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CHANGES OF BIOLOGICAL COMMUNITIES IN THE EASTERN GULF OF FINLAND DURING THE LAST CENTURY

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ABSTRACT

Changes in biological diversity of the Neva Estuary (eastern Gulf of Finland), which is one of the largest Baltic estuaries, were assessed by means of BSRP SGEH priority indicators. They include macrophytobenthos, macrozoobenthos, alien species, ichthyofauna, avifauna, mammals and a portion of the territory covered by the protected areas. The most prominent biodiversity changes were observed in the upper freshwater Neva Bay, and moderate changes, in the lower brackish part of the estuary. Eutrophication, alien species and dredging activities are the major threats to biodiversity of the estuary. At present, alien species contribute about 8 per cent of species richness, however, 60–90 per cent of the biomass of bottom animals. Filamentous algae blooms affect biodiversity of zoobenthos in the shallow coastal zone. The climate-mediated fluctuations in near-bottom oxygen conditions are responsible for deterioration of zoobenthos in the open waters of the estuary. The decline of the benthic aboriginal crustaceans led to impairment of food conditions for fish and to a sharp reduction of their populations, which, in turn, was partly responsible for the population decline of ringed seals. Milder winters have also contributed to the decline in the numbers of this species. Dredging activities related to construction of new lands and ports are the main factor affecting fish, submerged macrophytes and waterfowl in Neva Bay. A considerable part of fish spawning grounds and waterfowl habitats in Neva Bay has been lost during the last decades. The long-term measures for conservation and improving of biodiversity should take into account periodicity of climatic changes and planned development of the region.

Key words: anthropogenic impacts, Baltic Sea, biodiversity, benthos, invasive species, ringed seal, protected areas

ИЗМЕНЕИЯ БИОЛОГИЧЕСКИХ СООБЩЕСТВ В ВОСТОЧНОЙ ЧАСТИ ФИНСКОГО ЗАЛИВА ЗА ПОСЛЕДНЕЕ СТОЛЕТИЕ

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РЕЗЮМЕ

С помощью индикаторов, предложенных международной группой экспертов, проведена оценка изменения биологического разнообразия эстуария реки Невы (восточная часть Финского залива), крупнейшего эстуария Балтийского моря. Индикаторами считались изменения в состояние сообществ макрофитобентоса, макрозообентоса, чужеродных видов, рыб, водоплавающих птиц, водных млекопитающих и доля охраняемых территорий от общей площади акватории. Наиболее значительные изменения в состоянии индикаторных сообществ наблюдались в верхней пресноводной части эстуария, Невской губе, умеренные изменения – в его нижней солоноватоводной части. Наибольшую угрозу биоразнообразию эстуария несут эвтрофирование вод, чужеродные виды, грунтонамывные и дноуглубительные работы. В настоящее время число чужеродных видов в зообентосе примерно равно 8% общего числа видов, однако, их биомасса составляет 60–90% от общей биомассы донных животных. Массовое развитие нитчатых водорослей отрицательно влияет на биологическое разнообразие зообентоса в мелководной прибрежной зоне. Вызванное изменением климата уменьшение содержания кислорода у дна ответственно за разрушение сообществ донных животных в глубоководной части эстуария. Упадок популяций нативных видов донных ракообразных привел к ухудшению условий питания и способствовал сокращению численности промысловых видов рыб, которое, в свою очередь, отрицательно повлияло на численность популяции кольчатой нерпы. Другим важным фактором, отрицательно влияющим на этот вид – учащение мягких зим с отсутствием ледового покрова в западной части эстуария. Работы, связанные с намывом новых территорий и строительством портов являются основным фактором, отрицательно влияющим на рыб, погруженные макрофиты и водоплавающих птиц в Невской губе. Значительная часть нерестилищ рыб и мест обитания водоплавающих птиц были потеряны в течение последних десятилетий. Долгосрочные программы по сохранению и восстановлению биологического разнообразия должны учитывать как периодичность изменения климата, так и планируемое развитие региона.

