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„Red tide" in the Vranjic basin (Kaštela bay)

»Red tide« u Vranjičkom bazenu (Kaštelanski zaljev)

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»Red tide« or »red sea-water bloom« is a phenomenon known since very long ago. However, it was described for the first time by Darwin 1832 during his well known »Beagle« voyage. It is manifested as an uncontrolled production of phytoplankton organisms, most commonly dinoflagellates, even though some other phytoplankton groups may be responsible for »red tide« (such as *Trichodesmium erythraeum* of cyanophiceae group).

Dinoflagellates have relatively high mobile ability which is a considerable advantage over the other phytoplankton organisms and particularly over diatomeae the mobility of which is dependent on water mass motions. Metabolic products of the maior part of these organisms are toxic and under certain conditions, may produce lethal effects to other marine organisms. Under normal conditions, any toxin released during cell decomposition is rapidly diffused in the marine environment since at higher pH levels it is rather unstable. However, in the »red tide« circumstances these toxins may cause the mass mortality of marine organisms. It should be mentioned that nevertheless »red tide« is a very serious problem, intensively studied in many of the world areas, its main cause has not yet been adequately identified.

The greatest problem is the sudden outbreak of this phenomenon so that the events which lead to »red tide« remain enknown. It has, however, been established that certain conditions are inevitably present preceding the outbreaks of »red tide«. These are calm, sunny weather, relatively high sea temperatures and increased nutrient levels. The layering occurs due to the lack of vertical and horizontal mixing and the water with higher nutrient concentrations is retained in surface layer (sewage water of town outfalls). With the sufficient nutrient quantities and appropriate temperature dinoflagellates begin an intensive reproduction migrating vertically in search for more favourable light conditions. At surface and under optimum light conditions they rapidly create a monoculture. It may be of interest the fact, which has not yet been given an adequate explanation, that not any significant increase in zooplankton production occurs either under the conditions of toxic »red tide« or those of the non-toxic »red tide«. Owing to this grazing pressure remains constant like under normal conditions and the non-migratory species (diatomeae) are subjected to more intensive mortality.

In September 1980 »red tide« (Fig. 1) occured in a part of the Kaštela Bay upon a longer period of calm and warm weather. The area of Vranjic basin was most threatened even though »red tide« occured in the adjacent areas as well, however of much lower intensity. Vranjic basin is rather isolated and shallow area on the Kaštela Bay, where water mass dynamics is considerably reduced if compared with other bay areas. Since large quantities of town sewages are discharged there nutrient levels are costantly increasing. The possibility of »red tide« occurence has already been pointed at (Pucher-Petković and Marasović, 1979) since the species composition of phytoplankton earlier recorded there during warmer part of the year differred from that of the other Kaštela Bay areas and the percentages of the dinoflagellates were considerably higher than normal (with the increased *Gonyaulax polyedra* Stein density). In our case this armoured dinoflagellate mass bloom was responsible for »red tide«. It is held to be a tycipal »red tide« organism. *Prorocentrum micans* Ehrenberg and *Eutreptiella pascheri* Butcher accompanied the forementioned species. In the central part of the area attacked by the bloom the number of celles of *G. polyedra* was $1,6 \times 10^7$ per litre of the sea water, of P. micans 2×10^6 and of E. pascheri 8×10^5. The sea water was dense, intransparently rusty coloured. Going towards the margins of the area the colour changed from the light brown and orange to the greenish (Fig. 1).

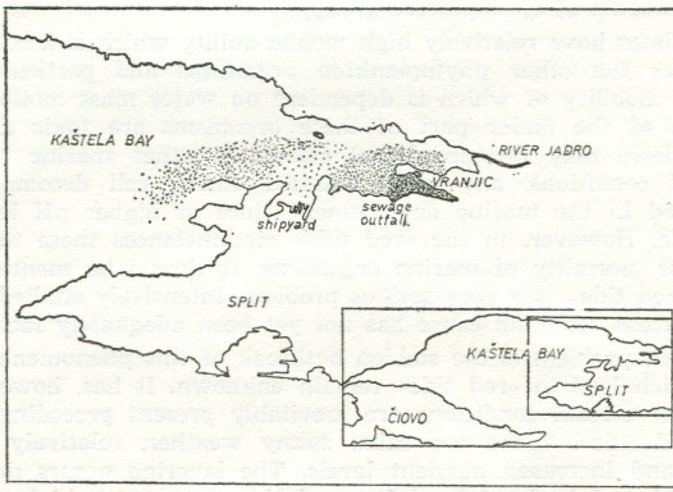

Fig. 1. Distribution of *Gonyaulax polyedra Stein* at the investigated area (September 1980)

