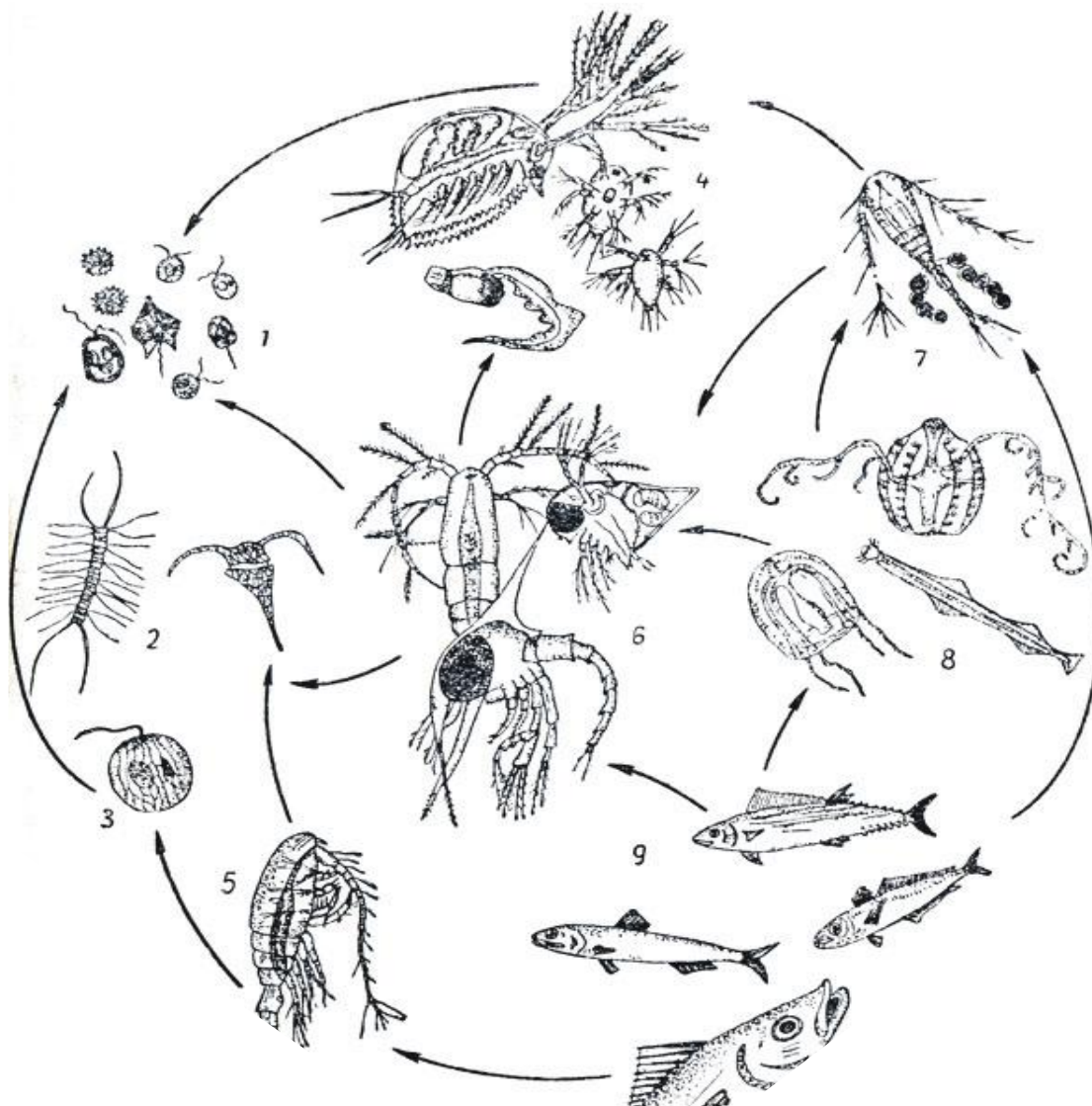


Zh.P. Selifonova

# ECOSYSTEMS OF BAYS AND HARBOURS OF THE NORTHEASTERN BLACK SEA AND THE SEA OF AZOV



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**ECOSYSTEMS OF BAYS AND HARBOURS  
OF THE NORTHEASTERN BLACK SEA  
AND THE SEA OF AZOV**

**Monograph**

**Novorossiysk  
«SMU named after admiral F.F. Ushakov»  
2018**

**UDK 574 + 577.4**

C29

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C29 Ecosystems of bays and harbours of the northeastern Black Sea and the Sea of Azov: monograph. – Novorossiysk: SMU named after admiral F.F. Ushakov, 2018. – 60 p., 24 il. – ISBN 978-5-89426-140-9

The monograph is devoted to researches of coastal marine ecosystems of the northeastern Black Sea, including areas of intensive shipping and recreation as well as the Kerch strait and the Sea of Azov exposed to anthropogenic impact. Results of research of phytoplankton, heterotrophic bacteria, protozoan, holoplankton, meroplankton, ichthyoplankton are presented. The analysis of zoobenthos as an indicator of eutrophication of benthic sediments is performed. It is revealed that sulfides accumulation in the top layer of benthic sediments is the most dangerous ecological consequence of anthropogenic pollution. Results of monitoring of biological invasions and ships' ballast water in the Novorossiysk port are presented. The estimations of ecological risks of marine biological invasions with water transport to the northeastern Black Sea and the Sea of Azov are given. Trophodynamic models of bays and harbours ecosystems have been developed. Common and specific features of their transformation under the influence of intensive anthropogenic impact are submitted. Tendencies of variability of quality of water resources and their potential abilities to natural self-purification are revealed. Role of zooplankton in structurally functional organization of ecosystem has been shown.

The book is addressed to hydrobiologists, oceanologists, teachers and students of institutes of higher education.

UDK 574 + 577.4

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ISBN 978-5-89426-140-9

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## INTRODUCTION

The southern seas of Russia – the Black Sea and the Sea of Azov are exposed considerable anthropogenic loading. Their ecosystems are considerably transformed. Along with that the processes of gradual decline of eutrophication and of chemical pollution of waters are observed at the present stage (Matishov, Matishov, 2003; Yunev, etc., 2009; Zaika, 2011). Such phenomena occur along with the accelerated exploitation of biological resources of these seas (navigation, tanker transportations of oil, petroleum production and gas-extraction, prospecting drilling, overfishing of valuable species of fishes, recreation and others). Historically the Sea of Azov was characterized as the reservoir with high biological efficiency having significant importance for fishery. The regulation of the rivers Don and Kuban, the change of the hydrological condition, the uncontrolled exploitation of natural resources and the mass development of predatory ctenophore of *Mnemiopsis leidyi* led to profound changes in ecosystem. The Sea of Azov, as one of the most productive basins of the world, lost the former fishery importance. As a result, we are seeing the development of unusual in density of blooms of toxic species of phytoplankton, the hydrogen sulphide contamination of bottom sediments, the benthic anoxia which had catastrophic consequences for planktonic and benthic fauna and led to their degradation. Such development became by typical for ecosystems of ports and bays of the northeast shelf of the Black Sea where the known climatic and balneological health resorts of Russia are located, the massive trans-shipment centers of overland and shipping and the Black Sea fleet are based. The change of habitat of hydrobionts, the climate, the intensification of shipping promote to introduction and distribution in the southern inland seas of Eurasia of an aggressive alien species of flora and fauna including toxic species of phytoplankton (Alexandrov, 2004; Zvyagintsev, et al., 2009; Shiganova, 2009; Shiganova, et al., 2012 and others).

At the same time, despite considerable attention to a problem of anthropogenic transformation of coastal ecosystems of the northeast shelf of the Black Sea and the Sea of Azov, a specific concept ideas of their reaction to anthropogenic influence, concerning change of their structure and functioning and, especially the role of zooplankton in such degraded ecosystems is missing. Functional destabilization of ecosystem usually precedes to changes of their structural organization. By through the monitoring of flows of matter and energy is considered a possible to predict the development a potential crisis processes in biological communities and to observe the existing processes.

However most researchers consider the implications of anthropogenic impact only on individual components or indicators of quality of environment. Thus, the ecosystem are still not fully studied. In this regard, the research of structural functional organization of the ecosystems of various pattern of crisis process including gulfs and bays of the northeast shelf of the Black Sea and the Sea of Azov is exclusively actual and demanding deep studying. The revealed features of functioning of zooplankton in such ecosystems can be used in system of ecological control and early diagnostics of sanitary condition of reservoir (Kreneva, 2002).

The analysis of literature has shown that prior to our researches there weren't full data characterizing system "organization" of the coastal biological communities of the northeast shelf of the Black Sea and the Sea of Azov. The taxonomical composition and structure of net zooplankton has been considered in many works, but often these results were incomparable among themselves because they differed in methods and terms of sampling. Knowledge on key components of communities of the most vulnerable areas of the northeast shelf (zone of recreation and navigation) remained very poor or absolutely were absent. An assessment of risk of biological invasions with ballast waters of commercial vessels in the Russian ports wasn't carried out. The full list of taxonomical composition of meroplankton of the northeast shelf of the Black Sea was absent. In papers (1980-1990) the study of heterotrophic bacteria, infusorians, zooflagellates and other groups of zooplankton were carried out only in the coastal zone of the Gelendzhik bay and the Novorossiysk bay (Mamaeva, et al., 1980; Moiseev, 1983; Bolgova, 1994; Kopylov, Sazhin, 1987; Selifonova, 2001; Kopylov et al., 2004 and others). The descriptions of energetics and structural functional organization of pelagic ecosystem of the Black Sea, the Gelendzhik, Novorossiysk bay, biotic balance of coastal waters of the northwest part of the Black Sea are known in literature (Sorokin, 1982; 1996; Shushkina, et al., 1980; 1987; Vinogradov, et al., 1992; Alexandrov, 2002; Selifonova, 2002).

In the Sea of Azov, which is least studied in the faunistic relation, such researches didn't carry out, except of development of mathematical trophodynamics model of invasions of alien species (Berdnikov, 2004; Berdnikov et al., 1999) and the simplified model of the lower trophic levels of ecosystem (Il'ichev, 2008). The detailed studying of ecology the Sea of Azov infusorians was made by K.V. Kreneva (2006), the functioning of zooplankton of the Taganrog Bay – V.V. Povazhnyi (2009). However specially the authors didn't consider a question of relationship between infusorians, holoplankton, meroplankton as a result of the succession changes of their structure in pelagic estuarial communities. They didn't carry out inventory of taxonomical structure of holoplankton and meroplankton. In this regard, our task consisted in receiving of complex of manifold data allowing to give the assessment of condition and tendencies of change of the coastal ecosystems of the northeast shelf of the Black Sea and the Sea of Azov subject to considerable anthropogenic influence.

We have studied the ecosystems of different trophic pattern exposed to various anthropogenic stress. Among them, the Sea of Azov, the Strait of Kerch, gulfs and bays of the northeast shelf of the Black Sea – Novorossiysk, Tuapse, Taman', Anapa, Gelendzhik, Sochi, the Liman "Zmeinoe ozero" ("Snake lake", Big Utrish).

The object of investigation was zooplankton (zooflagellates, ciliates, holoplankton, meroplankton, ichthyoplankton), as one of key components of ecosystems, and also heterotrophic bacterioplankton and zoobenthos of bottom sediments. The researches of environment and population of ships'ballast waters of commercial ships have been executed on oil terminals of the Novorossiysk port.

The subject of investigation has been taxonomical composition, regularities of quantitative distribution, a ratio of taxonomical groups in communities and a role of the mentioned elements in the structural functional organization of ecosystems.

Aim of study is to reveal of the features of the structural functional organization of ecosystems of the gulfs and bays of the northeastern Black Sea, the Strait of Kerch and the Sea of Azov, subject to various anthropogenic influence. The definition of the general and specific characteristics of their transformations, and of zooplankton' role in this process.

#### Statement of actual tasks

- the investigation of taxonomical composition and abundance of zooplankton communities (zooflagellates infusorians, holoplankton, meroplankton, ichthyoplankton), heterotrophic bacterioplankton in ecosystems of different trophic types extending from coastal waters of the northeast shelf of the Black Sea to the Sea of Azov;

- the research of spatial and temporary changes of structural characteristics of communities in each ecosystem and clarification of the factors defining these changes; an assessment of a role of separate species and taxonomical groups of zooplankton in structure of communities;

- the exposure of the regularities defining the structural organization of zooplankton depending on an abiotic factors of environment (water temperature, salinity, currents) and zoobenthos of bottom sediments depending on an oil products and labile (acid and soluble) sulfides in bottom sediments;

- the calculation of energy balance and the creation of model schemes of energy flows in ecosystems of different trophic pattern; the reveal of their peculiar features, the types of anthropogenic transformation; the assessment of zooplankton' role in the organization of ecosystems; the definition of tendencies of variability of water ecosystems and their potential abilities to natural self-purification;

- the assessment of role of invasions of alien species of zooplankton in a biodiversity and productivity of the studied ecosystems; the reveal of the main sources and ways of penetration of alien species of fauna to coastal waters of the northeast shelf of the Black Sea and the Sea of Azov; the assessment of ecological risks of marine biological invasions of zooplankton with water transport in the Black Sea and the Sea of Azov; the making of alien species list.

In studies of the most vulnerable ecosystems of the northeast shelf of the Black Sea and the Sea of Azov, the ecosystem approach has been used. Taxonomical and quantitative treatment of zooplankton have been carried completely out by the author by uniform techniques with the use of same quantitative accuracy of the account (uniform equipment of catch). Common pecies and alien species of planktonic and the benthic animals are subjected to detailed taxonomical processing. Calculations of biomass are carried out with use of the unified standardized weight scales of planktonic animals. It has allowed to carry out reliable interregional comparisons. Calculations of the approximate biotic balance, of the functional parameters and the construction of energy trophodynamic of models of ecosystems are made according to the standard scheme with attraction of necessary literary material. Research of

planktonic organisms from ballast waters of commercial ships are executed with use of original techniques of the author.

The author was directly involved in the expeditionary collecting, the treatment and the analysis of materials of heterotrophic bacterioplankton, zooflagellates, infusorians, holoplankton, meroplankton, ichthyoplankton and zoobenthos of bottom sediments. In 2004 by author has been organized and has been headed laboratory for control of ballast waters of commercial ships, which was located in the Federal State Budgetary Establishment “Administration of seaports of the Black Sea”. It was the first laboratory of control of ships’ballast water among the Russian ports. At its base author has been conducted pioneering researches of planktonic organisms of ballast waters (holoplankton, meroplankton, infusorians, heterotrophic bacterioplankton). The author actively promoted to development of the direction of invasive researches in MMBI KSC Russian Academy of Sciences. Scientific ideas, substantiations, statement of scientific tasks, methodical developments belong to the author that is confirmed by independence of publications of the main materials of work.

**Acknowledgment.** The author expresses gratitude and appreciation of methodical help, benevolent interest and attention to work to their teachers to professor Yu.I.Sorokin and P.Yu. Sorokin. The author sincerely thanks of the colleagues who were directly involved in the conducted researches and expeditions – academician G.G. Matishov (Murmansk Marine Biological Institute KSC RAS), V.K.Chasovnikov, (South Branch Institute Oceanology RAS), V.I.Radashevsky (Institute Marine Biology of FEB of RAS), V.V.Murina, A.A.Shmeleva, E.V.Lisitskaya, N.G.Sergeeva (Institute Marine Biological Researches named after A.O. Kovalevsky of RAS), O.N. Yasakova (Institute Arid Zones of RAS), A.V. Kurilov (Institute Marine Biology of NAS Ukraine), V.V. Erygin (Authority of seaports of the Black Sea).



## Chapter 1. MATERIAL AND METHODS

We collected the samples of zooplankton and zoobenthos in coastal waters of the northeastern Black Sea, the Kerch strait, the Sea of Azov during 2003–2014. Collecting of samples in the ports and the bays of the Taman' Peninsula and the northeast shelf of the Black Sea were executed with the participation of author. A total of 3061 samples were analyzed by author. The periods of execution of works, the areas of sampling, the components of processing and the number of samples is given in table 1, scheme of station of sampling – at figure 1. The sampling in ports and bays was made according to scheme of stations in dependence to their morphometry, hydrological and hydrophysical structure of waters, sources of anthropogenic pollution and character of benthic biotopes. The investigations of inhabitants of ballast waters of commercial vessels have been executed on oil terminals of the Novorossiysk port. A total 381 ballast samples of plankton were analyzed.

Table – 1 Total data collected in coastal waters of the northeast part of the Black Sea and the Sea of Azov

Area of investigation, port	Number of trips	Heterotrophic	Zoo-flagellata	Ciliata	Holo-plankton	Mero-plankton	Ichthyo-plankton	Zoobenthos
The Kerch strait, The Taman' Prichernomor'e								
The Taman' Prichernomor'e (2010), The Kerch strait (2004, 2010)	1	4	–	5	35	35	39	–
The Taman' port (2013–2014)	4	12	–	48	24	24	7	15
Bays and harbours of the northeastern Black Sea								
The Novorossiysk Bay (2004–2011)	51	88	79	132	182	182	124	157
The Tuapse port (2004–2006; 2009–2011)	17	80	–	80	125	125	104	176
The Anapa Bay (2006–2007; 2009–2011)	11	44	44	48	56	56	24	14
The Gelendzhic Bay (2005–2007; 2009–2011)	14	64	56	44	90	90	28	–
The Liman «Zmeinoe ozero» (2010–2011)	5	15	–	15	15	15	2	36
The Sochi port (2012–2013)	5	30	–	30	30	30	28	15
The Novorossiysk port, ships' ballast water								
5th pier, oil harbor «Sheskharis» (2004–2006, 2009–2010)	167	9	–	22	167	167	–	–
Sea of Azov								
The Sea of Azov, the Taganrog Gulf (2003–2005)	3	10	–	–	68	68	–	–
The Temryuk Gulf (2005–2006, 2009–2010)	6	12	–	34	34	34	–	–

Heterotrophic bacterioplankton, zooflagellates, and ciliates were analyzed in samples from the surface water layer. Heterotrophic bacterioplankton and zooflagellates were studied under an epifluorescent microscope using Acridin orange and Primulin fluorochromes (Hobbie et al., 1977). Infusorians were counted in live (nonfixed) water samples using a pencil box type cell (Sorokin, 1999). Species were identified in vivo, in temporal preparations and preparations impregnated a protargoly and a silver carbonate according to A.V.Kurilov

(Kurilov, 2010). The biomass of infusorians was determined standard method as well as according to the average volume and abundance in each size group (Mamaeva, 1979, 1980; Kurilov, 2004).

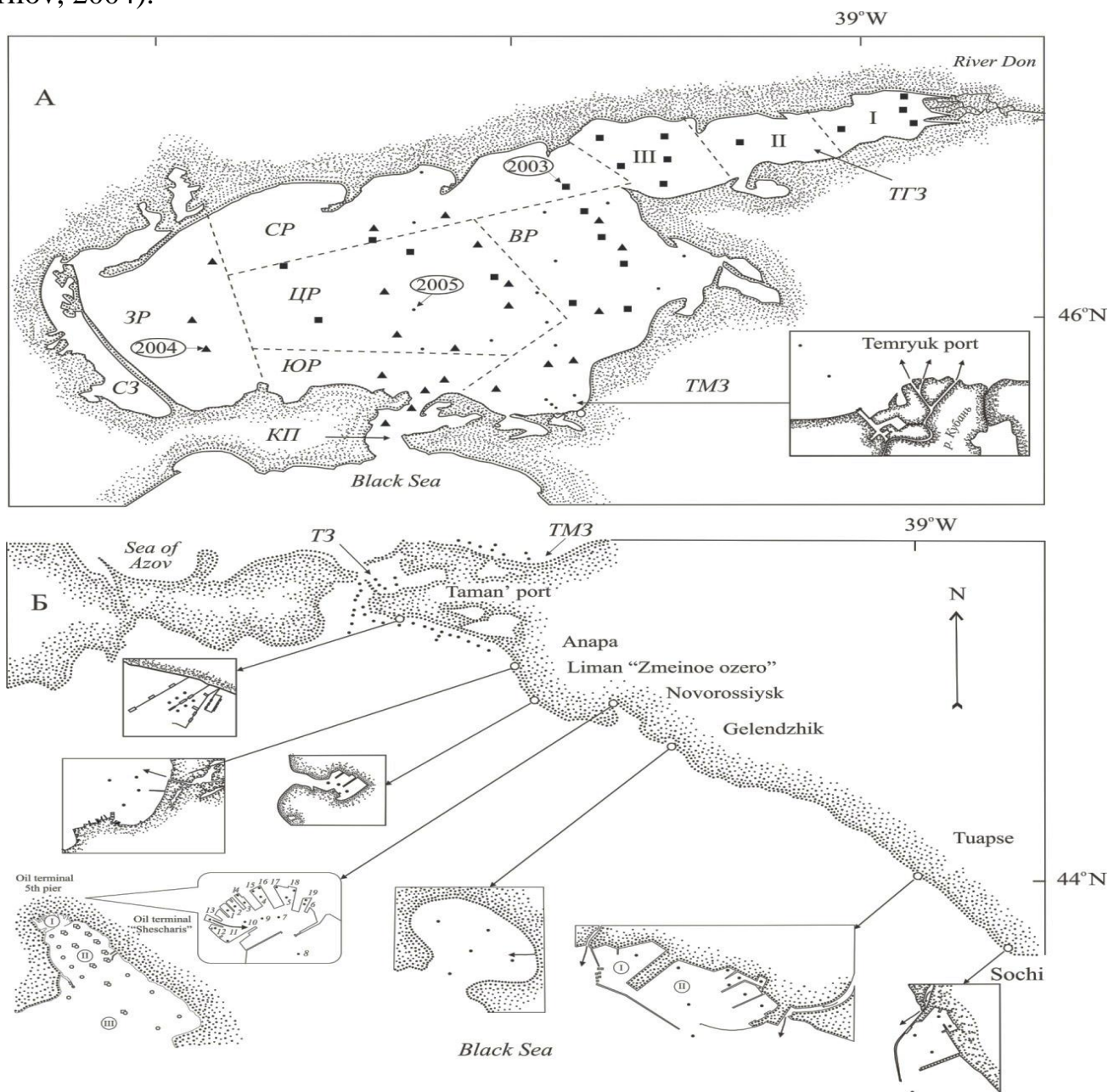


Figure 1 – A – Scheme of sampling of zooplankton in the Sea of Azov. Areas of investigation: CP – northern, BP – east, ЦР – central, IOP – southern, 3P – western, TT3 – the Taganrog Gulf, TM3 – the Temryuk Gulf, T3 – the Taman' Bay, KII – the Kerch' Strait, C3 – the Sivash Gulf.

