Functional response of midsummer planktonic and benthic communities in the Neva Estuary (eastern Gulf of Finland) to anthropogenic stress*

OCEANOLOGIA, 45 (1), 2003.
pp. 53–66.

KEYWORDS
Gulf of Finland
Estuary
Eutrophication
Primary production
Coastal zone

Sergey M. Golubkov
Alexander F. Alimov
Irena V. Telesh
Lydia E. Anokhina
Alexey A. Maximov
Vera N. Nikulina
Elena B. Pavel'eva
Vadim E. Panov
Zoological Institute,
Russian Academy of Sciences,
Universitetskay nab. 1, 199034 St. Petersburg, Russia;
e-mail: golubkov@zin.ru

Manuscript received 12 December 2002, reviewed 17 January 2003, accepted 13 February 2003.

Abstract

Long-term hydrobiological research has shown that the functioning of the ecosystem of the Neva Estuary, one of the largest Baltic estuaries, has changed greatly since the beginning of the 20th century. Ineffective local water management in St. Petersburg during the last twenty years has stimulated the development of a natural 'biological plug' in the salt barrier zone in the inner part of the estuary and has altered the ecosystem's functioning. These changes include an increase in primary production, in the primary production : organic matter decomposition ratio, and in pelagic-benthic coupling. It has also given rise to filamentous algae blooms and intensive secondary pollution in the coastal zone of the Neva Estuary. The primary production of phytoplankton in the inner part of the estuary

---

* This paper was presented at the ECSA Symposium 34 'Estuaries and other brackish areas – pollution barriers or sources to the sea?', Gdańsk–Sopot, 15–20 September 2002.

The complete text of the paper is available in PDF format at http://www.iopan.gda.pl/oceanologia/index.html

has reached 2.3 gC m^{-2}, that of the filamentous algae *Cladophora glomerata* 5.5 gC m^{-2}; these figures are much higher than in other regions of the Gulf of Finland.

1. Introduction

The Neva River is among the most important sources of pollution for the Baltic Sea and the Gulf of Finland, because it provides about 60–80 per cent of the nutrient loads to the Gulf (Kondratyev et al. 1997, Pitkänen et al. 1997) and about 15 per cent of the nutrient loads to the whole Baltic Sea (Leppänen et al. 1997). Affected by a number of human activities, the Neva Estuary is also one of the most degraded parts of the Baltic Sea (Telesh et al. 1999, Panov et al. 2002). Historical data show a gradual deterioration in the environmental quality in the Neva Estuary during the last few decades (Telesh et al. 1999), which have made this estuary one of HELCOM's 'hot spots'. On the other hand the ecosystem of the Neva Estuary may be considered a marginal filter, which detains and decomposes a considerable part of the pollutants due to the very high intensity of self-purification processes (Golubkov et al. 2001). The construction of the storm-surge barrier (Dam) and wastewater treatment plants in the 1980s has altered the hydrodynamics in the estuary and could affect the ecosystem's functioning.

An understanding of the ecosystem's structure and function is a basic prerequisite for all kinds of management decisions to be taken by the environmental local authorities at different levels. The intensive long-term hydrobiological research which has been conducted in the Neva Estuary since the beginning of the 1980s provides an excellent opportunity to evaluate the ecosystem's response to the large-scale water management of estuaries.

2. Description of the Neva Estuary

The Neva Estuary consists of three main parts: the Neva Bay (surface area 400 km^2), the inner and the outer estuary (total surface area 3200 km^2). The Neva Bay receives water from the Neva River, a major contributor of fresh water to the Baltic Sea. The catchment area of the Neva exceeds 280 000 km^2, and its water discharge averages 2490 m^3 s^{-1}, or 786 km^3 a^{-1}. The Neva Bay is freshwater and shallow (mean depth 3.5–4.0 m). It is connected with the lower brackish water inner and outer estuaries, with a salinity up to 4–6% and depth down to 40 m.

A description of the temperature and salinity regimes in the estuary is provided in Panov et al. (1999), while Alenius et al. (1998) described its hydrological features. The waters in the estuary are generally well mixed vertically and near-bottom oxygen concentrations are usually relatively high (Pitkänen 1991), except for the extreme situations when intrusion of saline waters causes strong vertical stratification of water in the outer estuary and, as a consequence, anoxic conditions near the bottom, such as were observed in summer 1996 (Lyakhin et al. 1997).

