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Seasonal Changes in the Composition and Abundance of Zooplankton in the Seas of the Mediterranean Basin

Alexander Vasilievich KOVALEV
Institute of Biology of the Southern Seas, Nakhimov Ave. 2, Sevastopol, UKRAINE

Maria Grazia MAZZOCCHI
Stazione Zoologica "Anton Dorn", Villa Communale, 80127, Naples, ITALY

Ahmet Erkan KIDEYS
Institute of Marine Sciences, P.O. Box 28, Erdemli, TURKEY

Benin TOKLU
Çukurova University, Faculty of Fisheries, Adana - TURKEY

Valeriy Alexandrovich SKRYABIN
Institute of Biology of the Southern Seas, Nakhimov Ave. 2, Sevastopol, UKRAINE

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Abstract: Seasonal changes in the composition, abundance and biomass of zooplankton in the seas of the Mediterranean basin (the Mediterranean, Black and Azov seas) have been reviewed using our own data and data from the literature. In the deep-water central regions of the seas, the seasonal cycle of zooplankton abundance is characterised by one maximum occurring in spring or summer. In the coastal regions, two to three peaks (spring, summer and autumn) exist for the zooplankton abundance. The amplitude of seasonal fluctuations in abundance for the coastal zone as a rule is much wider than for the deep-water regions. In both coastal and central deep-water regions, the amplitude of seasonal fluctuations increases from the Mediterranean to the Black and Azov seas, as well as from south to north in each sea. This corresponds to seasonal changes in the amplitude of water temperature and the abundance of phytoplankton as the basic factors influencing zooplankton abundance.

The dominant role in defining seasonal changes in total zooplankton abundance is played by the main group — copepods, which in some years form up to 90% of zooplankton numbers and biomass. During the warm period of a year, cladocerans may replace copepods.

Key Words: Abundance, Biomass, Phytoplankton, Zooplankton, Seasonal changes, Mediterranean Sea, Black Sea, Sea of Azov

Akdeniz Baseni'nin Zooplankton Bolluk ve Kompozisyonundaki Mevsimsel Değişimler

Özet: Akdeniz basenindeki (Akdeniz, Karadeniz, Azov Denizi) zooplankton kompozisyonunun bolluk, biomas, ve kompozisyonundaki mevsimsel değişimler kendi verilerimiz ve literatürdeki veriler kullanılarak gözden geçirilmiştir. Açık derin denizlerdeki zooplankton bolluğunun mevsimsel değişimi bahar ve yaz aylarında ortaya çıkan bir pik değeri ile karakterize edilir. Zooplankton bolluğu için kıyısal bölgelerde 2-3 pik (ilkbahar,yaz,sonbahar) vardır. Bir kural olarak kıyısal zon için bolluğa ait mevsimsel salınım sınırlar derin deniz bölgelerindekilere göre daha geniştir. Hem kıyısal ve hem de açık denizlerde mevsimsel salınım sınırları hem Akdeniz'den Karadeniz ve Azov denizine doğru ve hem de güneyden kuzeye gidildikçe artar. Bu da zooplankton bolluğunu etkileyen temel faktörler olan fitoplankton bolluğu ve sıcaklığındaki mevsimsel salınım değişimleri ile uygunluk gösterir.

Total zooplankton bolluğundaki mevsimsel değişimlerde baskın rol zooplankton sayısı ve biyomasın % 90 ını oluşturan kopepodlar tarafından oynanır. Yılın sıcak mevsimlerinde kladoserler kopepodların rolünü üstlenir.

Anahtar Sözcükler: Bolluk, biomas, fitoplankton, zooplankton, mevsimsel değişim, Akdeniz, Karadeniz, Azov Denizi

Introduction

The seas of the Mediterranean basin (the Mediterranean, Black and Azov seas) are characterised by a wide range of spatial and temporal variations in their environmental parameters affecting the seasonality of zooplankton.

However, studies on the seasonality of zooplankton in the Mediterranean basin began comparatively recently, about 20-30 years ago. These studies were mainly conducted in the inshore zones near cities where marine biological institutes or stations exist (Gaudy, 1985; Hure and Scotto di Carlo, 1968). In deep-water regions, specific studies in the seasonal changes of zooplankton are rare. However, the data accumulated in the literature, much of it belonging to the authors of this article, are valuable for analysis. In this paper, the comparative analysis of seasonal changes in the composition and abundance of zooplankton of the Mediterranean basin as well as in inshore and deep-water regions is conducted for each sea.

Materials and Methods

The information reviewed here was published in the related references. Studies of the seasonal changes in zooplankton and in particular its quantitative characteristics began in the Mediterranean Sea in the 1960s and in the Black and Azov seas as far back as the 1930s. A large amount of information, in general on coastal regions with far less information on the deep-water regions of the seas, has therefore accumulated to date (Table 1).

An analysis of the literature data shows differences in the research period and methods, in the number of stations and depth of the water column studied, in the type and mesh size of plankton nets employed etc. These factors obviously affect the levels of comparability of the results. However, each investigation presents general trends in seasonal changes in zooplankton for each studied region. Therefore the available data are comparable and can be used for comparing different parts of the Mediterranean basin.

