The Eastern Mediterranean as a Laboratory Basin for the Assessment of Contrasting Ecosystems

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COMPOSITION AND ABUNDANCE OF ZOOPLANKTON OF THE EASTERN MEDITERRANEAN SEA

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Abstract

Results of investigations on the composition and quantitative distribution of zooplankton of the eastern Mediterranean Sea were reviewed for the period 1950-1980. The studies reviewed comprise more than 250 stations (with about 2000 samples) mainly from the expeditions carried out by the Institute of Biology of the Southern Seas (IBSS), attached to the National Academy of Science of the Ukraine. Many of these stations are located in poorly studied deep-water regions. For comparison purposes data from the literature on the coastal regions were also used.

During these studies, >30 new species of zooplankton were identified from the eastern Mediterranean. The abundances of zooplankton from different locations in this region were evaluated. A trend was observed whereby the quantity of zooplankton was seen to decrease from the west to the east and from the north to the south. Such events correspond to an impoverishment of nutrients in the water.

The coastal regions, desalinized by river inflows, were poorer than the deep-water regions with respect to species number, but richer in abundance.

Key words: zooplankton, eastern Mediterranean, abundance, biomass, spatial changes.

1. Introduction

The Mediterranean Sea is conventionally divided into western and eastern regions. The border between them lies through the Appenin peninsula, the Island of Sicily and the relatively shallow strait of Tunisia [1, 2]. The eastern region includes the Ionic, Adriatic, Syrtis, Levantine and Aegean Seas. Some authors [3, 4] further divide the eastern

region according to the bottom topography and hydrological structure of the central (Syrtis, Ionic and Adriatic seas) and the eastern (Levantine and Aegean Seas) water bodies. However, the surface current system affects the whole eastern Mediterranean Sea [3], therefore, its planktonic fauna is sufficiently uniform [5], so in this study we have considered the eastern Mediterranean Sea as one unit. Of course, it is taken into consideration that in some regions, (e.g. river mouths), environmental factors and plankton differ greatly. But in the absence of geomorphological obstacles the waters of these regions are mixed with waters of the open Mediterranean.

The water exchange between the Mediterranean and Black seas occurs through the Marmara Sea. We consider the Marmara Sea as being of the same composition of the eastern Mediterranean Sea.

The eastern Mediterranean is distinguished from the western area by several factors namely; a reduced influence of the Atlantic Ocean whereas there occurs an increasing influence of the Indian Ocean, by the differences in river inflows (the Po, the Nile and rivers that flow into the Black and Azov seas), and by hydrological, hydrochemical and biological features [6, 3, 7, 8]. The reduced influence of the Atlantic ocean is expressed by the gradual decrease in the volume of Atlantic water in the North-African current. Due to evaporation the salinity of the water increases from 36.5‰ in the waters off Gibraltar to 39‰ in the eastern shores [3], where the temperature of the water near the surface in summer is raised from 20^{o} to 27^{o} C. The temperature and salinity of the water also greatly changes from the north to the south of the Mediterranean Sea. The concentration of the nutrients in the waters of the North-African current decreases five-fold from a westerly to an east direction [9, 10, 11]. Production values also decrease accordingly [7]. However the nutrient content and zooplankton abundance in the eastern Mediterranean are characterised by a rather significant unevenness of distribution. An increase in these values is noted in the Marmara Sea and the northern Aegean Sea, in the regions of river estuaries and some other areas.

Environmental factors pertaining to the Mediterranean, as mentioned here, play an important role in shaping the composition and abundance of plankton as a whole and zooplankton in particular.

Studies of zooplankton in the Mediterranean Sea, including its eastern sector, began in the second half of the 19th century. The first large expedition in the eastern Mediterranean Sea was carried out by an Austrian ship the R/V "Pola" between 1890-1894. Later a substantial contribution to the study of plankton was made by the Danish on board the R/V "Tor" during 1908-1910 and the R/V "Dana" in 1930. The quantitative study of plankton was initiated during these two expeditions. Jespersen [12] observed the relative poverty of macroplankton in the eastern Mediterranean Sea with respect to the west.