Since the early 1980s the freshwater Neva Bay has been separated from the estuary's lower brackish-water reaches by a storm-surge barrier, which is still under construction (Fig. 1). The storm-surge barrier has several water-leaking gates in its northern part and a broad ship gate in the southern part.

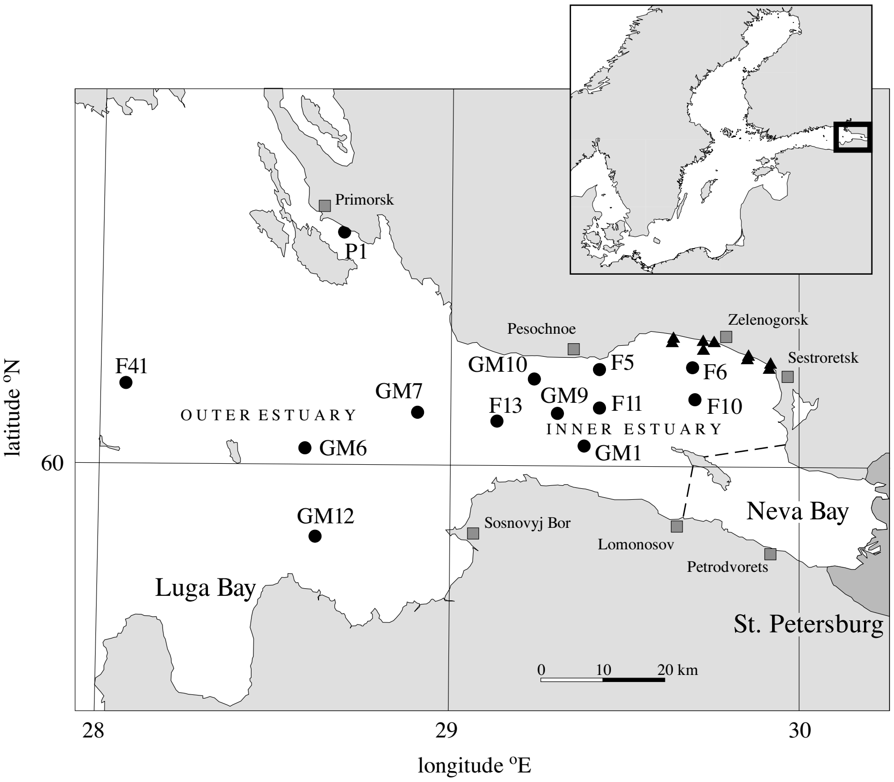

Fig. 1. Sampling station in the Neva Estuary in 2001. Triangles show the sampling stations in the coastal zone of the inner estuary

The Neva estuary is the recipient of discharges of treated and untreated waste waters from sources that are located mainly in the lower Neva River and in the Neva Bay. At present, heavy nutrient and organic matter loading, mainly from the Neva River and point sources in the upper estuary, is the most serious environmental problem for the Neva Estuary and adjacent parts of the eastern Gulf of Finland (Leppänen et al. 1997, Panov et al. 2002). The coastal zone of the estuary has been intensively used for recreation (especially in the Resort District of St. Petersburg), sport and commercial fishery, and different industries, including a nuclear power station and shipping (Fig. 1). The invasion of alien species is also a serious environmental problem for the Neva Estuary (Panov et al. 2002).

3. Methods

The rate of primary production, decomposition of organic matter in plankton, species composition, abundance and biomass of zooplankton and zoobenthos were calculated at 13 sampling stations in the inner and outer estuaries in August 2001 (Fig. 1).

Primary production of phytoplankton was measured in 100 ml bottles by the radiocarbon (C^{14}) method (Golterman 1975). Integrated water samples were taken at 3–4 depths from the photic zone (the water layer of two Secchi disk depths). Bottles were exposed on the ship's deck in an aquarium during six hours at surface temperature water to calculate the photosynthesis at optimal depth (P_{ph}). Measurements were conducted in three replicates. The gross primary production under the surface was calculated according to Bulion (1983):

$$\mathrm{PP} = \mathrm{P_{ph}Sec},$$

where Sec – Secchi depth.