Ключевые слова: антропогенное воздействие, Балтийское море, бентос, инвазивные виды, кольчатая нерпа, охраняемые территории

INTRODUCTION

Achieving a favourable conservation status for the biodiversity of the Baltic Sea is the most important segment of the Baltic Sea Action Plan (BSAP) developed by the Helsinki Commission (HELCOM: Baltic Sea Marine Environment Protection Commission), which is "an ambitious programme aiming to restore the good ecological status of the Baltic marine environment by 2021" (http://www.helcom.fi/BSAP/en_GB/intro/). Implementation of the BSAP needs coordinated efforts of all Baltic countries and instruments for comparison of modern status of biodiversity in different Baltic regions. As a basis for this comparison a limited number of biodiversity indicators were proposed by the Study Group on Baltic Ecosystem Health (SGEH) of the International Council for the Exploration of the Sea (ICES) during the implementation of the international Baltic Sea Regional Project (BSRP) as priority indicators (ICES 2006; ICES 2007).

The indicators are dealing with long-living organisms whose populations respond to long-term anthropogenic impacts and have low ability to restore after cessation of the impacts: macrophytobenthos, macrozoobenthos, alien species, ichthyofauna, marine avifauna and mammals. They include area covered by submerged vascular plants and macroalgae and percentage of endangered species, changes in macrozoobenthos including (extinct) threatened and/or declining species, rate of new invasions of alien species and their impact on aquatic communities, fish community structure including (extinct) threatened and/or declining species and status of commercial fish species, changes in abundance and distribution of coastal marine birds and seal numbers. Percentage of the water area covered by marine protected areas (MPA) was considered as a special indicator related to implementation of biodiversity protection measures in the area. Long-term target level of protected areas for the eastern Gulf of Finland, which was proposed by the SGEH, is 20% of the whole water area.

The eastern Gulf of Finland has been selected by the BSRP (ICES 2006; ICES 2007) as one of the demonstration areas for the assessments of biological diversity in the Baltic Sea on the basis of priority indicators. The reasons for this selection are concerned with long-term research of different biodiversity patterns in the region and importance of their goods and services that have been seriously affected by anthropogenic impacts. These impacts have resulted mainly from the largest Baltic megalopolis: Saint Petersburg City. The aim of this paper is to describe the main changes in the biodiversity in the Russian part of the eastern Gulf of Finland on the basis of the priority indicators, to identify the main natural and anthropogenic factors affecting biodiversity patterns and to propose some remedial measures to improve its status in the region.

DESCRIPTION OF THE RUSSIAN PART OF THE EASTERN GULF OF FINLAND

The Russian part of the eastern Gulf of Finland practically coincides with the boundaries of the Neva Estuary: the largest Baltic estuary (surface area is 3600 km^2). The Neva Estuary receives water from the Neva River, a major contributor of fresh water to the Baltic Sea. The catchment area of the Neva River exceeds 280 000 km^2, and its water discharge averages