During the most intensive bloom (18 September 1980) the unusual behaviour of pelagic fish (*Sardinella aurita* Valenciennes) was observed. These fish jumped onto the shores where died probably due to the gill blocking which did not allowed their normal breathing. Eight days later mass mortality of fish and shellfish occured. Fish schools came to the surface layers swimming towards the coasts. A part of fish died while large part of them were stunned and simply floated in the shoals. The sea water analyses showed minimum oxygen concentrations at that time. In the bottom layers values were about 0,6 ml O_2/l and on the surface about 1,8 ml O_2/l. In addition, pH values were slightly reduced (7,94 on the surface and 7,77 on the bottom) if compared with the pH values measured on June 19 1980 (surface 8,7) as well in relation to the ordinary pH values in this area which are somewhere about 8,3 (Tab. 1). All the data indicated that an intensive decomposition took part on the bottom where the organic matter was accumelated due to the large quantities of dead cells of G. polyedra. This caused oxygen consumption to increase considerably.

It is well known that decomposition processes consume 2,67 g O_2/g C and 4,57 g O_2/g N_2 for the organic matter oxidation. Since the sea water contains, on an average, about 6—7 ml O_2/l what corresponds the 9 mg O_2/l value, this quantity is sufficient for the oxydation of 1—3 mg C or about 1 mg N_2 in the sea water. In polluted areas in which organic carbon concentrations may exceed 10 mg C/l the overall sea water oxygen quantity may be consumed up for organic matter oxydation. There upon the organic matter may be further decomposed by the means of bacteria which use NO_3 and SO_4 as H^+ acceptor. The increased cell density is held to have the highest effect on the reduction of phytoplankton cell reproduction activity viz. the lack of illumination rapidly minimizes the reproduction. Krupatkina and Burlakova (1980) established that the increase in cell density caused the drop of physiological indicator values (photosynthethic activity, chlorophyll and phosphorus quantity per cell) what they accounted for by the accumulation of organic phosphorus (as a metabolism product) in the sea water. Lowered nutrient concentrations in the adjacent medium may have the same effect. However, this, for sure, was not the limiting factor in our case, since nutrients were repeatedly supplied through the sewage waters.

Wyatt and Horwood (1973) gave the following »red tide« model, which shows that in the final phase the oxygen depletion and toxic substances released from dead phytoplankton cells the mass death of marine organisms:

Stability of water column
↓
layering or swarming of motile organisms
↓
enchanced reproduction and release from grazing
↓
»pure culture« conditions (nutrient depletion and self shading; colour change) ⟶ »RED TIDE«
↓
aging, cell death and release of toxyns ⟶ poisoning and mass mortality
↓
putefaction and exygen depletion ⟶ poisoning and mass mortality

Some »red tied« organisms as well as their toxic substances are relatively well known *(Gymnodinium breve, Gonyaulax catenella, G. monilata, G. tamarense).* It was established that the majority of their toxic substances belong to a group of neurotoxins which may have lethal effects on marine organisms. For a lot of other species and thus for *G. polyedra* this has not been laboratory proved but the data on their toxicity have been exclusively visually obtained. On this basis majority of authors report *G. polyedra* to be a poisonous organism (Schiller, 1933—1937; Adams *et al.,* 1968; Riley and Chester, 1971; Gorjanova and Demina, 1974).

Tables 1 and 2 give chemical parameters during »red tide« in the Vranjic basin and central part of the Kaštela Bay and at the same station a month earlier and a month later than the »red tide« occurence (long-term permanent control station). These data suggest that nutrient concentrations were increased in relation to the central part of the Kaštela Bay.

Table 1. Quantities of nutrient salts, pH and oxygen at the station in the Vranjic basin (P_V)

Date	Depth	NO_3-N	NO_2-N	NH_3-N	SiO_3-Si	PO_4-P	pH	O_2
19. 9. 80.	0 m	2,86	0,113	0,92	10,42	0,100	8,70	4,60
25. 9. 80.	0 m	1,03	0,113	1,67	6,67	0,180	7,94	1,84
	10 m	1,59	0,092	4,02	12,86	0,119	7,77	0,58
26. 9. 80.	0 m	0,75	0,119	0,54	15,43	0,838	8,13	4,91
	10 m	0,98	0,101	0,92	5,28	0,162	8,03	1,82

Table 2. Quantity of nutrients at the station in the middle of the Kaštela Bay (P_k) prior, during and after »red tide« in the Vranjic basin

