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EFFECT OF WINTER CONDITIONS UPON PHYTOPLANKTON PRODUCTION IN NORTH-WESTERN PARTS OF THE MEDITERRANEAN SEA

PRODUCTION PRIMAIRE HIVERNALE EN MEDITERRANEE NORD-OCCIDENTALE

Z.Z. FINENKO

Institute of Biology of South Seas,
Academy of Sciences YCCP, Sevastopol (URSS).

The results of systematic observations, carried out in recent years near the shores of Spain and France, have made it possible to describe in detail the seasonal periodicity of production cycle (Jacques, 1970 ; Margalef, Ballester, 1967 ; Margalef, Castellvi, 1966 ; Minas, 1968). Similar to other middle latitude seas, two maximums in phytoplankton production were found that is, spring and autumn ones, the former being usually higher than the latter. Determination of production cycle in off-shore waters presents a far more complicated problem. Only the investigations, conducted opposite to the shore of Monaco and on the floating buoy in western part of the Mediterranean Sea (at 42°47' N, Long 7°29' E 9), may be regarded as useful in this respect. In spite of a quite considerable time gap, the investigations covered the periods when sharp biological changes were expected, therefore, one may well believe that they correctly demonstrated the seasonal changes of primary production. Comparing the results obtained in coastal and off-shore waters, it is possible to notice that the production cycle range and duration are of similar character though shifted in time. Maximum production of phytoplankton in north-western part of the Mediterranean Sea was observed at the end of March -beginning of April, while that in inshore waters - in February. One of the main reasons for the phytoplankton maximum shift is conditionned by the earlier formation of water stability in coastal areas. The latter are more readily subjected to both - the dry land fresh water effect and heating in spring. These lead to decreasing the water vertical mixing intensity thus resulting in improving the conditions for vital activity of phytoplankton. The second reason is conditionned by the difference in mechanisms supplying the biogenic elements to the photosynthesis zone. In coastal areas they are replenished mainly by regeneration from the bottom sediments while in open seas by the deep water ascent. Vertical transfer of biogenic elements from the layers located below the photosynthesis zone is closely connected with hydrologic regime, with convectional mixing in particular, which may amount to 1.5-2.5 km in certain areas of north-western part of Mediterranean Sea (Ovchinnikov *et al.*, 1976). Mixing of water masses produces a double effect upon the phytoplankton production, because this process results not only in the biogenic elements replenishement in the layer of photosynthesis but also in simultaneous carrying of the phytoplankton algae beyond the limits of euphotic zone. Therefore, the primary production amount in winter, as well as the range and duration of production cycle in spring, depend upon the relationship of the processes'rates.

