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Phytoplankton distribution in the upwelling area off NW Africa

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ABSTRACT: In spring 1968, the centre of the upwelling region off NW Africa was investigated using R. V. "Meteor". The hydrographic structure in this area is characterized by irregular upwelling in space and time. The complicated distribution of the biological components (phytoplankton and dissolved plus particulate organic substances) is expressed only within the limits given by the resolving power of the system. Therefore, the basic values have been smoothed statistically to suppress accidental irregularities. The problematics of such manipulation are discussed. The phytoplankton distribution shows a pronounced maximum in the Cap Blanc region with extreme values in the range of $> 50\ \mu g\ C \cdot l^{-1}$ in the surface layer. A decrease was observed not only in the direction of the open sea, but also along the coast. This distribution pattern is repeated (1) at the depth of the vertical phytoplankton maximum, which is near the surface in the Cap Blanc region; (2) at the large proportion of diatoms characteristic for upwelling water; (3) at the phytoplankton stock in the euphotic zone with maximum values up to $> 0.5\ g\ C \cdot m^{-2}$. It is calculated that (minimum) daily production is almost equal to the stock. Processes of decomposition demonstrate the upwelling by regionally different relations between O_2 consumption and PO_4 liberation. An anchor station situated near the centre of the upwelling area indicates another small-scale development of phytoplankton as demonstrated by distribution charts of the total area. Pronounced daily rhythms are revealed after extensive smoothing procedures.

INTRODUCTION

In spring 1968 (from May to the beginning of June), investigations on plankton distribution were made using R. V. "Meteor" in the upwelling region off NW Africa (19° to 22° N and 17° to 19° 30′ W) with the centre near Cap Blanc (Fig. 2). During these studies an attempt was made to examine and to interpret the three dimensional plankton distribution under the questionable assumption of a quasi-stationary condition. Further, the situations found at two anchor stations are discussed with reference to the observed temporal changes. In both cases it was necessary to consider the interrelations between biotic and abiotic (physical and chemical) components.

The hydrographical and chemical situations during the cruise including a cruise report, the sample depths and other details have been described elsewhere (Mittelstaedt, 1972; Mittelstaedt & Koltermann, 1973; Weichart, 1974).

MATERIAL AND METHODS

The plankton (sedimented samples from water bottles) was counted using the Utermöhl microscope. The conversion into $\mu g\ C \cdot l^{-1}$ was calculated applying the method of Lohmann (1908). Attention must explicitly be drawn to the considerable sources of error in this method (changing size of the single species, incomplete record of the small and naked forms). In order to investigate as many samples as possible, only small fractions were counted (Gillbricht, 1962).

The quantity of the particulate plus dissolved organic carbon [$mg\ C \cdot l^{-1}$] was determined by means of a permanganate method (Gillbricht, 1957). This procedure is a little dubious and the results obtained in this way are not very suitable to be used for complex statistical calculations (multiple correlations etc.). But it is no problem to employ the carbon values for simple examinations, for instance for the construction of mean distribution charts.

The determination of nitrate plus nitrite has been reported and discussed by Weichart (1974).

REGIONAL DISTRIBUTION

It may be expected that phytoplankton distribution is highly correlated with environmental factors indicating a common binding to water bodies and mixing zones. In fact, these correlations do not exist with the possible exception of temperature which has a special status in this respect. It is of some interest, therefore, to investigate the surface distribution of phytoplankton (Fig. 1). Since the plankton gradients are logarithmic in the first range, the interpolation between the points of observation is made in the same way as with the distances between the isolines.

The hydrographical processes in this upwelling region are extremely complicated as a consequence of topography and changing meteorological conditions (Shaffer, 1976). Therefore, single observations only provide more or less random information without details on the fine structures. This is also true with respect to other distances between samples. Consequently, every measuring strategy leads to other limited insight into reality. It is necessary, therefore, to use different ways to describe the respective mean conditions. Without discussing these problems in detail (see also Shaffer, 1976) it can easily be seen that Figure 1 does not allow an interpretation of small water bodies and their fronts (Tomczak, 1973). The cutting into respective structures may be explained as disturbances without significance (single observations). It would be a good idea, therefore, to use a reasonable method to produce smoothed distribution curves for a description of the mean situation. Thus it is necessary to suppress the "accidentality" (in accordance with the resolving power of the observation) to the advantage of the basic structure. Such an attempt is possible only with some reservations. The problem is handled in this paper in such a way that the two or three dimensional distributions of different components are calculated following a proposal given by Warnke et al. (1970).

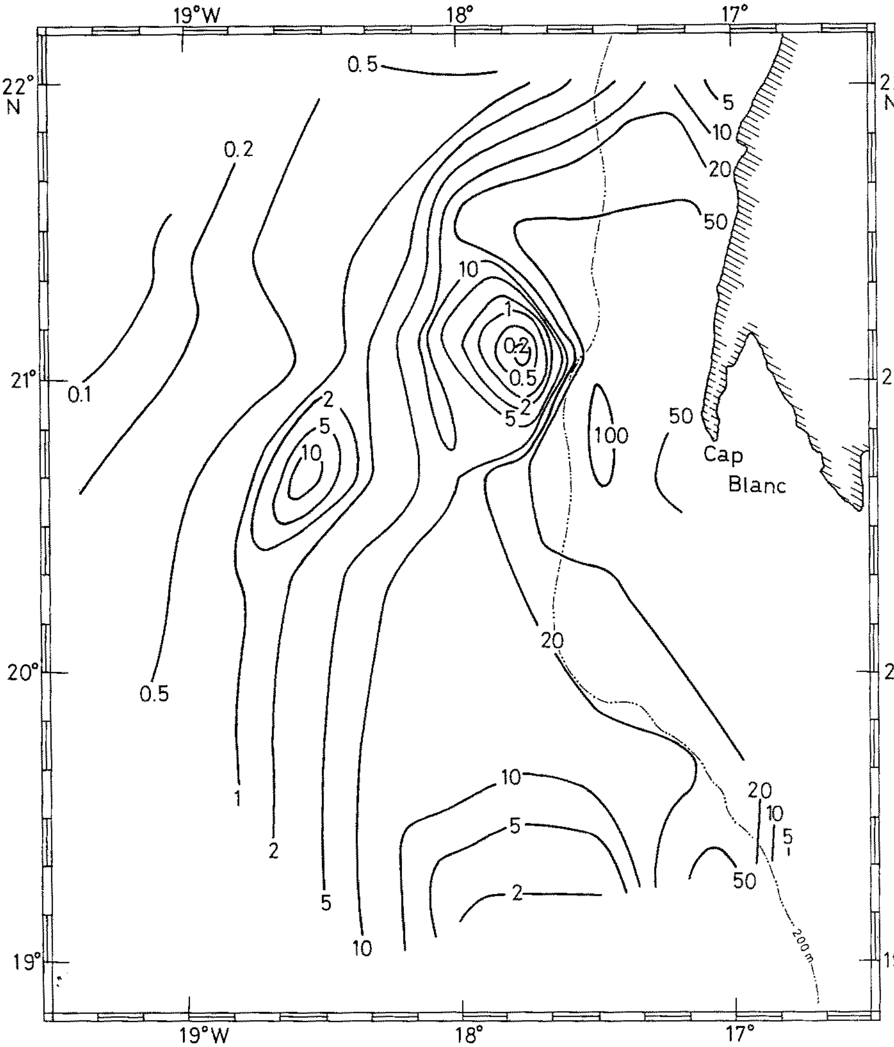

Fig. 1: Surface distribution of phytoplankton [μg C · l^{-1}] (mean values between 0 and 20 m depth). Interpolated in a logarithmic scale between the observation points (Fig. 2). Therefore one zero value had to be neglected

The following equation has been optimized:

$$Y = a + b \cdot \varphi + c \cdot \varphi^2 + d \cdot \varphi^3 + e \cdot \lambda + f \cdot \lambda^2 + g \cdot \lambda^3 + h \cdot D + i \cdot D^2 + k \cdot D^3 + l \cdot \varphi \cdot \lambda + m \cdot \varphi^2 \cdot \lambda + n \cdot \varphi \cdot \lambda^2 + o \cdot \varphi \cdot D + p \cdot \varphi^2 \cdot D + q \cdot \varphi \cdot D^2 + r \cdot \lambda \cdot D + s \cdot \lambda^2 \cdot D + t \cdot \lambda \cdot D^2 + u \cdot \varphi \cdot \lambda \cdot D$$

φ = geographical latitude, λ = geographical longitude, D = sampling depth [m]. Y must not correspond directly with the component to be investigated.