Results

Analysis of data on the volume of mesozooplankton samples (mm^3/m^3) in the 0-200 m layer collected by the Institute for the Biology of Southern Seas (Ukraine) allow us to evaluate seasonal changes in zooplankton biomass in the offshore Mediterranean Sea (Kovalev, 1970), despite the material having been collected in different years and in different regions of the sea. The reason for this conclusion was the significant and sharp reduction in biomass seen from spring to summer followed by variations within close limits (Table 2).

Table 1. Sampling data of the studies reviewed here for evaluating seasonal changes of zooplankton quantity of the Mediterranean basin.

	The Mediterranean Sea					
	Region	Year, Season	Layer, m	Type of net	Mesh Size	References
1	Monaco, Offshore	1979-1983 perennial	0-200	WP 2	200 µ	Boisson et al. (1985)
2	Castellon, Coastal	1960-1961	0-60	Juday	250 µ	Vives (1966)
3	Naples, Coastal	1984-1990	0-50	Nansen	200 µ	Mazzocchi and Ribera d'Alcala (1995)
4	Villefranche Bay, Coastal	1972	0-15	WP 2		Fenaux and Quelart (1977)
5	North Adriatic	1965	0-20	Nansen		Stirn (1971)
6	Gulf ofTrieste, Coastal	1976-1979				Specchi et al. (1981)
7	Kastella Bay, Coastal	1960-1969				Vucetic and Regner (1973)
8	Split Bay, Coastal	1970-1974	0-bottom	Hensen	3	Regner (1985)
9	Saronicos Gulf, Coastal	1984-1985	0-50	WP 2	200 µ	Siokou-Frangou (1996)
10	South-eastern Mediterranean, Offshore	1975-1976	0-400	Juday	250 µ	Porumb et al.(1982)
11	Egypt Coastal	1956-1957	0-bottom		250 µ	El-Maghraby and Halim (1965)
12	Eastern Harbour of Alexandria, Coastal	1976-1977	0-5		145 µ	Khalil et al.(1983)
13	Lebanese, Coastal	1979-1981	0-50	WP 2	200 µ	Lakkis and Zeidane (1983)

Table 1. continued.

			The Black Sea			
1	Western part, Offshore	1948-1951	0-150	Juday	200 μ	Kusmorskaya (1955)
2	Western part, Offshore	1957 February-November	0-200	Juday	125 μ	Delalo et al. (1965)
3	Eastern part, Offshore	1959-1974 March-August	0-100	Juday	200 μ	Fedorina (1978)
4	North-western part, Offshore	1959-1974	0-100	Juday	200 μ	Fedorina (1978)
5	North-western part, Offshore	1957May-August	0-200	Juday	125 μ	Sazhina (1964)
6	Batumi Bay, Coastal	1933-1934	0-bottom	Juday		Nikitin (1949)
7	Gelenjik, Coastal	1974-1976, 1978	0-4 0-20	Juday	95 μ	Pasternak (1983)
8	Sevastopol Bay, Coastal	1976	0-10	Juday, bottle	125 μ	Kovalev (1980,1991)
9	Near mouth of Danube, Coastal	1972-1979	0-10			Porumb (1980)
			The Sea of Azov			
1	The whole sea (without Taganrog Gulf)	1937-1938	0-10	Apstein, Juday	100 μ	Pitsyk and Novozhilova (1951)
2	Taganrog Gulf	1937-1938	0-10	Apstein, Juday	100 μ	Pitsyk and Novozhilova (1951)
3	The whole sea (without Taganrog Gulf)	1952-1976	0-10	Apstein, Juday	100 μ	Kopets (1978)
4	Mariupol, Coastal	1975-1976	0-bottom	Juday, bottle	125 μ	Kovalev and Svetlichny (1986); Kovalev (1991)

Table 2. Concentration of net seston (mm^3/m^3) and wet weight of plankton (mg/m3) in the 0-200 m layer for the Mediterranean Sea in different seasons (Kovalev, 1970).

Region (sea)	Date	Volume of seston (mm^3/m^3)	Wet weight (mg/m^3)
İonic	May, 7-8, 1968	288	31.3
Ligurian	May, 19, 1968	213	11.5
Ligurian	May, 24-25, 1968	170	
Tyrrhenian	June, 11-12, 1968	84	5.8
Aegean	June-September, 1958, 1960	68*	12.1
İonic	July-August, 1959	72*	35
Tyrrhenian	July-August, 1959	40.5*	
Sirt	August, 1959	78*	
Levant	September, 1959	64*	16.9

* unpublished data of V.A. Vodyanitskiy.

In various articles (Baldina and Kovalev, 1979; Kovalev and Baldina, 1976; Shmeleva et al., 1975) the data on sample volume for both the same and different months of different years are close to the values shown in Table 2, which suppors the conclusion on the seasonal character of changes given in this table. This is confirmed by data on the numbers and biomass of zooplankton (Table 2) based on the same materials (Delalo, 1966; Greze, 1963; Moryakova et al., 1975; Pavlova, 1966).

The Western Mediterranean Sea

The characteristics of seasonal changes in zooplankton abundance were revealed in 1969-1970 in the offshore zone of the Ligurian Sea 20-40 miles from the coast above a depth of about 200 m. An increase in zooplankton abundance from February to a maximum in May was discovered. This was followed by a decline in zooplankton until August. From August to January abundance remained stable and low (Nival et al., 1972). In the Monaco region, from 50 m to 1000 m, regular monthly observations from 1979 to 1983 found the peak of zooplankton biomass in the layer down to 200 m occurred in April-May, whereas until June-July the biomass decreased sharply. In different years, from August to October a second small peak was observed (Boisson et al., 1985). Annual maximum and minimum values for all years studied differed by 8.5 - fold. The amplitude seasonal changes in zooplankton numbers and biomass in some offshore and coastal regions of the western Mediterranean are shown in Table 3.