Date	Depth	NO_3-N	NO_2-N	NH_3-N	SiO_3-Si	PO_4-P
27. 8. 80	0 m	0,95	0,089	0,26	2,96	0,094
	35 m	0,85	0,053	0,72	7,70	0,128
17. 9. 80.	0 m	1,40	0,059	0,54	2,96	0,077
	35 m	0,71	0,077	0,36	7,70	0,077
23. 10. 80.	0 m	0,71	0,083	1,67	8,64	0,068
	35 m	1,78	0,059	0,78	7,10	0,137

It is well known that NH_3 plays a role of marked significance in phytoplankton production. The experiments with diatomeae and dinoflagellate cultures carried out in plastic tanks (Strickland *et al.,* 1969) showed phytoplankton first to consume the ammonia from the environment to begin to consume nitrates only upon the ammonia has been consumed up. Grant *et al.,* (1967) have experimentally proved that urea is also made part of phytoplankton cells before nitrates. In addition to the experiments carried out in plastic tanks, Strickland *et al.,* (op. cit.) simultaneously carried out the experiments with the laboratory cultures of the same organisms in which they observed their growth and development in an environment enriched in ammonia and nitrates respectively. It was generally shown that the phytoplankton cell growth was very similar in both above mentioned media. Due only to the quantitative relations between ammonia and nitrates in enrichment were noted some differences in the cell constituent relations. It was still established for *G. polyedra,* and it is likely to be applicable to other dinoflagellates, that cell production in the nitrate enriched medium exceeds for the whole order of magnitude that in the medium enriched in nitrates.

In the Vranjic basin the major part of waste waters are of town sewage origin and this water contains higher ammonia levels (see Table 1) what, after Strickland, is favourable for this species.

As it has been already mentioned and given in Table 3 phytoplankton cell quantity was $1,8 \times 10^7/l$ on 18 September 1980 to decrease to $5 \times 10^6/l$ on 19 September 1980. Further on, on 25 September 1980 when the mortality of fish occured this quantity dropped to as low quantity as $1,6 \times 10^4/l$ which is unusually low even for the normal conditions in this area (spores of *G. polyedra* were predominant in the sample of 25 September 1980 while mature cells were very poor). Since the weather was stable through out this period the cell number started to increase once again on 26 September 1980, viz. the new »red tide« periode occured. This resulted in the oxygen concentration increase in the surface layer (4,6 ml O_2/l of sea water) whereas the low oxygen concentrations in bottom layers indicated that the bacterial decomposition was still intensive.

Table 3. Number of cells/l during »red tide« in the Vranjic basin (P_v) (surface)

Date	Depth	No cells/l
18. 9. 80.	0 m	$1,8 \times 10^7$
19. 9. 80.	0 m	$5,0 \times 10^6$
25. 9. 80.	0 m	$1,6 \times 10^4$
26. 9. 80.	0 m	$9,0 \times 15^5$

Table 4. Number of cells/l in the middle of the Kaštela Bay (P_k) before, during and after »red tide« in the Vranjic basin (surface)

Date	Depth	No cells/l
27. 8. 80.	0 m	$6,0 \times 10^4$
17. 9. 80.	0 m	$1,9 \times 10^5$
21. 10. 80.	0 m	$1,0 \times 10^6$

As shown by Table 2 it may be assumed that the slight increase in nitrates and ammonia occured even in the central part of the Kaštela Bay during the outbreak of »red tide« in the Vranjic basin. However, the qualitative composition of phytoplankton from these two adjacent areas showed no characteristics in common. In the central part of the Kaštela Bay both the qualitative and quantitative phytoplankton composition were normal for this part of the year (Table 4). However, the fact that the number of *G. polyedra* cells was only $8,4 \times 10^2/l$ lead us to conclude that the water masses circulation between these two areas was almost negligible. After 26 September weather situation changed (the bora started blowing) which caused a sudden break of the »red tide«. After .Zore-Armanda (1967) the bora appears to have double favourable effect in the Kaštela Bay since it intensifies both the horizontal and vertical circulation (the bora drives to surface water out of the Bay) what is favourable for the ventilation (airation) and purification of the basin. This is particularly significant for the Vranjic basin since the same author established that the flow is considerably slower there and reaches not more than 65% of the flow speed in the rest of the Bay.

