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КАЧЕСТВО ВОДЫ И БИОРАЗНООБРАЗИЕ ДОННЫХ ЖИВОТНЫХ В ЭСТУАРИИ РЕКИ НЕВЫ В УСЛОВИЯХ АНТРОПОГЕННОГО СТРЕССА

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В 1994—2015 гг. в эстуарии реки Невы были зарегистрированы 188 таксонов бентосных животных. В настоящее время в сообществах зообентоса эстуария доминируют эврибионтные виды-индикаторы, населяющие «загрязненные» и «грязные» воды. Мы использовали интегральный показатель IP', специально разработанный для водоемов и рек северо-западной части России, для оценки качества воды и состояния экосистем эстуария реки Невы. Он основан на структурных характеристиках сообществ зообентоса и позволяет учитывать смешанное загрязнение токсичными и органическими веществами. В среднем качество вод Невской губы, оцениваемое по интегральному показателю (IP′) оставалось достаточно постоянным в течение 1994—2015 гг. Её воды оценивались как «загрязненные» за исключением 2006 и 2015 гг., связанным с крупномасштабными дноуглубительными работами. Среднее количество видов зообентоса в Невской губе в период 1982—2015 гг. увеличилось почти в 2 раза с 11 ± 1 в 1982 г. до 20 ± 2 видов на одной станции в 2014 г. Средние значения индексов Шеннона бентосных животных в Невской губе увеличились в полтора раза от 2 ± 0.1 в 1982 г. до 3.0 ± 0.3 бит/экз. в 2014 г. В 1994—2015 гг. значения видового богатства и индекс Шеннона, средние для курортного района восточной части Финского залива, варьировали от 5 ± 0.6 до 11 ± 2 видов на одной станции и от 1.1 ± 0.2 до 2.1 ± 0.3 бит/экз. и были намного ниже, чем в Невской губе. Это обусловлено не только влиянием солености, но и более интенсивным загрязнением этого района.

Ключевые слова: антропогенное воздействие, биоразнообразие, зообентос, качество воды.

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WATER QUALITY AND BIODIVERSITY OF BENTHIC ANIMALS IN THE NEVA ESTUARY UNDER ANTHROPOGENIC STRESS

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188 taxa of benthic animals were recorded in the Neva estuary in 1994—2015. At present, zoobenthic communities in the estuary are dominated by eurybiont indicator species inhabiting “polluted” and “dirty” waters. We used integrated index IP' specially devised for water-bodies and rivers of the north-western Russia to assess the water quality and a state of ecosystems of the Neva estuary. It bases on structural parameters of zoobenthic communities and makes it possible to take into consideration the pollution by toxic and organic substances. On average the water quality of the Neva Bay assessed from IP′ values was relatively stable during 1994—2015. It was assessed as «polluted» with exception for 2006 and 2015 caused by large-scale dredging works. The average number of zoobenthic species in the Neva Bay increased during the period of 1982—2015 almost 2 times from 11±1 in 1982 to 20±2 species on a single station in 2014. Average values of Shannon’s indexes of benthic animals in the Neva Bay increased by one and half from 2±0.1 in 1982 to 3.0±0.3 bit/ind. in 2014. In 1994—2015 values of species richness and Shannon’s index, average for the Resort zone of the eastern Gulf of Finland, varied from 5±0.6 to 11±2 species at single station, and from 1.1±0.2 to 2.1±0.3 bit/ind. that were much lower than in the Neva Bay. This is caused not only by the influence of salinity, but also by the more intensive pollution of this zone.

Key words: anthropogenic stress, biodiversity, zoobenthos, water quality.

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Introduction. During the last decades the substitution of chemical water quality control by biological one goes on in many countries and in Russia as well, and the priority of biological indices became evident for ecosystem state assessment [1]. Methods of ecosystem state and water quality assessment based on structural characteristics of benthic communities have been applied traditionally and successfully in the entire world. It was underlined that distribution, structure and dynamics of benthic communities are a key for understanding of conditions and changes in the freshwater ecosystem functioning [2]. In the monitoring of Finnish coastal waters macrozoobenthos is used as a measure of a state of ecosystems (The state of Finnish coastal waters in the 1990s, 2001). The Neva estuary conditions have been studied by the scientists of the Zoological Institute of the Russian Academy of Sciences (RAS) since 1982. The structural and functional characteristics of benthic communities were also used for the assessment of the state of the Neva bay and the eastern Gulf of Finland since the early 1980s to present time [3—9]. The long-term studies of Zoological Institute have shown that the state of biological communities of the eastern Gulf of Finland are directly related to the water quality and the quality of bottom sediments reflecting such kinds of anthropogenic impacts as eutrophication of open and coastal waters of the Gulf of Finland and their contamination by toxic substances. The long-term studies have also shown a further eutrophication of the open and coastal waters of the Neva estuary, which began in the late 1990s and apparently was brought about mainly by the unfavorable climatic changes. This has led to an increase of primary production and phytoplankton biomass, predominance of cyanobacteria, “green tides” of macroalgae in the coastal zone, development of near-bottom hypoxia, deterioration of aboriginal communities of benthic animals, invasion of alien species, and a decrease in the food supply of fish [10—12]. The aims of the present work is to study characteristics of the benthic community of the Neva Bay and Resort zone of the Neva estuary and their changes induced the natural and anthropogenic factors, and to assess the water quality and ecosystem conditions in the Neva estuary.

