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Bacteria and their distribution under red-tide conditions

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Abstract

Survey of the density of red-tide organisms and bacterioplankton as well as simultaneous determinations of temperature, salinity, pH, secchi disc and dissolved oxygen were carried out at four stations in the Kăstela Bay (middle Adriatic Sea) on a weekly basis between June 15 and September 20, 1989. A close connection between bacterioplankton and *Gonyaulax polyedra* was observed during the bloom manifested by high coefficients of correlation between them in the surface layers. No correlation was established in the bottom layers since vertical gradients of bacterioplankton density were considerably weaker than in phytoplankton. These differences were also shown in strong vertical gradient of pH and O_2-saturation.

Introduction

Red-tide due to dinoflagellate (*Gonyaulax polyedra)* bloom has regularly occurred in the Kaštela Bay every summer since 1980. Occasionally it even caused kills of marine organisms (MARASOVIĆ and VUKADIN 1982, MARASOVIĆ and PUCHER-PETKOVIĆ 1985, MARASOVIĆ 1989). In the beginning, the red-tide occurred only in the eastern part of the bay not earlier than mid summer and lasted for a week or two. For the last few years, however, it has persisted throughout summer and extended all over the bay. Since large scale geographic and vertical distribution of phytoplankton and bacterioplankton suggest a general dependence of bacteria on phytoplankton production (DUCKLOW 1984, BIRD and KALFF 1984) it would be of interest to observe their behaviour under these specific conditions at a shorter time scale.

Material and methods

Study area: The Kaštela Bay is the largest bay in the central region of the Yugoslavian coast. It is a closed and shallow basin very exposed to land influence, with a surface area of 61 km^2 and an average depth of 23 m. Its western and northwestern parts are shallow whereas its central part is the deepest one (ZORE 1955). The freshwater inflows are numerous, coming from the Jadro river in its eastern part and a number of permanent or temporary submarine springs. Furthermore, the bay is under the constant influence of untreated municipal and industrial effluents, which are loaded by different inorganic and organic compounds affecting the ecosystem of this area, especially its eastern part.

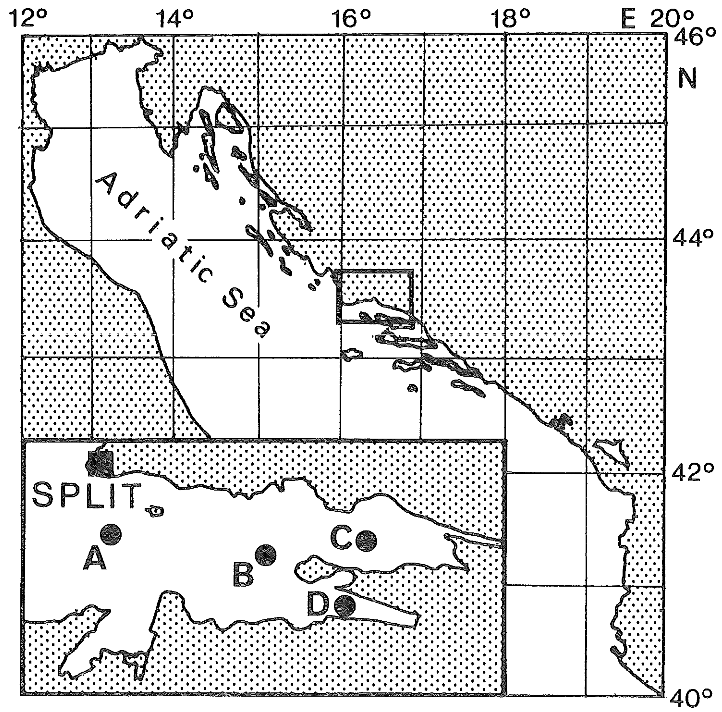

Fig. 1. Study area.

Monitoring of the red-tide organisms and bacterioplankton density with the simultaneous measurement of temperature, salinity, dissolved oxygen and pH were carried out at four stations in the eastern part of the Kaštela Bay (Fig. 1) on a weekly basis between June 15 and September 20, 1989. Samples were taken at the surface and immediately above the bottom.

Total bacterial abundance was estimated with acridine orange direct counts (AODC) (HOBBIE et al. 1977) using a Zeiss epifluorescent microscope. For the determination of the phytoplankton concentration samples were preserved by 2 % formaldehyde solution. Phytoplankton organisms were then enumerated with an inverted microscope after a 24 h sedimentation by the Utermöhl method. Oxygen was determined by the Winkler method, pH was measured using a Radiometer pH-meter. Temperature was measured with reversing thermometers and salinity was determined with a Beckman salinometer.

