(VNIRO). These expeditions continued until 1927, and the results were summarised by its chief - N.M. Knipovich [1], together with results of other expeditions (Main Hydrographic Board and Sevastopol Biological Station). These data, which covered the north part of the sea approximately to the limits of the economical zone of the former USSR, permitted estimation of the distribution of water transparency in the region, with some information on the seasonal variability using data from hydrometeorological stations in ports. The maximum values of transparency ever observed were: $Z_d = 30.5m$ - at a point opposite the Kerch Strait (44°50.5'N, 36°49'E, March 30 1924) and $Z_d = 30m$ - in the south part of the sea (42°39'N, 33°30'E, May 04 1925).

Secchi disk measurements were performed in different expeditions in the following years, giving extensive information about spatial distribution and time variability of the water transparency. However, the data do not provide any information on the vertical optical structure of the water column.

In 1929, academician V.V. Shuleykin, well-known by his fundamental work on physics of the sea, founded the Black Sea Hydrophysical Station in Crimea. Hydro-optical research was started there under his leadership. At first the research was directed towards theoretical analysis of light penetration in the sea, and laboratory verification of theoretical results in turbid media, which modelled sea water. In the 1940s, the Black Sea Hydrophysical Station began *in situ* hydro-optical investigations directed towards verification of theoretical results under natural conditions. In 1948, measurements of angular distribution of light radiance at different depths confirmed *in situ* the existence of the asymptotic radiance distribution, which had been predicted by Shuleykin. In 1959 the first measurements of underwater irradiance were conducted in the deep part of the sea down to 100 meters at three spectral bands, and water transparency measurements down to 200 meters; the scattering function *in vitro* was also measured for surface water. In 1960, investigations of sunlight polarisation in the sea were started, showing that asymptotic radiance distribution characterised not only the steady radiance, but also the degree of polarisation.

Field research conducted by the Black Sea Hydrophysical Station (reviewed in [2]) gave some idea about vertical distribution of optical properties of the sea. But the technical capabilities in those years were severely limited, so many questions of optical properties of the Black Sea water, including their vertical and horizontal distribution, remained open.

A new stage in optical investigations in the Black Sea came after the relocation of the Marine Hydrophysical Institute (MHI) from Moscow to Sevastopol in 1963. The Marine Optics Department was established under the leadership of professor G.G. Neuymin. The department began a broad based work program, including construction of modern instruments for field hydro-optical measurements. Up to the 1970's a number of sounding and towed instruments were constructed, which permitted measurements of both inherent and apparent (light field parameters) optical properties of the sea: the attenuation and scattering coefficients, the scattering function, underwater irradiance, angular distribution of the underwater radiance and polarisation, colour index, bioluminescence, and fluorescence. During the next decade, instruments were constructed for remote studies of the sea using the spectra of sea radiance. The Department initiated a long-term program of measurements, for the study of the optical

structure of water and its relationship with hydrological, chemical and biological fields. The beam attenuation coefficient was chosen as the main parameter and its vertical profiles were measured in expeditions. The measurements of Secchi disk depth were continued.

The quantity of hydro-optical investigations conducted by MHI in these years surpasses many times those conducted by other institutions. These investigations focused on the optical structure of the sea and processes of its formation, such as the following example: During August - September 1964, the vertical structure of water transparency was studied down to 1000 meters (spectral band 640nm) and down to 1700 meters at some stations using a wireless transmissometer with acoustical communications. The research was performed along two transects crossing the entire sea - along 43°N and 34°E. Besides the turbid layers of biological origin, there is an additional interesting layer in the Black Sea below the euphotic zone at depths of 100-200 meters, near the upper boundary of the anoxic zone. The mechanisms of its formation are discussed in [3,4]. It corresponds with intense bacterial activity and with complex geo-chemical processes occurring in the oxic/anoxic interface.