During 1911-1914, the faunistic investigations in the Adriatic Sea were conducted by the Austrian expedition on the R/V "Naiad" and the Italian expedition on the R/V "Vila Velebita". The Yugoslavian R/V "Hvar" worked in the Adriatic Sea in 1948-1949. In the Mediterranean Sea in 1958 multi-disciplinary oceanological investigations began on the R/Vs "Akademik A.Kovalevsky", "Crystal", and in 1977 on the R/V "Professor Vodyanitsky". Besides, biological studies were executed in a number of hydrophysical expeditions of Soviet vessels "Akademik S.Vavilov", "Mikhail Lomonosov" and others. Consequently, zooplankton studies in the central

regions of the eastern Mediterranean basins over the last forty years were conducted most actively by Soviet scientists, mainly from the Institute of Biology of the Southern Seas (IBSS). Extensive studies of zooplankton were recently conducted by scientists of Mediterranean countries under the international program POEM-BC-091 [13, 14].

In some coastal regions of the Mediterranean Sea, near the biological stations, institutes or universities of Italy, Greece, Turkey, Syria, Lebanon, Israel and Egypt, regular seasonal and perennial studies of plankton are conducted.

A great number of zooplankton species had defined during early faunal studies. Here it is worth mentioning that scientists of the IBSS identified 50 species of copepods not previously noted in the Mediterranean Sea and another 32 species that are new to the science [5]. Faunistic data of zooplankton resulted in many articles and monographs from various biogeographical areas in the eastern Mediterranean [6, 7, 8, 15,]. The fauna of the coastal and central regions were compared in the book of Kovalev [8].

Regular studies performed in the eastern Mediterranean Sea had explained the seasonal changes in the taxonomic composition, quantity and biomass of plankton [7]. The results of such studies on quantitative indices of zooplankton of central regions of the sea were summarised in Greze et al. [16]. The results of the investigations carried out by scientists of the Mediterranean countries were presented in a review by Moraitou-Apostolopoulou [17].

In the present work, results of the IBSS investigations were re-evaluated for the open waters of the eastern Mediterranean Sea with a comparison among its subregions as well as changes in the zooplankton composition from the west to the east and from the north to the south.

2. Material and methods

From 1958 onwards, the IBSS periodically conducted zooplankton studies in different regions of the eastern Mediterranean Sea, usually in deep waters. Sampling information of these studies are presented in Table 1. Location of sampling stations was shown in Fig. 1.

Usually the upper 200 or 500 metre stratum of water from the standard layers of 0-10, 10-25, 25-50, 50-75, 75-100, 100-150, 150-200, 200-300 m was processed. For sampling a Juday net (mouth diameter 3 cm, mesh size 112 μ) was used.. During the 1970s - 1980s, additional samples were sometimes collected using a Bogorov-Rass net or oceanic model of the Juday net (mouth diameter 80 cm, mesh size >200 μ) and also a water sampler [18] was employed for specific purposes, for instance to study the size composition of the zooplankton [19, 20, 21].

After taxonomic identification, the abundance and biomass of organisms (given as per cubic meter) were calculated by means of weight-dimensional characteristics of plankton. For rare animals the whole sample was screened whilst for mass organisms subsampling was performed.

TABLE 1. Cruises of the IBSS for zooplankton in the eastern Mediterranean Sea.