Generally, it is desirable to perform transformations on the basis of theoretical

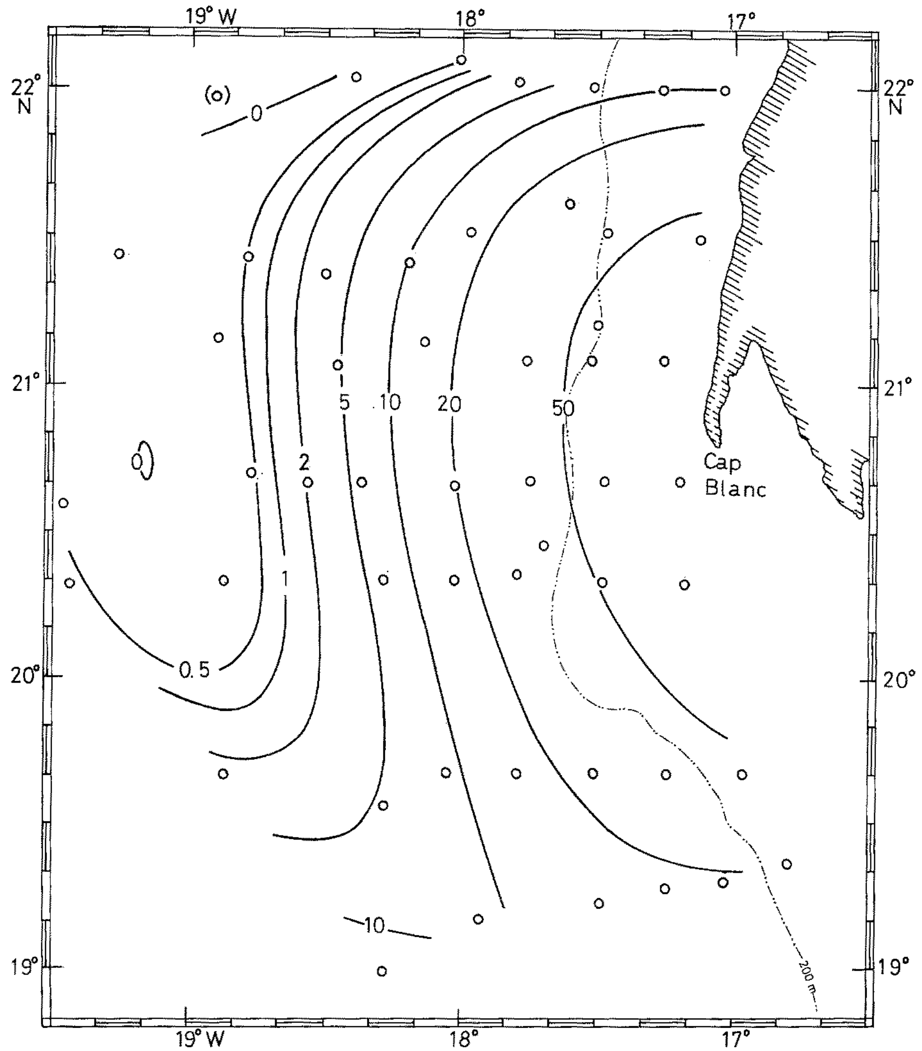

Fig. 2: Smoothed surface distribution of phytoplankton [μg C · l^{-1}] calculated by means of square roots (mean values between 0 and 20 m depth). N = number of observations = 51; R = multiple correlation coefficient = 0.828; α = probability of error $\leqslant$ 0.001; o = point of observation; (o) = zero value

considerations (for instance logarithms), so as to give a better description of the distribution (Gillbricht, 1969). The depth-dependent links in the equation are cancelled in the case of a two dimensional smoothing.

The possibility of an error α (to secure the multiple correlation coefficient R) is calculated by means of the F test (Linder, 1964):

$$F = \frac{(N - p - 1) \cdot R^2}{p \cdot (1 - R^2)}$$

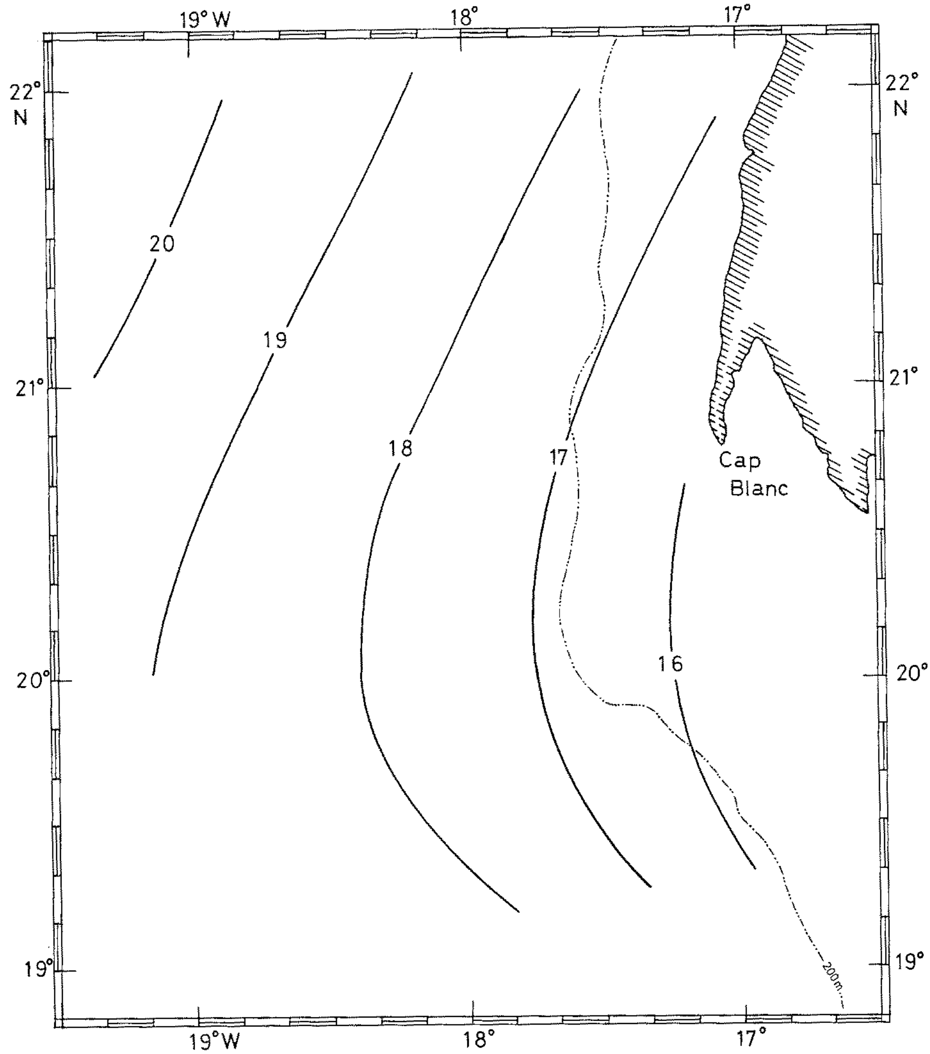

Fig. 3: Smoothed surface distribution of temperature (mean values between 0 and 20 m depth). $N = 54$; $R = 0.922$; $\alpha \ll 0.001$

N = number of observations, p = number of independent variables with $n_1 = p$ and $n_2 = (N - p - 1)$ degrees of freedom.

It must be considered in this case that the assertion of α is dubious. It is an ever existing problem that theoretical assumptions (for instance random distribution) are rarely fully satisfied. In this case the absence of the required stochastic independence is added.

All terms of the equation are always used without examination of their statistical significance because eliminating some of them entails a simplification of the mathematical formulation which results in too monotonous curves.