Vives (1966), studying the coastal zone of Spain (Castellon) from November to September 1961, observed that there were two peaks of zooplankton biomass, in February and June-July. The February maximum exceeded the September minimum by nearly fourfold.

Three peaks of biomass during a year (spring, summer and autumn) were noted in the Spanish coastal region of the Alboran Sea to the east from the Straits of Gibraltar from 1976 to 1979 (Caminas, 1983; Rodrigues, 1983) and in other regions.

In the Gulf of Naples in the inshore station (0-50 m layer) at biweekly intervals from 1984-1990, two peaks in zooplankton abundance were revealed. The first small peak was apparent from average values for April for the whole investigated period, the second peak was observed in August. The minimum zooplankton abundance occurred in January. The seasonal changes in zooplankton abundance can be defined mainly by the seasonal cycle of copepods. Zooplankters forming the summer peak are mainly composed of cladocerans (Mazzocchia and Ribera d'Alcala, 1995).

The Eastern Mediterranean Sea

According to the results of monthly observations on 18 stations (Stirn. 1971) in the offshore regions of the northern Adriatic Sea, the annual maximum of zooplankton abundance in August was found to exceed the winter minimum by 50 - fold. A small peak was also noted in spring (March-June). Particularly in the Gulf of Trieste, where the temperature varies between 6º and 26º, the amplitude in seasonal changes of zooplankton organism abundance is highest in the Mediterranean Sea (Specchi et al., 1981). The south-eastern offshore region is characterised by a considerably smaller amplitude of abundance and biomass changes (Table 4).

Table 3. Amplitude of seasonal changes in zooplankton number and biomass in the western Mediterranean Sea.

Region	Max.		Min.		Max. / Min.		References
	Abundance (ind/m^{-3})	Dry Wt. (mg/m^{-3})	Abundance (ind/m^{-3})	Dry Wt. (mg/m^{-3})	Abundance	Dry Wt.	
Monaco, Offshore 1979-1983		17 April		2 January		8.5	Boisson et al. (1985)
Castelon coastal, 1960-1961		12 Feb.		3.0 Sept.		4.0	Vives (1966)
Ville-franche-sur-mer Bay, Coastal		35.41 June		1.7 Feb.		21.0	Fenaux and Quelart (1977)
Naples, coastal, 1984-1990	11148 Summer 1984		223.0		49.0		Mazzocchi and Ribera (1995)

Table 4. Amplitude of seasonal changes for the zooplankton abundance and biomass (wet weight) in the eastern Mediterranean Sea.

Region	Max.		Min.		Max. / Min.		References
	Abundance (ind/m^{-3})	Wet Wt. (mg/m^{-3})	Abundance (ind/m^{-3})	Wet Wt. (mg/m^{-3})	Abundance	Wet Wt.	
Northern Adriatic, Offshore		110.0 August		2.5 January	44.0		Stirn (1971)
South-Eastern Mediterranean, Offshore 1975-1976	373.0 Winter	23.7 Winter	211.0 Summer	14.2 Summer	1.8	1.7	Porumb et al. (1982)
Egypt, Coastal 1956-1957	44330 July		3695.0 Feb.		12.0		El-Maghraby and Halim (1965)
Eastern Harbour of Alexandria Coastal 1976-1977	82700 June	447.0 June	10340 Sept.	64.0 Sept.	8.0	7.0	Khalil et al. (1983)
Lebanese, Coastal 1979-1981	1900.0 June		269.0 Sept.		7.0		Lakkis and Zeidane (1983)
Kastella Bay, Coastal 1960-1969	6450.0 March		1930.0 Dec.		3.3		Vucetic and Regner (1973)
Split, Coastal 1970-1974					2.0-23.0 inshore 2.0-4.0 shore		Regner (1985)
Triest Bay, Coastal 1976-1979	10000 May		~100 Dec.		100.0		Specchi et al.(1981)
Saronicos Gulf, Coastal 1984-1985	~6000 August August		~300 Nov.-Dec.		20.0		Siokou-Frangou (1996)

Research carried out at three stations in the Saronicos Gulf from 1984 to 1985, particularly at the shallowest station nearest to Athens, revealed a seasonal cycle of general zooplankton abundance. Two maximum peaks were noted here: in March-April and in June-September and one minimum in winter. The summer maximum and winter minimum values obtained for different years differed 10-12 - fold. At the two other stations, which were more influenced by the open sea, the seasonal fluctuations were less marked. As in other regions, variations in seasonal changes are largely defined by the dynamics of copepods and cladocerans (Siokou-Frangou, 1996).

Similar seasonal changes in zooplankton abundance and biomass were observed in other inshore regions of the eastern Mediterranean Sea (Table 4).