Year	Month	Vessel	Region	Layer (m)	#of stations	#ofsamples
1958	II, V, VII, XI	Krystall	Southern Adriatic	0-200	84 (8 daily)	920
1960	VII	Akademik Kovalevsky	North Adriatic	0-100		
1982	II - V	Professor Vodyanitsky	North Adriatic	0-100	25	55
1967	VII	Akademik Kovalevsky	North Adriatic	0-200	16	48
1959	VI - IX	Akademik Vavilov	Syrtis Sea	0-200	3	21
1959	VI - IX	Akademik Vavilov	Levantine Sea	0-200	7	49
1958	VIII - IX	Akademik Kovalevsky	Aegean Sea	0-200, 0-500		
1960	VI - VII	Akademik Kovalevsky	Aegean Sea	0-200, 0-500	20 (2 daily)	151
1960-1961	XII - I	Akademik Vavilov	Aegean Sea	0-200, 0-500		
1980	VIII, XII	Akademik Kovalevsky	Aegean Sea	0-200	4	16
1959	VII - VIII	Akademik Kovalevsky	Ionian Sea	0-200, 0-500		
1960	VII	Akademik Kovalevsky	Ionian Sea	0-200, 0-500	14	156
1968	V	Akademik Kovalevsky	Ionian Sea	0-500	1 (daily)	35
1972	XII	Mikhail Lomonosov	Ionian Sea	0-500	1 (daily)	
1973	IV	Mikhail Lomonosov	Ionian Sea	0-500	1 (daily)	
1976	IV	Mikhail Lomonosov	Ionian Sea	0-500	1 (daily)	81
1976	VIII	Mikhail Lomonosov	Ionian Sea	0-500	1 (daily)	
1987	XI - XII	Professor Kolesnikov	Ionian Sea	0-200	40	40
1970	I - II	Akademik Kovalevsky	Tunisian strait	0-200		
1972	VII - IX	Akademik Kovalevsky	Tunisian strait	0-200	33	271
1980	VIII - X	Akademik Kovalevsky	Tunisian strait	0-200	5	20
1982	II - V	Professor Vodyanitsky	Tunisian strait	0-200	5	14

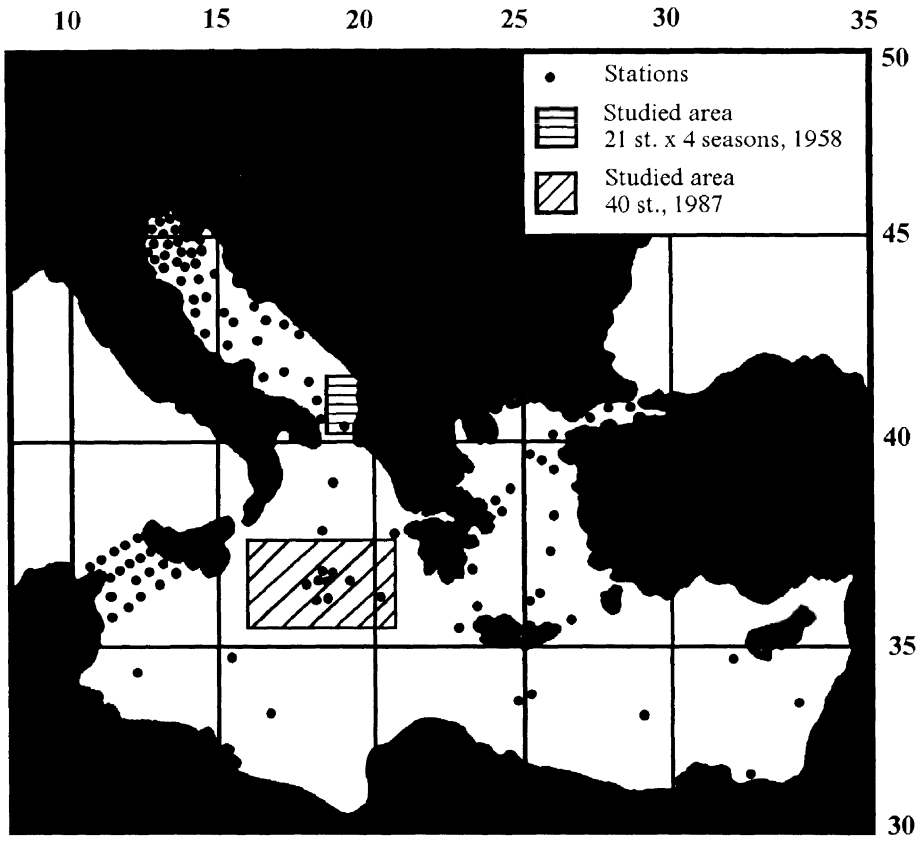

Figure 1. Location of zooplankton stations of the IBSS in the eastern Mediterranean Sea during 1958-1987.

