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The Black Sea Zooplankton: Composition, Spatial/Temporal Distribution and History of Investigations

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Abstract: Investigations into the composition, spatial and temporal distribution of the Black Sea zooplankton were reviewed in context with its historical development. The review comprises the main zooplankton studies published by the riparian countries of the Black Sea beginning with the earliest faunistic publications in the 1860s and 1870s up to the recent multinational ecosystem investigations carried out within the framework of the NATO-TU-Black Sea Project. The reviewed material covers a wide subject range of zooplankton investigations from descriptive studies to distribution and the production mechanisms in the ecosystem.

The main findings of recently performed large scale investigations into the horizontal and vertical distiribution of zooplankton were also summarized and short and long term fluctuations in the composition and biomass were also analysed. Additionally, the influences of natural and anthropogenic factors on these changes were discussed and problem areas to be investigated in future were underlined.

Key Words: Black Sea, zooplankton, history, composition, distribution, fluctuation.

Karadeniz Zooplanktonu: Kompozisyonu, Yer ve Zamana göre Dağılımı ve Araştırmaların Tarihçesi

Özet: Karadeniz zooplanktonunun kompozisyonu, yer ve zamana göre dağılımı araştırmaların tarihi gelişmesi çerçevesinde derlendi. Bu derleme, Karadeniz'e kıyısı olan ülkelerde 1860'lı ve 1870'li yıllarda fauna tespitine yönelik yapılan ilk belli başlı yayınlardan başlayarak günümüzde NATO-TU-Karadeniz projesi çerçevesinde yapılan çok-uluslu eko-sistem araştırmalarını kapsamaktadır. Derlenen materyal, tanıtımcı çalışmalardan zooplanktonların dağılımına ve eko-sistemdeki üretim mekanizmalarına kadar uzanan çok geniş konuları içermektedir.

Zooplanktonların yatay ve dikey dağılımlarına ilişkin son yılların geniş ölçekli araştırmaları ile kompozisyon ve biyokitlede görülen kısa ve uzun süreçli artma ve azalmalar da analiz edildi. Ek olarak, bu değişmelere doğal ve insan etkisinden kaynaklanan faktörlerin etkileri tartışıldı ve gelecekte yapılması gereken araştırmaların altı çizildi.

Anahtar Sözcükler: Karadeniz , zooplankton, tarihçe, kompozisyon, dağılım, artma ve azalma.

Introduction

The Black Sea is one of the most interesting seas of the world both in scientific and non-scientific aspects. Its history is full of romantic and dramatic events. Its diverse marine fauna has been influenced by the long and short term (geological, climatic, hydrological) natural and anthropogenic processes of the last three decades. Approximately 200 million people live around the Black Sea basin. However, its catchment area is much larger and numerous (waste) products from this area accumulate in this relatively small basin. Along with other human activities, they influence the Black Sea ecosystem in general and the zooplankton communities in particular.

In recent years some zooplankton species have either disappeared or become rare whilst others have flourished and reached huge numbers (e.g., *Mnemiopsis*; Shushkina, et al., 1997). The study of qualitative and quantitative changes occurring in this ecosystem is necessary in order to understand and preserve the biodiversity.

Zooplankton, being the major consumer of he primary production, constitute the food source of organisms at higher trophic levels, some of which are of high economic value. Additionally, since the majority are filter feeders, this serves to cleanse the water column of suspended matter and hence contributes significantly to the improvement of the water quality, which is especially important in coastal zone management for recreational purposes. More than 1000 publications and the continuing interest in zooplankton studies in the Black Sea acknowledge their important role.

Of course not all publications (even, if they are thematically grouped) can be analysed in one article. However a significant number of them are taken into account for the present review, mainly dealing with the composition and distribution of zooplankton, its evolution, history of investigations and the main results of these investigations as well as future tasks to be undertaken in the Black Sea. In fact, no such review is available up to now, which covers research results of the last 150 years. Some available reviews consider only short time periods and evaluations are limited to the activities of one institution (1-4). The present review evaluates investigations starting from the first faunistic proceeding of the Sevastopol Biological Station up to the present day interdisciplinary and multi-institutional analysis of combined long-term data series of riparian countries. This latter development (establishment of a common database and joint evaluation and analysis) could be realised with the support of the NATO-Science for Stability Programme through the Institute of Marine Sciences of the Middle East Technical University of Turkey (5).