In 1967 the sounding transmissometer with cable-rope connection was completed, which permitted measurements of the beam attenuation coefficient in the visible and near ultraviolet spectral bands. Measurements using this instrument showed the spectral difference in vertical profiles of transparency in the deep anoxic layer. The attenuation coefficient in this layer is constant in the red band but it increases with depth in violet, and especially in the near-ultraviolet spectral band. This regularity suggests that the concentration of so-called "yellow substance" (gelbstoff), which is included in dissolved organic matter, increases with depth. This substance absorbs light strongly in the short wave band of the spectrum and does not affect the red band.

In 1970, the first measurements of the scattering function were conducted *in situ* using an underwater nephelometer at a meridian section along 34°E. Measurements to 200 meter depth clarified the mistake of early views about scattering of light in deep water layers, which were based on laboratory measurements using water samples. In such samples, if one does not take special efforts, the hydrogen sulphide is oxidised and a turbid colloid is formed from sulphur particles, which scatter the light considerably.

In 1972-1973, investigations of the vertical bioluminescence light field structure in the regions with different hydrological conditions [5] showed that bioluminescence in the Black Sea exists only in the upper oxic zone and is absent in deeper anoxic layers. As distinct from other seas and oceans, the daily vertical migration of bioluminescent layers is absent. The *in situ* first measurements of bioluminescence in the Black Sea using an underwater photometer were performed by Institute of Biology of the Southern Seas in 1965-1966 [6]. However, these limited measurements at a fixed point near Crimea at small depth (near 60 m) did not provide information about the spatial structure of bioluminescence.

Since 1974, measurements of colour index have been conducted in Black Sea expeditions. The new research vessel "Akademik Vernadsky" (obtained by MHI in 1969) was a very effective vessel for this purpose. A vertical hull hole permitted measurement of colour index and other parameters while she was sailing, and permitted the study of the small-scale variability of optical parameters in the surface layer of the sea.

During hydro-optical research near the Bosphorus in 1976 some peculiarities in the vertical distribution of transparency in deep waters, connected with Marmara Sea water inflow, were observed. Strongly turbid layers were found here at depths of 200-400 meters, within the anoxic zone. The beam attenuation coefficient was sometimes 1.6 1/m in the violet band in these layers. Research conducted here in 1978 showed the intensity of the turbid layers decreased rapidly with distance from the Bosphorus, but it could be observed at the depth of Marmara Sea water penetration easterly along the Turkish coast up to Caucasus.

In the early 1980's MHI started the research on spectra of sea radiance in various optical bands in conjunction with the satellite oceanography program. The multiple measurements of the radiance spectra of the Black Sea were conducted in 1983-1985 as part of the experiment "Inter-Cosmos." The measurements were performed from ship, aircraft and the orbital space station "Salut-7." Algorithms were constructed to extract information about optical and biological properties of sea water from the sea radiance spectrum.

By the middle of the 1980s, the large data set accumulated in MHI permitted analysis of the climatological structure of the optical fields in the Black Sea. The first maps were constructed of the mean distribution of the beam attenuation coefficient for 1977- 1985 for different depths down to 400 meters, and the depth of characteristic optical layers for summer and winter seasons. These maps showed the main features of space - time variability of water transparency on climatological scales, and the close relationships of optical fields with other oceanographic fields.

At the end of the 1980's, the data base of the Black Sea optical parameters was created by MHI. The stimulus for this research was the extremely low values of water transparency which appeared in the Black Sea in the late 1980's.

During the last few years, the hydro-optical investigations conducted by MHI in the Black Sea have been directed on the study of the time and space variability of optical parameters in the framework of international monitoring programs. A specific focus is optical structure in the near-shore zone, where the anthropogenic loading is maximum.

The main optical parameters measured now by MHI expeditions include: vertical profiles of the beam attenuation coefficient down to 250 meters in different bands of visible and near-ultraviolet spectra, spectral distribution of the radiance index of the sea, colour index, Secchi disk depth, and colour of the sea. The ultimate goal of the optical investigations in the Black Sea is to construct a hydro-optical model of the basin, from which one can make operative diagnosis and forecast of the optical sea state.

