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A synoptic survey on bacterial numbers, biomass and activity along the middle line of the Baltic Sea

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Abstract

Between 28 August and 5 September 1982 thirty water samples (5 m depth) were taken on a transect between the Bothnian Bay and the Kiel Bight. Despite substantially differing hydrographical situations within the different subregions of the Baltic Sea, the total bacterial numbers showed a remarkable regional uniformity. Bacterial numbers fluctuated between 3 and 4 x 10^6 cells ml^{-1}. A distinct pattern was observed: mean bacterial cell volumes were high in the Bothnian Bay (0.145 μm^3) and low in the Gotland- and Bornholm Sea (0.094 and 0.091 μm^3, respectively). The bacterial biomass fell in the range of 184 - 117 μg C l^{-1}. The activity parameters were somewhat more variable than bacterial numbers and biomass.

Introduction

The Baltic Sea, the world's largest brackish water system, is characterized by strong vertical and horizontal gradients of several important chemical and biological properties. In the western transition area (Belt Sea) the salinity in the mixed surface layer is relatively high (around 15 - 20 ‰). From here towards the east it decreases first rapidly, then from the Arkona Sea onwards the decrease is gradual until almost limnetic conditions are reached in the Bothnian Bay (VOIPIO 1981).

In an area, where environmental conditions differ on such a scale, effects of physico-chemical variables and concomitant biological factors on the regional distribution of bacterial numbers and activity should be specially interesting to study. Surprisingly, such investigations are quite scarce at least those, which cover a larger part of the Baltic Sea. To our knowledge, the present study which describes a synoptic survey during the late summer season on bacterial numbers and activity along the middle line of nearly the entire Baltic Sea, represents the first of its kind.

Material and methods

Between 28 August and 5 September 1982 seawater samples were collected from RV "Poseidon" in a horizontal transect from the Bothnian Bay to the Kiel Bight.

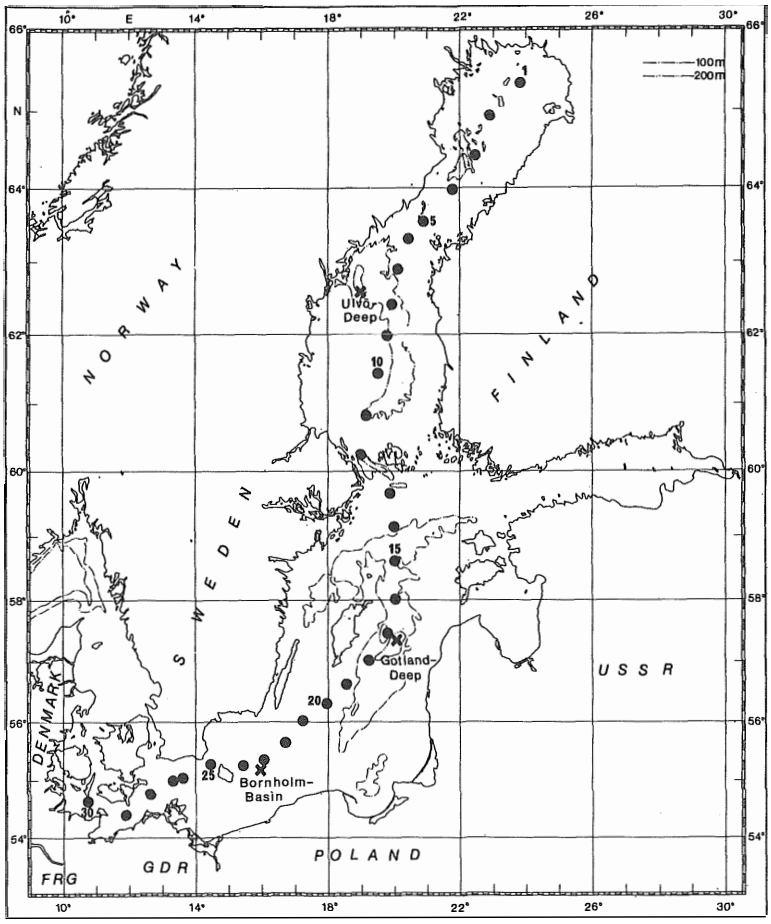

Fig. 1. Location of sampling sites in the Baltic Sea.

Samples were taken from 5 m depth with a sterilized bacteriological sampler. Fig. 1 shows the locations of the 30 stations. Salinity was measured aboard ship using standard procedures (GRASSHOFF et al. 1983). Chlorophyll **a** concentrations were determined with the "trichromatic" method according to SCOR-UNESCO (1966). The total bacterial number (TBN) and the mean cell volume (MCV) of bacteria were measured with a fluorescence microscope using acridine orange as dye (ZIMMERMANN 1977). For converting bacterial cell volume into biomass units a conversion factor of 0.35×10^{-6} µg C μm^{-3} was applied (BJÖRNSEN, 1986). The number of saprophytic bacteria (colony forming units = CFU) was determined on yeast extract-peptone-agar medium with a salinity of 8 ‰ (RHEINHEIMER 1971). The maximum uptake velocity (V_m) and the turnover rate (T_r) of glucose were measured by adding ^{14}C-labelled glucose at a final concentration of 20 µg C l^{-1} (V_m) and 0.25 µg C (T_r) to the samples (RHEINHEIMER et al. 1989). Since only the net uptake was measured the gross uptake was calculated assuming a mean percent respiration of 25 % (GOCKE unpubl.).