Study area. The Neva Bay is located from the mouth of the Neva River in the east to the St.-Petersburg Flood Prevention Facility Complex.The Neva Bay is a freshwater part of the Gulf of Finland, where salinity does not exceed 0.2 ‰ (fig. 1). Area of the Neva Bay is 380 km², its length is 21 km, the greatest width — 15 km. The predominant depths are 3—5 m in the area of natural depressions of the bottom to 6.4 m [1, 13]. One of the major features of the state of the Neva Bay is the high rate of water exchange. Water in the Neva Bay renews every 2.5—5.5 days [14].

The eastern Gulf of Finland can be divided conventionally into a shallow zone (inner estuary) with depth 13—25 m and salinity 1—2 ‰, and a deep water zone (outer estuary) with depth 25—50 m and salinity

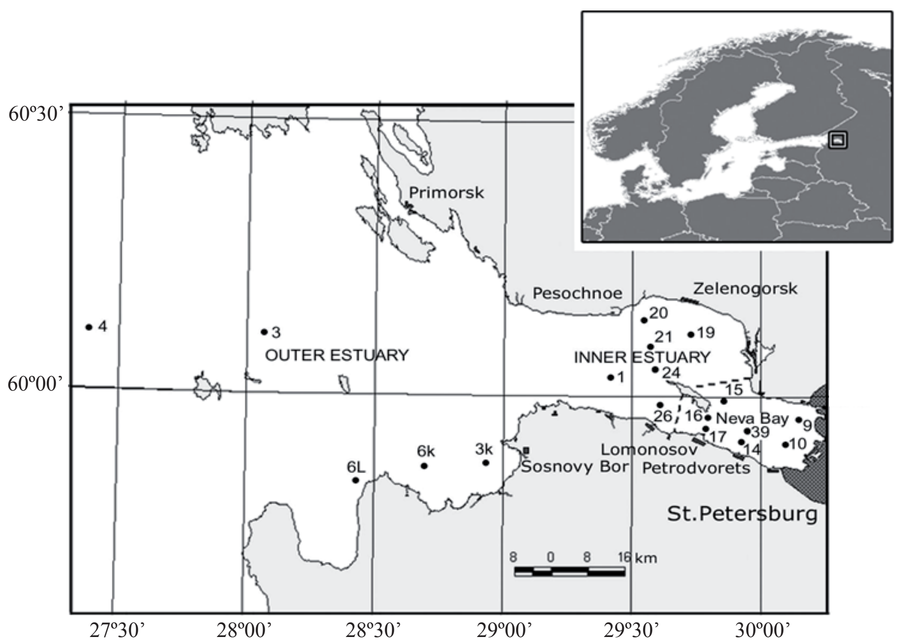

Fig. 1. Neva Estuary at the eastern Gulf of Finland.

Рис. 1. Невский эстуарий в восточной части Финского залива.

2—7 ‰. The Resort zone of the eastern Gulf of Finland with depths 13—25 m and the salinity 1—2 ‰ is bounded on the east by "dam" and includes the stations 19, 20, 21, 24 and 26 (fig.1).

Materials and methods. Samples of macrozoobenthos, were used to analyze the species composition, the quantitative characteristics of zoobenthos, and the assessment of water quality and ecosystem state in the Neva Bay and the eastern Gulf of Finland. They were collected by the scientists of the Laboratory of Freshwater and Experimental Hydrobiology of Zoological Institute of RAS at the beginning of October 1994 and 1995; in August 1996—1998; June 2001; July 2003; and in July and August 2002, 2004—2015. The number of stations studied in different years are presented in table 1. Location of investigated stations is shown in fig. 1.

Zoobenthos was sampled using the modified Van Veen grab (20×20 cm) and sieved in the field through a 0.4 mm mesh. In 1994—2015 the identification of animals' species was conducted by the scientists of Zoological Institute of RAS: oligochaetes by N. P. Phynogenova and I. G. Tsyplenkina; mollusks by Ya. I. Starobogatov; chironimids by E. V. Balushkina; and amphipoda by A. A. Maximov and T. D. Slepukhina, and the scientists of Lymnology Institute of RAS. The list of the species was published in [15—17]. The zoobenthos community of the Neva estuary was characterized by its species composition, number of species, biomass, and indexes, which were estimated on their basis.

For the assessment of water quality and a state of ecosystems of the Neva estuary we used an integrated index *IP*' specially devised for water-bodies and watercourses of the north-western Russia [18—20]. It is based on structural parameters of zoobenthic communities and makes it possible to take into consideration pollution by toxic and organic substances. The scale of integrated index *IP* sums the data of four indices: 1) Trent Biotic Index BI [21], 2) Index Kch [22], 3) Goodnigth and Whitley's index No/Nc [23], Saprotoxobic index St [24].