Б – Scheme of sampling of zooplankton in coastal waters of the Taman' peninsula and the northeastern Black Sea. the Novorossiysk Bay: I – the port (insertion) The stations of sampling of holoplankton and meroplankton are designated by circles (2005 г.) and squares (2004–2011). 1–8 – planktonic stations, 1–19 – benthic stations, 11–19 – stations located near sewer outlet; the Tuapse port: I – old port, II – new port

Holoplankton and meroplankton (crustaceans, larvae of benthic organisms, rotifers and others organisms  $> 200\text{--}500\ \mu\text{m}$ ) was sampled throughout the water column using a medium-sized Juday net with an opening diameter of 25 cm (mesh size  $120\ \mu\text{m}$ ) by total catch. The material was fixed by 2–4% neutral formaldehyde and processed in the laboratory by the conventional procedure. The abundance of zooplankton was calculated taking into account

the catching efficiency of net (net/ bathometer coefficient) (Pavel'eva, Sorokin, 1972; Shushkina and Vinogradov, 2002). Calibration of nets was carried out with use of 12 plastic of 5 liter Niskin bathometers (hydrophysical Rosette complex and sonde of "Sea Bird-19" of firm Sea-Bird Electronics, Inc., the USA) in the 82/83 and 120 cruises of scientific vessel "Akvanavt" (Selifonova, Yasakova, 2012). Bathometers closed through each 3–5 m. Collected samples filtered through 40 micron filter. At the same time on same horizons we collected zooplankton layerwise with the use of medium and major Juday nets (mesh size 100, 120 and 150  $\mu\text{m}$ ). The nets were closed by means of a compact lock designed by N.V. Yasakov (Yasakova, Selifonova, 2007) and Nansen's lock. In particular, the coefficient was accepted equal 1.5–2 for a net with mesh size 120  $\mu\text{m}$ , for organisms < 200  $\mu\text{m}$  – equal 10. Calculations of biomass were made using Petipa's (1957) tables (Mordukhay-Boltovskoy, 1954; Chislenko, 1968). The fish eggs and larvae were sampled using Bogorov–Rass net (80/114 cm, mesh size 500  $\mu\text{m}$ , mouth area 0.5 m) and horizontal 10 min trawling using MNT net (Modern methods ..., 1983).

Samples of zoobenthos and mud bottom sediments for analyze for sulfides were collected by Petersen grab (aperture 0.04 m<sup>2</sup>). Benthic animals were filtered through a sieve (mesh size 500  $\mu\text{m}$ ). Index of density of zoobenthos counted on a formula  $\sqrt{R \times B}$ , where R – occurrence frequency, B – biomass. Cameral treatment was made using a paper (Guide ..., 1983).

The inhabitants of ballast waters of commercial ships were researched using of an original techniques of author (Selifonova, 2010a; 2011f). Primary production of macrophytes was defined by an oxygen method (Vinberg, 1969). Samples of water with alga were selected in light calibrated capacities of 1.5 l and were exhibited at the experimental pool in the conditions *in situ* (illumination and temperature). The oxygen was measured by Vinkler's method.

The approximate biotic balance and functional parameters of ecosystem were calculated according to Yu.I.Sorokin (Sorokin, 1999) with the use to necessary published data on phytoplankton, combjelly (ctenophores) and zoobenthos. The fish biomass was calculated according to the known ratio between fish production and catches (Sorokin, 1982). The necessary coefficients of specific production per day ( $P/B$ ), efficiency of use of assimilated food for growth ( $K_2$ ), assimilability of consumed food ( $U$ ), and caloric equivalents of the wet biomass of major components of ecosystem were acquired from the literature. These values were used to construct energy flow model between main components of communities (phytoplankton, bacteria, zooflagellates, ciliates, holoplankton, meroplankton, ctenophores, zoobenthos, fishes) and environments, taking into account both the energy of allochthonous organic matter (OM) and losses of organic matter due to sedimentation.

The specificity of taxonomical composition of holoplankton in studied areas was revealed by method of many-dimensional scaling (MDS analysis) (Clarke, Warwick, 1994). The estimate of species variety was performed on Shannon's index. Differentiation of faunistic groups on quantitative development of individuals organisms was carried out using of the cluster analysis. Material was processed by means of a package of applied programs for the analysis of biological data (PAST).

## Chapter 2. TAXONOMICAL COMPOSITION AND SPATIAL STRUCTURE OF MAIN ELEMENTS OF COASTAL ECOSYSTEM OF THE NORTHEASTERN BLACK SEA

### 2.1. Heterotrophic bacteria, zooplankton, ciliates

**Heterotrophic bacteria.** The high density and biomass of bacteria were recorded in the investigated bays and ports (Selifonova, 2014b). In waters of the port of Novorossiysk the average abundance ranged from 3.5 to 4.7 million cells/ml and biomass ranged from 0.63 to 0.94 g/m<sup>3</sup>. Beyond the port area, these values were two times lower. The maximal values of abundance and biomass were recorded in summer and at the beginning of autumn. The rise of water temperature led to an increase of number of microbial populations up to 7.5–8.6 million cell/mL (biomass up to 1.5–2.0 g/m<sup>3</sup>).

In corners of port with subjected to strong pollution by coastal runoff, the maximal abundance of bacterioplankton could reach 12 million cells/ml. Chainlike and filamentous forms of bacteria and bacteria in the composition of detritus particles and aggregates made a significant contribution to biomass. Significant fluctuations of bacterial biomass were marked ( $B_{max}/B_{min} = 4.5$ ).

At the port of Tuapse, the average abundance of heterotrophic bacterioplankton was 2.0–2.7 million cells/ml in 2009 and 2010 and 3.2 million cells/ml – in 2011. The biomass fluctuations was 0.42–0.47 g/m<sup>3</sup> and 0.54 g/m<sup>3</sup>, respectively. The abundance and biomass of bacteria in the port area were 1.4 times higher than in its open part. During the summer peak, the bacterial density was 4.8–7.0 million cells/ml. At near the sites of coastal runoff, the maximal abundance of bacteria reached 8.2–14.5 million cells/ml and biomass reached 1.2–1.5 g/m<sup>3</sup>. The share of the bacterial microflora abundance in detritus particles and aggregates was 60–70%.

Annual number of bacterioplankton at the Liman “Zmeinoye ozero” averaged 2.1 million cells/mL and 0.46 g/m<sup>3</sup>. The bacteria in microcolonies and detritus particles contributed to 71.5% of their abundance. In August – September the number of bacteria increased to the level of eutrophic waters 3.1–4.78 million cells/ml, биомасса – 0.64–0.85 g/m<sup>3</sup>.

Annual dynamics of the heterotrophic bacteria abundance in regions of the resort cities differed from the port areas; the record high density of the bacterial population was observed during the abnormally warm year of 2010 in the recreational zones. Average values of abundance in the Gelendzhik Bay varied from 2.8–3.8 million cells/ml in 2005, 2006, and 2011 to 7.1 million cells/mL in 2010; biomass varied from 0.5–0.7 g/m<sup>3</sup> up to 1.45 g/m<sup>3</sup>; and in Anapa Bay the abundance varied from 2.8–3.1 million cells/mL in 2006 and 2011 up to 8.6 million cells/mL in 2010 and biomass varied from 0.5–0.58 g/m<sup>3</sup> to 2.1 g/m<sup>3</sup>, respectively. In August 2010 at a water temperature of 29.2–29.5°C, parameters of the bacterial population corresponded to the level of hypereutrophic waters (12.7–14.2 million cells/ml; biomass 2.4–3.6 g/m<sup>3</sup>). These values were maximal for the coastal zone of the northeastern shelf. The abundance and biomass of

bacteria were high until September and constituted 7.9–10.2 million cells/ml and 1.4–2.4 g/m<sup>3</sup>. Chainlike and filamentous bacteria contributed to 57–65% of their biomass. In some parts near the Su-Aran (Gelendzhik) and Anapka rivers, the biomass of filamentous bacteria exceeded the biomass of bacilli and cocci.

Average values of the biomass of bacteria in the ports of Novorossiysk and Tuapse were twice as large as values obtained 10–15 years ago. (Selifonova, 2000; Selifonova et al., 2001). Dynamics of the abundance and biomass of bacterioplankton in the Gelendzhik Bay subjected to the load of coastal runoff demonstrate the same tendency to increase.

Over the past years, the rise of water temperatures in the northeastern part of the Black Sea increased the abundance of the bacterial population. Thus, in summer the maximal biomass of bacteria reached 1.3–1.7 g/m<sup>3</sup> (at the average values 1.07 g/m<sup>3</sup>) in the port of Novorossiysk and 0.7–1.0 g/m<sup>3</sup> (at the average values 0.8 g/m<sup>3</sup>) in the port of Tuapse. Waters in the port cities can be regarded as eutrophic–hypertrophic in terms of biomass values. The total development of the bacterial population in waters of the health resort cities of Gelendzhik and Anapa corresponded to the level of hypereutrophic waters 3.6–3.9 g/m<sup>3</sup> (at average values of 1.3 g/m<sup>3</sup>).

**Zooflagellates.** At the ports and bays of the northeast shelf of the Black Sea 10 taxonomical forms are identified. An increase in abundance of bicosoecids and kinetoplastids was recorded in summer and at the beginning of autumn; the abundance of choanoflagellates increased in spring. In the port of Novorossiysk and Gelendzhik Bay, representatives of the genera *Bodo*, *Parabodo*, and *Monas* were numerous (75–82% of the total abundance). They were represented by relatively small (<2–3 μm to 68–75% of the total abundance) and larger forms (3–5 μm to 25–32% of the total abundance). When water warmed up, small kinetoplastids almost completely replaced other representatives of zooflagellates. In partially isolated areas, the level of zooflagellate development was higher than in the open areas. In the port of Novorossiysk, their average abundance was 2.5–2.8 billion ind/m<sup>3</sup> in 2006 and 2007 and 4.65 billion ind/m<sup>3</sup> in 2011, which was 1.5 times larger than in the open part; in Gelendzhik Bay the average abundance was 1.4–2.5 billion ind/m<sup>3</sup> in 2005, 2006, and 2011 and 4.4 billion ind/m<sup>3</sup> in 2010; lion ind/m<sup>3</sup> in 2006 and 2011 and 2.3 billion ind/m<sup>3</sup> in 2010. The maximal abundance of zooflagellates in the port of Novorossiysk reached 4.1–9.7 billion ind/m<sup>3</sup> (biomass 0.4–0.45 g/m<sup>3</sup>); in Gelendzhik Bay the maximal abundance was 4.1–6.2 billion ind/m<sup>3</sup> (0.2–0.37 g/m<sup>3</sup>). In the open Anapa Bay, values of abundance and biomass of zooflagellates were the lowest and constituted 3.0–3.9 billion ind/m<sup>3</sup> (0.07–0.09 g/m<sup>3</sup>). Compared to 1990 (Selifonova, 2001), the biomass of zooflagellates increased twice in the port of Novorossiysk and 3.5 times in the Gelendzhik Bay according to the data obtained at the end of the 1970s (Moiseev, 1983). Peaks of the bacteria abundance are usually followed by an increase in the zooflagellate abundance. The share of zooflagellates in total biomass of protozoan was 24%.

**Infusorians.** Ciliatoplankton in coastal waters of the northeastern shelf of the Black Sea was represented by 54 taxonomical forms, 17 of which were tintinnids. 31 taxonomical forms of planktonic infusorians not mentioned previously for the region (Mamaeva, 1980; 1983).

The largest number of taxonomical forms, 54 (17 tintinnids), were recorded in the Novorossiysk Bay; 46 (14) forms were found in the port of Tuapse; 40 (14) – the Liman “Zmeinoe ozero”, and 36 (11), and 43 (6) were found in the Gelendzhik bay and the Anapa bay, respectively; and 26 (2), and 37 (9) – the ports of Taman’ and Sochi respectively; 20 (4) – the Kerch’ Strait. Naked forms dominated in plankton and reached on the average 75–95% of ciliatocenosis abundance. The complex of dominant species included *Mesodinium rubrum*, *Mesodinium pulex*, *Strombidium conicum*, *S. emergens*, *S. vestitum*, *S. dalum*, *Foissneridium constrictum*, *Pelagostrobilidium spirale*, *Tiarina fusus*, *Tontonia appendiculariformis* и *Urotricha* sp. Along with these species, *Laboea strobila* prevailed in the Gelendzhik Bay. In water of the Liman “Zmeinoe ozero”, a naked form of the infusorians *Holophrya pelagica*, *Lohmaniella oviformis*, *S. conicoides*, *Pelagostrobilidium spirale*, *M. rubrum*, *S. vestitum*, *Urotricha pelagica*, *Uronema marina* was a mass species; the Kerch’ Strait – *Urotricha* sp., *M. rubrum*, *S. conicoides*, *S. emergens*, *S. vestitum*; the ports of Taman’ – *Holophrya*, *T. fusus*, *L. strobila*, *S. conicoides*, *S. emergens*, *S. vestitum*, *S. conicum*, *T. appendiculariformis*. The taxonomical composition of naked ciliates in more desalinated areas was comparable to the composition obtained in of coastal waters of the northwestern part of the Black Sea (Kurilov, 2010). Tintinnids *Tintinnopsis directa*, *T. minuta*, *T. beroidea*, *T. tubulosa*, *T. campanula* и *Favella ehrenbergii* were established at the subdominant level. The abundant development of Tintinnids was recorded, as a rule, in a warm period of the year (10–25%; the maximum 40% of the total abundance of infusorians). Their share during the period of mass development was  $\leq 10$ –15% in the Gelendzhik Bay and in the open part of the port of Tuapse. *Tintinnopsis minuta*, *T. campanula*, *T. tubulosa*, and *Favella ehrenbergii* prevailed. In the Anapa Bay the abundance of tintinnids did not exceed 5% and only two species (*Tintinnopsis minuta* and *Favella ehrenbergii*) were mass ones.

In autumn 2010, alien species *Tintinnopsis tocaninensis* with the abundance of 0.3–5.5 thousand ind/m<sup>3</sup> was detected in areas of commercial ports. Together with this species, *Amphorellopsis acuta* developed in the Novorossiysk Bay. Its abundance was 5.5 thousand ind/m<sup>3</sup>. In October 2011 the number of *A. acuta* in the region increased to 0.25 million ind/m<sup>3</sup>, and the number of *Tintinnopsis tocaninensis* increased to 0.34 million ind/m<sup>3</sup>. At the Liman “Zmeinoe ozero”, density of alien species tintinnids *Tintinnopsis directa*, *T. tocaninensis*, *Eutintinnus tubulosus*, *Amphorellopsis acuta*, *Salpingella* sp. was maximal for the coastal zone of the northeastern shelf from the late summer to the beginning autumn 2010–2011. These values were two to eight times higher than in the water of the port of Novorossiysk. Maximal density of *T. tocaninensis* reached 2.1 million ind/m<sup>3</sup>, *T. directa* – 1.3 million ind/m<sup>3</sup>, *A. acuta* – 0.9 million ind/m<sup>3</sup>, *E. tubulosus* – 0.4 million ind/m<sup>3</sup>, *Salpingella* sp. – 0.4 million ind/m<sup>3</sup>.

Average long-term values of the infusorian density in water of the port of Novorossiysk constituted 70.6 million ind/m<sup>3</sup> (biomass 0.48 g/m<sup>3</sup>); in the open part the values were twice as low and constituted 31.4 million ind/m<sup>3</sup> (0.25 g/m<sup>3</sup>). The maximum development of infusorians was recorded in summer–autumn. In June 2009 and October 2011 the biomass increased to 1.2–1.3 g/m<sup>3</sup> and corresponded to the level of highly eutrophic waters. In the

area of the port of Tuapse, where accidental spills of oil products often occur, the density and biomass of infusorians were 3–4 times lower than in the port of Novorossiysk and constituted 15 million ind./m<sup>3</sup> and 0.16 g/m<sup>3</sup>, respectively. Outside the port area, the abundance of infusorians was comparable to their abundance in the open part of the port of Novorossiysk and biomass was twice as large. Three peaks in the dynamics of biomass were registered in spring, summer, and autumn (0.5–0.7 g/m<sup>3</sup>).

In the Gelendzhik Bay the density of infusorians reached 65.7 million ind./m<sup>3</sup> and biomass was 0.28 g/m<sup>3</sup>; in the open Anapa Bay the density of infusorians was 31.1 million ind./m<sup>3</sup> and the biomass was 0.1 g/m<sup>3</sup>. Over the past 2 years the abundance of infusorians increased 3–4 times in water areas of the resort cities. In summer and autumn, the maximal biomass was 0.5–0.7 g/m<sup>3</sup> in the area of the city of Gelendzhik and 0.13–0.3 g/m<sup>3</sup> in the area of the city of Anapa.

In the Liman “Zmeinoye ozero” density of infusorian averaged 18.4 million ind./m<sup>3</sup>, biomass 0.35 g/m<sup>3</sup> and reached maximal abundance in August up to 46.1 million ind./m<sup>3</sup>, biomass 0.82 g/m<sup>3</sup> (Selifonova, 2015). Minimal values were registered in the open Taman’ port – 7.4 million ind./m<sup>3</sup>, biomass 0.12 g/m<sup>3</sup> (in August max – 14.0 million ind./m<sup>3</sup>, 0.21 g/m<sup>3</sup>).

The quantified development of infusorians population corresponded to the level of trophic waters. The reaction of infusorians to a stress was defined in increase of number of small species of oligotrichids. The increase in the infusorians biomass occurred simultaneously with the development of heterotrophic bacteria (from June to the beginning of September). The level of heterotrophic microorganisms correlated with the density of nanoplanktonic oligotrichids. The infusorians density are regulated on one side by the availability of trophic resources (“bottom up” control) and on the other side by the press of consumers (“top down” control). The biomass of naked ciliates in investigated areas was 1.5 times lower than the maximal values, which were recorded in highly polluted zones of sea bays of the northeastern shelf (Mamaeva, 1994; Selifonova, 2001). Apparently, the predator press and extremely high rates of metabolism led to a decrease in infusorian development. At the studied ecosystem processes of autotrophic production and heterotrophic destruction were balanced. It should be mentioned that values of the abundance of infusorians in the open parts of water areas near the bays and ports of Novorossiysk and Tuapse and Taman’ and Anapa were comparable to the values obtained in the northwestern part of the Black Sea in 1999–2000 (Kurilov, 2006).

## 2.2. Holoplankton.

Totally, 35 taxonomical forms were found in the holoplankton at the northeastern shelf of the Black Sea, including 20 – Copepoda, 4 – Cladocera, 6 – Rotifera, 2 – Ctenophora, 1 – Dinophyceae (*Noctiluca scintillans*), 1 – Chaetognatha, 1 – Appendicularia (*Oikopleura dioica*) (Selifonova, 2012e, 2014a). The highest number of species were revealed in the Novorossiysk Bay (30 taxonomical forms), Tuapse harbor (24), the Anapa Bay – 29, the Gelendzhik Bay – 26, the port of Sochi – 16, the Liman “Zmeinoe ozero” and the port of Taman’ – 15 (in each), the Kerch strait – 22.

In the harbor area of the port of Novorossiysk, the quantity of food organisms (without noctiluca, ctenophores, rotifers synchaetes) averages 24.5 thousand ind./m<sup>3</sup>, biomass – 0.29 g/m<sup>3</sup>, and that outside the harbor, these parameters were averaged 1.8 time higher – 0.5 g/m<sup>3</sup>. The holoplankton reached 67–77% of sum zooplankton number on the harbor water, outside the harbor – 73–88%. Its maximum biomass is noted in the summer – in an early autumn in waters of port (0.4–0.8 g/m<sup>3</sup>) and outside the port (0.8–2.0 g/m<sup>3</sup>).

Two groups of communities are allocated in zooplankton of bays: 1) the communities of open waters wherein oligotrophic forms of crustacean prevailed *Pseudocalanus elongatus*, *Calanus euxinus*, *Paracalanus parvus*, *Centropages ponticus*, *Acartia clausi*, *Oithona similis* (Copepoda), *Penilia avirostris*, *Pseudevadne tergestina*, *Evadne spinifera* (Cladocera), Parasagitta, Appendicularia. 2) the communities of the rich detritus port waters. These communities consisted mainly of organisms sustainable against high content of OM – the neritic forms of crustacean *Acartia tonsa*, *Oithona davisae*, *Pleopis polyphemoides*, meroplankton, rotifers.

Climatic features of the last years (the anomalously hot summer – the early autumn) and earlier appearance in plankton of comb jelly of *Beroe ovata* have led to increase of abundance of holoplankton. In seasonal dynamics of the most numerous taxocoenosis of copepods the winter-and-spring peak of abundance and the summer-and-autumn peak of abundance are registered. The first peak was caused by cold water species *P. elongatus*, *C. euxinus* and eurythermic species *A. clausi*, more considerable second peak – thermophilic species *C. ponticus*, *A. tonsa*, *O. davisae* and eurythermic species *P. parvus*. The lowest indicators of copepod abundance and holoplankton are noted in April – the early July, i.e. during the reproduction periods of rotifers, Noctiluca and a predatory ctenophore *M. leidyi*. As part of Copepoda, the genus *Acartia* is most abundant: in the port waters (81–91%), in open part (34.6–63%). Reproduction of *A. clausi* had happened for a year except one or two months (August-September). Population of *A. tonsa* had existed in plankton from June to November. Since the late June *A. tonsa* outnumbered *A. clausi* (> 60%), reaching a peak in development in July-September (24–26 thousand ind./m<sup>3</sup> in port, 6–8 thousand ind/m<sup>3</sup> in open part). Beginning with 2010, the population of recent invader of *O. davisae* completely dominated in the holoplankton from the late August to December, composing 80–85% of total quantity. In September, the maximum number of species in waters of port reached 30 thousand ind/m<sup>3</sup>,



outside the port – 17 thousand ind/m<sup>3</sup>. The peaks of cladoceran number *P. polyphemoides* and *P. avirostris* alternated: in May – the early June a number of *P. polyphemoides* increased, in August-September – of *P. avirostris*. In 2007 against the background of increase of temperature of water was noted unusual development of *P. polyphemoides* that 30 times exceeded of abundance in former years. In open part of bay, the increase of number of *P. avirostris* was recorded. In waters of the port, the long-term average values of number of rotifers *Synchaeta* sp. were twice time higher than in the open part. In May-June their maximum number in waters of port reached up to 200–300 thousand ind/m<sup>3</sup>. In May-July the number of *N. scintillans* was 30–60 thousand ind/m<sup>3</sup>. Since 2006 this species has begun to appear in the samples less often. In anomalous warm years (2008–2010) was registered the lowest development of Noctiluca. In open part in September and June the quantity of appendicularia *Oikopleura dioica* has increased up to 1.3 thousand ind/m<sup>3</sup>, the predatory *Parasagitta setosa* in October-November – 3.3–14 thousand ind/m<sup>3</sup>. Biomass of *Parasagitta* reached 0.3–1.7 g/m<sup>3</sup>.

The value of long-time annual average number of holoplankton in waters of the Tuapse port was two times lower, than in the Novorossiysk port. In open part holoplankton organisms composed 80% of total number of zooplankton, in the port waters – 65%. In 2009 the increase of quantity of holoplankton was noted both in port, and outside the port (20–47 thousand ind/m<sup>3</sup>, biomass of 0.25–0.7 g/m<sup>3</sup>) at preservation of lowest parameters in the port zone polluted by oil. Oil pollution of habitat was adverse for vital functions of oligotrophic species of crustaceans, and appendicularia and parasagitta. Their number was low. At the same time, in the port waters was noted the increase of number of *Synchaeta* sp. Their numerical density was maximum for the northeast shelf 623 thousand ind/m<sup>3</sup> (96–99% of total number of holoplankton).