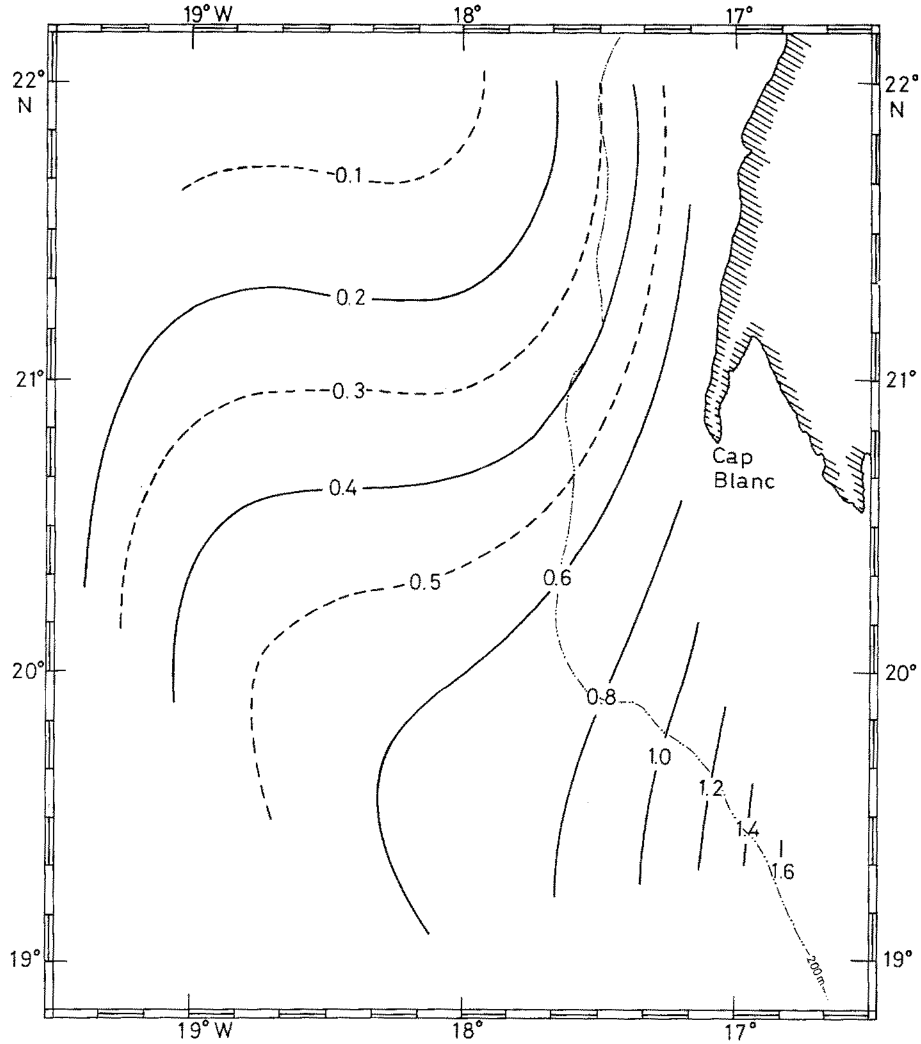

Fig. 4: Smoothed surface distribution of phosphate [μg at P · l^{-1}] (mean values between 0 and 20 m depth). N = 49; R = 0.897; $\alpha \ll 0.001$

For description of the phytoplankton distribution near the surface (Fig. 2), the transformations into logarithms (which is better from theoretical points of view) is not used but as one of the possible alternatives in the case of very small values (near zero) the square roots of the quantities of the stock are taken. The trend of the curves demonstrates a pronounced growth region in the Cap Blanc area. It must be expected that here is an upwelling of considerable importance (Shaffer, 1976). Therefore it should be examined whether or not this upwelling directly stimulates the growth of the plankton (reduced sinking velocity).

Temperature (Fig. 3) directly reflects upwelling too. Salinity (Mittelstaedt, 1972) follows the complicated hydrographical structure, and phosphate distribution (Fig. 4) is nearly identical. The latter two factors have therefore only a subordinate influence upon the development of the regional phytoplankton maximum.

Composition and spatial distribution of phytoplankton

An optimum growth region is characterized by a high multiplication rate of the single cells (logarithmic phase). This normally results in an increase of the phytoplankton stock in the euphotic zone. The sunken relics in the depth have therefore descended from a former, smaller population, i.e. the (logarithmic) vertical plankton gradient has an especially large range. It is dubious whether or not this consideration is justified in such a stationary system having a steady drift in the surface layer in the range of 20 cm · s^{-1} to SW (Mittelstaedt & Koltermann, 1973; Tomczak, 1973; Shaffer, 1976). The upwelling of the water should reduce the sinking rate in this region and thereby compress the weakening of the plankton as a function of time in a shorter depth range, i.e. the production of large vertical plankton gradients. This is truly the case. The regional distribution of the relation between the plankton in the surface layer (0 to 20 m) and below the euphotic zone (30 to 50 m) reflects our concepts on the upwelling system. But the α value (as a measure for the significance of this calculation) is not at all satisfactory in this case. It is therefore necessary to demonstrate the plankton stratification by means of a different method. For this reason the smoothed three dimensional distribution of the phytoplankton is calculated. The maximum depth for this operation is 50 m. Below this stratum there are irregularities (discontinuity layer) not to be handled by such a mathematical manipulation. The equation derived in this way also gives the regional depth distribution of the phytoplankton maximum (Fig. 5); thus the plankton stratification is indicated as well. As a consequence of the mathematical procedures the curves have a very simple structure in this case. Nevertheless, they complement the results obtained to date. Also, other environmental factors may influence the regional distribution (for instance different turbidities).

In tropical waters there are normally a lot of phytoplankton species associated with small numbers of individuals comprising a great portion of peridinians. However, diatoms prevail in the cold upwelling regions as can be seen for the surface layer in Figure 6.

Figure 7 gives an impression of the three dimensional phytoplankton distribution mentioned above. The quantity of the plankton decreases starting from a centre in the Cap Blanc area to the N, S and W, whilst the vertical distribution has a pronounced intermediate maximum in most cases.

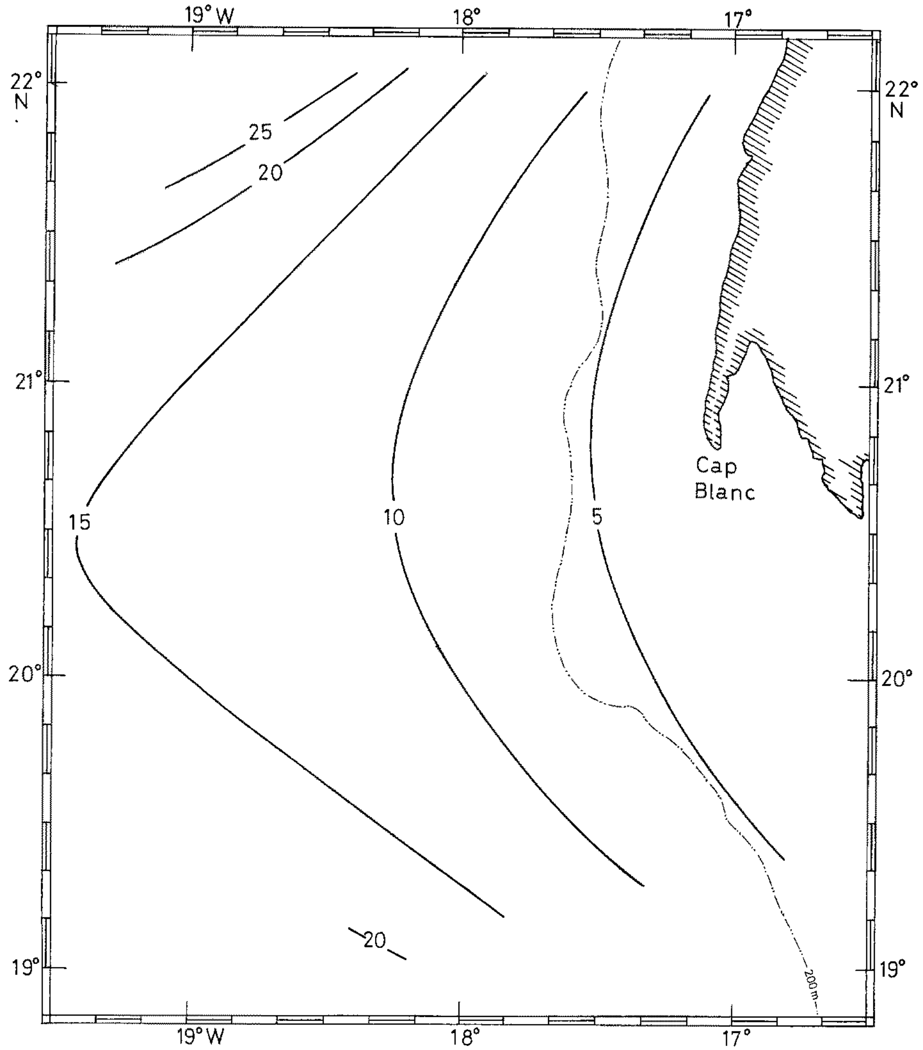

Fig. 5: Smoothed three-dimensional distribution of phytoplankton [μg C · l^{-1}] calculated by means of square roots. Depth [m] of the maximum. N = 258; R = 0.746; $\alpha \ll 0.001$