With an increase of pollution values of indices ST, No/Nc and Kch increased, whereas values *BI* declined. Values of the *No*/*Nc* index are expressed as a percentage, which hampers comparison of results of assessment by the index. Therefore, we expressed the value of *BI* index by an inverse value (1/*BI*) and values of the index will increase with an increase of pollution from 0.1 to 1. In this case index 1/*BI* acquires the same directionality as the other three indices. Different dimensionality of the indices also hampers comparison of their absolute values. For this reason parameters *St*, *Kch* and 1/*BI* were expressed as a percentage of their maximum values.

In brackish waters chironomids were frequently absent and it was not possible to calculate *Kch* index based on structural characteristics of chironomids. For the assessment of impact of biotic and abiotic factors in fresh and brackish waters it is more convenient to use average values of these four or three indices — the integrated index (*IP′*). The new integrated index *IP′* may be used for determining water quality of fresh and brackish water bodies with mixed pollution, organic and toxic. The character *IP′* scale allows quantifying continuous anthropogenic changes of water quality. In more detail the method for the assessment of water quality, information on each index, methods of their calculation and application are given by E. V. Balushkina [18—20].

We accepted gradations of water quality and a state of ecosystem according to recommendations of S. M. Drachev [25] and the Ministry of Natural Resources of Russia [26]. The following water quality gradations were used: 1st class of waters — «very clean», 2nd class — «clean», conforming to «relatively satisfactory» state of the ecosystem, 3rd class — «moderately polluted», conforming to «tense» state of ecosystem, 4th class — «polluted», conforming to «critical» and 5th class — «dirty», conforming to «catastrophic» state of ecosystem.

Table 1

The number of stations, studied in the Neva Bay and the eastern Gulf of Finland

Число станций, исследованных в Невской губе и восточной части Финского залива

Study area	Years									
	1994	1995	1996	1997	1998	2001	2002	2003	2004	2005
Neva Bay	5	5	31	36	34	23	14	11	10	20
Gulf of Finland	9	9	14	24	—	13	36	18	23	31
Study area	Years									
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Neva Bay	10	10	10	11	9	12	10	15	10	10
Gulf of Finland	9	—	5	5	5	4	4	13	7	6

Because in the majority of European countries 5 quality gradations and in Russia 6 quality gradations were defined we highlighted a transitional 4-5 class of waters «polluted-dirty» where *IP'* values exceeded 66.2 (table 2).

Results. In total 188 taxa of benthic animals were recorded in the Neva estuary in 1994—2015. 127 species and superspecies taxa of benthic animals were found in the Neva Bay and 129 taxa — in the eastern Gulf of Finland. Among these 68 were common for the Neva Bay and the eastern Gulf of Finland. At present, zoobenthos communities in the estuary are dominated by eurybiont indicator species inhabiting "polluted" and "dirty" waters responding positively to an increase of organic pollution and eutrophication of the ecosystem and resistant to high concentrations of heavy metals and pollutants. Oligochaetes, bivalve molluscs, and chironomid larvae are predominant in the zoobenthos of the Neva Bay. These groups of animals constitute nearly 100 % of zoobenthos biomass and occur in certain proportions throughout the entire bay. Animals of other taxa are relatively rare.

Four stages were noted in the study period 1994—2015. During the first one (1994—2002), processes of restoring of the ecosystem in the Neva Bay, related to the decline of industry in St.-Petersburg in those years, were observed. In 1994—1997, due to an industry decline and a decrease in anthropogenic impact on the ecosystem of the Neva Bay, the species diversity of benthic animals increased. In the mouth of the Neva River and in the region of maximal flowage of the Neva Bay (fig. 1, stations 7, 9, 11), the state of the ecosystem and water quality improved by one class (from fourth to third class). Freshwater species of chironomids from subfamilies Diamesinae and Orthocladiinae appeared. *IP'* consistently reduced from 58.8 to 48.5 %. As a result, the waters assessed as "polluted" in 1994—1995 were assessed as "moderately polluted" in 1996—2005 (except for 2004) and "critical" state of this part of the estuary changed for the "tense" state. However, positive changes in communities of benthic animals in the Neva Bay cannot be regarded as stable.

Average for the Neva Bay values of *IP'* declined with some fluctuations from 64.5 in 1994 to 56.8 % in 2002. The state of the ecosystem of the Neva Bay during that period was assessed as "critical", and waters as "polluted" (4th class). The average number of species of benthic animals at one station during the first stage increased from 11±1 to 23±2 species, and the average value of Shannon index of species diversity increased from 2±0.2 to 3±0.2 bit/ind.

