1. Introduction

Long-term changes in the Black Sea ecosystem in general and in particular of plankton coincide with an increase of anthropogenic impact on this reservoir. Changes in species composition and quantitative indices of all basic planktonic components, at least for the shallow northwestern Black Sea, seem to be connected with eutrophication, pollution and also with the new invader *Mnemiopsis leidyi,* ctenophora [1, 2]. Long-term changes in the Black Sea plankton may also be due, to a certain extent, to the oscillations in hydro-meteorological (i.e. climatological) conditions [3, 4, 5].

It is suggested that long-term fluctuations in the abundance and catches of small pelagic fishes are sometimes the result of cyclic climatic changes [6, 7, 8]. The biomass of fodder zooplankton, being the major food component of these fish should correspond to these changes. Long-term changes of zooplankton biomass in different regions of the world's oceans have sometimes been related to the variability of physical characteristics of the atmosphere and water, in particular wind stress and to global temperature anomalies [7]. The abundance of zooplankton and fish have also been reported to change in relation to certain hydrological conditions of the Black Sea [9, 10, 11]. In this study, long-term changes in the biomass of the phytoplankton and mesozooplankton of the Black Sea in relation to natural and anthropogenic factors have been reviewed for two different regions of the Black Sea: the shallow northwestern shelf, where we suppose anthropogenic impact must be the leading factor, and the deep northeastern Black Sea where climatological changes could be the main influence on the quality and quantity of the plankton.

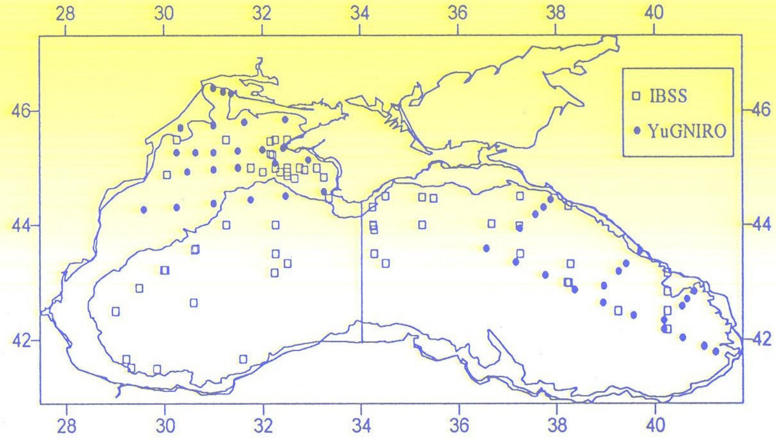
2. Methods

For the evaluation the following data sets were used:

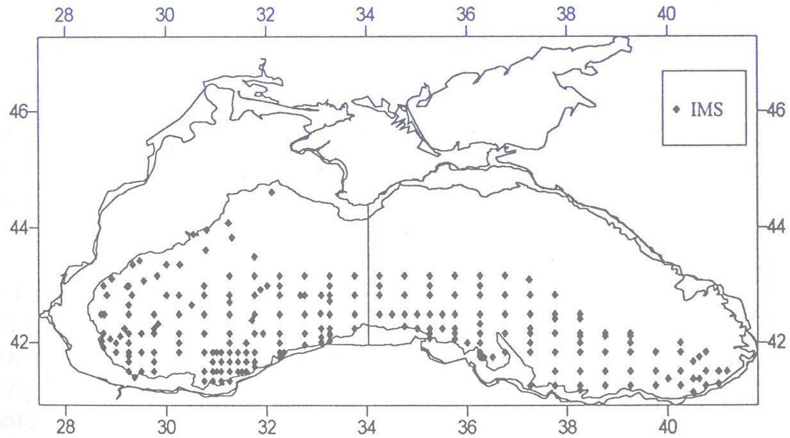
2.1. SEA SURFACE TEMPERATURE (SST) AND SALINITY

- 1951 to 1994, inshore: sea surface temperature (SST) and salinity for March, measured at meteorological stations situated along the former Soviet Union Black Sea coast. The temperature was registered eight times daily. Monthly averages were then taken. The inshore long-term data series for inshore waters were then grouped into two coastal regions: the north-western area represented by the meteorological stations at Odessa, Khorly, Evpatoria and Sevastopol and the north eastern area on the Caucasian coast with stations at Anapa, Novorossisk, Tuapse, Pitsunda and Batumi [13].
- 1956 to 1993, offshore: sea surface temperature (SST) and salinity for February in the northwestern and northeastern regions of the Black Sea [13]. These data were also registered eight times daily and averaged for two offshore areas (Fig.1a): the

northwestern area (44°-44°.40'N and 31°-33° E; 216 records), and the northeastern area (43°20'-44°20'N and 37°- 38°30' E; 176 records).



