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PREFACE

The better understanding of the changing problems facing the marine environment is a continuing goal of UNEP's Ocean programme, as it provides the necessary scientific background for shaping UNEP's policy towards the protection of the oceans.

The main sources of factual information used in the assessment of the state of the marine environment are data published in open scientific literature, data available in various reports published as "grey literature" and data generated through numerous research and monitoring programmes sponsored by UNEP and other organizations.

Several procedures are used to evaluate critically the large amount of available data and to prepare consolidated site-specific or contaminant-specific reviews.

GESAMP, the IMO/FAO/Unesco/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on Scientific Aspects of Marine Pollution, is charged by its sponsoring bodies with preparation of global reviews. Reviews dealing with several contaminants have been already published by GESAMP and others are being prepared for publication. The first global review on the state of the marine environment was also published by GESAMP in 1982, and the second global review was published in 1990[1/].

In parallel with the preparation of global assessments, the preparation of a series of regional assessments, following the general format of the second global review by GESAMP, was initiated by UNEP in 1986, with co-operation of the Food and Agriculture Organization of the United Nations (FAO) and the Intergovernmental Oceanographic Commission of Unesco (IOC). Fifteen task teams of scientists were set up, involving primarily experts from the relevant regions, to prepare the regional reports under the joint overall co-ordination of UNEP, FAO and IOC, and with the collaboration of a number of other organizations.

The present document is the product of the Task Team for the Black Sea Region. The final text of the report was prepared by T. Balkas, as Rapporteur of the Task Team, in collaboration with G. Dechev, R. Mihnea, O. Serbanescu and U. Unlüata, whose contributions are gratefully acknowledged.

The report was edited and prepared for publication by Philip Tortell of Environmental Management Limited, New Zealand.

1/ Publications of GESAMP are available from the organizations sponsoring GESAMP.

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1. INTRODUCTION

1.1 Geomorphology of the region

The Black Sea (Fig. 1) is situated between the latitudes 40°55' and 46°32' N and the longitudes 27°27' and 41°42' E. It is the world's largest land-locked inland sea. To the south, the Black Sea is connected to the Mediterranean through the Bosphorus, which is the world's narrowest strait, with an average width of 1.6 km, an average depth of 36 m and a total length of 31 km. To the north, the Black Sea is connected with the Sea of Azov through the shallow Kerch Strait, which has a depth of less than 20 m.

The maximum and average depths of the sea are 2,200 and 1,240 m respectively (Zenkevich, 1963; Ross, 1977). With the exception of the northwestern Black Sea, the shelf areas are narrow. Typically, the abyssal depths are reached through steep slopes, in the order of 4-6°. A depth of less than 200 m constitutes 27% of the total area and is mostly found in the northwestern Black Sea.

The countries bordering the Black Sea are the Union of Soviet Socialist Republics (USSR), Romania, Bulgaria and Turkey.

1.2 General ecological characteristics of the region

1.2.1 Meteorological conditions

Temporal and spatial variability of atmospheric conditions is a distinguishing feature of the Black Sea climate. Detailed information on various aspects of these conditions is documented by the USSR Admiralty (1950), United Kingdom (1969) and Turkey (1967, 1984). A fairly general account of the basin's meteorology, primarily based on the material presented in United Kingdom (1969), is given below.

Over the Black Sea, meteorological conditions vary in both east-west and north-south directions, particularly during winter months. The region is affected by the travel in a generally easterly direction of weather across the area. In winter the center of maximum pressure over Siberia dominates the region. The average pressure is about 1,020 mb in the north and 1,016 mb in the south. Lower pressures are observed in summer, when the overall picture is characterized by relatively low pressure to the east and south and high pressure to the west. The latter is an extension of the Azores anticyclones, frequently observed during the October-March period, which disturb atmospheric conditions and lead to a drop in air temperature, precipitation and strong winds. Two main tracks of depressions are particularly noted, i.e. (i) from the Mediterranean, moving in a north-eastward direction over the Sea of Marmara, and (ii) from Bulgaria and Romania, moving in the eastward and south-eastward directions. The average rate of advance of these depressions is about 20 knots.

Most of the depressions affecting the area are accompanied by fronts. The cold fronts are typically more active than warm fronts and are often associated with the abrupt veer of winds, usually from the northwest, with a northerly component. An appreciable drop in air temperature and a rise in barometric pressure and precipitation in the form of snow and rain accompany the frontal passages.

Depending on the passage of depressions, wind conditions over the Black Sea vary considerably in winter. The dominant wind direction is north-northwest in the western half of the Black Sea, whereas southerlies dominate in the eastern half.

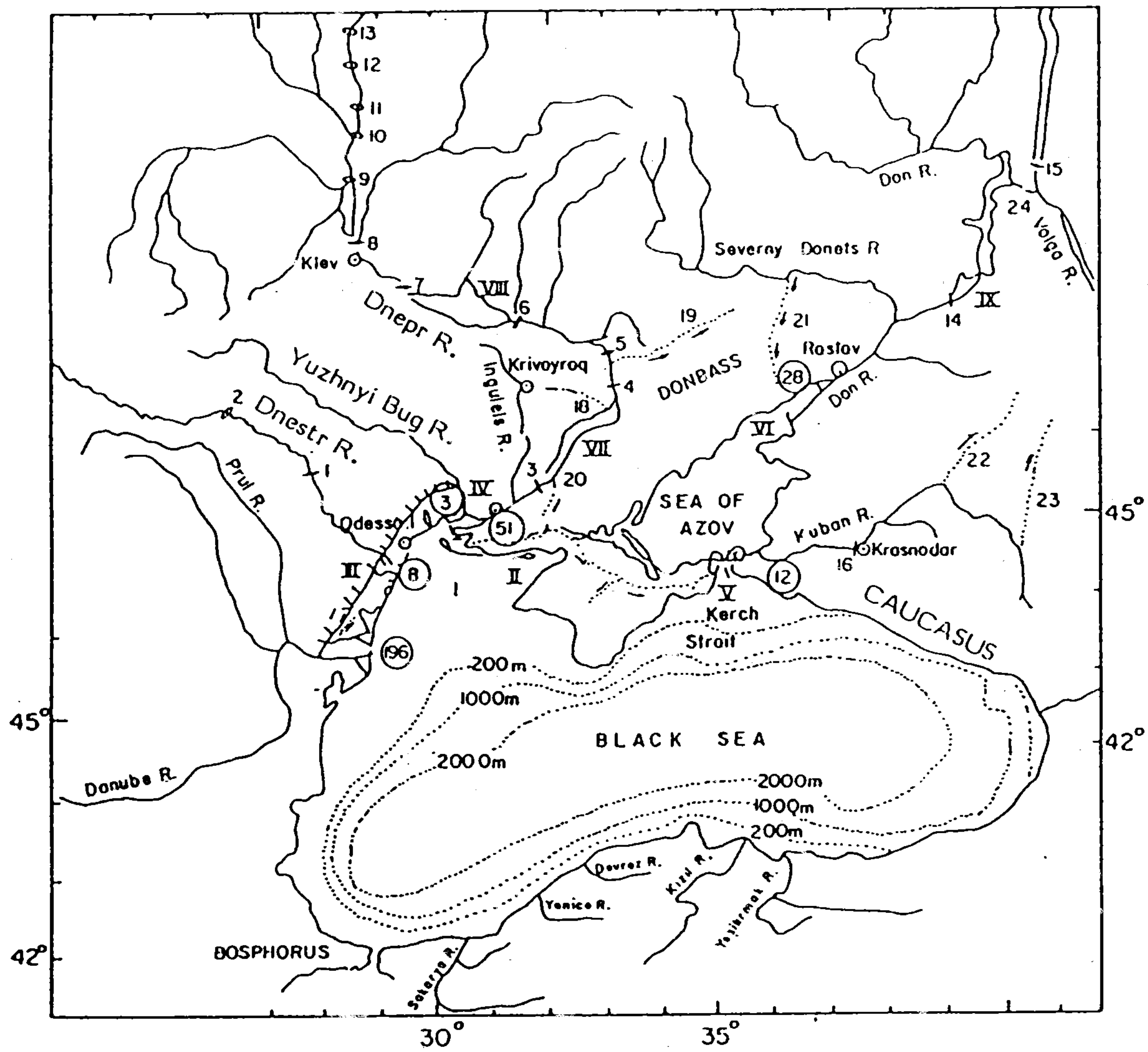

Fig. 1. Major rivers, estuarine regions, and associated geographical features of the Black Sea (depth in metres)

Water bodies: I, Northwestern Black Sea; II, Karkinitsky Bay; III, Dnestr Estuary; IV, Dnepr Estuary; V, Kerch Strait; VI, Taganrovsky Bay; VII, Kokovskove Vdkhr (Vodokkhranilishtche storage lake); VIII, Kremenchugskoye Vdkhr; IX, Tsymlianskoye Gvdkhr; 1-16, hydropower stations; 17-24, irrigation and water supply channels. The arrows indicate the direction of water transport. Encircled numbers indicate the annual river water discharge in km^3/year.

Source: Tolmazin, 1985b

The highest average wind speed, observed in January and February, is about 16 knots.

Ahead of depressions approaching from the west, gales also occur during winter. The gales are predominantly from the north-east and their average frequency amounts to nearly 5% of wind observations.

In all parts of the region rapid changes during April and May precede summer conditions, which are characterized by lower winds and more stable and uniform conditions as compared to winter. The average wind speed does not exceed 10 knots in the central Black Sea and is less than 6 knots in southern parts. These conditions persist with minor variations until September - early October, after which there is a rapid change back to winter conditions. There are significant seasonal changes in air temperatures over the Black Sea. Summer months are characterized by relatively higher air temperatures with essentially uniform distribution over the entire Black Sea. The highest average temperatures are 24°C in the central and northern parts and 22°C in the southern parts. The average daily minimum and maximum values in August are about 19°C and 28°C respectively along the southern coast of the Black Sea. Similar daily variations are observed in the northern sector.

Air temperature begins to fall in September, with the biggest drop during late October and November. The temperature approaches its minimum values in January and February. The regional variations in air temperature in the southern Black Sea can reach 8°C. Below-zero temperatures are frequently encountered in the northern sector, particularly in the region between the Danube delta and the Crimea. After February, the temperature rises gradually at first and then more sharply towards May, when it attains a value of 15-16°C throughout the region.

1.2.2 **Oceanographic conditions**

Some excellent reviews of the oceanography of the Black Sea are available (Caspers, 1957; Grasshoff, 1975; Ross, 1977; Sorokin, 1983; and Tolmazin, 1985a, 1985b). The salient aspects of the Black Sea region as related to its health are summarized in the following paragraphs.

The Black Sea is located in a semi-arid climatic zone, and as a result, evaporation (332-392 km^3/y) exceeds rainfall (225-300 km^3y). The run-off (350 km^3/y) originating primarily from the catchment lying in the humid zone to the north, leads to an excess of net freshwater inflow and the subsequent dilution of surface sea waters. In the Mediterranean, on the other hand, evaporative losses exceed net freshwater input (Bethoux, 1979, and the references cited therein). As a result, the relatively less saline and lighter waters of the Black Sea flow into the Mediterranean as a surface flow through the Bosphorus. In return, saltier and denser Mediterranean water flows into the Black Sea as an underflow. The dynamics of the Bopshorus have been reviewed by Unlüata & Oguz (1988) and Ozsoy et al (1986).

The predominant semi-permanent elements of the general circulation in the Black Sea consist of a cyclonic boundary current that essentially runs parallel to the basin's periphery, two cyclonic gyres that nearly split the basin area into two and a series of cyclonic and anticyclonic mesoscale eddies that appear to be the take-offs of the larger-scale features (Neumann, 1942; Marchuk et al, 1975; Fashchuk & Ayzatullin, 1986). These elements of the general circulation are displayed in Fig. 2.

