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Phytoplankton productivity of the Adriatic Sea in relation to pelagic fisheries

Produktivnost Jadrana u odnosu na pelagično ribarstvo

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The estimation of phytoplankton biomass by means of chlorophyll *a* concertations was introduced in Adriatic investigations at the beginning of seventies. It was, therefore, of interest to try to prove the already made distinction between different productive zones in the Adriatic applying this method in relation to the earlier estimation which was made by Buljan, 1964. He made an assessment of the Adriatic productivity on the basis of phosphate quantities and concluded that four productive zones may by distinguished in the Adriatic (Fig. 1). Later on, the zones were supported by the primary production data (Pucher-Petković, 1974). The major part of the Adriatic (about 57%) constitutes the zone A of lowest production which is affected by periodical ingressions or inflow of the eastern Mediterranean water (Buljan, 1953; 1968; Zore-Armanda, 1966; 1969a; 1969b; 1971). These occasions were always associated with increase of Adriatic productivity (Županović, 1955; Vučetić and Pucher-Petković, 1969; Zore-Armanda, 1970; Pucher-Petković *et al.*, 1971; Pucher-Petković and Zore-Armanda, 1973; Pucher-Petković, 1974; Vučetić and Kačić, 1973; Karlovac *et al.*, 1974; Revelante and Gilmartin, 1977). After Buljan (1964) about 23% of the Adriatic area covers zone B of high productivity directly affected by the Po river. Zone C of moderate productivity is the area of channel waters along the eastern Adriatic coast, partly affected by the land and partly by ingressions. The zone of the highest productivity is the area of more or less closed bays along the Adriatic coast (zone D). However, the results obtained in this work were somewhat different from expected since the chlorophyll *a* distribution showed partly a difference from the defined productivity zones. These aber-

rations were recorded in all the seasons, both during productive and non-productive part of year. This led us to conclude that some relationships between the zones as defined by Buljan in 1974—86 period had been changed. Even though the data were obtained under quite different situations, that is during different seasons, all the results given in Figs. 2, 3, 4 point to the fact that the zone of low productivity (A) was reduced while the zone of moderate productivity (C) was enlarged (Fig. 1). At the same time the zone of high productivity (B) sometimes extends to the half of the Adriatic, that is boundary of this zone has been shifted almost to the line connecting Split and Ancona. As it is well known this is the area of sardine spawning and intensive fishing for small pelagic fish. From 1967 on a continuous increase of small pelagic fish catch has been recordeed with a contemporaneous reduction of the number of fishing days (Fig. 5). This is one of the best indicators that fish population density has been continuosly increased. This event is very likely the result of an increase of the trophic basis of the population due to the gradual eutrophication of the Adriatic and less to cyclic variations, which for the Adriatic are 2.3, 3.5, 8 and 11 years (Županović, 1968; Regner and Gačić, 1974; Regner, 1985).

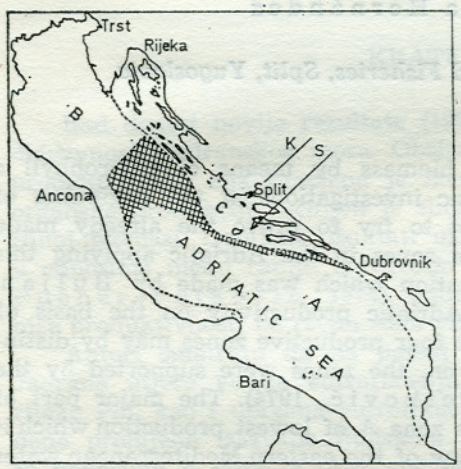

Fig. 1. Scheme of division of the Adriatic on 4 productivity zones. Zone D includes semi-enclosed bays along the coast (from Buljan, 1964). Cross-hatched part — the supposed reduction in the extent of the zone A (estimation on the basis of chlorophyll *a* distribution for the 1974—1986 period). K and S — permanent oceanographic stations

The results of researches, carried out by the Institute of Oceanography and Fisheries in Split for over three decades, including permanent and complete oceanographic observations and measurements at two fixed stations in the middle Adriatic, show that the increase of fish catch recorded since 1970 has been accompanied with a trend of increase in both, primary production (Steemann Nielsen's method by 14C) and phytoplankton biomass determined from chlorophyll *a* concentrations. The station S (Fig. 1.) represents the open waters of the middle Adriatic, the station K is situated in one of of the most productive bays of the eastern Adriatic (Kaštela Bay). The data obtained by these measurements show that primary organic production has been considerably increased both in the coastal and open sea for the last decade (Pucher-Petković and Marasović, 1988). An accelerated increase of production in the coastal area was recorded for the first time as