Organic substances

The (soluble plus particulate) organic substances determined by means of the permanganate method show a three dimensional distribution similar to that of the phytoplankton (Fig. 8) but the gradients are smaller and disturbances are more frequent. This is also demonstrated by such smoothed curves. The reason for this structure may be that here are products of an enrichment which reflects the regional phytoplankton production and, in addition, the history of the different water bodies. Nevertheless,

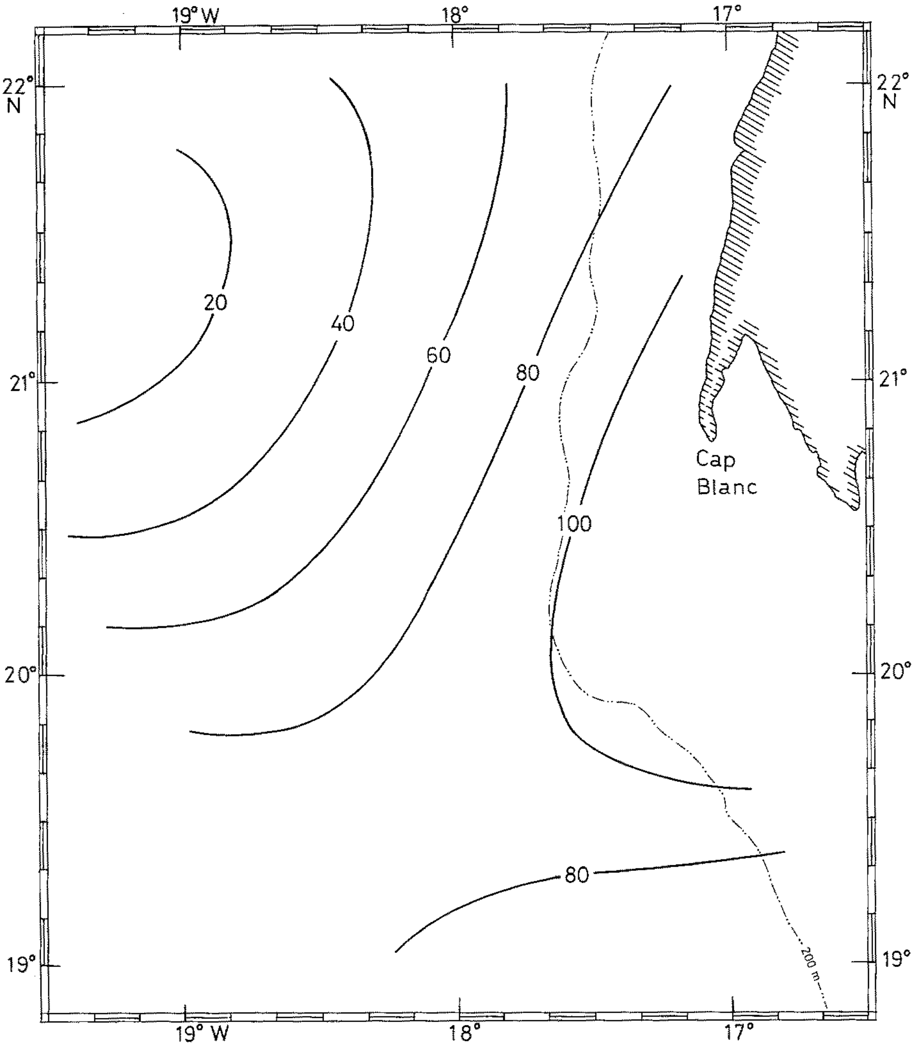

Fig. 6: Smoothed distribution of the diatom fraction of the phytoplankton in % calculated from C content in the surface layer (0 to 50 m depth). $N = 51$; $R = 0.733$; $\alpha < 0.001$

between the plankton and the mostly soluble organic substances a good connection exists.

Phytoplankton production

One of the important aims of such investigations is to formulate certain concepts with respect to the conditions of phytoplankton production. Therefore, an attempt is made to do so also in the absence of respective direct measurements. Such efforts are

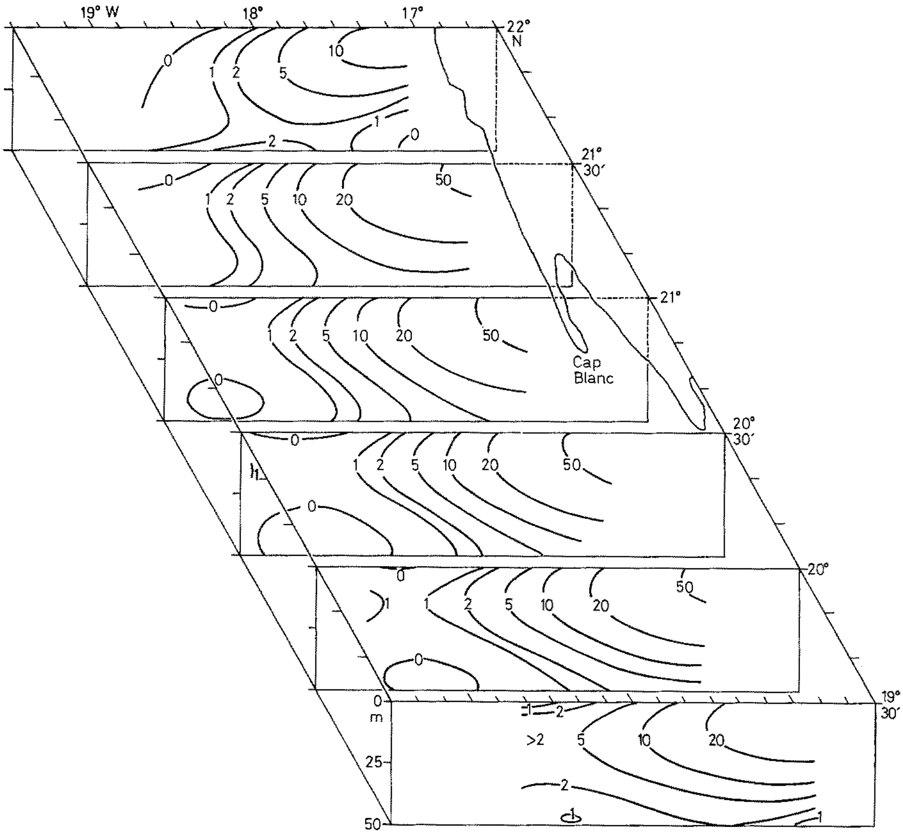

Fig. 7: Smoothed three-dimensional distribution of phytoplankton [$\mu g\ C \cdot l^{-1}$] calculated by means of square roots. Vertical sections from 0 to 50 m depth

of considerable practical importance, since the physiological data of the organisms necessary to gain conceptions for models (for instance Radach & Maier-Reimer, 1975) can be obtained only with difficulty and hardly in a sufficient number. The main problem in this respect is that living organisms have no constant metabolic rates etc. Therefore it would be necessary to make respective measurements on board parallel to other observations. It is difficult to do so practically. Therefore, it is desirable to draw conclusions from simple measurements (for instance quantity of plankton) for complicated production processes occurring in the sea.