It can be inferred from Fig. 2 that the speed of the boundary current increases up to 40 cm/sec in certain regions. In particular, high intensity jet-like flows are observed along the entire east coast. In general, the intensity of

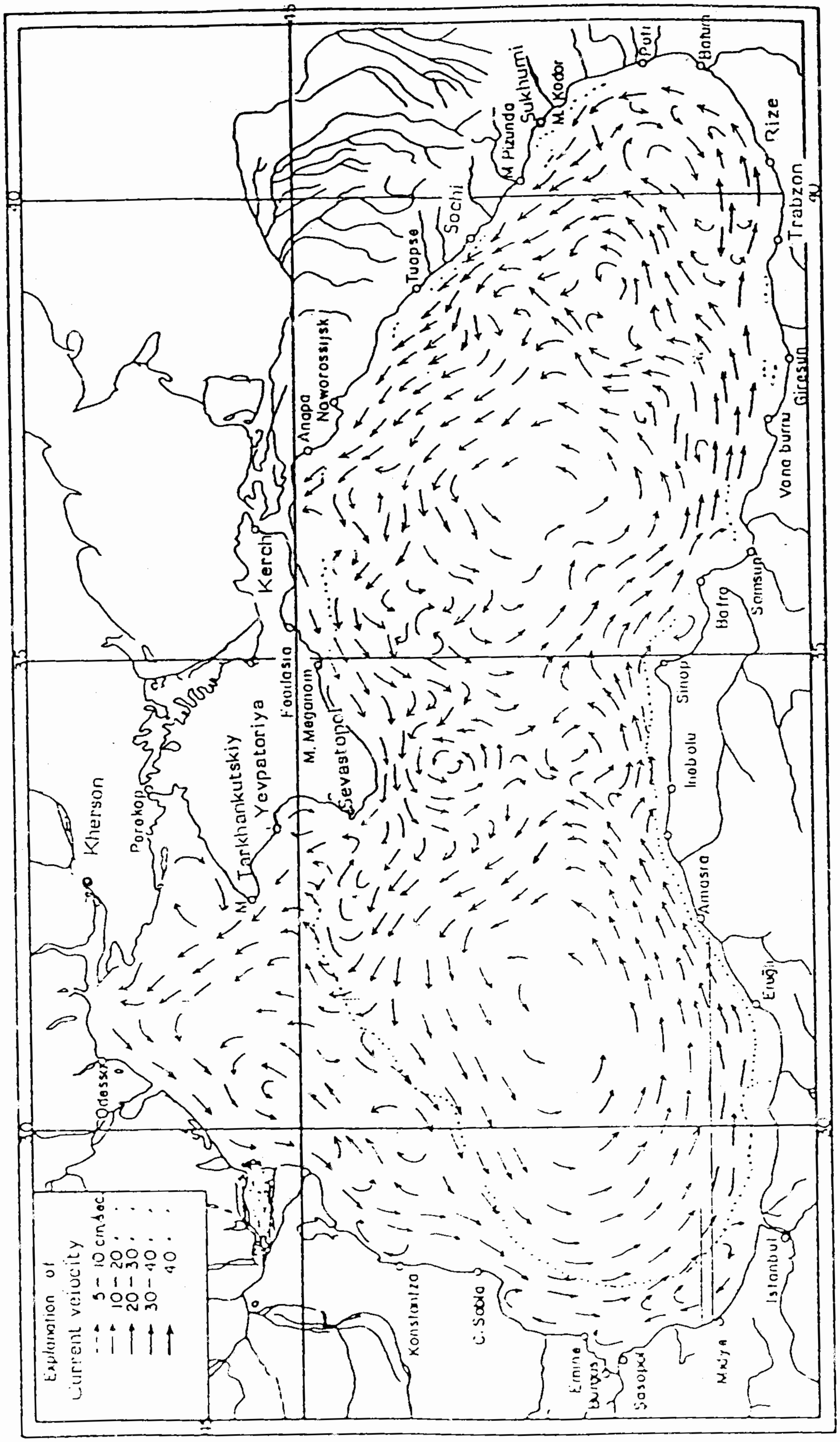

Fig. 2. General surface circulation (after Neumann, 1942)

the boundary current decreases within 30-40 km of the coast. In the south and the north the boundary current bifurcates near 34°E and 35°E respectively to form two cyclonic eddies in the interior of the Black Sea, one located in the eastern and the other in the western basin. The motion within the central parts of these gyres is relatively small. A complex series of mesoscale eddies that are evidently associated with the instability and the interaction with the coast of the boundary current are also found. Most of these eddies are cyclonic, though an anti-cyclonic eddy off the city of Rize at the southeastern corner of the basin appears to be a major feature.

Spatial variability with scales extending from mesoscale to gyral scales and to the scale of the basin is shown in Fig. 2, which is based on relatively old data. Recent studies also confirm the existence of a wealth of scales not only in space but in time as well (Marchuk et al, 1975; Plakhin et al, 1985; Trukchev et al, 1985 and the references cited therein).

A distinguishing characteristic of the Black Sea is the presence of a permanent halocline located between 100 to 200 m. In fact, the Black Sea is the world's largest body of water with this characteristic. The stratification is generated by the freshwater input and the Mediterranean inflow of water of a higher salinity.

The vertical pattern of salinity is essentially the same everywhere in the basin, except in the coastal and nearby shelf regions located particularly in the north-eastern part of the basin. In the deeper sections of the basin, variation of the salinity from this mean value is insignificant, not exceeding 0.2-0.4 °/oo S. The mean salinity of the deep waters in the Black Sea is 22.2-22.4 °/oo S depending on the regional deep water convection and mixing characteristics of the basin. In particular, vertical convection generated by the geothermal heat flux from the bottom generates a uniform distribution of salinity and a series of parameters below 1,000 m. Above 600 m and towards the surface, much more significant changes are however observed, and salinity is reduced at first almost uniformly and then more rapidly across the halocline. The typical salinity difference of surface water from its mean value amounts to approximately 4-5 °/oo S. A salinity profile representative of such average conditions is shown in Fig. 3.

Salinity of surface waters of the Black Sea undergoes considerable seasonal and geographical variations depending on the amount of evaporation, precipitation and river run-off, while such variations are almost absent below 200 m. The average surface salinities are about 18.0-18.5 °/oo S during winter and are typically 1.0-1.5 °/oo S higher than those observed in summer, particularly in the western and southeastern parts of the Black Sea. Salinities in summer may attain much lower values even in the shelf and coastal areas of the north-northeastern Black Sea where values of about 14-16 °/oo S are frequently observed due to a large river run-off. An example of the summer surface salinity distribution at the southern half of the Black Sea is given in Fig. 4, which is based on the hydrographic observations conducted by the Turkish Navy Hydrographic and Oceanographic Office during July 1965. It is evident that the westernmost parts of the Black Sea are characterized by relatively less saline surface water, having values of about 17.25-17.50 °/oo S in the pre-Bosphorus region and along the coast of Turkey. This is in accordance with the presence of a series of major rivers discharging into the Black Sea along the northern coast of Turkey as well as the presence of cyclonic circulation, giving rise to a relatively strong easterly current along the southern Black Sea as discussed above. Towards the central parts of the Black Sea, salinity increases eventually to a value of about 18.5 °/oo S with a slightly lower value in the central eastern half of the basin. This agrees with the main circulatory features of the basin.

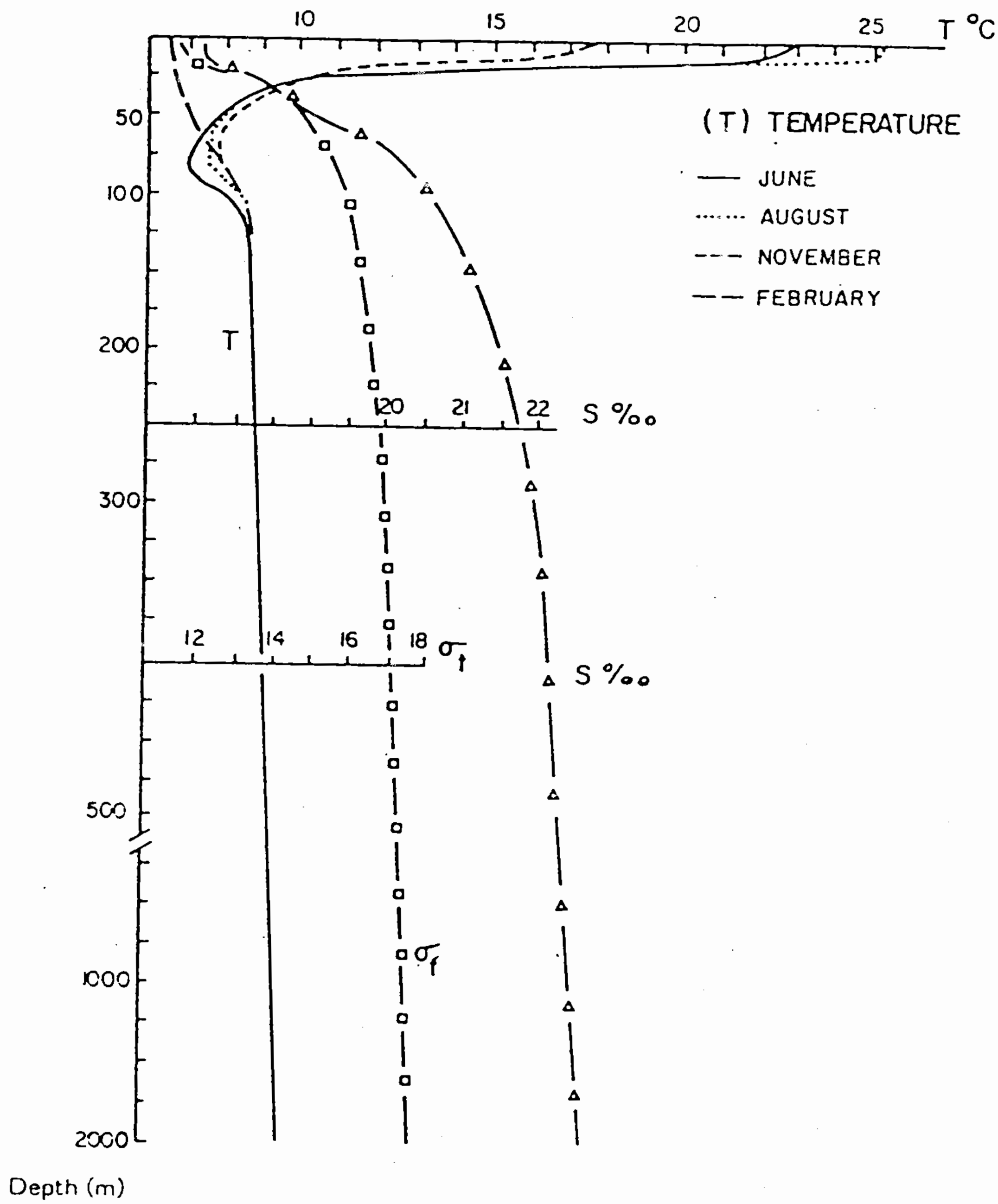

Fig. 3. Vertical profiles of temperature (T), salinity (S) and density (σ_t) in the Black Sea

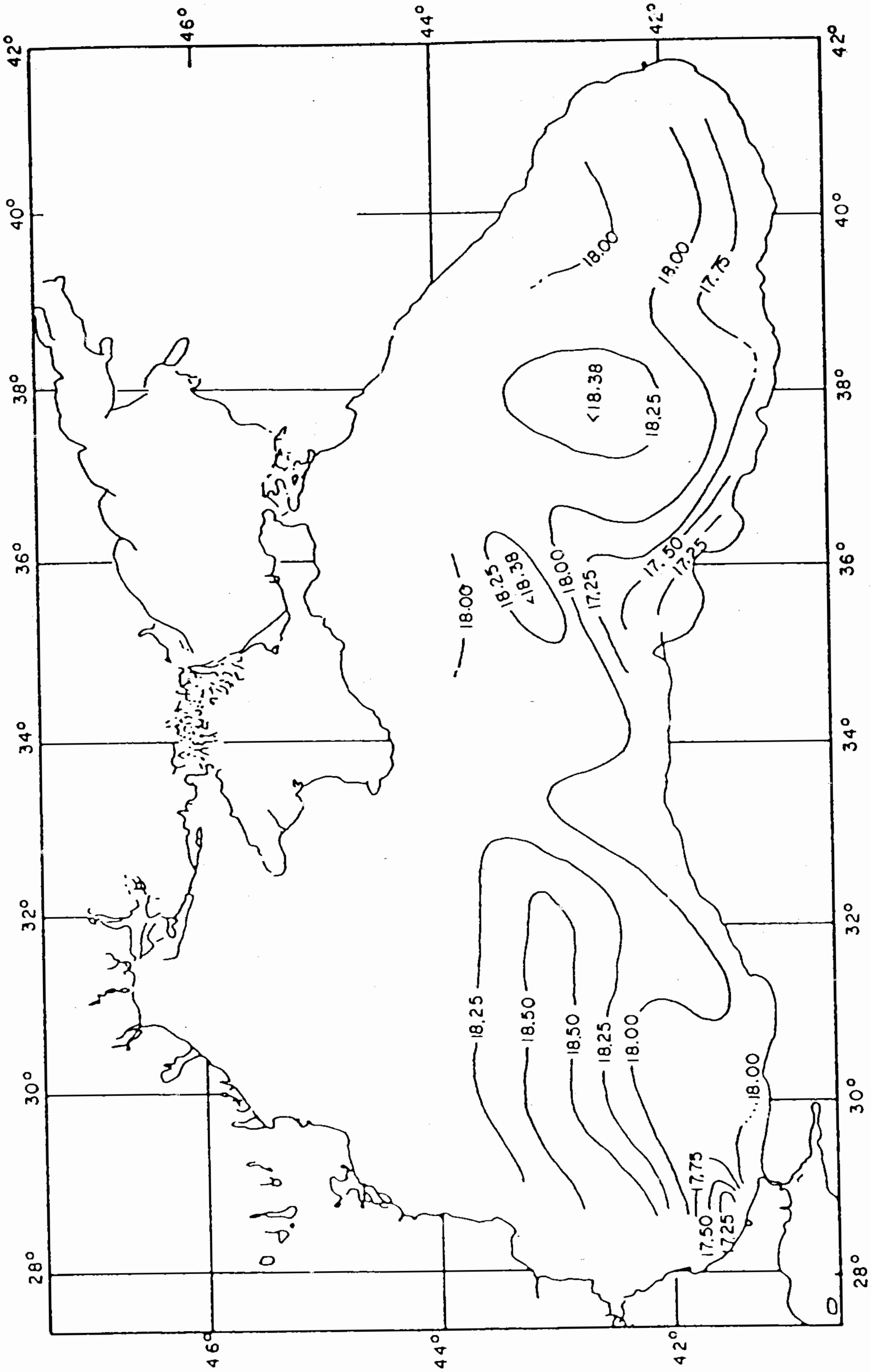

Fig. 4. Surface salinity distribution in °/oo S (July 1965)

Temperature shows much more pronounced variations than salinity on a seasonal, as well as regional, basis. The mean annual surface temperature varies from 16°C in the southern, to 13°C in the north-eastern and 11° in the north-western parts. As may be noted in Fig. 5, sea surface temperature decreases substantially in the December-February period and attains a value of 7-8°C in the central and southern basins, and 3-4°C in the northern parts of the Black Sea. The coldest surface temperature occurs in the north-western coastal and shelf areas where a temperature of 0°C is frequently observed. Surface temperature increases toward spring and reaches approximately 15°C, with somewhat lower values in the southern basin. July-August is the warmest period, in which temperatures increase to 24-25°C on the average in the western half of the Black Sea, with the exception of the north-western sector, where it may attain values as low as 10°C. The eastern basin presents slightly lower values as compared with those found in the western plain.