A. Ukrainian stations (IBSS and YugNIRO) for phyto-and zooplankton sampling.



B. Turkish stations for zooplankton sampling during 1991-1996 (IMS).

Figure 1. Map of plankton stations

Temperature and salinity measurements were taken during February and March, because these months reflect the winter strength and determine the scale of planktonic development [12].

2.2. RIVER DISCHARGES INTO THE NORTHERN BLACK SEA

1951 to 1995: the annual discharges of Romanian and former Soviet Union rivers into the Black Sea were calculated as a sum of the monthly run-off of the Danube, Dniepr, Dniestr, Yuzniy Bug, Rioni, Ingouri, Bzyb, Mzymta, Chorokh, Kodory [13].

2.3. ROSSBY INDEX (RI)

1950 to 1990: the RI was calculated as the difference of the sea level air pressure (SLP) of the Azores High and Iceland Low areas. The annual SLP in the Azores High and Iceland Low was determined as an average of (10 by 10 degree) squares centred at 35°N, 25°W and 65°N, 20°W, respectively [13].

2.4. PLANKTON DATA

Phytoplankton data used in this study cover the period from 1959 to 1985 for the northern Black Sea. Zooplankton data cover the period from 1957 to 1996. All data from 1959 - 1988 were collected by the Southern Institute of Marine Fishery and Oceanography (YugNIRO, Ukraine) in the northwestern and the northeastern Black Sea [11, 14]. The samples were collected annually in March, May, June, July and August at 24 stations in the northwestern shelf and at 25 stations in the northeastern offshore region with a nearest distance of 5 nautical miles from the coast (Fig.1A).

The phytoplankton samples were collected using a 1 liter bathometer at standard depths (0,10, 25, 50, 100 m). The zooplankton samples were collected with a Juday net (d = 0.1 m^2; mesh size = 168 microns) from 100 to 0 m (or bottom to 0 m). The annual average numbers and biomasses of the total zooplankton for each region (about 500 samples per year) were calculated. Unfortunately the published information did not present information about standard deviations of the average values.

From 1988 - 1996 the annual average means were obtained from the data of the Institute of Biology of the Southern Seas (IBSS, Ukraine) and the Institute of Marine Sciences (IMS, Turkey; 1991-1996). The data were collected in shallow areas with water depth 50-200 m and in offshore areas (> 200 m water depth) from all over the Black Sea during national and international programs (Fig.1B). All data were stored in the database (TU-Black Sea Data Bank, IMS Erdemli Turkey), which was established during the international TU-Black Sea project [15]. IBSS and IMS used the same evaluation methodology as YugNIRO. The large and rare animals were counted in all samples. The small and numerous individuals were calculated in 0.01-0.5 cm^3 subsamples. The IBSS collected the samples by a Juday net (0.1 m^2; mesh size 145 micron) in the layer 0-100 m (or 0-150 m). The IMS zooplankton samples were taken with a Hensen net (0.385 m^2;300 micron;) [15].

3. Results

3.1. PHYTOPLANKTON

The average phytoplankton biomass was in general higher in the shallow northwestern region compared to the deep northeastern Black Sea (Fig. 2). While the phytoplankton biomass in the northwestern area oscillated more or less in a steady state between 500 and 2000 mg l^{-1}, it increased gradually between 1959 and 1976 in the northeastern region. Since then the biomass of the northeastern area has been in a similar range to that of the north western region. Despite high fluctuations, the northwestern biomass was at its highest level in the period 1973-1980. The northeastern biomass reached a peak level 3 years later between 1975/76 and was high until 1981. Then a decline in the biomass for both areas of the Black Sea was obvious. However during 1991-1992 the biomass was seen to increase to the same level as observed in 1980 [16].