Results of optical research in the Black Sea till the end of the 1970's were reviewed in [7,5], and to the end of the 1980's in [8]. The results of remote sensing of the Black Sea and ground truth measurements were described in [9].

Another major institution studying the hydro-optics of the Black Sea is the South Branch of the Oceanology Institute (Russian Academy of Science) located in Gelendzhik. This Branch performed research primarily in the eastern near-shore part of the Black Sea. In 1989-91 it carried out long-term (18 months) optical measurements in the Caucasus near-shore zone using a series of transects between Gelendzhik and Novorossiysk. Results of these measurements (reviewed in [10]), showed typical profiles of the attenuation coefficient in the near-shore zone and its seasonal variability. They also showed the possibility of optical monitoring of cyclonic and anticyclonic eddies on a synoptic scale. In winter 1991 (cruise 21 of R/V *Vityaz*), the South Branch performed hydro-optical research in the central and eastern part of the sea. The optical structure of the water (using beam attenuation coefficient) and its connections with water dynamics were determined for the end of the winter season [11]. They also studied the dependence between quanta irradiance of photosynthetic-available radiation and spectral values of the downward irradiance [12], recommending that now, since transparency has decreased significantly for Black Sea, one must use the spectral band of 520-555 nm, rather than 465 nm as was recommended by N. Jerlov earlier, for the calculation of photosynthetic-available radiation.

Some optical research in the Black Sea also was conducted by the Institute of Biology of the Southern Seas (Ukrainian Academy of Sciences). Except for bioluminescence measurements [5,13], the research conducted in 1986-1989 for the determination of the euphotic layer depth (1% of surface irradiance) used Secchi disk depth in the Northwest part of the sea (in press).

In 1986 optical research in the Black Sea was started by the Institute of Marine Sciences (IMS METU, Turkey). The measurements of the water transparency, Secchi disk depth, fluorescence and PAR were performed in the south part of the Black Sea.

A notable event in Black Sea optical research was the measurements of vertical profiles of water transparency in the red spectral band up to full depths conducted in autumn 1988 by R/V *Knorr* (USA). This research covered the southern part of the sea in the Turkish economic zone. Previous measurements to such depths were performed only once in 1964 by R/V *Mikhail Lomonosov*. Interesting results were obtained by the R/V *Knorr* expedition about the fine structure vertical distribution of transparency in the intermediate layer and about its connections with thermohaline parameters. The transparency decreased in layers having thermohaline anomalies. Using these data they traced the evolution of anomalies on transects from the coast to the sea and discussed transport of particulate matter from the Turkish shelf to the deep zone of the sea in the intermediate water layer [14].

3. Relationships between the Secchi disk depth and bio-optical parameters of the Black Sea surface waters

The simplicity of Secchi disk measurement attracted researchers' attention long before knowledge of the connections between the Secchi disk depth and different hydro-optical parameters measured by precise optical instruments. A Complete examination of the different factors of underwater vision was provided by [15,16]. For specific external conditions (irradiance, sea surface state, etc.) the maximum Secchi disk depth (Z_d) depends on optical water properties (so-called inherent optical properties) and on parameters of the underwater light field (apparent optical properties). Although Z_d depends on the combination of inherent and apparent optical water parameters, there is a high correlation between Z_d and these parameters taken separately. This correlation results because hydro-optical parameters in the sea are strongly connected. The main factor that causes this correlation is phytoplankton and its life products, which influence both absorption and scattering characteristics of light. Thus, there is a high correlation between Secchi disk depth and biological parameters (phytoplankton). Different bio-geo-chemical conditions in different regions of the World Ocean, especially the changes in the species composition of phytoplankton populations, influence the relationships between optical and biological parameters. Therefore regional optical relations are more reliable than global relationships. Table 1 lists empirical regression equations which connect the different bio-optical parameters of the Black Sea:

c_m (0-Z_d) - mean value of the beam attenuation coefficient in the layer from surface down to Z_d, m^{-1};

k_m(0-Z_d) - mean value of the vertical attenuation coefficient for the daylight in the layer from surface down to Z_d, m^{-1};