The second stage (2003—2006) was accompanied by revival of industry, construction of ports, active navigation, development of Sea Facade and completion of the construction of the St. Petersburg Flood Prevention Facility Complex. The area of «moderately polluted» (3-rd class) waters in the Neva Bay decreased, and adjoining areas were assessed as «polluted—dirty», the ecosystem state as "crisis". In 2005 waters of class 3 were recorded only at three stations of the Neva Bay in the regions of maximum flow velocity, in 2006 — only at two stations.

Average for the Neva Bay values of *IP'* increased during the second stage from 60.9 % in 2003 to 68.2 % in 2006. The state of the ecosystem of the Neva Bay in 2006 was the worst during the period of observations and was assessed as "crisis", waters - as "polluted-dirty" (4-5th class).

Table 2

Classes of water quality and ecosystem state according to zoobenthos indices

Классы качества вод и состояния экосистем по показателям зообентоса

Water class	Water quality	Ecosystem state	Zoobenthos indices, %				
			St	No/Nc	Kch	1/BI	*IP'*
1	Very clean		<25	25	<1.22	<10	<9.05
2	Clean	Relatively satisfactory	25—37.5	0—50	1.22—9.4	10—20	9.05—29.2
3	Moderately polluted	Tense	37.5—62.5	50—60	9.4—56.5	20—33	29.2—53
4	Polluted	Critical	62.5—80.2	60—77.6	56.5—74.2	33—33	53—66.2
4 – 5	Polluted-dirty	Crisis	80.2—87.5	77.6—80	74.2—78.26	33—50	66.2—73.9
5	Dirty	Catastrophic	87.5—100	80—100	78.26—100	50—100	73.9—100

The average number of species of benthic animals in the second period regularly declined from 23±2 to 15±2 species at one station, and average value of the Shannon index of species diversity declined from 3±0.2 to 2.6±0.2 bit/ind.

Results of statistical analysis show that in 2003—2004 the number of species and species diversity of bottom animals in the Neva Bay declined with increased primary production and chlorophyll a concentration.

In the subsequent years (the third stage, 2007—2011) the Neva Bay was restoring, in 2009 the state of bottom sediments was essentially better than in the previous year's [27]. The improvement of the state of the Neva Bay was related to cessation of large-scale dredging that accompanied the construction of St.-Petersburg Sea Facade. At that stage the average for the Neva Bay values of *IP′* declined with certain fluctuations from 63.4 % in 2007 to 58.7 % in 2011. The state of the ecosystem was assessed as "critical" and water quality improved to class 4 ("polluted"). The average number of species of benthic animals increased from 14±1 to 20±1 species at one station and average value of the Shannon species diversity index also increased from 2.4±0.2 to 3.1±0.2 bit/ind.

It is likely that improvements of the state of the Neva Bay in those years was due to the completion of construction of sewage treatment plants and enhancement of the sewage treatment.

The fourth stage (2012—2015), accompanied by a large-scale hydrotechnical works in the south-western Neva Bay: building of a Marine Multifunctional Reloading Complex (MMRC) "Bronka" and approach fairway to it.

Average for the Neva Bay values of *IP*' increased during the fourth stage from 62.8±2 in 2012 to 67.6±3 % in 2015. The state of the Neva Bay in 2015 was almost the same as in 2006 and was assessed as «crisis» and the water — as «polluted-dirty» (4-5 class).

The average number of benthic species at one station in the fourth stage regularly declined from 18±1 to 15±2 species at one station, and the average for the Neva Bay value of Shannon index of species diversity almost did not change from 2.8±0.2 to 2.7±0.2 bit/ind.

In 2014 waters on a large part of the Neva Bay were estimated as "polluted" (*IP*' values from 57 to 66 %) and only at one station from ten ones (st. 9; *IP′*=50.9 %), having the biggest flowage, the water was assessed as "moderately polluted". Waters of 4-5 transition class were noted near the Lomonosov District (st. 17, *IP*'=66.7) and at the station no. 11 (*IP*'=67.7). The worst water quality «dirty» (5th class) in 2014 year was registered near cape Lisy Nos (st. 42; *IP′*=74.2 %). The average for the Neva Bay values of *IP*' was 63.2 % in 2014, and water assessed as "polluted", state of ecosystem — as "critical" (4th class). In 2015, the state of the Neva Bay deteriorated, and the state of 6 out of 10 stations assessed as a "crisis", the quality of water decreased from 4 to 4-5 class.

On average the water quality of the Neva Bay according to *IP′* values was relatively stable during 1994—2015 period. It was assessed as «polluted» (4th class) with exception for abnormality in 2006 and 2015 (4-5th class) caused by large-scale dredging work (fig. 2).