In the open bay of Anapa resort, the value of number of holoplankton averaged 11.7 thousand ind/m<sup>3</sup>, biomass – 0.21 g/m<sup>3</sup>. In July and September its maximum number reached 31.7–37.4 thousand ind/m<sup>3</sup>, biomass – 0.7 g/m<sup>3</sup>. In this area copepods, cladocerans and rotifers developed poorly. Their abundance was lower in comparison with a half-closed gulfs and bays.

In the Gelendzhik Bay, the value of long-time annual average number of holoplankton was 19.7 thousand ind/m<sup>3</sup>, biomass 0.27 g/m<sup>3</sup>. A Number of copepods was twice time higher, than in the Anapa Bay. However in recreation zones the copepods developed poorly. At the same time the abundance of cladoceran *P. avirostris* increased three times over the past years and reached a maximum in August – 11 thousand ind/m<sup>3</sup>. The rise of number a rotifers was noted in March – 560 thousand ind/m<sup>3</sup>, *O. dioica* – in June, September and November – 1–2 thousand ind/m<sup>3</sup>. *P. setosa* contribution to abundance of holoplankton was small.

The number of holoplankton in waters of the Sochi port averaged 21.3 thousand ind/m<sup>3</sup>, biomass – 0.18 g/m<sup>3</sup>; outside the port – 17.8 thousand ind/m<sup>3</sup>, biomass of 0.16 g/m<sup>3</sup>. A low development of *P. setosa*, *O. dioica* and *N. scintillans* was noted. The maximum number of rotifers reached 121.1 thousand ind/m<sup>3</sup> in the spring. In November, 2012 at temperature increase of water to 20 °C was registered an expressed peak of density of holoplankton (54–62.2 thousand

ind/m<sup>3</sup> at biomass of 0.4-0.5 g/m<sup>3</sup>). Copepods of *P. parvus*, *C. ponticus* have been plentifully presented in the holoplankton, especially population of *A. clausi* which in open part reached a maximum of the number of 47 thousand ind/m<sup>3</sup>.

Low indicators of abundance of holoplankton are noted in waters of the Taman' port and the Liman "Zmeinoe ozero". In waters of the Taman' port holoplankton composed 70% of total number of zooplankton, and its average number – 6.5 thousand ind/m<sup>3</sup>, biomass of 0.06 g/m<sup>3</sup>. The highest development of holoplankton is revealed in August. At that time in plankton of port, the population of *A. tonsa* prevailed 6.2 thousand ind/m<sup>3</sup> (73.4% of total number of holoplankton).

In Liman "Zmeinoe ozero" the number of holoplankton averaged 4.2 thousand ind/m<sup>3</sup>, biomass of 0.06 g/m<sup>3</sup>. Cladoceran in waters of the Liman were absent. The decline in development of holoplankton was noted in November, May, the increase – in September (31.3 thousand ind/m<sup>3</sup>) during a outburst of development of population of *O. davisae* (85% of total quantity of zooplankton).

In the Taman' Gulf in July, the number of holoplankton reached 28.3 thousand ind/m<sup>3</sup> (54.5% of total number of zooplankton). A population of *A. tonsa* was dominated (26.6 thousand ind/m<sup>3</sup>).

At area of the spit Tuzla – the cape Panagia, the number of holoplankton was 3.5 times lower (8.5 thousand ind/m<sup>3</sup>, biomass – 0.14 g/m<sup>3</sup>). Share of *A. tonsa* in the total number of holoplankton was high – 83%. At the Taman' Prichernomor'e (coast of the Black Sea) large cladoceran *P. avirostris* contributed up to 83% of total number of holoplankton.

Near the Bugaz liman the population of *P. avirostris* formed an aggregations to 14–19 thousand ind/m<sup>3</sup>, biomass of 0.5-0.7 g/m<sup>3</sup>, *E. spinifera* – 0.7 thousand ind/m<sup>3</sup>. Totally, the biomass of holoplankton reached high values 0.7 g/m<sup>3</sup> and number 15.4 thousand ind/m<sup>3</sup>.

**Main feature of seasonal succession of holoplankton of coastal waters of the northeastern Black Sea on example of the Novorossiysk Bay.** Spring development of holoplankton of coastal waters was defined by "blossoming" phytoplankton. In the following we observed the reproduction of a large cold water copepods *C. euxinus*, *P. elongatus* and the eurythermic *A. clausi* and *P. parvus*. Intensive of development of rotifers Synchaets, heterotrophs dinophytes algae of *N. scintillans* has been noted at the end of March – the beginning of April. These organisms are capable to increase a biomass rapidly. Their high quantity is a reaction to content in water of a detritus and digestible OM. At this time, we observed the regress in development of copepods. At the end of May, the sharp raising of number of *P. polyphemoides* (Cladocera), *A. clausi*, *P. parvus*, (Copepoda) was recorded. In a follow-up the number of thermophilic stenothermic copepods of *C. ponticus*, *A. tonsa* has increased quickly. These species are capable to give the first peak of abundance by the end of month. The balanced alternation of maxima of development of ctenophore *M. leidy*, *B. ovata* and holoplankton is typical for the current state of holoplankton. The abundance of holoplankton decreases quickly at the end of July – the beginning of August under press of zooplanktonophage of *M. leidy*. Time period of influence of a predator on holoplankton are controlled by a comb

jelly of *B. ovata*, it helps make the further reorganization of holoplankton and all pelagic ecosystem in general. For this reason in the middle of the summer the significant increase of number a copepods *A. tonsa*, *P. parvus*, *C. ponticus* can be observed. In August–September, copepods *A. tonsa*, cladocerans *P. avirostris* and, since 2010 a species invader *O. davisae* (Copepoda) reach the maximum of number. The peaks of crustaceans replace by the peaks of predatory organisms *P. setosa*. These organisms form a summer-autumn maximum of holoplankton biomass. In process of cooling of water, in the coastal waters the quantity the eurythermic copepods *A. clausi*, *P. parvus* and cold water copepods *C. euxinus*, *P. elongatus* gradually increases, the reproduction of thermophilic stenothermic copepods and cladocerans decreases.

**Analysis of long-term dynamics of holoplankton.** Positive changes in holoplankton of the Novorossiysk Bay testify to stabilization of the port ecosystem at a higher production level than in the 1990s. The present state of pelagic communities is characterized by a weaker press of predatory comb jelly *Mnemiopsis leidyi* and heterotrophic sea sparkle *Noctiluca scintillans*. Since 2002, in the Novorossiisk Bay the abundance of holoplankton have been gradually restored to the level of the 1960s and 1970s. The autumn maximum of the biomass of holoplankton is observed (0.4–0.8 g/m<sup>3</sup> in the port aquatic area and 1.8–2.0 g/m<sup>3</sup> in the open part). This peak was not noticed in the 1990s, during the peak of *Mnemiopsis leidyi* development. In summer and autumn, a multifold increase in the density of the rare oligotrophic forms of Copepoda and Cladocera *Paracalanus parvus*, *Centropages ponticus*, *Podonevadne tergestina*, *Evadne spinifera* and the common Black sea species *Pleopis polyphemoides*, acartia, sagittae and appendiculariae was recorded. In 2010, an earlier unknown autumn peak of development (30 000 ind/m<sup>3</sup>) of cyclopoid copepods *Oithona davisae* was recorded. This species was introduced into the bay via ballast waters of commercial ships,

Similar processes took place in the more polluted port of Tuapse, but the rate of their development was twice time lower. The same tendency of the summer-and-autumn increase in abundance of copepods *O. davisae*, cladoceran *P. avirostris* and appendiculariae was noted in the Anapa and Gelendzhik bays. In waters of the Sochi port over the past years, the multifold increase of a number of copepods *A. clausi*, and outside the port along with this species *P. parvus*, *C. ponticus* was registered. Such profound changes in pelagic community could happen under the effect of climatic features of the past years (positive anomalies of water temperature) and introduction in the Black Sea of a comb jelly of *B. ovata*, which controls the biomass of the zooplanktophage *M. leidyi*. Long-term changes in zooplankton biomass accompanied by the decrease in abundance and biomass of phytoplankton and its structural reorganization (Selifonova, Yasakova, 2012). Constructive changes in the holoplankton and recession in development of phytoplankton is process of a gradual weakening of an eutrophication or «de-eutrophication» of the Black Sea ecosystem observed since 2002 (Yunev et al., 2009; Zaika, 2011).

**Comparative analysis of taxonomical composition of holoplankton.** Analisis of multidimensional scaling revealed maximum similarity of the first region, which united the

ports of Novorossiysk, Tuapse, Sochi and the Liman "Zmeinoe ozero", the Taman' Gulf by the distribution of frequency of occurrence holoplankton species. Similarity of fauna is explained by physiographic and ecological features of the studied areas – the low transparency, the weak circulation of waters and their high trophic status. We have defined the Kerch Strait, the port of Taman, the Anapa Bay in a separate second region which is closer to the first region by a combination of factors. The third region included the open parts of the ports of Sochi and Tuapse, the Gelendzhik Bay and the fourth region – the open part of the Novorossiysk port, Taman' prichernomor'e. The Index of biological diversity of Shannon in half-closed port areas was lower (0.85–1.5 nit/ind) than in the open waters (1.75–2.4 nit/ind). The minimum values of an index ( $\leq 1.0$  nit/ind) were noted in the Liman "Zmeinoe ozero", the Sochi port, the Strait of Kerch' (the Gulf of Taman'). The results of similarity of taxonomical composition and numerical density of holoplankton we obtained by method of hierarchical clustering for spring – autumn. They showed the division into two groups of organisms at the level of 40% of similarity. The first group have been included Parasagitta, Cladocera, thermophilic species of copepods, such as *A. tonsa*, *O. davisae*, *C. ponticus* and year-round species *P. parvus*, *O. dioica* with similar dynamics of development in summer and autumn seasons. The cold water complex of species with the level of similarity of 75–90% have been allocated in separate group. Noctiluca and rotifers, who gave outburst of numerical density in the spring, adjoined to them.

### 2.3 Meroplankton

The meroplankton of coastal waters of the northeastern Black Sea comprised 78 taxonomical forms, including 27 taxa of Polychaeta, 4 – Cirripedia, 1 – Phoronida, 21 – Decapoda, 11 – Bivalvia, 11 – Gastropoda, and 3 – species of Hydrozoa (Selifonova, 2012a). The greatest number of taxa (67) were recorded in the Novorossiysk Bay. In the Tuapse port and the bays of Gelendzhik and Anapa we found 46, 58, and 53 species, respectively. In the Sochi port, the Kerch' Strait we recorded 23 species in each, in the Liman "Zmeinoe ozero" – 22, Taman' Prichernomor'e – 18, the Taman' port – 17. The contribution of meroplankton to the overall zooplankton density averaged 23–35% and reached more than 50% at the height of the spawning period (the Tuapse port – 15%, the Gelendzhik Bay, Taman' port – 17% in each, the Liman "Zmeinoe ozero" – 6.5%). In the plankton of coastal waters, the larvae of bottom invertebrates appeared all the year round, their specific structure and number changed on seasons. The spawning season of bottom invertebrates is confined to May–September. The spring plankton was dominated by larvae of bivalve mollusks *Mytilus galloprovincialis* and Cardiidae gen. sp.; larvae of gastropod (*Bittium reticulatum*) and bivalve (*Mitilaster lineatus*) mollusks were dominant in the summer; the autumn plankton was dominated by larvae of bivalve mollusks (*M. galloprovincialis*, *Anadara inaequalis*, and *Chamalea gallina*). Larvae of *Polydora* spp. and *Amphibalanus improvisus* constituted the bulk of the meroplankton pool from the early spring to the late autumn. The set of dominant meroplankton species in the apex parts of half-closed bays and ports consisted of the

pollution tolerant larvae of *A. improvisus*, *B. reticulatum*, *M. lineatus*, and *Polydora* spp., that indirectly testifies about the intensification of anthropogenic impact at these water areas. Among of larvae of *Polydora* spp. we distinguished two morphologically different polychaete species

*P. ciliata*, *P. cornuta*. In 2009 *P. cornuta* was found in bottom substrates of the Tuapse port for the first time, in 2011 – the Liman “Zmeinoe ozero”. In open part of the bays and ports, at the Gelendzhik Bay and the Taman’ prichernomor’e was noted high density of larvae of gastropod and bivalve mollusks and low density of larvae tolerant to pollution. A certain role in the meroplankton structure of the half-closed bays and ports is played by larvae of allochthonic origin, mostly mollusks and decapods, which were introduced with a currents. We noted the impact of temperature on the number of meroplankton. The increase of temperature of water in 2007–2010 induced sharp rise of density of a summer meroplankton to 28–30.6 thousand ind./m<sup>3</sup> at the Novorossiysk Bay and the Kerch’ strait (the Taman’ Bay). At the half-closed bays and ports, the average density of larvae ranged from 1.8 thousand ind./m<sup>3</sup> at the Liman “Zmeinoe ozero” to 18.7 thousand ind./m<sup>3</sup> at the Novorossiysk port. At open water of the Taman’ Prichernomor’e the density of the meroplankton was significant lower– 3–8.2 thousand ind./m<sup>3</sup>, excluding the Anapa Bay – 18.2 thousand ind./m<sup>3</sup>, where the hypereutrophication of the water is a cause of the absolute domination of the pollution tolerant larvae of the cirripede barnacle *A. improvisus* (56 thousand ind./m<sup>3</sup>).

**Main feature of seasonal and long-term dynamics of meroplankton on example of the Novorossiysk Bay.** The density of the meroplankton was the lowest in November–December, while its share in the zooplankton in that period did not exceed 0.016–3.1%. The winter increase in meroplankton density in February was mostly due to the larvae of the bivalve mollusks *M. galloprovincialis* and *Cardiidae* gen. sp., whose density in 2004 and 2006 ranged from 2.4 to 7.2 thousand ind./m<sup>3</sup>. In March the plankton demonstrated increased densities of larvae of polychaetes *Polydora* spp. and *Spio filicornis*, up to 400/m<sup>3</sup> and the cirripede barnacle *A. improvises*, up to 0.8 thousand ind./m<sup>3</sup>. The April fall in meroplankton abundance (down to 45/m<sup>3</sup>) corresponded to the seasonal cycle of zooplankton development in the northeastern Black Sea. The annual maximum of density of the larvae of bivalve mollusks *M. galloprovincialis* and *Cardiidae* gen. sp., 14.5 thousand ind./m<sup>3</sup>, was recorded in May 2006. In June, when the water temperature increased to 19–20°C, we recorded an increasing density of the larvae of the cirripede barnacles *A. improvisus* and *Verruca spengleri*, polychaetes of the *Polydora* spp., and the bivalve mollusk *Bittium reticulatum* in the plankton; we also observed larvae of polychaetes *Capitella capitata capitata*, *Nephtys hombergii*, *Scolelepis squamata*, *Alitta succinea*, and *Microspio mecznikowianus*. The larvae of

*A. improvisus* (12.6 thousand ind./m<sup>3</sup>) and polychaetes (10 thousand ind./m<sup>3</sup>) determined the summer peak of plankton density observed in June 2004, while the larvae of *B. reticulatum* (Gastropoda) were responsible for the peak observed in mid June of the same year (28 thousand ind./m<sup>3</sup>). In the first third of August we recorded the maximum density of the larvae of *Mytilaster lineatus* (Bivalvia), 11 thousand ind./m<sup>3</sup>, which constituted 89% of the

total zooplankton. In 2005 the summer density peak was mostly provided by the larvae of *B. reticulatum* (17 thousand ind/m<sup>3</sup>). The degree of this species domination in the total zooplankton density reached 83%. From July to late August larvae of the decapods *Diogenes pugilator*, *Upogebia pusilla*, *Pilumnus hirtellus*, *Athanas nitescens*, and *Palaemon elegans* were common in plankton. Among the latter, the most common were *D. pugilator* and *U. pusilla*, whose overall density reached 2 thousand ind/m<sup>3</sup>. In August–September we observed the larvae of polychaetes *Sabellaria taurica* and *Prionospio* spp., the gastropod mollusk *Rapana venosa*, and bivalve mollusks *Chamelea gallina* and *Anadara inaequalvis*, and the hydroid *Sarsia tubulosa* in the plankton; however, the densities of these species were rather low. In November the meroplankton mostly consisted of the larvae of bivalve mollusks *A. inaequalvis* and *M. galloprovincialis*, gastropods *Rissoa* spp., polychaetes *Polydora* spp., and the cirripede barnacle *A. improvisus*. Well-pronounced peaks of meroplankton density (several tens of thousands per m<sup>3</sup>) were recorded in June–August 2004, in May and August of 2005, and in May–June 2006. In 2007–2010 the water temperature in the Novorossiysk Bay was several degrees higher compared with the indexes of the preceding years; the year of 2010 was the warmest. In late May 2007 we recorded a striking increase in meroplankton density up to 24.5 thousand ind/m<sup>3</sup>, due to mass release of the larvae of *Polydora* spp. (12 800/m<sup>3</sup>), *A. improvisus* (5.3 thousand ind/m<sup>3</sup>) and *B. reticulatum* (3 thousand ind/m<sup>3</sup>), the larvae of the bivalve mollusks Cardiidae gen. sp. and gastropods *Nassarius reticulatus* and *Rissoa* spp. The spawning of bottom invertebrates continued up to October, when the contribution of meroplankton to the total zooplankton reached 58–65%. In the summer period, the complex of dominating species comprised *Polydora* spp., *A. improvisus*, *B. reticulatum* and *M. lineatus*; their overall density ranged from 7 to 23 thousand ind/m<sup>3</sup>. In June 2009 a significant contribution to the overall density was provided by the larvae of *A. improvisus*

(8.6 thousand ind/m<sup>3</sup>), whereas in June 2010 this was made by larvae of *B. reticulatum* (14.8 thousand ind/m<sup>3</sup>), *A. improvisus* (3.3 thousand ind/m<sup>3</sup>), *M. lineatus* (2.3 thousand ind/m<sup>3</sup>), and *Polydora* spp. (1.4 thousand ind/m<sup>3</sup>). From late August we recorded, besides the listed species, the larvae of bivalve mollusks *A. inaequalvis* and *C. gallina* and the hydroid *C. tubulosa*, while in the first third of October we observed the larvae of *A. improvisus*, *Polydora* spp., *A. inaequalvis*, and *M. galloprovincialis*.

At open parts of the Novorossiysk Bay, the larvae mollusks were the most abundant. The bivalve mollusks *M. galloprovincialis* and Cardiidae gen. sp. constituted the bulk of the meroplankton pool In May. Their maximal density in 2006–2007 reached 25.7 thousand ind./m<sup>3</sup>, the share of meroplankton to the overall zooplankton density averaged 38.9–62%. In July we observed increased concentrations of the larvae of gastropod mollusks *N. reticulatus* (7800/m<sup>3</sup>), in July *M. lineatus* (Bivalvia) – 4.7–6.9 thousand ind./m<sup>3</sup>, *B. reticulatum* (Gastropoda) – to 28 thousand ind./m<sup>3</sup>; in early September the density peak (3.6 thousand ind/m<sup>3</sup>) was provided by larvae of *A. inaequalvis* and *C. gallina* (Bivalvia).

## 2.4. Ichthyoplankton

33 taxonomical forms of fish eggs and larvae were found in the ichthyoplankton at the northeastern shelf of the Black Sea and the Kerch Strait (Selifonova, 2012d). The highest number of species were revealed in the Novorossiysk Bay (31 taxonomical forms), the Tuapse harbor (17), the Taman' Prichernomor'e, including the Taman' port (15), the Anapa Bay and the Gelendzhik Bay (14 species in each), in the Kerch Strait (9), and the Taman' Bay (3). At the harbor areas and the Kerch Strait, the eggs of migrating fish, anchovy in particular (70–92% of total ichthyoplankton abundance) prevailed; outside the harbor areas, along with anchovy (50–60%), the eggs of goatfish (*Mullus barbatus ponticus*), annular sea bream (*Diplodus annularis*), horse mackerel (*Trachurus mediterraneus ponticus*), gold sinny wrasse (*Ctenolabrus rupestris*), and corb (*Sciena umbra*) were abundant; in the waters of Taman' Prichernomor'e, eggs of anchovy (74%) and goatfish prevailed. At the resort areas the structure of dominant species was other: in the Anapa Bay the eggs of settled fish prevailed – scaldback (*Arnoglossus kessleri*; fam. Bothidae), *Scorpaena porcus* and the migrating fish – annular sea bream; in the Gelendzhik Bay – the eggs of migrating fish (anchovy, goatfish, horse mackerel, annular sea bream), in waters of the Sochi port – the eggs of goatfish.

The richest ichthyoplankton in terms of species diversity and abundance was found in the Novorossiysk Bay. Taxonomical composition revealed in 2006-2010 was comparable to the level of 2002–2003 (Bolgova, 2005). The eggs and larvae of migrating fish (goatfish, horse mackerel, sea bream) prevail in the ichthyoplankton composition at the pronounced domination of anchovy (70% of total number). Along with the above mentioned species, in the open part of the bay, the eggs of corb and goldsinny wrasse are noticeable. In the harbor area, the number of ichthyoplankton averages 10.8 ind./m<sup>2</sup> in the vertical catches, that in the horizontal averages 171.8 ind./100 m<sup>3</sup>, and that outside the harbor averages 64.6 ind./m<sup>2</sup> and 214.8 ind./100 m<sup>3</sup>, respectively. According to the data presented here, gradual recovery of spawning populations of pelagophylic fish takes place in the Novorossiysk Bay as indicated by increasing species diversity and abundance of ichthyoplankton occurring in the last decade.

In 2006–2010, the abundance of ichthyoplankton in the harbor area increased by an order on average. Presumably, in the middle of the harbor and near the western peer, where most part of the ichthyoplankton is aggregated, the active spawning of fish takes place. It is quite possible that pelagic eggs, as well as the larvae of bottom animals (meroplankton) are transported to the harbor area with water currents. Uneven distribution of meroplankton in the Novorossiysk Bay and formation of aggregations of larvae in the stagnant head part of the bay is determined by the peculiarities of water circulation. It is worth noting that, in the harbor area, 50–80% of eggs were nonviable and exhibited the developmental abnormalities, which is 2.0–2.5 times higher than that outside the harbor area. Maximal amount of dead eggs were found at their transition from developmental stage II to stage III and at the beginning of stage IV (the stage of formation of a germ band). Presumably, more favorable conditions for feeding and spawning of fish in the open part of the bay determined high density of

ichthyoplankton with maximal abundance reaching in certain months 500–700 ind./100 m<sup>3</sup> and more. In the long-term aspect, a slight decrease in the elimination of ichthyoplankton may be traced in the Novorossiysk Bay. The signs of positive trend in the survival of ichthyoplankton may reflect an increase in the fish population numbers. As assessed by indices of taxonomical composition and abundance of the ichthyoplankton, the open part of the bay corresponds to the state of the 1980s.

The dynamics of the situation in the Taman' Prichernomor'e is similar. Near the Bugaz Liman, most of the eggs exhibited no signs of developmental pathologies and the values of the abundance indices were close to those noted in the open part of the Novorossiysk Bay – 87.0 ind./m<sup>2</sup> и 233.5 ind./100 m<sup>3</sup>. The eggs of migrating commercially important fish prevailed in the ichthyoplankton: anchovy (74%) and goatfish (11.9%). The eggs and larvae of scaldback were found in noticeable amounts (2.4%). The share of larvae in the ichthyoplankton ranged from ≤9 to 14%. At the Zheleznyi Rog test area (Taman' harbor), the number of ichthyoplankton in 2010 and 2013 was 1.5 times higher above than a level of 2004 (Bolgova et al., 2005) indicating improve of the environmental conditions for the spawning populations of pelagophylic fish. However between port berths, despite the high number of ichthyoplankton – 42.3 ind./m<sup>2</sup> (in the horizontal catches – 124.1 ind./100 m) the quantity of a nonviable organisms reached 40–50%.