The material for the evaluation of spatial distribution and biomass of filamentous algae in the coastal zone was collected along 4 transects across the costal zone in the Resort District of St. Petersburg (Fig. 1). Each transect had 4 stations: at depths of 0.5, 1.5, 3.0 and 5.0 m. Samples of hard substrates (pebbles and stones) with attached filamentous algae were collected in three replicates using the SCUBA method. After sampling, the algae were detached from the substrate and their dried weight per square decimetre of substrate was determined. The projective cover and surface area of hard substrates available for the growth of filamentous algae was also worked out.

The rate of primary production of filamentous algae *Cladophora glomerata* (L.) was determined by the oxygen method. The algae were scraped off the stones, carefully rinsed from detritus and epiphytes in water taken from the gulf and passed through 100 μ mesh filters. The, *Cladophora* were then dried on filter paper, and subsamples of 0.025–0.036 g wet weight made. The subsamples were placed in light and dark, calibrated 250 ml bottles. The bottles were filled with water from the deep (5 m) station, which had been passed through 100 μ mesh filters. Light and dark bottles in three replicates were exposed during 24 h at the sampling depth. The Winkler method was used to determine the oxygen contents in the light and dark bottles at the end of the experiments. The increase in oxygen content in the light bottles and its depletion in the dark bottles was on average about 30% of the initial oxygen content in the water (5.5 mg l^{-1}). The photosynthesis rate was recalculated to organic carbon using a factor for recalculating mlO to mgC, which is equal to 0.43 mgC mlO^{-1} (Håkanson & Boulion 2002).

20–40 litres of the water from several depths of the 0–20 m water layer were filtered through a 50 μm mesh plankton net to collect zooplankton. Zoobenthos was sampled using a modified Petersen grab (20 × 20 cm^2) and sieved in the field through a 0.25 mm mesh. Three grabs were taken at each station. Zooplankton and zoobenthos samples were preserved with 4% formalin and treated in the laboratory using standard methods (Telesh 1987, Telesh et al. 1999).

To calculate the rate of decomposition of organic matter (D [gC d^{-1}]) in the zooplankton and zoobenthos the following equations of relationships between the respiration rate (R [mlO h^{-1}]) and the wet body mass of animals (W [g]) at a temperature of 20°C were used:

Polychaeta: $R = 0.186W^{0.810}$ (Kamluk 1974),
Oligochaeta: $R = 0.105W^{0.750}$ (Kamluk 1974),
Rotifera: $R = 0.106W^{0.796}$ (Galkovskaya 1980),
Copepoda: $R = 0.200W^{0.777}$ (Suschenya 1972),
Cladocera: $R = 0.143W^{0.803}$ (Suschenya 1972),
Amphipoda: $R = 0.142W^{0.790}$ (Suschenya 1972),
Chironomidae: $R = 0.088W^{0.750}$ (Balushkina 1987).

The mean body weight of the different groups of animals found in the samples was used for calculating R. The decomposition of organic matter by animal communities (zooplankton or zoobenthos) was calculated as $D = \Sigma R\ k\ N\ 24$, where N is the abundance of different groups of animals, and k is a factor for recalculating respiration in mlO to mgC, which is equal to 0.43 mgC mlO^{-1} (Håkanson & Boulion 2002).

4. Results

The average values of gross primary production (PP) and decomposition of organic matter (D) in plankton in the inner and outer parts of the Neva Estuary are given in Table 1. The primary production of plankton in the inner estuary was on average almost twice as high as that in the outer estuary, but the rate of decomposition of organic matter in both parts of the estuary was practically the same. The ratio of primary production to the rate of decomposition of organic matter was higher in the inner (PP/D>1) than in the outer Neva Estuary (PP/D<1).

C. glomerata was the dominant species of filamentous algae in the Neva Estuary. It proliferated vigorously on hard substrates in summer. Its average biomass in the shallow littoral was about 100 g of dried weight per m^2 and gross primary production amounted to about 5.5 gC m^{-2} d^{-1} in the northern coastal zone of the estuary (Table 2). With increasing depth, primary production of *C. glomerata* decreased owing to the lower light penetration and a diminution of the projective cover of hard substrates available for the growth of filamentous algae at greater depths. In the shallow littoral (0.5–1.5 m) primary production of filamentous algae considerably exceeded the production of phytoplankton in the open waters of the Neva Estuary (Tables 1 and 2).