An essential contribution to seasonal dynamics is made by many species of copepods and cladocerans (Gaudy, 1971; Hure and Scotto di Carlo, 1968). In the Tunisian (Sicilian) Strait one can see how large are the seasonal changes in the composition of mass organisms in the Atlantic water mass (Kovalev, 1982). The data in Tables 3 and 4 lead us to conclude that the curve of seasonal changes in zooplankton abundance in the coastal regions of the Mediterranean Sea has as a rule two peaks, whilst only one peak is present for offshore regions. In both offshore and inshore waters the amplitude of seasonal changes increases from south to north (Gaudy, 1985). Some authors have recorded a positive correlation between the abundances of zooplankton and forage phytoplankton (Malej and Fonda Umani, 1995; Siokou-Frangou, 1996; Stirn, 1971).

The Black Sea

There are several published studies devoted to seasonal changes in the abundance and biomass of zooplankton in the Black Sea. According to Nikitin (1949), zooplankton biomass in the 0-25 m layer changed by 3.5 - fold, reaching maximum values in August and falling to a minimum in winter during the course of the year. A reduced second peak was noted in October. The amplitude of seasonal fluctuations deceased with depth. Unfortunately, the sampling region and period of his study are not clear. Therefore, we have included a table (Table 5) from Fedorina's (1978) work from long - term data.

In the offshore waters of both the western and eastern regions of the Black Sea, only one peak for abundance and biomass was noted in summer (Delalo et al., 1965; Fedorina, 1978; Kusmorskaya, 1955). A summer peak was also registered in the north-western part of the sea (Sazhina, 1964). However, the range in seasonal fluctuations of abundance was almost twofold wider compared to offshore areas of the eastern and western Black Sea (Table 6).

The data obtained from different offshore regions of the Black Sea by Vinogradov and Shushkina (1992) during the period of high abundance of *Mnemiopsis* are of interest. Table 7 shows the seasonal changes in the zooplankton community structure in the water column from the surface to the hydrogen sulphide zone considering all basic components of meso- and macrozooplankton.

Maximum total biomass values were recorded in spring because of the high abundances of *Mnemiopsis* and *Aurelia*. As recorded by other authors, prior to the arrival of *Mnemiopsis*, the maximum biomass of zooplankton excluding gelatinous organisms occurred in summer.

Therefore, in the offshore regions of the Black Sea as a rule there exists one peak in zooplankton abundance and biomass, which occurs during the summer. The significant seasonal fluctuations in river input and water temperature in the shallow waters of the north-western Black Sea correspond to a broader range of seasonal changes in the abundance and biomass of zooplankton than in the deep-water region.

Several studies are solely related to the coastal regions of the Black Sea. Based on regular, lengthy observations (from one to several years) the seasonal changes in the composition, abundance and biomass of zooplankton were examined in detail (Table 6). In the Bay of Batumi, besides the maximum peak in July, both abundance and biomass formed secondary peaks in April and November (Nikitin, 1949). In the region of Gelendzhik at four stations in 1978 three peaks of net zooplankton biomass were found. The largest peak was usually observed in April. Another two peaks were noted in May-June and August-October, but without *Noctiluca* there were two peaks: in April and August-September. The biomass peak were determined by the quantity dynamics of such all-year-round species as *Paracalanus parvus, Acartia clausi, Oithona nana* and *Oikopleura dioica,* as well as by the

Table 5. Seasonal average values for changes zooplankton biomass (wet wt as mg/m^3) in the north-western and eastern Black Sea (in 0-100 m layer) from 1959-1974 (Fedorina, 1978).

Components of zooplankton	March	May	June	July	August
The north-western Black Sea					
Without *Noctiluca* and *Pleurobrachia*	59	68	173	285	261
Noctiluca	44	151	353	504	159
Pleurobrachia	90	65	45	62	41
Σ	193	284	571	851	461
The eastern Black Sea					
Without *Noctiluca* and *Pleurobrachia*	65	56	85	76	106
Noctiluca	148	204	332	224	136
Pleurobrachia	79	73	37	99	39
Σ	292	333	454	399	281

Table 6. Amplitude of seasonal changes in abundance and biomass of mesozooplankton in the Black Sea.

Region	Max.		Min.		Max. / Min.		References
	Abundance (ind/m^{-3})	Wet Wt. (mg/m^{-3})	Abundance (ind/m^{-3})	Wet Wt. (mg/m^{-3})	Abundance	Wet Wt.	
Western, Offshore 1948-1951		excluding gelatinous 140.0 August		excluding gelatinous 46.0 October		3.04	Kusmorskaya (1955)
Western, Offshore 1957	6753.0 May	221.4 Feb.	5000.0 Nov.	87.5 August	1.3	2.5	Delalo et al. (1965)
Eastern, Offshore 1959-1974	6040.0 August	454.0 June	3926.0 May	281.0 August	1.3	1.6	Fedorina (1978)
North-western, Coastal 1957	75635.0 Nov.	414.0 Aug.	37320.0 May	95.0 May	2.3	4.4	Sazhina (1964)
North-western, Coastal 1959-1974	14771.0 August	851.0 August	4782.0 March	193.0 March	3.1	4.4	Fedorina (1978)
Batumi Bay, Coastal 1933-1934	July		Dec.		7.0	9.0	Nikitin (1949)
Gelendzhik Bay, Coastal 1978		~1100 April		~40 Feb.		28	Pasternak (1983)
Sevastopol Bay, Coastal 1976	<0.5 mm 1.3939· · 10^{7} March	<0.5 mm 4312.0 Sept.	<0.5 mm 46500.0 Aug.	<0.5 mm 43.0 August	300.0	100.5	Kovalev (1980, 1991)
	>0.5mm 26660.0 Sept.	>0.5mm 684.0 April	>0.5mm 3090.0 July	>0.5mm 96.0 May	8.6	7.1	
Near mouth of Danube, Coastal 1972-1979					40.0	40.0	Porumb (1980)
North-western, Lagoons						45.0 - 68.0	Stakhorskaya (1970)
Offshore, 1991		147.47 g/m^{2} Summer		49.35 g/m^{2} Winter		3.0	Vinogradov and Shushkina (1992)

