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Major modifications of the Black Sea benthic and planktonic biota in the last three decades

by

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ABSTRACT

During the last three decades, increasing eutrophication and other man-made activities have considerably changed the structure and functioning of the Black Sea ecosystems, mainly in its NW corner, affecting both the qualitative and the quantitative state of the benthic and planktonic communities.

Marked changes have been registered especially in the structure of littoral ecosystems. The macrophytobenthos has shown a gradual but continuous decline, approximately since 1945-1950, due to both natural (e.g. occasional massive frosts) and anthropogenic factors (silting of the rocky bottom, increased turbidity, diminution of light penetration). The previously large belts of *Cystoseira barbata*, a perennial brown alga, along the western coast have practically disappeared as have numerous other associated and/or epiphytic algal and animal species. The present algal flora, which displays a reduced species diversity, is uniform. Generally it is dominated by *Enteromorpha intestinalis, E. linza, Ceramium elegans* and *C. arborescens*. These newly dominant species with short and nearly seasonal life cycles show considerable production but, nevertheless, they do not reach the levels attained by *Cystoseira* during previous decades.

The evolution of zoobenthos communities is marked by a qualitative impoverishment, expressed by a 50 to 60% reduction of species number

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since the 1960s, and by the decline in density of the numerous populations formerly omnipresent. Thus species which were prevailing and characteristic formerly (*Spio filicornis, Corbula mediterranea, Syndesmia fragilis, Spisula subtruncata, Mytilus galloprovincialis*) have given place to fewer opportunistic species (*Neanthes succinea, Polydora limicola, Melinna palmata, Mya arenaria, Scapharca inaequivalvis*) which have proliferated. The resulting population increases did not compensate however for the reduction of general biomass and density, which are lower by 35-84% than those measured 25 years ago. While zoobenthic communities have become more and more homogeneous as a result of mass proliferation of a few species, their structure is now more unstable owing to the permanent disturbance generated by blooms and related benthic mass mortalities.

Due to intense eutrophication phytoplankton biomass surpasses that of the past. Some essential structural changes have occurred and new quantitative and qualitative characteristics have been recorded. The increase of the amplitude and frequency of algal blooms is a significant ecological consequence of the accumulation of nutrients in sea water. Since 1970, blooms are no longer exceptional phenomena. For example, in the 1980's alone, 46 blooms due to 15 algal species were recorded in the Romanian littoral waters. Besides the bloom-producing species, other numerous mass species have remarkably developed. During the 1980's, 79 species recorded densities larger than 100,000 cells l^{-1}, as compared to 57 species in the 1970's, and only 38 species in the 1960's. Numerical density of the main species increased from the levels of the 1960's, for 66% of the species in the 1970's, and for 78% of the species in the 1980's.

From the 1960's to the 1980's the proportion of non-diatoms in the numerical density of phytoplankton increased from 8% to 62% of the total. Changes in the quantitative proportions of the main algal groups are due to the changes in the nutritive basis. These changes include the diminution of the ratios Si:N and Si:P (which is detrimental to diatoms), and the increase of organic matter (which favors the phytoplankters with mixotrophic affinities belonging to Dinoflagellata, Euglenida, and Chrysophyta).

Between 1983 and 1990 the average biomass of phytoplankton in Romanian coastal waters was more than 8 times higher than that assessed between 1959 and 1963.

The evolution of the zooplankton communities was marked by a simplification of structure and a diminution of species diversity, especially in the shore areas. Besides the total disappearance of some species (three species of copepods belonging to the family Pontellidae), the populations of some holoplanktonic species have diminished greatly, as for example *Centropages kröyeri*, *Penilia avirostris*, *Evadne tergestina* and *E. spinifera*. The populations of the meroplanktonic component of the zooplankton (the planktonic larval stages of benthic biota) have also diminished as a consequence of the mortalities produced in the benthic fauna. In contrast the density of a small number of opportunistic species (e.g. *Acartia clausi* and *Pleopis polyphemoides*) increased, the species becoming dominant in the communities. Another characteristic feature is the explosive development of *Noctiluca scintillans*, especially during the summer, following a significant algal bloom (in the summer of 1986 and 1987, this species represented 91-99% of the entire zooplankton biomass). Massive accumulation of the jellyfish

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Aurelia aurita has also been recorded. Between 1980 and 1987 the mean values of density and biomass of total zooplankton increased up to 10 times compared to those recorded in the decade 1960-1970, because of massive stocks of *Noctiluca* in the summer. The trophic zooplankton experienced a substantial decline of the population (especially during 1990-1991) and a decrease of planktivorous fish, concomitently with the appearance in the Black Sea waters of *Mnemiopsis leidyi* (a big consumer of plankton and fish juveniles). For the ecosystem components of the Black Sea as a whole, the strong relation between the dynamics of the structure of biocoenoses with space and time, as well as the variable character of dynamic processes at community level, became obvious during the last thirty years.

The number of bottom fish inhabiting the shallow coastal water sharply declined because of hypoxia. Pelagic fish have also undergone changes in the last two or three decades. Changes in the Black Sea ecosystem were reflected in the taxonomic composition of commercial catches.

Three species of dolphins inhabit the Black Sea. At present all riparian countries restrain from catching these marine mammals. Despite these measures, however, dolphin standing stocks have continued to decline.

INTRODUCTION

The dominant environmental feature of the Black Sea is the near total ecological collapse of this semi-enclosed brackish-water basin: the enormous hydrological, chemical and biological changes in the Danube river and other major tributaries in the North-Western part of the Black Sea over the last three decades have triggered disastrous changes in the Danube delta, the predanubian zone and/or the western Black Sea (e.g. ALEXANDROV, 1992). While pollution from land-based coastal sources plays a role in the degradation of these areas (e.g. BRONFMAN, 1992), the paramount source of the problems lies up in the Danube river and, to a lesser degree, in the Dniestr and Dniepr rivers.