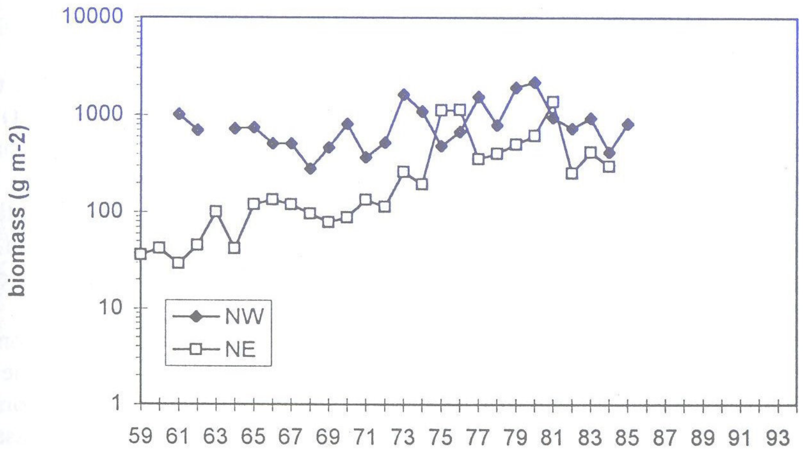


Figure 2. Phytoplankton biomass (1959-1985) in the northeastern (NE) and northwestern (NW) Black Sea (Data of YugNIRO)

3.2. FODDER ZOOPLANKTON

The fluctuations in total biomass of the fodder zooplankton (i.e. mesozooplankton except gelatinous organisms as *Noctiluca* and jellyfish) are shown in Figure 3 for different regions of the Black Sea. The total biomass of the fodder zooplankton at the northwestern shelf oscillates with a higher amplitude than that of the northeastern Black Sea (Fig 3A, B). From the late 1950's till mid 1960's the biomass of the shelf region was about 3 times higher than that of the northeastern region. In 1966 the biomass of the northeastern areas increased, while the shelf biomass decreased. However, in the early seventies the biomasses of both areas fluctuated at approximately the same level. During 1975-1979 a general decrease in biomass was observed followed by a sudden increase at the end of the 1970's. While the biomass levels were more or less stable in the northwestern shelf until the end of the 1980's/beginning of the 1990's (Fig. 3A), the biomass increased in the northeastern region till 1990 (Fig. 3B). Then the biomass of both areas dropped to levels, which were well below the average for the previous years. Since 1988 the biomass of the northwestern shelf has been lower than the northeastern biomass, which is the opposite situation as seen during the 1960's (Fig. 3A, B). In the northwestern Black Sea the biomass of the fodder zooplankton has essentially reduced during the last 30 years. In contrast to this, the biomass of the northeastern Black Sea zooplankton increased in overall view until the 1990's. In both regions the biomass increased after 1993 reaching a maximum level in 1995 (Fig. 3C, D). In the southeastern offshore area the biomass increased much faster than in the southwestern offshore region and displayed a biomass, which was about twice as high as in the southwestern area during 1994-1996 (Fig. 3C, D).

4. Discussion

Many authors have related the changes in the composition and quantity of the Black Sea plankton mainly to the changes in environmental conditions due to anthropogenic impact during the last decades [17, 18, 19]. One dominant factor is eutrophication. The concentration of nutrients in rivers flowing into the Black Sea is several fold higher than in the sea. In the area of the Danube river mouth (up to 10 miles from the coast) the average concentration of nitrates is 30 times higher than in the open sea [20]. The annual nutrient load received by the Black Sea in the 1980's increased more than 3 fold compared with previous decades [17]. Due to this nutrient input to the shallow northern shelf waters the phytoplankton biomass (in the layer 0-25 m) was more than two fold and the zooplankton biomass (in layer 0-100 m) about 1,5 fold than the biomass in the deep waters of the north eastern Black Sea [11].

Another result of eutrophication in the Black Sea has been the increase in the biomass of the jellyfish species *Aurelia aurita*. It is known, that the jellyfish quantity in the sea grows in accordance with eutrophication of waters [19]. In the oligotrophic regions of the open Black Sea jellyfish account for about 15% of the total zooplankton biomass. In frontal zones and off-shore upwelling regions where nutrient concentrations are high, the contribution of jellyfish increases up to 65% [21, 22].