I_c (540,440)=B^{540}/B^{440} - colour index, where B^{540} and B^{440} are the spectral radiance in upward light under the sea surface at wavelengths of 540 and 440 nm;

L(R_{max}) - the wavelength corresponding to the maximum on the spectral curve of the radiance index of the sea, nm;

L_d - the dominant wavelength in spectral distribution of the sea radiance index calculated in the X, Y, Z system of colour co-ordinates, nm;

C_o - chlorophyll "a" concentration near the sea surface, $mg \cdot m^{-3}$;

P_o - primary production near the surface, $mgC \cdot m^{-3}$ day^{-1};

S - integrated production in the euphotic zone of the sea, $mgC \cdot m^{-2}$ day^{-1};

M_o - concentration of particulate matter in the near surface layer, $mg \cdot l^{-1}$.

TABLE 1. Relationships between Secchi disk depth and bio-optical parameters for the Black Sea

#	Equation y=f(x)	Wave length (nm)	Limits for x / y	# of point	σ^2 of regr.	Correlation coefficient r	Ref.
1	$c_m(0-Z_d)=(8.75/Z_d)-0.11$	422	4.5-27/0.1-0.93	302	0.17	0.80±0.05	20
2	$k_m(0-Z_d)=1.43/Z_d$	490	10-26/0.02-0.14	20	0.018	0.81±0.05	@
3	$I_c=123 \cdot Z_d^{-2.02}$	540, 440	3-44/0.05-16	124	-	0.93±0.02	21
4	$L(R_{max})=593-37 \cdot \ln(Z_d)$	-	1.5-28/475-580	89	-	0.95±0.02	9
5	$L_d=463+285/Z_d$	-	3-40/470-560	121	-	0.89±0.02	9
6	$C_o=52.5 \cdot Z_d^{-2.11}$	-	1-27/0.02-79	307	0.33	-0.85	22
7	$P_o=2400 \cdot Z_d^{-2.24}$	-	1-24/0.7-2700	156	0.37	-0.85	22
8	$S=5012 \cdot Z_d^{-1.28}$	-	1-24/22-3585	156	0.28	-0.77	22
9	$M_o=14.8 \cdot Z_d^{-1.29}$	-	0.05-29/0.12-1390	284	0.24	-0.97	23

@ - unpublished data of the MHI

The equations for I_c, L(R_{max}), L_d and M_o were calculated using data obtained not only in the Black Sea, but in other marine basins [9, 21, 23]. Data from the Black Sea alone are in good agreement with these equations. High correlation coefficients for the equations for Table 1 permits the use of Secchi disk depth for estimating the bio-optical state of the Black Sea upper layer. Strong changes which occurred in the Black Sea

ecosystem during the last years suggest that equations 3-8 (Table 1) can be applied only to data obtained till 1985; these equations can give high deviations for the recent data.

For comparison, analogous equations obtained in basins other than the Black Sea have nearly the same range of variability of the Secchi disk depth. We shall not discuss here the difference between the equations for different basins.

For Norway and Barents seas [17]: k_m (0-Z_d)=1.5/Z_d; L=465nm, Z_d=5-18m.

For Lake Baikal [18]: c_m (0-Z_d)=7.3/Z_d; L=480nm, Z_d =5-28m.

For the region of Peru up-welling [19]: C_o=670·(Z_d)$^{-3}$; Z_d =4-15m.