Results and discussion

Means and standard deviations for all studied parameters are presented in Table 1. Surface temperature ranged, on the average, from 23 to 24 °C and bottom temperature from 19 to 21 °C throughout the study area; salinity from 34 to 36 ‰ at the surface and from 37 to 38 ‰ at the bottom. Dissolved oxygen content was very high in the surface layers (on the average between 6 and 8 ml l^{-1}) which suggests particularly high photosynthetic activity. It is noteworthy that the number of *Gonyaulax polyedra* cells was, on the average, 1.83 - 8.85 x 10^6 l^{-1}.

Table 1. Arithmetic means and standard deviations of temperature, salinity, secchi-disc, pH, dissolved oxygen, numbers of bacteria (AODC) and *Gonyaulax polyedra* (G.p.).

Station	Depth	T°C		$S\times10^3$		Secchi-disc(m)		pH	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
A	surface	23.72	2.31	35.58	1.05	2.2	2.3	8.30	0.22
	bottom	19.32	1.29	38.03	0.40			8.07	0.09
B	surface	23.63	2.53	35.93	1.01	1.6	1.5	8.33	0.24
	bottom	21.14	1.88	37.66	0.35			8.10	0.15
C	surface	23.79	2.53	34.00	4.17	1.6	1.3	8.26	0.12
	bottom	20.26	2.08	37.80	0.32			8.05	0.12
D	surface	23.79	2.13	35.36	0.89	1.4	1.2	8.15	0.15
	bottom	19.41	1.80	37.92	0.30			8.02	0.12

Station	Depth	$O_2 ml^{-1}$		O_2 %		$AODC\times10^9\ l^{-1}$		$G.p.\times10^6\ l^{-1}$	
		$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
A	surface	7.87	3.26	154.47	65.05	4.12	5.93	6.34	13.50
	bottom	4.16	1.45	78.28	27.69	0.87	0.39	0.13	0.11
B	surface	7.29	2.52	146.16	50.50	1.74	0.56	8.85	21.16
	bottom	3.93	1.81	73.03	37.41	1.16	0.77	0.14	0.15
C	surface	7.52	2.29	150.40	64.15	1.90	1.75	2.90	3.56
	bottom	3.78	1.42	48.88	26.12	1.20	0.70	0.15	0.30
D	surface	6.18	2.40	126.48	47.28	2.71	1.53	1.83	1.75
	bottom	3.47	1.28	71.29	34.01	1.33	0.86	0.04	0.09

In the bottom layers oxygen content dropped to 3 to 4 ml l^{-1}. For the study area as a whole bacterioplankton density varied, on the average, between 1.74 and $4.12\times10^9\ l^{-1}$ in the surface layers and between 0.87 and $1.16\times10^9\ l^{-1}$ in the bottom layers. However, it should be pointed out that the values of standard deviations both for the bacterioplankton and phytoplankton density as well as for oxygen saturation were very high showing that the variability of these parameters was very high during the research period. The highest bacterioplankton den-