number of warm-water organisms, particularly Cladocera and benthic larvae (Pasternak, 1983). In the same year and at the same stations in the Gelendzhik region, the biomass of two studied groups of microzooplankton changed in different seasons by as much as 100 - fold. The peaks of zooflagellates were noted in June and September-October (38), and the peaks of Infusoria in May, August and November (Mamaeva, 1980).

In Novorossiysk harbour (Uralskaya, 1964) and in the Karadag region of the Crimean coast (Klyucharev, 1952; Lazareva, 1957), two biomass peaks were found. Maximum values exceeded the minimum by 7-9 - fold. The results of investigations in Sevastopol Bay (Kovalev, 1980), near the mouth of the Danube (Porumb et al., 1982), and in lagoons and estuaries of the north-western Black Sea (Stakhorskaya, 1970) together with all other data (Table 6) bear witness to the wider amplitude of

Table 7. Seasonal changes in biomass (g·m^{-2}, wet weight with standard deviation values) of the main zooplankton contributors in the offshore regions of the Black Sea in 1991 (Vinogradov and Shushkina, 1992).

Components of zooplankton	Winter, 12.II – 1.III	Spring, 10.II – 1.IV	Summer, 12 – 22.VII	Autumn, 07 – 12.X
Mnemiopsis	529.00 ± 122.00	891.00 ± 329.00	1320.00 ± 425.00	470.00 ± 94.00
Aurelia	307.00 ± 67.00	727.00 ± 170.00	119.00 ± 41.00	587.00 ± 107.00
Pleurobrachia	44.00 ± 10.00	119.00 ± 41.00	104.00 ± 26.00	82.00 ± 13.00
Noctiluca	1.90 ± 0.96	3.55 ± 1.25	2.93 ± 1.07	1.12 ± 0.24
Forage Zooplankton	0.64 ± 0.18	4.18 ± 1.50	0.98 ± 0.23	1.90 ± 0.30
Nannotrophs	0.43 ± 0.12	1.58 ± 0.47	0.47 ± 0.13	0.91 ± 0.16
Calanus	2.30 ± 0.56	4.70 ± 0.97	3.07 ± 0.62	2.12 ± 0.44
Sagitta	0.08 ± 0.02	1.92 ± 0.68	0.02 ± 0.01	0.18 ± 0.12
Total Zooplankton	885.35	1735.93	1586.47	1145.23
Total excluding *Mnemiopsis* and *Aurelia*	49.35	117.93	147.17	88.23

seasonal changes in zooplankton abundance and biomass in the coastal zone than in the offshore regions. These data also show the increase in amplitude from south to north the Black Sea.

Data from Sevastopol Bay show that the leading role in zooplankton is played by microzooplankton, not only because of their abundance but also because of their biomass (Fig. 1).

The compilation of seasonal changes in the biomasses of different zooplankton components collected together with seasonal changes in phyto- and bacterioplankton and water temperature (Senicheva, 1979; Shumakova, 1979) revealed that the spring increase in zooplankton abundance in Sevastopol Bay follows the peak in phytoplankton biomass, which was observed in February. Herewith the maximum biomass of Infusoria was registered in March, mesoplankton in April-May and the remaining microzooplankton groups showed maximum biomasses in April (Fig. 1). The biomass of bacterioplankton gradually increased until June on account of the spring development of phyto- and zooplankton and remained at nearly the same level (approximately 500 mg/m^3) until September. It decreased by nearly two fold in November, and again there was a several - fold increase in December, similar to the levels of the autumn increase in phyto- and zooplankton biomasses. Autumn exhibited the largest microzooplankton peak and a small mesozooplankton peak, noted in September, contrasting with spring values, a month before the phytoplankton peak, but at the end of the summer bacterioplankton maximum . Only the second small autumn zooplankton peak development follows the autumn phytoplankton peak (Fig.1).

On the basis of data on the sequence of biomass peaks of different plankton components, it is possible to draw a conclude that the first increase in zooplankton biomass occurs following the main phytoplankton bloom in spring, and the accurs second in autumn (in September) in the coastal waters of the Black Sea.

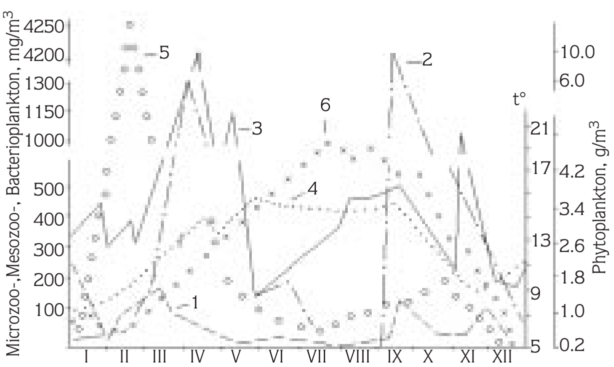

Fig.1. Seasonal changes in plankton components' biomass and water temperature in Sevastopol Bay in 1979. *1. Infusoria; 2. Microzooplankton; 3. Mesozooplankton; 4. Bacterioplankton; 5. Phytoplankton; 6. Temperature* (Kovalev, 1991).