4. Seasonal and long-term variability of water transparency

Figure 1 shows the seasonal variability of the Secchi disk depth (Z_d) analysed using monthly mean values, calculated for 1922-1985 for the central deep part of the Black Sea, limited by the latitudes 42°20' and 44°15'N and longitudes 31° and 38° E. There are two minima in the inter-annual variability of Z_d , namely in spring and at the end of autumn and two maxima, namely in summer and at the end of winter. The difference between maximum and minimum mean values is about 6.2 meters or 37% of mean annual value (16.8 m).

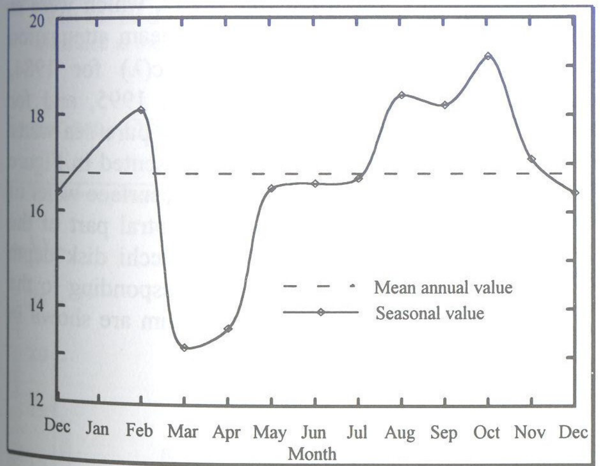

Figure 1. Seasonal variations of the mean Secchi disk depth (m) in the central part of the Black Sea in 1922-1985.

The strong changes in the optical properties of the Black Sea which have taken place in recent years are of great interest [8]. From the early 1920's to the mid-1980's, only a weakly pronounced transparency decrease was observed. Over 60 years, the Secchi disk depth had decreased from 20-21 to 15-16 meters (mean values in the deep central part of the sea), however, single values up to 25 meters were occasionally observed. The Black Sea water transparency has decreased dramatically since 1985. In 1990-1993, values in excess of 15 meters were no longer observed and mean values were only 6-10 metres. It is worth to mention that the water transparency in the Black Sea started to increase after 1993 (Figure 2).

Water transparency measurements using *in situ* instruments, which were performed by MHI during the Black Sea surveys, also indicate the same decrease of transparency. Mean, maximum, minimum values and standard deviation of the attenuation coefficients (wavelength 410-420 nm) in the surface layer

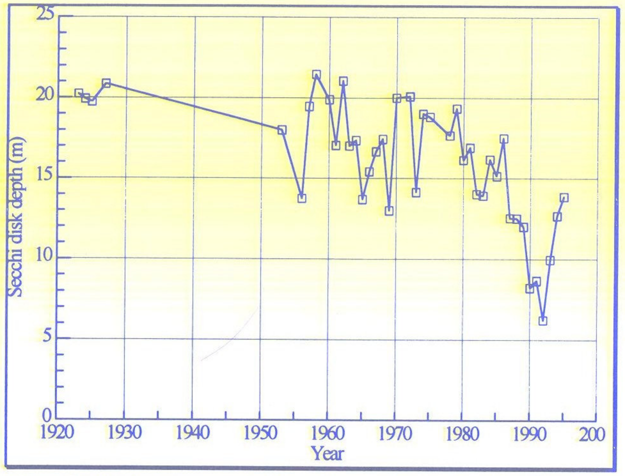

Figure 2. The long-term variability of annual mean Secchi disk depths in the central deep part of the Black Sea in 1922-1995.

of the central, deep part of the sea for the summer period are shown in Figure 3. Values obtained in the period 1977-1985, which are considered as the "background" data, show significant changes compared to 1990, 1991, and 1992 data. Specifically, a continuos increase in the attenuation coefficient is observed.

Spectral optical properties of the Black Sea water have also changed in the same periods. In the 1990s compared with 1984, not only the values of the beam attenuation coefficient strongly increased, the shape of spectral curves changed as well, due to the initial enhanced increase in the short wavelength band. The minimum values, which were at 480 nm in 1984, shifted to the 550-570 nm in 1992. Spectra of the beam attenuation coefficient c(λ) for 1984, 1991, 1992, 1995, and for the optically pure sea water [24] are presented in Figure 4 for the subsurface water of the deep central part of the sea. The Secchi disk depth values corresponding to the each spectrum are shown in the legend.

