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Spatial and temporal variation of bacterioplankton abundance and biomass in a coastal lagoon (Ria Formosa, Southeastern Portugal)

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Abstract

Water samples were taken at bimonthly intervals (April - October 88) from three stations located in the Ria Formosa, a coastal lagoon in SE Portugal. Bacterial abundance and biovolume ranged between 1.2 - 18 x 10^6 cells/ml and 0.107 - 0.216 μm^3/cell, respectively. Lowest values were detected at the station close to the ocean and highest values at the station near a domestic effluent. Total bacterial counts showed slight temporal fluctuations while saprophyte numbers presented a much stronger variation, with maxima in summer. The biovolume exhibited minimal values in summer. Reasons for the different patterns of spatial and temporal variability of the bacterial population are discussed.

Introduction

The Ria Formosa is a salt marsh-mud flat ecosystem located on the southern portuguese coast. Information on bacterioplankton is scarce and reduced to studies which used traditional methods (e.g. plate counts) to assess water quality for sanitary purposes.

The aim of this study was to evaluate temporal and spatial variations of the bacterial populations in the Ria Formosa, and to investigate the environmental factors associated with their distribution.

Material and methods

The Ria Formosa (Fig. 1) is a shallow (average depth <3 m) coastal lagoon, with 110 km^2. It is a well mixed system with a low freshwater input. A continuous sewage outflow enters the Ria increasing during summer owing to the increase of the population. The Ria is characterized by extensive *Spartina* saltmarshes, and *Zostera* beds. It is a natural fish nursery and a very important shellfish production area.

Water samples were collected at bimonthly intervals, between April and October 1988. Samples were taken aseptically from 0.2 - 0.3 m below the surface in three locations: Sta.1, main outlet of the lagoon; Sta.2, inner channel; and Sta.3,

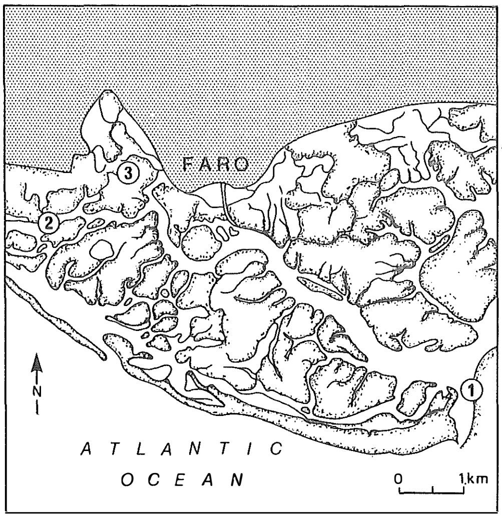

Fig. 1. Map of the Ria Formosa showing the sampling stations.

near a sewage outflow (Fig. 1). Sampling was always carried out at the same hour (09^{00} - 10^{00}) and stage of tide (midebb tide).

Water temperature, dissolved oxygen, and salinity were assessed during the study. Chlorophyll a was determined spectrophotometrically and corrected for phaeopigments (LORENZEN and JEFFREY 1980). BOD_1 was determined after 24h incubation at 20 °C in the dark by the Winkler method.

The saprophyte bacteria were assessed by the pour-plate method according to RHEINHEIMER (1977) with salinities of 0 ‰, 17.5 ‰, and 35 ‰.

Total bacterial number was estimated by the acridine orange method (HOBBIE et al. 1977), with minor changes. Cell sizes of 100 cells were measured with a calibrated ocular micrometer (NEW PORTON G-12) under a Leitz epifluorescence microscope, at x1.250. Bacterial biomass was calculated as a non-linear function of cell volume according to SIMON and AZAM (1990).

Results and discussion

Water temperatures (Fig. 2) and salinity (data not shown) fluctuated between 14.0 - 27.0 °C and 30.80 - 35.18 ‰, respectively. Dissolved oxygen, as percent saturation (data not shown), varied between 85 and 116 % at Sta.1 and 2, and showed values usually below 60 % at Sta.3. Chlorophyll a concentrations (Fig. 2) fluctuated between 0.48 and 6.62 µg/l and showed peaks around summer at all stations. BOD_1 (Fig. 2) ranged between 0.185 and 1.93 mg/l and showed significantly higher values at Sta.3.

Saprophyte bacteria abundance (Fig. 3) fluctuated between 0.44×10^3 and 11.26×10^6 and showed pronounced spatial variability. Bacteria culturable in medium with salinity of 35.0 ‰ (S 35 ‰) dominated saprophyte counts from April to June and in October at all stations. From July to September bacteria from medium with S 17.5 ‰ showed a strong increase and they became dominant during this period.