History of investigations

Investigations of the planktonic fauna in the Black Sea began in the middle of the 19th century carried out by Ukrainian scientists and were soon followed by others. The rising interest in marine life was the main reason for the subsequent foundation of marine biological stations and institutes. The Sevastopol Biological Station which was founded in 1871 was the first of its kind around the Black Sea basin. The founding and early managers (V. N. Ul'yanin; S. M. Pereyaslavtseva and A. A. Ostroumov) focused their studies on the planktonic fauna occurring in inshore areas. ın 1891, A. A. Ostroumov and V. A. Karavaev (zoologists from Kiev) pioneered the offshore collection and describtion of dominant zooplanktnoic species (6-8). Among others, the following scientists of the Sevastopol Biological Station (since 1963: Institute of Biology of the Southern Seas of the National Academy of Sciences of Ukraine) studied the zooplankton: S. A. Zernov, V. N. Nikitin, M. A. Galadzhiev, M. A. Dolgopolskaya, T. S. Petipa and V. N. Greze.

Many stations and institutes which carried out important investigations into the Black Sea zooplankton appeared in the 20th century. These were:

Ukraine-Karadag Biological Station, now Karadag Reservation. -Odessa Biological Station now Odessa branch of IBSS (Institute of Biology of Southern Seas), ---Southern Scientific Research Institute of Marine Fishery and Oceanography, Kerch.

Russia-All-Russian Institute of Marine Fishery and Oceanography, Moscow. -Shirshov Institute of Oceanology in Moscow and its Southern Department, in Gelendzhik. -Novorossiysk Biological Station (now Biological Station of Krasnadar Univ, Novorossiysk.

Georgia-Batumi Fisheries Station.

Turkey-Hydrobiological Research Institute (now Institute of Marine Sciences and Geography)-İstanbul University. -Institute of Marine Sciences (IMS-METU), Erdemli/İçel -Institute of Marine Sciences and Technology, İzmir.

Bulgaria-Research Institute of Fisheries, Varna. -Institute of Oceanography, Varna. -Laboratory of Marine chemistry in Bourgas.

Romania-Romanian Marine Research Institute, Constanza.

In the past studies were carried out by individual scientists for personal scientific interest, however, nowadays scientists of different countries develop programs in which they combine their efforts in international programs such as the NATO-TU-Black Sea Project or the EROS 2000 program.

The subjects, contents and techniques of investigations naturally changed with time (2, 4, 9, 10). During the early studies various new species were described [6, 7, 11-14, (Chernyavskiy, 1868 and Krischagin, 1873; c.f., 15), and many others].

Zoogeographical analysis of the faunistic investigations were completed at the end the 19th century (15). Although some species and even higher taxons were revised later (e.g., 16-19). These basic taxonomic works were followed by wider and more detailed studies of the zooplankton in the Black Sea. For example, zooplankton including meroplanktonic larvae were investigated by Kiseleva, (20), Petran, (21), Murina, (22) and others, and the holoplanktonic larvae of copepoda were studied by Sazhina, (23, 24). Investigations carried out in the 1960s resulted in a series of 3 volumes concerning the "Identification of the Black Sea nad Azov Sea fauna", the main contributors being Braiko et al. (25-27). However, faunistic research is still being carried out even today (28-32). One direction within such research is the Mediterraneanization of the Black Sea fauna.