The Sea of Azov

Significant seasonal fluctuations in water temperature and the biomass of phytoplankton probably defines the wide range in seasonal changes of zooplankton abundance in the Sea of Azov (Table 8). Based on the data of Okul (1941), Pitsyk and Novozhilova (1951) and other authors, the lower zooplankton biomass in offshore waters was noted at the beginning of the year, when the zooplankton is represented mainly by copepods (more than 90%) and a small amount of Rotatoria. In March, with the increase in phytoplankton biomass, Rotatoria (80% of biomass) and tintinnids reproduce intensively. The total zooplankton biomass increases significantly. In April there are no considerable changes. May is characterised by the intensive reproduction of Cirripedia, Cladocera and Molluscs. Cirripedia larvae consist up to 50% of the biomass. Total biomass increases a little. In June copepods are dominant, their biomass reaching 90% of the total. July, as a rule, displays the highest values of zooplankton biomass over a year. Rotatoria, Cladocera and larvae of molluscs are comparatively numerous, but not Copepoda. In August the biomasses of all groups, especially larvae, begin to decrease, reaching their minimum in February. Here, biomass values differ from the maximum values in June in some years by as much as 30 - fold (Novozhilova, 1955).

In the past, one long summer maximum with a peak in July or less commonly in June or August was noted for the offshore zone (Kovalev, 1970; Novozhilova, 1955; Okul, 1941). Some authors noted the presence of a second peak in the biomass of some planktonic animals in October-November (Dolgopolskaya and Pauli, 1964;

Table 8. Amplitude of seasonal changes of mesozooplankton abundance and biomass (wet weight) in the Sea of Azov.

Region	Max.		Min.		Max. / Min.		References
	Abundance (ind/m^{-3})	Wet Wt. (mg/m^{-3})	Abundance (ind/m^{-3})	Wet Wt. (mg/m^{-3})	Abundance	Wet Wt.	
The whole Sea (excluding Taganrog Gulf), 1937		1284.0 July		43.0 Feb.		30.1	Pitsyk and Novozhilova (1951)
The whole Sea (excluding Taganrog Gulf), 1938		463.0 July		55.0 Feb.		8.4	Pitsyk and Novozhilova (1951)
Taganrog Gulf, 1937		2334.0 June		572.0 May		4.1	Pitsyk and Novozhilova (1951)
Taganrog Gulf, 1938		1835.0 July		175.0 April		10.5	Pitsyk and Novozhilova (1951)
The whole Sea (excluding Taganrog Gulf), 1952-1970		700.0 May - June		160.0 April		4.4	Kopets (1978)
The whole Sea (excluding Taganrog Gulf), 1971-1976		590.0 May - June		140.0 April		4.2	Kopets (1978)
MSariupol, Coastal, 1975-1976	<0.5 mm $2.67785 \cdot 10^7$ Sept. >0.5 mm 97578.0 Nov.	Total 3459.0 Nov.	<0.5 mm 3000.0 October >0.5 mm 165.0 July	Total 22.4 April	892.0 591.4	154.0	Kovalev and Svetlichny (1986), Kovalev (1991)

Okul, 1941). In Taganrog harbour more often than in the open sea, the presence of a secondary peak of zooplankton biomass in October and even in December was noted (Novozhilova, 1960).

After the reduction in Don inflow to the Sea of Azov, another peak of biomass was noted, usually in May (Kopets, 1978; Novozhilova, 1960). The zooplankton biomass decreases in June, remains at a constant level during July and August and decreases again in September-October. From 1971 (average data for 1972-1976) after the May peak, the biomass sharply decreased until the end of the year (Kopets, 1978). In Taganrog harbour, the before and after the reduction of the Don inflow, in some years an autumn maximum of biomass was seen in October, in addition to the spring-summer maximum (Novozhilova, 1960).

The absence of a summer maximum in the offshore zone coincides with the decrease in production of planktonic animals because of the reduction and redistribution of river input during the year (Novozhilova, 1960). The sharper decrease in zooplankton biomass during the summer of 1971 was connected with the appearance of new zooplankton consumers (medusae *Aurelia aurita* and *Rhizostoma pulmo* from the Black Sea) in large amounts in the Sea of Azov (Kopets, 1978).

Following the analysis of the literature on average data values spanning many years, it was seen that after the reduction of river inflow the range in seasonal changes of zooplankton biomass became lower by half. The reason for this is probably not the reduction, but the seasonal redistribution of river inflow, and also the high number of medusae present at the time of the summer zooplankton maximum.

Unlike in the offshore region, in the coastal zone, as in other seas of the Mediterranean basin, seasonal changes in quantitative indices are characterised by the presence of two peaks: spring-summer and autumn.

The range of seasonal changes in zooplankton abundance and biomass is exceptionally wide (Table 8). The minimum biomass value is 154 times lower than the maximum and 30 - fold lower than the average inter-annual range of seasonal changes in the open sea after the reduction in river inflow. This is undoubtedly due to differences in the environmental conditions between coastal and offshore zones.