The largest rivers flow through regions of intensive agriculture, developed industry, heavy transport and densely populated cities contributing to the discharges of human activity. Annually, these rivers carry into the western Black Sea (in tons, approximately): – solid particle, 1.3 10^8 – salts, 6.9 10^7 – calcium carbonate, 8.6 10^6 – Fe, 4.5 10^5 – Zn, 1.7 10^5 – detergents, 4.0 10^4 – Cu, 7.5 10^3 – Pb, 5.5 10^3 – As, 1.8 10^3 – Cd, 170 – Hg, 60. Owing to the large catchment area of river run-off and to limited water exchange with the Mediterranean and the Sea of Azov, the Black Sea has become in the last two decades an "ecological target" of land-based sources of pollution, especially in the western part (ZAITSEV, 1992a). Data on the direct and indirect influence of the Danube run-off on the bottom and pelagic ecosystems of the Black Sea have been generalized; it has been shown that the zone of the Danube influence of the Black Sea makes up not less than 100 000 km^2 (ZAITSEV *et al.* 1989).

The ecological changes in the Black Sea, stem largely from the pollution load of the Danube river; they have resulted in a massive reduction of biota, both vegetal and animal, including fish stocks and fish catches.

Yet there is little direct evidence for the influence of heavy metals and other pollutants on Black Sea organisms in natural conditions, although

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sharp declines in populations have been registered in some cases in biotopes where toxicants do accumulate, such as the surface microlayer, the surf zone, estuaries and zones of river influence (ZAITSEV, 1992b). Biogenic substances such as nitrates and phosphates have caused the most profound and extensive changes in the Black Sea ecosystem during the second half of the 20[th] century. These changes are most evident in the NW waters where, adjacent to the coastline of Ukraine, Romania and Bulgaria, lies two-third of the total Black Sea shelf with an area of 64 000 km^2.

MACROPHYTOBENTHOS

Along with increasing eutrophication, marked changes have been recorded in the structure and functions of the macrophytobenthos.

Due to the large amount of suspended particles and plankton, the transparency of sea water has significantly decreased (Fig. 1). The position of the compensation depth changed as a result, and bottom seaweeds growing deeper than 7-8 m became shaded. This accounted for the large decline of macrophytes, in spite of high nutrient levels.

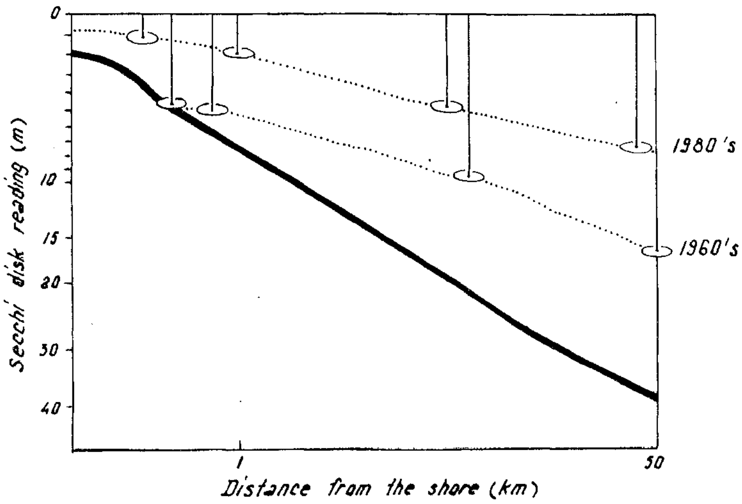

Fig. 1 – The penetration of light into Black Sea waters in the 1960s and 1980s (cf. ZAITSEV, 1992b).

Due to the variability of the ecological factors, these changes of the ecosystems and community structure led to the replacement of some phytocenoses by others. The consequence was a change in the seasonal and multiannual dynamics of the algal communities.

For example, in the bays of Sevastopol and Novorosiisk, a sustained destruction of the phytocenoses took place in the course of several years. Multiyearly modifications of the community structure have also been noticed in the open littoral areas, where there is a weak influence of the anthropogenic interactions; observations on the benthic vegetation in those areas have shown the increasing part of the oligosaprophyte species (KALUGINA-GUTNIK, 1979).

The negative influence of the various forms of anthropogenic action is obvious first of all at the level of the coastal algal belt, which plays a special role in the protection of the littoral, in the cleaning of littoral waters, and in the protection of associated species.

Important ways of anthropogenic interactions influencing the phytobenthos in the NW corner are the following:

- hydrotechnical constructions placed along the littoral (harbours included),
- water course regulation for the Danube, Dniestr and Dniepr,
- opening of the Danube – Black Sea Canal,
- deterioration of the quality of river inputs,
- increase of mineral and organic pollutants,
- pollution by uncontrolled overfalls and oil,
- human concentration on the seaside during summer time.

The interaction of these various anthropogenic factors on the vegetation brings different results, ranging from structure simplification to complete disappearance (CELAN, 1977; EREMENKO, 1979; BOLOGA, 1989a). The most obvious consequences followed landslides due to construction works (dams, barrages, ways), when the algal carpet was covered by sand and/or mud. In such circumstances, the communities of *Cystoseira* have been replaced by *Cladophora* or *Ceramium*; macrophytes are encountered today in the narrow fringe near the shore itself at a depth less than 3-5 m, where species tolerant to eutrophication: *Enteromorpha intestinalis*, *E. prolifera*, *Cladophora vagabunda*, *Ceramium elegans*, etc., occur (EREMENKO, 1977, 1979).

The brown alga *Cystoseira barbata*, a species very sensitive to the amount of detergents in sea water, has practically disappeared along the NW coast of the Black Sea (ZAITSEV, 1992b).

As to the unique "Zernov's field" of *Phyllophora* in the central part of the NW Black Sea, it covered in 1950s an area equal to 10 000 km^2, with a total biomass reaching about 10 000 000 t; towards 1980, it was reduced to 3 000 km^2 in area and to 1 400 000 t in biomass. In 1990, these values had declined to 50 km^2 and 300 000-500 000 t (ZAITSEV, 1992b).

The aggregation of *Phyllophora* was an important source of oxygen. According to some data, these seaweeds produced up to 12 000 000 m^3 of O_2 per day (ZAITSEV, 1992b).

Many losses have occurred on the shelf due to consequent reduction of "Zernov's field" (Fig. 2). The associated fauna disappeared, especially sponges, sea anemones, isopods, amphipods, shrimps, crabs, ascidians, plus more than 40 species of fish, specific to this area (ZAITSEV, 1992b).

In the last 20 years the standing stock of eelgrass, *Zostera*, has decreased tenfold in the shallow waters. Eelgrass serve as a favourable biotope for many species of invertebrates and fish. The reason for the degradation of *Zostera* communities was the mobilizing of silt when dredging in the coastal zone (ZAITSEV, 1992b).