Parallel to the faunistic investigations, during nearly the same time period, ecological studies were started by

Zernov (33, 34). He investigated the quantitative distribution of zooplankton and its seasonal changes off Sevastopol. Following this, intensified research activities took place in several riparian countries of the Black Sea (e.g., 35-53 and many others). Meanwhile some authors characterised zooplankton communities of different regions including open waters and various depths (e.g., 54-57). V. N. Nikitin (35, 36) was the pioneering scientist who first described the vertical distribution of zooplankton in the open waters of the Black Sea. He also investigated features of diurnal and seasonal vertical migrations of the dominant planktonic species and demonstrated the relationship between diurnal migrations and water temperature. Investigations by V. N. Nikitin created the basis for further intensive studies of species ecology and peculiarities in the zooplankton dynamics in the Black Sea. The earlier findings of Nikitin on the vertical distribution of plankton organisms,were later verified using large volume water samples of 100-150 liters by Vinogradov et al., (56).

The comparative analysis of the spatial distribution of the dominant zooplankton species in the Black Sea and other seas of the Mediterranean basin was carried out by Kovalev (58). In recent decades quantitative studies have also been carried out, to describe features of the horizontal and vertical distirbution of zooplankton in regions with different pollution and eutrophication levels (30, 31, 56, 59-63).

Routine monitoring of the zooplankton composition in different regions of the sea began in the 1950s. The impacts of natural and anthropogenic factors on the fluctuation of the zooplankton communities were studied by various authors (59, 64-74).

By the 1940s physiological investigations of single species were already included in plankton studies. Respiration, repoduction and feeding habits were studied both in the field and laboratory (75-82). The knowledge gained from these investigations formed the basis for the analysis of the structure, productivity, condition (well-being) and functioning of the zooplankton communities and populations (e.g., 3, 64, 79, 80, 84-87 and several others).

Since the 1970s studies on zooplantkon dynamics have gained a multidisciplinary approach by the modeling of complex interactions of the biota (e.g., 3, 88-94).

Qualitative and quantitative field observations are the prerequisites for the understanding of the dynamics of the zooplankton in particular and the ecosystem in general.

Sampling methods and treatment

In the first decades of investigations the Nansen and Genze Net were used for the collection of samples. Later Ukrainian, Russian, Romanian and Bulgarian investigators used the Juday Net. This net, having an openinig of 0.1 m^2 is still in use in these countries as the basic device for zooplankton sampling. Long-term usage of the Juday net has been important in the comparison and analysis of results obtained in different countries. However the mesh sizes of the nets varied between 125 and 160 µm, which is insignificant for mesozooplankton sampling. Either a Hensen net of 300 µm mesh size or Nansen net of 112 µm mesh size have been used by Turkish zooplanktologists.

In the later zooplankton studies, size spectra were taken into account when sampling. Microzooplankton (<0.5 mm), mesozooplankton (0.5-10 mm) and macrozooplankton (> 10 mm) were studied by Zaika et al., (95). The material was sampled by either Juday or Bogorov-Rass nets. Meantime special trawls were developed for the collection of macrozooplankton (96). During recent studies large volume water samplers of 100-150 liters capacity were used for mesazooplankton sampling (97 & others). The advantage of the latter sampler is that these collectors can also be used at greater depths with a higher accuracy of depth recording and they allow the study of the vertical distribution of organisms in relatively thin layers. Furthermore with the development of neuston nets, specially designed for surface or near surface sampling, dense populations of zooplankton were discovered in the surface layers (55). The application of various sampling devices allowed the characterisation of species composition, abundance and biomass of all size groups of zoplankton as well as the description of trophic structures (98).

During the majority of field studies, standard depths (0, 10, 25, 50, 75, 100, 150, 200 m) or depth layers (10-0, 25-10, 50-25, 100-50,150-100, 200-150) were sampled. However, in recent years the sampling was performed with respect to the physical and chemical characteristics of the water column, most notably the density (99). The simplets type of this sampling procedure considered the upper mixed layer, thermocline layer and from the lower boundary of the thermocline to the hydrogen sulfide layer. The boundary of the oxic/anoxic layer was identified according to the sigma theta depth of 16.2, indicating the start of the H_2S-zone (100). In recent international surveys the whole oxic zone was sampled by vertical hauls, to collect all migrating species during both day and night (101). The results were expressed per m^{-2}.