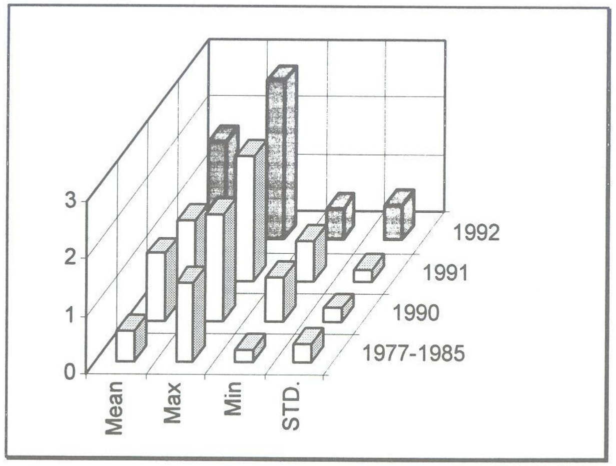

Figure 3. Beam attenuation coefficient, c (m^{-1}) in 1977-1992.

5. Factors influencing the drastic decrease of water transparency

The detail analysis of the collected data has helped to understand the main reasons for the drastic transparency decrease in the deep basin of the Black Sea in the 1986 - 1992 period and to reach the conclusions stated below [25].

Significant eutrophication occurs both in the near-shore areas of the Black Sea and in the deep basins, being connected with the long-term increase in the input of nutrients of anthropogenic origin.

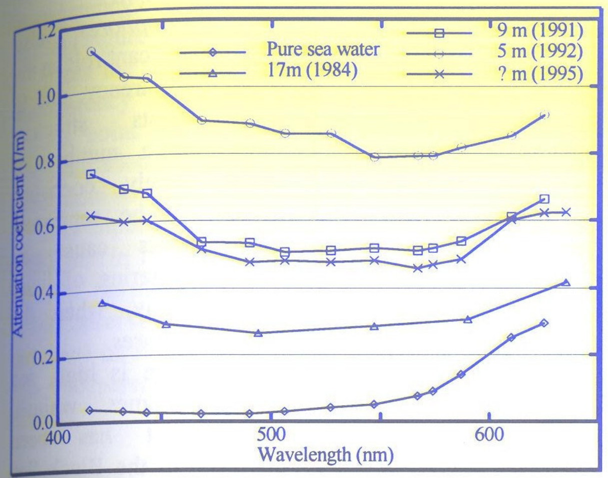

Figure 4. Spectra of the beam attenuation coefficient c(λ) for the subsurface water of the deep central part of the sea for the different years and for the pure sea water. The Secchi disk depth values measured at the same station are given in the legend (it was not measured in 1995).

For example, input of biogenic compounds of nitrogen and phosphorus by the Dnieper and Danube rivers, which are responsible for 3/4 of the overall riverine input to the Black Sea, increased 5-7 times from the 1960s to the 1980's [26]. The mean chlorophyll concentration has become one and a half time larger in the deep part of the sea during the same period [27].

Water transparency gradually declined due to the increase of the content of optically active matter in the sea. Over 20 years, from the mid-1960s to the mid-1980s, the mean annual decrease of the Secchi disk depth has attained about two meters.

However, the main reason for the drastic transparency decrease from 1986 till 1992 was the enhanced bloom of *Peridinium* and *Coccolitophores*. Their number in the Black Sea was 1.5 - 2 orders of magnitude larger than the in previous years and has reached 2-3 billions per cubic meter (Figure 5). A significant increase in the biomass of these plankton organisms has changed the structure of the plankton community. Nanoplankton, which contributes immensely to the light scattering, accounted for 90% of the phytoplankton content in this period.