The average number of zoobenthos species in the Neva Bay increased in the period of observations 1982—2015 almost 2 times: from 11±1 in 1982 to 20±2 species at one station in 2014. The average values

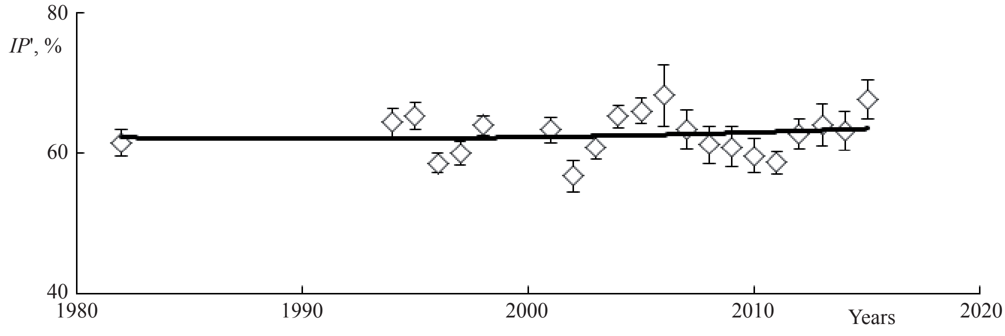

Fig. 2. Water quality assessment in the Neva Bay according to Integrated Index IP′ in 1982 and 1994—2015. Calculated with the data of 307 research stations.

Рис. 2. Оценка качества воды в Невской губе по интегральному показателю IP′ в 1982 и 1994—2015 гг. Рассчитано по данным 307 исследованных станций.

of the biodiversity indices of benthic animals in the Neva Bay increased by half from 2±0.1 in 1982 to 3.0±0.3 bit/ind. in 2014.

The average number of benthic animals in the water area of the Neva Bay changed insignificantly in 1994–2006, from 11320 to 18305±3373 ind./m^2, with an exception of 2001 and 2004, when it reached 61126±1935 and 47219±21619 ind./m^2, respectively, due to an outbreak of oligochaetes from the subfamily Naididae. In subsequent years 2007-2015 the number of benthic animals with some fluctuations decreased successively by more than 2 times (from 15054±3549 to 6832 ± 2138 ind./m^2), that was associated with large-scale hydraulic works in this period (fig. 3).

The average biomass of macrozoobenthos of the Neva Bay in 1994—2015 successively decreased from 16.313±3.430 in 1994 to 1.5 g/m^2 in 2015, which was associated with a reduction in the biomass of small Pisidiidae bivalves, and oligochaetes (fig. 4).

The state of the Resort zone of the eastern Gulf of Finland in 1994—2015 was more unfavorable. In shallow area eurybiont species of freshwater animals were noted: oligochaetes, chironomid larvae. At present, relict crustaceans *Mysis relicta* Loven, *Saduria entomon* (L), and *Monoporeia affinis* Lindstr in that zone are represented by only rare specimens.

Using results of an investigation of 118 stations, we estimated the average values of the *IP*' index, number of species, indices of species diversity, and biomass of zoobenthos for 1994—2015 for the water area of the

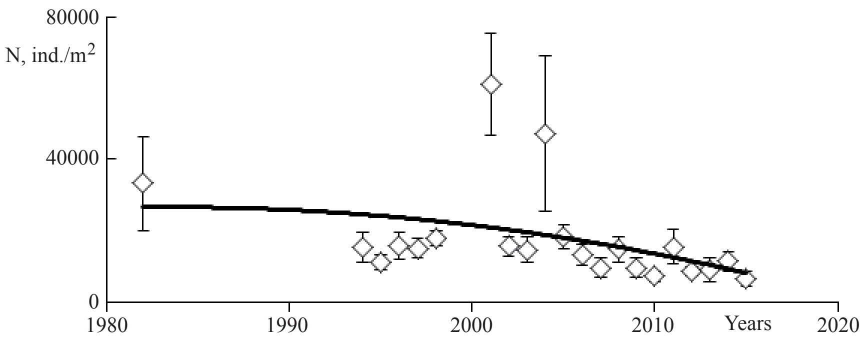

Fig. 3. Average values of the number of macrobenthos in the Neva Bay in 1994—2015.
Calculated with the data of 307 research stations.

Рис. 3. Средние значения численности макробентоса в Невской губе в 1982 и 1994—2015 гг.
Рассчитано по данным 307 исследованных станций.

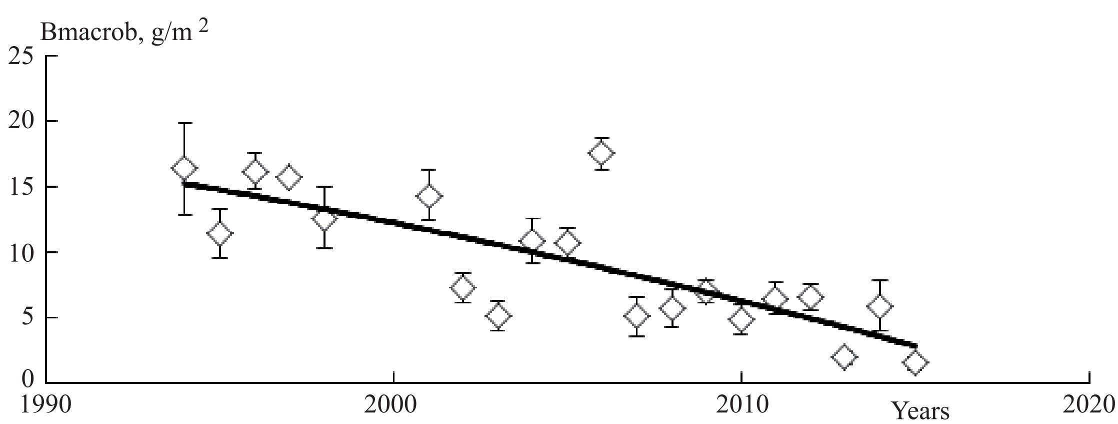

Fig. 4. Average values of the biomass of macrobenthos in the Neva Bay in 1994—2015.
Calculated with the data of 296 research stations.