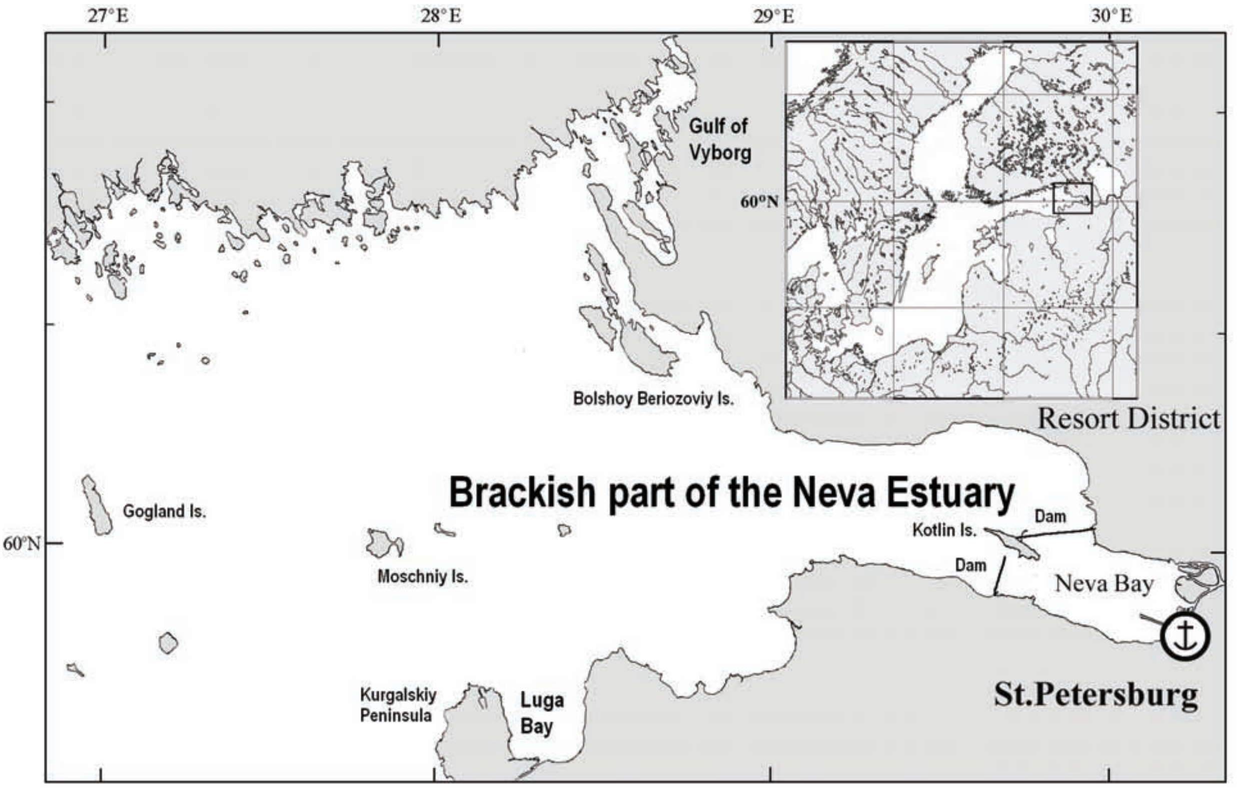

Fig 1. The Neva Estuary in the eastern Gulf of Finland.

2500 $m^3 s^{-1}$ (78.6 $km^3 yr^{-1}$). The Neva Estuary consists of two parts: the upper freshwater Neva Bay and the lower brackish-water part of the estuary (Fig. 1).

Surface area of Neva Bay is about 400 km^2, salinity, 0.07–0.2‰, with the exception of short-term intrusions of brackish water from the lower part of the Neva Estuary during surge events when brackish waters from the lower part of the estuary come to Neva Bay and mix there with fresh water; the depth of the bay is 3.5–5 m. In the middle 1980s, Neva Bay was separated from the lower part of the estuary by a storm-surge barrier (Dam). The Dam has several water gates in its northern part and a broad ship gate in the southern part.

Salinity in the lower brackish part of the Neva Estuary (Fig. 1) ranges from 1.5–3‰ in its eastern part to 3–8‰ in the western part, depth – from 12–14 m in the east to 40–50 m in the west. Several large bays are located in the western part of the estuary, e.g., Luga Bay in the south and the Gulf of Vyborg in the north. There are numerous islands in different parts of the estuary. The largest ones are the Kotlin Island, which is located at the boundary between Neva Bay and the lower brackish part of the Neva Estuary, the Beryozovyye Islands in the north, the Moschniy Island and Gogland Island in the middle-western part of the estuary.

The Neva River is among the most important sources of pollution for the Gulf of Finland (HELCOM 2004). A considerable part of pollution comes from Saint Petersburg, which is one of the largest megalopolises in the world with a population of 4.5 million citizens and well developed industry. The coastal zone of the estuary has been intensively used for recreation (especially in the Resort District of Saint Petersburg situated along the northern coast of the gulf), sport and commercial fishery, different industries, including the nuclear power station, and shipping.

Oil transportation in the eastern Gulf of Finland has increased almost five times since 1987. Two large oil terminals were constructed in its north-western part and cargo port in Luga Bay in the early 2000s (Fig. 1). As a result, there is a considerable increase in ship traffic during the last decades.

High anthropogenic impact comes also from intensive dredging activity related to creation of the new building lots and passenger terminal in the delta of the Neva River. Considerable amounts of bottom sediments and sand are dragged from the bottom in the eastern part of Neva Bay, a part of them are suspended in the water decreasing its transparency and pass to the western part of the bay and even in the lower brackish part of the Neva Estuary.