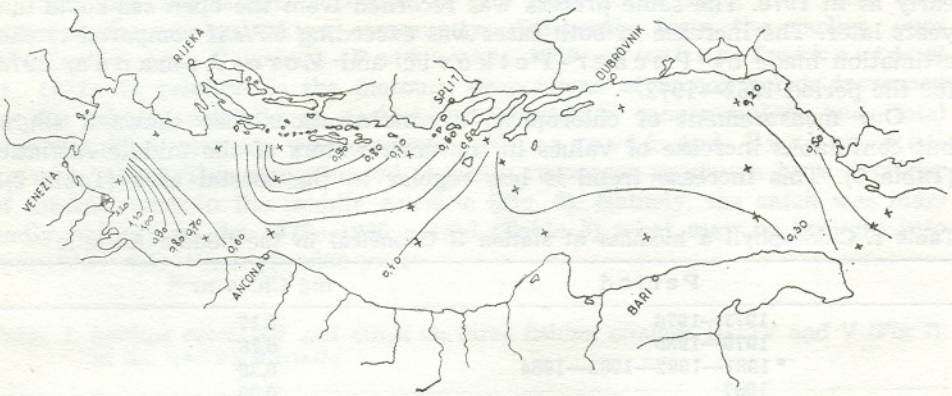

Fig. 2. Spatial distribution of chlorophyll *a* (mean values for 0—50 m), April 1976. (»ANDRIJA MOHOROVIČIĆ«, 1982)

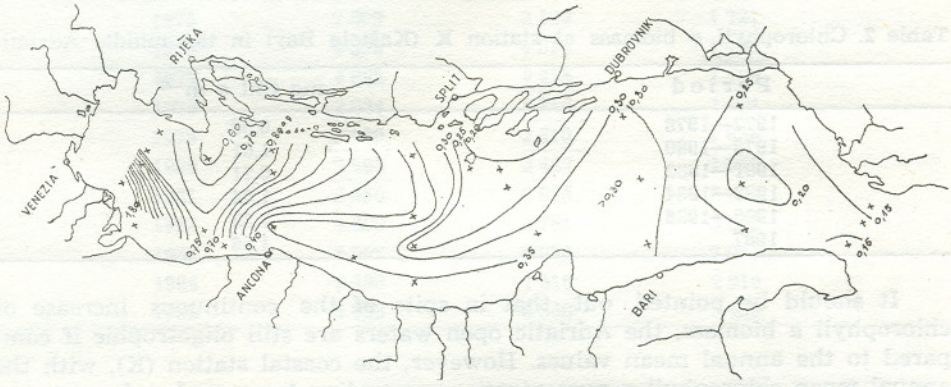

Fig. 3. Spatial distribution of chlorophyll *a* (mean values for 0—50 m). Cruises in 1974, 1975 (»ANDRIJA MOHOROVIČIĆ, 1982) and 1985/1986 (unpublished data)

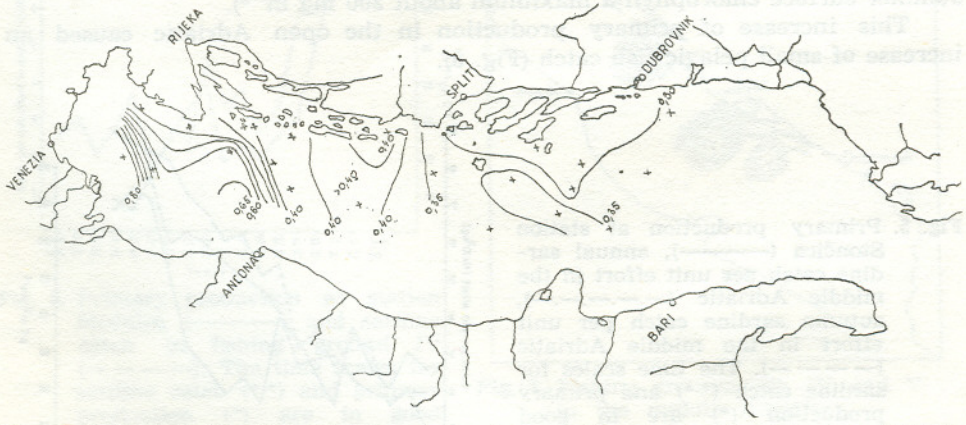

Fig. 4. Spatial distribution of chlorophyl *a* (mean values for 0—50 m), cruise »BIOS«, March 1982

early as in 1970. The same process was recorded from the open sea some ten years later. The increase in both cases was exceeding 60% if compared to the estimation made by Pucher-Petković and Zore-Armanda, 1973 for the period 1962—1972.