While in the upper 50-70 m water layer the temperature has seasonal fluctuations and considerable vertical variations, the temperature of deeper waters remains constant through the year. Typically, the temperature at a depth of 1,000 m is about 9°C and shows a slight increase of 0.1°C per 1,000 m towards deep-water sections of the Black Sea, which is due to the geothermal heat flux from the bottom (Fig. 3).

1.3 General aspects of marine pollution in the region

Due to natural causes, the subhalocline waters of the Black Sea are anoxic. In spite of this natural deficiency, the Black Sea has served mankind well in the past through its productivity in terms of food resources, as a natural setting for recreation and transportation and even as a disposal site for waste, including perhaps nuclear wastes. In return, it has been exploited and degraded in many ways, such as with the unregulated and unplanned freshwater withdrawal for irrigation purposes, hydro- and thermal-power generation, the use of coastal areas for permanent human settlements, and the many untreated industrial and agricultural wastes discharged into the rivers that drain into the sea. This variety of activities has had detrimental effects on the health of the Black Sea.

2. MARINE CONTAMINANTS: LEVELS AND DISTRIBUTION

2.1 Concentrations in water, sediments and biota

In the Black Sea the vertical exchange of dissolved material is hindered by the permanent halocline. Because of the suppressed vertical exchange and insufficient supply of oxygen through the Bosphorus underflow, for the past 7,000 years decomposition, oxidation, sinking and accumulation of organic matter has resulted in anoxic conditions in the deeper waters of the Black Sea (Dueser, 1971). Today, nearly 90% of the volume of the basin is anoxic. The depth of the oxygen zone varies, being greater (ca 200 m) near coastal areas and generally less over deeper parts of the basin. This spatial variability reflects the influence of the general circulation and the doming of hydrogen sulphide occuring in the central parts of cyclonic circulations.

Inputs by rivers and through macrophytes play a secondary role in the production of organic matter, the predominant source being primary production (Shimkus & Trimonis, 1974). Views regarding the Black Sea as an oligotrophic sea have changed significantly in recent years (Sorokin, 1983). Estimates of primary productivity range from 150-200 $gC/m^2/y$ to 250 $gC/m^2/y$, the higher concentrations recorded in coastal regions. These figures are comparable to those found for fertile seas such as the Baltic (Kullenberg, 1983). It is quite clear, therefore,

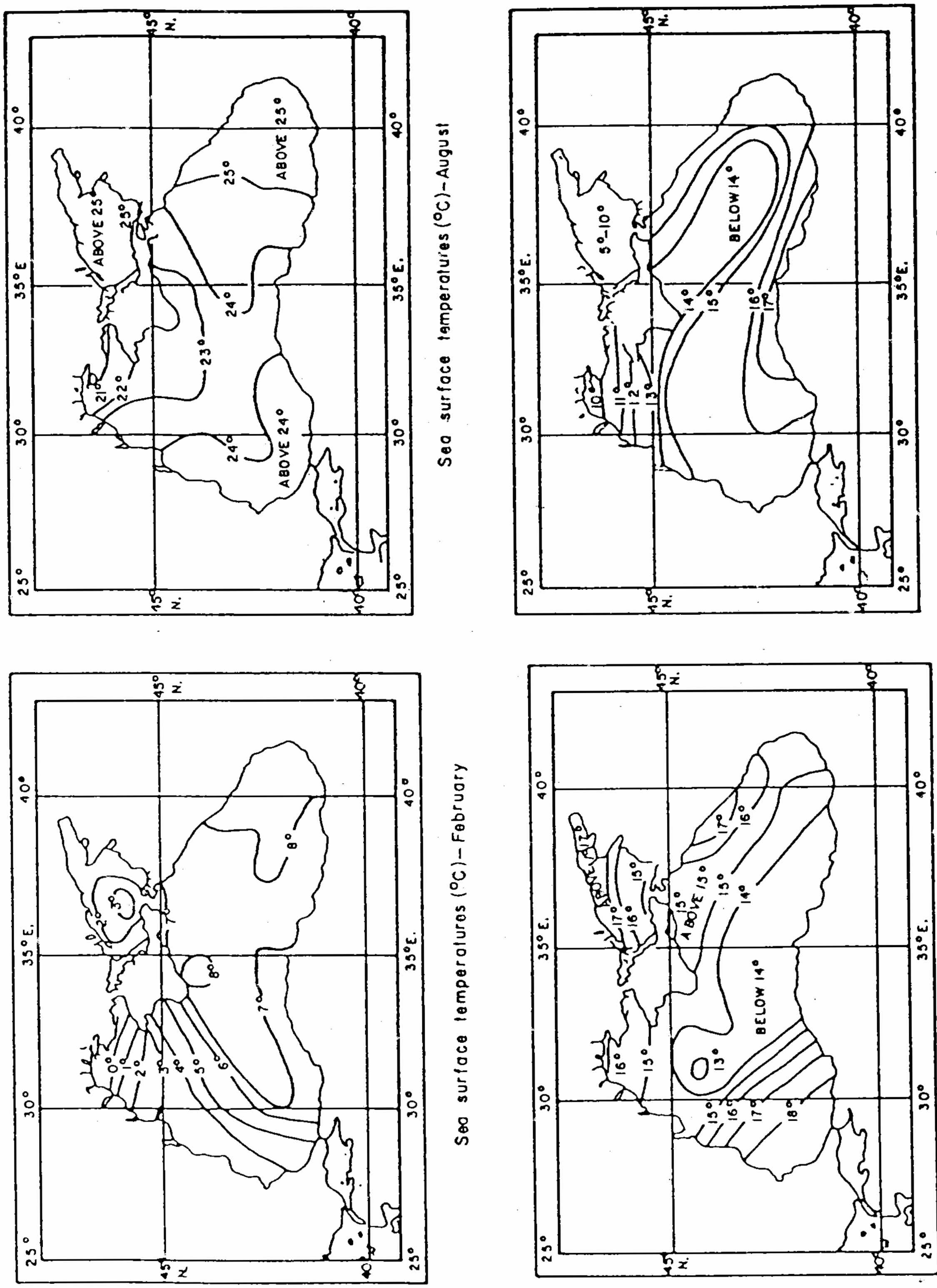

Fig. 5. Variation in sea surface temperature (after United Kingdom, 1969)

that the health problem of the basin, namely the existence of anoxic waters at depths below the euphotic zone (50-70 m and deeper) is intimately associated with natural organic material of biogenic origin.

Primary production in the Black Sea shows both temporal and spatial variability. The spring bloom is typically followed by a secondary maximum in the autumn. The most productive areas appear to be the northwestern and the northeastern (including the Sea of Azov) parts of the basin. Vertical mixing in the relatively shallow area to the northwest, coupled with the relatively high loads of nutrients from inflowing rivers, make it the most productive region in the Black Sea.

Concentrations of dissolved organic carbon in the surface layers of the Black Sea range between 3-4 mgC/l (Datsko, 1961, and Skopintsev, 1975, quoted in Sorokin, 1983). Dissolved organic carbon decreases with depth, reaching values of 2.2-2.6 mgC/l below 1,000 m. Deuser (1971) found dissolved organic carbon to first decrease to approximately 200 m but then to increase to 6 mgC/l near 2,000 m. Such concentrations are much higher than those found elsewhere in the world's oceans. Particulate organic carbon concentrations in the surface layers vary between 0.2 and 0.3 mgC/l, with relative maxima occurring at the lower boundary of the oxygen zone (Sorokin, 1983). Deuser's (1971) organic carbon budget for the Black Sea (slightly modified by Sorokin, 1983) involves sources reflecting primary production, inputs from the Seas of Azov and Marmara and rivers and losses accounting for the oxidation within the oxygen zone, oxidation in the anoxic zone, export to the Seas of Azov and Marmara, solubilization with depth and sedimentation. This budget is summarized in Table 1.

Table 1. Organic carbon budget of the Black Sea
(after Deuser, 1971)

Sources and sinks of organic carbon	**Amount ($gC/m^2/y$)**
<u>Sources</u>	
Primary production	100
Inputs from the Sea of Azov and of Marmara	7
Total	**107**
<u>Sinks</u>	
Oxidation in the oxygen zone	80
Oxidation in the anoxic zone	10
Export to the Sea of Azov and of Marmara	4
Solubilization with depth	6
Sedimentation	7
Total	**107**

In comparison with average conditions in the world's ocean, relatively high concentrations of carbonates are observed in the surface and in anoxic layers of the Black Sea, the former reflecting the relatively high terrestrial input and the latter the anoxic decomposition of sinking particulate organic carbon. The carbonate concentrations of surface waters represent 0.5% of the total weight of major ions and they increase by nearly 100% in the anoxic zone, accompanied by an increase in alkalinity.

The redox potential in the Black Sea decreases rapidly below the oxygen zone. This is due to the relatively intensive biochemical oxidation of the reduced compounds by microbial activity in the anoxic environment (Sorokin, 1983, and the references cited therein). The large gradient in the redox potential leads to significant variations in the vertical distribution of trace metals (Brewer & Spencer, 1974). Particulate iron and manganese concentrations exhibit a sharp maximum just above the lower boundary of the oxygenated zone, being relatively insignificant throughout the remaining water column. The dissolved forms of these elements have their maximum essentially absent in the oxygenated zone. Because of their accumulation as sulphides or carbonates, the total iron and manganese concentrations are higher in the anoxic zone. In contrast, dissolved zinc and copper have higher concentrations in the oxygenated zone since they are present as sulphides in the anoxic zone. The concentrations, in μg/l, of copper, mercury, iron and manganese in the oxygen and anoxic zones are 1-7, 0.3, 1-10, less than 4; and, 0.3-1.8, 0.3-0.8, 5.45, 250-450 respectively.

The vertical distribution of nutrients in the Black Sea is summarized in Table 2. Rather high concentrations of ammonia and phosphate are present in the anoxic zone as compared to those observed in deep oceans. The decomposition and modification of sinking particulate organic carbon within the anoxic environment is the main cause of high concentrations of ammonia. Decomposition of organic matter under anoxic conditions also explains the relatively high inorganic phosphate concentrations.

Table 2. Average content of inorganic nutrients, total organic carbon and organic nitrogen and phosphorus in water of the Black Sea, vertical profile
(N, P, Si as μg-at/l, organic carbon as mgC/l)

(after Sorokin, 1983)

Depth	**Inorganic nutrients**						**Organic C,N,P**		
	NH_4	N NO_3	NH_4+NO_3	P-PO_4	N:P	Si-SiO_2	C	N	P
1-10	2.8	0.8	3.6	0.4	9	50	3.6	17.0	0.13
25	3.3	0.8	4.1	0.3	14	50	3.6	-	-
50	3.6	0.7	4.3	0.5	9	60	3.5	17.8	0.13
100	5.8	1.8	7.6	1.3	6	80	3.2	16.3	0.50
200	12.8	0.8	13.6	4.0	3	120	3.5	14.2	0.80
300	17.5	0.2	17.7	4.4	4	150	3.0	15.3	0.84
500	58.5	0	58.5	5.6	10	180	2.8	16.0	0.90
1,000	81.8	0	81.8	7.0	12	220	2.5	16.0	1.10
2,000	96.0	0	96.0	8.4	11	300	2.3	14.8	1.10

Another aspect of the Black Sea is the existence of a large biomass of micro-organisms, which are observed in nearly 80% of the water volume and in regions where other forms of micro-organisms cannot exist. An excellent summary of this aspect of the Black Sea can be found in Sorokin (1983). The maximum microbial population is found in the region of maximum redox gradient, rapidly decreasing towards both the oxygenated and anoxic zones. Surface values of bacterial concentrations are typically larger reflecting the chemosynthesis by thiobacilli predominating over the methane-oxidizing bacteria. The most recent Black Sea sediments rich in carbonates formed less than 3,000 years B.P. and have a thickness of 30 cm (Ross, 1977; Sorokin, 1983). Below lie sediments rich in organic carbon content which formed between 3,000-7,000 B.P. The deeper layer reflects the time when the basin was a freshwater lake (Hsu, 1978). The organic carbon content of the sediments varies between 1 and 5% of dry weight. A detailed discussion of the recent sedimentation in the Black Sea is given in Shimkus and Trimonis (1974).