The increase of mesoplankton predators such as *Aurelia aurita* and especially the recently introduced ctenophore *Mnemiopsis leidyi* is according to many authors one of

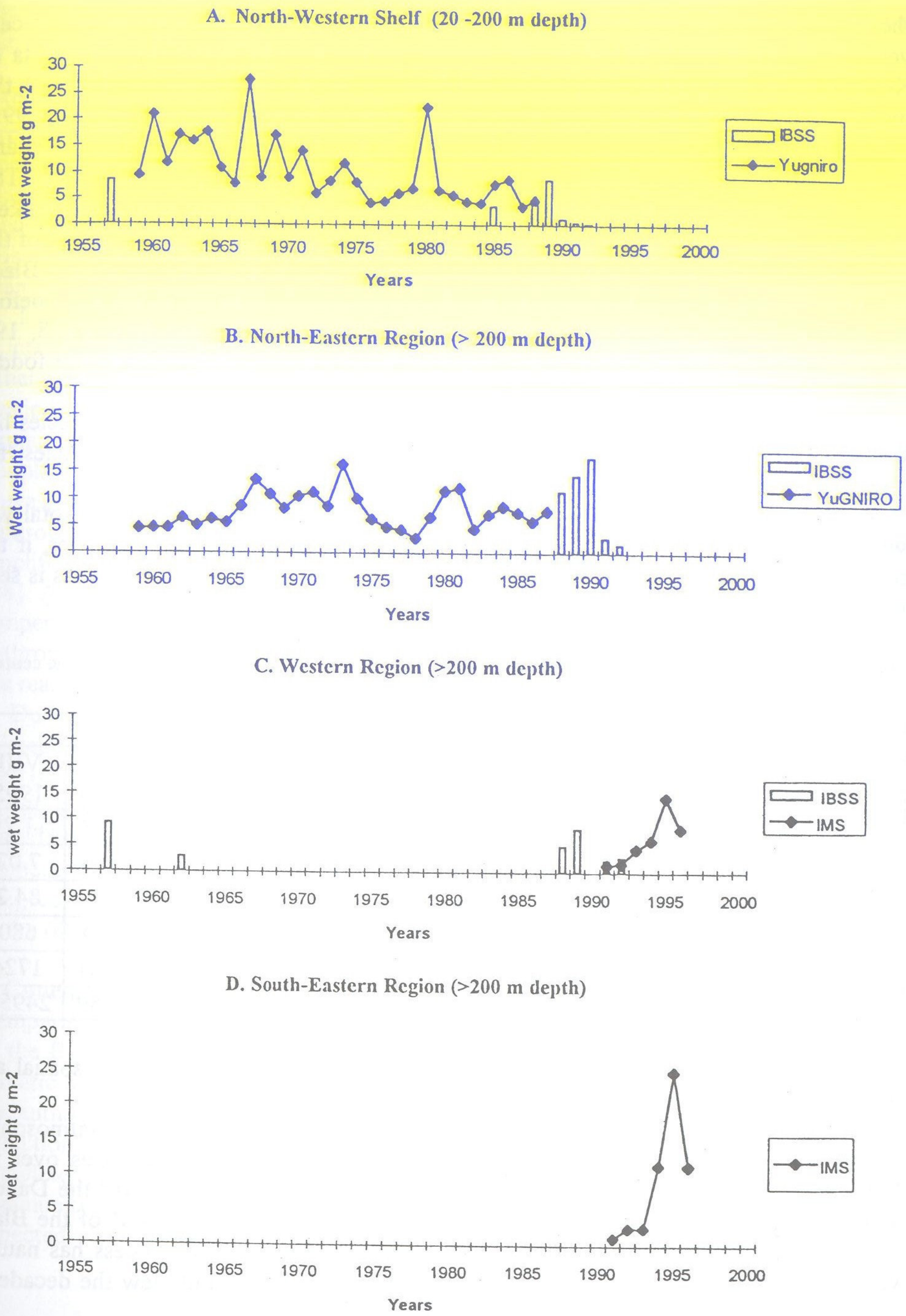


Figure 3. Long-term changes in the fodder zooplankton biomass in different regions of the Black Sea (data of YugNIRO, IMS and IBSS)

the basic reasons for the reduction of the fodder zooplankton biomass during recent years [1, 2, 17, 18, 23, 24]. A similar conclusion can also be drawn from the data of Kovalev et al. [24] (Table 1.). After the outburst of *M. leidyi* during 1989/90 the biomass of the fodder zooplankton decreased more than 10 fold between 1988 and 1991.

