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Dimension variations
Dinoflagellates
Salinity and temperature
Multiple regression

Interdependence between dimensions of two *Dinoflagellata* species (*Dinophysis norvegica* Claparede et Lachmann, *Ceratium tripos* O. F. Müller/Nitzsch) and selected parameters of the environment

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Abstract

Differences in size (length, breadth) of cells of *Dinophysis norvegica* and *Ceratium tripos*, occurring with respect to salinity and temperature water regions of the Baltic and Atlantic, have been observed. The differences are accounted for by the species autecology, indicating an oceanic character of *Dinophysis norvegica* and an intermediate character (maximum size at 30‰ salinity) of *Ceratium tripos*. A mathematical method of multiple regression for an ecological interpretation of the studied phenomenon has been used.

1. Introduction

An intraspecies morphological variability of algae is a commonly known phenomenon. In case of species of the genus *Ceratium* the phenomenon is associated with changes in water temperature in an annual cycle. This interdependence has been observed in the past (Wesenberg-Lund, 1900). An intraspecies variability of *Ceratium* has been noticed for both fresh-water (Huber, Nipkow, 1922; Huber-Pestalozzi, 1968) and marine individuals (Ostenfeld, 1903; Paulsen, 1908; Apstein, 1911). Temperature as a factor influencing the length, breadth and distance between horns has been reported for *Ceratium tripos, C. fusus*, and *C. furca* from the Kattegat (Nielsen, 1956).

Steemann Nielsen (1934) believes that in addition to temperature the effect of neritic or oceanic water is also significant for seasonal morphological variations. Cyclomorphical variations of *Ceratium* are associated with settlement of organisms in water, which is related to thermal properties and, in result, viscosity of water (Fritz, 1935). On the other hand, it is known that the degree of salinity has an effect on the size of organisms (Remane, 1971). For macroalgae this phenomenon was reported by Levring (1940) and in the case of diatoms the problem was briefly discussed by Hustedt (1925) and Kolbe (1927, 1932). In relation to *Dinoflagellates* the problem was fragmentarily studied in terms of cyclomorphic variations of *Ceratium tripos v. subsalsum* (Arndt, 1967).

The literature data indicate that the problem of intraspecies morphological variability in algae is almost unexplored despite its significance in ecological and taxonomic studies.

2. Material and methods

Material for investigations was taken from plankton samples collected by means of a speed plankton sampler (MFG and Instrument Corp., USA) with gauze N 25 during an expedition to Spitsbergen in June 1972. The material was preserved on board, with a 4% formalin solution, directly after sampling. In order to obtain a clear difference in the values of temperature and salinity, the analyzed material derived

Table 1. The values of salinity and temperature at particular stations

Station No.	Salinity [%]	Temperature [°C]
1	10	16
2	30	13
3	35	13
4	35	13
5	35	10
6	35	3

from 6 stations only, distributed from the western Baltic (Stn 1), through the Skagerrak (Stn 2), North Sea (Stn 3), Norwegian Sea (Stn 4 and 5) to the Greenland Sea in the region of Bear Island (Stn 6) (Fig. 1). Over 100 individuals from each species at each station were always taken for biometric measurements. Cell length and breadth were measured for both species. In the case of *Ceratium tripos* the measured length included an apical horn. No data are available for *Certium tripos* from the station No 6 due to difficulties in collection of a statistically representative sample. Water temperature data were acquired from the measurements carried out during the voyage and pertain to a surface layer, while the salinity values were taken from the literature (Raymont 1963) (Table 1).

3. Results and discussion

Analysis of the obtained results clearly reveals the differences in length and breadth between the two species at the respective stations (Fig. 2). The length and breadth of *Dinophysis norvegica* cells exhibit an upward trend towards the oceanic