Taking these aspects under consideration a determination of the range of the euphotic zone was made (Fig. 9). For this purpose light transmission data in water were used, measured with the thin light beam of a transmission meter. As Joseph (1950) has shown, the extinction coefficient of daylight becomes essentially smaller with an increasing portion of scattered light as compared to measurements using a beam of small diameter. This effect should be much more pronounced in turbid coastal water than in the clearer open sea. To compensate for this influence the following correction is used which should be satisfactory for the range in question:

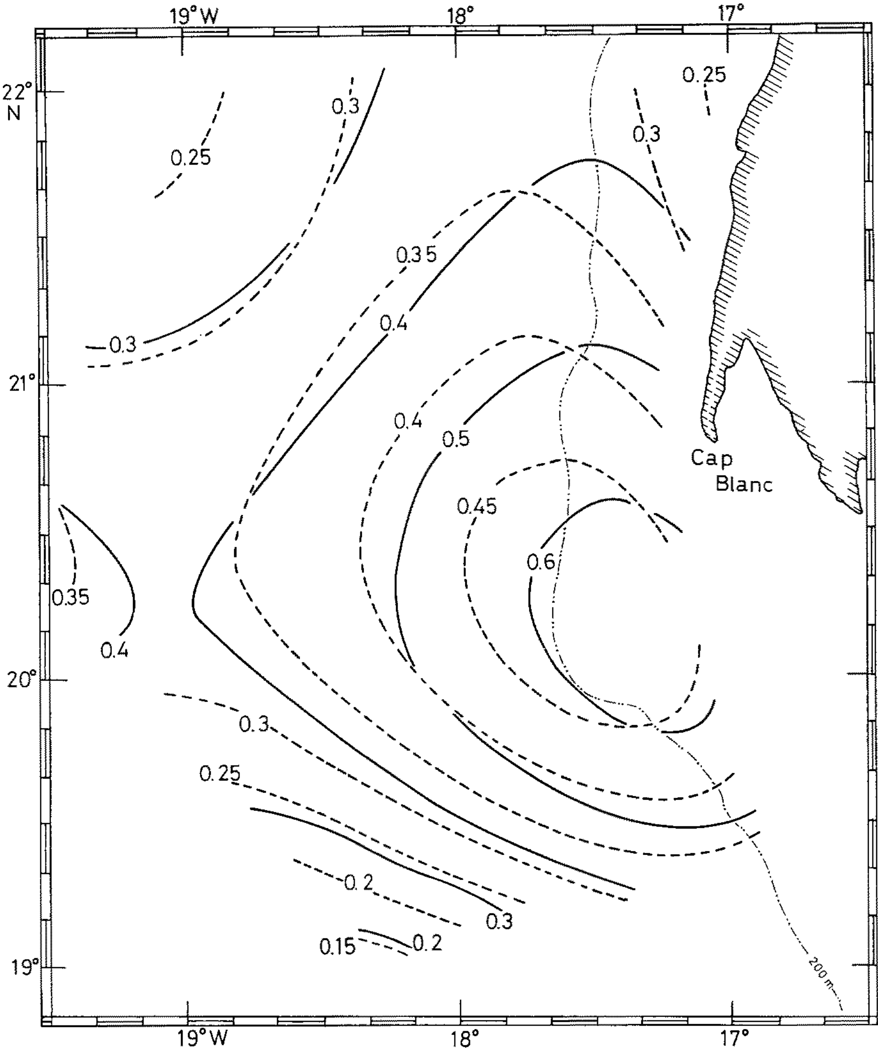

Fig. 8: Smoothed three-dimensional distribution of (dissolved + particulate) organic substances [mg C · l^{-1}] calculated by means of logarithms. Regional distribution in 10 (————) and 30 (– – – –) m depth. N = 250; R = 0.691; $\alpha \ll 0.001$

$$E_{eff} = \frac{E}{1 + 2 \cdot E}$$

E_{eff} = corrected extinction coefficient per metre (common logarithm), E = extinction coefficient measured against "pure" sea water. E may be affected by a small systematic error, which may first become evident in the case of a large euphotic zone. Calculating the depth of the 1 % intensity of surface light by assuming a linear change of turbidity between the measuring points and after smoothing, the results

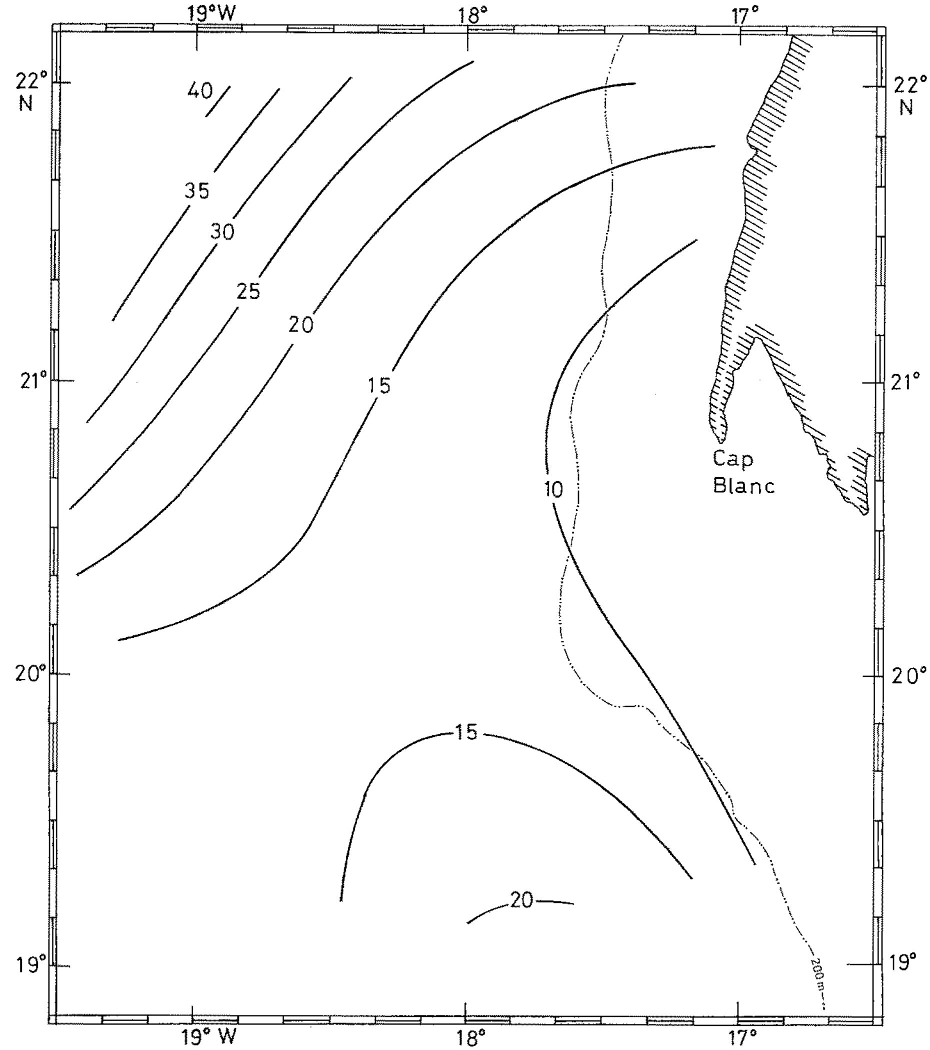

Fig. 9: Smoothed distribution of the depth of the euphotic zone [m]. N = 55; R = 0.887; $\alpha \ll 0.001$

given in Figure 9 are obtained; they demonstrate a pronounced turbidity (whirled up sediment) in the centre of the upwelling region.

There is no difficulty using these results to calculate the quantity of the phytoplankton in the euphotic zone (Fig. 10). In spite of these recalculations the distribution presented in Figure 2 is still applicable.