Table 1. Gross primary production (PP) and decomposition of organic matter (D) in plankton of the inner and outer parts of the Neva Estuary in August 2001

	Inner estuary	Outer estuary
PP [gC $m^{-2}d^{-1}$]	2.32	1.43
± Em of PP	0.45	0.29
D [gC $m^{-2}d^{-1}$]	1.61	1.65
± Em of D	0.34	0.32
PP/D	1.44	0.87

Table 2. Average biomass (B) and gross primary production (PP) of filamentous algae *Cladophora glomerata* at different depths of the northern coastal zone of the inner estuary in midsummer

	0.5 m	1.5 m	3.0 m
B [$g_{\text{dr.weight}}$ m^{-2}]	103	53	16
± Em of B	0.29	0.18	0.09
PP [mgC $gC_{\text{Cladophora}}{}^{-1}d^{-1}$]	107.4	79.2	1.5
± Em of PP	12.3	9.3	0.2
Projective cover of hard substrates, %	90	60	40
PP [gC $m^{-2}d^{-1}$]	5.53	2.10	0.12

Density, biomass and contribution of zooplankton to the decomposition of organic matter were higher in the inner estuary than in the outer estuary (Table 3). Rotifers of the genera *Keratella*, *Synchaeta* and *Polyartra* were most abundant in both parts of the Neva Estuary. They were also dominant in the biomass of zooplankton in the westernmost part of the outer estuary.

Copepods and cladocerans predominated in the biomass of zooplankton in the other parts of the inner and outer estuaries. They comprised 42–54% and 36–40% of zooplankton biomass, respectively.

Table 3. Density (N), biomass (B) and the rate of decomposition of organic matter by zooplankton (D) in the inner and outer parts of the Neva Estuary

	Inner estuary	Outer estuary
N [indiv. m^{-3}]	661900	352859
± Em of N	83291	50837
B [mg m^{-3}]	938	656
± Em of B	179	126
D [mgC $m^{-2}d^{-1}$]	406	331
± Em of R	41	39

Table 4. Abundance (N), biomass (B) and the rate of decomposition of organic matter by bottom animals (D) in different parts of the Neva Estuary

	Inner estuary	Outer estuary
N [indiv. m^{-2}]	12008	3442
± Em of N	2588	1162
B [g m^{-2}]	16.56	1.95
± Em of B	2.86	1.09
D [mgC $m^{-2}d^{-1}$]	96	8
± Em of R	23	3

The zoobenthos included only four groups of bottom animals: Oligochaeta (18 species), Polychaeta (1 species), Crustacea (2 species) and Insecta (Chironomidae, 3 species). The abundance and biomass of zoobenthos, as well as their contribution to the decomposition of organic matter, were much higher in the inner estuary than in the outer estuary (Table 4). Two species of Oligochaeta, *Potamothrix hammoniensis* (Mich.) and *Limnodrillus hoffmeisteri* Clap., and larvae of *Chironomus plumosus* L. (Insecta) dominated in the bottom animal communities in the inner estuary. The crustaceans *Monoporeia affinis* Lindstrom and *Saduria entomon* (L.) were prevalent in the zoobenthos of the outer estuary. A new, invasive species *Marenzelleria viridis* (Verrill) (Polychaeta) was found at all sampling stations of the estuary, but its biomass was relatively low: 0.04–1.45 g m^{-2}.

The contribution of zooplankton to the decomposition of organic matter in the inner part of the Neva Estuary was almost the same in both parts of the estuary (Table 3). But in the outer estuary the biomass and significance of zoobenthos in the ecosystem's functioning was much lower than in the inner estuary (Table 4).