3. Results and Discussion

3.1. COMPOSITION OF ZOOPLANKTON

The planktonic fauna of the Mediterranean Sea is basically Atlantic in origin. It is characterised by the presence of representatives of practically all taxonomic groups, known in the region of the Atlantic that adjoins Gibraltar [6, 8]. However this is usually not the case for the deep-water organisms of which penetration into the Mediterranean Sea is limited by the shallow strait of Gibraltar.

Because of a single source of fauna and the presence of a basin wide current system (i.e. the north-African current), there is a high degree of resemblance of fauna in different regions of the Mediterranean Sea. At the same time it is necessary to note a certain influence of the water exchange through the Suez Channel on the zooplankton composition of the eastern Mediterranean [15]. However, there are differences in the fauna that are dependent on latitude. Some subtropical and tropical species that occurs in the southern regions of the sea, are absent in the northern regions. The boreal species are absent in the south regions [6, 16]. A comparison of species lists of copepoda from the Adriatic and the Ionian Seas (including the Syrtis Sea), and between the Levant and Aegean Seas revealed that 57% - 67% ofspecies were common to each pair of seas [5, 8].

The composition of zooplankton greatly differs between regions of neritic waters and of deep-water regions. The latter are inhabited basically by the oceanic species. Of the Copepoda, multiple species of the families Eucalanidae, Calocalanidae, Spinocalanidae, Aetideidae, Euchaetidae, Phaennidae, Scolecithricidae, Metridiidae, Lucicutiidae, Heterorhabdidae, Augaptilidae are represented. Many species of the families Calanidae, Clausocalanidae, Centropagidae, Pontellidae, Oncaeidae, Sapphirinidae, Corycaeidae are present in equal numbers in the open sea and in the neritic area. The main species found in the neritic area are members of the families Paracalanidae (*Paracalanus parvus, P. denudatus, P. nanus*), Centropagidae (*Centropages ponticus*), Temoridae (*Temora stylifera, T. longicornis*), Pontellidae (*Labidocera brunescens, L. madurae*), Acartiidae (*Acartia discaudata, A. longiremis, A.latisetosa* and others), Oithonidae (*Oithona nana, O. hebes*) [8].

Deep-water regions of the sea like open regions of the oceanic tropics and subtropics are characterised by a high number of species, but a low abundance of organisms. In the Ionian Sea (grid position 36^{o} 45' N; 18^{o} 45' E) a series of observation at four stations were recorded in December, 1972 and April, 1973 (27th cruise of RV "Mikhail Lomonosov") and in April and August, 1976 (30th cruise RV "Mikhail Lomonosov") and findings were made of 188 copepod species. From these only 8 species were found in numbers exceeding 10 specimens/m3 [21b]. However, near the Egyptian coasts in depths of less than 110 m (120 samples) 132 species of copepoda were discovered [22]. At the same time from the entire Levantine Sea 171 species were known [5]. Nearer the coast, where the influence of Nile is strong, only 31 copepod species were occuring [23]. Among them were semi-oceanic or even oceanic species. Zooplankton in the coastal zone and in bays. is characterised by a low species number. Near Alexandria and in the Abu Qir bay, in depths of less then 15 m, 13 basically neritic species of Copepoda were noted before the Nile overflow [24].

Cladocera (*Evadne tergestina, E. nordmani, E. spinifera*) and other inhabitants of water with low salinity were quite numerous. During the Nile overflow when the salinity of the uppermost ten metre layer was reduced to 3-10‰, the amount of planktonic species had decreased. The same changes in plankton composition between the open sea and the coastal zone and between bays and harbours are known from the literature for other regions of the eastern and western Mediterranean Sea [6, 25, 26, 27, 28, 29, 30]. A few representatives of the fresh-water fauna were noted only near estuaries of large rivers and in desalinised lagoons. It is in the plankton of the deep-water of the eastern Mediterranean that species of Copepoda are most numerous (Table 2).