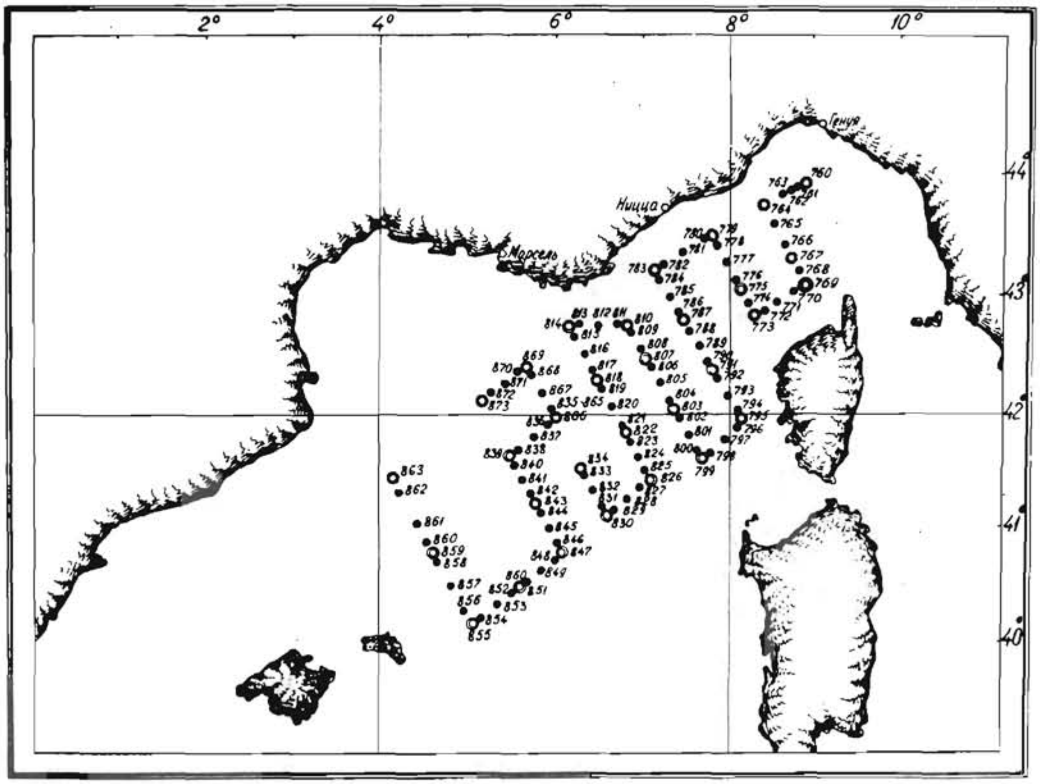

Figure 1 - Stations' location diagram.

To clarify these points, the investigations have been carried out aimed at determining the effect of winter conditions upon the spatial distribution of phytoplankton in the areas featured by different convectional mixing.

MATERIALS AND METHODS

The investigations were conducted from the 1st to 10th of December in north-western part of the Mediterranean Sea (Fig.1). The samples from surface were taken 5-10 miles, from various depths within euphotic zone, after 30 miles. The rate of photosynthesis was measured by radiocarbon technique according to the pattern developed by Sorokin (Sorokin, 1956; Sorokin, Klyashtorin, 1961). Carefully purified solution of radioactive carbonate with initial radiactivity of 1.10 pulses per minute, determined with the aid of relevant reference book (Sorokin, 1960), was put into light and dark or second half of the day in the desk through-type incubator at a temperature close to ambient one. The samples were filtered the U.S.-made membrane filters having the pores'size of 0.8 micrometers ; the sediment was washed by 1 % of HCL solution prepared by using the filtered sea water.

To find the coefficient of phytosynthetically active phytoplankton's vertical distribution (Kp), the samples were selected at the depth of extreme values of fluorescence and transparency measured by fluorimeter and logarithmic photo and transparency meter LFP-2 which functionned in a continuous probing mode from 0 to 200 m.

The Kt coefficient, showing the dependance of photosynthesis upon the light intensity, was determined at 5 stations located at different places of the water samples, taken from the depth of 5-10 m, were put into the dish in which the sunlight was reduced down to 80, 25, 10 and 1 % of the incident solar radiation with the aid of neutral light filters. The bottles were exposed during dayling hours at a temperature of a surface layer. Together with this, the team of opticians mesuared the relative intensity of submarine illuminance within the entire FAR range from 0 to 100 m. The coefficients of light absorption by water in the course of experiments were calculated on the basis of the obtained data. The latter, as well as the total solar radiation values, measured by pyranometer, were utilized for calculating both the value of solar energy penetrating into various depth. The values of photosynthesis, obtained with full natural illuminance, were taken as 100 %. One time, the dependance of photosynthesis rate upon submarine illuminance was found by placing the samples at different depths of euphotic zone.

RESULTS

The daily of primary production in the surface layer and under 1 m of euphotic zone, obtained in 8 meridional and 8 latitudinal sections, are given in Table 1. They allow to distinguish several areas differing in their productivity in the investigated part of the Mediterranean Sea.

Western part of the Ligurian Sea is the region of cyclonic cycle. Here, the phytoplancton production considerable differences regardless the relatively small area and short distances between the stations. In surface layer at stations 760-769, it amounted to 1,6-33.6 $mgC.m^{-3}$, or 39-460 $mgC.m^{-2}$ per 24 hrs. Maximums values (215-460 $mgC.m^{-2}$) were found in central area of the cycle. They are conditioned by intensive penetration of nutrient salts into the photosynthesis zone as a result of deep water ascent. Phytoplankton production gradually decreased as