5. Discussion

Eutrophication is a major consequence of human activities, and influences the functioning of estuarine ecosystems (Schernewski & Schiewer 2002). Historical data show that at the beginning of the 20th century the whole Neva Estuary could be classified as oligotrophic, and the state of the ecosystem was determined by natural processes (Alimov et al. 1996, Telesh et al. 1999). Plankton communities were dominated by the clear-water diatoms *Asterionella* and *Melosira*, chrysophytes *Dinobryon* (Visloukh 1921, Kisselev 1924) and rotifers, mainly *Conochilus unicornis* Rouss., *Synchaeta pectinata* Ehrbg and *Synchaeta grandis* Zach. (Rylov 1923). In the benthic communities of the freshwater Neva Bay the glacial relict crustaceans *Pallasea quadrispinosa* Sars, *Mysis relicta* Loven were distinctly dominant, as were *M. affinis* and *S. entomon* in the brackish inner and outer parts of the estuary (Skorikov 1910).

There are no data on the rate of primary production (PP) and decomposition of organic matter (D) in the Neva Estuary of that time, but it is known that in oligotrophic waters PP does not exceed 30 gC m^{-2} per year (Håkanson & Boulion 2002), which yields an average of 0.2 gC m^{-2} d^{-1} for a growing season of 150 days' duration. According to the data from Table 1, the modern rate of primary production is about ten times higher than this threshold in the inner and about 7 times higher in the outer part of the estuary. $PP/D>1$ demonstrates the continuation of eutrophication processes. Nowadays, both parts the Neva Estuary may be regarded as eutrophic waters.

The average rates of primary production of the Gulf of Finland and the Baltic Sea as a whole are about 148 and 139 gC m^{-2} yr^{-1}, respectively (Elmgren 1984), which gives 1.0–1.2 gC m^{-2} d^{-1}. Thus, the modern rate of primary production in the Neva Estuary, especially in its inner part (Table 1), is considerably higher than in most of the open waters of the Baltic Sea. This fact may be explained not only by anthropogenic factors, but also by some natural ones. Hydrobiological studies in the estuaries of the Volga and the Neva Rivers have shown that pollution and self-purification processes in estuarine ecosystems should be considered with respect to the hydrodynamic and salt barriers which exist in estuaries (Golubkov et al. 2000, Golubkov et al. 2001). The processes occurring in the transition zone from riverine to sea waters are not a simple mixing of fresh and saline waters, but a complex combination of different physical, chemical and biological transformations within the 'marginal filter' (Lisitzin 1999). The major consequence of barrier effects in river estuaries is the particular spatial zoning of the structural-functional characteristics of ecosystems of estuaries and the existence of biologically active zones with high concentrations of living organisms, the so-called 'biological plugs'. The main 'biological plug' with a high phytoplankton abundance is situated in the salt barrier zone, where riverine and sea waters mix. In the eastern Gulf of Finland this zone is located in the Neva Estuary with a surface water salinity ranging from 1 to 5‰. Anthropogenic input of nutrients further stimulates this natural factor (the formation of 'biological plugs') and leads to the very high primary production of phytoplankton in the Estuary (Table 1.).

Another consequence of eutrophication in this zone is the large-scale growth of attached filamentous algae along the coast. The biomass of filamentous green algae *C. glomerata* on hard substrates reaches very high values in summer (Table 2). At the optimum depth of 0.5–1.5 m its biomass may exceed 1 kg of wet weight per m^2, because the substratum, light and temperature are favourable at this depth. The littoral zone in the Neva Estuary is rather shallow. 3 m deep waters, where *Cladophora* can still be observed, can be found at a distance of more than 1 km from the shoreline.

Wave action dramatically affects growing algae. As a result of storms, great masses of filamentous algae are detached from the stones and spoil the coastal zone of the Neva Estuary. This causes intensive secondary pollution of the coast and creates serious problems for recreation in the Resort District of St. Petersburg. Storm casts of filamentous algae may reach 2 tons of wet weight per 100 m of shoreline (Orlova et al. 1999). After storms the biomass of *Cladophora* recovers rapidly owing to its high rate of growth. The primary production of filamentous algae considerably exceeded the production of phytoplankton in the open waters of the Neva Estuary (Tables 1 and 2). Thus, eutrophication in the coastal zone of the Neva Estuary appears to be much more intensive than in the open waters of the estuary. Therefore, water quality in the coastal zone of the Neva Estuary should be a target object for water management in the eastern Gulf of Finland.