Danube sediments contain low concentrations of heavy metals, e.g. 28-76 µg/g (dry weight) Zn, 5-10 µg/g Cu, 3-7 mg/g Fe. The iron concentration increases in predeltaic marine sediments as the salinity of the water increases. Higher concentrations are also found in Black Sea sediments, and the concentration gradient increases from the less saline northwestern region to the open sea. Serbanescu (pers. comm.) reports a notable increase in the concentrations of Fe, Cu, Pb and Zn near Constanta harbour, where industry and ore-handling constitute obvious sources of pollution. Nevertheless, all concentrations measured appear to be below those quoted for Mediterranean sediments.

Bulgarian coastal rivers are limited in number and do not carry significant amounts of sediments or polluting substances as the effluents of big industrial, urban and agricultural centers run into two coastal lakes which function as purification plants. Many Bulgarian rivers have a low and sporadic discharge into the sea for most of the year, being cut off from the sea by sand walls. The Bulgarian coast is influenced largely by the discharge of the big rivers in the northwest and especially that of the Danube, whose waters flow southward along the Bulgarian coast to the Bosphorus. This flow can be seen during algal blooms.

Only few data on concentrations of marine contaminants in biota along the coast of Turkey are available. Organochlorine insecticides in samples of mussels and seven species of fish, i.e. <u>Engraulis encrasicolus</u>, <u>Merlangus merlangus exuxinus</u>, <u>Mugil auratus</u>, <u>Mullus surmuletus</u>, <u>Mullus barbatus</u>, <u>Trachurus trachurus</u>, <u>Scophthalmus maeoticus</u> and in samples of fish oil and flour, were analysed by Akman et al (1978). The samples were taken within a large segment of the coast extending from the town of Eregli, located to the east of the Bosphorus, to the town of Trabzon, near the Soviet border (Fig. 6). A total of 280 samples taken from April 1974 to June 1975 were analysed. DDT derivatives, BHC isomers, dieldrin, aldrin and endrin were found to be present frequently in these samples in relatively large concentrations. The frequencies of detection for DDT, BHC, dieldrin, aldrin and endrin were: 100, 100, 97, 95 and 52 percent respectively. In the same order and in µg/g, the concentrations were: 0.281 (± 0.0013), 0.032 (± 0.0022), 0.013 (± 0.007), 0.009 (± 0.0001). Larger concentrations were observed in the samples of fish oil and flour. The organochlorine insecticide residue levels do not show a geographical distribution and tend to be higher in the summer.

The results of Akman et al (1978) are summarized in Tables 3, 4 and 5. Overall levels indicate that, at the time the measurements were taken, the organochlorine insecticide residue concentrations did not constitute a health hazard.

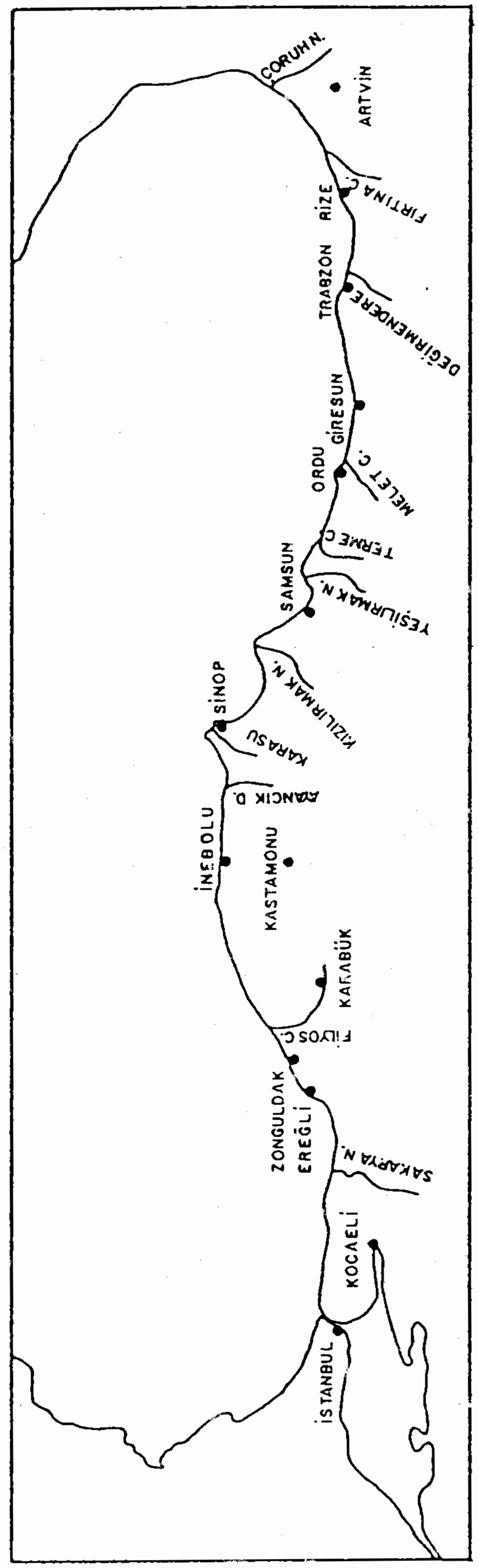

Fig. 6. Major Turkish rivers and Black Sea coastal towns

Table 3. Pollutant levels in grey mullet according to fishing area (in $\mu g/g$)

(Akman et al, 1978)

Insecticide	Sample type	Fishing areas				
		Kdz.Ereglisi	Sinop	Samsun	Ordu	Trabzon
Total DDT	Meat	0.284 ± 0.0422	0.034 ± 0.0423	0.241 ± 0.0431	0.288 ± 0.0393	0.285 ± 0.1239
	Fat	8.660 ± 1.124	7.738 ± 1.152	6.711 ± 0.7416	8.388 ± 0.7155	9.082 ± 1.1300
Total BHC	Meat	0.065 ± 0.0025	0.078 ± 0.0106	0.071 ± 0.0067	0.075 ± 0.0100	0.080 ± 0.0102
	Fat	2.155 ± 0.2048	2.583 ± 0.2751	2.384 ± 0.1482	2.669 ± 0.2969	2.360 ± 0.1698
Aldrin	Meat	0.012 ± 0.001	0.015 ± 0.0023	0.013 ± 0.015	0.014 ± 0.0020	0.012 ± 0.009
	Fat	0.446 ± 0.0444	0.555 ± 0.769	0.429 ± 0.0616	0.495 ± 0.05569	0.409 ± 0.463
Endrin	Meat	0.011 ± 0.0273	0.008 ± 0.0024	0.007 ± 0.0022	0.008 ± 0.0017	0.012 ± 0.0080
	Fat	0.361 ± 0.0815	0.290 ± 0.985	0.252 ± 0.0748	0.288 ± 0.0589	0.374 ± 0.926
Dieldrin	Meat	0.031 ± 0.0579	0.027 ± 0.0055	0.025 ± 0.0050	0.040 ± 0.0050	0.034 ± 0.0042
	Fat	1.027 ± 0.1905	0.988 ± 0.1549	0.782 ± 0.1113	1.344 ± 0.1537	1.100 ± 0.1303
Total	Meat	0.403	0.362	0.357	0.425	0.423
	Fat	12.649	12.094	10.588	13.184	13.335

Table 4. Pollutant levels in economically important fish species (in μg/g)

(Akman et al, 1978)

Insecticide	Sample type	Fish species: Anchovy	Whiting	Grey mullet	Red mullet	Horse mackerel	Turbot	Mussel
Total DDT	Meat	0.645 ± 0.0863	0.114 ± 0.0116	0.100 ± 0.0080	0.282 ± 0.0399	0.513 ± 0.0547	0.212 ± 0.0519	0.247 ± 0.0565
	Fat	14.942 ± 0.4804	5.773 ± 0.4115	4.122 ± 0.5086	7.154 ± 1.0552	12.075 ± 0.9574	7.752 ± 1.4118	0.949 ± 0.3045
Total BHC	Meat	0.0466 ± 0.0010	0.056 ± 0.0050	0.054 ± 0.0040	0.100 ± 0.0145	0.105 ± 0.0153	0.053 ± 0.01006	0.082 ± 0.0069
	Fat	1.328 ± 0.2380	3.137 ± 0.2955	2.252 ± 0.2490	2.078 ± 0.3245	2.172 ± 0.1912	2.053 ± 0.2850	3.433 ± 0.266
Aldrin	Meat	0.0096 ± 0.0002	0.610 ± 0.0002	0.011 ± 0.001	0.015 ± 0.0023	0.015 ± 0.0029	0.011 ± 0.0022	0.018 ± 0.0018
	Fat	0.290 ± 0.0561	0.581 ± 0.0561	0.481 ± 0.0664	0.319 ± 0.0344	0.357 ± 0.0384	0.479 ± 0.0662	0.767 ± 0.0764
Endrin	Meat	0.018 ± 0.0039	0.006 ± 0.0021	0.003 ± 0.0001	0.014 ± 0.0096	0.017 ± 0.0028	0.006 ± 0.0021	0.019 ± 0 045
	Fat	0.434 ± 0.650	0.312 ± 0.1057	0.123 ± 0.0422	0.117 ± 0.0366	0.425 ± 0.0794	0.210 ± 0.1108	0.748 ± 0.1001
Dieldrin	Meat	0.027 ± 0.0074	0.024 ± 0.0050	0.016 ± 0.0021	0.049 ± 0.0070	0.064 ± 0.0082	0.023 ± 0.0053	0.007 ± 0.0057
	Fat	0.656 ± 0.264	1.014 ± 0.1448	0.663 ± 0.0799	1.244 ± 0.1866	1.464 ± 0.1556	0.482 ± 0.1792	1.102 ± 0.2100
Total	Meat	0.746	0.210	0.184	0.460	0.713	0.305	
	Fat	17.645	10.812	7.941	10.912	16.486	10.976	

Table 5. Pollutant levels in grey mullet according to the age of the fish (in μg/g) (Akman et al, 1978)

Insecticide	Sample type	Age (years) 0-2	2-3	3-4	4-5	More than 5
Total DDT	Meat	0.210 ± 0.0047	0.143 ± 0.0025	0.260 ± 0.502	0.377 ± 0.0708	0.425 ± 0.1281
	Fat	6.319 ± 1.245	6.230 ± 1.130	9.357 ± 1.244	9.767 ± 1.977	12.400 ± 3.9009
Total BHC	Meat	0.045 ± 0.0008	0.061 ± 0.0009	0.086 ± 0.5533	0.087 ± 0.0200	0.092 ± 0.0171
	Fat	1.923 ± 0.0387	3.034 ± 0.5138	3.683 ± 0.6964	2.647 ± 0.3074	2.872 ± 0.3535
Aldrin	Meat	0.010 ± 0.0001	0.011 ± 0.0019	0.016 ± 0.0031	0.017 ± 0.0033	0.023 ± 0.0047
	Fat	0.399 ± 0.0717	0.517 ± 0.0691	0.648 ± 0.1396	0.543 ± 0.1000	0.747 ± 0.1035
Endrin	Meat	0.005 ± 0.0002	0.002 ± 0.0004	0.010 ± 0.0030	0.013 ± 0.0124	0.023 ± 0.0075
	Fat	0.183 ± 0.0774	0.131 ± 0.454	0.445 ± 0.1204	0.353 ± 0.1095	0.839 ± 0.2828
Dieldrin	Meat	0.025 ± 0.0077	0.019 ± 0.0048	0.034 ± 0.0070	0.030 ± 0.0063	0.045 ± 0.0138
	Fat	0.724 ± 0.1987	0.777 ± 0.1911	1.289 ± 0.2156	0.922 ± 0.1643	1.369 ± 0.4122
Total	Meat	0.295	0.236	0.406	0.524	0.608
	Fat	9.548	10.689	15.232	14.232	18.227

Measurements of selected heavy metal concentrations taken along the Romanian coast are shown in Table 6. Samples were taken from five stations (Navodari, northern Constanta, North Eforie, Costinesti and Neptun) twice a year at 0.5m depth along the 10m contour line off the coast.

Table 6. Surface water concentration (in µg/l) of some heavy metals along the Romanian Black Sea coastline (range and mean values)

(Pecheanu & Mihnea, 1986)

Year	Cu	Pb	Zn	Cd
1982	2.40 - 4.90 (3.80)	n.d.	7.10 - 10.10 (8.2)	0.05 - 0.16 (0.08)
1983	0.60 - 4.06 (1.44)	n.d.	1.87 - 46.50 (20.36)	0.17 - 1.60 (0.65)
1984	2.06 - 6.25 (1.44)	n.d. - 1.87 (0.83)	2.20 - 27.50 (7.95)	n.d.
1985	n.d. - 7.0 (1.81)	n.d. - 12.70 (3.0)	1.40 - 91.10 (22.48)	n.d.

n.d. = not detected

2.2 Quality assurance, data validation and management

The oceanography of the Black Sea has been relatively well studied and documented in the literature. The same, however, cannot be said for documentation of the levels of marine pollution and the regions that are affected by various activities, especially in coastal areas. This situation persists in spite of the fact that marine research in the Black Sea countries is sufficiently well developed.