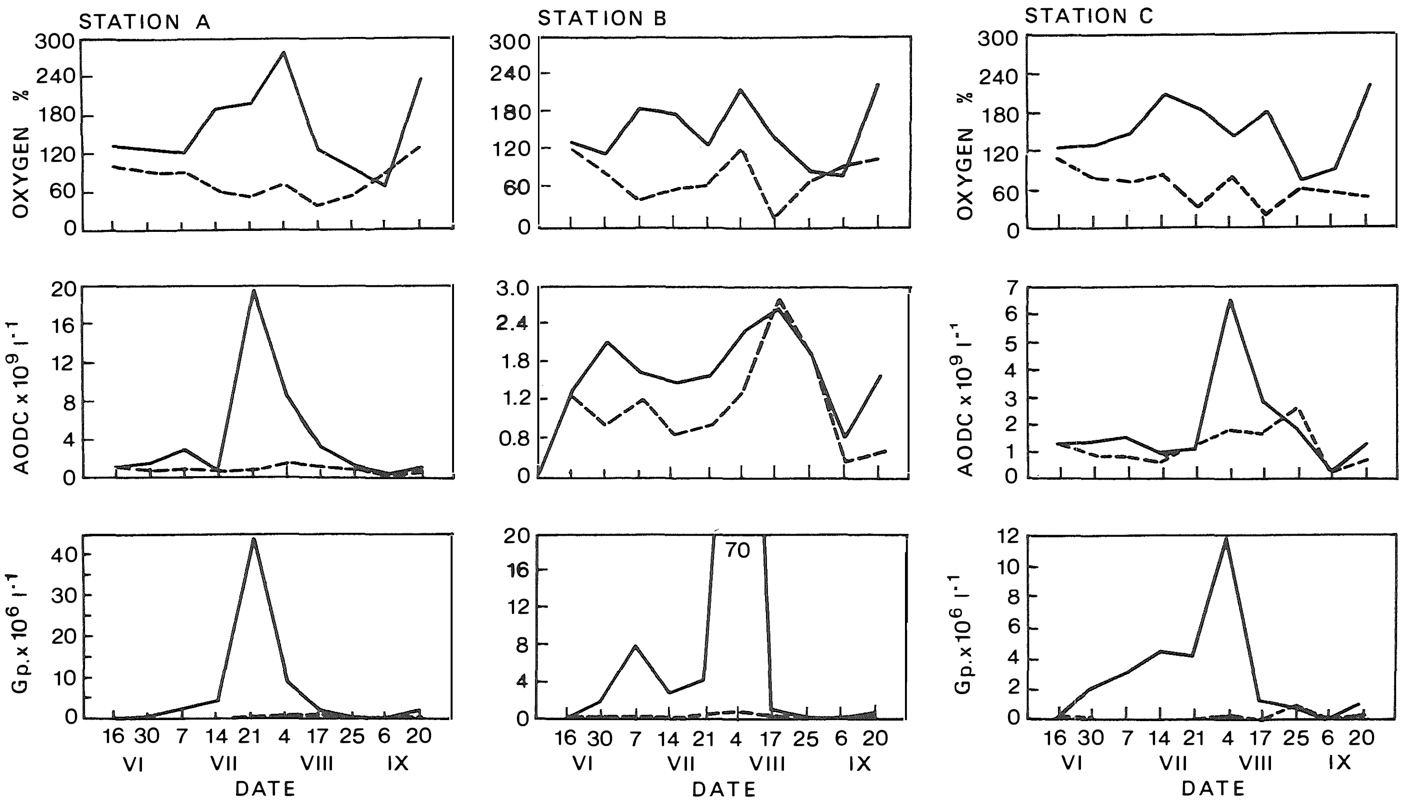

Fig. 2. Time series of oxygen, bacterioplankton (AODC) and *Gonyaulax polyedra* (G.p.) at the surface (continuous line) and bottom layers (dashed line).

sity was recorded during the most intensive *Gonyaulax polyedra* bloom (from July 21 to August 17, 1989). The coefficients of correlation between bacterioplankton density and *Gonyaulax polyedra* density in the surface layers were 0.813 - 0.875 ($p<0.01$) at stations A, B and C. Such regular patterns were not recorded from station D, most likely due to the fact that this station is in the close vicinity to the municipal sewage outfall from where the sea receives considerable quantities of coliform bacteria all year round.

For the period of investigations the bloom was most intensive during calm meteorological conditions. Therefore, it seems that short term changes of phytoplankton and bacterioplankton concentrations are only due to the vertical mixing and horizontal advection induced by the wind events. It should be pointed out that bacterioplankton density variations during the bloom were far less than those found for phytoplankton. So, whereas the phytoplankton density changed by 1 to 3 orders of magnitude the bacterial density varied not more than by one order of magnitude. Similar observations were reported by RIEMANN and SØNDERGAARD (1981), who studied the relationship between bacterioplankton and phytoplankton during diatom blooms in the lake Morso, as well as by DUCKLOW and KIRCHMAN (1983), who studied the relationship between bacterioplankton and *Skeletonema costatum* in the Hudson River plume and USA coastal waters.

Vertical density gradient of bacterioplankton was rather pronounced but far lower than that of phytoplankton and oxygen saturation (Fig. 2). So, the bacterioplankton density was of the same order of magnitude in the surface and bottom layers, whereas the difference was 1 to 2 orders of magnitude in phytoplankton. This marked difference in phytoplankton density and considerable smaller difference in bacterioplankton density between the surface and bottom layers caused a sudden drop of both oxygen content and oxygen saturation in the bottom layer, even though the area was very shallow (not exceeding 10 m). However, it should be pointed out that Secchi disc values did not exceed 1.4 to 2.2 m (Table 1) during the research period. A dramatic example of the gradients was recorded on August 17, 1989 (particularly pronounced at station B), when the oxygen saturation was 215.5 % at the surface and only 13.8 % at the bottom (Fig. 2). A fish kill caused by suffocation was recorded the same day.

To conclude, a close connection between bacterioplankton and dinoflagellates (*Gonyaulax polyedra)* was established during the bloom manifested by high coefficients of correlation between them for the surface layers. No correlation was established in the bottom layers since the vertical gradient of bacterioplankton density was considerably weaker than in phytoplankton. These differences were also expressed in strong vertical gradient of pH and oxygen saturation.

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