The decisive step, however, is to come from standing stock to production. For this purpose the assumption made by Ryther & Yentsch (1957) is used which gives 3 g C · d^{-1} · (g phytoplankton C)$^{-1}$ maximum gross production applying a 7 ‰

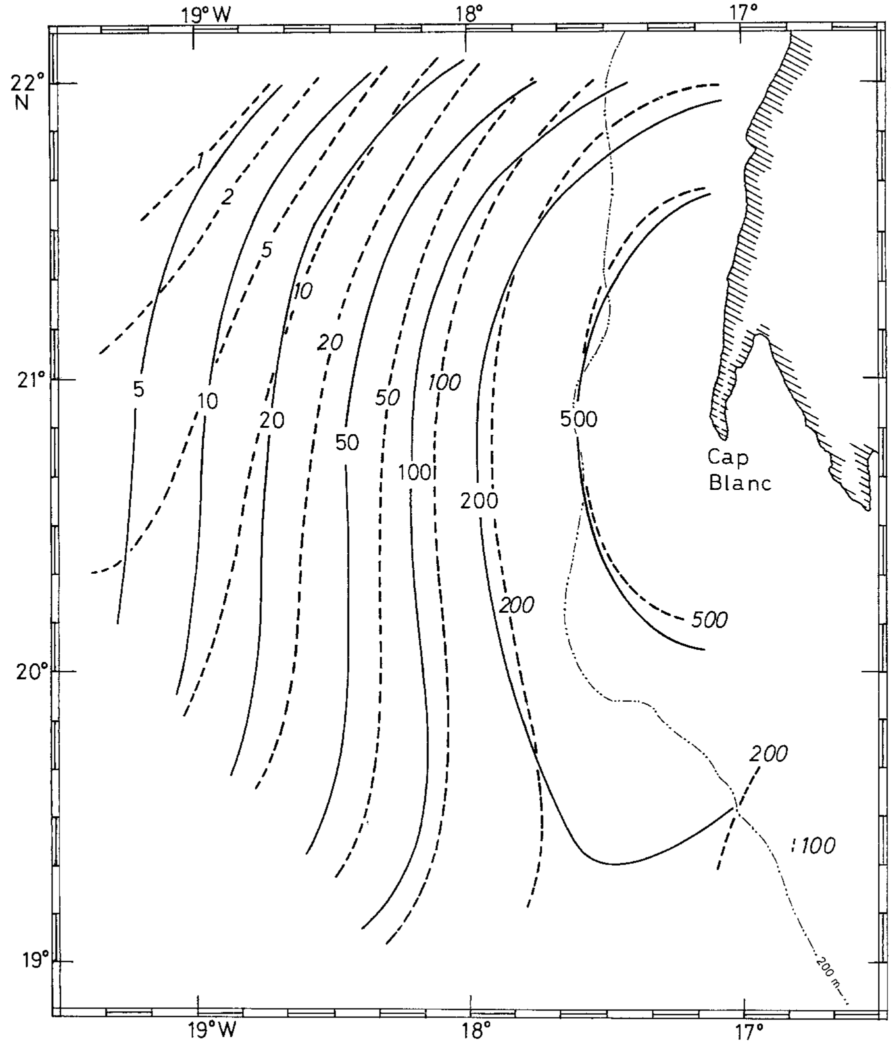

Fig. 10: Smoothed distribution of the phytoplankton stock in the euphotic zone (————; mg C · m^{-2}; N = 49; R = 0.869; $\alpha \leqslant 0.001$) and of the gross production (— — — —; relative values; N = 49; R = 0.903; $\alpha \leqslant 0.001$) calculated by means of logarithms

chlorophyll content (with respect to C) and 12 h day length. The following formulation is adopted from Radach & Maier-Reimer (1975) (I_{opt} = 80 % I_{surf}):

$$r_i = \left(\frac{I}{I_{opt}}\right)^{\left(1 - \frac{I}{I_{opt}}\right)}$$

I_{opt} = optimum light intensity, I_{surf} = light intensity on the surface, r_i = relative assimilation value for light intensity I.

Under these assumptions it is possible to determine the gross production for the different stations [mg C · m^{-2} · d^{-1}]. Figure 10 gives the smoothed distribution curves resulting from these values. Recent investigations (e.g. Barber & Ryther, 1969; Barber et al., 1971) indicate an assimilation rate twice as high with reference to chlorophyll. As a consequence the information presented in Figure 10 is a relative (minimum) value only.

Both sets of isolines in Figure 10 are nearly equal with maximum values in the range of 0.5 g C · m^{-2} with respect to standing stock and daily production, bearing in mind the relative value of the latter. The structure of the isolines fairly reflects the upwelling situation. With reservations, the coincidence assumed between standing stock and daily production could provide a reasonable basis for calculations (Krey, 1953). This simplification may be useful for many purposes, although it does not allow one to draw more precise conclusions.

These production values coincide with the statements by Schemainda et al. (1975) who observed a permanent upwelling and obtained a production value of 0.6 g C · m^{-2} · d^{-1} in the area off Cap Blanc. The results of Dandonneau (1973) for the Ivory Coast and the mouth of the Congo River are of similar magnitude. By means of water exchange and nitrate content, Shaffer (1976) calculated a minimum value of 0.4 g C · m^{-2} · d^{-1} for the Banc d'Arguin region.

Vertical distribution of chemical components

The theoretical vertical curves of oxygen and phosphate content are given in Figure 11 assuming a phytoplankton production in the surface layer, an intermediate decomposition zone and (necessary to keep an equilibrium) a horizontal water renewal in the depths effecting a considerable O_2 influx and a small P decrease. This model provides a distribution pattern which has actually been observed (Weichart, 1974); it is calculated by use of a constant vertical turbulence coefficient. The smoothing curves between the straight lines are correct if sources and sinks have the given vertical extensions. It is assumed that this concept, although neglecting the water movements to be observed (Mittelstaedt, 1972; Tomczak, 1973; Shaffer, 1976), permits certain quantitative statements to be made. In the case of a decomposition zone with a sufficient vertical extension the depth difference observed between O_2 minimum and P maximum is demonstrated in Figure 11.

The concentration of certain chemical components of biological interest should alter linearly with depth in suitably selected vertical ranges; this has also been demonstrated. But it is to conclude that the vertical transport of dissolved substances by turbulence is proportional to these gradients without knowing absolute values. Therefore, one can calculate the transport relation, respectively the turnover relation, between two substances in a certain vertical zone in this way. It is possible to determine e. g. O_2 and P gradients from the decomposing layer up to a depth of 100 m (the zone near the surface is not used for this with respect to possible disturbances) and down to the bottom. The sum of these two gradients gives a relative value of the total transport and the quotient of these two sums indicates the atomic relation of

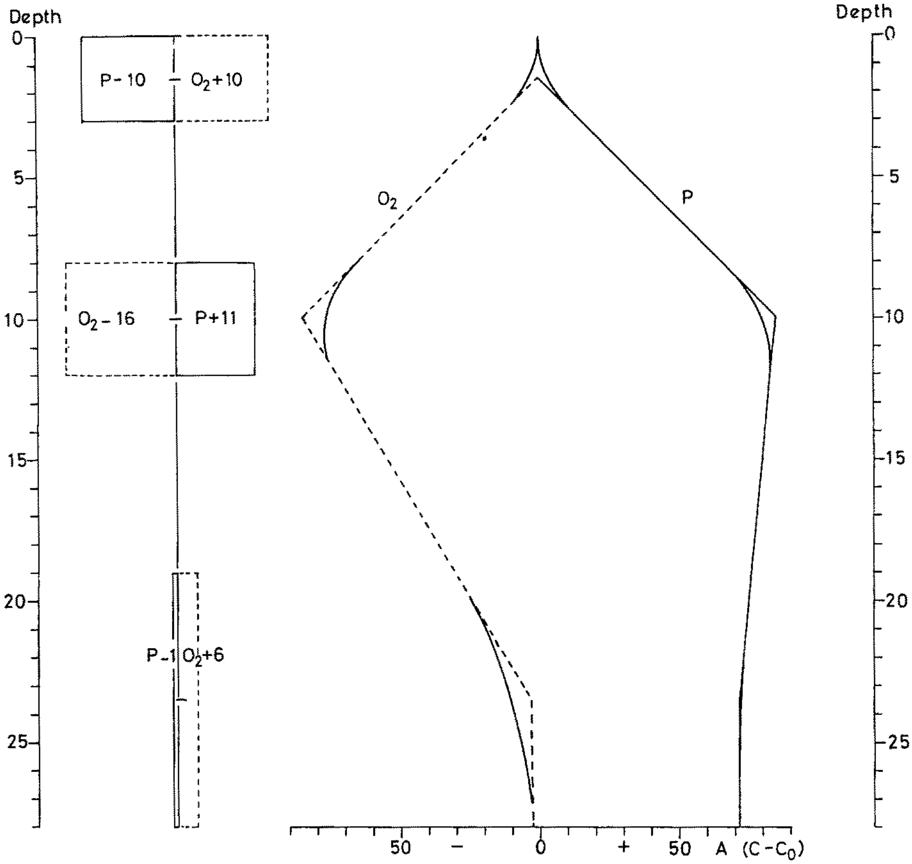

Fig. 11: Schematic vertical distributions of O_2 (– – – – – –) and of PO_4 (————). The straight lines indicate pointlike production or consumption, the adjusting curves are correct in the case of production and consumption of the given vertical extension

O_2 and P turnover. In this way significant results can be obtained from eight stations indicating 162 as a mean relation. This value is very low as compared to the normal situation for organic substances (minimum 212) (Sverdrup et al., 1963). The same calculation made for three stations with respect to the relation between O_2 and N (nitrate plus nitrite) results in a value (9.6) distinctly below the theoretical value (minimum 13). The mean quotient $\Delta N : \Delta P$ for three stations (15) may not be distinguished from the normal composition of organic substances (16). This fact leads to the impression that formation of nitrate and release of phosphate proceed with the same velocity whilst oxidation of organic substances is much slower.