»Red tide« has occured in the area of Pula harbour on several occasions during the last ten years. Maretić *et al.* (1978) assume that high phosphate quantities (constituent parts of detergents) of domestic sewages significantly affect this phenomenon. Even though we assume that, in addition to favourable meteorological conditions, the large waste water quantities caused the »red tide« occurence in the Vranjic basin, we should mention that there is another possible cause of this phenomenon. During 1979, large quantities of soil were thrown into the Kaštela Bay for the marina erection. However, no protection measures were undertaken to prevent the washing off of this soil. At the same time it is well known that phytoplankton production may be adding some humus components. This is in connexion with the higher possibilities of iron utilization, which plays a very important role in all plant species. Iron ionic form quantities are extremely low in the sea, since iron is mainly present in the form of infusible iron hydroxide $Fe(OH)_3$ not favourable for helatization (Prakash, 1971). In humus, however, iron is present in the forms of Fe-humate and Fe-fulvate which are better acceptable forms for utilization by plant organisms. The long-term researches of dinoflagellate *Pyrodinium bahamense* by Taylor *et al.* (1966) and Carpenter and Seliger (1968) established that the addition of humus matter may decrease the 63 hour generation time of this organism to 59 hours. Otherwise it is well known that the generation time of dinoflagellates varies a lot in dependence of different factors and that they even stop the reproduce during certain periods. During »red tide«, however, there is no regularity and the generation time cannot be precisely determined.

On the basis of everything that has been said above it may be assumed that in addition to the previously mentioned factors (temperature, water mass stability, sewage waters rich in nutrients) the throwing of soil into the sea along the southern part of the Marjan peninsula might have significant effect on the »red tide« occurence in the Vranjic basin. Large quantities of this material were washed off into Kaštela Bay and the adverse effects were reflected in its most threatened part.

REFERENCES

Adams, J. A., D. D. Seaton, J. B. Buchanan & M. R. Longbottom. 1968. Biological observations associated with the toxic phytoplankton bloom of the East coast. Nature, 220 (5162): 24—25.

Carpenter, J. H. & H. H. Seliger. 1968. Studies at Oyster Bay in Jamaica, West Indies. II. Effects of flow patterns and exchange bioluminescent distributions. J. Mar. Res., 26 (3): 256—272.

*Grant, B. R., J. Madgwick & G. Dal Pont. 1967. Growth of *Cylindrotheca closterium* var. Californica (Mereschk) Reimann and Lewin on nitrate, ammonia and urea. Australian J. Marine Freshwater Res., 18: 129—136.

Gorjanova, S. V. & N. S. Demina. 1974. Vodorosli-producenti toksičeskih vešestv. Nauka, Moskva: 256 p.

Maretić, Z., I. Pojed, R. Zekić & M. Bujan. 1978. Red tide due to dinoflagellates in the harbour of Pula. Period. biol., 80 (Suppl. 1): 153—159.

Prakash, A. 1971. Terrigenous organic matter and coastal phytoplankton fertility. In Fertility of the sea, 2: 351—368. Ed. by J. D. Costlow. Gordon and Breach Science Publishers Inc., N. Y. 622 p.

Pucher-Petković, T. & I. Marasović, 1979. Projekti zaštite mora u užoj regiji Splita. Utjecaj eutrofikacije na fitoplankton Kaštelanskog zaljeva. II Konferencija o zaštiti Jadrana. Zbornik referata, 2: 263—269, Hvar,

Riley, J. P. & R. Chester. 1971. Introduction to marine chemistry. Academic Press Inc., London—New York : 465 p.

Schiller, J. 1933—1937. Dinoflagellatae. II. Rabenhorst's Kryptogamen-Flora von Deutchland, Osterreich und der Schweiz. Akademische Verlagsgesellschaft M. B. H., Leipzig : 590 p.

* quoted by Costlow, 1971.

Strickland, J. D. H., O. Holm-Hansen, R. W. Eppley & R. J. Linn. 1969. The use a deep tank in plankton ecology. I. Studies of the growth and composition of phytoplankton crops at low nutrient levels. Limnol. Oceanog., 14 (1): 23—34.

Wyatt, T. & J. Horwood. 1973. Model which generates red tides. Nature, 244 (5413): 238—240.

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»RED TIDE« U VRANJIČKOM BAZENU (KAŠTELANSKI ZALJEV)

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KRATAK SADRŽAJ

U rujnu 1980. godine u jednom dijelu Kaštelanskog zaljeva došlo je do pojave »red tide«, prouzročene masovnom cvatnjom dinoflagelata *Gonyaulax polyedra* Stein. Osam dana nakon najveće »eskplozije« populacije *G. polyedra,* uslijedio je pomor ribe i školjaka. Analize morske vode su pokazale da je u to vrijeme na području, koje je tjedan dana ranije bilo zahvaćeno cvatnjom, vladalo anoksično stanje (0,58 ml O_2/l u pridnenom sloju), koje je vjerovatno i uvjetovalo masovni pomor. Prema podacima iz literature, može se pretpostaviti da je ovaj osnovni uzrok bio kombiniran i sa toksicitetom samog *G. polyedra.* U radu se na osnovu poznatih činjenica pokušava ustanoviti razlog nastanka »red tide« na ovom području, te se iznose neke pretpostavke pomoću kojih bi se to moglo objasniti.

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