CHANGES IN BIOLOGICAL COMMUNITIES

Macrophytobenthos. The first evaluations of composition and distribution of macrophytobenthos in the Neva Estuary were conducted at the end of the 19th century and in the first half of the 20th century (Gobi 1874, 1877; Rozanova and Golubeva 1921; Derjugin 1947). The investigations were continued in the second half of the 20th century mostly in relation to eutrophication process in the estuary (Belavskaya 1987; Korelyjkova 1997; Golubkov et al. 2003b), because macrophytobenthos is considered a good indicator of negative environmental changes and anthropogenic impacts in the Baltic Sea (Kautsky et al. 1986; Dahlgren and Kautsky 2004). A hundred and six species of aquatic vascular plants are recorded in Neva Bay nowadays (Zhakova 2008).

At the beginning of the 20th century, submerged macrophyte meadows were widely distributed in the coastal zone of Neva Bay. Reeds were mostly recorded along the southern and north-eastern coasts (Rozanova and Golubeva 1921; Derjugin 1947). In the 1980s, most of submerged macrophyte meadows (probably 80–90%) were lost. More than 20 species of submerged macrophytes, e.g., *Isoetes lacustris*, *I. echinospora*, *Zannichelia palustris*, disappeared (Zhakova 2008). Submerged macrophyte meadows were replaced by reed beds, which widely expanded along the northern coast of the bay (Belavskaya 1987; Korelyjkova 1997). The reason for deterioration of submerged vegetation was intensive dredging activity in summer time related to creation of the new building lots in Saint Petersburg along the eastern cost of Neva Bay and to construction of the storm-surge protection barrier (the Dam) in the middle 1980s. This activity decreased water transparency to 0.1–0.3 m in summer time (Golubkov et al. 1987). After cessation of dredging in the 1990s and early 2000s and increase of transparency to 1.0–1.5 m, which was only a little less than at the beginning of the 20th century (Zalesskiy and Volf 1913), the sparse meadows of submerged vegetation reestablished in the littoral zone of Neva Bay, but their area was smaller as compared with that of reeds, which considerably increased during the last three decades. Some species, e.g., macroalgae *Nitella gracilis, N. syncarpa, N. mucronata,* that disappeared in the 1980s, appeared anew in the coastal zone of the bay, two new species *Chara braunii* and *Ch. fragilis* were also found (Zhakova 2008). Since summer 2006 intensive dredging activities in Neva Bay renewed, which has negatively affected the submerged vegetation in Neva Bay and adjacent brackish part of the estuary.

In contrast to Neva Bay, where reeds are a dominant type of water vegetation nowadays, submerged vascular plants and macroalgae are widely distributed in the coastal zone of the lower brackish part of the Neva Estuary. Dominant species of submerged vascular plants in this part as well as in Neva Bay are *Potamogeton perfoliatus*, *Stuckenia* (*Potamogeton*) *pectinatus*, *Potamogeton gramineus* (Zhakova 2008). Perennial macroalgae are widely distributed in the western brackish part of the Neva Estuary where salinity is more favorable for marine species. Fifteen species of Phaeophyta and 6 species of Rhodophyta have been found there (Kovalchuk 2008). Unfortunately, progressive eutrophication is observed in the coastal and open waters of the eastern Gulf of Finland for the last decade (Golubkov et al. 2003a). As a result, depth distribution of macroalgae is restricted only to 3–6 m (Kovalchuk 2008). Six species of Phaeophyta and one species of Rhodophyta (*Hildenbrandtia rubra)* were listed in the Red Data Book of Nature of the Leningrad Region (2000) as endangered. Among them is *Fucus vesiculosus,* which was common at the end of the 19th century (Gobi 1874). The role of brown and red algae in littoral vegetation of the islands in the western part of the Neva Estuary decreased during the last four decades. They were succeeded by green filamentous algae (Kukk 1988; Kovalchuk 2008).