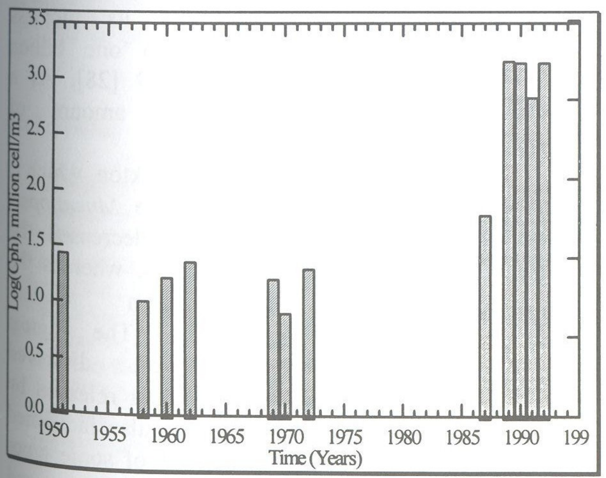

Figure 5. Dynamics of the phyto-plankton amount in the euphotic layer of the Black Sea western deep area in 1950 - 1992.

The intense blooms of *Peridinium* might have been also caused by the increased concentration of particulate organic matter, as *Peridinium* can switch to heterotrophyc nutrition.

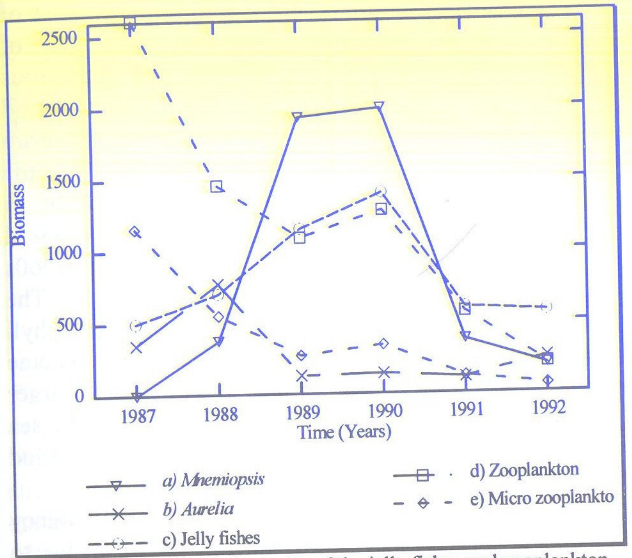

Figure 6. Inter-annual dynamics of the jelly fishes and zooplankton bio-mass in the Black Sea in 1987 - 1992 (Jelly fishes - 10^3 g·C·m^{-2}, Aurelia and Mnemiopsis - g·m^{-2}, others - 10^2 g·m^{-2}).

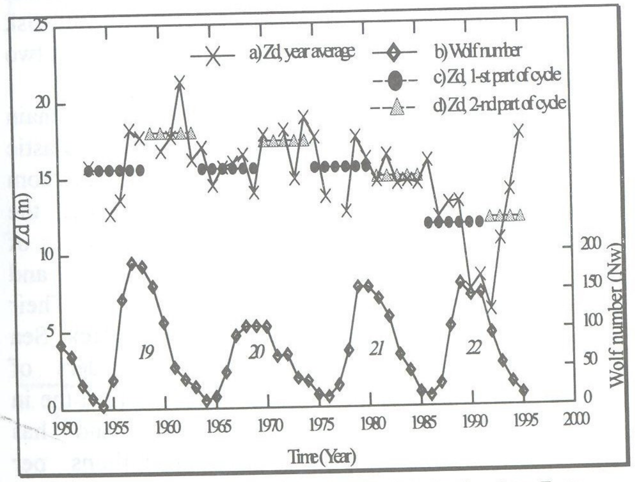

Figure 7. Dynamic of the Secchi disk depth values Z_d on comparison with Solar activity cycles.