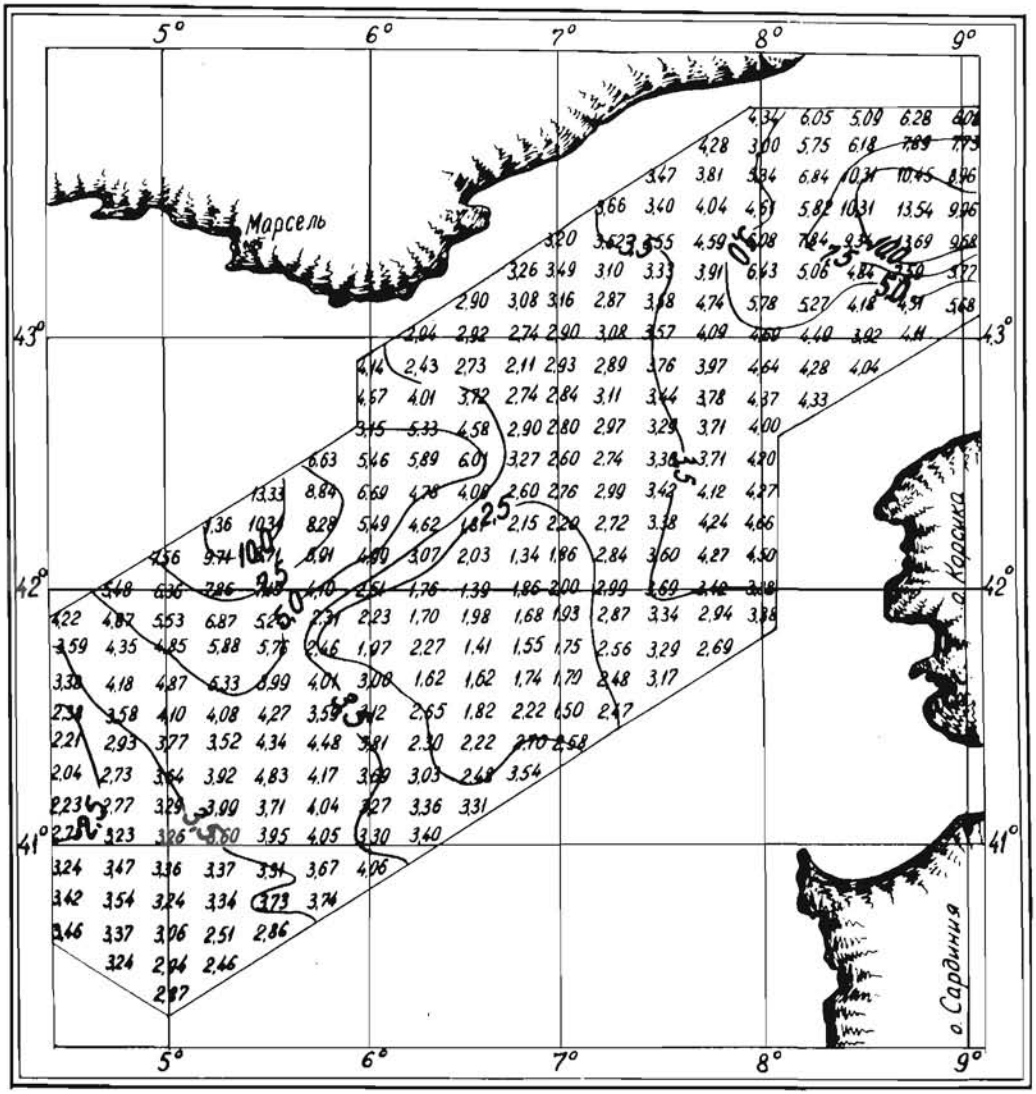

Figure 2 - Values of primary production distribution (mgC.m^{-3} .day^{-1}) in surface layer in north-western part of the Mediterranean Sea.

it drifted away from the cycle center in northern and western directions. In average, it was three times smaller at the stations located along the cycle periphery compared to the central area.

NORTHERN PART OF THE ALGERIAN-PROVENCAL BASIN

The results of measurements at stations 795-835 and 843-863, located between Long 4° and 8° E, show that the amount of primary production considerably decreases as it drifts in the western direction from the Ligurian Sea. Minimum values were registered in central and south parts of the investigated area (10-50 mgC. m^{-2}). This results from the fact that, in winter, northern part of the Algerian-Provençal Basin is featured by powerful cyclonic circulation with the boundary coming along southern part of the investigated area. This system of currents, typical for the whole year, causes the waters' descent and, hence, lowering of the temperature, salinity and phosphates' isolines which was registred in the course of our investigations. Consequently, the thickness of upper layer subjected to mixing sharply increases thus leading to the phytoplankton concentration reduction in photosynthesis zone and decrease of its production.