The Romanian algological literature concerning the Black Sea macrophytobenthos covers at present a period of over 100 years (BOLOGA, 1987/88). This research, initially restricted to field observations and descrip-

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Fig. 2 – Progressive reduction of Zernov's field of *Phyllophora* on the NW shelf of the Black Sea in 1950 (1), 1960 (2), 1970 (3) and 1980 (4) (cf. ZAITSEV, 1992b).

tions of the main species of green, brown and red algae off the Romanian coast, was to know a permanent development with time (BOLOGA, 1989b). Later on, checklists of macrophytes added to the relevant reference in this field.

From 1935 (CELAN, 1935) up to the 1980's, 154 species of macrophytes have been identified along the Romanian Black Sea shore (BAVARU *et al.*, 1991): 47 Chlorophyta, 2 Xanthophyta, 30 Phaeophyta, and 79 Rhodophyta. Their number decreased with time to 77 (SKOLKA, 1969). For the period 1970-1981 only 69 species have been recorded (VASILIU, 1984).

It is obvious that the benthic algal flora has endured a gradual, but continuous decline since the years 1946/1950 (CELAN, 1977, 1981; CELAN *et al.*, 1969; CELAN and BAVARU, 1973), a decline both qualitative and quantitative (CELAN *et al.*, 1979). The accentuation of this decline during the last three decades is due to natural and anthropogenic factors that have disturbed the quality of the marine environment (BOLOGA, 1989a).

The uniform aspect of the present algal flora is due to the total or almost total disappearance of many species during the last 30 to 50 years. The quasi-complete disappearance of the previous *Cystoseira* belts is the most striking. Its two species, *C. barbata* and *C. crinita f. bosphorica* (= *C. bosphorica*), have represented the dominant perennial phytobenthic biota in the NW Black Sea. Their important ecological role has consisted mainly in offering a substrate for the mass development of other epiphytic macrophytes. Among the high number of recently disappeared Phaeophyta and Rhodophyta the species *Laurencia* deserves special consideration. The phanerogames *Zostera marina* and *Z. nana* have also endured a severe decline.

During the last decade a higher specific diversity was peculiar only to the southern sector of the Romanian shore where, in 1982, 24 taxa were registred (CELAN and BOLOGA, 1983). This survey allowed interesting observations, especially on the species of *Ceramium*, the most common, productive and adaptable taxa, showing a high individual and ecological variability.

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Due to eutrophication, an intensification of the production of persisting macrophytes also took place. The free substrate, previously populated by *Cystoseira*, with a slow growth rate, is now usually covered by species with a short life cycle, more or less seasonal, but having a rapid growth. The most frequent species belong to the genera *Enteromorpha* and *Ceramium*, and to a smaller extent to *Ulva*, *Cladophora*, *Bryopsis* and *Callithamnion*. There is a distinct relation between the degree of coastal eutrophication and the thaloma of algae: in eutrophic waters, algal species with a high thaloma surface are the most common (MINICHEVA, 1990).

The physiognomy of the present flora is dominated by several species of *Enteromorpha* and *Ceramium* (BOLOGA, 1989a). At the beginning of the algal decline, a belt composed by species of *Enteromorpha* and *Cladophora* first developed in the warm period of the year; with time, different *Ceramium* species replaced the previous ones, reaching depths to 8-9 m. In the last years, *Bryopsis plumosa* also developed during the whole summer season. Southward, along the Bulgarian coast, the biomass of *Ulva lactuca, Cystoseira barbata* and of *C. crinita f. bosphorica* increased. The relatively high biomass of these macrophytes with short life cycles is not comparable however to that, much higher, of *Cystoseira* belts in the previous decades.

The causes of the algal decline is not yet completely elucidated. The almost complete disappearance of *Cystoseira* – at least along the Romanian shore – is due to increasing water turbidity and silting of the rocky bottom. This caused a decline of animal populations and even the disappearance of whole faunistic groups, affecting negatively the ichtyofauna and thus marine fishing.

The most important feature of the new algal community consists in the very small number of species. These species show however considerable production; some of them (*Enteromorpha*, *Ceramium*) displaying a degree of cover up to 80% (BOLOGA, 1989a).

On other shores, research on the Bulgarian macroflora did show a large regression in the quantitative distribution of *Cystoseira barbata*, *Zostera marina* and *Z. nana* (PETROVA-KARADJOVA, 1975, 1982). The first publication on marine algae off the Turkish coasts appeared in 1899 when 61 algae were recorded in the Bosphorus and Golden Horn (GÜVEN *et al.*, 1991). A collection of algae from 1894-1895 was revised and its content published (ÖZTIG, 1971). The studies on marine algae of Turkey were summarized for 1843-1978 (CIRIK and GÜNER, 1979), for 1894-1970 (GÜVEN and ÖZTIG, 1971), and for 1899-1990 (GÜVEN *et al.*, 1991).

The recovery of algal life is delayed not only by the increasing eutrophication, but also by other human activities. In the last 20 years, the littoral of the western Black Sea coast bears ample transformation directly related to harbour, industry and tourism development (SKOLKA *et al.*, 1980). These constructions bring huge amounts of terrigenous material to the sea, contributing to the increase of suspended matter in the shallow waters with the mentioned ecological consequences.

PHYTOPLANKTON

In the last two decades, increased loads of nitrogen, phosphorus and organic matter in the Danube and other rivers in the NW Black Sea

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(PECHEANU *et al.*, 1977; SERBANESCU *et al.* 1978; DOROGAN *et al.*, 1985, 1986; ZAITSEV *et al.*, 1985, 1987; FASHCHUK *et al.*, 1991) and in the direct discharges of waste waters found their way in the marine environment. The western Black Sea is the most affected; since 1970, the nutrient concentration in that area is markedly higher (GARKAVAYA *et al.*, 1978; COCIASU and POPA, 1980; COCIASU *et al.*, 1981; GARKAVAYA *et al.*, quoted by ZAITSEV, 1992b; COCIASU, 1990). For example, in the Romanian sector, nitrogen concentrations in 1971-1990 were 2.5 to 8.4 times higher, those of phosphates 1.4 to 5.1 times higher than in the 1960's. In zones, such as Constantza, close to strong polluting sources, the increase was up to 20 times (BODEANU, 1992).