Discussion

Analysis of the literature and our own data shows that the seasonal changes in abundance and biomass in the central regions of the Mediterranean, Black and Azov seas are usually characterised by one maximum per year in the spring-summer period (Fig. 2). In different years in the same sea the time of the maximum changes from May to August and depends mainly on the winter temperature conditions (Fedorina, 1978). In the warm Mediterranean Sea the maximum occurs earlier than in the Black or Azov seas. However, in the rapidly warmed Sea of Azov, after the reduction of river inflow the maximum shifts to an earlier period, as a rule, to May (Kopets, 1978; Novozhilova, 1960).

The level of seasonal changes in zooplankton abundance and biomass in the central regions of the Mediterranean and Black seas varies within similar limits. In the Sea of Azov, before the anthropogenic reduction in the sewer load of rivers the annual variation between the maximum and minimum was 14 - fold, but after the reduction it was seven fold. The range of seasonal changes in the quantitative indices of zooplankton in the central regions increases from the Mediterranean Sea to the Sea of Azov, corresponding to the increase in the range of seasonal variations of temperature and quantity of phytoplankton. Similarly, the level of seasonal changes in zooplankton quantity in the offshore regions of the northern Adriatic and Black seas with a more variable annual temperature regime and with very variable anthropogenic load through rivers is also high, as in the central deep-water regions.

According to Kostrichkina (1984), Nikolev (1957) and Simm (1976), in the Baltic Sea offshore regions are characterised by one peak level (in summer) in zooplankton biomass during the course of the year. In the offshore regions of the World's oceans one to three seasonal peaks are noted. For example, in the offshore regions (35°N, 48°W) of the Sargasso Sea at a latitude similar to that of the Mediterranean Sea, one maximum in June was noted (Fish, 1954), and 24 km away from the Bermuda islands an increase (for the 0-500 m layer) in zooplankton abundance (but not in biomass) was observed in autumn (Deevey, 1971). In temperate and high latitudes one to three seasonal maxima are noted (Gruzov, 1965; Hainrih, 1961; Voronina, 1984). However, analysis of the literature data shows that only

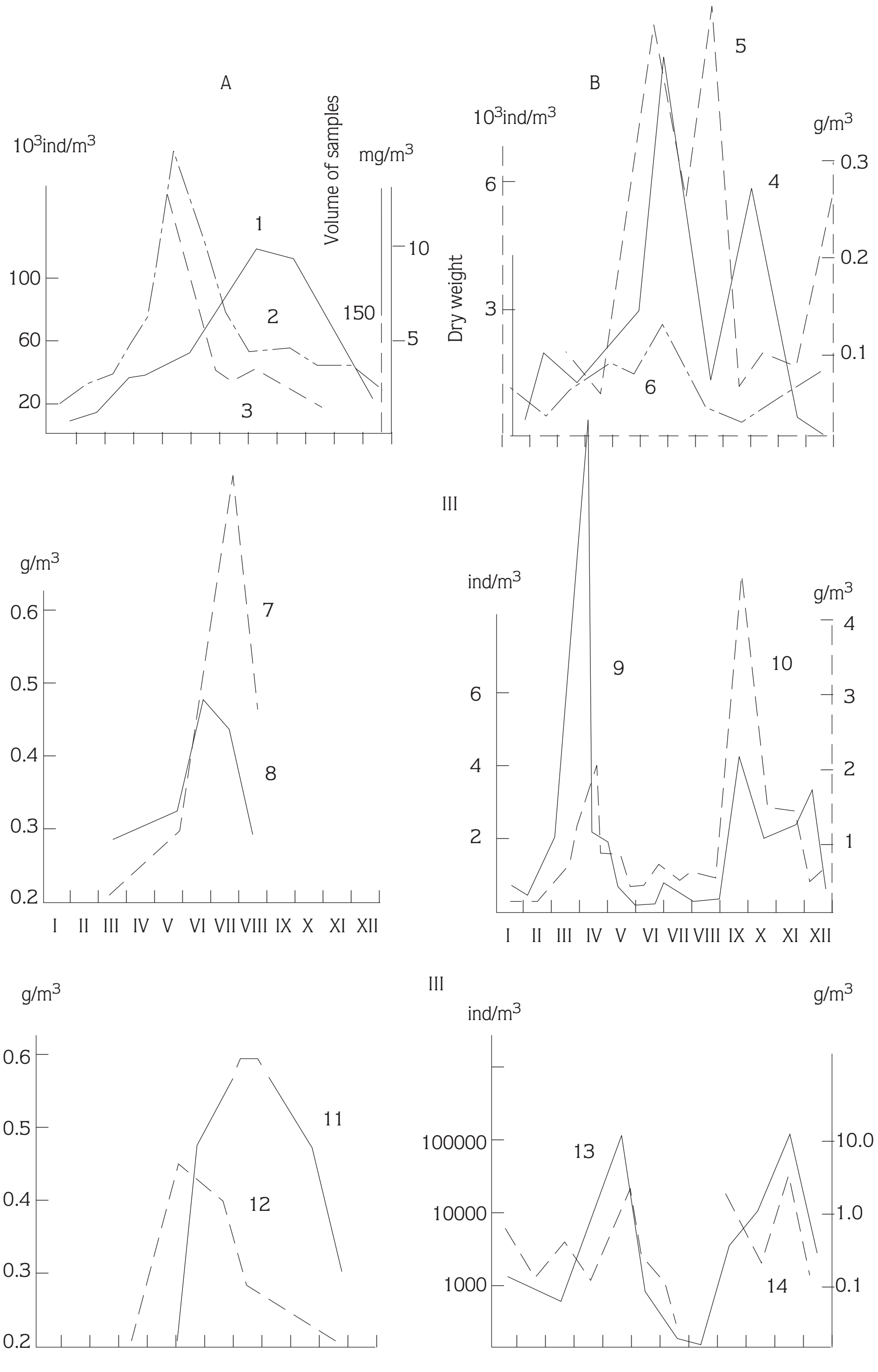

Fig. 2. Seasonal changes in zooplankton abundance (ind/m^3) and biomass (mg/m^3).