Macrozoobenthos. Composition and community structure of zoobenthos in the eastern Gulf of Finland is closely related to natural and anthropogenic factors. A hundred and eighty-eight species and higher taxonomic groups of macrozoobenthos were recorded in the Neva Estuary in 1994–2005 (Balushkina et al. 2008). The first investigation of zoobenthos in Neva Bay showed the dominance of glacial relict crustacean *Pallasea quadrispinosa* and small mollusks, *Sphaerium* *corneum* and *S. solidum* (Pisidiidae); another relict crustacean *Mysis relicta* was also common (Skorikov 1910). Later, in 1920–1930, their dominance was succeeded by large freshwater mollusks, Unionidae (Derjugin 1947). Oligochaeta worms were rare in the 1910s, but common in the 1920–1930s. The further succession of zoobenthos was related to a progressive decline of glacial relicts (today *P. quadrispinosa* occurs only occasionally) and the increase of the dominance of Oligochaeta worms, which probably resulted from eutrophication processes in this part of the Neva Estuary. The influence of natural climate-mediated factors evinces in periodic high increase in zoobenthic biomass with a dominance of Pisidiidae in the eastern part of the bay near the delta of the Neva River for the periods of a high river run-off (Maximov 2004) and periodic dominance of large mollusks, Unionidae, in the other parts of the Neva Bay for the periods of a low river run-off (Golubkov 2008).

Similar changes have happened in the most eastern brackish part of the Neva Estuary where the dominance of relict crustaceans was succeeded by the dominance of oligochaetes and chironomids due to a progressive eutrophication of the eastern Gulf of Finland (Golubkov et al. 2003a). Nowadays two species of Oligochaeta, *Potamothrix hammoniensis* and *Limnodrillus hoffmeisteri*, and larvae of *Chironomus plumosus* (Insecta) dominate in bottom animal communities there (Balushkina et al. 2008).

A more complicated situation is observed in the deep-water western part of the estuary. Glacial relict crustaceans *Monoporeia affinis*, *Saduria entomon* and *Pontoporeia femorata* sharply dominated in the bottom animal communities until the early1990s. Since the middle 1990s these communities were deteriorated several times by periodic intrusions of near bottom oxygen-poor waters from the western part of the Gulf of Finland (Maximov 2003). As a result, vast areas in the western part of the estuary became free from the native benthic fauna and were populated in the 2000s by alien species: oligochaetes *Tubificoides pseudogaster* and polychaetes *Marenzelleria neglecta* (Maximov 2007). Negative changes in benthic animal communities are observed also in the coastal zone of the eastern Gulf of Finland, where several alien amphipods and non-indigenous mollusk *Dreissena polymoprha* sharply dominated since the late 1990s (Orlova et al. 2006). One of the reasons for establishment of alien species in the shallow littoral zone is the deterioration of the native animal communities as a result of filamentous algae blooms which are observed there nowadays (Berezina et al. 2007). At present, alien species contribute 60–99% of the total benthic biomass of the brackish part of the Neva Estuary (Orlova et al. 2006).

Alien species: non-indigenous species. The problem of invasions of non-indigenous species is one of the most urgent environmental problems of the eastern Gulf of Finland (Panov et al. 2002) due to its location at the termination of the Volga-Baltic invasion corridor and high intensity of cargo and oil ship transportation in the region. Dominant freshwater and brackish-water non-indigenous species (NIS) have originated from the Ponto-Caspian region, from the coastal waters of North America and from the inland waters of eastern Asia. A very high rate of new invasions was observed from 1998 to 2004 and now about 8% of all animal species inhabiting the eastern Gulf of Finland are invasive (Orlova et al. 2006). One of the key alien species from the Ponto-Caspian region is zebra mussel *Dreissena polymorpha* occupying deep littoral zone in the brackish part of the Neva Estuary. Now *D. polymorpha* contribute up to 96% of total biomass at stony and stony-sandy bottoms (Orlova et al. 2006). Apart from the damage for hydraulic structures, its main negative impact on environment is facilitation of filamentous algae blooms in the coastal zone of the brackish part of the Neva Estuary by means of clearance of the water and recycling of nutrients (Golubkov et al. 2003b).

Two key benthic alien species in the deep western part of the Neva Estuary are worms *Marenzelleria neglecta* (Polychaeta) from North America and *Tubificoides pseudogaster* (Oligochaeta) from the North Sea, that established in the eastern Gulf of Finland during the last decade and contribute up to 70-99% of the total benthic biomass in the western part of the estuary (Orlova et al. 2006). They replaced the native glacial relict crustaceans *Saduria entomon* and *Monoporeia affinis* that were widely distributed there until the middle 1990s (Maximov 2007). Replacement of the native nectobenthic crustaceans by alien worms negatively affects the population of Baltic herring, the most important commercial fish in the lower part of the Neva Estuary, decreasing availability of food for this species. Establishment of dense population of *M. neglecta* also contributes to eutrophication of this part of the Gulf of Finland due to its ability to enhance nutrient fluxes from bottom sediments (Golubkov et al. 2004).