The intense eutrophication has produced changes in the phytoplankton quantitative development (Fig. 3) and structure as well as in the primary production (Fig. 4). Most important is the increase in amplitude, frequency and spatial extension of algal blooms. Until the 1970's large algal blooms were exceptional; they have since become yearly phenomena (BODEANU, 1984a,b,c, 1987, 1987-1988, 1989, 1992), with much higher densities (NESTEROVA, 1977, 1979, 1981, 1982, 1985, 1987, 1990; BODEANU, 1984a, 1987, 1992; PETROVA-KARADJOVA, 1984, 1985, 1986, 1990; SUKHANOVA *et al.*, 1988) and a broader range (FASHCHUK *et al.*, 1991).

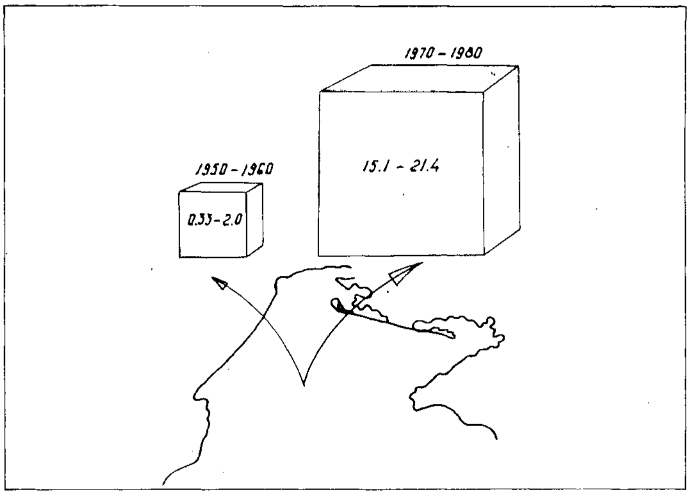

Fig. 3 – Total summer phytoplankton biomass (in N x 10^6t) in the North-Western part of the Black Sea (cf. ZAITSEV, 1992b).

The largest and most frequent algal blooms have occurred in the western Black Sea. During the last decade (1981-1990), 46 algal blooms produced by 15 species were registered in Romanian littoral waters (BODEANU, 1992). The most frequent species is the dinoflagellate *Prorocentrum cordatum* causing blooms each summer since 1973 (BODEANU and ROBAN, 1975, 1989, BODEANU and USURELU, 1979; ZAITSEV, 1979; BODEANU, 1983, 1984c, 1987, 1989, 1992; ZAITSEV *et al.*, 1987; FASHCHUK *et al.* 1991), then *Heterocapsa triquetra*, *Eutreptia lanowii*, *Skeletonema costatum*, *Coccolithus huxleyi*, *Hillea fusiforme,* etc.

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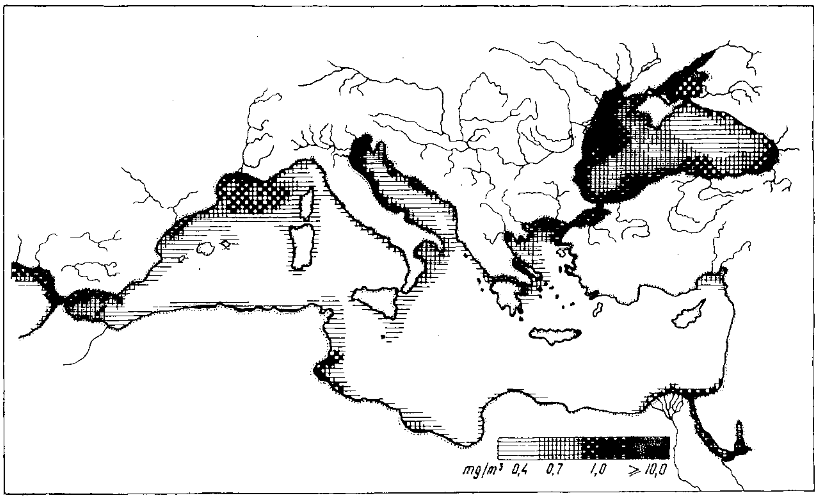

Fig. 4 – The concentration of chlorophyll *a* (mg/m^3) in the upper layer of different seas in the Mediterranean basin.

For most of the bloom species, population peaks were achieved recently. For the period 1981-1990, *Prorocentrum cordatum* reached 807.6 million cells l^{-1} compared to 50.8 million in 1960-1970, *Coccolithus huxleyi* – 291.2 million compared to 95 thousand, *Skeletonema costatum* – 141.4 million compared to 18 million, *Cyclotella caspia* – 300 million compared to 28.1 million, *Cerataulina pelagica* – 6 million compared to 922 000, *Nitzschia closterium* 13.1 million compared to 110 000 (BODEANU, 1984a, 1989, 1992).

Among the forms causing blooms recently, some were only modestly abondant until the 1970's, with numerical maxima of the order of thousands or tens of thousands per litre. Some of those (with the values of cells per litre achieved in 1971-1990 off the Romanian shore) are: *Scripsiella trochoidea* (25.8 million), *Heterocapsa triquetra* (97.6 million), *Eutreptia lanowii* (108 million), *Skeletonema subsalsum* (18.7 million) *Chaetoceros similis f. solitarius* (21.5 million), *Nitzschia tenuirostris* (74.8 million), *Chromulina* sp. (one billion) (BODEANU, 1984a, 1989, 1992).

Regarding the extension of blooms in the western Black Sea, it must be noted that until the 1950's, there were three zones affected by the red tide at the confluences of the Danube, Dniestr and Dniepr in summer time (IVANOV, 1959). Today, these are united in a large region, covering practically up to 50 % of the surface of the western Black Sea and exceeding 8 to 10 times the sum of the initial areas (FASHCHUK *et al.*, 1991).

Besides the bloom-producing species which cause a change of water colour, numerous other algae have achieved remarkable numerical densities. Thus, in Romanian waters, species with densities exceeding 100 000 cells l^{-1} have increased from 38 in the 1960's to 57 in the 1970's (BODEANU, 1989) and 79 in the 1980's (BODEANU, 1992).

The algae with declining densities are mainly diatoms, with large and thick silicate shell: *Rhizosolenia calcaravis, Thalassionema nitzschioides Diatoma elongatum*; these species lost in the last two decades the impor-

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tance they had in the 1960's (BODEANU, 1969, 1987-1988). Their replacement by small species such as *Prorocentrum cordatum*, *Eutreptia lanowii*, *Coccolithus huxleyi*, *Hillea fusiforme*, having high division speed and high metabolic potential, is characteristic of immature communities (SEMINA, 1974), such as those disturbed by the eutrophication of the NW Black Sea.