For the quantification of organisms in the samples the same procedures were used by all countries. Small and abundant species were counted applying sub-sampling techniques, large animals were enumerated in the whole sample. Biomasses were determined using respective conversion factors for each stage/animal, obtained from the literature (102). Volumetric measurements were also utilised for certain zooplankton groups, [for example the ctenophores; (101)].

Main results

In the following, the overall results of the Black Sea zooplankton research concerning composition, spatial and seasonal distribution and temporal changes are presented.

Zooplankton composition

Earlier investigations carried out demonstrated that the planktonic fauna of the Black Sea is sparse compared with the Mediterranean Sea (14 & others). This fact was attributed mainly to salinity. Typical marine stenohaline organisms (Radiolaria, Spihonophora, Pteropoda, Salpae), inhabiting the Mediterranean Sea (salinity: S=36-38‰), are not able to survive in the Black Sea (salinity: S=17-20‰). Medusae, Ctenophora, Copepoda and other groups, that have a high species number in the Mediterranean Sea are also represented by only one or few species in the Black Sea (9). About 80 holoplanktonic species, mainly coming form the Mediterranean Sea, occur in the Black Sea. Koval (60) discovered about 150 species of planktonic animals in different regions of the northwestern shelf. Almost half of these species are brackish-water and fresh water species inhabiting estuarine regions and gulfs. Besides these, meroplankton which is made up of numerous larvae of benthic invertebrates were an important part of zooplankton (>30 species of Polychaeta, >50 species of Gastropoda, >20 species of Bivalvia; (22).

Zooplankton inhabiting the Black Sea can be divided into three ecogeographical groups. These are Mediterranean invaders, Pontic relicts and fresh-water species (9). Although the species number of the Mediterranean invaders in the Black Sea is not high, they are the main component of the zooplankton communities in this sea.

Despite the fact that the Black Sea zoplankton has been studied relatively well, taxonomic studies carried out in the Black Sea can not be considered as complete. For example detailed morphologic investigations of copepoda species of he Black Sea led to changes in the taxonomic status of some species. The sole species of the genus *Centropages* occuring in the Black Sea, *Centropages ponticus* KARAV, is not a variation of the Mediterranean species *Centropages kröyeri* GIESBR. (16). The predominant species of *Calanus* of the Black Sea was previously identified as *Calanus helgolandicus* CLAUS. This was then reclassified as *Calanus helgolandicus ponticus* (17), and later as *Calanus ponticus* KARAV., (18). Recently this species was renamed as *Calanus euxinus* KRICH., 19). Regarding the taxonomic status of large and small forms of *Acartia clausi* GIESBR., it was supposed that they were sibling specise (103). Furthermore, the Black Sea species of *Oithona* is *O. nana* (104) but not *Oithona minuta* as previously thought by some authors (102, 105 & others). It can be assumed that taxonomic investigations on some other zooplankton species may reveal similar results.

Mediterraneanization is an important process for the enrichment of the Black Sea zooplankton. Studies of the planktonic species transported by the lower Bosphorus flow through the Bosphorus Strait first began in the 1960s (106) and reusulted in interesting findings: Bogdanova & Shmeleva, (107) have shown that few individuals of some Mediterranean species were distributed not only off the Bosphorus or in the central regions of the Black Sea but also as far north as Sevastopol Bay. Porumb (108) and Kovalev et al., (109) have recorded similar findings for the area around the Danube delta. The total number of Mediterranean species in the Black Sea was estimated to be around 50, the majority being concentrated in the Bosphorus region (110, 111). Some of the individuals sampled far from the Bosphorus area bear well developed gonads indicating possible adaptation and reproduction at the lower salinity conditions of this sea. With increasing salinity, they may become a permanennt member of the Black Sea fauna as stressed by Puzanov (112). For example Gordina et al., (113) have observed recently eggs of the Sea of Marmara anchovy in the southern Black Sea coasts implying adaptation of this stock to the Black Sea. Another good example for this process, i.e. the enrichment of Black Sea flora and fauna by organisms originating in the Mediterranean Sea, is the copecod species *Acartia tonsa* which has been found in large quantities in recent years (111, 114). Apparently, this species adapts well to the Black Sea conditions. It is worth noting that *Mnemiopsis leidyi* (accidentally introduced into the Black Sea from the north Atlantic via ballast water of vessels) which formed a huge biomass in the whole basin must also have adapted well to the Black Sea conditions (115-117).