TABLE 2. Number of copepod species in different seas of the eastern Mediterranean [8].

Seas	Number of species
Adriatic	234
Ionian and Syrtis	236
Levantine	171
Aegean	161
Marmara	53

Copepoda account for 70-90% of the total zooplankton abundance. Of the copepods, in the surface 50 m layer, *Paracalanus aculeatus, P. parvus, P. nanus, Calocalanus plumulosus, Temora stylifera, Centropages typicus, Acartia negligens, Oithona plumifera* dominate. In the layer 0-200 m *Calanus minor, C. tenuicornis, Calocalanus pavoninus, Clausocalanus furcatus, Centropages violaceus, Oithona setigera* and others were frequently observed. At the depths greater than 200 m, the species *Spinocalanus abyssalis, Aetideus armatus, Chiridius poppei, Scolicithricella abyssalis* were seen. In the surface layers Appendicularia, Ostracoda, Chaetognatha were rather abundant.

From the other groups a few specimens of Foraminifera, Tintinnoinea and Hydromedusae were found. Siphonophora, Polychaeta and Mollusca were also numerous. Of the Siphonophora, *Eudoxoides spiralis, Lensia subtilis, L.conoidea, Hippopodius hippopus, Abilopsis tetragona, Chelophies appendiculata* and others were found [6, 16, 31, 32, 33, 34].

On the shelf region adjacent to the eastern coasts of the Mediterranean Sea, unlike the region of Nile, zooplankton in different areas was distinguished with a higher number of species. For instance, in the region of Beirut during 25 years of studies 173 species of copepods were registered [35]. In Lattakia port (Syria) and in the estuary at three stations studied in the period from March to October, 1991, 54 species of copepods were registered [36].

From five stations sampled four times during 1983-1984 (August, November, February, May) around the northwest coast of Island of Rhodes (from a depth profile of 50-350 m), 85 copepod species were registered [37]. This high number of species in this region is probably related to the fact that the east branch of the North-African current flows past close to the coast causing upwelling. This current brings the Atlantic zooplankton there. In the zooplankton composition there are also species from the

Indian ocean, which are transported into the Mediterranean Sea through the Suez channel.

3.2. DISTRIBUTION OF ABUNDANCE AND BIOMASS OF ZOOPLANKTON

Analysis of the works on zooplankton of the deep eastern Mediterranean [7, 8, 13, 14, 16, 19, 20, 21b, 31, 32, 33, 34, 38, 39] shows that most of this region is characterised by a comparatively even distribution of abundance and biomass of zooplankton. Their values were not high. High values for zooplankton abundance were registered in the Adriatic and Aegean seas (Table 3).

TABLE 3. Average values of the number (ind./m^3) and biomass (mg/m^3) of zooplankton in the eastern Mediterranean Sea in the 0-200 m layer in summer [16].

Seas	Number (ind./m^3)	Biomass (mg/m^3)
Mid and southern Adriatic	1724	56
Ionian	1041	33
Syrtis	1007	15
Levantine	1438	18
Aegean	1032	23

As some authors consider [17], the eastern Mediterranean can be distinguish from the western region by zooplankton biomass values. However the results of our studies on mesozooplankton agree with the conclusion of Jespersen [12] that there is a significant reduction in biomass of macrozooplankton from the west to the east in the Mediterranean Sea. As it is well known, annual and seasonal variability in the number and biomass of zooplankton are great. So the most reliable material in the evaluation of spatial distribution are those sampled from different areas with close time intervals. At the time of such observations in 1972 from daily sampled stations, the average quantity of zooplankton in the Sardinian Sea was nearly twice of the Ionian Sea [21b]. More significant are the samples of the 90th cruise of the RV "Akademik A.Kovalevsky" (September-October, 1980), collected from the four different areas from Alboran to the Aegean Sea (Table 4).