The phytoplankton community changed drastically as a result. In particular, the proportion of diatoms has declined remarkably, falling in Romanian waters from 92.3% in the 1960's to 38.3% in the 1980's (BODEANU, 1992).

Dinoflagellates on the other hand have increased, especially during summer (NESTEROVA, 1987; BODEANU, 1989) due to an affinity for warm water. For the NW Black Sea (Odessa bay, Romanian coast and northern half of Bulgarian coast), the proportion of dinoflagellates in the total phytoplankton biomass increased from 18.8% in the 1960s during summer season (IVANOV, 1967) to 54.5% in 1975-1980 (NESTEROVA, 1987). Even in weakly eutrophicated areas such as Sevastopol bay, the dominant species are now in summer-autumn forms with heterotrophic peculiarities such as dinoflagellates and other small flagellates (ROUHIAINEN, 1988).

Among non-diatoms, one notes the frequent blooms produced by the dinoflagellates *Prorocentrum cordatum* and *Heterocapsa triquetra*, the euglenid *Eutreptia lanowii*, the chrysophyte *Coccolithus huxleyi*, and more recently the appearance of blooms caused by the dinoflagellate *Scripsiella trochoidea* or the chrysophyte *Hillea fusiforme* (BODEANU, 1992).

The modifications in phytoplankton community structure in the last two decades are linked to changes in the structure of the nutrient basis (BODEANU, 1992), mainly:

1. the decrease in the ratios of Si:N and Si:P; the decrease of silicate concentration is due mainly to dams construction limiting the solid flow in the tributary rivers (BONDAR, 1972; BONDAR and STATE, 1977);

2. the surplus of organic matter enriches the nutrient base, thus ensuring favourable conditions for the development of certain species with mixotrophic affinities (Dinoflagellata, Euglenida, Chrysophyta).

In the Romanian sector of the Black Sea, phytoplankton average biomass reached 4105 mg m^{-3} in 1983-1990 (BODEANU, 1992), that is 8 times higher than the average of 495 mg m^{-3} recorded in 1959-1963 (SKOLKA, 1967). For the NW Black Sea (Odessa bay) the increase is even more important as biomass increased 26 times in 30 years (ZAITSEV *et al.*, 1985). For the whole Black Sea, maximum values have increased from 52 to 800 g m^{-3} during the last three decades (ZAITSEV *et al.*, 1987).

The eastern Black Sea lacks the direct influx of large tributary rivers and for the time being is less eutrophic. Still eutrophication is present in this area, where intensive developments of microflora are registered (NIZHEGORODOVA *et al.*, 1980).

ZOOBENTHOS

The exuberant growth of the phytoplankton during the last decades, culminating in very frequent and extensive blooms, has had serious consequences on the zoobenthos.

As algal blooms generate enormous quantities of dead organic matter in

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the water column, the oxygen shortage thus created causes gradually the death of other organisms in the ecosystem, mainly in the benthos. As a consequence, the last years have seen precarious conditions for benthic populations, with profound modifications in the community structure.

First, the number of species has been much reduced, and previously abundant species are now less frequent (*Corbula mediterranea, Abra milaschevici, Cardium paucicostatum, Chione gallina, Hydrobia ventrosa* among molluscs; *Spio filicornis, Glycera alba, Nereis diversicolor, Nerine cirratulus*, etc. among polychaetes; the tunicates *Ascidiella aspersa* and *Ciona intestinalis*; very many crustaceans, etc.). The crustaceans are the most affected group by the reduction of the number of species.

The quantitative structure of the benthic communities has changed, sensitive populations have diminished while those resistant to the alteration of the environment conditions have proliferated. Thus, such molluscs as *Corbula mediterranea, Chione gallina, Moerella tenuis, Hydrobia ventrosa*, which 25 years ago formed 94% of the mollusc density and 96% of the benthic general biomass in the fine sands biocoenosis (BACESCU *et al.*, 1965), are about to disappear. The same is true for the polychaete *Spio filicornis*, that reached hundreds of thousands of specimens per m^2 once, and for *Spisula subtruncata, Abra milaschevici* which often dominated some silt communities in the past at depths of 20 to 40 m (BACESCU *et al.*, 1971). The populations of *Mytilus galloprovincialis* and *Modiolus phaseolinus* have also decreased, but they still represent an important part of the silt community. On the other hand, the populations of some opportunistic species have proliferated and they have become dominant in some communities: *Mya arenaria, Scapharca inaequivalvis, Neanthes succinea, Polydora limicola, Melinna palmata* (fig. 5) (GOMOIU, 1976, 1984; TIGANUS, 1982b, 1986a,b, 1988a,b, 1990; LOSOVSKAYA *et al.*, 1990).

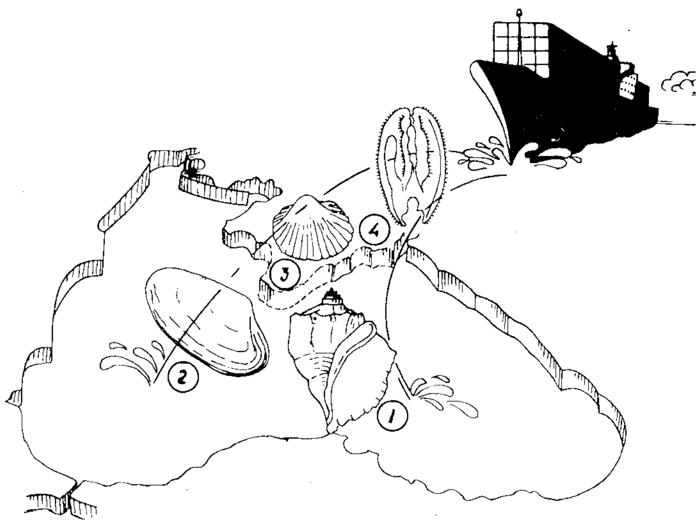

Fig. 5 – Additional Black Sea fauna from bilgewater and fouling of. (Not to scale, cf. Zaitsev, 1992b). 1 – *Rapana thomasiana thomasiana* (first reference in 1947), 2 – *Mya arenaria* (1967), 3 – *Cunearca cornea* (1984), 4 – *Mnemiopsis leidyi* (1988).