Despite good water turnover rate, the average number of the ichthyoplankton in the Tuapse harbor is two to three times lower and the species composition is poorer than in Novorossiysk Bay. The average number of ichthyoplankton reached on the harbor water 6.3 ind./m<sup>2</sup> и 50.7 ind./100 m<sup>3</sup>, outside the harbor – 38.0 ind./m<sup>2</sup> and 214.3 экз./100 м<sup>3</sup>. The most likely reason for low abundance of the fish eggs and larvae is chronic oil pollution of the harbor area caused by periodic spills of the oils from the underground lens. The share of dead eggs and exhibited the developmental abnormalities was on the harbor area averages 68%, outside the harbor – 52%.

Minimal values were registered in the shallow Taman' Bay (depths <5 m) where the ichthyoplankton was extremely poor in diversity (three species). At many sampling stations, fish eggs were either solitary or were absent. In the vertical catches, the eggs of only one species, anchovy, prevailed with 2–6 (1.3) ind./m<sup>2</sup>. The share of dead and abnormal eggs was 37.5%. The elimination of ichthyoplankton near the Tuzla Spit–Cape Panaghiya varied from 34.7 to 58.9%. At this area, the development of nine fish species dominated by anchovy was noted. A high proportion of dead eggs (58.9%) was noted in the deepwater zone of the Kerch Strait where transshipment of bulk cargo (mineral fertilizers, sulfur, grain, etc.) takes place. In the vertical catches the number of ichthyoplankton averages 23 ind./m<sup>2</sup>, in the horizontal averages 118.7 ind./100 m<sup>3</sup>. Sum abundance of ichthyoplankton in the coastal waters was 2.4 times lower than in the deepwater zone where mainly anchovy eggs were found.

At the health resort areas, we found 14 taxonomical form of the eggs and larvae. The eggs and larvae of migrating fish (horse mackerel, anchovy) prevail in the ichthyoplankton composition of the Sochi port at the pronounced domination of goatfish (50% of total



number). At this area, the share of larvae in the ichthyoplankton was  $\leq 0.5\%$ . In the harbor area, 45% of eggs were nonviable and exhibited the developmental abnormalities, outside the harbor – 18%. The number of ichthyoplankton in the bay averaged 11.6 ind./m<sup>2</sup> (vertical catches) and 47.6 ind./100 m<sup>3</sup> (horizontal); that outside of the harbor area was 39.3 ind./m<sup>2</sup> and 89.9 ind./100 m<sup>3</sup>, respectively. The total number of ichthyoplankton collected during horizontal 10 min trawlings in the open part of the Sochi Bay was 3.5 times lower, than 2007 near area Khosta (Goryainova et al., 2011). At the same time, the number of a rare species such as a *Liza saliens* (fam. Mugilidae) included in the Red Data Book was an order more compared to as such the open part of the Novorossiysk Bay (Studigrad, 2011).

At the Anapa Bay, the density of ichthyoplankton in the vertical catches averaged 69.7 ind./m<sup>3</sup>, in the horizontal catches – 290 ind./100 m<sup>2</sup>. The larval complex was expressed poorly ( $\leq 2\%$ ). The share of dead and abnormal eggs ranged from 6.5 to 13.9%. The abundance of fish eggs of rare species and species included in the Red Book, such as goldsinny wrasse (*Ctenolabrus rupestris*) and scaldback (*Arnoglossus kessleri*) at the Anapa Bay was the highest compared to the northeast shelf of the Black Sea. The number of the eggs of *Arnoglossus kessleri* in the horizontal catches averaged 116 ind./100<sup>3</sup>, goldsinny wrasse – 52 ind./100<sup>3</sup>. These parameters were almost an order more of the maximum values known for the northeast part (Studigrad, Bolgova, 2011). Some authors found positive dynamics of number of goldsinny wrasse in the waters of the ports of Novorossiysk, Tuapse and Sochi in comparison with the 1990<sup>th</sup> (Nadolinsky, 2004; 2006; Studigrad, Bolgova, 2011).

At the Gelendzhik Bay, we revealed a small number of species (14 taxonomical forms) and the highest density of ichthyoplankton averaged 179 ind./m<sup>3</sup> and 641.5 ind/100<sup>3</sup>. The eggs of anchovy, goatfish, annular sea bream, horse mackerel were abundant (73.6% of total ichthyoplankton abundance). In the area, the share of dead and abnormal eggs and larvae was  $\leq 11.3\text{--}12.5\%$ . The richness of the pelagic eggs and larvae of fish is determined by preserving around capes Tolsty and Tonky where the natural biotope of rocks and stones remained in the coastal area by benthic vegetation favorable for development of zoobenthos and fishes. It is quite possible the ichthyoplankton are transported to the open part with water currents. At this area, the eggs of migrating species of fish prevailed: anchovy, goatfish, horse mackerel, and annular sea bream. The eggs of the rare species of fishes *Serranus scriba* (Red Data Book) are noted in noticeable quantities. Its number was 6 times higher, than in the open part of the Novorossiysk Bay. As for other rare species of fishes such as corb (Red Data Book), the eggs and larvae this species are registered annually in the open parts of the Gelendzhik Bay and the Novorossiysk Bay with maximal abundance 20–60 ind/100<sup>3</sup>.

## **2.5. Zoobenthos and pollution of mud bottom sediments**

36 taxonomical forms of benthic invertebrates were found in the port of Novorossiysk. In the port water area, zoobenthos is represented mainly by worms highly resistant to anthropogenic pollution. There were polychaetes *Capitella capitata* and nematodes

dominated (75–95%) (Selifonova, Chasovnikov, 2013). The biocoenosis of *Capitella* was distributed on the better half of the bottom of port. *Plagiocardium papillosum* was distributed in the entry to the port and beyond the port area. The benthic biocoenosis of the port area was very poor. In 2006 and 2007, the density of zoobenthos varied from 2.5 to 12.5 thousand ind./m<sup>2</sup>, the biomass – from 0.1 to 40–60 g/m<sup>2</sup> (on average 6.4 thousand ind./m<sup>2</sup> and 9.0 g/m<sup>2</sup>, respectively). In the mud samples in close proximity to sewage outlets live representatives of macrozoobenthos were not found. The proportion of nematodes in these samples reached 80-100%. The biomass of zoobenthos near sewer outlets is extremely low, averaging 0.1 g/m<sup>2</sup> (10–20 times lower than at stations between piers).

Previous researchers have considered the impact of organic enrichment of ground on zoobenthos as the accompanying factor to pollution of bottom sediment by petroleum hydrocarbons (PH). Organic substance penetrates Novorossiysk port water area with wastes from sewer outlets and accumulates in bottom sediments containing PH. Bottom sediments in the better half of the Novorossiysk port consisted mainly of black aleurite–pelite silts smelling of hydrogen sulfide. According to (Sorokin, Burkatsky, 2007; Sorokin, Zakuskina, 2008) the content of labile (acid-soluble) sulfides in the upper layer of bottom sediments is most informative hydrochemical evaluation parameter of marine environment condition in the shallow polluted basins. In summer, the concentration of sulfides in the upper layer of bottom sediments of the Novorossiysk port varied from 80 to 1980 mg S/dm<sup>3</sup> wet silt depending on proximity to the sources of pollution, such as the city and port sewage. The excess values of sulfides (above 600 mg S/dm<sup>3</sup> of wet silt) were found at stations between piers near sewer outlets. The maximal concentrations 1620–1980 mg S/dm<sup>3</sup> of wet silt were noted at the areas adjacent to sewer outlets. Sulfide content in these areas reached highest values ever registered in zones of intensive pollution of marine bays by city sewage (Sorokin, Zakuskina, 2008). The concentrations of PH (1.38–2.35 mg/g) in the mud bottom sediments of port exceeded the permissible level. These values were 28 to 47 times higher than the criteria of Neue Niederlandische Liste (Selifonova, Chasovnikov, 2013). However correlation between the level of the biomass of zoobenthos and the concentration of PH in bottom sediments was not found. High concentration of PH was observed not only on areas of almost lifeless silt near sewerage (to 3–6.87 mg/g) but also between the piers (1.0–2.28 mg/g), in the center of the port (1.1–1.96 mg/g) where biomass of benthic animals was sufficiently high. According to Petrov's (2000) scale of organic matter enrichment of bottom sediments, the Novorossiysk port water area is characterized by a high level of eutrophication (grade IV). This is shown by the high intensity of sulfate reduction in bottom sediments as well as from the decline in quantitative parameters of benthic macrofauna and dominance of most pollution tolerant species of polychaetes and nematodes in communities.

In the port of Tuapse 22 taxonomical forms of benthic invertebrates were found. The benthic fauna of the Tuapse port was poorer in comparison with the Novorossiysk port. The biomass of zoobenthos in 2009–2010 averaged 1.9 thousand ind./m<sup>2</sup>, density 6.5 g/m<sup>2</sup>. The main component of community is polychaetes, nematodes and oligochaetes. Three

communities of tolerant to pollution polychaetes were defined *Heteromastus*, *Capitella*, *Nephtys*.

The sampling in the port of Tuapse was made at the distance from the zones of coastal sewage. In 2009–2010 the concentrations of PH in port averaged 2.08–2.73 mg/g. These values exceeded 42–55 time the permissible level (1.3 higher than the indexes of the port of Novorossiysk). Maximal concentrations of PH noted at the half-closed station 1 (14.8–16.3 mg/g). At station 5 regular dredging works Herefore, despite the chronic emergency oil spill in the area oil content was low (1.8–3.5 mg/g). In winter the concentration of sulfides in the port of Tuapse varied from 220 to 940 mgS/dm<sup>3</sup> of wet silt. Their high values (640–940 mgS/dm<sup>3</sup>) were noted at the stations exposed to direct organic pollution. The excess values of sulfides are registered at station 5, where the zoobenthos biomass was  $\leq 1.9$  g/m<sup>2</sup>. In autumn the concentration of sulfides varied from 172 to 860 mgS/dm<sup>3</sup> of wet silt. Maximal concentration of sulfides (835–860 mgS/dm<sup>3</sup>) was registered at station 1. In summer and autumn, the zoobenthos biomass in this area was extremely low, ranging from 0.4 to 0.6 g/m<sup>2</sup>. Beyond the zone of direct pollution impact, the content of sulfides depended on sediment character. In the better half of port of their amount it didn't exceed 345–365 mgS/dm<sup>3</sup>.

The data obtained by the author show that, the accumulation of labile sulfides in the upper layer of bottom sediments in the port areas of Novorossiysk and Tuapse is dangerous environmental consequence of anthropogenic pollution, which causes degradation of benthic biocoenoses. The concentration of sulfide more than 600 mg/ dm<sup>3</sup> of wet silt leads to the elimination of macrozoobenthos.

### Chapter 3. INVESTIGATION OF SHIPS' BALLAST WATER AND MONITORING OF BIOLOGICAL INVASIONS ON COAST WATERS OF THE NORTHEASTERN BLACK SEA

**Investigation of ships' ballast water in the Novorossiysk port.** The water salinity ranged from 17.7‰ to 25.9‰ in the ballast tanks that arrived in the Novorossiysk port in 2004–2006 and 2009–2010 for loading by petroleum (Selifonova, 2009a; 2010a; 2011f; Zvyagintsev, Selifonova, 2010). Larvae of euphausiids in the calyptopis II and furcilia I stages, the larvae of Black Sea alien polychaetes of the Spionidae family with unusual morphologies, larvae polychaetes *Polydora cornuta*, holoplankton polychaetes and the larvae of alien bivalve belonging to the Cardiidae family, the larvae of gigantic oyster *Crassostrea gigas*, the unusual for the Black Sea copepods (19 taxonomical form) and tintinnid infusorians (7 taxonomical form) were found (figure 2)

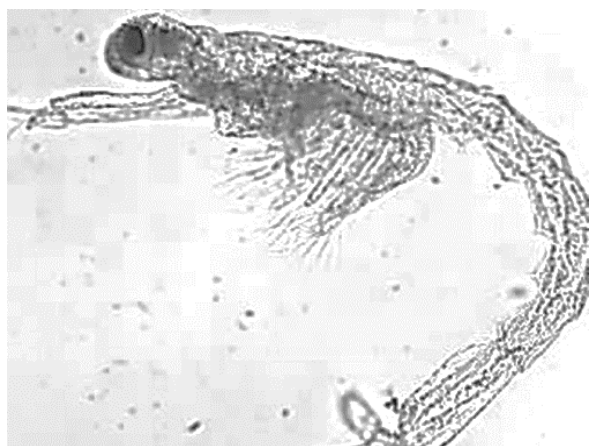


Figure 2 – Larvae euphausiids in the furcilia I stages from water ballast

The zooplankton density varied from 1.3 up to 60 thousand ind./m<sup>3</sup>. We recorded, that the *Prosky* tanker dumped more than 85 million meroplankton at one time in the bay. In "live" samples of ballast waters is noted the high number of planktonic aloricate infusorians belonging to the Strombidiidae family and *Mesodinium rubrum* – 17.6–116 million ind./m<sup>3</sup>, that testified about considerable pollution of waters of donor-port. The parameters of the bacterial density and biomass in the waters ballast of some tankers corresponded to the level of eutrophic waters (4.7–7.5 million cells/mL). In total, 381 samples were taken. The international technique of research of ship ballast waters was adapted for local conditions. A technique of control of ships' ballast water included the investigation of ship ballast waters (determination of the salinity and the taxonomical composition, density of hydrobionts) and ecosystem monitoring of the bay area (study of the plankton, benthos, and ichthyofauna), with subsequent assessment of the risk of invasive species. It has been established, that the risk of invasion of species from the Mediterranean Sea is the most probable. From this region into the Novorossiysk Bay comes 62% of the ships' ballast water.

The key "risk groups" of bioinvasion are tintinnids and copepods and polychaetes. The investigation of ships' water ballast and the inspection of ship documentation «Ballast' water reporting form» have led to an increase of the number of ships, which have taken measures

on water ballast management. In this period the replacement of water ballast in the open Black Sea was implemented on 70–90% of tankers (figure 3).

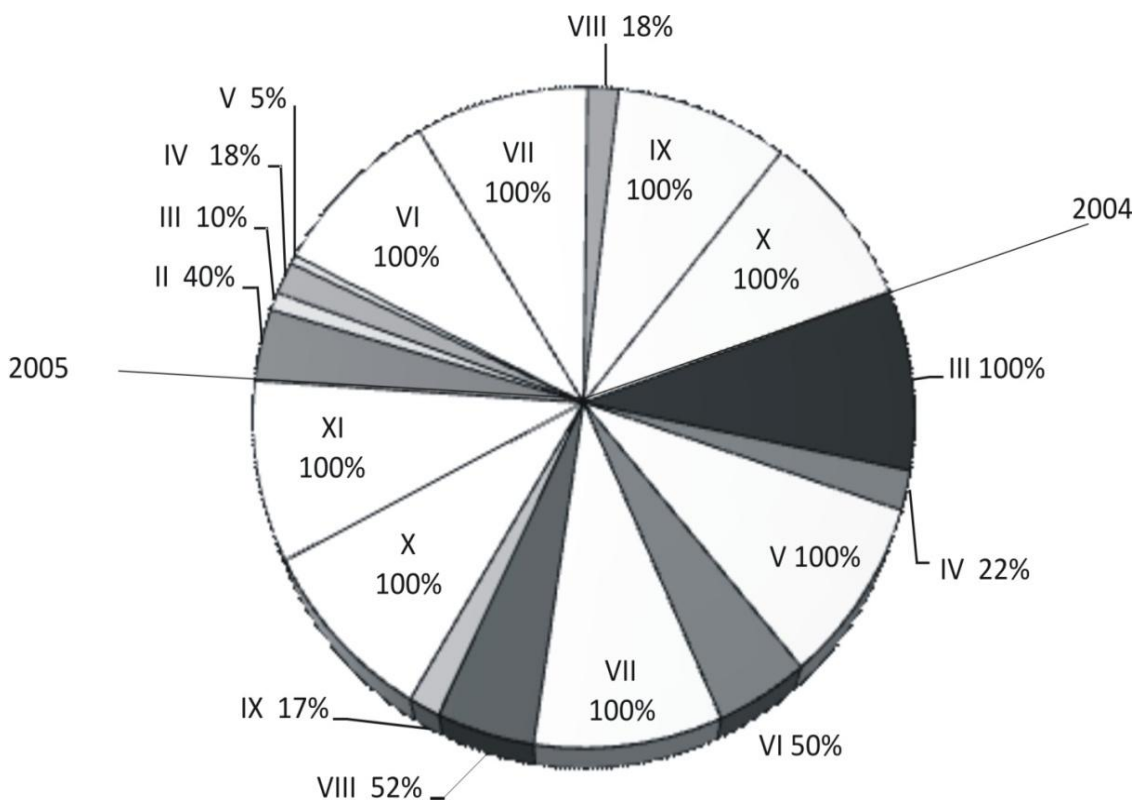


Figure 3 – The share of the tankers which have arrived in 2004-2005 to the Novorossiysk port for loading: without replacement or with partial replacement of ballast waters (dark gray color)

### Monitoring of biological invasions in coastal waters of the northeastern Black Sea.

In coastal waters of the northeastern shelf of the Black Sea were established a six invasive species *Tintinnopsis directa*, *T. tocaninensis*, *Amphorellopsis acuta* (Ciliata: Tintinnida), *Oithona davisae* (Copepoda: Cyclopoida), *Polydora cornuta*, *Streblospio gynobranchiata* (Polychaeta: Spionidae) and the Sea of Azov one species was invasive ones (Selifonova, 2009b; 2011d; 2012c). A total of 53 introduced non-native species at different stages of acclimatization were recorded in the port area: 45 Copepoda, including 44 casual taxonomical form, 2 Polychaeta, 6 Tintinnida (3 taxonomical form with non established status). The largest number of alien species (53) was recorded in the Novorossiysk Bay, in the port of Tuapse 18 (12 casual taxonomical form, 3 – non established), in the Liman “Zmeinoe ozero” 12 (5 – Copepoda, 2 – Polychaeta, 5 – Tintinnida, including 4 casual, 2 non established). The casual taxonomical form of copepods are found in the Anapa Bay and the Strait of Kerch – 9 and 2 respectively. The main “risk groups” of invasions via water transport are tintinnid infusorians, neritic copepods, polychaetes and phytoplankton. A discovered organisms had different halopathy. The majority of them were the Mediterranean origin (Selifonova, 11e; Selifonova et al., 2008) (figure 4).



was noted at the coast of Turkey in the Aegean Sea (Cinar et al., 2005), in 2004 – in the southern Caspian Sea (Taheri et al., 2008), in 2007 – in the Sevastopol Bay (Boltacheva, 2008) and in 2011 – in the Liman ‘Zmeinoe Ozero’ (Radashevsky, Selifonova, 2013). Spionid polychaetes *P. cornuta* was first recorded in the mud sediments of the port of Tuapse in August 2009 (Selifonova, 2011c). Distribution of this species along Romania coast was recorded in 1997 (Radashevsky, 2005), in the southern Crimea in 2005 (Boltacheva & Lisitskaya, 2007) and in the Liman ‘Zmeinoe ozero’ in 2011 (Radashevsky, Selifonova, 2013) (figure 6).

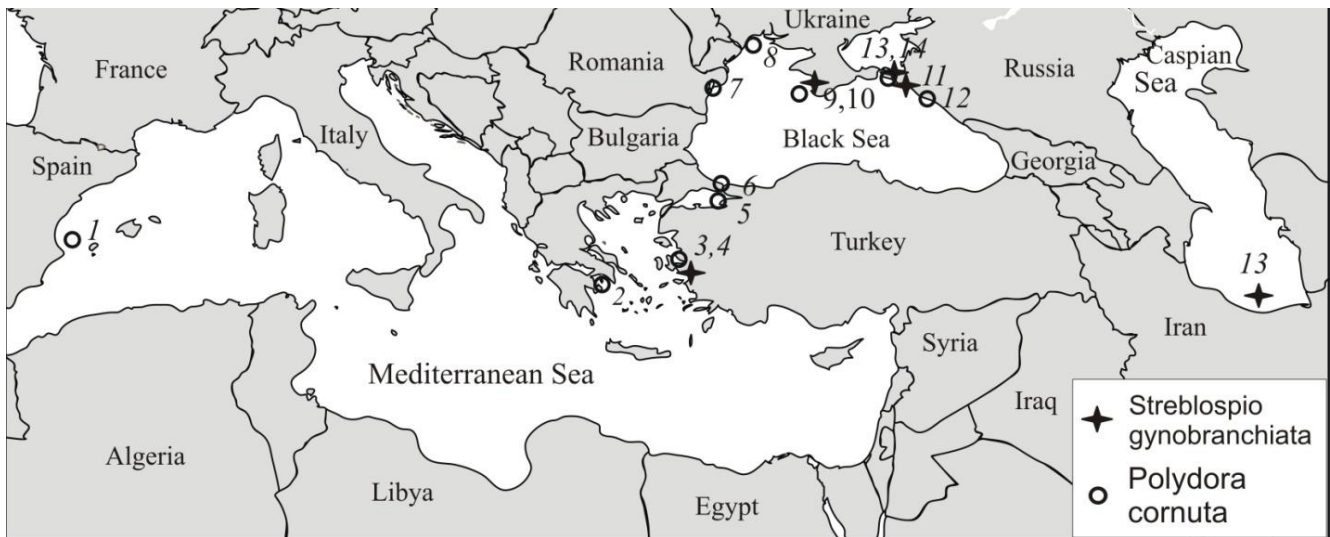


Figure 6 – Distribution of polychaetes spionid family in the southern inland seas of Eurasia. 1 – Tena et al., 1991; 2 – Simboura et al., 2008; 3, 4 – Çinar et al., 2005; 5 – Dagli, Ergen, 2008; Karhan et al., 2008; 6 – Çinar et al., 2009; 7 – Radashevsky 2005; 8 – Losovskaya, 1976; 9 – Boltacheva, Lisitskaya 2007; 10 – Boltacheva, 2008; 11 – Murina et al., 2008, 12 – Selifonova, 2011, 13 – Taheri et al., 2008, 14, 15 – Radashevsky, Selifonova, 2013.

An occurrences of single finds of introduced organisms and local outbreaks of abundance alien species tintinnid became more frequent in recent years in the Black Sea. Totally, in the Novorossiysk Bay established six taxonomical form of non-native species ciliates (Gavrilova, 2010; Selifonova, 2011; 2012), in the port of Tuapse and in the Liman “Zmeinoe ozero” – five taxonomical form in each. The abundance of alien tintinnids such as *Tintinnopsis directa*, *T. tocantinensis*, *Eutintinnus tubulosus*, *A. acuta*, *Salpingella* sp. in Liman “Zmeinoe ozero” was maximal for coastal waters of the northeastern Black Sea (see chapter 2.1).