The influence of climatic factors on the shallow areas of the sea was outstripped and modified by the effects of chemical pollution (pesticides, oil pollution, etc.). The continuous reduction in fodder zooplankton, especially in the surface layer is most likely connected to amplification of pollution [18, 19]. This is obvious from comparison of the fodder zooplankton trends in the north western shelf and in deep regions of the Black Sea (Fig. 3). The gradual reduction of the fodder zooplankton began at the shelf before the mass development of *Aurelia aurita* in the Black Sea during the 1970's [18, 19]. Since the outburst of *Mnemiopsis leidyi* during 1989 a further reduction of the fodder plankton biomass was observed [1987] .

In the surface waters and coastal regions the stocks of many zooplankton species has decreased by one or two fold during the last 2 decades [1, 18, 19]. Some species, for example, *Oithona nana* (Copepoda), has not been observed since1989 [1].

Due to the increased biomass of *Aurelia aurita* and *Mnemiopsis leidyi* the total wet weight of the zooplankton has increased during the last 10 years [1]. However, if the total zooplankton biomass is expressed in terms of carbon, then the total biomass is seen to have decreased by 3-4 fold recent years [25].

TABLE 1. Average biomass (g m^{-2}) of fodder and main gelatinous species of zooplankton in the central Black Sea. (after Kovalev et al., 1996 [24])

	Months and Year								
Zooplankton	VII-IX 1980	VII 1988	VIII-IX 1989	IX 1990	XI 1991	VII 1992	IX 1993	IX-X 1994	VIII 1995
Fodder	27.20	15.30	10. 8	12.00	1.07	1.47	1.78	1.18	11.29
Noctiluca	11.30	9.81	9.80	0.53	0.27	3.65	1.10	0.68	7.02
Pleurobrachia	89.4	30.0	100.0	191.0	95.6	201.0	266.3	107.8	84.2
Aurelia	150	107	290	69	167	1449	396	149	680
Mnemiopsis	0	117	1480	1029	265	347	795	2201	1724
Σ gelatinous	251	264	1880	1290	528	2528	1458	2459	2495

Nevertheless, anthropogenic impact on the Black Sea ecosystem varies in a spatial and temporal scale.

The variability of the river run-off is dependent on global ocean-atmosphere processes. In years with high Rossby indices (RI), the cyclones trajectories over the North Atlantic shift to the north-east over Europe [26]. Precipitation over the Danube and Dnieper catchment basins, which provide about 80% of river run-off of the Black Sea, decreases, and, consequently the run-off diminishes [13]. This process has natural variability with periods from 1-2 up to 40-60 years [13]. In overall view the decade of

the eighties displayed a period with an increasing Rossby indices and decreasing river run-off (Fig. 4, 5).

Taking into account, that the Black Sea plankton is concentrated in the upper 100-150 m layer, it becomes clear, that in contrary to the ocean, the regional climatic processes on the land have an essential impact on the marine inshore areas. Thus, it becomes obvious, that the river run-off cycles could trigger long-term changes of the plankton biomass especially in coastal areas. During the last several decades the general trend of phytoplankton biomass in the Black Sea until the beginning of the 1980's was positive. Due to the river run-off the eutrophication of the shelf area is essentially higher than in the deep area resulting in a higher phytoplankton biomass (Fig. 2).

To verify the possible influence of the climatic factors on the Black Sea ecosystem it is interesting to compare processes in the relatively unpolluted eastern Black Sea area to other non polluted areas of the world oceans. For example in the region of Plymouth, cyclic long-term changes of phosphate concentration, fish larvae and zooplankton were explained by climatic change [26]. The decrease of chlorophyll 'a' and the decrease of zooplankton biomass in the Gulf of Naples (Mediterranean Sea) during 1984-1990 corresponded with an increase of temperature and salinity [27]. The increase of chlorophyll 'a' in the Pacific Ocean during 1968-1985 could be connected to the amplification of winter winds and a decrease in the temperature of the superficial layer [28]. A similar increase of plankton biomass occurred during 1951-1976 due to a global temperature anomaly in the North Pacific in the Oyasio Kuroshio region [7]. Since the anthropogenic influence was low in these regions climatic variability was assumed to be the reason for the fluctuation of the plankton biomass.