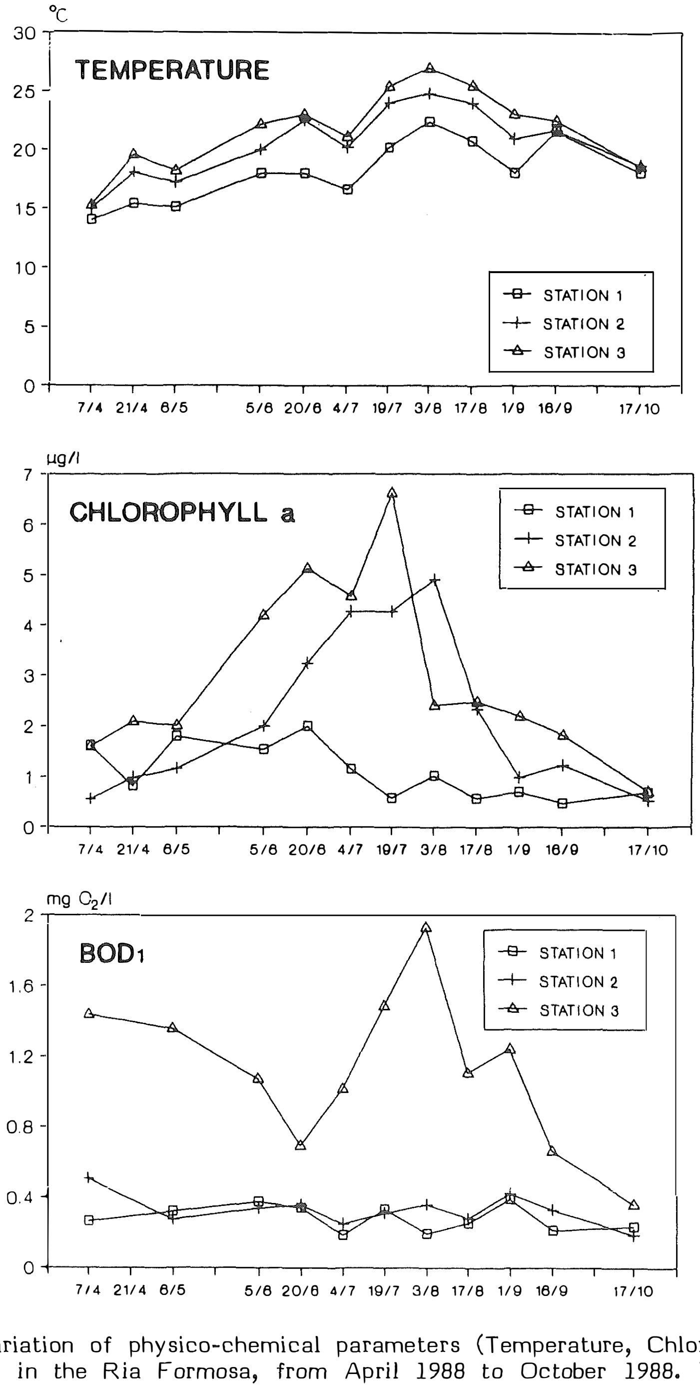

Fig. 2. Variation of physico-chemical parameters (Temperature, Chlorophyll **a**, and BOD_1) in the Ria Formosa, from April 1988 to October 1988. Values of Chlorophyll **a** and BOD_1 represent a mean of three replicate subsamples.