Data on marine contaminants are practically not comparable due to lack of intercalibration of instruments and analytical techniques used for pollutant determination. There is an urgent need for intercalibration among the Black Sea countries carrying out pollution studies.

In 1986, Turkey launched a long-term national pollution monitoring programme for the Black Sea. This programme is being carried out by several Turkish oceanographic institutes and covers, among others, quality assurance and data validation via calibration and intercalibration exercises. A data bank is being established for the purpose of this programme as well as for other national programmes that are being carried out in the Aegean and north-eastern Mediterranean Sea.

In Bulgaria, data on the nature and concentration of pollutants have been collected sporadically. Some significant ecosystem parameters have been regularly monitored. The analytical techniques applied are atomic absorption spectrophotometry, neutron-activation analysis, infrared and UV-VIs spectroscopy.

Physico-chemical, biological and microbiological parameters are being monitored along the Romanian coastline. They include water temperature, pH, suspended matter, transparency, dissolved oxygen, BOD_5, dissolved organic substances, phosphorus (PO_4), silicates, nitrates, nitrites, NH_4, chlorophyll a, salinity, detergents, heavy metals in water, sediments and organisms, pesticides in water and organisms. Microbiological quantitative determinations of normal and pathogenic fungi, Streptococcus fecalis and total and faecal coliforms are also carried out. Natural and artificial radioactivity of water, sediments and organisms are studied, as is the bioaccumulation of radionuclides. A data bank for chemical and biological parameters is planned for the near future. An intercalibration programme for heavy metal determination in seawater samples was executed by some Black Sea countries with good results.

2.3 Transport and fluxes across boundaries

Discharges of fresh water and sediments from the various drainage areas and major rivers along the periphery of the Black Sea as estimated by Shimkus and Trimonis (1974) are summarized in Table 7. The highest inputs come from Soviet rivers, while those from Bulgarian and Turkish rivers are much lower.

River discharges for the Turkish coast and their sediment loads, based on data obtained from publications of the Turkish authorities, are summarized in Table 8. The total annual water and sediment input by Turkish rivers is 36 cubic kilometers and 51 million tons respectively. This discharge is in reasonable agreement with that estimated by Shimkus and Trimonis (1974) (see also Table 7), while the estimate of the sediment load for Turkish rivers is three times higher than that of Shimkus and Trimonis (1974). The water and sediment inputs by Turkish rivers are much lower than those of rivers discharging into the north-western Black Sea. Recent estimates of the annual Bosphorus in- and outflows are approximately 290 and 590 cubic kilometers respectively (Ozsoy et al, 1986). These flows are of the same order as the total river run-off of 352 km^3. Based on recent data, it is estimated that the Bosphorus underflow introduces 0.6 x 10^6 t of sediment into the Black Sea, the amount transported out into the Sea of Marmara being 13 x 10^6 t. The transport of sediments through the Bosphorus flows thus constitutes only a small percentage of the total sediment budget of the Black Sea.

The input of various indicators of pollution by the rivers located along the Turkish coast is not completely known. The inputs of a number of chemical components and their concentrations for the three major rivers, i.e. Yesilirmak, Sakarya and Kizilirmak, are summarized in Table 9. Based on recent studies carried out in the vicinity of the junction of the Bosphorus with the Black Sea (Ozsoy et al, 1986; Basturk et al, 1986), the annual influxes of phosphate, nitrate and petroleum hydrocarbons through the Bosphorus underflow are estimated to be: 22, 29,000-45,000 and 135 t respectively. The outflows of the same parameters by the Bosphorus surface flow are 17, 12,000-33,000 and 270 t respectively.

2.4 Selected contaminants

No substantive data are available on the levels of organotin compounds and the use of anti-fouling paints in Bulgaria, Turkey and Romania. Serbanescu et al (1980) report increased levels of detergents in domestic and industrial waters as

Table 7. Water and solid discharge of rivers in the Azov-Black Sea basin (Shimkus and Trimonis, 1974)

	Water discharge (km^3/y)	Solid discharge (100 tons/y)
Platform area of drainage system, plains rivers		
Dnepr	52.0	2.12
Southern Bug	3.0	0.53
Dnestr	10.0	2.50
Don	28	6.40
Sub-total	93.0	11.55
Geosynclinal-platform area of drainage system, mountain, plains rivers		
Danube	198.0	83.0
Kuban	12.8	8.4
Sub-total	211.8	91.4
Folded mountain area of drainage system, mountain rivers		
Rivers from Kerch Strait to Batumi	41.0	*
Bzyb		0.60
Kodori		1.01
Inguri		2.78
Riuoni		7.08
Chokrokh (Coruh)		15.13
Others		2.40
Sub-total	41.0	29 (?)
Rivers of Turkish coast	25.0	17.00**
Rivers of Bulgaria	3.0	0.5 **
Sub-total	28.0	17.5
TOTAL	373.8	149.45

* No amount given

** Very approximate estimate made by writers of this paper on the basis of liquid discharge

Table 8. Water and sediment fluxes from Turkish Black Sea rivers

(Turkey, 1982)

	Water discharge (km^3/y)	**Sediment transport** (in 10^6 t/y)
Sakarya River	6	5 (1964-79)
Karasu River	0.6	
Filyos Brook	3	3 (1967-79)
Lahana Creek	2	
Ayancik Brook	3	
Yesilirmak River	6	18 (1968-70)
Kizilirmak River	6	16 (1967-79)
Folderesi Creek	1	
Firtina Creek	1	
Terme Brooke	0.2	
Melet Brook	1	
Degirmendere	0.3	
Elekci Creek	0.1	
Coruh River	6	0 (1967-79)
Total	35.7	51

Water quality measurements have only been conducted in the rivers Kizilirmak, Yesilirmak and Sakarya. See Table 9.

Table 9. Physico-chemical characteristics and annual loads of water constituents of three large Turkish rivers

Parameter	Sakarya River 1983	Sakarya River 1984	Yesilirmak River 1983	Yesilirmak River 1984	Kizilirmak River 1983	Kizilirmak River 1984
Average flow rate, $km^3/y \times 10^3$	6,003.73		5,567.78		5,920.63	
Average temperature, ^{o}C	13.8	14.0	15.8	15.8	8.8	9.2
Average pH	8.0	8.0	7.7	7.8	8.0	7.9
Average electrical conductivity, μmhos/cm	477	481	408	415	1,592	1,532
Total dissolved solids, kg/y	2.41×10^{9}	2.59×10^{9}	1.59×10^{9}	1.60×19^{9}	5.93×10^{9}	5.67×10^{9}
Suspended material, kg/y	4.19×10^{9}	3.63×10^{9}	0.63×10^{9}	0.49×10^{9}	-	-
Average turbidity	1,001 1/	573 1/	12 2/	9 2/	1,041 3/	874 3/
Colour, Pt-Co	-	-	3	6	55	76
Phenolphthalein alkalinity, $CaCO_3$, kg/y	12.61×10^{8}	31.22×10^{8}	1.31×10^{8}	1.31×10^{8}	40.85×10^{8}	-
Chloride, kg/y	1.25×10^{8}	1.31×10^{8}	6.10×10^{7}	6.40×10^{7}	13.33×10^{8}	13.80×10^{8}
NH_3-N, kg/y	2.70×10^{6}	2.58×10^{6}	1.84×10^{6}	1.56×10^{6}	2.43×10^{6}	2.96×10^{6}
NO_2-N, kg/y	1.38×10^{5}	1.26×10^{5}	-	-	1.36×10^{5}	3.08×10^{5}
NO_3-N, kg/y	6.90×10^{6}	6.84×10^{6}	-	3.17×10^{6}	10.12×10^{6}	4.50×10^{8}
Dissolved oxygen, mg/l	9.5	9.5	11.0	11.0	9.9	9.3
Permanganate value, O_2 kg/y	1.55×10^{7}	1.59×10^{7}	8.29×10^{6}	8.07×10^{6}	10.18×10^{6}	11.25×10^{6}
BOD_5, kg/y	10.81×10^{6}	11.41×10^{6}	6.12×10^{6}	6.68×10^{6}	-	-
Total hardness, $CaCO_3$, kg/y	16.51×10^{8}	16.75×10^{8}	10.91×10^{8}	10.91×10^{8}	30.43×10^{8}	30.84×10^{8}
o-PO_4, kg/y	9.66×10^{5}	10.21×10^{5}	2.78×10^{5}	2.78×10^{5}	4.74×10^{5}	4.14×10^{5}
Sulphate, kg/y	5.76×10^{8}	6.06×10^{8}	3.18×10^{8}	2.96×10^{8}	18.33×10^{8}	18.46×10^{8}
Iron, kg/y	10.38×10^{6}	10.45×10^{6}	1.28×10^{6}	1.56×10^{6}	-	-
Sodium, kg/y	18.71×10^{7}	19.91×10^{7}	10.78×10^{7}	11.43×10^{7}	-	-
Potassium, kg/y	2.71×10^{7}	2.73×10^{7}	1.21×10^{7}	1.15×10^{7}	-	-
Calcium, kg/y	3.71×10^{8}	3.72×10^{8}	2.44×10^{8}	9.09×10^{8}	8.47×10^{8}	-
Magnesium	1.78×10^{8}	1.82×10^{8}	1.16×10^{8}	1.81×10^{8}	2.05×10^{8}	2.31×10^{8}
Total coliform count/100 ml	>240	>240	-	-	-	-
Chemical oxygen demand, kg/y	$<1.2 \times 10^{8}$	$<1.2 \times 10^{8}$	-	-	-	-
Total Kjeldahl Nitrogen, kg/y	6.96×10^{6}	10.15×10^{6}	-	-	-	-
Hydrogen sulphide, kg/y	8.52×10^{6}	8.23×10^{6}	-	-	-	-
Pb, kg/y	$0-<3.0 \times 10^{6}$	$0-<3.0 \times 10^{6}$	-	-	-	-
As, kg/y	$<3.0 \times 10^{4}-6.0 \times 10^{5}$	-	-	-	-	-
Cr, kg/y	$<3.0 \times 10^{4}-<3.0 \times 10^{6}$	$<3.0 \times 10^{4}-3.0 \times 10^{6}$	-	-	-	-
Cu, kg/y	$<3.0 \times 10^{4}-3.0 \times 10^{5}$	$<3.0 \times 10^{4}-3.0 \times 10^{5}$	-	-	-	-
Cd, kg/y	$3.0 \times 10^{5}-<1.2 \times 10^{5}$	$3.0 \times 10^{5}-<1.2 \times 10^{6}$	-	-	-	-

1/ Nephelometric Turbidity Unit; 2/ Jackson Turbidity Unit; 3/ SiO_2 Unit well as in coastal waters of Romania. A survey carried out in 1978-1980 showed concentrations of sodium laurylsulphate ranging between 0.05 and 0.4 mg l^{-1}. The higher concentrations were found in front of the Danube Delta and in areas affected by discharge of domestic waste waters. Seawater concentrations of certain important pollutants along the Turkish coast are presented in Table 10. Pesticide concentrations in horse mackerel, anchovy and sprat in Romanian waters are shown in Table 11.

Table 10. Sea water concentrations of mercury and polychlorinated hydrocarbons 30 miles north of the Bosphorus entrance (Turkey, 1987)

Date	**Depth**	**Hg**	**PAH** 1/	**TSM** 2/	**COD** 3/
September 1985	0	37	0.14	0.75	0.14
	10	-	-	0.80	0.22
	50	33	-	0.72	0.27
January 1986	0	7	-	2.33	0.30
	10	-	-	-	0.50
	50	-	-	-	0.30
	125	-	-	0.13	0.10
May 1986	0	49	0.10	0.53	0.14
	10	-	-	0.38	0.23
September 1986	0	28	0.06	2.62	0.19

1/ Polyaromatic hydrocarbons
2/ Total suspended matter
3/ Chemical oxygen demand of total suspended matter

Table 11. Pesticide concentrations in some economically important species (1979) (in µg/g) (after Serbanescu et al, 1981)

Fish species	**DDE**	**DDD**	**DDT**2/	**Total DDT**	**αHCH**1/	**βHCH**2/	**γHCH**1/
Horse mackerel	0.04	0.367	0.114	0.521	0.052	0.033	0.084
Anchovy	0.065	0.375	0.262	0.703	0.087	0.045	0.113
Sprat	0.160	0.502	0.264	0.926	0.132	0.085	0.113

1/ Since 1979, α and γHCH concentrations decreased for sprat and anchovy but not in horse mackerel.

2/ βHCH, absent in 1981-82, was determined again on and after 1983, showing a slight tendency to increase. DDT was present during the whole period. Sprat samples showed increasing DDT concentrations.