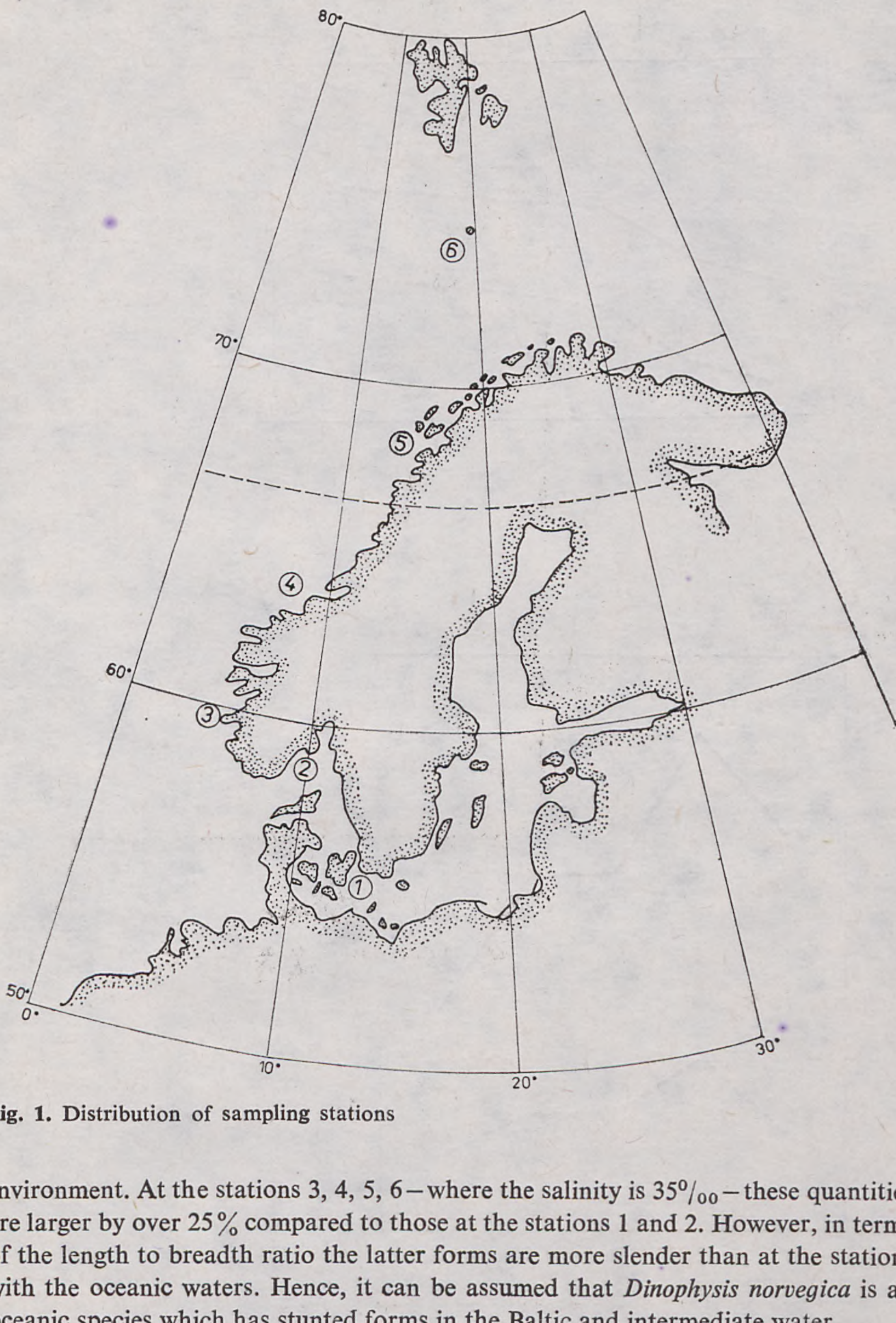

Fig. 1. Distribution of sampling stations

environment. At the stations 3, 4, 5, 6 – where the salinity is 35$^0/_{00}$ – these quantities are larger by over 25% compared to those at the stations 1 and 2. However, in terms of the length to breadth ratio the latter forms are more slender than at the stations with the oceanic waters. Hence, it can be assumed that *Dinophysis norvegica* is an oceanic species which has stunted forms in the Baltic and intermediate water.