SOUTHERN PART OF THE GULF OF LION - THE AREA OF CYCLONIC GYRAL

The data obtained at stations 839-841 and 866-873 testify to the higher productivity of these areas compared to southern ones. In surface layer the photosynthesis rate varied from 6 to 25 mgC.m^{-2}, or 0,14-0,65 gC.m^{-2} per 24 hrs. The highest values were registered along the northern boundary of the investigated area (stations 870-873).

To correctly draw the map of phytoplankton production distribution in surface layer with the aim of distinguishing the areas of different productivity, we used the objective analysis technique described by Andruschenko and Belyaev (1978). The essence of such an analysis is to split the process of investigations into deterministic and random components by means of optimal interpolation. After this, the calculated values were interpolated into the stations' grid nodes having spacing of 7.5' in latitude and 15 in longitude. The gotten in such a manner mean values of photosynthesis rate in surface layer were used for drawing the map by a computer. The final results of these calculations, made by Andruschenko, are presented in Figure 2. The map shows two distinct zones with high amount of a primary production located within the cyclonic cycle zone. It is worth mentioning that the area of relatively high mean values of phytoplankton production extends beyond the limits of cyclonic gyrals distinguishes by hydrological features (Andruschenko, 1984), that is, the disturbances, caused by cyclonic system of currents, produce an effect upon the boundary regions. The latter occupy 20 % of the entire testing area in the Ligurian Sea and the Gulf of Lion, but it is just here where 40 % of the total amount of production are produced (Table 2). The remaining part is created in the low productive regions occupying 80 % of the entire testing area.

The data, given in figure 3, provide the whole picture of changes in phytoplankton production depending on the sea depth. In all four sections elongated from the south-west to the north-east, the basic role in the respect of productivity is played by the phytoplankton which is concentrated in the 0-20 m layer. The total values of primary production in this layer amount to 80-95 % of those registered under 1 m of the euphotic zone which constituted 40-50 m at the majority of stations. Therefore, the difference between the values of photosynthesis in surface layer and under 1 m was quite narrow, and did not exceed 18-25 times. The given sections vividly exhibit the zones between stations 863-869, 767-765, 769-773 located close to the cyclonic cycles'centers in the Gulf of Lion and the Ligurian Sea. In these zones, relatively high values photosynthesis rates may reach 30- 30-35 m, that is,10-15 m deeper than beyond the circulation area. It is quite evident that such differences are not accidental, they reflect the effect of cyclonic gyral upon the changes in photosynthesis rate and phytoplankton concentration within the euphotic zone. The data pertaining to the K value are given for the typical areas in figure 4. In the absence of distinct thermocline and pycnocline near the gyrals' centers, the maximum K_p values were obtained in surface layer where the illumination conditions are most favorable for photosynthesis (Fig.3 station 767). In this case, curves K_p are similar to those of K_T showing the dependence of photosynthesis upon submarine illumination. As the phytoplankton drifts away from cyclonic vortices, the K_p value and temperature gradient exhibit the tendency to lowering (Fig.3, stations 775, 757, 807). At these stations, the productive capacity of phytoplankton within the sharp temperature change layer is 1.5-2 times higher than near the surface. A similar picture was observed at the stations located in north-western part of the Algerian-Provençal Basin (Fig.3, st. 839, 851, 826).

Therefore, it is possible to distinguish on the investigated area several specific types of vertical distribution of photosynthetically active phytoplankton according to its productive capacity. The first is characteristic of the areas located close to cyclonic cycles. The second is observed when temperature gradient is available within the photosynthesis zone. The third is registered when the abrupt temperature change takes place below the photosynthesis zone.