Two alien amphipods, *Gmelinoides fasciatus* and *Pontogammarus robustoides,* together contribute up to 45% of the total biomass of zoobenthos in the shallow littoral of Neva Bay and the lower brackish part of the Neva Estuary (Orlova et al. 2006). They are omnivores and affect strongly other species of zoobenthos. In the 1990s, they replaced the native amphipod, *Gummarus lacustris* (Berezina and Panov 2003). Establishment of another important alien species, a fish, *Perccotus glenii*, in the littoral zone of Neva Bay directly (by predation) and indirectly (by competition) affects the native fishes such as roach and juveniles of other species in this part of the Neva Estuary. The feeding range of *P. glenii* is very wide and adults effectively prey on the juveniles of other fish. This species is also more resistant to hypoxia, high temperatures, and other abiotic stressors compared to native fishes. Predation and higher tolerance may explain the dominance of *P. glenii* in the fish community of the coastal Neva Bay and a decline of abundance of native fishes (Orlova et al. 2006).

Predatory cladoceran *Cercopagis pengoi* should be mentioned among the planktonic NIS. Nowadays, this species contributes up to 33% of the total zooplankton biomass in the second half of summer and considerably affects planktonic community in the brackish part of the estuary (Telesh 2004). Calculation showed that the size structure of zooplankton community and trophic webs in the ecosystem have been modified as a result of the elimination of small planktonic filtrators and sedimentators by C. *pengoi* (Litvinchuk and Telesh 2006). It also negatively affects *Eurytemora affinis*, a dominant native species in zooplankton of the eastern Gulf of Finland (Lehtiniemi and Gorokhova 2008).

All the above-mentioned species that established in the eastern Gulf of Finland during the last two decades nowadays affect different aspects of biodiversity and function of its ecosystem. Most of them arrived with ship ballast waters, but some, such as crustacean *G. fasciatus,* came as a result of secondary invasions from continental water-bodies where they were deliberately introduced by humans.

The reasons for considerable increase in the rate of NIS introduction are deterioration of native communities as a result of high eutrophication, a many-fold increase of ship traffic in the region and climate-mediated changes in hydrological regime in this part of the Baltic Sea. The last factor is related to the frequency of the intrusions of oxygen-poor salt water into the Neva Estuary from the western part of the Gulf of Finland, depending on salt water inflows into the Baltic Sea from the North Sea (major Baltic inflows). These inflows are related to the weather conditions in the Baltic Region (Matthäus and Schinke 1999; Meier 2007). The decline of the frequency of intrusions of salt water into the Baltic Sea since the middle 1970s up to the middle 1990s and their nearly total absence from 1983 to 1993 were related to the climatic phase of intensive cyclonic activity and increase of river run-off (Matthäus, Schinke, 1999). In the last 10 years a decline of intensity of zonal circulation is observed. As a consequence, heavy intrusions of salt water into the Baltic Sea were observed in relatively dry years: in 1996 and 2003 (Matthäus, Schinke, 1999, Meier 2007). They were followed by the intrusions of the oxygen-poor salt water into the Neva Estuary from the western part of the Gulf of Finland (Averkiyev et al 2004). As a result, vast areas in the western part of the estuary became free from the native benthic fauna and were populated in the 2000s by alien species: *T. pseudogaster* and *M. neglecta*.

Fish. Fifty-three species of cyclostomes and fishes have been recorded for the eastern Gulf of Finland including the most valuable but rare species, like sea sturgeon *Acipenser sturio* and alien species like *Perccotus glenii,* which is now widely distributed in the coastal zone of Neva Bay (Kudersky 1997). Fish populations include three ecological groups: marine, freshwater and anadromous species, but only some of them are of commercial importance. Important marine Baltic species, sprat and cod, periodically come to the Neva Estuary and considerably contribute to fish catch, but do not spawn there.