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The benthic communities are characterized by a large instability. Every year, hypoxia and even anoxia affect large areas, but their location is different, depending on the specific hydro-meteorological conditions. There are always zones where the communities are affected by mortalities and other zones where the communities are recovering following a temporary improvement of the environmental conditions (TIGANUS, 1982a, 1986b). The sequence of these processes with rather short periods has caused a certain size and age structure of the bivalve populations, which need several years to reach maximum sizes. Thus, 90 to 100% of their populations consist of young specimens.

The reduction of the bivalve populations along with the dominance of young small specimens have produced a diminution of the natural biofiltre; this has contributed to the increase of the organic matter surplus and consequently aggravated the effects of eutrophication.

The seasonal dynamics of the zoobenthic populations has been disturbed and is now atypical: densities and biomasses are higher during the cold months of the year than during the warm ones, when the spawning and growing processes are usually most intense. The recovery of the benthic populations is slow and incomplete, because it takes place especially during cold months.

Lastly the maintenance and increase of unfavourable conditions affected the enduring species, which gradually diminished their effectives although they form an increasing part of the macrobenthos density and biomass. In the period 1976 to 1986, when eutrophication was less advanced, the macrobenthos density and general biomass increased owing to the proliferation of the opportunistic species, while more recently (since 1989) the zoobenthos declined constantly and steadily.

The periazoic level, limited at depths of 120 to 130 m in 1950-1960, has expanded to the coast recently, so that its boundaries now begin at the depth of 100 m. This is also a proof of the regressive evolution of the pontic benthos (GOMOIU and TIGANUS, 1990).

ZOOPLANKTON

Environmental changes in the Black Sea – first of all the increase of eutrophication, of primary production and of organic matter content in the water – have been reflected by the zooplankton community as well.

For the last decade, the simplification of the qualitative structure and the reduction of the species diversity was more obvious, particularly in coastal waters, where the closer influence of some pollution sources such as waste water flows represent an additional aggressive factor for the more sensitive species. The multiyearly observations carried out in such areas of the Black Sea littoral have identified communities including sometimes two or three species using in a high degree the organic matter found there in large quantities (planktonic ciliates, rotifers, *Noctiluca*), with very low diversity indices during summer (H = 0.07-1.2) (PETRAN, 1986, 1988a,b). The high concentrations of bacterioplankton in those areas have favoured the development of a rich microzooplankton including mostly ciliates and rotifers that depend on a rich energetic source (see PAVLOVSKAYA, 1976; LEBEDEVA *et al.*, 1982, SHUSHKINA *et al.*, 1985).

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The superficial and ultrasuperficial ecosystem inhabited by hyponeustonic species have been the most exposed to pollution. Here copepod species belonging to the family Pontellidae – *Anomalocera patersoni, Pontella mediterranea, Labidocera brunescens* – once forming large concentrations, especially in the contact zones between the marine and fresh waters in the basins influenced by the Danube, Dniepr, Dniestr (PETRAN, 1962, 1976; ZAITSEV, 1979), suffered a considerable reduction of their populations during the following years (fig. 6). In 1983, there were two specimens m^{-3} in the waters nearer the offshore zones.

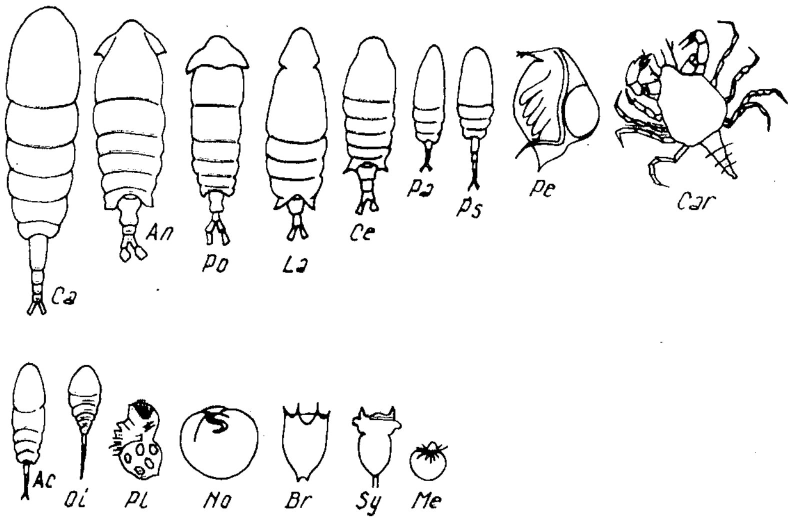

Fig. 6 – Large size planktonic organisms which dominated in Black Sea coastal waters till the 1960s were replaced by small-size in the 1980s (cf. ZAITSEV, 1992b).

Besides the fact that their ecosystem is the most exposed to the human influence, the Pontellidae avoid waters where the Peridineans are much developed. Yet it is the surface water layer which contains the largest algal agglomerations during blooms (POLISCHUK, 1977).

Other zooplanktonic organisms which have not been found for the last 20 years are copepods species belonging to the family Monstrillidae. Three species of this family were steadily included in large numbers in the plankton at the Romanian littoral in the 1960's: *Monstrilla grandis, M. helgolandica, M. longiremis* (PORUMB, 1961).

The planktonic mysid *Mesopodopsis slabberi*, an important species in the fish food, abundant in the 1950's in the whole predanubian zone of the Black Sea where ten thousands of specimens m^{-3} were found, diminished much of its populations since 1970. So, a special assessment in 1975 revealed that the highest density did not exceed 94 specimens m^{-3} and subsequently, up to 1984, only isolated specimens have been recorded.

Regarding the decrease of some zooplanktonic group populations, the status of the meroplanktonic organisms is self-evident. The sizes of the populations of this larval component of zooplankton mirrored the changes in the benthic communities and suffered important modifications in the 1980's.

BOOK IN STOCK

On the Romanian littoral, the larval stages of the benthic biota in the plankton (especially molluscs, but also polychaete worms and the crustacean *Balanus improvisus*) have represented an important fraction of the zooplankton biomasses until the 1970's (PETRAN and GOMOIU, 1965; PORUMB, 1969; PETRAN 1980). In the predanubian zone, as a consequence of extension over this sedimentary zone of the populations of *Mya arenaria* and *Melinna palmata*, the meroplankton species maintained their importance in the zooplankton communities until 1980 (PETRAN and ONCIU, 1979; PETRAN, 1986).