Determination of the relationship between photosynthesis rate chlorophyll content in plankton is of great significance for analyzing the phytoplankton productive capacity. It is quite clear that different rate of photosynthesis in the samples taken from various depths when exposed under equal conditions may depend not only on the phytoplankton biomass but also on its photosynthetic activity. The latter is conditioned by quite a few factors. The basic factors for the studied area are : provision by biogenic elements, light and probably chromatic adaptation of the algae, dimensional structure of phytoplanckton. The data given in Table 3 show that assimilative numbers of plankton, measured under equal illuminance conditions, differ 3-7 times within the limits of euphotic zone. As a rule, maximum values were observed in surface layer and they were higher within cyclonic circulations than beyond their boundaries. The differences in absolute values and in the nature of their changes according to depths in the investigated areas were more significant in the lower layers. Such differences mean that beyond the boundaries of cyclonic gyrals the plankton assimilative number up to 80 m is usually the same while close to the centers it decreases with depth. We believe that such phenomen is conditioned by different intensity of water mixing in the surface layer. In central areas of cyclonic circulations the horizontal movement of water and turbulent diffusion occur lower than along their periphery. Due to this, the algae in the gyrals centers are capable to adapt themselves to average and low light intensities natural for such depths. It is known that the maximum assimilative number of phytoplankton, adapted to low illumination, is 1.5-3 times lower than that of the algae adapted to high intensities of light (Finenko, 1979). Beyond the gyrals boundaries, phytoplankton is adapted to a certain average illumination as a result of intensive mixing of water, and that is why, its response to light is the same. To our opinion, the obtained data prove that one of the basic factors, affecting the productive capacity of phytoplankton which develops at different depths, is the adaptation to light but not the content of biogenic elements because despite their higher quantity in cyclonic cycles and more dramatic changes with the depth increase than beyond the gyrals boundaries they could not influence the nature of changing the plankton assimilative number.

Figure 5 presents the confidence intervals and mean curve relecting the effect of light upon the surface phytoplancton photosynthesis rate. The photosynthesis maximum in all five types of measurements, conducted in different parts of the investigated area, was registered with light intensity amounting to 40 % of the incident solar radiations which corresponds to 30-50 cal.cm^{-2} day^{-1} . Starting from the depth of 5-10 m, the photosynthesis rate decreased in direct proportion to the light intensity value obtained by measuring both the total solar radiation per day and the coefficient of light attenuation by water within the FAR range. On may see that the pattern of curves for phytoplankton from different areas varies within the range of 10-20 %.

In general, the aforegiven results prove that in contrast to the open areas of the Algerian-Provençal Basin having relativity low phytoplankton production, it is possible to distinguish the areas with high values of primary production which are characteristic of cyclonic cycles. These results demonstrate that it would not be quite correct to speak about the extremely poor productive capacities of the Mediterranean Sea though the production areas occupy a limited part of its water surface.

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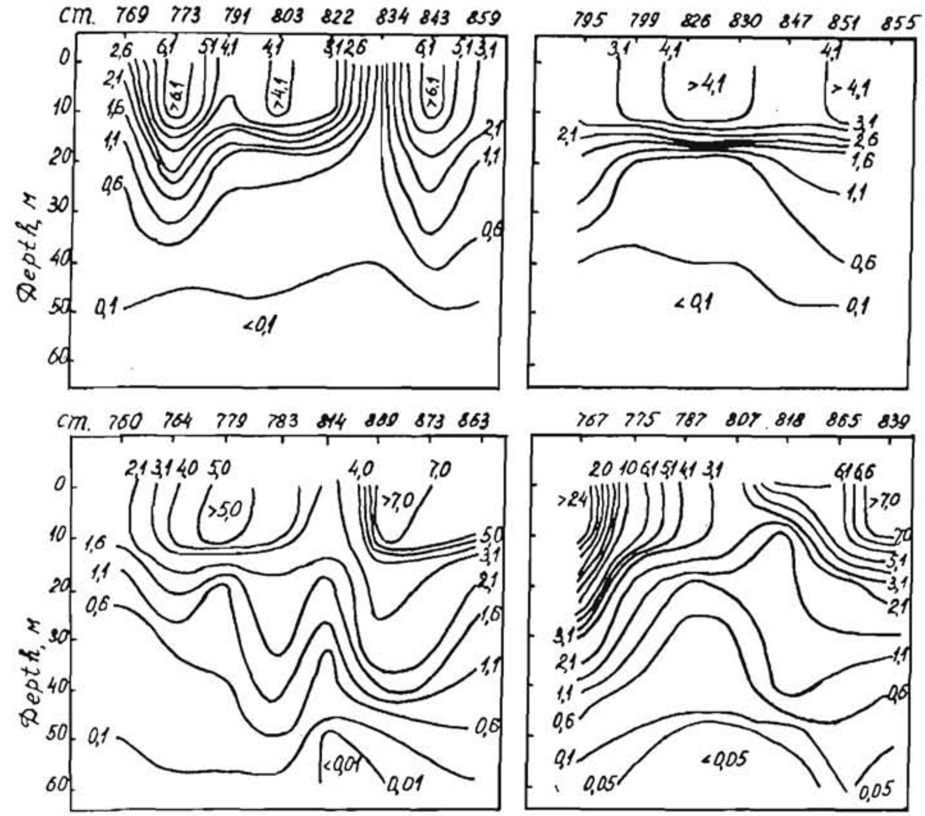