Results and discussion

The results of the horizontal transect between the northernmost parts of the Baltic Sea and its western transition zone are shown in Fig. 2. The highly different salinity distribution of the Baltic Sea with lowest values in the north (around 3 ‰), an almost continuous increase towards the Arkona Sea (values around 10 ‰) and then a sudden rise to about 16 ‰ in the Kiel Bight is clearly recognizable.

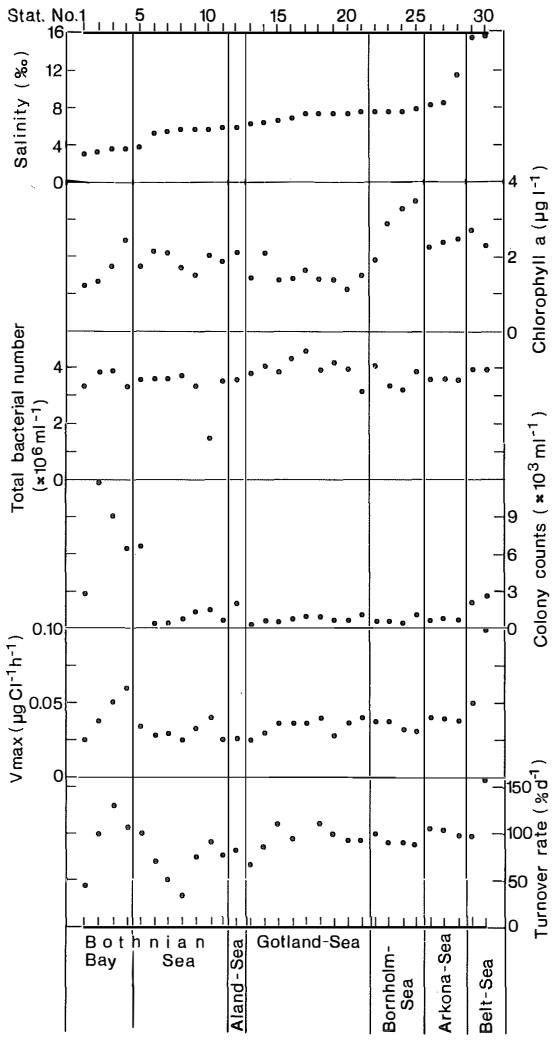

Fig. 2. Salinity, chlorophyll a and microbiological variables on a transect between the Bothnian Bay and the Belt Sea (31 Aug - 5 Sept 1982). See also Fig. 1.

Table 1. Values of several microbiological parameters averaged for the mixed surface layer of distinct subregions of the Baltic Sea. Chlorophyll **a** (Chl **a**: µg l^{-1}), total bacterial number (TBN: 10^6 cells ml^{-1}), mean volume of bacteria cells (MCV: μm^3), bacterial biomass (BBM: µg C l^{-1}), saprophytic bacteria grown on brackish water medium (CFU: 10^3 ml^{-1} and also given as fraction of TBN), maximum uptake velocity of glucose (V_m: µg C $l^{-1}h^{-1}$) and turnover rate of glucose (T_r: % d^{-1}).

Region see also Fig. 1	Salinity ‰	Chl a	TBN	MCV	BBM
Bothnian Bay	3.19 - 3.72	1.69	3.63	0.145	184
Bothnian Sea	3.79 - 6.00	1.87	(3.59)[1]	0.114	131
Aland Sea	5.94	2.12	3.67	0.110	141
Eastern Gotland Sea	6.26 - 7.70	1.49	4.01	0.094	132
Bornholm Sea	7.74 - 8.00	2.90	3.66	0.091	117
Arkona Sea	8.47 - 11.51	2.40	3.62	0.114	144
Belt Sea	15.96 - 16.05	2.50	3.99	0.124	173

	CFU		V_m	T_r
	x 10^3 ml^{-1}	‰ of TBN		
Bothnian Bay	7.79	2.14	0.044	95
Bothnian Sea	1.69	0.47	0.031	71
Aland Sea	2.01	0.55	0.027	82
Eastern Gotland Sea	0.69	0.17	0.034	90
Bornholm Sea	0.67	0.18	0.035	93
Arkona Sea	0.69	0.19	0.039	103
Belt Sea	2.47	0.62	0.076	135

[1] The apparently erroneous value of Stn. 10 was omitted for the calculation.

