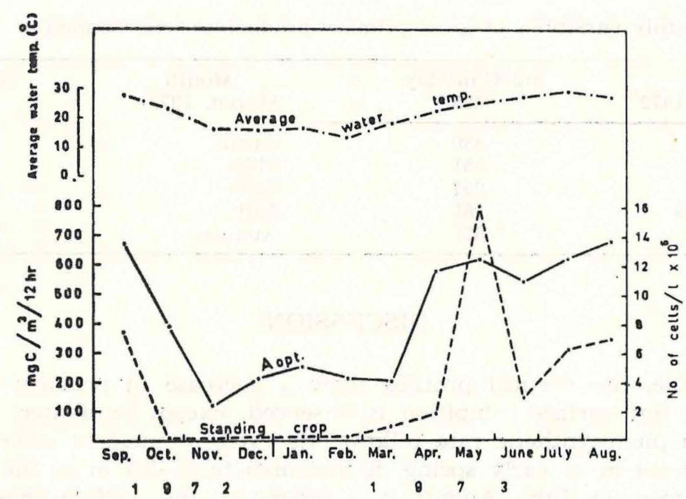

Fig. 15. Seasonal fluctuations of average water temperature (°C), of optimum prodution (mg C/m³/12 hr) and of phytoplankton standing crop (No cells/1x10⁶) during 1972—73

and crop density are at their lowest from November through March, repidly rising to a peak in May. June shows a drop in the phytoplankton density, which has but a reduced effect on producticity. The two curves rise again in July—August. The »production efficiency« of the phytoplankton was much higher in the early phase of the bloom than in the subsequent phases. Thus about 1.8 million *Skeletonema costatum* cells per litre in April yielded a higher production (2558 mg C/m^2/day) than about 16 million cells of the same species in May (2476 mg C/m^2/day).

The conditions at this station, investigated in 1972—73, differ from those observed by Halim *et al.* (in this volume) at their stations I to III in 1977—78. At the present station, turbity was much lower, the standing crop density considerably higher and the cycle bimodal, with a spring bloom and a smaller autumn bloom. In 1977—78, the cycle does not follow any seasonal trend. It appears that such changes have taken place as a result of the increasing eutrophication of Eastern Harbour in last few years.

The relation between Σ_{gross} and the product ($A_{opt} \cdot$ x Secchi depth) is not completely linear in all months. The factor F ranged from 1.14 to 1.86, averaging 1.5±0.36, the higher values being in summer (Table 5). An approximation of the gross production in the polluted zone of the Harbour can, therefore, be obtained from:

$$\Sigma_{gross} = A_{opt.}/\text{hr.} \times 1.5 \times \text{Secchi depth} \times \text{day length}$$

Tabela 5. Monthly variation in the factor $F = \Sigma_{gross} A_{opt.} \times$ Secchi depth

Month	F	Month	F
January	1.17	July	1.86
February	1.14	August	1.29
March	1.17	September	1.75
April	2.26	October	1.39
May	1.76	November	1.49
June	1.82	December	1.40

$A_{opt.}$ in the E. Harbour ranged from 120 to 676 mg C/m^3/12 hr and the gross production from 351.4 to 3025 mg C/m^2/ day. The average daily production amounted to 1.6 g C/m^2/day and the year's production to 584 g C/m^2/year. This is a high level compared to the yield of stations I to III on the continental shelf, respectively 314, 219 and 175 g C/m^2/year (Halim *et al.* in prep.).

The general mean value for the Mediterranean (mainly based on West Mediterranean values) approximates 80—90 g C (Sournia, 1973). Lagoons and harbours, however, yielded maximal values exceeding 350 g C.

REFERENCES

Dowidar, N. M. and A. A. Aleem, 1967. Phytoplankton production in relation to nutrients along the Egyptian Mediterranean coast. Trop. Oceanogr., Miami, 5/XX: 305—323.

El-Maghraby, A. M. and Halim Y. 1965. A quantitative and qualitative study of the plankton of Alexandria waters. Hydrobiologia (25): 1—2: 221—238.

Guerguess, S. K. 1969. Zooplankton studies in the U.A.R. Mediterranean waters with special reference to the Chaetognatha. M. Sc. Thesis, University of Alexandria, 263 pp.

Halim, Y., Al-Handhal, A. and Khalil, A. (in this volume). The diatom flora of a eutrophic bay, the Eastern Harbour of Alexandria.

Halim, Y., Sultan, H. H., Samaan, A. Primary productivity on the shelf waters off Alexandria in 1969—1979 (in preparation).