With reference to these processes, observations of the $\Delta O_2 : \Delta P$ values from 100 m to the depth of the O_2 minimum are not completely satisfactory. This relation is smaller than in the case of correct calculation. The reason for this can be seen in Figure 11. Large changes in O_2 content and small decreases in phosphate values be-

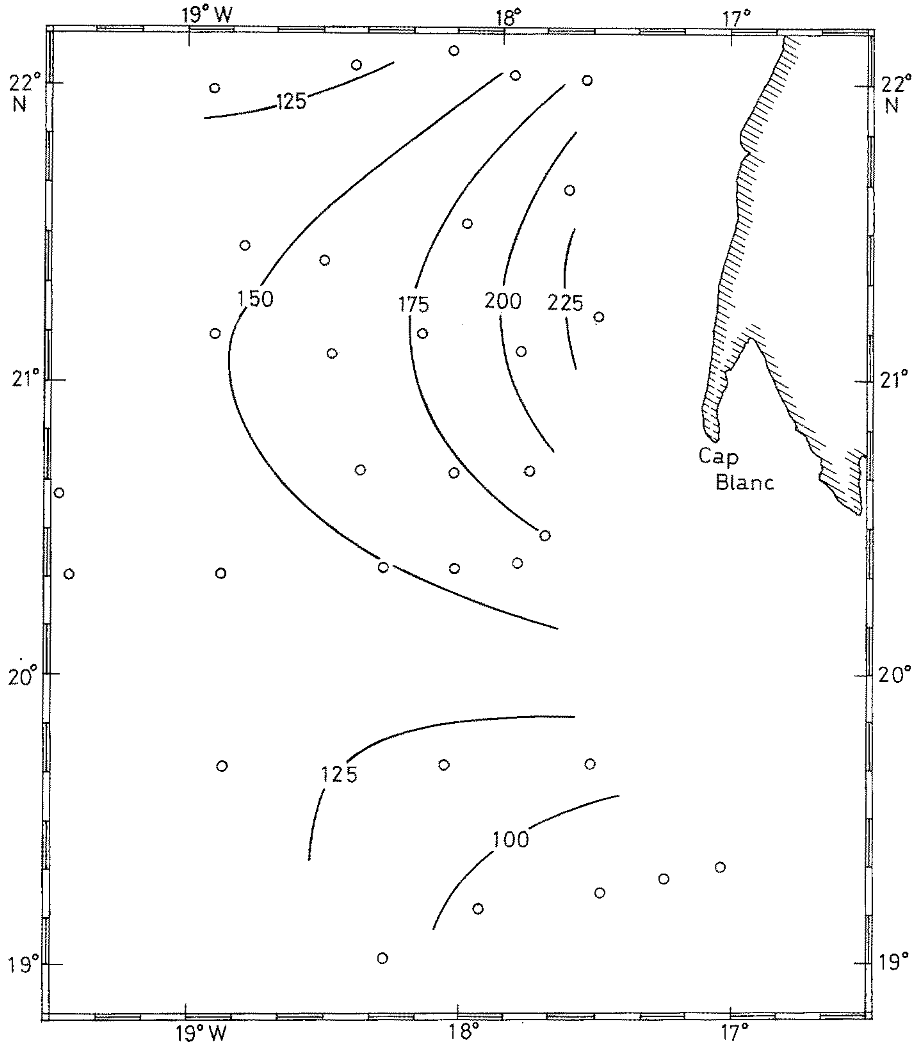

Fig. 12: Smoothed distribution of the linear (atomic) relation between O_2 and PO_4-P between 100 m depth and the O_2 minimum calculated by means of logarithms. o = point of observation; N = 32; R = 0.845; $\alpha \leqslant 0.001$

tween the decomposition layer and bottom may be expected. But a considerably higher number of data can be determined with this simplified method to detect regional differences. Practically, the linear relation between the concentrations of O_2 and PO_4 is calculated directly in this case using a suitable procedure (Gillbricht, 1974). The result of this investigation is illustrated by Figure 12. Accepting an initial PO_4-P production, and afterwards the oxidation of organic substances, the quotient increases consequently with the age of these substances. Therefore, the simplest explanation for these observations (Fig. 12) should be given by different vertical movements of the water effecting a different vertical transportation velocity of the substances in question. Once more the upwelling process is demonstrated (by excluding the coastal areas which are too shallow for these calculations). These results are not influenced by a distinct distribution pattern of the depth position of the O_2 minimum as shown by the data in question.

TEMPORAL CHANGES

Mittelstaedt (1972) and Weichart (1974) have described temporal changes of the structures of the water columns at two anchor stations caused by internal waves and currents (tides). As the same figures are given by plankton observations, this phenomenon needs not be repeated here. It seems to be more interesting, however, to investigate whether or not an increase or a decrease of the plankton stock or the carbon content during the observation time in a given water body and not on a fixed geographical position can be demonstrated. The water body is identified in this case by salinity. Although this method may be unsatisfactory for extensive investigations in the upwelling area (p. 418), it should be sufficient for studying small areas only. Initially the surface layer (down to 50 m) is investigated regarding the linear connection for the different depth levels between logarithms of phytoplankton stock and logarithms of carbon content and time after eliminating the influence of salinity. The use of logarithms is the optimum procedure in this case. All plankton and carbon values are relatively high (p. 422). The results obtained are given in Tables 1 and 2. At Station 37 no temporal alterations were observed. The situation is different with respect to Station 77 (Table 2). The Information obtained indicates a decrease of phytoplankton stock and carbon content. This observation supports the assumption of Mittelstaedt (1972) that both stations revealed no upwelling during this time.

Table 1

Details of the two anchor stations examined (Station 37 and Station 77)

Experimental conditions	Station 37	Station 77
Latitude	20° 30/25′ N	21° 12′ N
Longitude	17° 42/43′ W	17° 30′ W
Bottom depth	223/299 m	205 m
First plankton set:		
Date	May 10th 1968	June 5th 1968
Time [GMT]	4^30	12^15
Last plankton set:		
Date	May 12th 1968	June 7th 1968
Time	5^50	20^15
Number of sets	11	15
Mean interval between sets	4.9 h	4 h

Such statements are only partially appropriate to describe natural processes. This

Table 2

Partial correlations during Station 77 for different depths between phytoplankton stock (ph) respectively quantity of oxidizable organic substances (C) and time (t) after elimination of salinity (S) as an indicator for water bodies and mixing processes. $r_{ph, t. S}$ = partial correlation coefficient between ph and t after elimination of S, $r_{C, t. S}$ = partial correlation coefficient between C and t after elimination of S, n.s. = not significant

Depth (m)	N	$r_{ph, t. S}$	$r_{C, t. S}$
3	15	n. s.	n. s.
10	15	n. s.	—0.594
19	15	n. s.	n. s.
29	14	—0.680	—0.691
48	15	—0.741	—0.630

is also true for the more complex formulation of the equation given above (p. 419) smoothing lg phytoplankton or lg C three dimensional as functions of time, salinity and water depth. The results of this procedure are most significant in the case of Station 77 compared to Station 37 which shows a steady change of the total water body (salinity) as a function of time. An attempt made to describe the temporal