3. HUMAN ACTIVITIES AFFECTING THE SEA

3.1 Disposal of urban and industrial waste waters

The Black Sea receives large quantities of domestic and industrial waste water which is largely untreated. The exact amount of industrial and domestic waste water discharged is presently unknown.

Along the Turkish coast the annual urban liquid discharge and its organic load (in terms of BOD) is estimated as 5×10^8 and 2×10^5 t respectively (Turkey, 1985a). A series of marine outfalls have been planned for a number of towns, including Rize, Giresun, Ordu, Fatsa, Unye, Akcakoca and Eregli. Construction of some of these outfalls has already started. Reliable estimates for industrial discharge along the Turkish Black Sea coast are not available. The main industries and their type of waste are summarized in Table 12.

In Romania waste waters are discharged only in the southern part of the coast. Before reaching the sea they are treated in five treatment plants with a mechanical stage for all of them, but with biological and chemical treatment for only some. The quality of waste is controlled by national regulations enforced by special authorities for water management. Activated sludge from the biological treatment is used for biogas production or dried on special beds. In summer, in order to prevent the contamination of tourist areas, some waste waters are used for irrigation. Faecal coliforms do not reach the southern part of the Romanian coast alive and do not pose a threat to recreational activities. The real problem is represented by detergents, heavy metals, pesticides and nutrients, but this cannot be solved on a national basis. A joint effort of all countries along the Danube is needed.

Tolmazin (1985b) gives the distribution of major pollution sources located along Russian rivers discharging into the Black Sea. Fig. 7 reproduced from Tolmazin, 1985b) shows the primary sources and volumes of industrial pollution along the north-western Black Sea. Wastewater outfalls and discharges from coal and ore mines appear to be the major sources. Even heavy metals, cyanides, ammonia and phenols are discharged without treatment. Disastrous effects, involving complete destruction of habitats along some rivers, have been observed in the past (Tolmazin, 1985b). It is not known, however, how much of the pollutants discharged into rivers eventually reaches the Black Sea. Similarly, the input levels of pollutants introduced through the Bosphorus underflow need more detailed investigation. It is known however, that the terrestrial influxes of pollutants, as well as those introduced via outfalls located along segments of the coast that have a highly developed industry, are significantly affecting the coastal areas.

3.2 Marine transport of oil and other hazardous substances

There are no refineries along the Turkish Black Sea coast and most of the oil and other hazardous substances are transported by land.

A significant amount of oil is transported across the Black Sea from the USSR and Romania, and a number of Soviet and Romanian oil tankers pass through the Bosphorus. There is little doubt that this traffic leaves a mark on the Black Sea. It has been recently demonstrated that the degree of marine pollution by n-alkanes decreases from a value of ca 0.1 mg/l with increasing distance from the coast and then increases to 0.3 mg/l on the navigation route between the Bosphorus and the mouth of the Danube (Demyanov et al, 1985).

Table 12. The major Turkish industries and their type of waste in the Black Sea region

Industry	Number	Probable pollutants and characteristics of effluents	Location
Tea	38	Wastes from treatment of tea leaves	Rize, Artvin, Trabzon, Giresun
Cigarettes	3	Wastes from tobacco and its treatment	Samsun, Sinop, Trabzon
Dairy	4	High amount of organic material, protein, fat & lactose	Kirklareli, Samsun, Sinop, Trabzon, Giresun, Kastamonu
Sugar	3	High amount of dissolved and suspended material, organic material, sugar and protein	Kastamonu, Kirklareli, Sakarya
Pulp & paper	2	pH change, high amount of suspended solids, colloidal and dissolved material, paper-supported material, cellulose	Kocaeli, Zonguldak
Leather	52	High amount of solid material, hardness, salt, sulphite, chromium, pH, precipitable lime, increase in BOD	Samsun, Trabzon
Chemicals	22	pH change, organic and inorganic materials, high BOD, phenols, cyanides nitrates, sulphites and phosphates	Trabzon, Samsun, Bolu, Artvin, Zonguldak, Sakarya, Kocaeli
Cement, lime & plaster	10	Suspended material, chromates, phosphates, zinc and sulphites	Trabzon, Ordu, Kirklareli, Kocaeli, Sakarya, Zonguldak
Copper	1	Metal ions, pH changes, acid phenols, iron, copper	Artvin
Iron & Steel	2	High amount of suspended material, sand and coal, pH changes, acid cyanide, phenols, iron, coke, limestone, alkaline material and oil	Zonguldak
Beverages	8	Increase in BOD, suspended material, precipitable solid material, fat and oil	Giresun, Ordu
Canned fruits & vegetables	2	Suspended material, chloride, phosphate compounds	Zimsun, Sinop
Flour	50	Increase in BOD and COD, suspended material	Trabzon, Rize, Artvin, Ordu, Samsun, Sinop, Giresun
Rice mill	12	Increase in BOD and COD, suspended material	Trabzon, Giresun, Ordu
Food Processing	9	BOD, COD, suspended materials, chemical material	Trabzon, Ordu, Samsun, Giresun, Sinop, Rize
Feed (bait)	4	Suspended material, chemical material	Trabzon, Ordu, Samsun, Sakarya
Coal		SiO_2, $CaCO_3$, Al_2O_3, cobalt, cadmium, lithium in coal ash	Zonguldak
Hazelnut	14	Suspended material	Trabzon, Ordu, Giresun

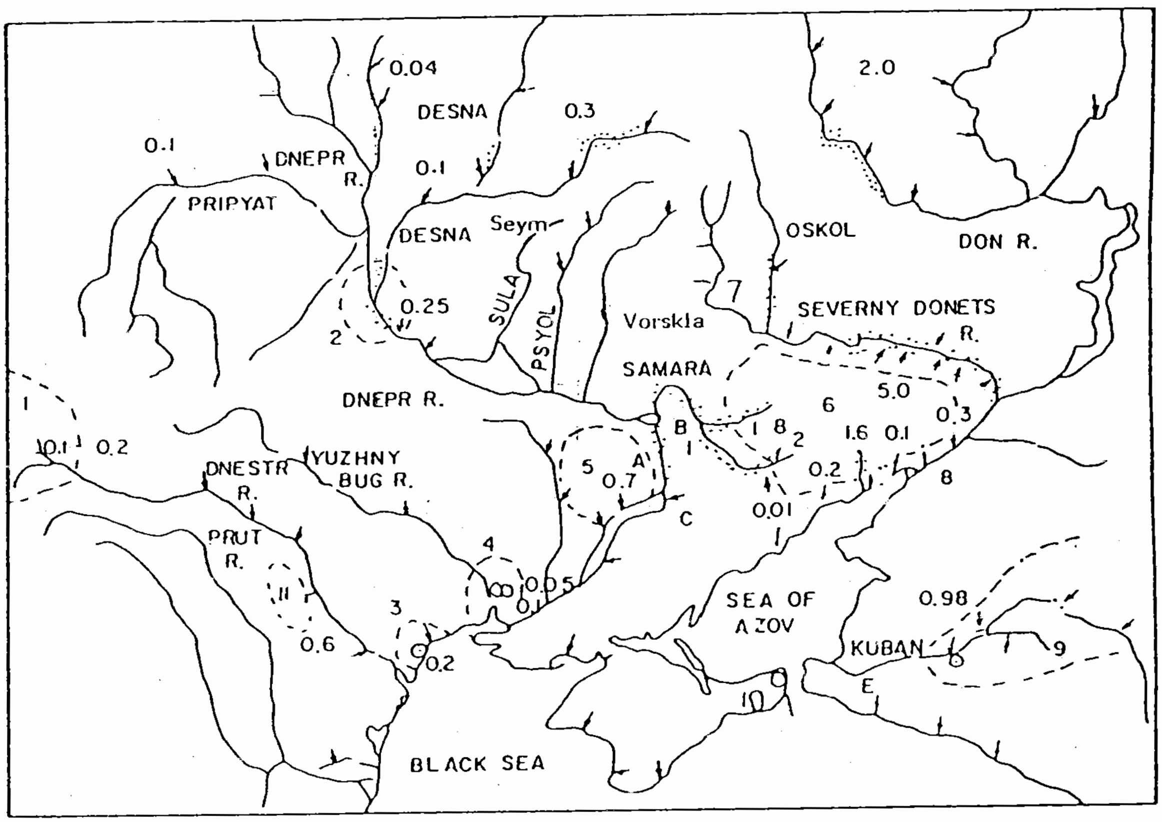

Fig. 7. Industrial regions (numbers) and known untreated industrial effluents (letters) in the Black Sea and Azov Sea basins

1. L'vov-Drogobych; 2. Kiev; 3. Odessa; 4. Nikolaev-Kherson; 5. Krivoy Rog; 6. Donbass; 7. Kharkov; 8. Rostovna Donu; 9. Krasnodar Maikop; 10. Kereh; 11. Kishinev; A. Krivoy Rog ore mines; B_1 and B_2, western and central Donbass coal mines respectively; C. ore mines and processing plant near Dneprorudnyl. Concentrated wastewater outfalls are indicated by the arrows; the double dots mark the place of reported complete destruction of river habitats.

Source: Tolmazin, 1985b.

3.3 Development of coastal areas

In the past the economy of the Turkish Black Sea coast, where nearly 20% of the population is located, was based on agriculture. Even though industry in certain areas of the region has been developing rapidly, agricultural activity has been preserved in others. Industrial development, supported both by the government and private enterprise, is mostly concentrated in the Samsun area (Turkey, 1981). Industrial development appears to be taking place in accordance with the availability of agricultural products. However, factors like the availability of agricultural products, population density, presence of transport facilities including ports and railways, determine the development of industry. Such industrial development puts heavy stress on valuable agricultural areas such as, for example, those where the best quality tobacco is grown (Turkey, 1981). Some such agricultural areas have already been replaced by industry and suffer from industrial pollution. Industrial development problems of the fertile Cukurova area in southern Turkey could also occur in the flatlands of the Black Sea region of Turkey. Among the various coastal regions of Turkey, the Black Sea coast is, as far as tourism is concerned, less developed. This is mostly due to the less favourable climate than that of the Aegean and the Mediterranean coast. The government is making efforts to upgrade and promote tourism along the Black Sea.

In Romania, during the past years important coastal engineering work has been undertaken to consolidate and protect the shore, to enlarge the Constanta harbour, etc. During these activities large amounts of material were dumped in coastal waters. Such dumping affected water quality, especially turbidity and transparency. Filter-feeding organisms were most affected. The macroflora in the rocky zones of shallow waters diminished greatly, both in quality and quantity. The most important perennial brown alga Cystoseira barbata, once very abundant and sheltering a rich fauna, has suffered greatly. Human impact, combined with some harsh winters when the sea froze, and high water turbidity did not allow repopulation. This has led to a drastic decline in biomass (only 3% of the original biomass in 1979).

3.4 Manipulation of hydrological cycles

Major engineering works have been completed along the Danube in the last 20 years. The most important one is the Iron Gates hydroelectric dam, which has been in operation since 1971. Its reservoir contains 3,535,000 m^3 of water. In 1971-1974 the rate of sediment accumulation in this reservoir varied between 160 and 530 kg/sec, while during 1948-1970 it varied between 615-2,210 kg/sec (Bondar, 1977). In addition to reduced sediment transport to the sea, nearshore currents were modified owing to recent coastal engineering activities which induced important changes in nearshore currents. In recent years, severe coastal erosion took place. In the central part of the coast some beaches lost about 12 m per year, and in the north the spring storms are responsible for important damage caused by wash-offs. Romania has initiated a major programme of consolidation of the coastal areas.

Discharges from Soviet rivers have been tampered with considerably, especially during the last three decades (Tolmazin, 1985b). Even though the Black Sea catchment constitutes only 4% of the total Soviet territory, a large proportion (ca 25%) of the population of the USSR lives in the Black Sea area formed by Ukraine, Moldavia and the Northern Caucasus. The area is an important region of the country because of high economic activity. The Dnepr, the Denstr, the Don and the Kuban rivers play a crucial role in the ecology of the Black Sea. These rivers and their tributaries form a complex aquatic ecosystem which is used extensively for agricultural, industrial and recreational purposes, as well as for fishing, waste disposal and hydroelectric energy generation. Thus, although there is no shortage of water in the USSR as a whole, the mismatch between distribution of available water and actual requirements has placed a great demand on the water resources of the Black Sea region. The manipulation of available water resources in the Black Sea region of the USSR for a variety of purposes has led to serious environmental problems. The adverse changes in the ecology of the Black Sea started during the fifties with the construction of a series of dams on major rivers discharging into the basin. The primary purpose of damming was hydroelectric power generation and diversion of water to arid areas. Some of the diverted water used for irrigation was lost when the water stored in reservoirs began to be heavily utilized by the rapidly growing industry (Neporozhniy, 1970; Blagoverov, 1973; both cited in Tolmazin, 1985b). Discharge from industry and agricultural effluents, further deteriorated the quality of water. Thus, in spite of some remedial measures, both the quantity and the quality of water reaching the Black Sea have been reduced considerably. At present about 50% of the water used is returned to rivers without sufficient treatment (Tolmazin, 1985b).