Harvey, H. W. 1957. The chemistry and Fertility of sea waters. Cambridge University Press, 242 p., 65 illus., 28 tables.

Hassam, A. K. A. 1972. Systematic and ecological study of the Dinoflagellates in the area of Alexandria. M. Sc. Thesis, Univ. Alexandria, 316 pp.

Sournia, A. 1973. Primary production of phytoplanktion in the Mediterranean. Newsletter Cooperative Investigation in the Mediterranean, 5, 127 p.

Steemann-Nielsen, E. 1952. The use of radio-active carbon (C^{14}) for measuring organic production in the sea. J. du Cons., 18 (2): 117—40.

Steemann-Nielsen, E. 1958. Experimental methods for measuring organic production in the sea. Repp. Proc. — Verb. Cons. Int. Explor. Mer: 144: 38—48.

Steemann-Nielsen, E. 1965. On the determination of the activity in C-14 ampoules for measuring primary production. Limnol. & Oceanogr. Suppl. Vol. X: 244—252.

Steemann-Nielsen, E. and Jensen, A. 1957. Primary organic production. The autotrophic production of organic matter in the Ocean. Galathea Rep., 1: 49 p.

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Y. Halim,* A. A. Samaan** i H. H. Sultan**

* *Odjel za oceanografiju, Fakultet znanosti, Aleksandrija, Egipat*
** *Institut za oceanografiju i ribarstvo, Aleksandrija, Egipat*

KRATKI SADRŽAJ

U toku jednogodišnjeg ciklusa (IX 1972 — VIII 1973) mjerena je u »Istočnoj luci« Aleksandrije mjesečna, »in situ« primarna proizvodnja, na dubinama od 1, 2, 3, 4 i 6 m, u intervalu od 9 h do 18 h. Paralelno su vršene pomoću obrnutog mikroskopa i kvalitativno-kvantitativne analize fitoplanktona, koji je bio sakupljan na dubinama od 1, 2, 3 i 4 m.

Srednja dnevna radijacija sunca iznosila je u Aleksandriji 1972. godine oko 435 g cal/cm^2. Prozirnost mora, mjerena Secchijevom pločom, kretala se u istom razdoblju između 1, 3 i 4 m. Mutnoća vode je jako ovisila o gustoći fitoplanktona i podizanju detritusa s dna. Najniža vrijednost, zabilježena u julu 1973, je bila praćena jakim cvatom dinoflagelata *Alexandrium minutum* Halim, a visoka mutnoća u oktobru, bila je uzrokovana turbulencijom pod utjecajem vjetra.

Simultana mjerenja Secchijevom pločom i fotoćelijom su pokazala da je u »Istočnoj luci« fotični sloj vrlo plitak (8,47 do 17,3 m), za razliku od voda van zaljeva, gdje se kompenzacijska tačka smješta na 70—80 m dubine.

Fotosintetska aktivnost fitoplanktona u pravilu opada od površine prema dnu. U samom površinskom sloju je, međutim, zapažena svjetlosna inhibicija fotosintetske aktivnosti, što jedino nije slučaj u zimskom razdoblju. U svim slučajevima produkcija je optimalna na 40—50% upadnog svijetla.

Dubina optimalne proizvodnje ne odgovara uvijek maksimumu fitoplanktonske gustoće, dok mjesečne promjene optimalne proizvodnje i gustoće fitoplanktona na odgovarajućoj dubini, slijede isti trend. Optimalna produkcija i gustoća fitoplanktona najniže su od novembra do marta, a maksimalne u maju. Obe krivulje uzdižu se opet u julu—augustu. »Produkciona efikasnost« je mnogo viša na početku cvatnje nego u slijedećim fazama.

Zadnjih godina (1977—78) gustoća fitoplanktona ne prati više uobičajeni sezonski trend kretanja. Autori smatraju ovu pojavu rezultatom pojačane eutrofikacije u Istočnoj luci.

Faktor F kretao se od 1,14 do 1,86, s najvišim vrijednostima ljeti.

Optimalna proizvodnja kretala se između 120 i 676 mg C/m^3/12 h, bruto proizvodnja od 351,4 do 3025 mg C/m^2/dan, odnosno 584 C/m^2/god., što je neusporedivo viša vrijednost od vrijednosti koje se općenito bilježe za Mediteran.

PRIMARNA PRODUKCIJA U ZALJEVU LUKE ALEKSANDRIJE

[illegible]

KRATKI SAŽETAK

[illegible]