Impact of Nutrient Enrichment and their Relation to the Algal Bloom in the Adriatic Sea

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Extraordinary manifestations of eutrophication in the Adriatic Sea during the last few years have been due to the combined effects of diferent physico-chemical and meteorological factors. Permanent inputs of nutrients, particularly in the northern Adriatic via river runoffs and municipal sewage during calm summers, cause marked stratification of the water column and reduction of horizontal advection. These two effects provide the ideal conditions for single a species bloom. An attempt has been made to calculate the nutrient balance which allows a better interpretation of algal blooms in the Adriatic.

Introduction

During the summer of 1988 and part of summer of 1989 very large quantities of organic aggregations and mucose substances were recorded along the coasts of the northern and middle Adriatic, and to a lesser degree along the coast of the southern Adriatic.
These occurred as a consequence of an intensive phytoplankton bloom due to the man-made eutrophication in the North Adriatic Sea.
This phenomenon has been recorded on several occasions during the last decade at a number of characteristic sites (northern Adriatic, Emilia-Romagna coast, Lagoon of Venice, town port of Pula, Kaštela Bay and some others). However, it peaked during the last two years.
Three deleterious effect categories are attributable to certain bloom-forming phytoplankton taxa. They are:
- perceptible water quality deterioration including trophic changes
- chronic or intermittent health hazards, including toxicity
- losses of aestetic, and hence recreational, values of affected waters.

Results and Discussion

In order to understand the complexity of the cycle of generation, and the causes and occurrence of phytoplankton blooms in the Adriatic Sea, which by its nature is a very dynamic system, a knowledge of the origin of nutrients in the marine environment, their rates of change as affected by the properties of the environment they are in, and a knowledge of the biogeochemical factors is indispensable.
Being a continental sea, the Adriatic is strongly affected by land factors. River runoffs are the main source of dissolved nutrients (Tables 1, 2 and 3). These effects are particularly pronounced in the northern Adriatic, manifested as high primary production in that area compared to the middle and southern Adriatic. The nutrient balance data are based an long-term nutrient data in the Adriatic Sea as well as data a number of other authors (Table 4).

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TABLE 1. Fresh water input by river runoffs and from other sources in the Adriatic Sea ($\times 10^6 m^3 y^{-1}$)

Rivers	107 000 $\times 10^6 m^3 y^{-1}$	(65.8 %)
Agricultural	53 200 "	(33.0 %)
Industrial	1 500 "	(1.0 %)
Domestic	283 "	(0.2 %)
Total input	162 500 $\times 10^6 m^3 y^{-1}$	

TABLE 2. Nutrient content in industrial wastes, rivers and the Adriatic Sea (mmol m^{-3})

	Industrial wastes	Rivers	Adriatic Sea
N - salts mmol m^{-3}	25 - 200	7.0 - 16.7	1.0 - 3.5
P - salts mmol m^{-3}	2.0 - 5.0	0.6 - 2.2	0.0 - 0.2
Silicates mmol m^{-3}	200 - 500	100 - 350	1.0 - 2.0

TABLE 3. Nutrient loads ($\times 10^3 m^3 y^{-1}$) in the northern Adriatic Sea

	P - salts	N - salts
Po	16.4 $\times 10^3 m^3 y^{-1}$	114.0 $\times 10^3 m^3 y^{-1}$
Other Italian rivers South of the Po River	4.4 "	37.9 "
North Italian rivers	8.6 "	70.0 "
Yu - rivers and industry	1.4 "	8.9 "
Total	28.8 $\times 10^3 m^3 y^{-1}$	230.8 $\times 10^3 m^3 y^{-1}$

The Adriatic Sea is fairly poor in nutrients, being an example of an oligotrophic sea. However, low nutrient levels do not cause low productivity, as shown by the in situ measurements recordered during the last few years amounts to 100-200 g C $m^{-2} year^{-1}$ (Pucher-Petković and Marasović, 1980; Pucher-Petković *et al.*,1988; Degobbis *et al.*, 1989). Such high productivity makes possible the rapid transport of nutrients from deeper layers to the surface, loading to rapid exreetion and regeneration of these salts. Large quantities of fresh water enter the Adriatic Sea (163 $\times 10^9 m^3 y^{-1}$) via river runoffs and sewage effluents both on its western and eastern coast. Nutrients are also introduced in large quantities via these discharges, particularly nitrates and silicates.