In 1986-1990, molluscs mortalities resulted in a substantial reduction of the meroplankton in the plankton biomass in that period (not exceeding 12%), with peaks at the Danube's mouths contributed by the larval stages of polychaetes (PETRAN and RUSU, 1990).

Thus, the increased frequency and extension of the blooms not only affected directly the benthic communities but also influenced indirectly the pelagic communities by reducing meroplankton, known as a basic food for planktivorous fish.

Other holoplanktonic populations playing an important trophic part in the ecosystem have been diminished. Among the copepods, one could note *Centropages ponticus* once abundant especially in the predanubian space (PETRAN and ONCIU 1977, 1979), whose populations were reduced two to three times during the 1980's. *Penilia avirostris*, dominant especially in the marine area off the Danube's mouths but with high densities in the whole basin, has gradually reduced its populations after 1980 when *Pleopis polyphemoides* became dominant. The large densities of this species during the last years in the Ukrainian and Bulgarian waters let it be considered as an indicator of highly eutrophic environment (ALTMAN *et al.*, 1990).

The reduction of species diversity has been accompanied by the spectacular development of a small number of species with large biomass. These are herbivorous and detritivorous opportunistic species. The copepod *Acartia clausi* is dominant, both in terms of frequency (F% = 83-100) and in terms of biomass: between 1980 and 1987, these were four to five times higher than in the previous decade. In Romanian coastal waters, in summer time, almost monospecific communities of *A. clausi* were noted (in July and August 1981 and 1985, the domination index of this species was 99.9%) (PETRAN, 1986). The second characteristic species is *Pleopis polyphemoides* (F% = 75-85), with densities in 1980-1987 five to six times higher than the means in the decade 1960-1970, an important food source for planktivorous fish, especially for *Sprattus sprattus* (PORUMB, 1986). Other observations carried out since 1980 in the NW Black Sea, in stations between the Danube's mouths and the Bosphorus, have confirmed the dominant status of *Acartia clausi* and *Pleopis polyphemoides* (KONOVALOV *et al.*, 1991).

Two other species with a minor part in the bio-economy of the Black Sea have developed exuberantly. The first of them is the cystoflagellate *Noctiluca scintillans*, which has had the most spectacular quantitative development during the last decade. Its population explosions, which are real blooms during the summer months, represent one of the structural features in the characteristic evolution of the Black Sea pelagic zone (Fig. 7). It is a rather saprophagous species, with detritus representing 70 to 90% of its food (PETIPA *et al.*, 1970) and its massive growths in the plankton immedia-

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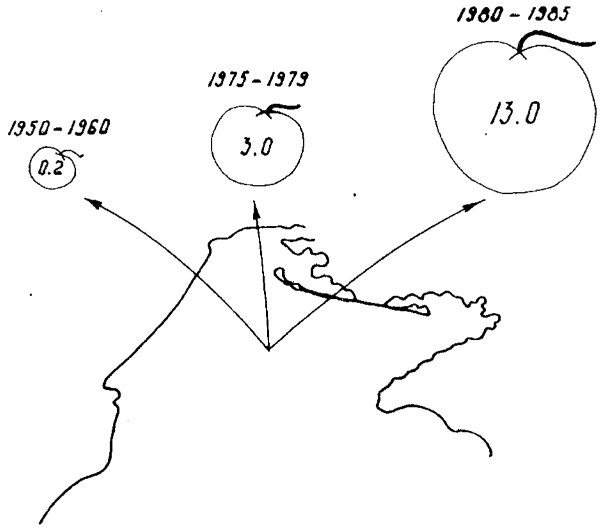

Fig. 5 – Total summer biomass of *Noctiluca miliaris* (in N · 10^6 t) in the North-Western part of the Black Sea (cf. ZAITSEV, 1992b).

tely follow large phytoplanktonic blooms. The densities and biomasses of this species in the 1980's were about 10 times higher than in the previous period (1970-1980), with peaks in the littoral waters north of Constantza at 2 048 000 specimens m^{-3} and 164 g m^{-3} in August 1987.

Along the Ukrainian coast, in the shallow waters of the NW corner of the Black Sea, intensive growths of *Noctiluca* have been noted for the last decade, with biomasses of 11 g m^{-3}, representing values 100 times higher than those recorded in 1960-1970 (ZAITSEV *et al.*, 1987). The research carried out between 1981 and 1985 on the Bulgarian littoral, between the bays of Burgas and Sozopol – highly eutrophic areas – indicated that the zooplankton was dominated by two species: *N. miliaris* and the copepod *Acartia clausi* (VINOGRADOV and SHUSHKINA, 1985; KONSULOV, 1986; KONSULOV, in press). Real blooms of *Noctiluca scintillans* (43 g m^{-3}) have also occurred on the eastern coast of the Black Sea and in Turkish waters (VINOGRADOV and ARNAUTOV, 1986; TUNCER and FEYZIOGLU, 1989).

On the Romanian littoral, with the exception of 1985, *N. scintillans* represented 91-99.9% of zooplankton density and general biomass during the summers of 1980-1991. The steady increase of zooplankton total quantities is clearly due to that species. Table I illustrates the numerical and weight maximum dominance (D%) of this species in the zooplanktonic community in Constantza area.

The important surplus of phytoplankton and detritus, as well as an abundant microzooplankton in the Black Sea pelagic zone, have favoured the massive growth of another species with a minor part in the bio-economy of the Black Sea – the jellyfish *Aurelia aurita*.

For the period 1950-1962, and for the whole Black Sea basin, assessments of that species were of 93 to 1600 thousand tons (MIRONOV, 1971). In 1978, they reached 300 to 450 million t (GOMOIU and KUPRIANOV, 1980).

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The quantitative increase of this jelly fish has resulted in a decrease of the number of planktivorous fish competing for food (ZAITSEV, 1979; ZAITSEV and POLISCHUK, 1984).

TABLE I

The numerical and weight maximum dominant (D%) of Noctiluca scintillans in zooplanktonic populations in Constantza area.

Years	Month	D% in total density	D% in total biomass
1982	July	91,5	95,8
1983	June	94,7	96,7
1984	August	95,6	99,1
1985	July	41,0	34,3
1986	July	91,5	98,3
1987	July	92,3	98,5
1988	August	91,5	98,5
1989	July	97,9	99,9
1990	August	97,5	99,3
1991	July	99,2	99,8

Not being consumed, the concentrations of jellyfish are in fact the dead end of pelagic food webs. They are brought by winds and currents into the coastal area where they create discomfort.