Strong vertical density gradients inhibiting vertical exchanges have formed in the coastal waters of the north-western Black Sea and the Sea of Azov as a result of manipulation of freshwater flows. The most drastic increases in the vertical density gradients have occurred in estuaries because of the intense saltwater intrusions that have accompanied reduced river discharges. The stratification in some areas has been so strong that it persists even under intense winds. The presence of strong effluents and increased agricultural activity, have led to depletion of dissolved oxygen and deterioration in biological activity. The increased levels of pollutants also constitute a health hazard. Oxygen depletion in the subthermocline waters increases especially in the summer months because of insufficient mixing. Oxygen deficiency, hydrogen sulphide and methane generation negatively affect the bottom fauna. Inshore transport of this water mass complicates the situation.

Nutrient concentrations are increasing due to human-induced alterations in river flows. Between 1952 and 1977, in the lower section of the Dnestr, the concentrations (in μg/l) of nitrite, nitrate, phosphate and silicon increased from 0-20 to 36-150, from 0-1,000 to 400-3,000, from 50 to 15-260 and from 1,000-5,200 to 2,300-9,200 respectively (Beklemishev et al, 1982; quoted in Tolmazin, 1985a). Thus, there has been a two- to eightfold increase in the maximum and an even higher increase in the minimum nutrient concentrations. Hypoxia, observed in the seventies, is primarily due to such changes. Following the reservoir construction in 1956-69, the transport of all forms of nitrogen in the lower Dnepr and its estuary increased by 53%. The transport of ammonia nitrogen increased threefold, whereas NO_3 discharge decreased by 14%. Tolmazin (1985b) reports the development of a serious case of hypoxia during 1973-1975 as a result of intensified agricultural activity in the Denpr and Dnestr basins. 35,000 ha of the seabed were affected by a water mass with hydrogen sulphide content as high as 1.2 mg/l, which destroyed mussel beds and led to mass mortality of fish. The coastal waters of Romania and Bulgaria were also affected. Another important example of the effect of freshwater effluents on biochemical cycles was observed in the Sea of Azov. Since the fifties, salinity has increased by nearly 2 °/oo S. Tolmazin (1985b) reports that high salinity has slowed down the major biochemical cycles as a result of inactivation of nitrogen and phosphorus through precipitation. The overall result has been the reduction in total biomass in the Sea of Azov from 34 million to 13-20 million t. An important question to be answered is whether the manipulation of the flows of northern rivers will eventually affect the ecology of the Black Sea. Since the volume of the sea is much larger than freshwater inflows, the water balance and salinity are not expected to be influenced. It is estimated that if the river run-off were reduced by 50%, it would take nearly a century before surface salinity is significantly altered. A water density change would require an even longer time, in the order of tens of centuries (Tolmazin, 1985a). An important water mass of the Black Sea, namely the cold intermediate layer, is formed in the north-western Black Sea region and dispersed into the entire basin below the seasonal thermocline. This could be a significant process through which the shift in the thermocline and biology of the Black Sea could be considerably affected on a small time scale by human-induced changes taking place in the north (Tolmazin, 1985a). This merits serious consideration.

3.5 Exploitation of non-living resources

The exploitation of non-living resources along the Black Sea coast of Turkey has been insignificant due to the narrowness of the shelf and the great sea depth beyond it. Along the Romanian coastline, the most important activity is oil drilling on the continental shelf, which started in 1977. There are several active oil rigs. From the very beginning of this operation, protective measures have been enforced. Monitoring has shown no important changes in the physico-chemical or biological parameters in the area. Some temporary dredging for sand (2 years) disturbed the bottom fauna, especially soft clam, cockle and small crustaceans.

Turkish rivers discharging into the Black Sea are not utilized for energy generation so that human-induced changes in their hydrological regimes are not significant.

3.6 Exploitation of living resources

The state of the Black Sea has changed from oligotrophic to highly productive. The brackish character of the surface waters limits the number of species of organisms present. With the exception of certain bacteria, marine life essentially ceases to exist at the boundary of the anoxic zone.

There are about 180 species of fish in the Black Sea, 57% of which are Mediterranean immigrants (e.g. mackerel, bonito, mullet). The freshwater species represent 22% of the total. Some of the species live in freshwater and low-salinity regions which form in the sea during floods. Another group of species are the relics of the Pontic fauna (beluga, sturgeon and some species of clupeoids). A small number of Arctic immigrants, including sprat, are also present (Zenkevitch, 1963; Sorokin, 1983; Tolmazin, 1985a).

Among the catches in the Black Sea, pelagic species dominate (Table 13). The main stocks of anchovy are migratory, and white eastern horse mackerel stocks are transboundary stocks, both being shared by Turkey and USSR. For example, anchovy (*Engraulis encrasicolus*) is represented by two stocks, one in the eastern and the other in the western Black Sea. Both stocks winter in the Turkish coast (Slasteninko, 1955/56), where they are fished. In 1984, Turkey and the USSR caught 327,626 and 268,841 t of anchovy respectively (GFCM, 1987). Horse mackerel, after wintering in the South, migrate clockwise (western population) and counter-clockwise (eastern population) to their northern spawning grounds (Lundbeck, 1975, and the references cited therein). During migration, both stocks pass either through Bulgarian, Romanian and USSR territories (western population) or only through USSR waters (eastern population) where they are also fished. The Turkish catch of horse mackerels in 1984 increased to 92,822 metric tons (GFCM, 1987). Therefore, the continuous assessment and monitoring of these and the other stocks (e.g. Scombridae, Pelamidae) constitute the essential requirement for their effective utilization. Turkey, Romania and the USSR are in the process of declaring their Exclusive Economic Zones (EEZ) in the Black Sea. Bulgaria has already declared it. For this reason alone, future fishing activities will require the establishment of a total allowable catch quota for each country.

To date, only few data exist on stock size and hydrobiological conditions in the Turkish Black Sea coast. A survey conducted in March-May 1972 by UNDP/FAO (Losse & Johannesson, 1973) is of relevance in this context. In view of the considerable increase in landings during the past 15 years, these data are obsolete and need to be updated (Turkey, 1976,1985b). Attention should be paid to the impact of high catches of anchovy and horse mackerel. In the years 1982-1983, the catches surpassed the potential annual yield indicated by the UNDP/FAO study (Losse & Johannesson, 1973). In spite of landings of anchovy and horse mackerel being seasonal, a sizeable processing industry has already been established on the Black Sea coast. Due to poor coordination in the sector, fishing and processing capacities are not properly matched. While their relation to the potential sustainable yields of the fish stocks to date can only be guessed, it is felt that the processing capabilities, especially the reduction to fish meal and oil, have been over-capitalized. Recent legal and administrative changes are expected to favour integrated and effective development of the fisheries sector. A fisheries law has been enacted which should enable the fisheries services within the Turkish Ministry of Agriculture, Forestry and Rural Affairs, i.e. the General Directorates for Project and Application and General Directorates for Conservation and Control, to play effective roles in a number of aspects related to fishing activities. The Turkish State Planning Organization is now actively involved in the planning and coordination of fisheries development within the framework of the Turkish Fifth and Sixth Five-year Development Plans.

Table 13. Catches of European anchovy (Engraulis encrasicolus), sprats (Sprattus sprattus and Clupeonella cultiventris) and horse mackerel (Trachurus mediterraneus and T. trachurus) and the total catch in the Black Sea and in the Sea of Marmara in metric tons

(from GFCM, 1987)

Year	Anchovy	Sprats	Horse mackerel	Sum of these groups	Total catch
1976	354,941	42,087	41,413	438,441	491,607
1977	258,270	46,698	27,572	332,540	389,340
1978	275,069	115,656	41,440	432,165	491,251
1979	286,660	147,658	82,790	517,108	628,229
1980	473,160	161,468	61,459	696,087	770,615
1981	453,061	143,702	59,919	656,682	745,101
1982	498,080	198,443	69,796	766,319	893,783
1983	517,714	161,276	80,812	759,802	876,563
1984	603,060	130,698	100,008	863,766	923,880

According to recent estimates, the total fish catch of Romania is about 15,000 t/year. The most common species are sprat, horse mackerel, anchovy, Danube herring (Alosa), sturgeon and turbot. In the last two decades, two valuable species have disappeared from Romanian waters, i.e. blue mackerel and bonito. They migrate into the Black Sea from the Sea of Marmara through the Bosphorus, where conditions adverse for reproduction have drastically diminished the stocks. Sprat (Sprattus sprattus) account for 50-60% of the total Romanian catch. It is a short-lived species which can withstand strong alterations in environmental conditions and thus maintain a constant population for many years. In 1984, 130,698 metric tons of sprat (i.e. Sprattus sprattus and Clupeonella cultiventra) were caught in the Black Sea (GFCM, 1987).

The manipulation of river flows and river discharges in the northern Black Sea, the increase in water pollution and over-exploitation of stocks have significantly affected fisheries. Fish and shellfish yields have declined substantially in the north, including the Sea of Azov. This decline has been attributed to the cut-off in freshwater inflow (Tolmazin, 1985b). In the precontrol period, the river-estuary-coastal-sea ecological system was balanced and could sustain a fish harvest of about 80 kg/ha in the Dnepr estuary (Zhuravleva et al., 1976). After water regulation, commercial fishing in the Dnestr estuary has virtually come to an end. In the seventies, fish catches in the Dnepr estuary dropped five times as compared to the fifties. Some valuable species such as pike, perch, roach, bream and vimba, disappeared altogether.

4. BIOLOGICAL EFFECTS

4.1 Eutrophication

In the last three decades the nutrient concentrations in Romanian coastal waters have increased significantly. Between 1959 and 1968 the phosphorus content ($P\text{-}PO_4$) was of 5-20 µg/l, with lower values in summer. This value increased five times in 1968-1971 and 10-20 times after 1971. The annual mean value for 1975 was 302.6 µg/l. Since then it has maintained the same level of 200-300 µg/l, with lower concentrations in summer (Cociasu & Popa, 1980). The same changes can be found for nitrates ($N\text{-}NO_3$): 22.5 µg/l in 1960, 78.95 µg/l in 1980 and 107.61 µg/l in 1985. Since the sixties, $N\text{-}NO_2$ and $N\text{-}NH_4$, as well as organic substances have increased significantly. The poor quality of the Danube water and waste water disposal are the major factors that have contributed to this situation.

As a result of eutrophication, there have been changes in the composition of the phytoplankton community (Mihnea et al, 1981). In the early sixties, the nutrient content was a limiting factor for phytoplankton development. Since 1970, the nutrients exceeded the phytoplankton requirements and stopped being a factor controlling primary production (Mihnea & Cuingioglu, 1985).

The following changes in phytoplankton ecology in Romanian coastal waters were noted:

(a) Increase in number of some indigenous species (Mihnea, 1985):

(i) Skeletonema costatum: from 1×10^4 - 14×10^6 cells/l (1962-1965) to 8.26×10^7 (1975-1977).

(ii) Cyclotella caspia: from 3.2×10^4 - 1.2×10^7 cells/l to 9×10^3 - 9×10^6 cells/l (1975-1977).

(iii) Cerataulina bergonii: reached a density of 3.58×10^5 cells/l (1983).

(iv) Exuviaella cordata: increased from a few million (1962-1965) to 1×10^8 cells/l (1975-1983).

A great number of species underwent important changes in 1983-1984. Forty species gave densities about 100,000 cells/l, 7 of which were between 1-10 million, and 4 species had densities of 16 to 141 million cells/l (Bodeanu, 1984).

(b) Appearance of new species in the ecosystem (Mihnea, 1982, 1985; Mihnea et al, 1981):

(i) Species permanently established or persisting for long periods of time:

Gonyaulax polygramma was found for the first time in inshore waters in 1976 at a density of up to 280,000 cells/l and reached 1.85

million cells/l in 1983. Raciborskiella salina developed at a density of 1,000-14,000 (1975) and 1.04-1.7 million cells/l 1983 and 1977, respectively. High concentrations of dissolved organic matter (BOD_5 ranged between 0.69 and 13.44) favoured the development of euglenophytes: Eutroptia lanowii was identified when values of BOD_5 ranged between 2.4 and 4.6 mgO_2l^{-1} (Mihnea, 1978). The maximum cell density was 8.1 million cells/l and was found in 1982 in the Constanta harbour.

Concentrations of other euglenophytes, i.e. Euglena pisciformia, E. viridis f. salina, E. acus, E. desses, E. limnophyla, Astasia parvula, A. pygmaea, A. curvata, were correlated with the composition of dissolved organic matter (Mihnea, 1979).

(ii) Species that have developed one more life cycle and whose number was reduced or have almost disappeared from the ecosystem:

The following species belong to this group: Polytima uvella, Apiococcus consociatus, Brachiomonas westiana, Chloromonas paupercula, Chaetoceros simplex var. calcitrans.

(c) Species whose life-cycle was modified (Mihnea, 1981, 1985): Skeletonema costatum and Cyclotella caspia.