However, particularly during the last two decades some species have either vanished or became rare in the pelagic ecosystem especially in the shelf waters (63, 118-120). The former mass occurring species, *Oithona nana* has not been found in samples collected by the IBSS or by other institutes since 1989. Now this species has again appeared in zooplankton samples, though very seldom. Many investigators (63, 70, 118, 120,) suppose that these changes are connected with anthropogenic impacts (i.e. pollution, eutrophication, predation pressure of *Mnemiopsis leidyi*) on the Black Sea ecosystem, because they are the most significant in coastal areas.

Distribution of zooplankton (abundance and biomass)

The large-scale horizontal and vertical distriubtions of zooplankton organisms have been the subject of several publications (37, 39, 44-46, 52, 60, 67, 121, 122). Earlier data (1960s and 1970s) were reviewed by Zenkevich (9), and Greze et al., (66), respectively. These authors discussed the natural factors determining the distribution patterns. It was shown that zooplankton abundance and biomass were quite variable in time and space. Nevertheless, the distriubtion patterns of zooplankton display some common features.

Temperature and wind stress were important for the distribution of the zooplankton (65): during warmer periods the abundance of zooplankton was generally high at the northwestern shelf zone (66). An important factor influencing the zooplankton abundance is certainly the riverine flow. A positive linear correlation between the volume of water discharged and the concentration of zooplankton was found by various authors (e.g., 42, 60, 62, 66).

High numbers of zooplankton occur usually in coastal and shelf areas, e.g. high patches occur southwestern Crimean coast and the Bulgarian, Romanian, Turkish and Caucasian coasts. Zooplankton numbers increase as well at convergence zones of the western and eastern gyres off the Crimean and Anatolian coast. Due to the dynamic characteristics of these regions a high productivity is ascertained (66).

The difference between the average biomass in central and coastal areas of the Black Sea is small, (excluding the northwestern shelf) in comparison with many other seas, including the neighbouring Mediterranean Sea (58). This is due to a fairly intensive vertical-exchange in central areas of this sea (123) and horizontal water-exchange between central and coastal areas (58, 124, 125).

The spatial variability in the zooplankton biomass differs between central and coastal areas. In the same season the maximum value could be two to three fold that of the minimum biomass value found in the central Black Sea. However, in the coastal areas this variablity is about ten fold (49, 58, 97, 121).

In the Black Sea the majority of zooplanktonic organisms are concentrated in the upper 50 meter layer. In the northwestern Black Sea zooplankton seem to be more evenly distriubted vertically compared with in the centres of the main gyres. At the centers of the main gyres, the upper boundary of hydrogen sulfide is high and vertical water exchange is less intensive, hence causing considerable patchiness.

Investigations carried out using the large volume water sampler with accurate depth recording revealed that high concentrations of *Pleurobrachia rhodopis, Calanus euxinus, Pseudocalanus elongatus, Sagitta setosa* occur at a depth of 60 m down to the lower boundary of the oxic-anoxic interface at around 120 m, where these species occur in a small band just above the anoxic layer during the day time (97, 126). Later it was shown that living and non-living organisms were accumulated at a certain layer of density gradient (between sigma theta 15.4 and 16.2) corresponding to low oxygen concentrations (82, 127).