Coastal areas especially in Neva Bay and also in the large Gulf of Vyborg and Luga Bay provide spawning and feeding habitats for many marine, diadromous and freshwater fishes. The most commercially important marine species, Baltic herring *Clupea harengus membras*, come to the coastal zone of the eastern Gulf of Finland for a short time to spawn. Also many diadromous species including the most numerous and commercially valuable smelt *Osmerus eperlanus* occur in near-shore areas and in inflowing waters during a short time of spawning. But some species, e.g. commercially valuable *Salmo solar, Salmo trutta* and river lamprey *Lampetra fluviatilis,* stay in rivers for several years until they reach the migration stage (Kudersky 1997).

The total catch of marine species increased since 1929–1950 until the middle 1970s when it exceeded 25,000 ton yr^{-1}, and was high until the early 1990s (Kudersky 1997). Since that time it decreased rapidly and now is less than 5,000 ton yr^{-1} (Kudersky et al. 2008). The reasons for this great decrease are probably related to progressive eutrophication of the coastal and open waters and deterioration of foraging conditions as a result of elimination of native benthic crustaceans in the western part of the estuary (Alimov and Golubkov 2008, Kudersky et al. 2008). The dynamics of herring catch in the eastern Gulf of Finland is similar to general dynamics of commercial catch of this species in the Baltic Sea, but in the Baltic Sea as a whole it decreased by only about 1.5 times during the last two decades (Kudersky and Alekseev 2005).

A dramatic decline in the populations of diadromous and freshwater fishes was also observed. But in contrast to marine species a substantial factor for these groups is the loss of spawning and feeding areas due to intensive dredging activities in the region owing to the construction of several new ports and lands in the coastal zone of the estuary (Kudersky et al. 2008). A very intensive public fishery is also partly responsible for the population decline of diadromous and freshwater fish during the last decade (Popov 2006). In contrast to some other Baltic coastal regions, where a tendency for increase of perch and roach catches was observed during the last decade (Ådjers et al. 2006), in the eastern Gulf of Finland populations of all species (except alien *Perccotus glenii*) declined in the last two decades. Twenty per cent of all species are endangered. Several species, e.g. sea lamprey *Petromyzon marinus* and trout *Salmo trutta,* are included in the Red Data Book of Nature of the Leningrad Region (2002) as endangered. The total catch of fish spawning in the Neva Bay has decreased about 4 times as compared to 1972–1984 (Kudersky et al. 2007).

Avifauna. The avifauna of the eastern Gulf of Finland is relatively well documented in scientific literature. Before the Second World War it was investigated by Finnish ornithologists (e.g. Putkonen 1936, 1942), then the investigations were continued by Russian scientists (e.g. Malchevskiy and Pukinskiy 1983; Khrabriy 1991; Noskov et al. 1993; Bublichenko 2000; Afanasyeva et al. 2001). Nowadays, the coastal zone of the eastern Gulf of Finland is used by 234 bird species for nesting, foraging and rest during seasonal migrations (Khrabriy 2008), which makes this part the Baltic Sea one of the most important regions for the conservation and protection of bird fauna.

There is a great difference in long-term dynamics of avifauna in different parts of the eastern Gulf of Finland. The western part of the Neva Estuary was restricted for public access and for most kinds of economic activities for a long time due to the proximity of the state border. Therefore, the changes in avifauna observed in this part of the Neva Estuary are probably mostly related to natural dynamics. The abundance of some species has decreased. For instance, the large merganser *Mergus merganser* and the middle merganser *Mergus serrator* were numerous in the north-western part of the area until the late 1970s, but their numbers decreased greatly during the last two decades and now they have become rare nesting species (Khrabriy 2008). On the other hand, the population of the large cormorant *Phalacrocorax carbo* considerably increased in number in the western part of the Neva Estuary during the last decades (Gaginskaya 1995), and this species has become as common as another cormorant *Phalacrocorax aristotilis*. Grebes *Pociceps auritus* and *Podiceps cristatus* are common species in this area, but loons *Gavia arctica* and *Gavia stellata* are endangered. Tufted duck *Aythia fuligula* is common, but greater scaup *Aythia marila* is rare (Khrabriy 2008). Auks *Alca torda* and *Cepphus grille* are relatively rare. In general, the present status of coastal bird populations of the lower brackish part of the Neva Estuary may be considered as good. However, their future is uncertain due to a great increase in oil transportation, which increases the risk of oil spills in the region. This is especially alarming because shallow coastal zone near the Kurgalskiy Peninsula in the south-western part of the Neva Estuary and near the islands in its central and northern parts is one of the most important resting places of waterfowl during its seasonal migrations in the eastern Baltic (Noskov 2002; Khrabriy 2008). A gradual increase in public and industrial companies' access to the region affects negatively its avifauna nowadays. This situation may be improved by establishment of national reserves, especially on the islands in the western part the estuary.