A –*Offshore regions;* B – *Coastal regions*

I – *The Mediterranean Sea;* II – *The Black Sea;* III – *The Sea of Azov*

1. North Adriatic (Stirn, 1971); 2. Monaco region (Boisson et al., 1985); 3. Central region (Kovalev, 1991); 4. Trieste Bay (Specchi et al., 1981); 5. Alexandria region (Khalil et al., 1983); 6. Beirut region (Lakkis and Zeidane, 1983); 7. Norht-west part (Fedorina, 1978); 8. Eastern part (Fedorina, 1978); 9,10. Sevastopol Bay (Kovalev, 1991); 11,12. Before and after reduction the river sewer (Kopets, 1978); 13,14. Mariupol region (Kovalev and Svetlichny, 1986).

one of the maxima is connected with the succession of native communities. The other two result from lateral transport, i.e. by the exchange of water masses of different origin and plankton concentration (Kiselev, 1980) or seasonal vertical migrations into the study area (Voronina, 1984).

In the coastal zone and harbours of all seas of the Mediterranean basin, two peaks (in spring and autumn) in zooplankton abundance and biomass are usually observed. Sometimes a third peak may appear in summer (Fig. 2). The range of seasonal changes in these areas is wider than that in the open regions. In the Mediterranean Sea this range varies from five- to 50-fold, although it becomes progressively narrower from east to west and from north to south. In the coastal zone of the Black Sea changes in zooplankton abundance in different seasons varies from Seven- to 25-fold, and in lagoons and estuaries of the north-western Black Sea up to 85-fold. The abundance and biomass of microzooplankton in Sevastopol and Gelendzhik bays in different seasons oscillate between 300- and 100-fold, respectively. The widest range of seasonal changes in zooplankton quantity is observed in the Sea of Azov. Near the city of Mariupol the abundance of total zooplankton changed 1100-fold and biomass 154-fold. The range for microzooplankton is even larger with corresponding values of 9000- and 590-fold due to huge variations in the abundance of Infusoria and Rotatoria, especially in the bay.

Consequently, for coastal regions, from the Mediterranean Sea to the Sea of Azov the range of seasonal changes in zooplankton abundance and biomass becomes wider in parallel to the wider range of seasonal variations of temperature and quantity of food for zooplankton (Kovalev, 1988).

In the coastal zones of other seas, for example the Baltic (Simm, 1976) and some other regions of the World's oceans encompassing the subtropical and temperate zones (Bogorov, 1941; Hainrih, 1961; Vives, 1980), two seasonal maxima were also noted, in spring and autumn. It is therefore possible to conclude that whilst the offshore regions of seas and oceans similar to the Mediterranean Sea are characterised by one maximum in zooplankton abundance, the coastal regions are characterised by two maxima.

These differences are undoubtedly caused by seasonal differences in the hydrological-hydrochemical regime of open deep-water and coastal shallow-water regions. Hydrological and hydrochemical processes, particularly seasonal changes in temperature, the speed of nutrient turnover and corresponding bioproductive processes in the coastal zone and harbours are less inert than in the open sea. Even in the shallow waters of the Sea of Azov, the temperature of the coastal regions reaches maximum nearly one month earlier than in offshore regions (Slavin, 1962). Therefore, in the harbours, zooplankton reach the maximum of biomass earlier than in the offshore zone. In the coastal zone, unlike in offshore areas, the regeneration cycle of nutrients in summer-autumn is more expressed. As a result of fast nutrient regeneration the biomass of bacterio- and phytoplankton increases in harbours during summer and the beginning of autumn. This process provides an autumn and sometimes a summer explosion in zooplankton quantity. In the offshore zone, however, elapsed timing in environmental parameters and temperature restricts the zooplankton peak to one, due to the approaching winter or an insignificant increase in phytoplankton biomass.

Conclusions

Analysis of the literature data on seasonal changes of plankton was first carried by Bogorov (1941). He showed global regularities in plankton seasonality. This was later confirmed by many investigations.

The data used by Bogorov were obtained only from the coastal regions of the World's oceans. Data on the Mediterranean basin were practically absent at that time.

Analysis of papers published to date on the question of seasonal changes in zooplankton in different regions of the Mediterranean basin allowed authors to contribute to a better understanding of the global characteristics of seasonal changes. In particular, it was shown that the offshore regions of temperate and subtropical zones of many seas and oceans are characterised by a single spring-summer maximum in zooplankton abundance and biomass.

The spatial distribution of seasonal changes in coastal regions of the Mediterranean Sea corresponds to known concepts of latitude changes and local environmental differences. The role of anthropogenic impact on seasonal changes is also important in this region.

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