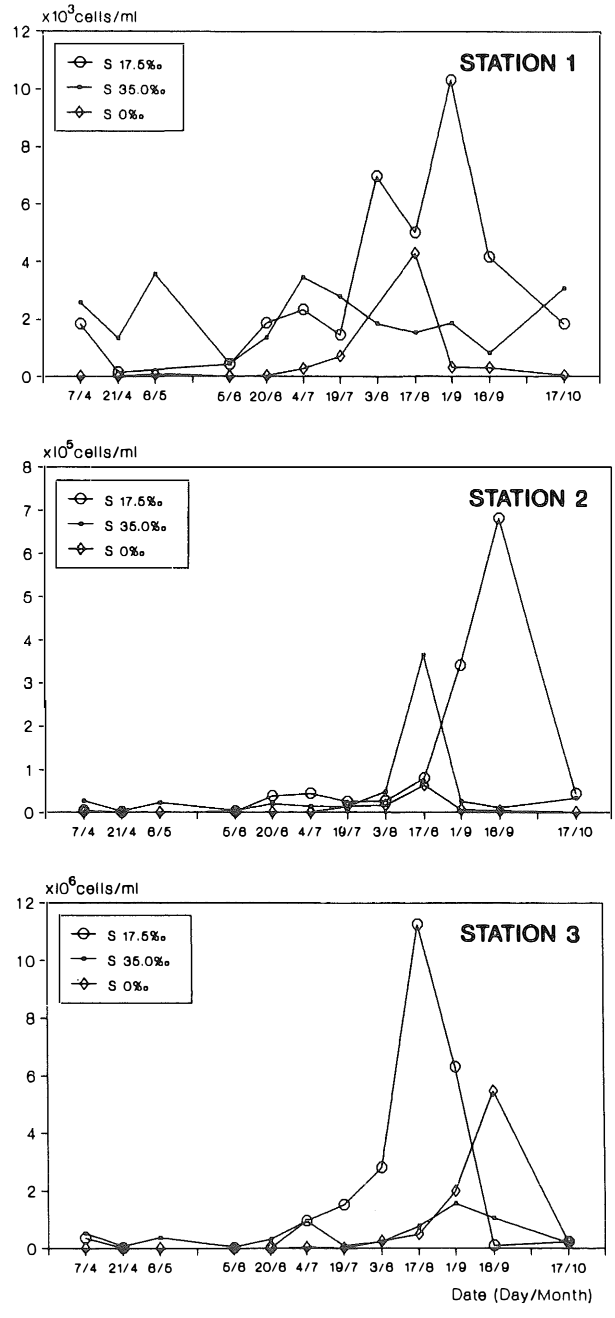

Fig. 3. Variation of saprophyte bacteria from the Ria Formosa, cultivated at different salinities (0 ‰, 17.5 ‰, and 35 ‰). Each point represents a mean of three replicate subsamples.

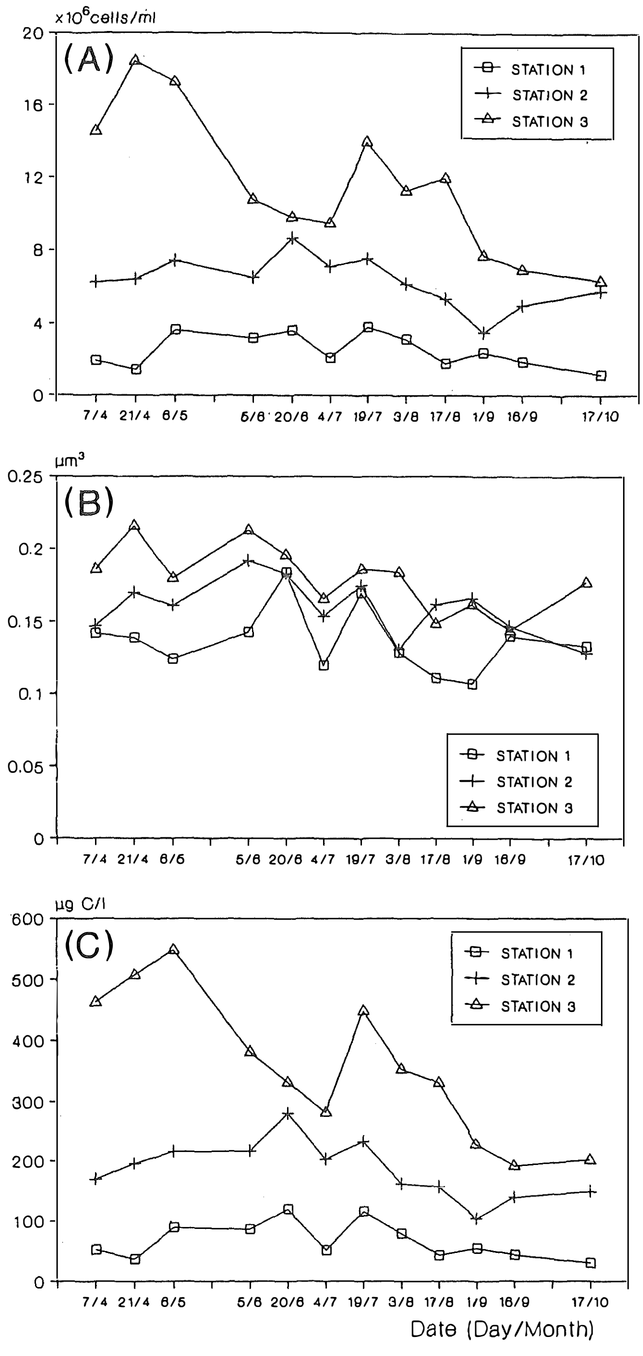

Fig. 4. Variation of total bacterial abundance (A), mean bacterial volume (B), and bacterial biomass (C) in the Ria Formosa, from April to October 1988.