Temporal changes

In the past and also in recent years the diurnal vertical migration of zooplankton has been studied by a number of authors (35, 39, 82, 128-131). As mentioned above, high concentrations of *Calanus euxinus, Pseudocalanus elongatus, Pleurobrachia rhodopis* and *Sagitta setosa* have been observed at depths just above the H_2S-zone during the day time. During night the concentration of organisms at this depth decreases considerably due to upward migration (97). In an experiment, zooplankton were collected at 3 hourly intervals, at the center of the western (anti-cyclonic) gyre at two stations visited in April and August 1976. A two fold change in zooplankton numbers within 24 hours was observed. During the night many species migrate to surface layers and during the day they are concentrated in deep layers (132).

This phenomenon could be explained by diurnal feeding and reproduction rhythms of planktonic animals. Laboratroy experiments on reproduction, hatching and moulting of three Black Sea copepod species have confirmed the existance of a diurnal rhythm during these processes (133, 134). However contradictory observations were also made at different regions of the sea.

Numerous authors investigated seasonal changes in zooplankton abundance and biomass in different regions of the Black Sea (40, 48, 57, 60, 61, 67, 108, 121, 135-140). It was noted that seasonal differences in migration patterns occur in the central and coastal areas (58). Usually two peaks for maximum zooplankton abundance were marked for coastal areas coinciding with spring and autumn periods. Sometimes a third peak was observed in summer. In central areas however only one peak was observed, during summer. This is due to some differences in hydrological and hydro-chemical conditions between shallow coastal and deep-water central areas. These conditions, in particular seasonal changes of temperature and nutrient input are important for reproduction; zooplankton respond to such variation faster in coastal areas and bays than in the open sea. In the shallow Azov Sea the maximum temperature of the coastal water is reached a month before that of the open sea (141) and thus the spring bloom of zooplankton starts earlier (58).

Unlike the open sea, coastal waters display more clearly defined regeneration cycles of biogenic substances in the summer-autumn period. Because of intensive bacterial degradation of dead phyto- and zooplankton after the spring bloom and of the faster regeneration of nutrients the bacterio- and phytoplankton may again increase to peak concentrations in coastal waters. These processes provide an autumn peak and sometimes a summer peak of zooplankton abundance. In the open sea these processes are slow and generally start much later (in summer). The phytoplankton prouduction is low and does not merit a second zooplankton peak in autumn (58).

Long-term changes in the zooplankton abundances of the Black Sea (45, 46, 64, 65) have been reviewed by Greze et al., (66). Recent investigations have revealed some changes in the long-term variability of zooplankton since the 1970s. Systematic observations during 1960-1981 in the open eastern sea area showed an increase in biomass of the main zooplankton species. During the 1960-1969 period the average biomass of the main zooplanktonic organisms in the upper 100 m was 308 mg/m^3, this increased to 471 between 1970 and 1975 and again rose to 527 mg/m^3 between 1976 and 1981 However, the increase was entirely due to two gelatinous species; the dinoflagellate *Noctiluca scintillans* and the ctenophore *Pleurobrachia rhodopis* (58, 67).

A similar increase in the zooplankton was observed in the western Black Sea between 1978 and 1980. In the upper 100 m the zooplankton biomass increased in offshore areas (water depth >200m) by 1.7-2 fold, at the northwestern shelf the increase was 3-4 fold, in shallow coastal areas (0-25m) this rose to 10 fold. These changes were caused exclusively by the increase in *Noctiluca scintillans* (59). This corresponds with a significant increase in the phytoplankton biomass in the northwestern Black Sea (142).

In the area off the Danube estuary (in the upper 100 m) the average zooplankton abundance and biomass increased by factors of 3 and 5 respectively from the 1970s to the 1990s (63). As for other areas the proportions of *Noctiluca* and *Acartia clausi* also increased significantly. Similar changes were noted by other authors (31, 62, 70). In the late 1970s a sharp increase in the medusa *Aurelia aurita* was discovered (143, 144 & others).