## Chapter 4 STRUCTURAL FUNCTIONAL ORGANIZATION OF COASTAL ECOSYSTEM OF THE NORTHEASTERN BLACK SEA OF DIFFERENT TROPHIC PATTERN

The data on the reserves of assimilable organic matter and the rate of its destruction confirm that in the ports and bays the plankton community of heterotrophs was formed and functioned effectively. It consumed not only the primary production of phytoplankton but excess organic matter which input into water with the runoff from the coastline.

The analysis of trophic relationship of a phytoplankton and zooplankton on the example of the large ports of Novorossiysk and Tuapse (Selifonova, Yasakova, 2012a) revealed the significant role of a detritus in food of some zooplanktonic organisms. It is noted that in holoplankton and meroplankton with increase of trophicity of water there a number of organisms preferring detritus – rotifers, larvae of benthic animals, small crustacean *P. polyphemoides*, species genus *Acartia* were consistently increased.

At present, the rate of filtration of water masses by zooplankton is 1.5 times higher due to the increase in the zooplankton biomass in the open part of the Novorossiysk Bay, but in the aquatic area of the port, it remained at the level of the 1990s. The process of sedimentation of organic matter by different groups of zooplankton was similar, but in the area of the port of Tuapse, infusorians clarified water two times faster than holo- and meroplankton. In summer, the processes of selfpurification occurred more intensely, and during other seasons their rates decreased. The data on filtration activity of zooplankton agree well with the parameters of selfpurification intensity of the Novorossiysk Bay (time of the full cycle of organic matter) (Selifonova, Lukina, 2001).

**The Novorossiysk Bay and the Tuapse port.** The elements of the daily balance of energy in the port ecosystems were calculated for July-August (Selifonova, 2012b). At this time, the crisis processes were developing in the coast waters. The level of organic pollution increased against high temperatures and recreations. The predatory ctenophore *M. leidy* consumed the pelagic filtration organisms. A schemes of energy flows in ecosystems were constructed according to the results of balance calculations (figures 7, 8). The elimination of zooplankton by ctenophore *M. leidy* leads to the simplification of the trophic web, the reduce the ecosystem's capacity for biotic selfpurification, and facilitates the further strong deformation of the ecosystem. With appearance the ctenophore of *B.ovata* (the consumer of *M. leidy*) in the Black Sea there was discernible tendency to restoration of an ecosystem. It has been evinced in the balanced alternation of development maxima of ctenophores of *B.ovata* and *M.leidy* and fodder zooplankton. According to the model calculations, at their peak of development, comb jelly consumes about 3–15% of the metazoic production in waters of the ports of Novorossiysk and Tuapse and 40–51.5% outside the port.

Our data testified to stabilization of the port ecosystem at a higher production level than in the 1990s. For comparison, in the Sea of Azov at their peak of development in the total absence of competitors, comb jelly *M. leidy* consumed about 83–97% of the zooplankton production. It led to a reduction of species diversity and biomass of planktic community and gave rise to an ecosystem crisis.



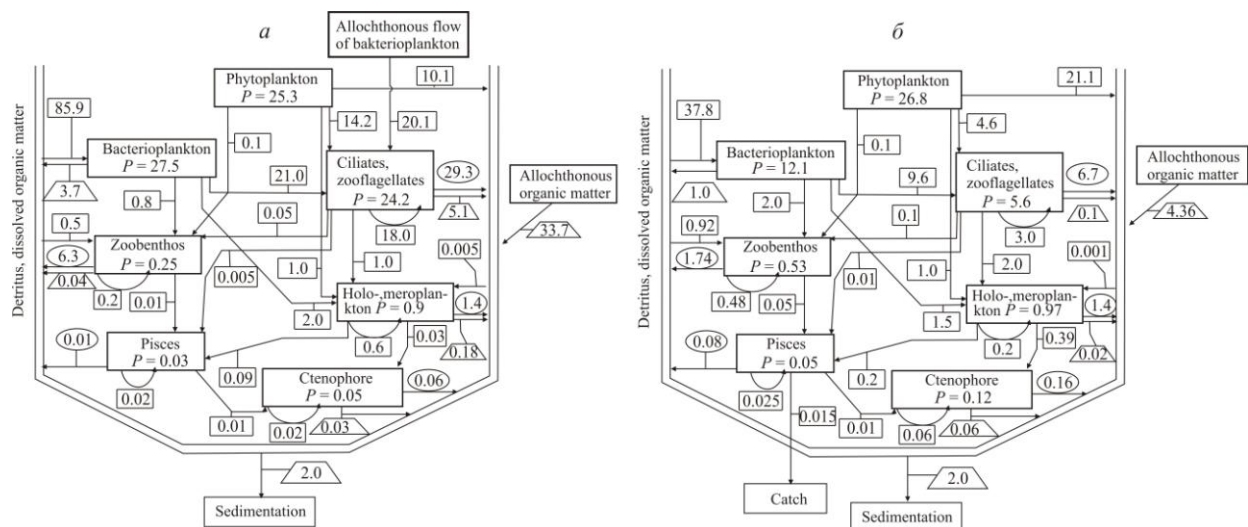


Figure 7 – Scheme of the daily energy flows ( $\text{kJ}/\text{m}^2$ ) in the ecosystems of the Novorossiysk port (a) and (b) outside the port (July-August): figures in squares denote the ration of the next trophic link; figures in circles denote an inassimilable portion of the ration; figures in trapezium denote unconsumed production.

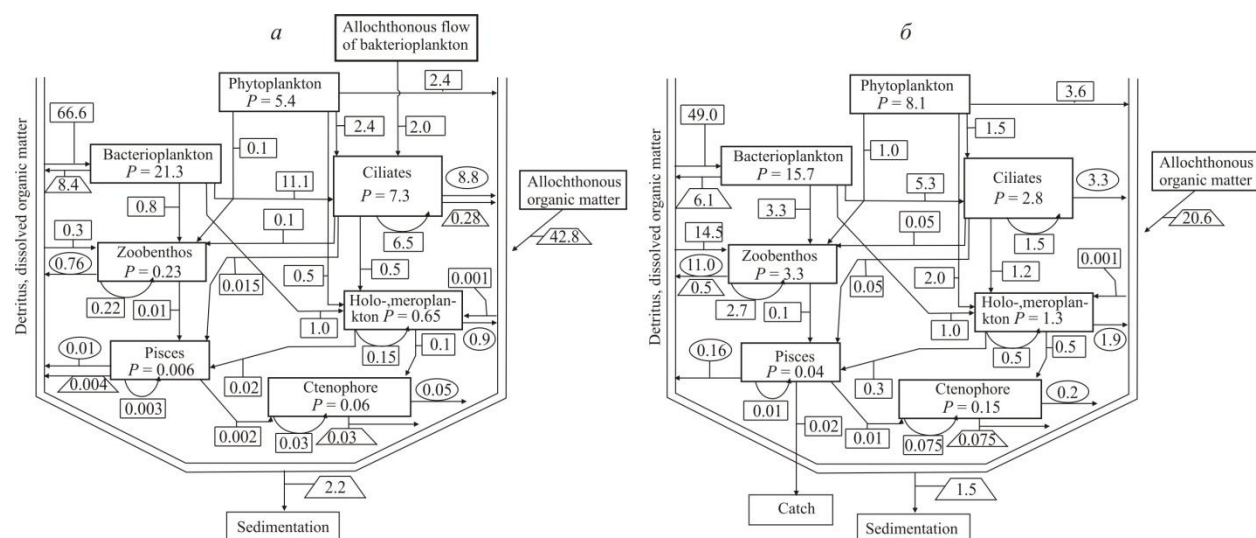


Figure 8 – Scheme of the daily energy flows ( $\text{kJ}/\text{m}^2$ ) in the ecosystems of the Tuapse port (a) and (b) outside the port (July-August)

The effect of pollution on the distribution of the energy flow in the port ecosystems was expressed as follows: the largest portion of the energy flow passed through the bacterial component (69.8–84.5% of the energy flow) and infusorians (11–24%).

The role of holoplankton and meroplankton in the total destruction was insignificant. Destruction activity of infusorians is aimed at assimilation and mineralization of accumulated bacteria biomass. A significant portion of the infusoria biomass was formed due to allochthonous bacterioplankton which brought into water along with the coastal runoff. An effective selfpurification of water in the port of Novorossiysk accomplished through the activity of microheterotrophs in the food chain ‘bacteria–zooflagelates–infusorians’.

The decrease in the role of animal components of the food chain in the metabolism of the ecosystem of the port of Tuapse subjected to oil pollution led to its low assimilation

capacity with respect to contaminants. The production of infusorians was three times lower as compared to the similar parameters in the port of Novorossiysk. Nevertheless, under existing level of phytoplankton development (five times lower compared to parameters in the port of Novorossiysk) and good water exchange, the plankton heterotrophs sustained the load of organic matter of autochthonous and allochthonous origin even during the crisis processes in the ecosystem. The intensity of biological selfpurification determined according to the total respiration of plankton heterotrophs during the period of the highest recreational load and predator press exceeded the primary production in the port of Tuapse by almost an order of magnitude and was 1.5–3 times higher than in the area of the port of Novorossiysk. Hence, both of the natural port ecosystems sustained the anthropogenic organic loading. Our results testify to an important role of zooplankton in the processes of selfpurification of polluted waters and make it possible to consider the heterotrophic plankton community in the port areas to be an ecological barrier of the effect of anthropogenic factors.

The Liman “Zmeinoe ozero”. The energetic balance of ecosystem of the Liman “Zmeinoe ozero” was calculated for summer and the beginning of autumn (August–September) in accordance with the terms of settlement it by non-native species (see. chapter 4) (Selifonova, 2015). Predatory ctenophores *M. leidy* in the Liman ecosystem were absent. The Liman ecosystem functioned appreciably at the expense of energy stored in OM in the water, which included in a food web with the assistance of bacteria (figure 9). It differed from other investigated port ecosystems, where the share of allochthonous OM was high enough. Stock of OM in such ecosystems was formed mainly during autotrophic phases of seasonal succession of the planktonic community. At the basis of anthropogenous transformation of the Liman ecosystem was degradation of elements of the trophic chain in benthic communities. The biocoenosis of polychaetes *Capitella* (biomass  $10.5 \text{ g/m}^2$ ) was noted on mud bottom sediments with the strong smell of hydrogen sulphide. Therefore, the functions of benthic communities have been redistributed to planktonic communities and ecosystem functioning was carried out at the level of microheterotrophs (bacteria and ciliates).

The share of heterotrophic bacterioplankton in total decomposition was 86.8%. The share of ciliates attained 10.4%. The bacteria and infusorians (total biomass  $1.67 \text{ g/m}^3$ ) assimilated and introduced in turnover  $4.0 \text{ g/m}^3$  of the primary food. The respiration of benthic animals in total decomposition was 1.2%.

The share of filtering holoplankton and meroplankton was minor – 0.5%. The difference between destruction and primary production characterizes the function of the natural cleansing carried out in the ecosystem of this basin. The capacity of heterotrophs, inhabiting

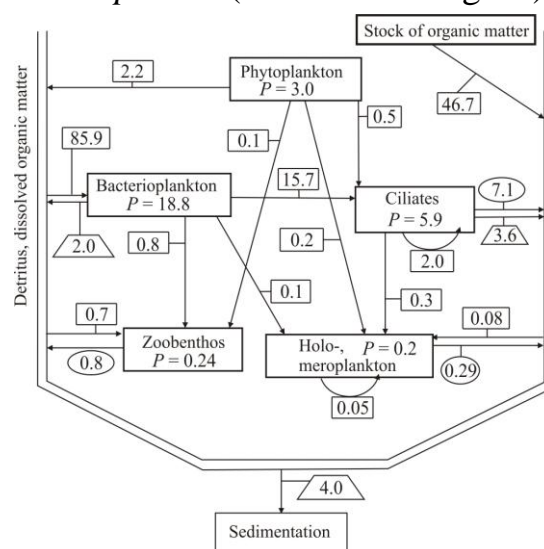


Figure 9 – Scheme of the daily energy flows ( $\text{kJ/m}^2$ ) in the Liman “Zmeinoe ozero” ecosystem in the late summer – the beginning of autumn

the Liman ecosystem, has been expected on an OM load 15–25 times exceeding the daily primary production of phytoplankton. Exclusively high intensity of ecosystem metabolism (a balance of the processes of autotrophic production and heterotrophic destruction) contained development of crisis processes. Against this background favourable conditions had been established for introduction in the Liman ecosystem of the alien species that were transported with ships' ballast water from the water area of the oil terminal of KTK-R.

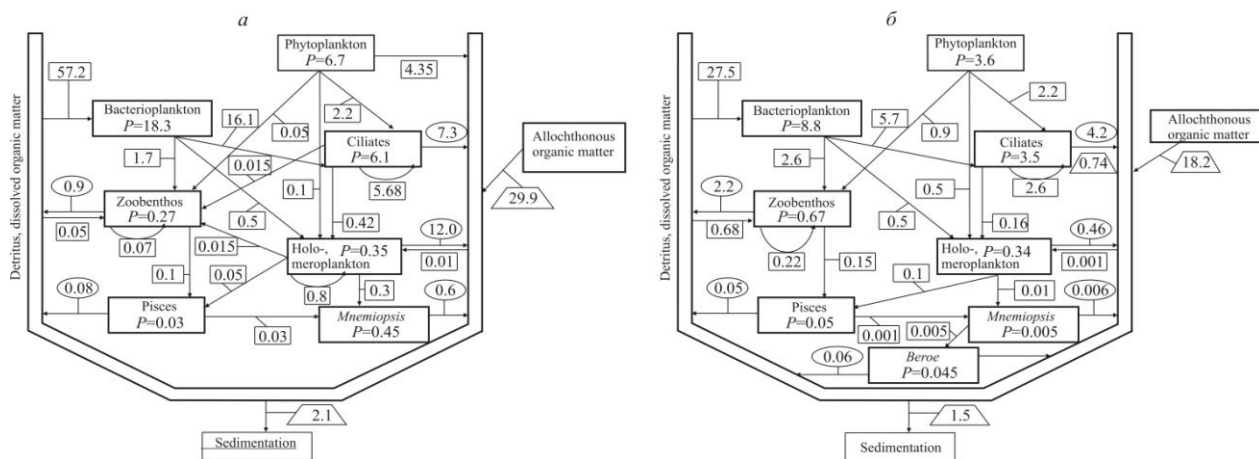


figure 10 – Scheme of the daily energy flows (kJ/m<sup>2</sup>) in the ecosystems of the Sochi port in July (a) and Taman' port (b) in July-August

**The Sochi port.** The elements of daily energy balance in the Sochi port ecosystem was calculated for July. At this time the ctenophore *M. leidyi* consumed about 85.7% of the zooplankton production and practically the totally production of fishes (figure 10a). Under such condition the holoplankton and meroplankton can be utilized only 1.5–3.0% of production of phytoplankton and bacteria. Fundamentally anthropogenic transformation of ecosystem was degradation of elements of the trophic chain in benthic communities. The polychaetes of genera *Heteromastus*, *Capitella*, *Nephtys*, nematodes, oligochaetes were found in the mud sediments with the strong smell of hydrogen sulphide. The biomass of benthic animals (15 g/m<sup>3</sup>) was two time higher as compared to the similar parameter of the ports Novorossiysk and Tuapse. The ecosystem functioned at the level of microheterotrophes (bacteria, infusorians). The share of heterotrophic bacteria in total decomposition of ecosystem attained 83.9%, the share of ciliates – 10.5%. The allochthonous organic matter (incoming from the river waters, 29.9 kJ/m<sup>2</sup>) serve as an energy base for the functioning of microheterotrophic organisms. At maximal biomass 1.18 g, the bacteria and the ciliates introduced in turnover approximately 2.3 g primary food. The respiration of zooplankton benthic animals in total decomposition was 1.3%, the zooplankton – 0.9%. Totally, the destruction of heterotrophs was seven times higher than the phytoplankton primary production that testified about the good self-purification capacity of ecosystem.

**The Taman' port.** The ecosystem of the open Taman' port with sufficiently effective natural self-purification of waters was a basis of the normal port ecosystems (figure 10b). Along with absence of intensive contamination of bottom sediments by sulfur hydroxide, in

an ecosystem remained the normal food chain, including of the mollusks of the shelly sandy biocoenoses of *C. gallina*. The crisis processes in such ecosystem didn't develop even in the period of greatest anthropogenic impact and press of predators. The energy balance in the port ecosystem was calculated for the biological community during the late summer. At this time ctenophore *B. ovata* has consumed practically the totally production produced by *M. leidy*. The increase of production of the planktonic filtration organisms has improved the self-purification capacity of port ecosystem. The major role in a food chain was played by bacteria and infusorians. Their biomass corresponded to the level of mesotrophic waters, i.e. 3–3.5 time lower than in the waters of the Novorossiysk port. The share of bakterioplankton in the total destruction composed 78%, a share of infusorians – 11.7%. The total respiration of the heterotrophs was almost six times higher than primary production of phytoplankton. The energy "input" to an ecosystem was formed by means of allochthonous organic matter incoming to waters of the Strait of Kerch (18.1 kJ/m<sup>2</sup>).

The elements of daily energy balance in the ecosystem of the bay of health resort cities of Anapa and Gelendzhic was calculated in July-August.

**The Gelendzhic Bay.** In ecosystem of the Gelendzhik Bay under the conditions of high eutrophication of waters and intensive local contamination of bottom sediments by sulfur hydroxide, the normal food chain has remained (figure 11a). The community of bivalves mollusk-filtration organism of *C. gallina* was noted on bottom sediments (Melnik, 2003). The structure of macrophytes testified about middle degree of pollution of waters of bay of OM (Berezenko, 2003). The benthic communities were degraded near the port and city sewages.

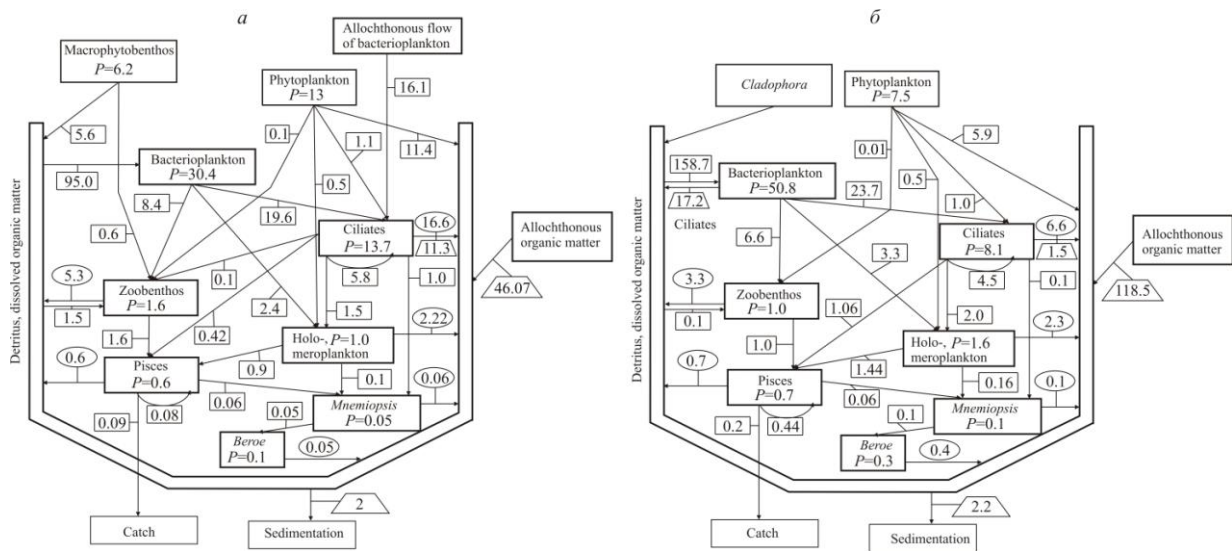


Figure 11 – Reconstruction of scheme of the daily energy flows (kJ/m<sup>2</sup>) in the ecosystem of the Gelendzhik Bay (a), in the ecosystem of the Anapa Bay (b) in July-August

In upper layer of bottom sediments of these areas, the damaging concentration of the labile sulfides for animals reached critical values 700–900 mg S/dm<sup>3</sup> wet silt (Sorokin, Zakuskina, 2008). The “capacity” of the community of heterotrophic organisms for the processing of OM as assessed by their sum respiration was 6.5 times higher than the phytoplankton primary production. The destruction of OM was carried out by bacterial community for 76.3%, by infusorians – for 13.2%.

ecosystem showed that the summarized rations of planktonic protozoan exceeds the production created by phytoplankton and bacteria. In this case, the allochthonous bacterial biomass incoming in bay from drainages could be the only source of additional food. Rations of infusorians for 38.7% consisted of this nutrient source. The main energy resource for microheterotrophs was the organic matter coming to the bay during of period of intensive recreation. Their activity was sufficient for effective self-purification of bay ecosystem. Bacteria and protozoan with summarized biomass  $2.37 \text{ g/m}^3$  introduced in turnover approximately 7.4 g of the primary food.

**The Anapa Bay.** In the summer high biomass the heterotrophic bacteria and the saprobic green algae are defined the ecological state of the Anapa Bay as hypereutrophic area. A quarter of number of phytoplankton have been formed by the euglena and blue-green algae, which indicatived for the polluted and desalinated area the sea (Yasakova, 2012). The main source of pollution of the Bay there is a river Anapka, which have been degraded into a bog. This river carries drainages from the city and the farmland. The local excessive fertilization of coastal waters of the Anapa beaches causes the annual summer "blossoms" of waters by filamentary green alga of genus *Cladophora* (Vershinin, Kamnev, 2001). About 7.5 thousand tons of the rotting algae accumulated into the supralittoral. Under the conditions of extremely high eutrophication of waters in such ecosystem was noted a normal food chain, including the communities of mollusks-filtration organisms of sandy biotope *C. gallina* (figure 116). The largest fraction of the energy flow in the ecosystem (88.2%) passes through the microbial food webs, 5.4% of the energy flow – through the links of ciliates and zooflagellates. A total respiration of heterotrophs and their ration were almost 15 times and 24 times higher respectively than the phytoplankton production. The activity of microheterotrophes in the food chain "bacteria–zooflagellates–infusoria" was sufficient for the effective self-purification of waters. The total number of heterotrophic bacteria reached up to the upper level of hypereutrophic waters. The allochthonous organic matter incoming from the river waters ( $118.5 \text{ kJ/m}^2$ ) served by energy base for the functioning of bacterioplankton. At maximal biomass  $3.5 \text{ g/m}^3$  bacteria and protozoan introduced in turnover ~8.5 g of the primary food.

## Chapter 5 TAXONOMICAL COMPOSITION AND SPATIAL STRUCTURE ZOOPLANKTON OF THE SEA AZOV

### 5.1 Holoplankton

Previous researchers analyzed in different way the key elements of net zooplankton of the Sea of Azov and their biomass. Therefore according to literary data, it is very difficult or impossible on the whole to make the idea about long-term trend of community. Taxonomical and quantitative treatment of zooplankton was carried out completely by the author by uniform methods with an identical quantitative measurement accuracy.