Figure 3 - Vertical distribution of phytoplankton production (mgC.m^{-3}.day^{-1}) within photosynthesis layer in 4 latitudinal sections.

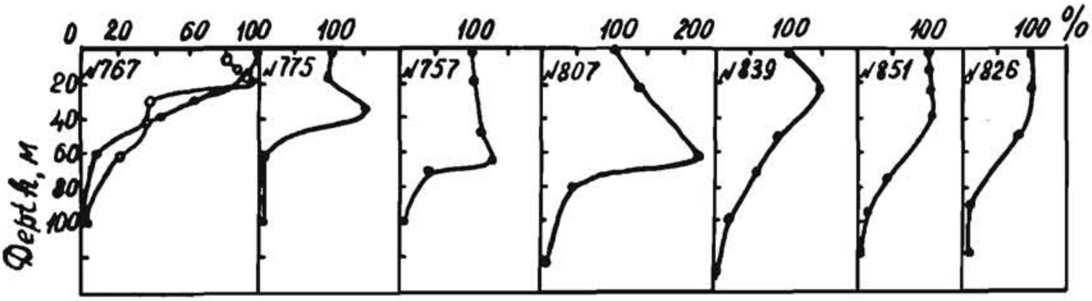

Figure 4 - Vertical distribution of phytoplancton photosynthetic activity in characteristic zones.

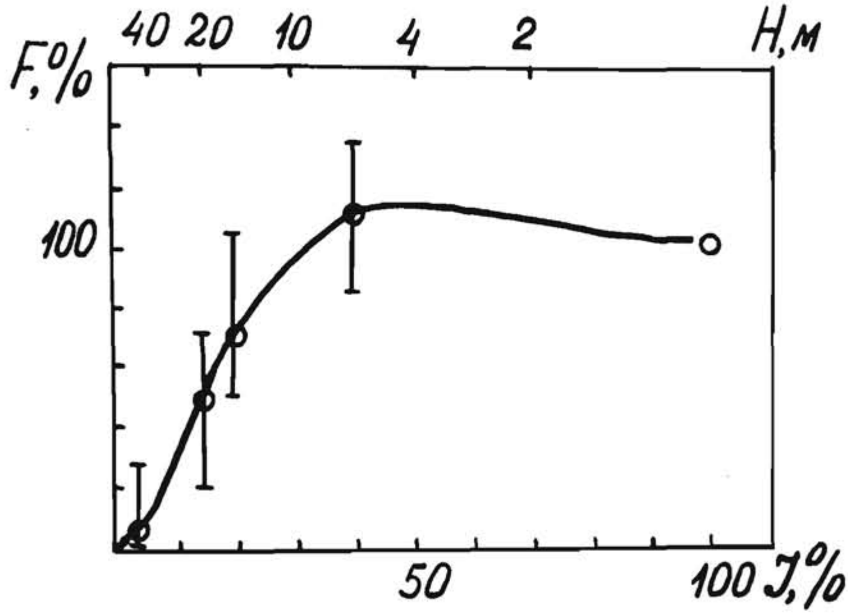

Figure 5 - Dependance of phytoplankton photosynthesis upon submarine illuminance. Horizontal scales : upper - depth in meters, lower -relative values of light intensity.