Then, during the 1980s drastic changes in the plankton communities occurred. Most markedy were severe changes in the phytoplankton and mesozooplankton composition and a sharp decrease in the total zooplankton biomass including *Aurelia aurita* at the end of the 1980s and beginning of the 1990s (32, 71, 111, 122, 145-147). Changes in the dominant species had already been observed at the north western shelf and in Sevastopol Bay over the last two decades (30, 63, 118-120). During 1960-1964 the share of *Acartia clausi* in the total copepod community was 17%. This increased to over 30 % during 1981-1985, and during 1991-1994 it rose to 75 %. Copepod species such as *Oithona nana* and *O. similis* and the cold water specise *Pseudocalanus elongatus* and *Calanus euxinus*, which were dominant before the 1980s, decreased during the 1990s (32). The species *O. nana* was not observed from 1989-1996. In offshore areas the dominant species *Pseudocalanus elongatus, Calanus euxinus* and *Sagitta setosa* decreased 10 to 100 fold (145, 146).

Most changes began at the beginning of the 1980s, when the northwestern Atlantic ctenophore *Mnemiopsis leidyi,* originating from eutrophic lagoons in North America, was accidentaly introudced into the Black Sea (105, 116, 148). *M. leidyi* reproduced intensively and bloomed during 1988-1990 reaching a remarkable total biomass of 800 million tons wet weight in the Black Sea during the summer of 1989 (116). *Mnemiopsis* displayed the typical pattern of a new coloniser. After its mass development in the years 1989 and 1990 with 2 kg m^{-2}

in the open sea and average numbers of 4.7 kg -m^{-2} at the northwestern shelf (145), its number and biomass had dropped to moderate levels by 1991 and afterwards fluctuated until 1996 in a range of 0.2 - 0.5 kg m^{-2} (146, 149, 150).

After the peak of *Mnemiopsis* the biomass of *Aurelia* increased again and since the summer of 1991 until 1994 the biomass of both species remained more or less at the same level (149). After 1993 the mesozooplankton biomass recovered and displayed an increasing trend (71, 111, 122, 145, 146, 147, 151). And during 1997 the species *Oithona nana* was present again in some zooplankton samples.

Numerous investigators consider anthropogenic impacts as the main reason for the changes in the zooplankton of the Black Sea in recent years especially stressing eutophication in esturaries (60, 63, 70, 105, 118, 120, 152). Additionally, the negative effect of pollution (e.g. oil pollution) could be the reason for the observed decrease in the zooplanketon in the upper water layers (59, 61). The early stages in the life cycle of zooplankton and fishes in particular, which are very sensitive to pollution, live in the near surface layer.

Another important factor for the decrease in the zooplankton after 1988 was assumed to be the mass development of *Mnemiopsis leidyi* being both a voracious predator and a strong food competitor (105, 111, 117, 122, 127, 145, 147, 153, 154). The arguments are: zooplankton which inhabit the same depth range (0-30m) as *Mnemiopsis* seem to have suffered most. For example in the northwestern Black Sea the total biomass of fodder zooplankton (discounting *Noctiluca, Pleurobrachia, Aureila* and *Mnemiopsis*) was 50 times less in 1990 than in the 1975-1980 period. Furthermore, the biomass of *Aurelia aurita* competing with *Mnemiopsis* at the same trophic level decreased 100 fold (120, 145). At the same time the change in the biomass of fodder zooplankton living mainly below the thermocline, where *Mnemiopsis* was only occasionally found, was significantly less compared with those found above the thermocline (151). In the last few years, since the *M. leidyi* biomass has remained at moderate levels, the total biomass (wet weight) of *Aurelia* has shown an increasing tendency along with other zooplankton (58, 145, 151).

The impact of *M. leidyi* on the Black Sea zooplankton fits the general view, that possible reasons for the fluctuation of the zooplankton biomass and the changes observed in the species composition could be due to long term changes in prey/predator relationships (3, 67). According to Bogdanova and Vodyanitskiy (155), and Zhorov and Boguslavskiy (156) long-term fluctuations in zooplankton could also be explained by interactions between biomass cycles and long-term climatic cycles (river flows and other hydrological parameters).