Рис. 4. Средние значения биомассы макробентоса в Невской губе в 1994—2015 гг.
Рассчитано по данным 296 исследованных станций.

Resort zone of the eastern part of the Gulf of Finland. Average values of integrated index *IP*' varied in 1994—2015 from 65.9±1.9 to 72.6±3.3 %, (except 2012—2013) characterizing on the average the state of the Resort zone of the eastern Gulf of Finland as "crisis", and waters as "polluted-dirty" (4-5th class of waters), one class lower than the waters of the Neva Bay. In 2012—2013 the average values of integrated index *IP*' decreased to 63.7±4.6 — 65.1±4.4 % and quality of waters improved to "polluted" (4th class), ecosystem state to "critical", as well as the water of the Neva Bay. In 2014—2015 the state of this part of the estuary worsened and assessed as in previous years (1994—2011) as "crisis", and the water as "polluted-dirty" (fig. 5).

As a result of more intensive pollution (*IP′*) species diversity (*H*) of benthic animals in the Resort zone of the eastern part of the Gulf of Finland was considerably lower than in the Neva Bay (fig. 6).

In 1994—2015 values of species richness, average for the Resort zone of the eastern Gulf of Finland, varied from 5±0.6 to 11±2 species at one station, Shannon's indexes — from 1.1±0.2 to 2.1±0.3 bit/ind. that were much lower than in the Neva Bay (fig. 3). This may be due to apparently not only the influence of water salinity (to 2—3 ‰), but also to the larger (in comparison with the Neva Bay) pollution of this zone. We also detected a clearly marked decrease in biomass (from 40.4±19.2 in 1994 to 3.34±0.84 g/m^2 in 2015 relatively) of benthic animals.

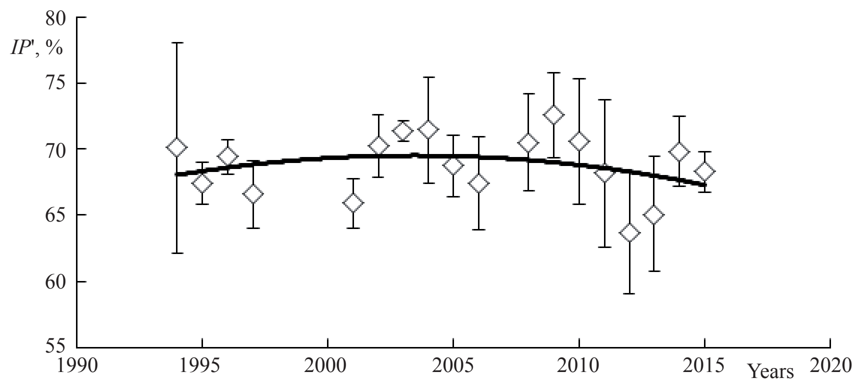

Fig. 5. Water quality assessment in the Resort zone of the eastern part of the Gulf of Finland according to integated index *IP′* in 1994—2015. Calculated with the data of 118 research stations.

Рис. 5. Оценка качества воды в Курортном районе восточной части Финского залива по интегральному показателю *IP′* в 1994—2015 гг. Рассчитано по данным 118 исследованных станций.

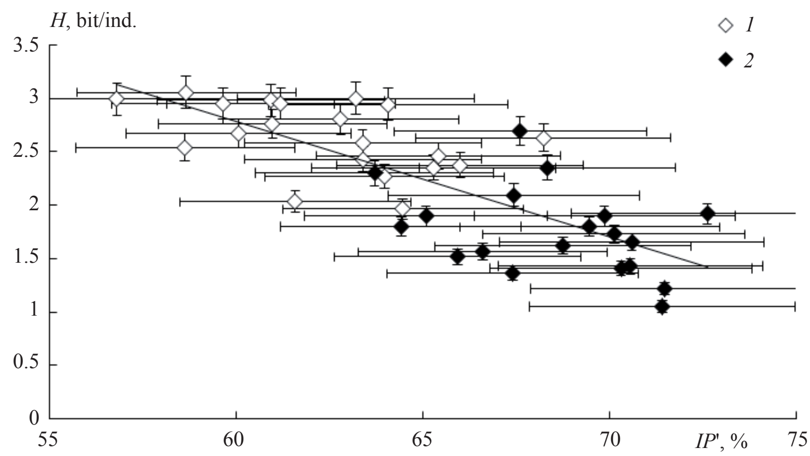

Fig. 6. Relationship of average Shannon's index (*H*) and integrated index (*IP´*) in the Neva Bay (*1*) and Resort zone of the eastern Gulf of Finland (*2*) in 1994-2015 for 414 examined stations. Correlation coefficient *R*=0.58 (*P* – 0.05).