Totally, 64 taxonomical forms were found in the holoplankton at the Sea of Azov and the Kerch Strait: Copepoda – 34 (Calanoida – 10, Cyclopoida – 15, Harpacticoida – 9), Cladocera – 11, Rotifera – 18, Ctenophora – 2; the Kerch Strait – 26 taxonomical forms: Copepoda – 15 (Calanoida – 5, Cyclopoida – 5, Harpacticoida – 5), Cladocera – 2, Rotifera – 4, Dinophyceae – 1 (*N. scintillans*), Ctenophora – 2, Appendicularia – 1 (*O. dioica*), Chaetognatha – 1 (*P. setosa*) (Selifonova, 2014).

While analyzing of holoplankton, as well as meroplankton of open part of the Sea of Azov, we were interested primarily the changes happening in these communities in June. June in the Sea of Azov is the most productive month with the highest species diversity and abundance of feeds zooplankton. In July, the density of zooplankton was sharply reduced by predation pressure from the pelagic ctenophore *M. leidy*. In August–September benthic invertebrate larvae and other plankters have been occurred in very small numbers.

In June 2003–2006, the value of long-time average annual density of food zooplankton (without rotifers and ctenophores) varied from 7.5–33.5 thousand ind./m<sup>3</sup> in open area of the Sea of Azov to 42.7 thousand ind./m<sup>3</sup> in the Taganrog Gulf, 27.5–49.5 thousand ind./m<sup>3</sup> in the Temryuk Gulf and 5.2–28 thousand ind./m<sup>3</sup> in the Kerch strait. In the open area of the Sea of Azov, the holoplankton composed 28.4–57.8% of total zooplankton amount, 70% – the Taganrog Gulf, 25–33% – the Temryuk Gulf and 26.6–50% the Kerch' strait. The average values of biomass varied from 0.7–0.43 g/m<sup>3</sup> in open area to 0.4–0.5 g/m<sup>3</sup> in the Taganrog and Temryuk gulfs to 0.08–0.27 g/m<sup>3</sup> in the Kerch strait.

The holoplankton was characterized by insignificant number of dominant species (structure-forming species). A low indicators of Index of biological diversity of Shannon (0.34–1.1 nit/ind) are peculiar for this community and define a weak degree of his organization. The multidimensional scaling analysis showed maximum similarity between the northeast area and the Temryuk Gulf on the distribution of frequency of occurrence holoplanktonic species. These areas are the most productive zones of the Sea of Azov. We have defined the low-productive areas (central, southern and western) in a separate second region which subject to strong influence of a comb jelly. In rectangular coordinates, the significant distance between of the Gulf of Taganrog and the Kerch Strait has been noted. In the Taganrog Gulf, inhabited by specific marine, brackish-water and fresh-water fauna, the change of taxonomical composition of holoplankton organisms was accompanied by

significant alterations in distributions of species. Results of similarity of taxonomical composition and density of holoplankton of the Sea of Azov have shown that the group of the sea species living in the Strait of Kerch' has been noted at the level of similarity of 65%. At gulfs, the role of brackish-water Cladocera – *Podonevadne trigona*, *Bosmina longirostris* increased. These species have the high level of similarity up to 72%. A typical brackish water species of copepods *Calanipeda aquaedulcis* and *Eurytemora affinis* also had the high level of similarity – 63%. The cyclopoid and harpacticoid copepods had greatest degree of similarity (98%). Degree of similarity of thermophilic euryhalinic marine species *P. polyphemoides*, *C. ponticus* was 40%. Prevailing species *A. tonsa* adjoined to them. This species had similar characteristics in relation to habitat. Rotifers differed by least similarity of taxonomical composition (8%).

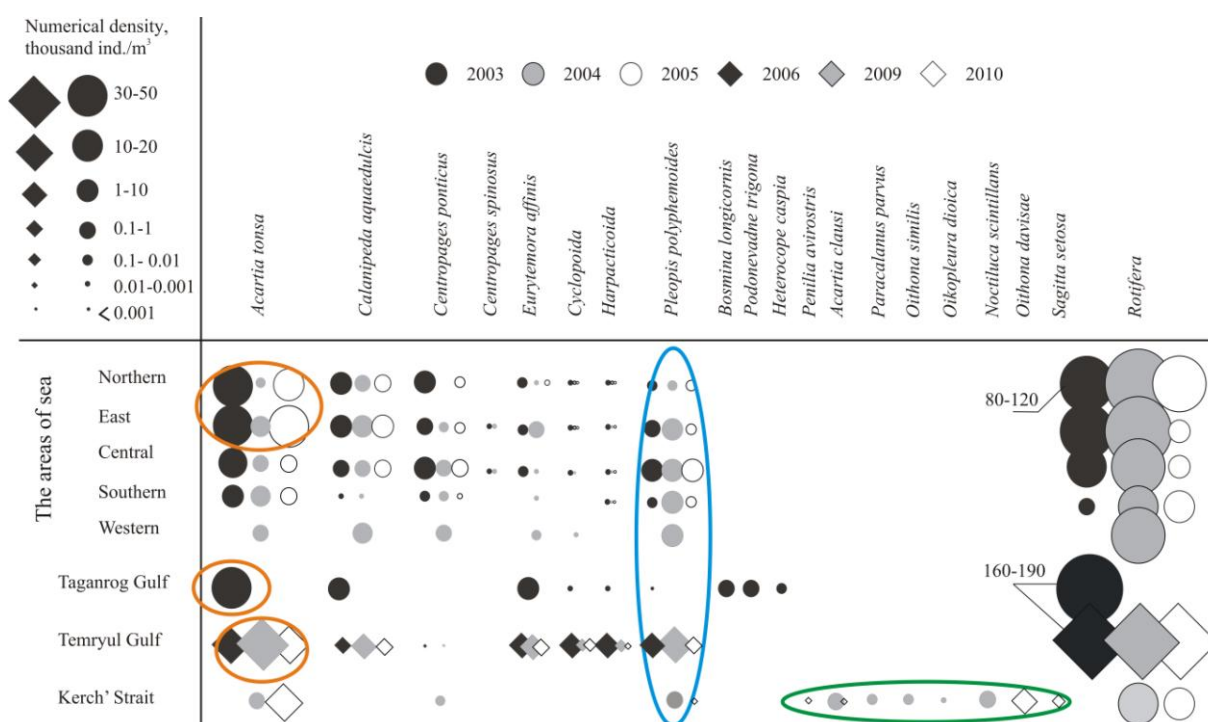


Figure 12 – Schematic illustration of numerical density of main taxonomic form of holoplankton of the Sea of Azov in June (thousand ind./m<sup>3</sup>)

In the Sea of Azov, the zones of concentration of a holoplankton are noted in the northeast region, the Temryuk Gulf and the western part of the Taganrog Gulf (figures 12, 13). Copepods prevailed over other taxonomical groups (64–81.8% in the Sea of Azov, 99.5% in the Strait of Kerch'). *A. tonsa* was dominant species. Organisms with parthenogenetic strategy of reproduction and frequent alternation of generations, such as rotifers of the genus *Synchaeta* with detritophagous strategy of food and the predatory form *Asplanchna priodonta*, determined the maximum density of holoplankton. Their of long-time average density in the Sea of Azov reached 68.4 thousand ind./m<sup>3</sup> (74.5% of sum holoplankton), in the Taganrog and the Temtyuk gulfs – 160–190 thousand ind./m<sup>3</sup> (60–80%). Biomass of rotifers increased in the northern and the east areas of the Sea of Azov (0.6–1.2 g/m<sup>3</sup>), in the Taganrog Gulf (0.6 g/m<sup>3</sup>), in the Temtuyk Gulf (0.9–1.2 g/m<sup>3</sup>). Other organisms with similar strategy of reproduction, such as Cladocera, weren't numerous. Average density *P. polyphemoides* varied within the range from 1–3.2

thousand ind./m<sup>3</sup> in the Sea of Azov and the Kerch strait (the Taman' Gulf) to 14.1 thousand ind./m<sup>3</sup> in the Temryul Gulf. In desalinated western area of the Taganrog gulf and the northern area the sea the quantity of this species was minimum. The brackish-water species Cladocera – *P. trigona* and *B.longirostris* are registered in the Taganrog Gulf.



Figure 13 – Schematic illustration of biomass of main taxonomic form of holoplankton of the Sea of Azov in June (g/m<sup>3</sup>)

**Structure and spatial organization of taxocoenosis of copepods.** The first phase of cardinal changes of structure of the Sea of Azov copepods has come in the 1960-1970th after river regulation of Don (Kovalev, 1991). Salinization of waters initiated the process of "pontization" of fauna and the introduction in the Sea of Azov of the Black Sea species, such as "small" *A. clausi*, "big" *A. clausi*, *O. nana*, *P. parvus*, *C. ponticus*, including of medusa. The second phase (since the end of the 1980th) – this is a phase of catastrophic reorganization of planktonic community under the influence of a predatory comb jelly of *M. leidyi*. The total number of copepod was reduced from 5–7 to 1–2 species in open part of the Sea of Azov, from 7-12 to 4–6 in the Taganrog Gulf (Ctenophore., 2000).

The copepods of 37 taxonomical form were identified in the Sea of Azov including the Kerch' strait in June 2003–2006: 12 calanoid, 16 – cyclopoid, 9 – harpacticoid (Selifonova, 2013). The marine, brackish water and fresh-water fauna inhabite in the Sea of Azov (figure 14).



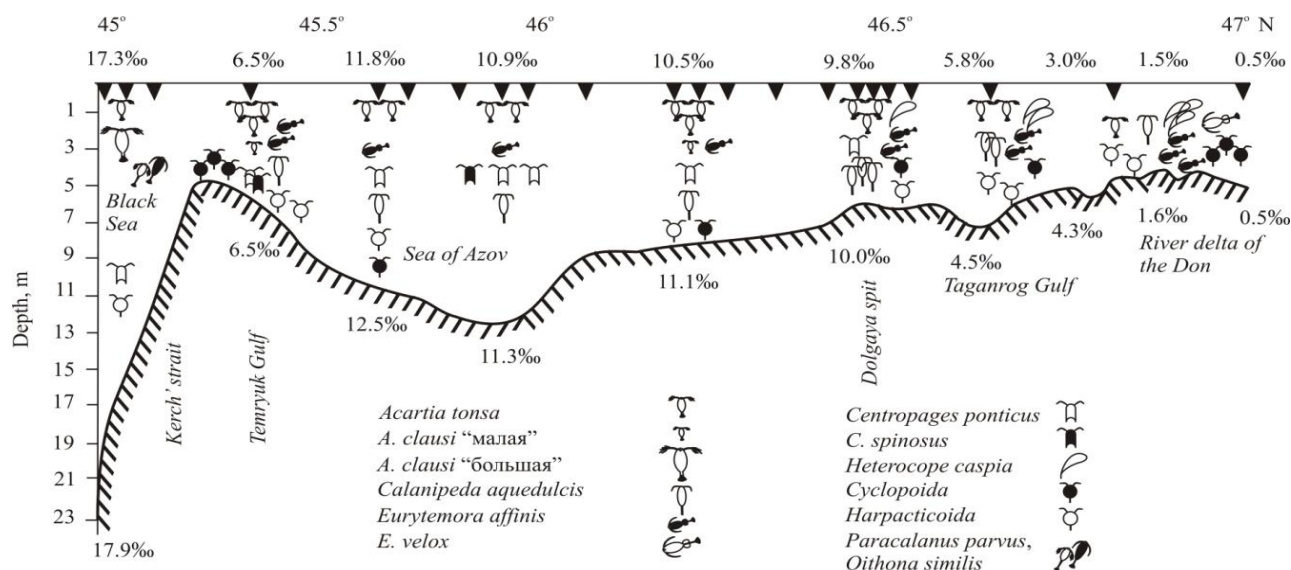


Figure 14 – Distribution of species of marine, brackish-water and fresh-water complexes of copepods in the Sea of Azov in 2003–2006. The stations of sampling have designated by triangles. The value of superficial and benthic salinity were specified according to data of hydrophysical sonde.

Among a small number of calanoid copepods, the euryhalinic marine species *A. tonsa* absolutely dominated till 2010. The euryhalinic species *C. aquaedulcis* was occurring widely. The aggregations of *E. affinis* were noted in the Taganrog Gulf and the Temryuk Gulf. Stenohalinic species *Heterocope caspia* had the limited area – the Taganrog Gulf. Fresh-water euryhalinic cyclopoid copepods and marine euryhalinic harpacticoid copepods formed an estuarial population of gulfs. Among marine species observed in the Strait of Kerch' only *C. ponticus* had penetrated into the Sea of Azov to an isohaline of 7‰ and had formed aggregations in the central part of the sea. The expansion of role of *Acartia* in the taxocenosis of copepods is common regularity for the Sea of Azov and the Black Sea. A degree of domination of *A. tonsa* in total numerical density of copepods composed 80–85%. The high numerical density of species is noted in the estuarial zones of the rivers – the Taganrog Gulf and the east region of the Sea of Azov.

The intensive development of population of *A. tonsa* (to 41 thousand ind./m<sup>3</sup>) was revealed in June 2003 and 2005 at optimum temperature for reproduction of species (21.3–21.7 °C) (figure 15).

Depression of populations we observed in places of mass development of predatory comb jelly. The maximum numerical density of *C. aquaedulcis* is noted in the northeast part of the sea and the Taganrog Gulf (3.2–7.6 thousand ind./m<sup>3</sup>) and in the Temryuk Gulf (1.1 thousand ind./m<sup>3</sup>), *C. ponticus* – in the central region of the sea (5.8 thousand ind./m<sup>3</sup>), *E. affinis* – the Taganrog and the Temryuk gulfs (1.4–2.5 thousand ind./m<sup>3</sup>), *H. caspia* – the Taganrog Gulf (0.14 thousand ind./m<sup>3</sup>). The taxonomical composition of copepods of the Sea of Azov is still insufficiently studied. The description of some morphotypes of the genus *Acartia* and *Centropages* is absent in literature. Alien species of the Black Sea origin and the Mediterranean Sea origin, and the Atlantic ocean origin, and the Caspian Sea origin continue to appear in the Sea of Azov copepod complex. Obviously, process of their introduction continues.

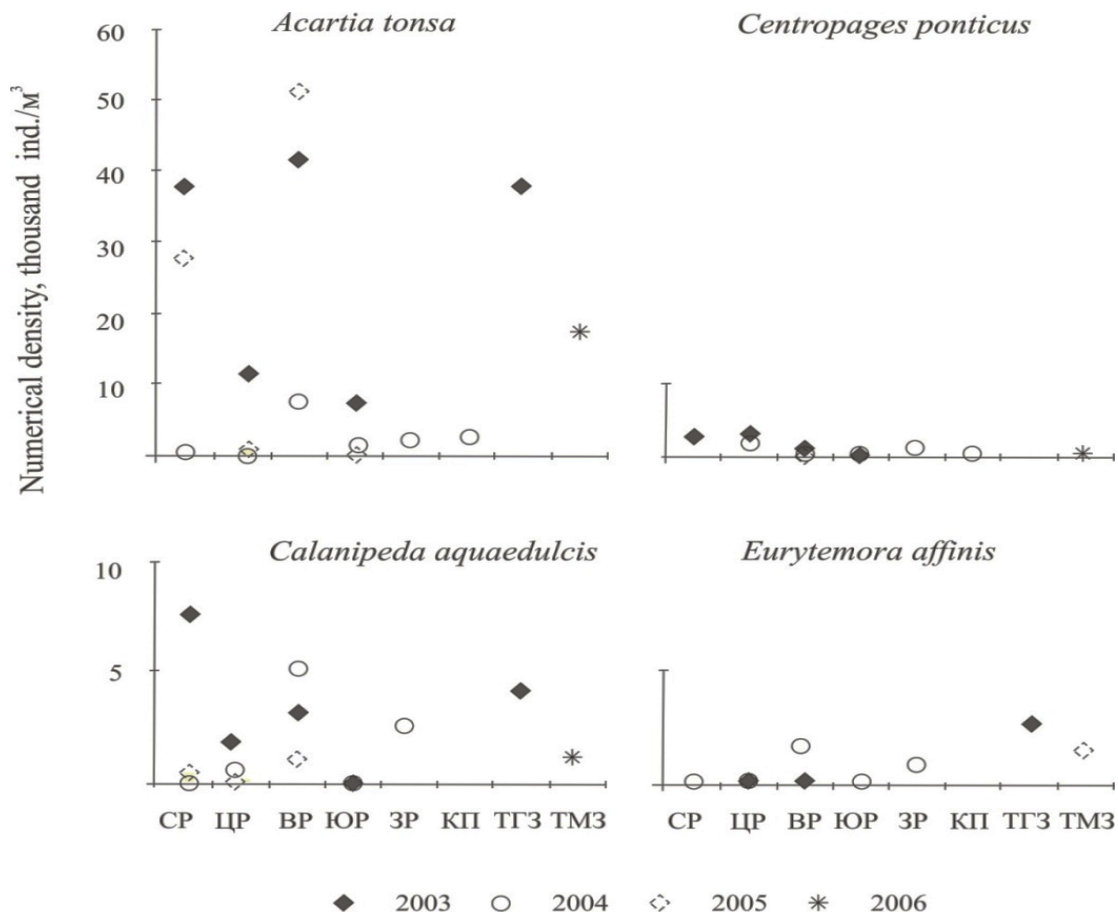


Figure 15 – Distribution of numerical density of mass species calanoids (in thousand ind./mm<sup>3</sup>) in June 2003–2006. Designations of areas of investigation according to figure 1.

This is shown by the appearance in 2010 and mass development in the Sea of Azov the cyclopoid copepods of *O. davisae*, which have been brought to the basin of the ports of the northeastern Black Sea with ballast waters of commercial vessels (Selifonova, 2011b; Svistunova, 2013).

## 5.2 Meroplankton

The benthic invertebrate larvae of 26 taxonomical form were identified in the Sea of Azov in June 2005–2007: Polychaeta – 7; Cirripedia – 1; Decapoda – 5; Gastropoda – 5; and Bivalvia – 8 (Selifonova, 2008a). Relative proportion of meroplankton was 55–75% of zooplankton. The abundance of meroplankton is to a large extent linked with the high trophic state of waters in the Sea of Azov, shallow depths (average depths 5–6 m), and, as a rule, spawning of one or several of the most common species. Meroplankton was dominated by larvae of species that are able to endure considerable concentrations of pollution by labile sulfides in bottom sediments and eutrophication: *M. lineatus*, *Cerastoderma* sp., *Abra segmentum*, *Hydrobia acuta* (Gastropoda), and *A. improvisus* (Cirripedia). The highest spawning of one or several of the most common species. Meroplankton was dominated by larvae of species that are able to endure considerable concentrations of pollution by labile sulfides in bottom sediments and eutrophication: *M. lineatus*, *Cerastoderma* sp., *Abra segmentum*, *Hydrobia acuta* (Gastropoda), and *A. improvisus* (Cirripedia). The highest

abundance of meroplankton was observed in 2003 and 2005: 15–20 thousand ind./m<sup>3</sup> on average, which is nearly 2–2.5 times greater than the value in 2004 (figure 16).

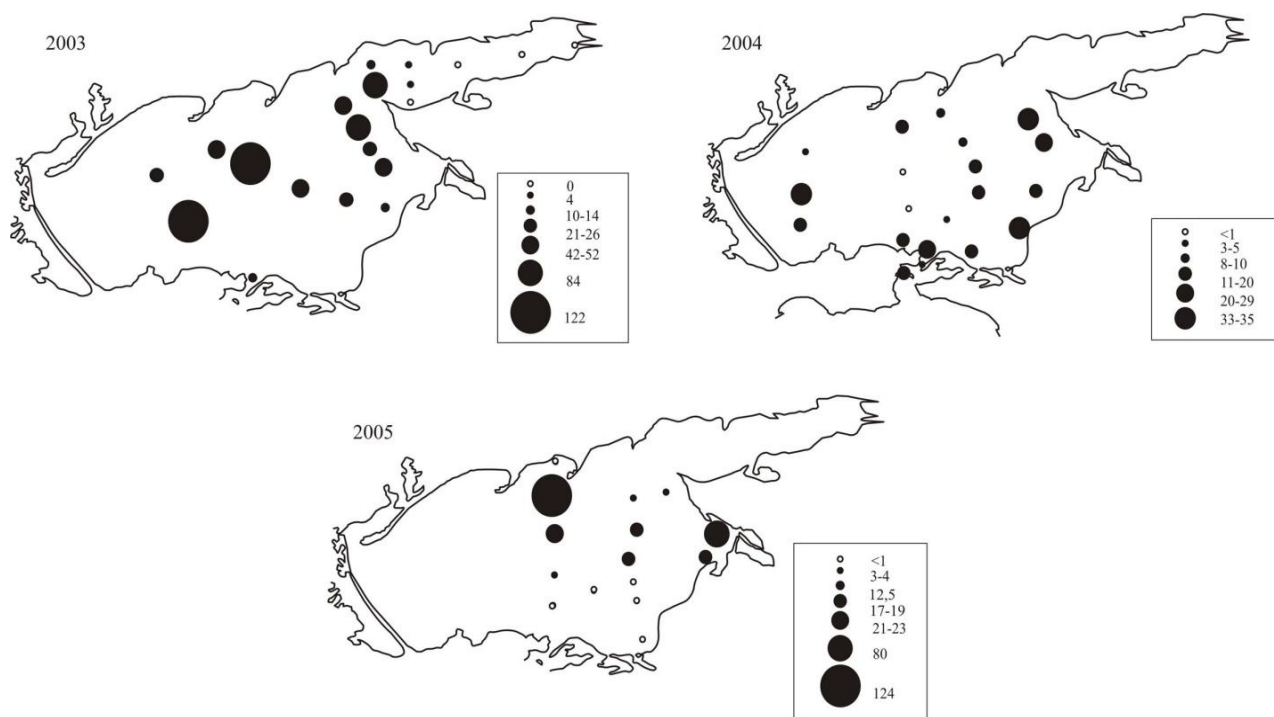


Figure 16 – Distribution of total numerical density (thousand ind./m<sup>3</sup>) in the Sea of Azov in June 2003–2005

The values obtained closely match the interannual differences in the water temperature in the investigated years. In June 2003 and 2005, average surface water temperature was up to 21.3–21.7°C; in June 2004, it was somewhat lower, 19.2°C. In 2003 and 2005, veliger and veliconch larvae of bivalves mostly contributed to the total abundance of meroplankton (53–71%), with *A. segmentum*, *Cerastoderma* sp., and *M. lineatus* being the most abundant (figure 17). Larvae of gastropods (18–20%) and cirripedes (5–22%) showed a lower abundance. The proportion of nektochaetes and trochophores of the polychaetes *A. succinea*, *N. hombergii*, *P. ciliata* and zoeae of the decapods *R. harrisi tridentate* was 4–6%. In 2004, the larval pool consisted for the greater part of *A. improvisus* (Cirripedia) (87%). In 2003, the numerical density of these organisms varied from zero values in zones of mortalities due to suffocation in the eastern Taganrog Bay to 122 thousand ind./m<sup>3</sup> in the central Sea of Azov. In 2005, the density of mollusks in the eastern and northern regions increased to 80–124 thousand ind./m<sup>3</sup>. Larvae of *A. improvisus* were fairly numerous and distributed throughout the sea in 2004. These were mainly early nauplii; cypris larvae were not greater than 7–11%. The maximum density (33–35 thousand ind./m<sup>3</sup>) occurred in eastern and western areas dominated by competent larvae of this species. In 2003–2005, relatively high concentrations of meroplankton were found in the eastern area (35–84 thousand ind./m<sup>3</sup>).