The biomass of zoobenthos and its role in ecosystem functioning were very low in 2001 in the outer Neva Estuary (Table 4). This can be explained by the oxygen deficit, which has often occurred in recent autumns in the outer estuary as a result of saline water intrusions into the deep parts of the Gulf of Finland from the Baltic Sea (Maximov 2002). A further reason may be that eutrophication processes in the estuary lead to the accumulation of organic matter in the deep, often unmixed, layer of water beneath the halocline.

The rate of primary production in August 2001 (Table 4) appeared much higher than in the 1980s (Shishkin et al. 1989) and early 1990s (Silina 1997). According to Silina (1997) the average primary production of phytoplankton was only 0.61 gC m^{-2} d^{-1} in the inner and 0.67 gC m^{-2} d^{-1} in the outer Neva Estuary in August 1991, and reached 0.72 gC m^{-2} d^{-1} in the outer estuary in August 1994.

Phytoplankton primary production began to increase in the early 1990s. For instance, the rate of phytoplankton photosynthesis at the optimum depth increased from 0.22–0.49 in the summers of 1984–1987 to 0.25–0.80 gC m^{-3} d^{-1} in the same seasons in 1988–1995 in the inner Neva Estuary (Silina 1997). According to our estimates the rate of phytoplankton photosynthesis in the inner estuary ranged from 0.45 to 1.8 gC m^{-3} d^{-1} in August 2001.

Table 5 gives the average rates of primary production and decomposition of organic matter for the Neva Estuary in 2001 and the mid-1980s (Shishkin et al. 1989). The main change in the functioning of the ecosystem since the 1980s has been the great decrease in the rate of decomposition of organic matter in the open waters of the estuary. In the 1980s, before the Northern Wastewater Treatment Plant was constructed, dissolved organic carbon (DOC) was the main component of total organic carbon (TOC) inflow to the eastern Gulf of Finland. This decomposed gradually, initially in the inner and then, owing to the water current, in the outer part of the Neva Estuary. Only as a result of this relatively slow process did the phytoplankton receive a substantial portion of the biologically available nutrients. There was almost no difference in the rate of primary production per m^2 between the inner and the outer estuaries at that time (Shishkin et al. 1989), nutrient recycling was relatively slow, and the average rates of primary production (Table 5) were lower than in the whole Gulf of Finland. The PP_{ph}/D ratio was then only 0.16. The Neva Estuary ecosystem, in fact, functioned like a huge wastewater treatment plant.

Nowadays, a considerable part of the DOC inflow is decomposed in the Central, Northern and in other smaller wastewater treatment plants in the St. Petersburg area. This may be the reason for the decrease in the DOC inflow, and the increase in the input of biologically available nutrients in the inner part of the estuary, because reduction of phosphorus in the effluents from the St. Petersburg treatment plants is not effective at the moment (Pitkänen et al. 1997). This has led to an increase in the primary production of phytoplankton and, probably, filamentous algae in the Neva Estuary (Table 5), especially in its inner part (Tables 1 and 2). The PP/D ratio exceeds 1, which is indicative of on-going eutrophication. The phytoplankton biomass has increased and blue-green blooms have been observed (Nikulina 2002).

Table 5. Average rates of primary production and decomposition of organic matter (PP, D [gC m^{-2} d^{-1}]) for the Neva Estuary in 1984–1988 (after the Shishkin et al., 1989) and in 2001

Producers, decomposers	1984–1988	2001
Producers		
Phytoplankton PP_{ph}	0.58	1.70
Cladophora glomerata	no data	0.11*
Decomposers		
Whole planktonic community (including bacteria), D	3.69	1.48
Zooplankton	0.41	0.37
Zoobenthos	0.04	0.04
PP_{ph}/D	0.16	1.15

* Value was calculated for the inner estuary.

There has also been a rise in the significance of the animal communities in the decomposition of organic matter as compared with the mid-1980s (Table 5). This implies an increase of pelagic-benthic coupling in the Neva Estuary.

Thus, anthropogenic stress has caused the progressive eutrophication of the Neva Estuary since the beginning of the 20th century. Ineffective water management has stimulated the formation of a natural 'biological plug' in the salt barrier zone of the inner estuary and has altered the way the ecosystem functions. These changes include an increase in primary production, in the primary production : organic matter decomposition ratio, and in pelagic-benthic coupling. It has also given rise to filamentous algae blooms and intensive secondary pollution in the coastal zone of the Neva Estuary.