Рис.6. Зависимость средних индексов Шеннона (H) от интегральных показателей (*IP′*) в Невской губе (*1*) и Курортном районе восточной части Финского залива (*2*) в 1994—2015 гг. по 414 исследованным станциям. Коэффициент корреляции: *R*=0.58 (*P* – 0.05).

Discussion. Conservation and restoration of biodiversity is a priority task of the Action Plan for the Baltic Sea. The long-term studies carried out by the Zoological Institute of RAS have shown that the state of biological communities of the eastern Gulf of Finland are directly related to the quality of water and benthic sediments, reflecting such anthropogenic impacts as eutrophpication of open and coastal waters of the Gulf of Finland and their pollution by toxic substances.

In the freshwater Neva Bay, crustacean glacial relict species, *Pallasea quadrispinosa*, and small mollusks, *Sphaerium corneum* and *Sphaerium solidum* (Pisidiidae), sharply dominated the benthic communities at the beginning of the 20th century [28]. Another crustacean species, *Mysis relicta*, was also common. Later in 1920—1930s this dominance was replaced by large freshwater Unionidae mollusks [29]. The further succession of zoobenthos was connected with progressive decline of glacial relicts and an increase of the dominance of Oligochaeta worms, which probably resulted from intensive organic pollution in the second half of the 20th Century.

In the middle 1980's the dominant groups in the Neva Bay become Oligochaeta worms (mainly Tubificiidae — indicator of "polluted" and "dirty" waters) and small Pisidiidae mollusks (Bivalvia).The biomass of Pisidiidae reached very high values: up to 1.0 kgWW/m^2, and total zoobenthic biomass reached 1.5 kgWW/m^2 in the eastern part of the Neva Bay [30]. A high biomass of zoobenthos was located near the hydrodynamic barrier, where an abrupt decline of flow velocity took place. Large-scale changes occurred especially in the eastern part of the Neva Bay, where the mean level of benthic biomass decrease from 100—150 gWW/m^2 in 1980's to about 50 gWW/m^2 in 1990's and to 1—17 gWW/m^2 in the early 2000's [31].

In 1980s, waters of the Neva Bay were characterized by zoobenthos as α-mesosaprobic (fourth-fifth class of waters according to *IP*') that were one class lower than in 1994—2005. The worst conditions in 1980, as well as in 1994—2005 were detected in the region of the Sea Port; its waters were characterized as dirty [32].

Moreover, in 1990s and early 2000s, the composition of benthic communities in the Neva Bay significantly changed due to an increase of the dominance of Oligochaeta, an increase of the importance of chironomid larvae, and a decrease of the share of bivalve mollusks [31].

In 1992 the waters of all regions in the Neva Bay were assessed by a complex of chemical indices (Water Pollution Index) as polluted (fourth class) [33]. In 2001 waters of a large part of the Neva Bay according to their chemical properties, *IP*' and the structural characteristics of the benthic animal were referred to the fourth class [34]. The water of the fourth class is unsuitable for drinking, fishing, and recreation. For usage in manufacture it needs more complicated preparation than waters of third class. Also, an analysis of the sanitary and microbiological condition of the water area in the Neva Bay in 2001 showed a high level of fecal pollution, which was indicated by high titers of the Coli Index and the occasional detection of pathogenic microflora [35].

The decrease in pollution in the zone of the greatest flowage of the Neva Bay and the increase in water quality up to the third class led to a recovery of species diversity and a decrease in the number and biomass of zoobenthos in 1996—1997, which was most considerable in the transit zone of the Neva Bay [5, 6]. Tendencies toward an improvement in the condition of the Neva Bay, which were detected in 1990s, were connected with a decline of industry in St. Petersburg and the reduction of anthropogenic load. Natural factors have also contributed to the rapid recovery of the Neva Bay. Due to the high speed of water exchange, most of suspended particles are washed out from the Neva Bay. The benthic animal community probably reacted very quickly on the changes in the environment quality.

Results of statistical analysis showed that in 1994—1997 the number of species in the Neva Bay was determined largely by toxic pollution (heavy metals, oil products and mercury in the water and bottom sediments) and to a lesser extent by primary production values of the ecosystem. Results of multiregression analysis showed that values of Shannon's species diversity index for benthic animals in the Neva Bay were determined equally by the values of primary production and chlorophyll *a* concentrations. Analysis of the factors influencing the values of biomass and production of benthic animal communities showed that these characteristics increased with growing chlorophyll a concentration. Toxic pollution did not have a suppressive impact on the biomass and production values of benthic animals in 1994—2005 [5—7, 36—38].