Coccolitophores also play a significant role in the water transparency, due to their crusts structure containing a number of disks, namely, coccolits, which can be separated. These disks cause an intense scattering of light. This is why, when the *Coccolitophores* concentration is high, sea water becomes whitish. This effect has been observed in the Black Sea over the last few years.

Phytoplankton structure was also strongly impacted by the biological invaders, such as *Mnemiopsis Leidyi* which appeared in the Black Sea in the early 1980s and its biomass amounted to one billion tons in 1989 [28]. As a result, the amount of herbivorous microzooplankton, which is a part of the *Mnemiopsis* food, has decreased by several times, whereas the phyto-plankton content increased. The great amount of dissolved organic matter released by *Mnemiopsis* also facilitated the increase of some types of phytoplankton and bacteria (Figure 6).

Long-term periodical oscillations in the Black Sea water transparency have been found to occur, which seems to be correlated with the 11-year cycle of solar activity [25]. Water transparency increases during the second half of the cycle and decreases during the first one. Drastic decrease in the transparency in late 1980s coincided with the second half of the 1980-1991 solar activity cycle. However, the magnitude of the transparency decrease was more intense during this cycle than those during the previous cycles (Figure 7).

From the analyses of the collected data, it may be concluded that the catastrophic transparency decrease in 1990-1992 took place due to the combined effect of three factors coinciding in time and sign: (1) the natural 11-year cycle, (2) increased eutrophication, and (3) the influence of the biological invader *Mnemiopsis Leidyi* on the ecosystem structure.

It is important to emphasize that the intense decrease in water transparency ended in 1992, and in 1993 water transparency started to improve. As a result, already by the end of 1995, the mean Secchi disk depth in the deep central part of the basin had reached the levels observed for the early 1980s, i.e. about 17 meters. Future research will give the evidence on the changes in the ecosystem of the sea during these years, which caused this transparency increase, but it coincides with the beginning of a new cycle of solar activity.

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INFLUENCE OF ANTHROPOGENIC IMPACT ON THE PHYSIOLOGY OF SOME BLACK SEA FISH SPECIES

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Abstract

The effect of the two major factors of aquatic environment (oxygen deficiency and food supply) on the physiology of Black Sea fish was investigated.

A considerable decrease of the rate of the oxygen uptake and sharp increase of the rate of the nitrogen excretion was observed in three fish species (*Trachurus mediterraneus ponticus Aleev, Diplodus annularis Linne and Scorpaena porcus Linne)* during experiments of short-term and long-term hypoxia. The decline of the value of O:N quotient from 40-80 to 2-7 was also observed. The data obtained indicated the involvement of proteins and nitrogenous compounds in the energy metabolism of fish under low oxygen concentration in water. The results are discussed in relation to the adaptation of fish to oxygen deficiency mostly of anthropogenic origin.

Moreover, the disintegrating effect of the long-term hypoxia on the structure of muscle fiber was found in golden grey mullet (*Liza aurata Risso)* and round goby *(Neogobius melanostomus Pallas*) in histological assay. The presumable scheme of the muscle destruction mechanism is suggested.

Additionally, data on the fatness of the Black Sea sprat by the end of the feeding season for the period from 1960 to1996 are presented. These data are discussed in connection with monitoring of the nutritive base and food supply of planktivorous fish and changes in pelagic ecosystem caused by anthropogenic impact in the Black Sea.

1. Introduction

The Black Sea has been most dramatically afflicted by pollution due to the river inflow carrying ever increasing amounts of products of human activity [1] and the extreme "narrowness " of the biotic zone which lies between the surface and water layer containing H_2S and seems to be sensitive to harmful impacts. Populations of mass Black Sea fishes seem to be also susceptible to the noxious influences that may be explained by two main factors :
1) hypoxic conditions (oxygen deficiency) of the environment and
2) worsening food supply (food deficiency).

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