Acknowledgements

The present study was supported by the Finnish Ministry of Environment, Maj and Tor Nessling Foundation, Russian Foundation for Basic Research project 02–04–48646 and INTAS 99–674 project.

References

Alenius P., Myrberg K., Nekrasov A., 1998, *Physical oceanography of the Gulf of Finland: a review*, Bor. Environ. Res., 3, 97–125.

Balushkina E. V., 1987, *Functional importance of chironomid larvae in continental reservoirs*, Proc. Zool. Inst. Russ. Acad. Sci., Nauka, Leningrad, 179 pp., (in Russian).

Boulion V. V., 1983, *Primary production of plankton in inland water bodies*, Nauka, Leningrad, 149 pp., (in Russian).

Elmgren R., 1984, *Trophic dynamics in the enclosed, brackish Baltic Sea*, Rapp. P.-v. Réun. Cons. Int. Explor. Mer., 183, 152–169.

Galkowskaya G. A., 1980, *The rate of oxygen consumption by rotifers from a natural population*, Izv. Akad. Nauk BSSR, 6, 114–118, (in Russian).

Golterman H. L., 1975, *Physiological limnology*, Elsevier, Amsterdam, 489 pp.

Golubkov S. M., Balushkina E. V., Anokhina L. E., Nikulina V. N., Orlova M. I., Panov V. E., Umnova L. P., 2001, *The role of biological active zones in the organic pollution and purification of the Neva Estuary*, Proc. Zool. Inst. Russ. Acad. Sci., 289, 95–100.

Golubkov S. M., Orlova M. I., Umnova L. P., 2000, *The impact of the Caspian Sea water level fluctuations on the productivity of the Volga River Estuary*, Tr. Zool. Inst. Akad. Nauk SSSR, 286, 49–54.

Håkanson L., Boulion V. V., 2002, *The lake foodweb – modeling predation and abiotic/biotic interactions*, Backhuys Publ., Leiden, The Netherlands, 344 pp.

Kamluk L. V., 1974, *Respiration of free living flat and annelid worms*, Zh. Obshch. Biol., 35, 874–885, (in Russian).

Kisselev I. A., 1924, *Phytoplankton of the Neva Bay and the eastern Gulf of Finland*, [in:] *Investigations of the Neva River and its drainage basin*, Izv. Leningrad Gidrol. Inst., 2, 3–54, (in Russian).

Kondratyev S., Yefremova L., Sorokin I., Alyabina G., Chernykh O., 1997, *External load on Russian part of the Gulf of Finland: Seasonal Dynamics of riverine inputs and atmospheric deposition in 1995–1996*, Proc. Final Seminar of the Gulf of Finland Year 1996, Helsinki, 19–29.

Leppänen J.-M., Pitkänen H., Savchuk O., Basova S., Drabkova V., Gran V., Heiskanen A.-S., Koponen J., Shpaer I., Silina N., 1997, *Eutrophication and its effects on the Gulf of Finland*, Proc. Final Seminar of the Gulf of Finland Year 1996, Helsinki, 31–49.

Lisitzin A. P., 1999, *The continental-ocean boundary as a marginal filter in the world oceans*, [in:] *Biogeochemical cycling and sediment ecology*, J. S. Gray, W. G. Ambrose & A. Szaniawska (eds.), Kluwer Acad. Publ. (The Netherlands), 69–103.

Lyakhin Y. I., Makarova S. V., Maximov A. A., Savchuk O. P., Silina N. I., 1997, *Ecological situation in the eastern Gulf of Finland in July 1996*, [in:] *Ecosystem Models. Assessment of the Contemporary State of the Gulf of Finland. Part 2.*, O. P. Savchuk & I. N. Davidan (eds.), Gidrometeoizdat, St. Petersburg, 416–434, (in Russian).

Maximov A. A., 2002, *Changes of bottom macrofauna in eastern Guld of Finland in 1985–2001*, Symp. Changing State of the Gulf of Finland Ecosystem, Tallinn, 28–30 October 2002, 26 pp., (abstracts).