A recover of the industry and the increase in the anthropogenic load led to a worsening of the water quality, a decrease in species number and diversity, and an increase in number and biomass of zoobenthos. In 2005 maximal concentrations of heavy metals and petrochemicals often exceeded standard pollution and sometimes even exceeded the level of extreme pollution. In 30 % of cases we detected an increase in the BOC5 values as comparing with 2004 [34]. We also noticed tendencies toward the enhancement of eutrophication and the worsening of water quality in riverside regions of the Neva Bay, where the growth of phytoplankton biomass was detected [10, 14, 36, 39, 40].

Statistical analysis showed that in 2005—2009 with growing concentrations of oil products, lead, zinc, caesium (Cs 137), and chromium in near bottom waters and bottom sediments of the Neva Bay a decline of species richness and species diversity in benthic animal communities was observed. In comparison with the 1990s, concentration of zinc in near-bottom waters increased notably in 2005—2009 and its negative impact on the species richness and species diversity of benthic animals grew considerably. At high concentrations of cesium, chromium and arsenic in 2005—2009 low values of species richness and species diversity of benthic animals were recorded [11, 17].

The morphological anomalies in abundant species of oligochaetes and chironomids in the Neva Bay and the Resort zone of the eastern part of the Gulf of Finland were connected with toxic pollution of bottom sediments of the estuary, in particular by heavy metal and oil product pollution. It should be emphasized that in 1994—1995, as compared to the 1980s, the portion of anomalous individuals having morphological deviations increased in common oligochaete species *Spirosperma ferox*. Abnormalities were also noted in chironomid larvae. Apparently the morphological abnormalities were caused by increasing toxicity of the habitat in the 1990s [16, 17].

Analysis of the factors influencing the values of biomass and production of benthic animal communities showed that these characteristics increased with growing chlorophyll concentration. Toxic pollution did not have a suppressive impact on the biomass and production values of benthic animals in 1994—2015, abundance and biomass of zoobenthos increased with growing pollution [7].

Habitat conditions of animals in the eastern part of the Gulf of Finland were less favorable than in the Neva Bay. As a consequence of the geochemical barriers more than 70 % of pollutants entering the Neva estuary settled in that area [41]. A water saltiness 5—7 ‰, which was recorded in deep area of the eastern part of the Gulf of Finland, negatively influenced both freshwater and brackish-water animals [42]. This influence was worsened by abrupt and nonperiodic changes of salinity. In low reliefs, where heavier saltwater accumulates, an oxygen deficiency was detected for many years [8]. This was the reason that the species composition and abundance of macrozoobenthos in the eastern part of the Gulf of Finland were determined by a combination of natural and anthropogenic factors that were unfavorable for their development.

The long-term studies showed a further eutrophication of the open waters of the Neva estuary, which began in the late 1990s and apparently, was brought about mainly by the unfavorable climatic changes. This led to an increase of primary production and phytoplankton biomass, growing predominance of cyanobacteria, development of near-bottom hypoxia, destruction of aboriginal communities of benthic animals, invasion of alien species, and undermining of fish food supply [30].

With the increase of salinity, progressing eutrophication of the Resort zone of the estuary, increase of heavy metal and oil product toxic pollution in 1994—2006 species richness, species diversity, numbers and biomass of zoobenthos declined, i.e. all the features of degradation of benthic animal communities were observed [5]. In 2006 values of these indices were minimal for the whole observation period, which was undoubtedly related to the dredging and damping works in the Neva Bay [16]. In subsequent 2007—2015 an increase of species richness, species diversity, abundance and biomass of zoobenthos were recorded that indicated a relative restoring of benthic animal communities.

Conclusions

1. The conducted studies showed a high extent of dependency of structural characteristics of benthic animals, species composition, number of species, abundance, biomass, Shannon species diversity index, and *IP′* on hydrophysical and hydrochemical characteristics of water and bottom sediments.

2. Integrated mean assessment of water quality over the entire Neva Bay during 22 years (1994—2015) remained relatively stable, waters (except in 2006 and 2015) were assessed as “polluted” (4^{th} class), and state of the ecosystem as “critical”.

3. As compared to the Neva Bay habitat conditions of animals in the eastern Gulf of Finland were worse and were determined by a combination of natural factors unfavorable for development of benthic animals and anthropogenic impact.

4. Average characteristics of benthic animal communities - species number and species diversity index showed a high value of dependency on pollution (*IP′*) in the Neva Bay and Resort District of the eastern Gulf of Finland.

5. Average values of integrated index *IP*' varied in 1994-2015 from 65.9±1.9 to 72.6±3.3, characterizing on the average the state of the Resort zone of the eastern Gulf of Finland as "crisis", and waters as "polluted-dirty" (4-5th class of waters), that was one class lower than waters of the Neva Bay assessed as waters of the 4th class. Therefore, in 1994-2015 values of species richness and species diversity in the Resort zone of the eastern Gulf of Finland were much lower than in the Neva Bay.

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