The reduction in the number and biomass of zooplankton along the North-African current from the west to the east is also observed from results of investigations carried out in different years (Table 5).

A reduction in the number and biomass of mesozooplankton from the Tunisian Strait to the Ionian Sea and an increase in the Levantine Sea was observed during the research program POEM-BS-091 in 1991 [13, 14]. Thereby, the trend of changes in the amount of zooplankton from a western to an eastern directon seems conclusive. Such a reduction in the biomass of zooplankton complies with the reduction in nutrient concentrations and phytoplankton [7]. In the Levantine Sea the amounts of zooplankton were higher than in the Syrtis Sea [16, 34]. It may be connected with the complex

dynamics of water in the Levantine Sea. It is characterised by the existence of three cyclonic and one anticyclonic large-scale cycles [3] and connected with them are areas of upwelling and downwelling [13]. In the southern Levantine Sea there occurs an influence of the Nile on the zooplankton. After the construction of the Aswan dam in 1965 this influence greatly decreased [40, 41]. In the Levantine Sea high concentrations of nutrients and nannoplankton were also noted [42].

TABLE 4. Changes in the number (ind./m^3) and biomass (mg/m^3) of net zooplankton from the west to the east of the Mediterranean Sea in September-October, 1980 in 0-100 m layer [8].

Region	Number of observations	Number (ind./m^3)	Biomass (mg/m^3)
Alboran Sea	19	1952	70.4
Sardinian Sea	6	2293	30.6
Tunisian strait	6	1050	27.0
Aegean Sea (middle)	6	867	22.0

TABLE 5. Average values of number (ind./m^3) and biomass (mg/m^3) of net zooplankton in the area of the North-African current in the Mediterranean Sea during summer [8].

Regions, years	Number of observation	0-100 m		100-200 m	
		ind./m^3	mg/m^3	ind./m^3	mg/m^3
Alboran Sea (1970, 1974, 1980)	34	1597	52	624	20
Sardinian Sea (1976, 1980)	18	1650	43	360	13
Tunisian strait(1972, 1980)	26	1005	28	282	11
Syrtis Sea (1959)	3	1265	17	735	9
Levantine Sea(1959, 1960)	7	1826	26	612	13

Other interesting changes affecting zooplankton biomass occur from north to south in two separate chain patterns of the seas: Adriatic-Ionian-Syrtis and Marmara-Aegean-Levantine Seas. Both chains in the north are characterised by the strong influence of river input, high dynamic activity and essential seasonal changes of the environment. This stimulates high productivity in the northern seas with a gradual reduction in productivity towards the south. As a result the number and biomass of zooplankton regularly and greatly decreases from the north to the south (Table 6, 7).

In the northernmost area of the Adriatic Sea, the number of zooplankton in the 0-25 m layer reaches 13000 specimen/m^3, biomass 300 mg/m^3 [16]. However, in a southward direction

these values greatly decreased (Table 6). But along the coast of the Appenin peninsula they remain rather high.

The number and biomass of zooplankton in the Sea of Marmara were also very high (Table 7) [21]. Mass organisms seen were those typical for the Black Sea: Tintinnoidea, Hydromedusae, Appendicularia, larvae of Mollusca and Polychaeta, copepods *Paracalanus parvus, Acartia clausi,* and *Oithona similis,* etc.

TABLE 6. Changes in the average values in the number (ind./m^3) and biomass (mg/m^3) of zooplankton from the Adriatic to the Syrtis Sea during summer [8].

Regions, years	Number of observations	0-100 m		100-200 m	
		ind./m^3	mg/m^3	ind./m^3	mg/m^3
Adriatic Sea, northern (1960, 1982)*	25	3354	90	-	-
Adriatic Sea, middle and southern (1958, 1963)	47	1735	58	1464	54
Ionian Sea (1959, 1976)	18	1104	41	547	15
Syrtis Sea (1959)	3	1265	17	735	9

*[43]

TABLE 7. Changes in average values of the number (ind./m^3) and biomass (mg/m^3) of the net zooplankton from the Marmara to the Levantine Sea during summer and autumn [8].