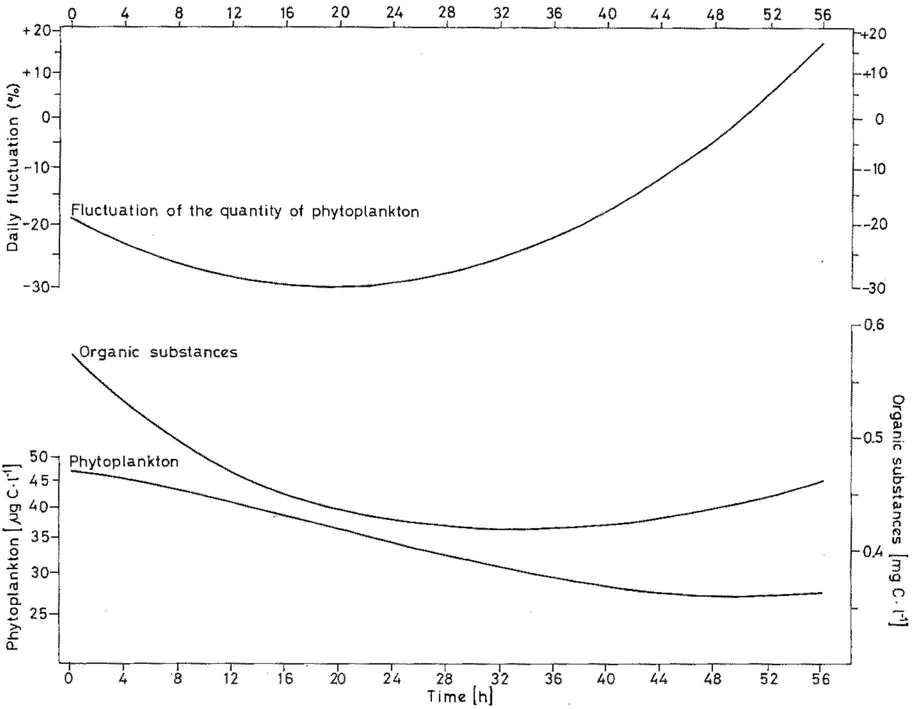

Fig. 13: Smoothed distribution of phytoplankton (μg C · l^{-1}) and of (dissolved + particulate) organic substances (mg C · l^{-1}) calculated by means of logarithms as a function of time, salinity and depth of the samples of Station 77. Change with time in 20 m depth evaluated for mean salinity of 36.046 ‰; beginning: June 5th, 1968 at 12^{15} p.m. N = 74; phytoplankton: R = 0.906; $\alpha \ll 0.001$; organic substances: R = 0.930; $\alpha \ll 0.001$

development of a given water body (at constant salinity) results in the latter case in widely extrapolated values. Use of extrapolations of this kind is inadvisable in the case of smoothing procedures and is more or less correct only in the range of observations. The calculated phytoplankton development during Station 77 is given in Figure 13 under the assumption of a constant mean salinity and mean water depth (20 m). As expected, the phytoplankton stock and the quantity of the organic substances decrease with a certain stabilization at the end of the observation time. The calculated daily changes in plankton values (given as ‰ of stock) are between − 30 and +15 ‰ and therefore within the range of previous observations (Gillbricht, 1955, 1964). It follows from these results that Station 77 situated near the centre of the upwelling area indicates a locally unfavourable situation.

The smoothing method used in Figure 13 is not suitable for reproducing short-term periodical variations; it cannot be expected that this is possible in any way without additional difficulties. Nevertheless, obtaining information regarding daily

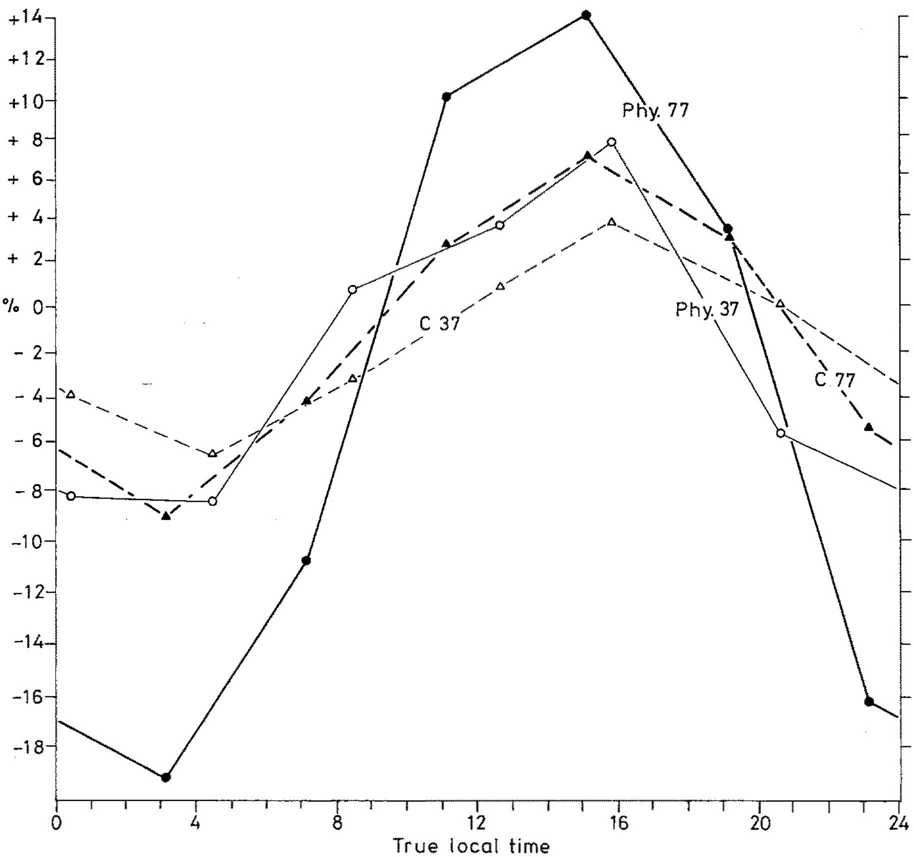

Fig. 14: Smoothed curves of the daily rhythms of phytoplankton (Phy. ————) and organic substances (C — — — —) for the Stations 77 and 37. The ordinate gives the deviation in ‰ with respect to a calculated compensating curve. (For more detailed explanation see text)

courses shall be attempted. The following method was used: The (logarithmic) differences were determined for the observation points in the surface layer (0 to 20 m depth) between the values measured and the calculations by means of the three dimensional smoothing function to derive relative deviations which scatter in a wide range. All results from observations made at the same time of day were combined and the three times overlapping mean values were calculated to lessen these disturbances (Fig. 14). The deviations in the observations as percentages of the calculated values for both stations show pronounced daily courses with respect to phytoplankton and organic substances, indicating maxima during the afternoon and minima during the early morning hours. The sampling interval, which is too long for such considerations, allows only an approximate determination of the times of extreme values. Accordingly, information on the amplitudes cannot give more than approximations. It must be expected that smoothing will produce flattening of the curves. The data are not symmetrical to the zero point induced by this method of estimating.

Quantitative investigations of this daily periodicity are restricted. More information can be obtained by taking other results into consideration. We must bear in mind that Station 77 is more suitable than Station 37 for such a treatment. The amplitude of C (organic substances) related to phytoplankton stock (mean values)

Table 3

Comparison of examined stations

Criteria	Station 77	Station 37
Daily amplitude of phytoplankton	33 %	16 % of the mean value
Daily amplitude of C	16 %	10 % of the mean value
Daily production minimum	163 %	102 % of the mean value of standing stock

is given in the last line of Table 3 as a measure for the daily (minimum) production. These results (163 or 102 %) are identical with former considerations (p. 430) in a reasonable range with respect to the accuracy to be expected; the other daily amplitudes also appear to be reliable. It may be supposed therefore that the daily courses demonstrated have a certain reality.

CONCLUSION

The manifold investigations discussed here indicate that the vertical upward movement of the water directly influences the planktological situation in a positive sense. This was determined by eliminating the initially large accidental scattering of single observations in order to obtain a clearer insight into what happens on the average.

Permanent discussions are necessary on how to handle such a large set of data. The question arises as to what degree is it better to use the presumably justified formalistic method in comparision to models developed for theoretical considerations.

The complexity of the processes in biological oceanography and the considerable scattering of the values measured lead to the consequence that the observations made must be described by means of relatively simple formulations which do not sufficiently reflect the complicated biological processes occurring in the sea. Calculations necessary for an evaluation of the results obtained from such complex studies have to be optimized for their respective purposes and, consequently, they must be developed anew for each sequence of other measurements.

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