(d) Quantitative changes in the phytoplankton community: In 1962-1965 the total number of phytoplankton reached 1-4 million cells/l only during the spring or summer blooms. After 1975 the number usually exceeded 1 million cells/l, sometimes reaching over 100 x 10^6 cells/l. This was the result of the frequent blooms that affected inshore areas 1-3 times a year (Mihnea & Cuingioglu, 1982; Bodeanu, 1984). This increase in numbers is related to the increase in biomass (as wet weight): 723-2 004 mg m^{-3} in 1962-1965 and 2,943-33,927 mg m^{-3} after 1980.

Particulate organic carbon ranged between 3.0 and 1,144 mg m^{-3} in 1984 (Mihnea, 1984). Chlorophyll a content variations (minimum and maximum in mg m^{-3}) were 0.025-54.59 (1982); 0.03-42.98 (1983); 0.009-62.5 (1985), with extremely high concentrations recorded during the blooms (up to 185 mg m^{-3} in shallow waters, e.g. in May 1983) (Mihnea, 1987).

A high increase in the density of the phytoplankton community affects vertical light transmission. A large amount of phytoplankton adds to the suspended matter, which results in the reduction of depth from 50 to 1% isolumes. During 1983, phytoplankton densities of 8.4-11 million cells/l (14.20-42.78 chlorophyll a mg m^{-3}) implied 50% isolumes in a station influenced by waste waters. In the same month at 10 nautical miles offshore, low quantities of phytoplankton (7,000 - 1 million cells/l and 0.21-2.19 mg chlorophyll a m^{-3}) determined a depth of 1.64 m for 50% isolumes and 10.8 m for 10% (Mihnea, 1985; 1986).

Phytoplankton blooms also deplete dissolved oxygen with the result that conditions in the environment become lethal to the majority of organisms.

4.2 Long-term biological impact of contaminants

The effect of long-term modifications on the Black Sea marine environment resulting from human activity has induced significant changes not only in phytoplankton but also in zooplankton and zoobenthos. The zooplankton community increased from 2.56 mg m^{-3} in 1961 to 18.30 mg m^{-3} in 1967 and 16.96 to 155.56 mg m^{-3} during 1976-1977 (Petran et al, 1977). In 1983 this was 8,719 mg m^{-3}. Noctiluca miliaris had an explosive increase, reaching 15,712 individuals m^{-3}, Acartia clausi reached 5,835 individuals m^{-3} and Pleopsis polyphemoides 1,760 individuals m^{-3}. Other species decreased, e.g. Paracalanus parvus, Centropages ponticus, Oithona nana and Penilia avirostris. Some species became rare, e.g. Evadne spinifera and Pleopsis tergestina (Porumb, 1980, 1984). The diversity indices of zooplankton have low values due to a few opportunistic species such as Pleopsis polyphemoides and Acartia clausii that produced a monospecific population (Petran, 1984).

Over the last years, there have been spectacular changes in the biomass of jellyfish (Aurelia aurita) (see Shushkina & Musayeva, 1983). In 1959-1962, its total biomass in the 0-80 m water layer of the Black Sea was 93-1,600 thousand tons (average: 670 thousand tons). In 1978, in the 0-10 m layer there were 47 million tons of Aurelia with a total biomass (wet weight) of 300-450 million tons for the whole of the Black Sea (Gomoiu, 1981). This is much greater than the biomass of the anchovy. This phenemenon can be related to the development of phytoplankton and zooplankton as a result of eutrophication and to the considerable reduction in the number of some plankton-feeding trophic competitors of the jellyfish. In the Black Sea the population of Aurelia consumes daily about 15% of the biomass of zooplankton in the fall, and up to 25% of the production of non-predatory zooplankton. Aurelia consumes 10% of the production of the whole non-predatory zooplankton per square meter every 24 hours and about 30% of the production of the non-predatory crustaceans. Since 1986, a jellyfish monitoring study has been carried out by the Institute of Marine Sciences of the Middle East Technical University, Turkey. The preliminary results (Bingel & Unsal, 1986) show strong biological interactions between the Sea of Marmara and the Black Sea. Seasonal averages of the jellyfish biomass were found to be as follows:

Time period	**Biomass** (Wet weight gm^{-3})
Winter 1985-1986	6.94
Spring 1985-1986	4.08
Summer 1985-1986	17.20

The current fluctuations in the jellyfish biomass in the Black Sea are indicative of the growing instability of this environment.

Benthic fauna has also shown qualitative and quantitative changes. Ostrea sublamellosa and Gibbula divaricata are now extinct along the Romanian coast. Other species, quite frequent in shallow-water zones 15-20 years ago, have also disappeared or are quite rare: Ophelia bicornis, Petricola litophaga, Irus irus, Solen vagina, Donax trunculus, Eriphia verrucosa, Upogebia pusila (Gomoiu, 1981). Organisms which were scarce became common, for example the tube polychaete Melinna palmata, have become extremely abundant. Melinna palmata populated the depths of 20-40 m in an area larger than 2,200 km^2, with a density of 2,331 specimens m^{-2}. It is suggested that this high biomass is related to the increase in concentration of particulate organic matter. As a consequence of the more frequent phytoplankton blooms, a great quantity of organic detritus is accumulating on the sea bed. This detritus is an ideal food for Melinna, which shows a great tolerance of large changes in dissolved oxygen concentrations and even temporary anaerobic conditions and the presence of hydrogen sulphide (Gomoiu, 1982). The blue mussel, Mytilus galloprovincialis, and soft clam, Mya arenaria, have been affected along the entire continental shelf. Since 1976-1977 the mussel stock has drastically diminished. However, in 1983-1984 new populations consisting of young specimens were found (Gomoiu, 1984). On the other hand, Mya arenaria has become very common along the Romanian coastline during the last 15 years. In some places there are more than 2,700 individuals m^{-2} and a biomass of about 1,000 g m^{-2}. It contributes substantially to the biomass but, at the same time, it disturbs the ecosystem by competitively excluding the endemic Corbula mediterranea (Tiganus, 1983). Owing to modified conditions, new organisms have penetrated into the Black Sea and formed large populations. These are Polidora ciliata, Callinectes sapidus, Rapana thomasiana, Mya arenaria and, more recently, Scapharca inequivalvis.

4.3 Public health effects

No cases of epidemic induced by water pollution along the Black Sea coasts of Bulgaria, Romania and Turkey have been reported. In the USSR, in the summer of 1970, there was a cholera epidemic in the estuarine areas of the northern Black Sea and the Sea of Azov, causing some deaths. Quarantine and related measures apparently stopped the spreading of the epidemic. Observations of active cholera bacilli in the regional marine ecosystem suggest that the event was generated by a sudden increase in pollutants as a result of the manipulation of river flows and disposal of wastes (Tolmazin, 1985b).

4.4 Recovery and rehabilitation of damaged habitats and species

In Turkey, regulatory measures have been introduced and scientific investigations are in progress to deal with the problems of over-exploitation of some fishery resources along the coast. These efforts are being supplemented by a number of pollution monitoring projects.

In the northern Black Sea region, rehabilitation programmes have been in progress for some twenty years. Several large hatcheries/fish farms were constructed. These farms presently constitute 50% of the fish-farming capacity of the USSR. Such measures have been successful in the preservation of fish such as sturgeon. Other rehabilitation efforts have failed because of demands for water for other purposes. Long-term regulatory projects on large estuaries and the Sea of Azov are being planned.

4.5 Episodic events and accidents

The release of large quantities of radionuclides to the lower atmosphere from the Chernobyl nuclear power plant in 1986 has had implications on the health of the Black Sea. Clouds containing radioactive material reached the Black Sea area on 2 May and subsequently. In addition to direct fallout, the Black Sea is expected to have received an advective input from the Danube and the Dnepr. Both rivers drain watersheds heavily impacted by the Chernobyl fallout, the Dnepr including the freshwater environment directly around the Chernobyl site itself. The ^{134}Cs, ^{137}Cs concentrations measured and ^{134}Cs/^{137}Cs ratios calculated from the data obtained during the cruise of the Turkish research vessel R/V PIRI REIS are presented in Table 14.

Table 14. ^{134}Cs and ^{137}Cs concentrations and ^{134}Cs/^{137}Cs ratios in surface waters (Livingstone et al, 1986)

Location	^{137}Cs concentrations (bg/m^3)	^{134}Cs concentrations (bg/m^3)	^{134}Cs/^{137}Cs
Black Sea	165 ± 14	78 ± 4	0.47
Black Sea	70 ± 5	35 ± 3	0.50
Black Sea	41 ± 6	17 ± 1	0.42
Bosphorus (mouth)	85 ± 4	35 ± 3	0.48
Bosphorus	74 ± 4	35 ± 3	0.46

Eutrophication and blooms leading to red tides have been observed in the past (Bodeanu & Roban, 1975). The review by Tolmazin (1985a) fully covers the oceanography of the basin, the development of hypoxia generated by alteration to the physical environment, changes in the biochemistry of the region by human-induced control of river flows and the consequent upwelling of anoxic bottom waters temporarily generated near the Danube-Dnestr region and in the southwest of the Dnepr estuary.

The manipulation of rivers, especially of the Dnepr, has not only decreased discharges but has also significantly altered seasonal flow patterns. The short and intense spring flood now extends over a longer period but has a lower intensity (Tolmazin, 1985a). As a result of this, there is now nearly permanent stratification in shallow coastal areas and estuaries that strongly precludes downward transport of dissolved oxygen. In the presence of increased organic loads, hypoxia episodes have developed in several areas. Hypoxia, possibly induced by transient upwelling events, was observed in a few areas before the reduction in the river discharge. Following the significant reduction in the discharges of rivers during 1973-1975, however, severe hypoxia (and, in some cases, anoxia) developed. Mass mortalities of major species within the subpycnocline waters occurred in water masses as large as 3,500 km^3 (Salsky, 1977; Losovskaya, 1977). The area affected extended from the mouth of the Dnestr to the Danube delta, resulting in high mortalities of benthic fish such as goby and flounder in coastal areas.

Bronfman (1976) and Tolmazin (1977) formulated a hypothesis on the dynamics of hypoxia involving the increase in the sinking of particulate organic matter generated by inland sources and eutrophication of coastal waters in the presence of high stratification, slow bottom circulation with consequent small amounts of external oxygen supply, and upwelling. Immobile benthic species die rapidly and contribute further to the depletion of oxygen. Water is recharged with dissolved oxygen with the onset of vertical mixing during the cooler period. According to Tolmazin (1985a), in recent years there has been an increase in hypoxia episodes covering nearly 20,000 km^2 of the northwestern shelf waters. He further reported that "catches of flounder and turbot decreased sharply. The population of grey mullet, red mullet, all species of crabs, some Idothea ostroumi and pontellid copepods have decreased by 1-3 orders of magnitude".

5. REGIONAL ASSESSMENT, TRENDS AND FORECASTS

The Black Sea receives large quantities of domestic and industrial waste water which is mostly untreated. The hydrological cycles of the northern rivers are being significantly manipulated. The quantities of industrial and domestic waste waters discharged into the basin are unknown but it can be said that such discharges significantly affect the Black Sea.

It is expected that the Black Sea coast will continue to develop rapidly. New townships and industries, through an increased input of wastes, will further stress the Black Sea.

As a result of the manipulation of the northern rivers, both the quantity and quality of the water reaching the Black Sea will continue to be considerably reduced. At present, about 50% of the water consumed goes back into the river systems without sufficient treatment.

The manipulation of rivers flowing into the northern Black Sea and the accompanying increase in the levels of pollution are significantly affecting fisheries, which are also faced with over-exploitation. Many economically important species of fish have disappeared regionally as well as from the entire Black Sea. Furthermore, increasing nutrient input through rivers and the alteration in the stratification of the coastal water masses have led to even more prolonged periods of eutrophication. Hypoxia has become a frequent phenomenon in certain areas in the northern Black Sea. Mass mortalities of the major species of the food chain accompany the hypoxia in water masses as large as 3,500 km^3. The change in the ecology of the Black Sea is indicated from the persistent explosion in jellyfish population. Even though the exact causes for this are not known, this increase in number and biomass of jellyfish could be the result of human-induced changes in the oceanography of the Black Sea.

Diversion plans involving a complex network of structures to transfer water to the southern territories of the USSR have been prepared. The diversions from the northern rivers into the Black Sea could bring in 70-95 km^3 of water per year.

Last but not least, significant amounts of oil emanating from some Black Sea countries are transported across the Black Sea. It is evident that this traffic poses a threat to the Black Sea, and will continue to do so. This requires serious monitoring efforts and regulatory measures.

6. PREVENTION AND CONTROL STRATEGIES

Biotic and abiotic changes in the Black Sea are not limited by national boundaries. Because of the north-south circulation, water from rivers entering the north-western part of the Black Sea influences the sea water of the USSR, Romania, Bulgaria and Turkey. Romanian wastewater disposal may affect the Bulgarian coast. Eutrophication is a common phenomenon of the western part of the Black Sea. To assess such effects, especially long-term ones, international cooperation is necessary.

Some Black Sea countries have joint monitoring projects on eutrophication, heavy metals, mariculture, fishing, etc. They also exchange scientists and organize joint expeditions. A convention of the four Black Sea countries to prevent pollution is being discussed. This convention stipulates measures and actions to be undertaken and scientific cooperation.

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