During 1980's until 1987 a negative trend in the sea surface temperatures and salinity existed both in the northwestern shelf area and more obvious in the northeastern offshore area of the Black Sea (Fig. 6). These trends, observed in both regions of the Black Sea correspond to the global temperature anomaly, which occurred during the eighties [7, 29]. The coincidence at the fluctuation in the fodder zooplankton with the surface temperature of the eastern Black Sea, which is in line with the global temperature cycle [29], could indicate the presence of a long-term zooplankton fluctuation, which is close to the 60 year global cycles of temperature.

5. Conclusions

Comparison of long-term changes on the north western shelf and in the deep water area of the Black Sea displayed similar features. At the northwestern shelf the influence of climatic factors is overlayed by the high variability of the hydrographic environment and the anthropogenic influence. This resulted in a high fluctuation of communities and a reduction of a number of species of the "fodder" zooplankton and further more in the complete disappearance of some species. Due to the anthropogenic impact the planktonic community of the northwestern shelf is not stable and therefore further changes could be expected.

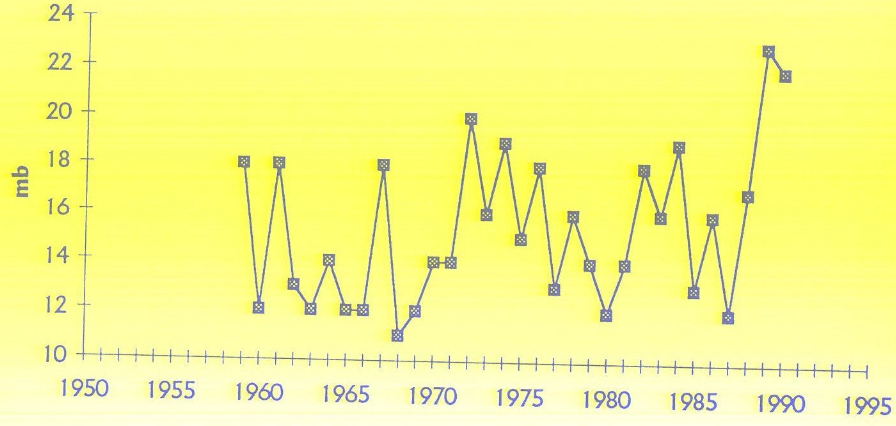


Figure 4. Rossby index (difference between the air pressure of Azores high and Iceland low).

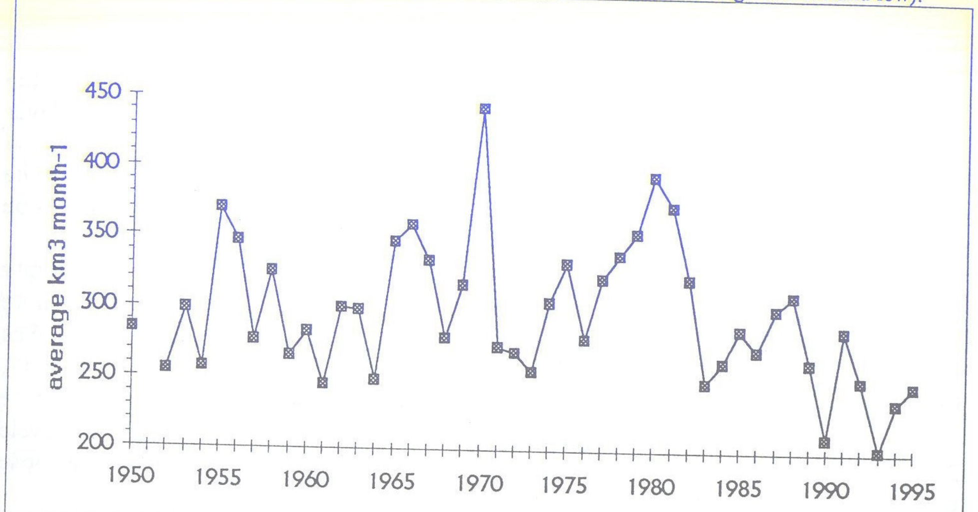


Figure 5. Run-off to the Black Sea from major rivers in the northwestern and northeastern Black Sea.