Chlorophyll **a** concentrations had a somewhat uneven distribution. The differences, however, were not very pronounced. A slight increase towards the west seemed to be present (see also Table 1, which shows the mean values in the different subregions according to WATTENBERG (1949). Highest values surpassed the lowest ones only by a factor of about 3 (3.5 µg l^{-1} versus 1.1 µg l^{-1}).

The range of variation of total bacterial numbers was still smaller. When the low TBN of Stn 10 is omitted (which probably is an erroneous value, since it is not paralleled by any one of the other parameters), a nearly perfect uniformity was observed over more than 900 nautical miles. The mean value of about 3.8 x 10^6 cells ml^{-1} probably is typical for the late summer situation in the Baltic Sea (GAST and GOCKE 1988, GOCKE and RHEINHEIMER, unpubl.). In comparison, the season before and at the onset of the vernal phytoplankton bloom is characterized by total bacterial numbers around 0.4 x 10^6cells ml^{-1} (GOCKE and HOPPE 1982).

Mean cell volumes (MCV) of the bacterial population are presented in Table 1. Largest mean values of up to 0.145 μm^3 were found in the northermost parts of the Baltic Sea. From this value volumes then decreased significantly to around 0.090 μm^3 towards the Central and Western Baltic Proper. GAST and GOCKE (1988) found increasing mean bacterial cell volumes between the mixed surface layer and the deep bottom waters of the Central Gotland Sea. The authors attributed this increase in cell size to the combined effect of very low temperatures and a shift from oxic to anoxic conditions, which may have caused an enlargement of the bacteria by influencing their growth patterns. The main reason, however, was seen in a change of the population structure due to changing environmental conditions. With respect to the observed large cell volumes in the surface waters of the Bothnian Bay anoxic conditions, of course, cannot be a reason. The effect of temperature probably is limited since the temperature fluctuated only between 12.0 °C and 15.9 °C over the entire transect. The Bothnian Bay, however, is characterized by high river discharge and concomitant high concentrations of "yellow substances" which have a direct influence on the chemistry of the region (KREMLING 1984). In combination with higher concentrations of organic nutrients, they probably lead to a bacterial population which is different from the other subregions of the Baltic Sea.

This latter assumption is supported by the relatively high number of saprophytic bacteria in the Bothnian Bay (Fig. 2). Whereas these bacteria were observed at $<10^3$ CFU ml^{-1} in the Baltic Proper and here represented a very small fraction of the total bacterial number (Table 1), both their absolute number and relative proportions increased dramatically in the Bothnian Bay and to a lesser degree also in the Bothnian and Aland Sea. In the Belt Sea again high numbers of saprophytic bacteria, both absolute and relative, were found. The mean bacterial cell volume also increased here.

Regionally differing mean cell volumes led to higher variability of biomass than total bacterial numbers (Table 1). Bacterial biomass had clear maxima in Bothnian Bay and Kiel Bight and its minimum in the Bornholm Sea (Table 1).

The maximum uptake velocity and especially the turnover rate of glucose again exhibited a more pronounced spatial variation than the total bacterial number (Fig. 2, Table 1). Changes in the population structure and differing environmental conditions may be responsible. However, even these activity measurements showed a relative uniform regional distribution. The lowest turnover rate, which was observed in the Bothnian Sea, amounted to 34 % d^{-1}. This value is equal to a turnover time of 70 h. The highest rate (171 % d^{-1} in the Kiel Bight) corre-

sponded to a turnover time of 14 h. No significant correlation was detected between total bacterial numbers and bacterial activity.

Similarly, no correlation existed between the bacterial variables and the chlorophyll a concentration. This lack of correlation seems surprising, since several studies have shown significant correlations between chlorophyll concentrations and bacterial numbers (FERGUSON and RUBLEE 1976, FUHRMAN et al. 1980). Other researchers (DUCKLOW 1984), however, were unable to detect such a correlation on a smaller spatial scale or on a relatively small span of chlorophyll concentration (BIRD and KALFF 1984). Nevertheless, when considering larger spatial scales or a wide span of chlorophyll concentrations the correlation between bacteria abundance and pigment concentration became obvious (DUCKLOW and KIRCHMAN 1983, BIRD and KALFF 1984, DUCKLOW 1984).

When we planned the synoptical horizontal survey we expected a more patchy distribution of the microbiological variables. We were therefore quite surprised when we obtained the rather uniform results. Several factors may be responsible for these findings. Most important probably is the fact that during the late summer, i.e. towards the end of the phytoplankton growth season, the bacterial numbers and activity are generally high and less variable than during the preceding months. Also, the samples were taken at 5 m depth, below the range of surface dwelling cyanobacteria, which tend to form patchy agglomerations with high bacterial numbers. Related to this, it also should be mentioned that during the entire transect long lasting and very strong winds blew almost exactly along the middle-line of the Baltic Sea, which gave rise to a deep reaching circulation, thus eliminating strong gradients of bacterial numbers in the uppermost meters.

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