The analyzed relationships are different for *Ceratium tripos*, which attains the largest size in the Skagerrak, thus, revealing its intermediate character in terms of salinity requirements. A steady decrease of the values of characteristics from the

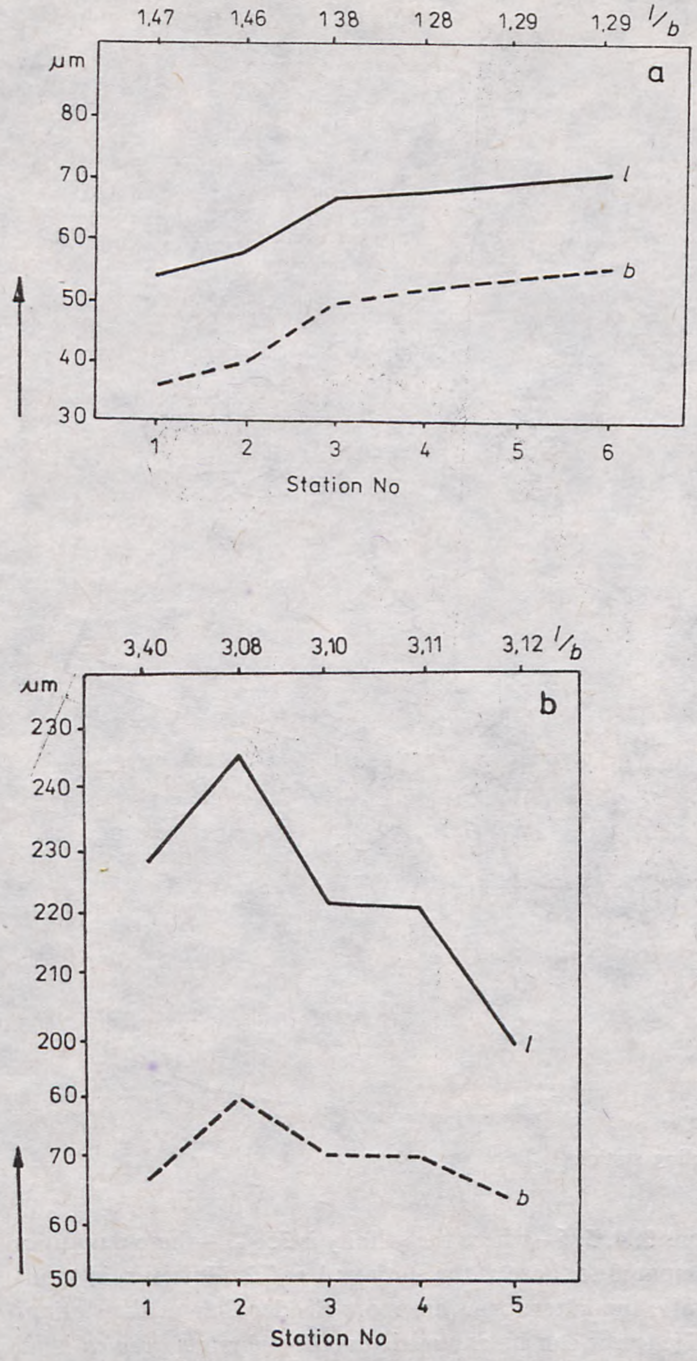

Fig. 2. Average values of length (*l*), breadth (*b*) and the ratio of average length to average breadth (*l/b*) at particular stations for *Dinophysis norvegica* (a) and *Ceratium tripos* (b)

station 2 to 5 indicates a simultaneous effect of temperature and salinity on water viscosity, which can be associated with the cause for cyclomorphic changes. Deviating from this trend, dimensions of the Baltic formae can be attributed to the stunting phenomenon which is exemplified by ***Dinophysis norvegica.*** This is confirmed by the length to breadth ratio, which is also smaller for the Baltic formae.

Owing to the fact that the above phenomenon exhibits a definite trend, rather different for both cases, an attempt was undertaken to describe it by means of a mathematical equation. A multiple regression, one of the modelling methods employed in the environmental ecology (Pliński, 1983), was used in this case. The values

Table 2. Correlation coefficients and regression equations for length, breadth, and the length to breadth ratio for *Dinophysis norvegica* and *Ceratium tripos*

Species	Characteristics	R_{yz}	R_{yx}	$R_{y,xz}$	Multiple regression equations	$R_{(y/\hat{y})}$
Dinophysis	Length (l)	0.85	−0.56	0.88	y=53.37+0.52x−0.44z	0.87
norvegica	Breadth (b)	0.86	−0.70	0.90	y=36.74+0.52x−0.52z	0.89
	l/b	0.18	0.63	0.90	y=0.92+0.01x+0.02z	0.76
Ceratium	Length (l)	−0.35	0.63	0.69	y=92.00+0.77x+8.35z	0.69
tripos	Breadth (b)	0.12	0.21	0.55	y=16.32+0.55x+2.94z	0.53
	l/b	−0.27	0.76	0.97	y=1.46+0.01x+0.10z	0.69