It is known that global atmospheric changes, such as the Southern Oscillation (SO), El Niño-Southern Oscillation (ENSO), and North Atlantic Oscillation (NAO) influence pelagic communites (157-161). Although the short and long term atmospheric variabilities in the Eastern Mediterranean/Black Sea regions are well known, hypotheses on tele-connections with global atmospheric events have recently been put forward (162). A good correlation between the Black Sea hydrology, the North Atlantic Sea Surface Temperature (SST) variability and the ENSO-type variability of the tropical Pacific Ocean, which indicates a global ocean-atmosphere coupling. Both types of variability lead to changes in the cyclone trajectories, precipitation over the river drainage basins, changes in river discharges, resulting in alterations in the northwestern Black Sea hydrography as shown by Polonsky et al., (163), which may finally cause changes in the Black Sea plankton community (74).

Comparison of the weather regime of the 1980s with previous decades showed indeed that the climate of the 1980s was unique. Especially the 1983-1990 period was dominated by a positive phase of the NAO, which increased strongly after 1988 (164). The oscillation of the global air temperature, which has a cyclic occurrence of 65-70 years gave its lowest amplitude during the mid eighties (165) which had again risen by the end of the 1980s. It may be interesting to note that the sun activity, which has a cycle of 11-12 years, was very low during the mid eighties and again increased to high values during 1988 (164). The 1980s displayed the largest annual variability on a global scale, of the 20th century (166). The Southern Oscillation experienced the strongest warm (El Niño) episode of the century (1982/83) and the strongest cold (La Niño) episode in 50 years (1988). According to Trenberth & Hurrel (167), the very strong La Niña event of 1988 apparently terminated the climate regime that was estalished in 1977.

Niermann et al., (74) compared the fluctuation of the plankton in different seas of the northern hemisphere and concluded hypothetically, that changes in the weather regime during the 1980s could have triggered the changes in the phyto- and mesozooplankton communities of the Black Sea, which caused the conditions for the outburst of *M. leidyi* and the subsequent decline in the anchovy stock during 1988-1990 (168).

Summarized are the significant changes in the zooplankton community of Black Sea which took place during recent decades. THe man-made eutrophicatioın and pollution, especially at the shelf regions and in the estuaries of large rivers, seem to have had a strong impact on the zooplankton fluctuation. But less attention should not be given to natural factors which represent the first driving forces of the zooplankton community and which are modified or intensified by anthropogenic impact. While analysing the long-term changes in the zooplankton during the NATO TU-Black Sea program a connection between climatic changes (water temperature in particular) and zooplankton biomass (71, 111) could be established. Similar developments were found for other regions, including areas with less important anthropogenic influence (74, 160, 169). Overall it could be supposed that climatic changes are the fundamental causes determining the processes leading to changes in zooplankton composition (in qualitative and quantitative terms), but anthropogenic factors may considerably influence and change the shape of these processes.

Future investigations needed

The experience gained during the taxonomic and faunistic studies carried out in recent years proves the necessity of their continuation. Revision of some groups such as Protozoa is necessary. A basic task is to standardize the scientific names of the species. This will minimize the confusion which occurs when dealing with different names thus enabling compilation of data from numerous investigations into an international database.

Monitoring of species composition (community structures) will enable investigators to estimate changing trends within the ecosystem. Trends in species successions, and the recording of acclimatisation or disappearance of immigrated or accidentally introduced species could be recorded only with systematic studies. Such investigations relate well to the actual problem of saving the biodiversity. Qualitative and quantitative monitoring of the living and non-living system is necessary in order to determine the healthiness of the Black Sea ecosystem and to detect changes due to natural or anthropogenic impacts, both on a short and long-term time scale.

It is important to continue studying the ctenophore *M. leidyi*, including its dynamics and interrelations with other zooplankton species. It should be monitored regularly to clearly understand if its biomass is now at a stable level.

Steps alreday made regarding the unification of sampling methods and continued cooperation amongst the riparian countries of the Black Sea should be maintained. This is the prerequisite for the succesful research and management of this basin.

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