The commonest trigger mechanism of spawning is the warming up of water to a specific temperature. Rather, the distribution of meroplankton was related to a complex of factors, of which the predation pressure from the ctenophore *M. leidyi* is of no small importance. The relatively high water temperature in the Sea of Azov in June 2005 and high food availability

apparently stimulated its earlier invasion from the Black Sea. At stations situated in the southeastern and central areas of the Sea of Azov where the ctenophore occurred in large numbers, the meroplankton was extremely poor ( $\leq 1$  thousand ind./m<sup>3</sup>).

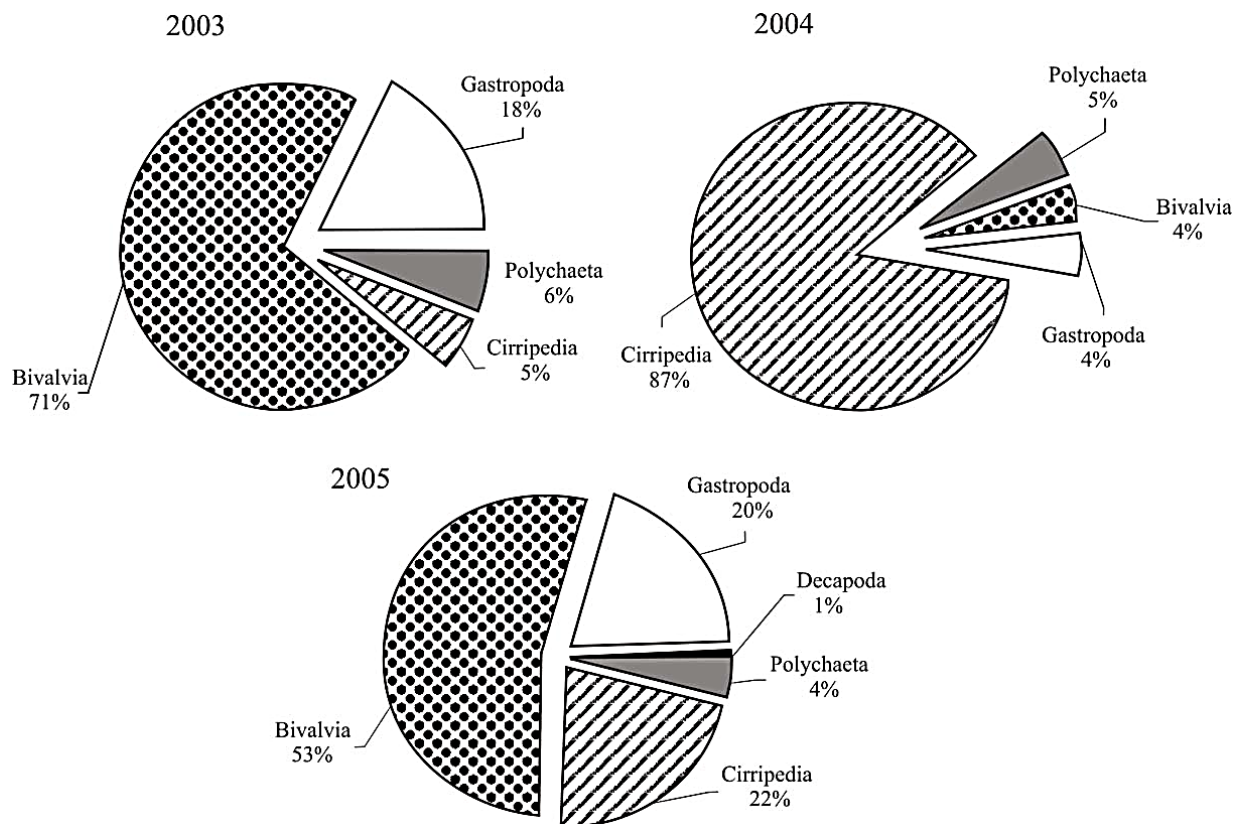


Figure 17 – Composition of meroplankton in the Sea of Azov (percent from the total numerical density) in June 2003–2005

A factor of no small importance in determining the distribution of meroplankton in the Sea of Azov is level of an eutrophication of waters and sulfide pollution of bottom sediments. A strong bloom of the noxious blue–green alga *Microcystis* observed in June 2005 in the northeastern part of Azov Sea (Yasakona, 2006) caused suffocation conditions, deterioration of water quality, and death of the fauna. Apparently therefore, the samples contained organisms (50–80%) that died before being fixed. The extreme paucity of meroplankton in the eastern Taganrog Bay in 2003 and in the central Sea of Azov in 2004 is a consequence of dangerous anthropogenic events, such as the hypereutrophication of the water. Allochthonous OM entering via the runoff from the Kuban River forms a resource available to meroplankton as suspended and dissolved OM. These sources are likely to contribute to a higher productivity of the eastern area, where the concentration of meroplankton in the period of study was up to 35–84 thousand ind./m<sup>3</sup>.

## Chapter 6 MAIN FEATURE OF SEASONAL DYNAMICS OF ZOOPLANKTON BIOMASS OF THE SEA OF AZOV ON EXAMPLE OF THE GULFS OF TAGANROG AND TEMRYUK

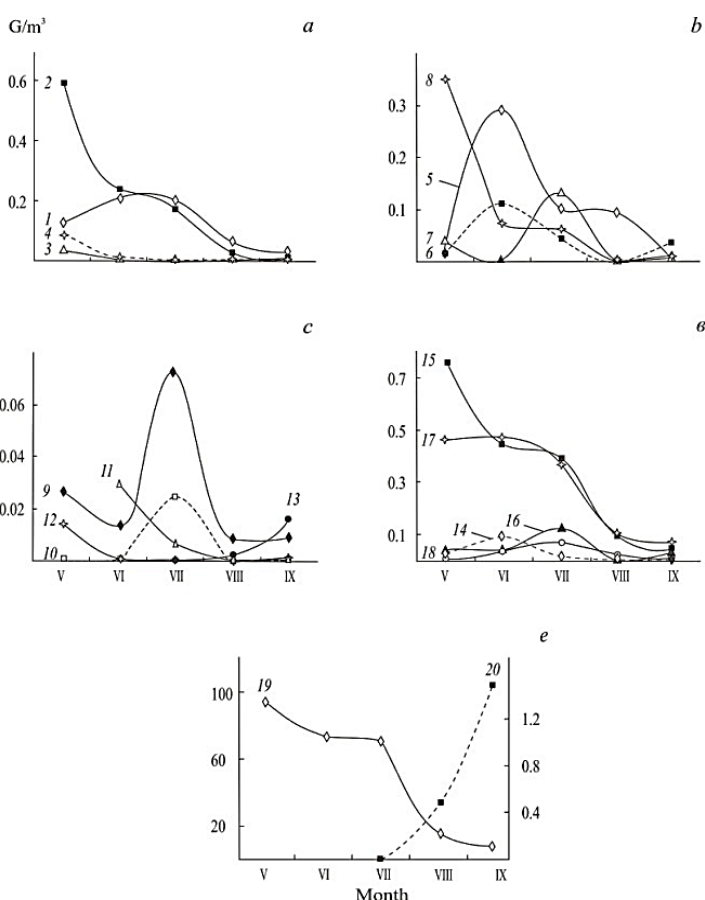
### 6.1 The Taganrog Gulf

The zooplankton of 66 taxonomical form were identified in the Sea of Azov in June 2003: 7 – Tintinnida, 18 – Rotifera, 11 – Cladocera, 20 – Copepoda, 1 – Ctenophora and 9 taxonomical form of meroplankton: 1 – Polychaeta, 1 – Cirripedia, 2 – Decapoda, 4 – Bivalvia, 1 – Hydrozoa (Selifonova, 2010b). The highest development is exhibited by *Acartia tonsa*, which determines the biomass of copepods during the vegetation season. The biomass of zooplankton is high in May (1.4 g/m<sup>3</sup>), in June-July – (1.0 g/m<sup>3</sup>) and low in August to September (0.2–0.15 g/m<sup>3</sup>). In May, the main zooplankton biomass consists of large freshwater rotifers dominated by *Asplanchna priodonta* (figure 18).

Figure 18 – Seasonal changes of zooplankton biomass (g/m<sup>3</sup>) in the Taganrog Gulf:

*a* – rotifers, *b* – Copepoda, *c* – Cladocera, *d, e* – main groups of zooplankton;

1 – *Brachionus* sp., 2 – *Asplanchna priodonta*, 3 – *Bipalpus hudsoni*, 4 – *Synchaeta* sp., 5 – *Acartia tonsa*, 6 – *Calanipeda aquaedulcis*, 7 – *Heterocope caspia*, 8 – *Eurytemora affinis*, 9 – *Bosmina longirostris*, 10 – *Diaphanosoma brachyurum*, 11 – *Podonevadne trigona*, 12 – *Cornigerius maeoticus*, 13 – прочие, 14 – Tintinnida, 15 – Rotifera, 16 – Cladocera, 17 – Copepoda, 18 – meroplankton, 19 – zooplankton (right axis ordinate), 20 – change of biomass of *Mnemiopsis leidyi* (left axis ordinate) (citer Povazhnyi, 2009).



The intensive development of rotifers is accompanied by the reproduction of copepods of *Eurytemora affinis*, in the western region of the gulf – larvae of barnacles. In June, the mass reproduction of ciliates tintinniids has been noted. Basic zooplankton biomass was formed by rotifers and copepods. In the western region of the gulf, *Brachionus quadridentatus* prevail; in the desalinated eastern region – *A. priodonta* and *Brachionus plicatilis*. Copepods of *A. tonsa* and *Calanipeda aquaedulcis* dominated and were widespread except for the Don River mouth, where *Eurytemora affinis* is localized. Zoea of decapods and larvae of polychaetes are present in meroplankton along with the larvae of barnacles. The fauna of cladocerans is reached most diversity in the eastern region, mainly *Bosmina longirostris*, in the western region – due to the presence of *Podonevadne trigona*. In the central part of the Taganrog Gulf zooplankton was weakly developed (0.016 g/m<sup>3</sup>) because the waters are “blossomed”

by a toxic blue-green algae *Microcystis aeruginosa*. In July zooplankton is still characterized by a high biomass of copepod *A. tonsa*, *E. affinis*, *C. aquaedulcis* and rotifer *A. priodonta*, *B. quadridentatus*, *B. calyciflorus*. At the time, the biomasses of the larvae of bivalve mollusks and of cladocerans *B. longirostris* and *Diaphanosoma brachyurum* increased significantly. In the central and eastern regions, the zooplankton biomass reaches maximal values of 1.4–2.2 g/m<sup>3</sup> and is seven to ten times higher than in the western region. In August and September, under the pressure of comb jelly, the zooplankton biomass in the western and central regions is less than 0.15–0.2 g/m<sup>3</sup>. The zooplankton was poor and consisted mainly from rotifers and *A. tonsa*. In the eastern part of the gulf, where the presence of comb jelly is limited by the salinity barrier (2.5–3‰), the copepods *C. aquaedulcis*, *H. caspia*, *E. affinis* and the cladocerans and rotifers *B. calyciflorus* and *Bipalpus hudsoni* actively reproduce.

## 6.2. The Temryuk Gulf

The zooplankton of 56 taxonomical form were identified in the gulf in 2005–2006 and 2010: 26 – Ciliophora, including 7 – Tintinnida, 13 – Rotifera, 1 – Ctenophora, 2 – Cladocera, 21 – Copepoda, 19 – meroplankton (Selifonova, 2011a). In the seasonal cycle of microplankton development, two peaks of biomass (spring (0.45 g/m<sup>3</sup>) and a more pronounced summer (0.9 g/m<sup>3</sup>)) were revealed; in zooplankton, there was one spring peak (3.7 g/m<sup>3</sup>) (figure 19). The share of holoplankton and meroplankton in the total biomass of

zooplankton reached 70% (1.3 g/m<sup>3</sup>) and was estimated as the maximal value for zooplankton of the Sea of Azov. The taxonomical structure of zooplankton was formed mainly under impact the runoff of the Kuban River. Marine and brackish water rotifers of the genus *Synchaeta* and *A. priodonta* constituted 55% of the zooplankton biomass. The most abundant meroplanktonic larvae of *A.improvisus* amounted to 30% of the total zooplankton biomass. Communities of ciliates and net zooplankton of the Temryuk Gulf are formed in correspondence with the phases of communities development in the pelagial. In May, holoplankton and meroplankton were dominated (the ratio of biomass of ciliates and zooplankton is 1 : 8) and, in August–September (the myxotrophic phase) the role of infusorians increased (8 : 1).

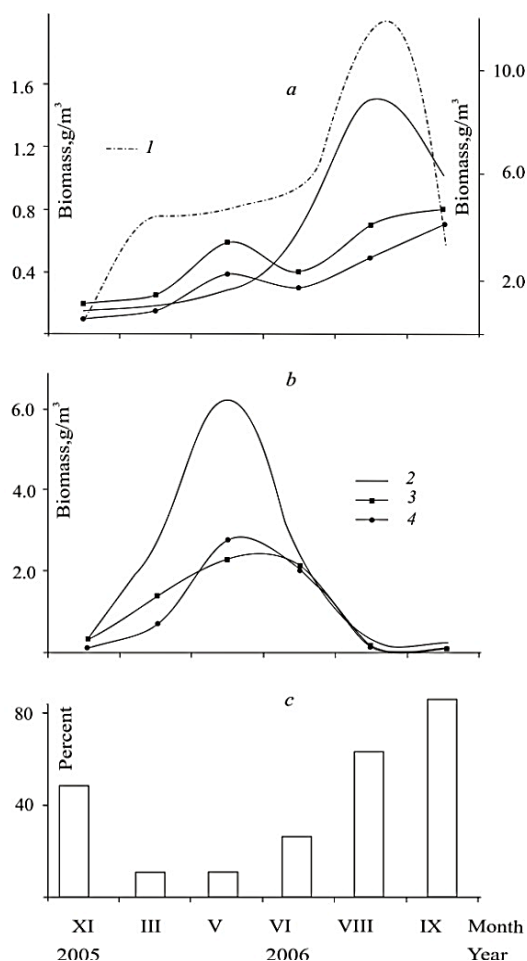


Figure 19 – Seasonal changes (g/m<sup>3</sup>) of phytoplankton (1, right axis ordinate), ciliates (a, left axis ordinate), holoplankton, meroplankton (b) and dynamics of content ratio (%) ciliates in zooplankton (c): 2–4 – at stations 1–3 homologous.

**Ciliates.** Among the ciliates, *Mesodinium rubrum*, *M. pulex*, *Halteria grandinella*, *Strombidium conicoides*, *Strombidium* sp. 1,2, *Strobilidium* sp., *Loxmaniella oviformis* и *Tintinnopsis minuta*. were dominant. The development of the planktonic community was determined by intensive water “bloom” at the expense of diatom algae (Yasakova, 2007). Biomass of ciliates averaged  $0.19 \text{ g/m}^3$  (11% of the total abundance of zooplankton). In its composition, the loricate form of infusorians tintinnids prevailed (~70–80% of biomass). The share of aloricate forms of the genera *Strombidium*, *Strobilidium*, *Didinium*, *Askenasia*, and *Urotricha* was small in the total amount of ciliates. In May, the biomass of ciliates increased to  $0.45 \text{ g/m}^3$ . This biomass formed after the degradation of the spring “bloom” of diatom algae. Along a phytophagous infusorians (big strombidiums and tintinnids), the role of small infusorians *M. rubrum* and *M. pulex* became evident ( $\leq 20\text{--}25\%$ ). A comparatively weak development of infusorians in near port waters is evidently determined by the abundance of the predatory rotifer *A. priodonta* and toxic blue-green alga *M. aeruginosa*. In June, the level of microplankton biomass did not undergo considerable changes. At the same time, along with phytophages, the role of bacteriophages (small strombidiums, strobilidiums, *L. oviformis*, and chalterids), peritrichs, and *M. rubrum* noticeably increased (70%). The mass development (biomass  $0.5 \text{ g/m}^3$ ) of *M. rubrum* was observed at the port water, which was embraced by the bloom of blue-green algae. The epibiotic peritrichs *Vorticella anabaena* developed on blue-green algae. Aggregations of blue-green algae evidently promoted the reproduction of infusorian *Coleps hirtus*. An intensive increase in the biomass of ciliates (maximal peak  $0.9 \text{ g/m}^3$ ) was observed from August to mid September. Infusorians were represented by *M. rubrum* and small mobile forms of the genera *Strombidium* and *Strobilidium*, many of which were at a stage of division. Infusorians dominated ( $1.5 \text{ g/m}^3$ ) at eutrophic port waters, having formed 60–80% of the biomass of zooplankton. At outside the harbor areas, were embraced by an intensive bloom of toxic dinoflagellate *Prorocentrum micans* (1 million cell/l) along with oligotrichids and species of the family Didiniidae, were recorded tintinnids *Tintinnopsis subacuta*, *T. cylindrica*, *T. baltica*, and *T. minuta* in noticeable concentrations. In November, infusorians biomassy decreased to  $0.2 \text{ g/m}^3$  became comparable to the biomass of zooplankton. *M. rubrum* and *Tintinnopsis lobiancoi*, diverse small strombidiums and strobilidiums developed in ciliates community.

**Holoplankton, meroplankton.** In March, the average biomass of zooplankton reached  $1.6 \text{ g/m}^3$  (figure 20). This biomass was formed on 93% by rotifers genus *Synchaeta*. An intensive development of rotifers *A. priodonta* was recorded at near-port area “blossoming” by green and blue-green algae. In May, the biomass and abundance of mesoplankton increased to  $3.7 \text{ g/m}^3$ , and the intensive development of synchaete rotifers, *A. priodonta* (>70%) and larvae of barnacle *A. improvisus* (27%) was observed. Freshwater cladocerans (*B. longirostris*), cyclopids, and larvae of bivalves dominated in the desalinated port area of the Temruyk gulf. In June, with a decrease in the role of predators (*Asplanchna*) in the community of zooplankton, the level of its biomass fell ( $2 \text{ g/m}^3$ ).

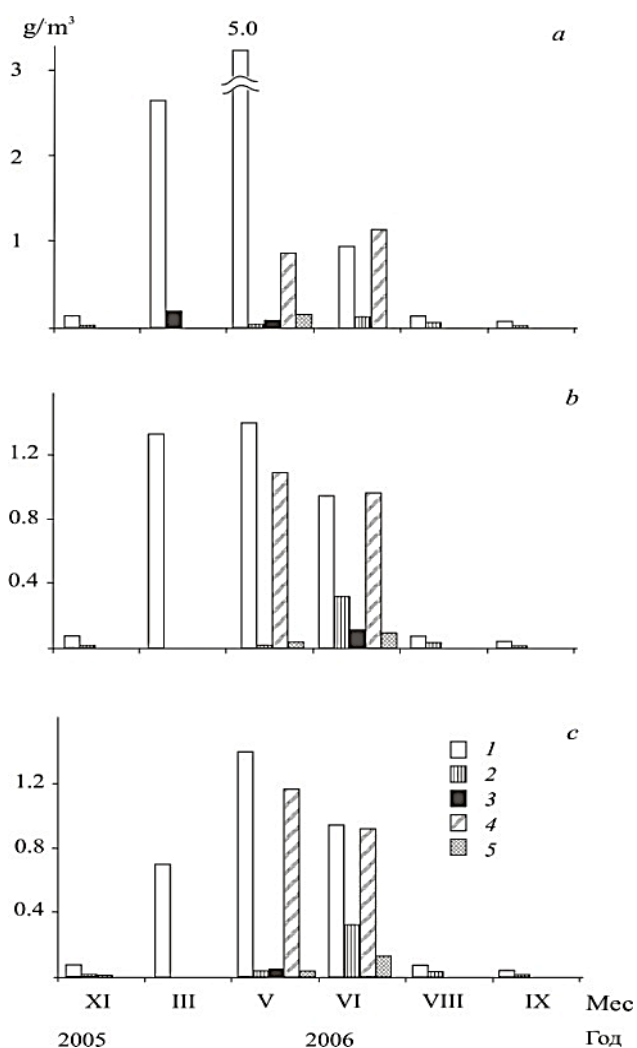


Figure 20 – Seasonal changes ( $\text{g/m}^3$ ) of main species and groups of holoplankton, meroplankton: *a* – station 1, *b*– station 2, *c* – station 3; 1 – Rotifers, 2 – *Acartia tonsa*, 3 – Cyclopoida, 4 – *Amphibalanus improvisus*, 5 – larvae of Mollusca

Along with synchaete rotifers and larvae of barnacle (86% of the total biomass of zooplankton) are noted a development of copepods biomass; among them, *A. tonsa* dominated ( $0.3 \text{ g/m}^3$ ). With a distance from the port, we observed increase of abundance of marine species of copepods, cladoceran *P. polyphemoides*, and larvae of bivalve mollusks. However their biomass was low (summarized  $0.2 \text{ g/m}^3$ ). In August, under the pressure of predatory comb jelly *M. leidyi* the zooplankton was absent an almost complete (biomass  $0.12 \text{ g/m}^3$ ). In September, the biomass of zooplankton in the study area continued to remain extremely low ( $0.06 \text{ g/m}^3$ ). Crustaceans *Acartia*, cyclopoid copepods, cladocerans, larvae of barnacles and polychaetes were by single individuals. In November, the reproduction of most organisms of holoplankton, neroplankton and predatory comb jelly at the Sea of Azov ceased and a decline occurred in their development. 85–90% of the zooplankton consists of synchaete rotifers. Comb jelly wasn't found. Crustaceans *A. tonsa* and *C. ponticus*, larvae of barnacles, polychaetes, gastropods, and bivalves mollusks occurred sporadically.



## Chapter 7. STRUCTURAL FUNCTIONAL ORGANIZATION OF THE SEA OF AZOV ECOSYSTEM OF DIFFERENT TROPHIC PATTERN

At the open part of the Sea of Azov under conditions of high water eutrophication and intensive contamination of bottom sediments by sulfur hydroxide, along with absence of a normal food web, a quite stable but transformed ecosystem has been formed (Selifonova, 2008b).