One can estimate that for the last two decades, even with increased eutrophication and a reduced species diversity, the structure and relations between the remaining species tend to maintain an organization ensuring a very efficient utilization of the energy sources (rich food including microphytes and organic matter) by the species with a high ecological plasticity: a smaller number of herbivorous and detritivorous species with massive growth.

Since 1986, a degradation of the zooplanktonic communities has been noted; their situation became very precarious especially during summer, a severe reduction of population being registered for most of the groups of organisms with trophic value.

The analysis of the evolution of the zooplankton quantities for the period 1986-1991 reveals a different dynamic between the total zooplankton (including *Noctiluca*) and the trophic zooplankton.

Thus, while total biomass increased from 1986 until 1990, owing to the blooms of *Noctiluca*, the trophic zooplankton biomass decreased so that in 1988 the useful biomass represented only 2% of the total.

In 1990 and 1991, the average values of the trophic zooplankton densities were six to seven times lower than in 1989, and in 1991 the numerical density was three times smaller than in 1990, due to the fact that even the species with intensive growth during the previous years (1980-1987) – *Acartia clausi*, *Pleopis polyphemoides* – had a very low quantitative level those two years.

This decrease of zooplankton has been correlated with a spectacular reduction of the catches of fish feeding on plankton (in the Romanian fishery, the anchovy production decreased from 6,354 t in 1984 to 1,946 t in 1988, 66 t in 1989, and only 5 t in 1990: the production of sprat was 8,912 t in 1989, 3,198 t in 1990, and 720 t in 1991; the production of horse mackerel was reduced from 1,459 t to 165 t in 1990.

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The structural degradation and population decrease of all zooplankton species with a trophic role in the coastal ecosystem during the last three to four years must be attributed to a great extent to the appearance of a new migrant in the pelagic zone of the Black sea – the predatory ctenophore *Mnemiopsis leidyi*. This species was first noted at the Russian and Ukrainian coasts feeding on huge quantities of plankton and fish juveniles, thus competing for food with planktivorous fish and causing the decrease of their stocks (SHUSHKINA *et al.*, 1990). In 1988 its presence was notified in the whole pontic basin, where it was considered a major consumer of zooplankton and held responsible for the fishery decline (KONOVALOV *et al.*, 1991).

Like the jellyfish *Aurelia aurita*, the ctenophore *Mnemiopsis leidyi* is a dead end in the trophic relations in the Black Sea, so that it represents a loss of organic matter generated in this basin. Currently, they are the main beneficiaries of the eutrophication process which is also amplified by the nutrients they release in the environment after their death.

FISH AND MAMMALS

The number of bottom fish inhabiting the shallow coastal waters has sharply declined because of hypoxia: Gobiidae, Blenniidae, Labridae, Callionymidae, as well as the stingray (*Dasyatis pastinaca*), thornback ray (*Raja clavata*), turbot (*Psetta maeotica*), flounder (*Platichthys flesus luscus*), sole (*Solea lascaris*), red mullet (*Mullus barbatus ponticus*), weever (*Trachinus draco*), stargazer (*Uranoscopus scaber*), sturgeon (*Acipenseridae*) (ZAITSEV, 1992a).

In the last two-three decades, pelagic fish have also undergone changes. Large predators, such as Atlantic bonito, bluefish, mackerel and the largest common tunafish and swordfish have disappeared. After the disappearance of predatory fish, the number of small pelagic fish – anchovy, sprat, Black Sea horse mackerel – has increased: now they make up more than 90% of the catch (ZAITSEV, 1992a).

Changes in the Black Sea ecosystem are reflected in the taxonomic composition of commercial catches. So, until 1960s, 26 commercially valuable fish species were caught in the NW waters. In the 1980s, this amount had declined to five – one deep benthic species and four pelagic (Table II) – while fish catches gradually increased during the last 50 years due to the development of fishing craft (Table III).

Three species of dolphins inhabit the Black Sea: the bottle-nosed dolphin (*Tursiops truncatus*), the common dolphin (*Delphinus delphis*), and the harbour porpoise (*Phocoena phocoena*).

There were almost one million dolphins in the Black Sea in the 1950's. Fishermen from the Black Sea countries caught 230 000 dolphins annually. Towards the mid-1960's, the population had dropped to 300 000 animals, with 62 000 annual catches (ZAITSEV, 1992a).

In 1966, the former USSR made it illegal to catch dolphins. At present, all Black Sea riparian States withold from catching dolphins. However, in spite of these measures, the standing stock of dolphins continued to decline, dropping at the start of the 1980's to 50 000 specimens.

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The reasons for this decline, despite abundant small pelagic fishs, are unknown. Possibly, it is due to the biological magnification of toxic substances at the end of the food chain.

TABLE II

Commercial fish of the Black Sea

	1960-1970	1980-1990
1.	*Squalus acanthias*	*1. Sprattus sprattus phalericus*
2.	*Raja clavata*	*2. Alosa kessleri pontica*
3.	*Dasyatis pastinaca*	*3. Engraulis encrasicholus ponticus*
4.	*Acipenser stellatus*	*4. Odontogadus merlangus euxinus*
5.	*Huso huso*	*5. Trachurus mediterraneus ponticus*
6.	*Acipenser guldenstaedti colchicus*	
7.	*Sprattus sprattus phalericus*	
8.	*Alosa kessleri pontica*	
9.	*Engraulis encrasicholus ponticus*	
10.	*Belone belone euxini*	
11.	*Odontogadus merlangus euxinus*	
12.	*Mugil cephalus*	
13.	*Mugil auratus*	
14.	*Mugil saliens*	
15.	*Atherina mochon pontica*	
16.	*Pomatomus saltatrix*	
17.	*Trachurus mediterraneus ponticus*	
18.	*Mullus barbatus ponticus*	
19.	*Sarda sarda*	
20.	*Scomber scombrus*	
21.	*Gobius batrachocephalus*	
22.	*Gobius melanostomus*	
23.	*Gobius cephalarges*	
24.	*Gobius fluviatilis*	
25.	*Psetta maeotica*	
26.	*Platichthys flesus luscus*	

TABLE III

Average annual catch of fish obtained by the countries bordering the Black Sea in 1936-1986 (in N x 1 000 t)

1936 - 1940	86
1955 - 1960	103
1961 - 1965	135
1966 - 1970	183
1971 - 1975	253
1976 - 1980	401
1981 - 1986	601

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