x – temperature; y – characteristic (length, breadth, length to breadth ratio); $\bar{y}$ – average value of experimental y; $\hat{y}$ – value of theoretical y, calculated from the model; z – salinity;
$R_{y,xz}$ – coefficient of multiple correlation between a characteristic (y) and temperature (x), salinity (z):

$$R_{y,xz}=\sqrt{\frac{\sum \hat{Y}^2}{\sum Y^2}},$$

where $\Sigma\hat{Y}^2$ is variability of $\hat{Y}$ variable and ΣY^2 is variability of Y variable;
R_{yz} – coefficient of single correlation between a characteristic (y) and temperature (x):

$$R_{yx}=\frac{\sum YZ}{\sqrt{\sum Z^2 \sum Y^2}},$$

where $Y=y_i-\bar{y}$, $Z=z_i-\bar{z}$ ($\bar{z}$ – average value of salinity);
R_{yz} – coefficient of single correlation between a characteristic (y) and salinity (z):

$$R_{yz}=\frac{\sum YX}{\sqrt{\sum X^2 \sum Y^2}}$$

where $X=x_i-\bar{x}$ ($\bar{x}$ – average value of temperature);
$R_{(y/\hat{y})}$ – correlation coefficient of agreement between the experimental (y) and theoretical ($\hat{y}$) values of a dependent variable:

$$R_{(y/\hat{y})}=\sqrt{1-\varphi^2},$$

where $\varphi^2=\frac{y_n-\hat{y}_n}{(y_n-\bar{y})^2}$

of temperature and salinity were selected as independent variables, while the length and breadth of a cell (including an apical horn in *Ceratium tripos*) and the length to breadth ratio constituted dependent variables. The regression equations for the values of dependent variables and the respective correlation coefficients are listed in Table 2. Calculation of the multiple regression coefficient was based on a method described by Krzysztofiak and Urbanek (1978).

An inspection of the correlation coefficients clearly reveals the difference in significance of a multiple correlation, taking into account a simultaneous effect of parameters (dimension – salinity – temperature), compared to single correlations (dimension – salinity and dimension – temperature).

The multiple correlation is good in all the cases, although the degree of significance varies. This allows to accept the calculated regression equations Interpretation of the equations indicates that in the case of *Dinophysis norvegica* the length and breadth are stimulated by salinity, whereas the temperature is a limiting factor. On the other hand, in the case of *Ceratium tripos* both parameters mentioned above act as stimulating factors, the significance of temperature being larger, which is revealed by a larger value of the vector coefficient in the regression equation.

The effect of temperature and salinity on the length to breadth ratio (slenderness) of cells of both species should be considered separately. For both *Dinophysis norvegica* and *Ceratium tripos* simultaneous changes of both parameters have a stimulating effect on the cell shape slenderness, the strength of the parameters interaction being similar. This is reflected by similar values of all coefficients of both regression equations. However, the effect of temperature on the length to breadth ratio is considerably larger (by an order of magnitude) than that of salinity.

Single correlations require a separate interpretation. For *Dinophysis norvegica* independent effects of salinity and temperature on the linear dimensions of a cellare identical as their simultaneous influence. On the other hand, the value of a single regression coefficient: the length to breadth ratio – salinity reveals the lack of independent effect of salinity on the cell slenderness In the case of *Ceratium tripos* the differences between simultaneous and independent influence of both environmental factors increase. The significance is exhibited only by coefficients of two single regressions: length – temperature and length to breadth ratio – temperature. All the remaining values of single regression coefficient demonstrate the lack of interdependence in case of independent interaction of one of the parameters.

Validity of the obtained regression is confirmed by the coefficient of agreement between experimental (y) and theoretical ($\hat{y}$) dependent variable This correlation coefficient is high in almost all cases except for the breadth of *Ceratium tripos*.

Thus far, the employed mathematical method has not found a broad application in the environmental ecology (Daget, 1976; Krishna Iyer and Lalithambika Devi, 1977; Shastri and George, 1977). The method is of larger significance only in fishery for predicting fishing yield (Manikowski, 1973). Our results and particularly their ecological interpretation indicate the possibility of utilization of the method to a greater extent for the description of biological phenomena, chiefly for the determination of their trends.

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