In the deep water area of the north eastern Black Sea the variability in phyto- and zooplankton was smaller. In this region the influence of anthropogenic impact appears lower compared to that on the northwestern shelf and therefore the influence of global climatic factors should be more easily recognised.

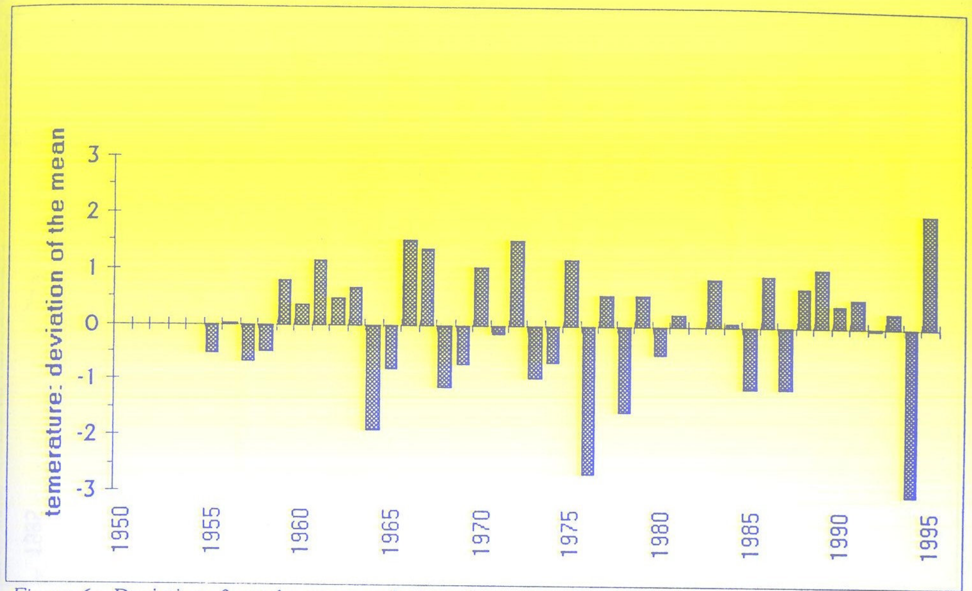


Figure 6a. Deviations from the mean surface sea temperature during 1950 - 1995 in the western Black Sea.

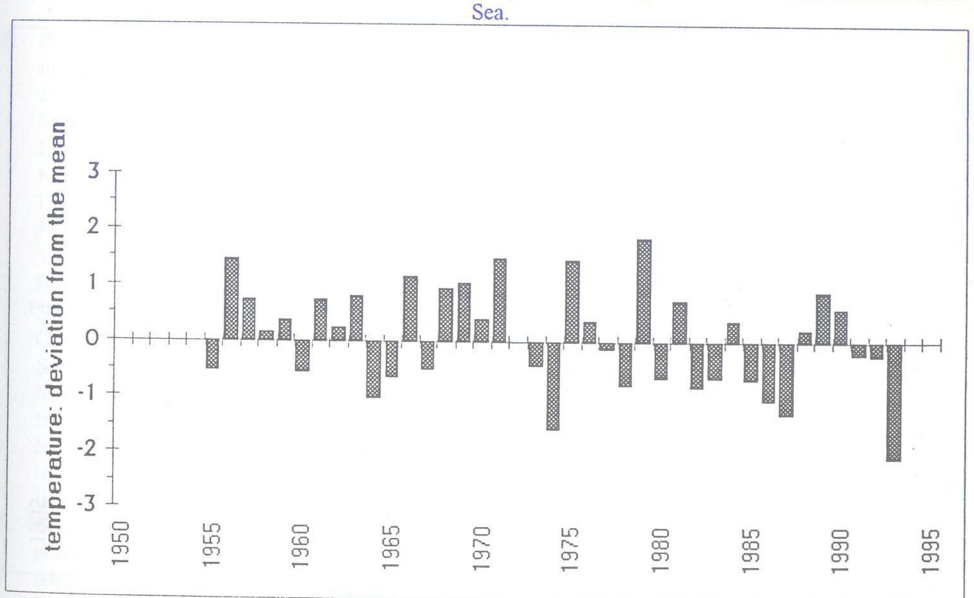


Figure 6b. Deviations from the mean surface sea temperature during 1950 - 1995 in the eastern Black Sea.