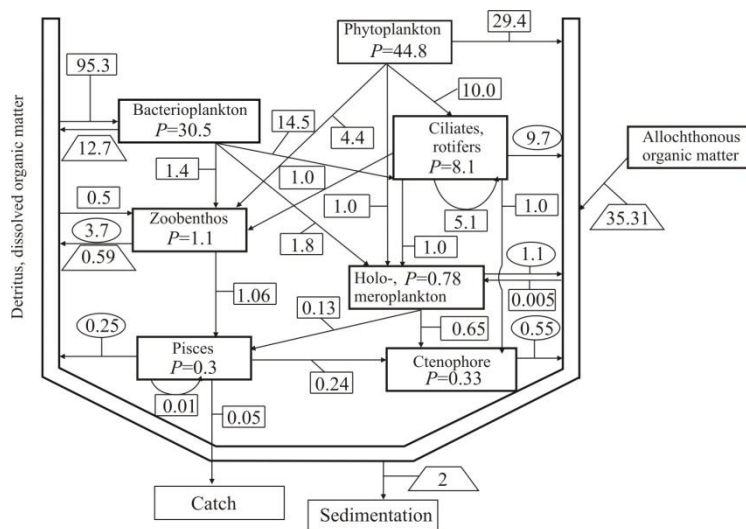


Figure 21 – Scheme of trophic chain and daily energy flows ( $\text{kJ}/\text{m}^2$ ) between its components in open part of the Sea of Azov

The main energy flow passed through the microbial food chain in which microheterotrophic organisms played a major role – bacteria (78.3% of energy flow), ciliates (8%). A total destruction of organic matter was almost twice as high as phytoplankton production. Along with eutrophication and sulfate reduction, the impact of the predatory ctenophore *M. leidyi* is an important factor determining, to a considerable extent, the character of transformation of the ecosystem, its further structure, and its low productivity. At their peak of development, comb jelly consumes about 83–99% of the

zooplankton production. This results in a sharp decrease in the species diversity and biomass of planktonic community and gives rise to an ecosystem crisis (figure 21). As a result of the disbalance of primary production and its expenditure by heterotrophic organisms ( $P/D = 4.6$ ), the OM accumulates in the water column and bottom.

The hypereutrophic ecosystem of the central region of Taganrog Bay was the most deeply transformed. There was destructed and simplified the animal trophic chain (degradation of the fish community, macrozoobenthos, and zooplankton, including the planktonic protozoans) (figure 22a). The ecosystem metabolism is provided mainly by the mixotrophic blue-green algae and heterotrophic bacteria, which accounts for 69.5% and 30.35% of the sum destruction, respectively. In such an ecosystem with a disturbed food chain and degraded a biofilter, OM produced by cyanobacteria is not in fact consumed. Accumulated on the bottom not consumed biomass of cyanobacteria contributes to a anoxia and sulfate reduction. At the critical regime (at the disbalance of energy flows), the OM accumulated in the water column and on the bottom sediments. The considerable part of flow of energy in the such ecosystem was spent for the intensification of sulfate reduction in the bottom sediments, that aggravated an ecological situation. An ecosystem lacks stability, undergoes deep transformation, and ends with an energetic collapse chain and the inability for the ecosystems to selfpurify.

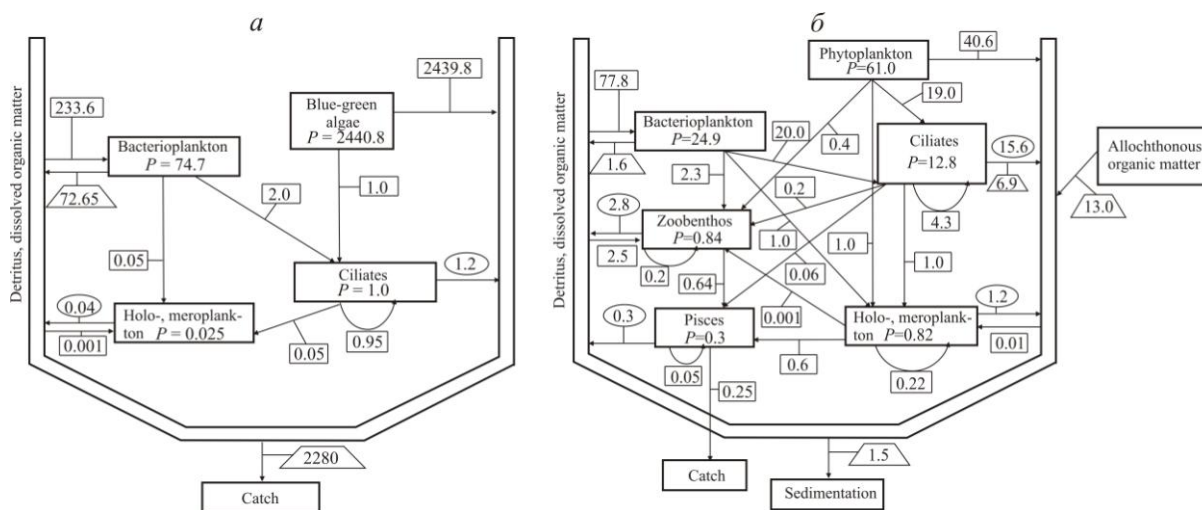


Figure 22 – Scheme of the energy flow ( $\text{kJ}/\text{m}^2$ ) (a) in the ecosystem of the central region of the Taganrog Gulf at the zone of the local water bloom by blue-green algae and (b) in the ecosystem of western region in June 2003.

A complicated food web with abundant zooplankton is a characteristic of such an ecosystem of the western region of the Taganrog Gulf (figure 22b). The largest fraction of the energy flow in the ecosystem passes through the microbial food chain: bacteria (~69.3% of the energy flow) and ciliates (14%). The destruction of hetero-trophs was 1.2 times higher than the phytoplankton primary production. At a relatively low biomass of zooplankton and depressed macrozoobenthos, the activity of microheterotrophs in the food chain “bacteria–infusoria” (the so called “microbial loop”) is sufficient for the effective metabolism of the western region ecosystem. Here, along with heterotrophic bacterioplankton, the infusoria, in particular consumers of a phytoplankton loricate infusorians Tintinnida, are intensively developed. Its production and metabolism are three to six times higher than those ones in holoplankton, meroplankton, zoobenthos, and fish. The Taganrog Gulf ecosystem has not fully collapsed in the period of ecological disasters triggered by the water hyper blooming of blue-green algae only due to the well developed loricate infusoria.

Predatory comb jelly *M. leidy* is an estuarine species reaching a high number at a water salinity of 3.5–4‰ (lowered salinity facilitates its reproduction). The mass development of *M. leidy* is confined to the central and western regions where, according to paper (Grebnevik., 2000), its average long-term biomass ( $226 \text{ g}/\text{m}^3$ ) is more than two times higher than in the open part of the Sea of Azov. The absence of considerable differences in the distribution of comb jelly biomass in the Taganrog Gulf (Grebnevik., 2000) makes it possible to consider the western and central regions as united ecosystem (figure 23). In the period of the mass development of comb jelly (August–September), the fraction of phytoplankton and bacteria in the ecosystem biomass reaches 75% and >80% of the total energy flow passes through the microbial food chain. The excreta of comb jelly (mucus excreted from the body surface) give favorable conditions for the development of microheterotrophs, first and foremost of the bacterial community (Shiganova, 2009), the biomass of which reaches  $\geq 2$

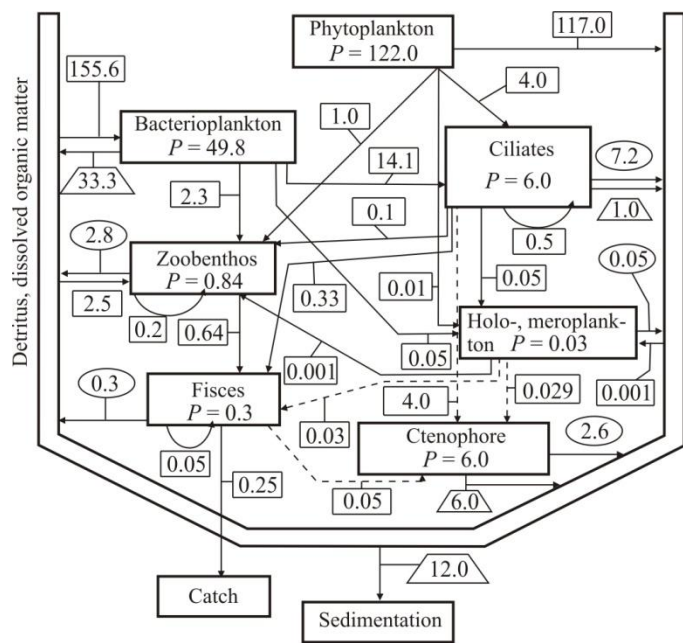


Figure 23 – Scheme of the energy flow ( $\text{kJ/m}^2$ ) in the ecosystem of the central and western regions of the Taganrog Gulf upon the mass development of comb jelly *Mnemiopsis leidyi* (August–September 2003)

$\text{g/m}^3$ . The phytoplankton is dominated by diatoms of g. *Leptocylindrus* and *Skeletonema costatum*, green filamentous forms Ulothrichaceae, and blue-green alga *Microcystis aeruginosa* (Makarevich, 2007). The net zooplankton biomass is very low and is similar to that observed in June at strong water blooms occurring in the central part of the gulf (see. figure 8a). Metazoic plankton (nauplii, holo- and meroplankton and small fish larvae) serves as the main food for comb jelly. According to the model calculations, at their peak of development, comb jelly consumes about 97% of the net zooplankton production. This results in a sharp decrease in the species diversity and biomass of planktonic community and gives rise to an ecosystem crisis. Only a negligible fraction of the phyto- and bacterioplankton can be utilized by the almost fully exterminated holo- and meroplankton, and its production can

cover only 2.5% of the fish demand for food. Eutrophication and a sharp decrease in the number of phytoplankton consumers is one of the main reasons for the increase in the phytoplankton production up to the level of water bloom in the Taganrog Gulf. Presumably, comb jelly can feed on the predatory rotifer *Asplanchna*, which consumes a large amount of crustaceans. In addition, it can eat smaller organisms, including infusoria stuck on the mucus of its lappets. It is also important that the mass development of comb jelly depresses the populations of pelagophylic fish due to the deterioration of the feeding conditions of the fish. Comb jelly eats almost all of the planktonic biofilter, decreasing the ecosystem's selfpurification ability, and its metabolites facilitate the intensification of sulfate reduction in the mud bottom sediments and the increase in oxygen deficiency.

The development of hyperdense communities of ciliates and detritophages during the specific periods of vegetative season characterized a hypereutrophic pelagic ecosystem of the Temryuk Gulf. However, the metabolism of this unique ecosystem remained very intensive due to the rapid development of community of heterotrophs. The rotifers and larvae of *A. improvisus* (total biomass  $3.7 \text{ g/m}^3$ ) assimilated and introduced in turnover  $1.6 \text{ g/m}^3$  of the phyto- and bacterioplankton that prevented the formation of steady bloom of toxic phytoplankton (figure 24a). The uniqueness of estuarial ecosystem consisted in that metazoic plankton is an important component of an ecosystem. Its share in the destruction of OM reached 6.5%. During the greatest warming up of waters in an ecosystem was noted the elimination of the higher element of trophic chain (planktonic filtration organisms) influenced by comb jelly (figure 24b). Phytoplankton production exceeded negligible a total destruction

of organic matter by heterotrophs ( $P/D = 1.05$ ). In such conditions the organic self-pollution of ecosystem could take place.

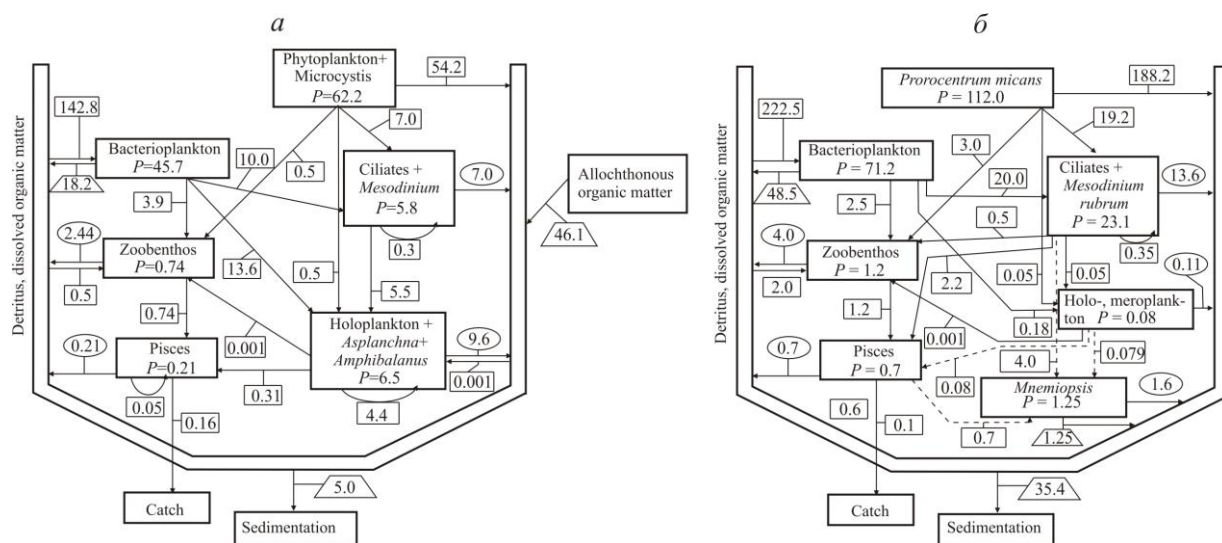


Figure 24 – Scheme of the energy flow ( $\text{kJ/m}^2$ ) in the ecosystem of the Temryuk Gulf in May 2006 upon the masse development of rotifers and the larvae of barnacles (a) and in August, when the predatory comb jelly *M. leidy* influences the damaging impact on an ecosystem (b)

However, the processes of energy accumulation by autotrophs and its consumption by heterotrophs were balanced, that restrained the development of crisis processes. In conditions, where the holoplankton and meroplankton could hardly exist the infusorians consumed and mineralized a significant amount of primary food. At maximal biomass  $0.9 \text{ g/m}^3$  ciliates assimilated and introduced in turnover  $\sim 2.0 \text{ g/(m}^3 \cdot \text{day)}$  of the bacteria and microalgae.

## CONCLUSION

Complete characteristic of an ecosystem was received for each studied region. The key components and the most important factors of the environment defining their structure and functioning are revealed. Model schemes of energy flows are constructed. Analysis of model energy flows in ecosystem of different trophic pattern showed that the ecosystems of the coastal waters of the northeast Black Sea and the Sea of Azov are in state of varying degrees of transformation and degradation, depending up the level of anthropogenic loading and coastal drain. Ecosystems of the bays of Gelendzhik and Anapa with the high level of recreation support the normal food chain, including zoobenthos and macrophytes. The open ecosystem of the Taman' port with intensive water exchange is the basis of the normal port ecosystem. The depressive state of zoobenthos of bottom sediments (polychaetes, nematodes) is shown in half-closed ecosystem of the ports of Novorossiysk, Tuapse, Sochi and the Liman "Zmeinoe ozero". The microheterotrophs (bacteria and protozoan) were main functional component of studied ecosystems. The most part of energy flow in ecosystem passed through a bacterial link (78–88% of energy flow) and an infusorians (< 12–22%). The biological communities had the high self-purification capacity and carried out destructive processing of incoming excess OM are completely.

Quite stable but transformed ecosystem was formed at the Sea of Azov under the influence of high eutrophication of waters and the intensive contamination of bottom sediments by sulfur hydroxide as well as the press of predator ctenophore *Mnemiopsis leidyi*. Microheterotrophic was a key functional component in this ecosystem with depressed zooplankton and zoobenthos. The main energy flow passed through the microbial food chain. Bacterial community carried out the destruction of OM at 70-80%, ciliate – at 5.3–14%. During the some seasons of the year a role of holoplankton and meroplankton (rotifers and larvae of cirripede barnacles) has increased in the metabolism of ecosystem of the Temryuk Gulf, a role of tintinnids infusorians – in the western region of the Taganrog Gulf. Hypereutrophic ecosystem of the central area of the Gulf of Taganrog have been most deeply transformed. In this ecosystem the animal food chain destroyed almost completely (degradation of zoobenthos, zooplankton, fish kills). The mixotrophic blue-green algae and heterotrophic bacteria were the key components of this ecosystem (69.5% and 30.35% of the energy flow, respectively).

Anthropogenic transformation of investigated ecosystem was based on the degradation of upper elements of the trophic chain in pelagic and benthic communities. Generally the number of infusorians and their role increased sharply in a sum metabolism of these ecosystem. The crisis processes in ecosystem happened under the influence of labile (acid-soluble) sulfides in the upper layer of bottom sediments and the press of predators *M. leidyi*. The productionally destructional functions of benthic communities were redistributed to planktonic communities. These ecosystem functioned at the level of microheterotrophs (bacteria and ciliates).

Totally, 211 taxonomical forms were identified in the northeastern Black Sea, including zooflagellates – 10, ciliates – 54 (31 taxonomical forms haven't been specified for the region earlier), meroplankton – 78 (49 taxonomical forms not mentioned previously for the region),

ichthyoplankton – 33. The zoobenthos of mud bottom sediments of the gulf and the bays of Novorossiysk, Tuapse, Sochi, Taman', Anapa and the Liman "Zmeinoe ozero" was represented by 62 taxonomical forms, including 2 taxonomic forms not mentioned previously for the region. 116 taxonomic forms were identified in the Sea of Azov: ciliates – 26, holoplankton – 64 (1 taxonomical forms not mentioned previously for the region), meroplankton – 26 (16 – taxonomical forms not mentioned previously for the region).

It has been established that the risk of biological invasion with ships' ballast water from the Mediterranean Sea to the northeastern Black Sea is the most probable. The main "risk groups" of biological invasion are tintinnids, copepods and polychaetes. A six invasive species *Tintinnopsis directa*, *T. tocaninensis*, *Amphorellopsis acuta* (Ciliata: Tintinnida), *Oithona davisae* (Copepoda: Cyclopoida), *Polydora cornuta*, *Streblospio gynobranchiata* (Polychaeta: Spionidae) were established in coastal waters of the northeastern Black Sea and an one invasive species *O. davisae* – in the Sea of Azov.

A positive constructive changes in the neritic communities of the northeastern Black Sea are shown. In long-term dynamics in ecosystem gulf and bays the press of predator ctenophore *M. leidy* and the heterotrophic noctiluca reduced. At the same time the abundance of holoplankton and meroplankton increased to the level of the 1960<sup>th</sup> and 1970<sup>th</sup>, of ichthyoplankton – to the level of the 1980<sup>th</sup>. The autumn maximum of holoplankton biomass, which was absent in the 1990<sup>th</sup>, was marked. A multifold increase of the density of a rare oligotrophic form Copepoda and Cladocera as well as common Black Sea species *Pleopis polyphemoides*, acartia, parasagitta, appendicularia, naturalized cyclopoid copepods *Oithona davisae* was recorded.

For the first time, the long-term monitoring of a meroplankton which included total taxonomic complex was performed. The larvae of new species of polychaetes *Polydora cornuta* are noted in the ports and the bays of the northeastern Black Sea. The seasonal complexes of a dominant species are defined. Tolerant species to pollution of bottom sediments dominated in the mass spawning of meroplankton. Interannual dynamics of numerical density of meroplankton had a significant variability. Influence of water temperature, wind-driven oscillations, eutrophication of waters and predators on density and distribution of a meroplankton was noted. At the Sea of Azov the most larvae of benthic invertebrates are unable to complete metamorphosis and to contribute to the replenishment of parental populations under anthropogenic stress and predation pressure.

The monodominant ichthyoplankton complex prevailed in the harbor water areas of the northeastern Black Sea and the Kerch Strait, the polydominant ichthyoplankton complex – beyond ports and resorts cities. The reaction of ichthyoplankton to a stress in polluted waters was manifested in high elimination and low abundance of eggs and larvae. In open part of the Novorossiysk Bay the structure of ichthyoplankton was most well-situated. The rise of the numerical density of eggs and larvae of the rare species of fishes (Red Data Book species) are registered in waters of health resort cities and open part of the Novorossiysk Bay.

The some of increase of trophic level of waters of health resort cities of the northeastern Black Sea was revealed according of the structure of heterotrophic bakterioplankton. The numerical density of microheterotrophs (bacteria, zooflagellates, infusorians) increased in summer – autumn. The peaks of bacteria abundance usually accompanied increased abundance

of zooflagellates. The infusorians density are regulated on one side the availability of trophic resources ("bottom up" control) and on the other side the press of consumers ("top down" control). In waters of the large ports cities the ratio of tintinnids to the total abundance of ciliates increased five times and reached 25–40%.

The degrading changes in holoplankton and meroplankton communities of the Sea of Azov under the influence of "the perturbing factors" – the press of a predatory comb jelly of *M. leidyi* and an eutrophication of waters are shown. Existence of peak of zooplankton in the spring – at the beginning of summer is revealed. In holoplankton is noted the insignificant quantity of structure-forming species in June (most productive month of year). In June zooplankton reached the greatest abundance in the northeast region of the Sea of Azov, the Temryuk Gulf and the western part of the Taganrog Gulf. The maximum number of holoplankton was formed by organisms with short and simple life cycles – the rotifers of genus *Synchaeta* and the predatory rotifer *Asplanchna priodonta*.

Te several faunistic complexes of the Sea of Azov copepods are allocated with regard to salinity. The marine euryhalinic species of *Acartia tonsa* was noted almost everywhere, excepting the most desalinated estuarial areas of the rivers. Fresh-water evryhalinic cyclopoid copepods and marine evryhalinic harpacticoid copepods were characteristic for the estuarial population of gulfs. Among marine species observed in the Strait of Kerch' only of *C. ponticus* penetrated into the Sea of Azov to an isohaline of 7‰. This species formed aggregations in the central part of the sea. Euryhalinic species *C. aquaedulcis* was found everywhere. *E. affinis* formed aggregations in the Taganrog Gulf and the Temryuk Gulf. Stenohalinic species *Heterocope caspia* had limited area – the Taganrog Gulf.

The relationship between infusorians, holoplankton, meroplankton in the process of sucesional cycle of changes of their structure in the Temryuk Gulf ecosystem was studied. In May, the ratio of biomass of ciliates and zooplankton (rotifers and larvae of cirripede barnacles) was 1 : 8 and in August–September due to of the consume of zooplankton by ctenophore *M. leidyi* and the increase of role of infusorians, had inverse proportion – 8: 1.

Results of these research promote to the development of ideas on the changes in the most vulnerable marine ecosystems of the Black Sea and the Sea of Azov under the influence of the intensive anthropogenic influence connected with their economic exploitation (navigation, recreation, refishing and other factors). Therefore they can be used as a scientific basis for diagnostic monitoring and ecological forecasting, when developing an actions for rehabilitation of water resources and their protection. The data on biological invasions can be applied to rational processing of ship ballast waters and the prevention of introduction of alien species. Scientific method of control ships'ballast water used by the Department of ecological control of Federal State Budgetary Establishment "Authority of seaports of the Black Sea". The study was became a scientific and practical basis for lawmaking activity in the sphere of marine and river transport of the Russian Federation.

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Оригинал-макет **В. Преображенская**

Подписано в печать 23.01.18. Изд. № 1540

Формат 60x84 1/16 . Печать оперативная

Усл.печ.л.3,5. Уч.изд.л. 4,6. Тираж 500. Заказ 3621.

Редакционно-издательский отдел

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ОК-005-93, том 2: 953000



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### Research experience

- Structural functional organization of ecosystem of bays and harbours of the northeastern Black Sea and the Sea of Azov (Russian sector);
- Ships'ballast water of the Novorossiysk port and the invasions of alien species of zooplankton and zoobenthos in biodiversity and productivity of ecosystems of the northeastern Black Sea and the Sea of Azov;
- Taxonomical composition, abundance and seasonal dynamics of zooplankton communities (zooflagellates infusorians, holoplankton, meroplankton, ichthyoplankton), heterotrophic bacterioplankton and zoobenthos of mud bottom sediments.