Total bacterial numbers (Fig. 4) fluctuated between 1.17 $\times 10^6$ and 18.44 $\times 10^6$ cells/ml and showed consistently lower values at Sta.1 and higher values at Sta.3. Sta.1 and 2 exhibited smaller temporal variations, with maxima between June and August. The pattern of Sta.3, with peaks in April and July, correlated significantly ($p < 0.005$) with that of BOD_1.

The proportion of saprophytes to total counts was usually lower than 1 % at Sta.1 and 2. Sta.3 exhibited higher values, generally lower than 12 %. However, the strong increase in S 17.5 ‰ between August and September increased the saprophyte proportion to extremely high values, particularly at Sta.3.

Despite the existence of strong currents and turbulent mixing, we detected spatial differences in the relative contribution of the different morphological cell types (data not shown). In all sampling dates, Sta.1 exhibited consistently higher proportion of coccoid cells, and Sta.3 showed higher proportion of rod shaped cells.

Mean cell volume of bacteria (Fig. 4) exhibited values between 0.107 and 0.216 μm^3, with usually lower values at Sta.1 and higher values at Sta.3. Bacteria biomass (Fig. 4) showed the same pattern as total bacterial abundance, ranging between 36.9 and 547.8 µg C/l.

The correlation between total bacterial counts and BOD_1 at Sta.3 was the only significant correlation we detected after the analyses of Pearson coefficients among all monitored variables.

Bacterial distribution in the Ria Formosa exhibited a pronounced spatial variation. The results of total bacterial counts were consistent with data reported for other coastal and estuarine environments (reviews by THINGSTAD 1987, and AUSTIN 1988). Sta.1, close to the ocean, consistently showed minimal values of saprophytes and total bacterial abundance, reflecting the proximity of an environment with less favorable nutritive conditions. The greater availability of organic substrates released by primary producers (phytoplankton, phytobenthos, and macrophytes) or resuspended from sediments inside the Ria should have enhanced bacterial populations at Sta.2 and 3. The bacterial parameters were, as would be expected, nearly always highest at Sta.3, reflecting the influence of sewage outflow.

The values of mean cell biovolume were usually higher than those reported for coastal and estuarine areas (see THINGSTAD 1987 for review). Differences in the mean cell biovolume, with higher values at Sta.3, may reflect a higher metabolic activity owing to a greater availability of nutrients (TORELLA and MORITA 1981) and/or the existence of different bacterial communities. The latter hypothesis seems to be confirmed by the analyses of cell morphology.

The spatial and temporal variations of saprophyte bacteria always exceeded those of direct counts. The fluctuation of different types of saprophytes and the proportion of saprophytes to total counts suggest a change in the population between August and September. This may be related to a greater availability of easily degradable organic compounds (RHEINHEIMER 1977) and/or to higher temperatures. In fact, during the summer the autochthonous inputs of organic substrates must have increased owing to the phytoplankton blooms, and the substrates released by the macrophytes which are usually more readily available during this period (TURNER 1978, PALUMBO et al. 1984). In addition, the sewage outflow increases during summer due to large number of tourists in the region.

Total bacterial counts exhibited maximal values in early summer or before (Sta. 3). Since the factors that enhance bacterial production were probably more favorable during summer, these values suggest that other factors were reducing total bacterial numbers. Among those factors, grazing by pelagic and benthic bacterivors were probably the most significant (see PACE 1988 for review). The lower biovolumes detected during the summer can be taken as evidence for the grazing control of cell size (ANDERSSON et al. 1986, GÜDE 1989).

Bacterial abundance maxima in salt marsh and coastal waters have been reported to occur around summer and are usually related to increases in temperature, substrates released by macrophytes, and chlorophyll values (WILSON and STEVENSON 1980, WRIGHT and COFFIN 1983, 1984, KIRCHMAN et al. 1984, RUBLEE et al. 1984). In the present study, the absence of significant relations between environmental and microbiological parameters may reflect the dynamic nature of this ecosystem. In fact, the Ria Formosa is a very heterogeneous and complex environment where the influence of a single factor can be easily overlapped by physical events (e.g. resuspension of sediments, turbulent mixing of different water masses), biological processes (e.g. grazing on bacteria, existence of different sources of organic substrates), or obscured by a limited frequency of sampling.

Acknowledgements

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