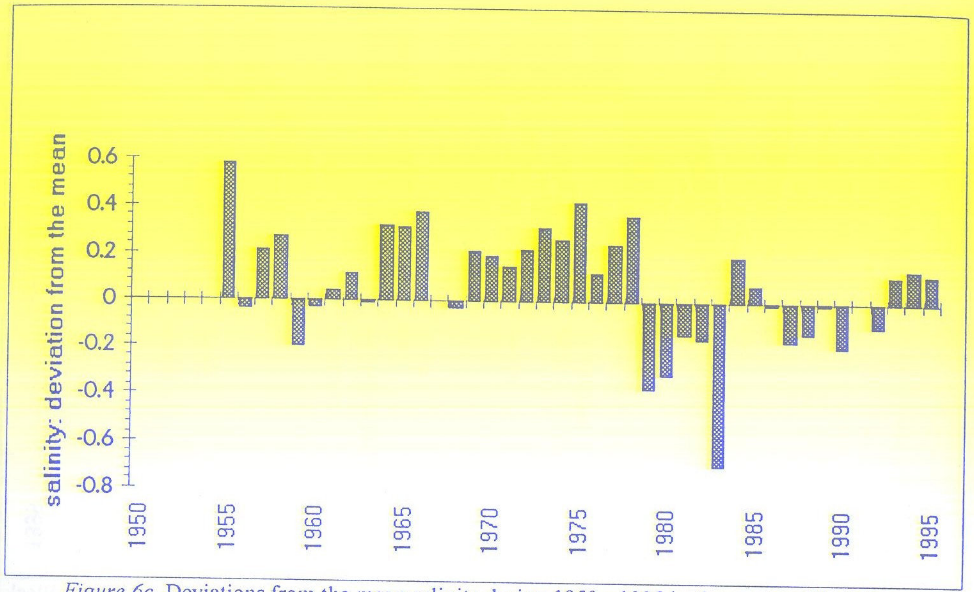


Figure 6c. Deviations from the mean salinity during 1950 - 1995 in the western Black Sea.

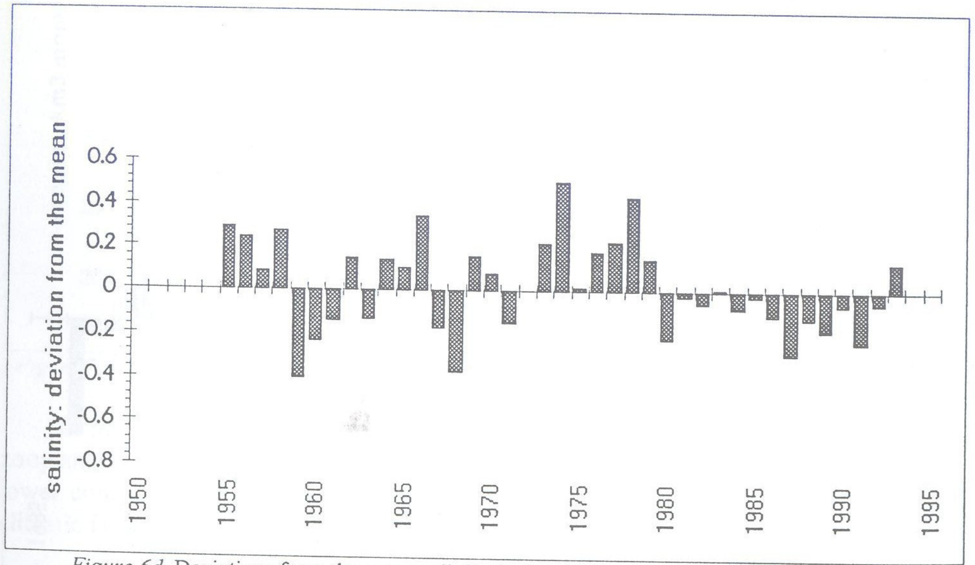


Figure 6d. Deviations from the mean salinity during 1950 - 1995 in the eastern Black Sea.

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CHANGES IN THE I
RESPECT TO PLANK

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1) Institute of Bio
2) Institute of Mar

Abstract. Data on the r
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1. Introduction

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