N° of st.	mgC·day⁻¹ / m^3	mgC·day⁻¹ / m^2	N° of st.	mgC·day⁻¹ / m^3	mgC·day⁻¹ / m^2	N° of st.	mgC·day⁻¹ / m^3	mgC·day⁻¹ / m^2
760	1.59	39	781	3.08	49	802	4.18	79
761	2.14	55	782	2.77	44	803	4.22	84
762	3.62	93	783	4.44	127	804	2.64	53
763	5.10	131	784	2.68	78	805	1.84	37
764	3.85	75	785	2.40	70	806	2.10	42
765	9.57	186	786	2.44	71	807	2.62	65
766	15.10	300	787	4.32	55	808	2.58	64
767	33.62	460	788	3.22	56	809	1.48	37
768	4.80	86	789	3.64	64	810	1.78	44
769	2.48	45	790	3.70	65	811	0.48	12
770	4.46	81	791	3.28	59	812	0.94	22
771	5.00	90	792	3.16	57	813	0.94	23
772	2.25	41	793	6.85	123	814	2.66	66
773	5.84	142	794	2.81	50	815	2.72	68
774	9.20	180	795	2.92	52	816	5.44	136
775	6.40	134	796	1.64	29	817	9.00	225
776	10.24	215	797	1.96	35	818	6.94	139
777	6.33	133	798	0.80	14	819	0.74	15
778	3.38	71	799	3.25	62	820	0.33	7
779	11.09	87	800	3.46	66	821	0.20	4
780	5.10	85	801	3.80	72	822	3.30	66

TABLE I - VALUES OF PRIMARY PRODUCTION IN NORTH-WESTERN PART OF THE MEDITERRANEAN SEA AT THE BEGINNING OF WINTER

N° of st.	$mgC \cdot day^{-1}$		N° of st.	$mgC \cdot day^{-1}$		N° of st.	$mgC \cdot day^{-1}$	
	m^3	m^2		m^3	m^2		m^3	m^2
823	0.02	4	838	0.78	18	853	0.54	14
824	0.06	12	839	7.82	179	854	2.00	53
825	0.24	5	840	7.22	166	855	2.10	55
826	1.50	72	841	6.00	138	856	2.46	65
827	2.10	41	842	3.74	85	857	2.62	69
828	3.50	70	843	6.00	156	858	4.54	120
829	4.00	60	844	3.12	72	859	3.00	79
830	4.50	67	845	3.42	85	860	0.88	23
831	0.80	18	846	2.76	63	861	0.32	8.5
832	2.10	48	847	3.24	74	862	0.60	14.3
833	0.36	8	848	5.88	135	863	5.49	145
834	0.44	10	849	3.34	77	866	10.5	232
835	0.56	13	850	3.60	83	870	13.1	298
836	0.62	14	851	4.50	116	871	25.1	651
837	0.56	13	852	0.80	16	873	18.0	411

TABLE I - CONTINUED

Phytoplankton production mean values near surface mgC/m^3 per day	Area of regions $10^3 km^2$	Production mean values for the regions, tC per day	% of total area	% of total production
10.0-13.5	3.0	36.7	3	8
7.5-10.0	4.7	41.0	4	10
5.0-7.5	13.2	81.9	13	20
3.5-5.0	32.2	135.2	33	32
1.5-3.5	46.3	115.7	46	28

TABLE II - PHYTOPLANKTON PRODUCTION IN SURFACE LAYER AND THE AREAS CORRESPONDING TO ITS MEAN VALUES

Depth, m	Number of measurements	$mgC \cdot m^{-3} \cdot hr^{-1}/mg$ Chl."a"$\cdot m^{-3}$	
		fluctuations' limits	mean
	Within cyclonic cycles zones		
0-10	18	0.65-5.13	2.61 ± 1.2
11-30	8	0.53-3.68	1.70 ± 1.0
31-50	8	0.23-1.23	0.73 ± 0.3
51-100	11	0.01-2.00	0.71 ± 0.6
	Beyond cyclonic cycles boundaries		
0-10	43	0.25-4.89	2.13 ± 1.5
11-30	7	0.71-4.57	2.10 ± 1.0
31-50	7	1.10-3.26	2.10 ± 0.9
51-80	8	1.48-3.91	2.50 ± 0.70
81-100	6	0.16-1.54	0.53 ± 0.4

TABLE III - RELATIONSHIP BETWEEN PHOTOSYNTHESIS RATE AND CONTENT OF CHLOROPHYLL "a" IN PLANKTON