Our measurement of chlorophyll *a* concentrations also shows a slight but continuous increase of values in the open waters of the middle Adriatic (Table 1). This increase trend is less regular in the coastal area (Table 2).

Table 1. Chlorophyll *a* biomass at station S (Stončica) in the middle Adriatic

Period	mg Chl *a* m^{-3}
1977—1978	0,17
1979—1980	0,18
* 1981—1982—1983—1984	0,20
1987	0,30

* In 1982 and 1984 regular sampling was discontinued, therefore a single value was given for the 1981—1984 period.

Table 2. Chlorophyll *a* biomass at station K (Kaštela Bay) in the middle Adriatic

Period	mg Chl *a* m^{-3}
1977—1978	0,88
1979—1980	1,01
1981—1982	0,71
1983—1984	1,04
1985—1986	1,35
1987	1,36

It should be pointed out that in spite of the continuous increase of chlorophyll *a* biomass, the Adriatic open waters are still oligotrophic if compared to the annual mean values. However, the coastal station (K), with the annual mean chlorophyll *a* concentrations exceeding 1 mg m^{-3} and maximum surface values 7,8 mg m^{-3}, shows high eutrophication (Chiaudani *et al.* 1982) the eastern part of the bay shows extremely high eutrophication with summer surface chlorophyll *a* maximum about 200 mg m^{-3}).

This increase of primary production in the open Adriatic caused an increase of small pelagic fish catch (Fig. 5).

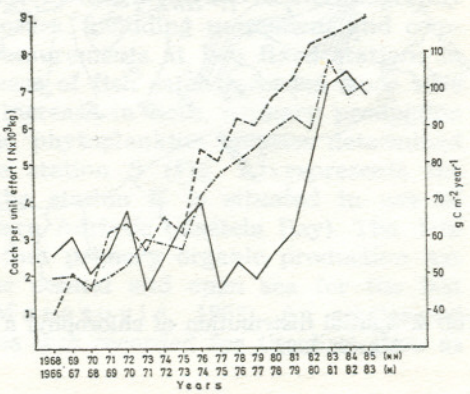

Fig. 5. Primary production at station Stončica (————), annual sardine catch per unit effort in the middle Adriatic (—.—.—.—.—), autumn sardine catch per unit effort in the middle Adriatic (— — — —). The time scales for sardine catch (* *) and primary production (*) are in good agreement but with time lag of two years

The last ingressions recorded in the Adriatic in 1976, 1977 and 1978 affected the phytoplankton community differently from the earlier ones (Vučetić and Pucher-Petković, 1969; Pucher-Petković *et al., 1971).* In relation to the diatoms, proportions of coccolithorids increased in the middle Adriatic as earlier but phosphate concentration and total phytoplankton biomass were reduced (Marasović and Pucher-Petković, 1983). This also affected fisheries resources as shown by a decrease of sardine catch in the middle Adriatic (Fig. 6). Namely, the catch was markedly reduced in the 1977—1980 period (Table 3) what may be brought into connexion with the ingression years.

Table 3. Sardine catch per unit effort on three fishing grounds III, IV and V (Fig. 7), in the middle Adriatic

	Catch per unit effort (kg)		
Year	III	IV	V
1975	2 609	2 129	1 721
1976	4 359	4 615	1 438
1977	4 682	3 425	1 785
1978	3 024	3 816	1 801
1979	3 109	2 610	1 856
1980	2 892	3 422	1 977
1981	4 356	6 025	2 220
1982	4 809	5 761	3 511
1983	6 862	6 976	2 081
1984	6 288	7 516	2 910
1985	5 823	8 860	3 455

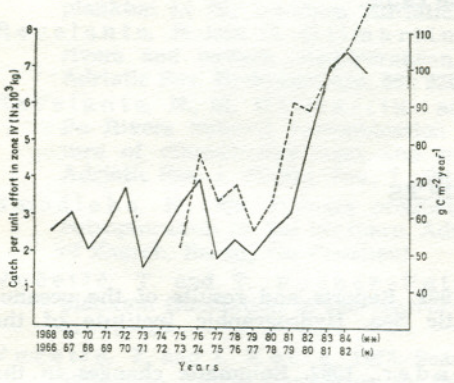

Fig. 6. Primary production at station Stočnica (————) and sardine catch in fishing ground IV (— — — —). The time scales for sardine catch (* *) and primary production (*) are in good agreement but with the time lag of two years