Nikulina V. N., 2002, *Seasonal dynamics of phytoplankton in the shallow zone of the eastern part of the Gulf of Finland*, [in:] *Estuaries and other brackish areas – pollution barriers or sources to sea?*, ECSA Symp. 34, Gdańsk–Sopot, 15–20 September 2002, 54–55, (abstracts).

Orlova M. I., Anokhina L. E., Panov V. E., Nekrasov A. V., Klimentenok S. N., 1999, *Preliminary environmental state assessment for littoral zone in Resort District of St. Petersburg*, Balt. Float. Univ. Res. Bull., 3, 37–42.

Panov V. E., Alimov A. F., Golubkov S. M., Orlova M. I., Telesh I. V., Balushkina E. V., Anokhina L. E., 2002, *Environmental problems and challenges for coastal zone management in the Neva Estuary (eastern Gulf of Finland)*, [in:] *Baltic coastal ecosystem. Structure, function and coastal zone management*, G. Schernewski & U. Schiewer (eds.), Springer–Verlag, Berlin–Heidelberg, (Central and Eastern Europe Development Studies), 171–184.

Panov V. E., Krylov P. I., Telesh I. V., 1999, *The St. Petersburg harbour profile*, [in:] *Initial Risk Assessment of Alien Species in Nordic Coastal Waters, Nord 1999:8*, S. Gollasch & E. Leppäkoski (eds.), Nordic Council of Ministers, Copenhagen, 225–244.

Pitkänen H., 1991, *Nutrient dynamics and trophic conditions in the eastern Gulf of Finland: the regulatory role of the Neva Estuary*, Aqua Fenn., 21 (2), 105–115.

Pitkänen H., Kondratyev S., Lääne A., Gran V., Kauppila P., Loigu E., Markovets I., Pachel K., Rumyantsev V., 1997, *Pollution load on the Gulf of Finland from Estonia, Finland and Russia in 1985-1995*, Summary report of Working Group Loading, Proc. Final Seminar of the Gulf of Finland Year 1996, Helsinki, 9–18.

Rylov V. M., 1923, *Zooplankton of the Neva Bay. In Investigations of the Neva River and its drainage basin*, Petrograd, 1–85, (in Russian).

Schernewski G., Schiewer U., 2002, *Status, problems and integrated management of Baltic Coastal Ecosystems*, *Baltic coastal ecosystem. Structure, function and coastal zone management*, G. Schernewski & U. Schiewer (eds.), Springer–Verlag, Berlin–Heidelberg, (Central and Eastern Europe Development Studies), 1–16.

Shishkin B. A., Nikulina V. N., Maximov A. A., Silina N. I., 1989, *The main characteristics of the biota in the top of the Gulf of Finland and its role in water quality formation*, Gidrometeoizdat, Leningrad, 95 pp., (in Russian).

Silina N. I., 1997, *Primary production and decomposition of organic matter by plankton*, [in:] *Ecosystem models. Estimations of modern state of the Gulf of Finland. 2. Hydro meteorological, hydrochemical and geological investigations*, I. N. Davidan & O. P. Savchuk (eds.), Gidrometeoizdat, St. Petersburg, 375–381, (in Russian).

Skorikov A. S., 1910, *To the fauna of the Neva Bay and surrounding waters of Kotlin Island*, Ezhegod. Zool. Mus. Akad. Nauk, 15, 474–489, (in Russian).

Suschenya L. M., 1972, *Respiration of crustaceans*, Naukova Dumka, Kiyev, 195 pp., (in Russian).

Telesh I. V., 1987, *Planktonic rotifers and crustaceans*, [in:] *Hydrobiological investigations*, G. G. Winberg & B. L. Gutelmakher (eds.), Nauka, Leningrad, 82–103.

Telesh I. V., Alimov A. F., Golubkov S. M., Nikulina V. N., Panov V. E., 1999, *Response of aquatic communities to anthropogenic stress: a comparative study of the Neva Bay and the eastern Gulf of Finland*, Hydrobiologia, 393, 95–105.

Visloukh S. M., 1921, *On the knowledge on microorganisms in the Neva Bay*, Proc. Russ. Hydrol. Inst., 1–3, 83–96, (in Russian).