Regions, years	Number of observations	0-100 m	
		ind./m^3	mg/m^3
Sea of Marmara (winter 1969-1970)	5	12000	90
Aegean Sea, northern (1958)	6	1473	47
Aegean Sea (1958, 1960, 1980)	17	1057	26.4
Levantine Sea (1959, 1960)	7	1826	26

In the Aegean Sea, the number and biomass of zooplankton decreased from the north to the south of the sea five fold during the 1959, 1960 and 1980 IBSS cruises. It is neccessary to note that in the Aegean Sea in the 0-100 m layer, despite low abundance, the biomass was as high as in the Levantine Sea (Table 7). This is explained by the fact

that in the 0-100 m layer in the northern Aegean Sea the biomass increases due to large organisms, in particular gelatinous ones: Salpae, Medusae, and Siphonophora. It is known that in other regions of the World's oceans the biomass of the gelatinous organisms also increases with eutrophication of the water [44].

TABLE 8. Quantitative indices of zooplankton in some coastal and deep-water regions of the Mediterranean Sea in the 0-50 m layer [8].

Regions	Number (ind./m^3)	Biomass (mg/m^3)	Reference
Coastal regions (average annual values)			
Triest harbour	2560	-	45
Region of Alexandria			
Easern harbour	29700	191.0	46
Coastal zone (<50m)	7400	-	47
Neritic zone (<20m)	1850	-	47
Neritic zone (>200m)	1230	-	47
Region of Beirut	5000	-	48
Near the sewage outputs	175	-	48
Saronicos harbour	1287	21.0 - 65.0	49
ibid	9224	-	4
ibid, 25km from sewage output	-	135.7	50
Elefsis harbour	-	195 - 265	49
Deep-water regions (in different seasons)			
Mid and southern Adriatic (III-IX. 1958, 1963, 1982)	-	54.0	8, 16
Tunisian strait (IX. 1980)	794	26.6	8
Ionian Sea (IV,VIII,XII. 1972,1973,1976)	651	29. 5	8
Syrtis Sea (summer, 1959)	1108	19.7	34
Levantine Sea (IX-XI. 1959, 1960)	1419	19.6	34
Aegean Sea (VIII. 1980)	756	23.1	8
Aegean Sea, south (VI-I. 1958, 1960, 1961)	903	14.1	33
Aegean Sea, north (summer, 1958)	1473	47.0	33

Note: The plankton net with a mesh size of 200-250 μ which was used in the coastal areas, does not catch organisms less than 0.5 mm length. So the data obtained by the Juday net with a mesh size of 112 μ in the deep-water regions was reduced by 22% for number and by 6% for the biomass prior to tabulation. This corresponds to their average share in the samples of the net with mesh size 112 μ [8].

The number and biomass of zooplankton in coastal and deep-water regions of the sea are often greatly distinguished (Table 8). In coastal regions they are characterised by higher values. The main reason for this is the eutrophication of coastal waters by the continental shelf runoff.

4. Conclusions

The results of this study allow us to define the composition and large-scale distribution of zooplankton in the eastern Mediterranean. During the course of investigations reviewed here, the species list of zooplankton (mainly copepods) was greatly enriched.

The regular reduction in the quantity and biomass of zooplankton seen from the west to the east of the Mediterranean was shown. This is connected with an impoverishment of nutrients due to the Atlantic water. The same phenomenon was observed in the direction from the north towards the south. Waters of the northern Adriatic and the Sea of Marmara, which are rich in nutrients due to river inflow flow southward, mixing with nutrient-poor water and therefore lose their abundance of nutrients. This is accompanied by a reduced amount of planktonic organisms.

It is also shown that the deep-water regions are richer in terms of taxonomic composition but are poorer with respect to biomass and quantity of zooplankton in comparison with the coastal regions which are under the influence of continental runoff.

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