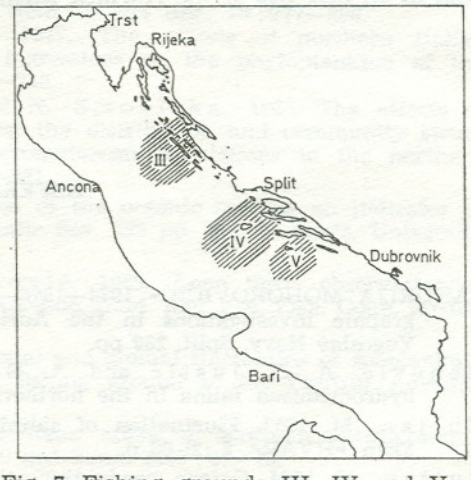

Fig. 7. Fishing grounds III, IV and V in the middle Adriatic

All the data brought out show that, at the moment, the effects of ingressions are very likely disguised by increased eutrophication, that is recent effects of ingressions on the Adriatic waters, particularly the coastal ones, are opposite to the earlier ones.

At mid seventies the first mass blooms began to occur in the coastal area causing the missing of summer phytoplankton minimum which had been characteristic of the seasonal phytoplankton cycle (Pucher-Petković, 1975). At the same time, these quantitative changes were followed by qualitative changes within the coastal phytoplankton community (Pucher-Petković et Marasović, 1980). It is of interest that summer minimum of phytoplankton density occurred in 1977 and 1978, affected by ingression, to disappear again in 1979. Since 1980 mass blooms have been from time to time accompanied with red tide occurrences. This is once again indicative of a considerably advanced eutrophication which has already begun to exert adverse effects in some bays (Marasović and Vukadin, 1982).

All the data presented in this paper support the fact that the process of intensified eutrophication has begun to develop in the open Adriatic waters, as well. This is very likely due to increasing intensity of the northern Adriatic impact on the middle Adriatic. Namely, affected by the Po river, the eutrophication has assumed very high levels in the northern Adriatic (Revelante and Gilmartin, 1976 a; 1976 b; 1977; Revelante *et al.*, 1985; Smodlaka, 1985; Benović *et al.*, 1987). The eutrophication of the open mid-Adriatic waters is, to a certain extent, also affected by highly eutrophicated coastal waters (Pucher-Petković and Marasović, 1988), the complete situation being superimposed by defined climatic changes (Hanson, 1988).

However, the eutrophication of the middle Adriatic open waters is a positive proces, which means that it positively affects living resources resulting in an increase of the Adriatic sardine catch.

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PRODUKTIVNOST JADRANA U ODNOSU NA PELAGIČNO RIBARSTVO

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KRATKI SADRŽAJ

Rad donosi novije rezultate (1974—1986) dugogodišnjih istraživanja produktivnosti Jadranskog mora. Obzirom na dosad već utvrđene zone različite produktivnosti, čija procjena je izvršena na bazi hranjivih soli i primarne organske produkcije, učinjen je sličan pokušaj na osnovu podataka o klorofilnoj biomasi. Dobijeni rezultati ukazuju da su nastupile izvjesne promjene u odnosima među ranije utvrđenim produktivnim zonama (Buljan, 1964; Pucher-Petković, 1974), odnosno da se postepeno reducira zona najniže produktivnosti na račun zona više produktivnosti.

Autori smatraju da na porast produktivnosti otvorenih voda srednjeg Jadrana utječe visoka eutrofikacija sjevernojadranske vode (pod utjecajem rijeke Po), kao i ubrzana eutrofikacija priobalnih voda, odnosno da su navedene promjene izazvane ljudskom aktivnošću. Ovakav zaključak potvrđuje se podacima o porastu primarne organske produkcije u srednjem Jadranu, kao i podacima o ulovu male plave ribe u tom području, koji je također u stalnom porastu posljednjih desetak godina.

Istovremeno je razmatran utjecaj ingresionih razdoblja (prodor istočnomediteranske vode u Jadran) na produktivnost otvorenih voda srednjeg Jadrana, pri čemu je uočeno da je za razliku od ranijih ingresionih perioda, u posljednjem ingresionom periodu (1977—1980) došlo do pada produktivnosti Jadrana. Na osnovu ovih rezultata autori postavljaju hipotezu, da zbog pojačane eutrofikacije Jadrana, u novije vrijeme prodori istočnomediteranske vode djeluju na obrnut način nego ranije, odnosno dovode do privremenog pada produktivnosti jer ublažavaju utjecaj obalnih i sjevernojadranskih voda.

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