Water and nutrient balances were calculated (Table 4). It was found that the water gain was in excess of the water loss during the year. The same applies to dissolved nitrogen and silica salts, so that their input to the Adriatic exceeds their loss. The situation is reversed for the phosphates (P-salts). A shortage of these salts in the Adriatic Sea is probably restored by their being dissolved from sediments or by regeneration and excretion.

TABLE 4. Nutrient balance in the Adriatic Sea (m^3y^{-1})

I n p u t	Volume(m^3)	N-salts	P-salts	Si-salts	Σ salts
From Medit.	7760×10^9	84×10^3	21.4×10^3	706×10^3	811×10^3
River runoff	103×10^9	250×10^3	82.0×10^3	1518×10^3	1850×10^3
Precipitation	0.1×10^9	73×10^3	-	-	73×10^3
Other	55×10^9	31×10^3	17.6×10^3	217×10^3	266×10^3
Total input	7922×10^9	438×10^3	121×10^3	2441×10^3	3000×10^3
O u t f l o w					
To Medit.	7770×10^9	127×10^3	20.2×10^3	812×10^3	959×10^3
Evaporation	148×10^9	4×10^3	0.8×10^3	10×10^3	15×10^3
Loss to sediments	-	179×10^3	104.0×10^3	1720×10^3	2078×10^3
Consumption by phytoplankton	-	25×10^3	31.0×10^3	-	56×10^3
Total outflow	7918×10^9	335×10^3	156×10^3	2542×10^3	3108×10^3
Balance	**$+4\times10^9$**	**$+103\times10^3$**	**-30×10^3**	**$+101\times10^3$**	**$+108\times10^3$**

The levels of individual nutrients show considerable seasonal variations (Degobbis 1988; Vukadin, 1990). These are probably caused by external factors as well as biological processes in the ecosystem itself. the variations show several maxima and minima during the year, leading to the conclusion that the Adriatic is an extraordinarily dynamic basin with high biological productivity. Minimum levels nutrient salts are usually recorded during spring or late summer when phytoplankton growth peaks or there is a high nutrient consumption in the sea. Maximum levels of nutrients occur during winter under destratified conditions. It is quite obvious that seasonal variations in nutrient content are mainly due to biological cycles.

The spatial distribution of nutrients in the Adriatic Sea shows the northern and southern Adriatic (the Po River and other runoffs for the northern, and the Mediterranean - Ionian Sea for the southern Adriatic) to be the main sources of nutrients in the Adriatic Sea. The middle Adriatic (Palagruža Sill) is the area of highest nutrient consumption (Buljan *et al.* 1975).

Cycles of nutrients in the Adriatic Sea are defined, not only by oceanographic and meteorological factors but, to a considerable extent, by biological cycles of the organic matter in the sea.

Conclusion

The calculation for nutrient balance quite clearly shows that the source of phytoplankton blooms is the northern Adriatic, that is the sea in front of the Po River estuary and the estuaries of other northern Italian rivers.

into this part of the Adriatic. The organic content of aggregations collected in 1988 from the middle Adriatic points to this fact since the proportion of carbohydrates was very high in relation to proteins, as well as bacterial biomass due to the presence of "old" pollution (Najdek *et al.*,1988). The data clearly show the Po River and other river runoffs and industrial wastes are the source and direct cause of eutrophication and bloom, while meteorological and hydrological conditions support the spreading and persistence of the bloom in the northern and middle Adriatic.

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