An entirely different biodiversity dynamics is observed in Neva Bay where it is greatly affected by anthropogenic factors. In former times the eastern part of the bay together with the delta of the Neva River was one of the most important habitats and resting places along the migration routes in the eastern Baltic for numerous species of waterfowl (Malchevskiy and Pukinskiy 1983; Khrabriy 2008). Unfortunately, these important habitats have been practically lost as a result of expansion of Saint Petersburg and its suburbs since the early 1980s. The number of coastal birds has decreased dozens of times. This loss is partly compensated through the expansion of reeds in the northern and southern parts of Neva Bay as a consequence of the Dam construction, as abundant bird colonies appeared near the Kotlin Island and in the reeds along the southern and northern coasts of Neva Bay.

Mammals. Two seal species, the Baltic subspecies of Gray Seal *Halichoerus grupus* and the Baltic ringed seal *Phoca hispida botnica*, were very abundant in the Baltic Sea at the beginning of the 20th century, when their numbers were estimated to be about 200,000 (Tormosov and Esipenko 1990). A progressive decline in the numbers of seals was observed throughout the last century.

The first data on the numbers of seals in the Gulf of Finland and in the Gulf of Riga, about 12,500 seals, were obtained in 1970 (Tormosov and Esipenko 1990). The most numerous species was the ringed seal. In 1982–1985, its numbers decreased to 4,000 (Tormosov and Esipenko 1990). At present, the population has dramatically declined and recent surveys documented only about 300 ringed seals (Verevkin and Sagitov 2004). This species lives in the eastern Gulf of Finland throughout the year: in winter it is most abundant in the northern part of the gulf: to the south and south-west from the Bolshoy Beriozoviy Island, but in summer it migrates to the southern part of the gulf. Therefore, the numbers of the main resident species of seals in the eastern Gulf of Finland decreased tenfold during the last decades.

In contrast to the ringed seal, the gray seal occurs in the eastern Gulf of Finland in summertime (Verevkin and Sagitov 2004). It is mostly abundant in the south-western part of the estuary. About 100 gray seals were recorded in the 1970s; 200–300 seals in the 1980s (Red Data Book of the Russian Federation 2001). Four hundred to five hundred gray seals occur in the Neva Estuary nowadays (Verevkin and Sagitov 2004). Therefore, the numbers of this species tend to increase, but are still very low in comparison with its numbers at the beginning of the last century.

Status of the Protected Areas. There are no special MPA in the eastern Gulf of Finland, but some protected natural land territories (PT) that have been already established at its coast include a part of the adjacent marine area. Eleven of them operate and four are at a planning stage. The largest and most important operating protected territories are the regional complex sanctuaries, Beryozovyye Islands and Kurgalskiy. The former is located in the north-western part of the Neva Estuary and includes 45,320 ha of marine area; the latter is located in the southern part of the gulf and covers 38,400 ha of water surface (Red Data Book of the Leningrad Region 1999). Both of them are very important for protection of marine bird populations, bird migration areas, Baltic seals and other components of marine biodiversity. Vyborgsky Sanctuary in the Gulf of Vyborg includes about 5,000 ha of water area. The large Ramsar Site, Lebyazhye, is situated along the south-eastern coast of the brackish part of the Neva Estuary. Its area is 6,400 ha. This site along with the Vyborgsky Sanctuary preserves the coastal landscape and stop-overs of migratory birds and nesting places of waterfowl and coastal birds. Very important PT, Ingermanlandsky State Natural Reserve, is to be established at several islands scattered in the western part of the Neva Estuary in 2009. It will also cover a considerable marine area (16,980 ha) near the coast of the islands and together with the sanctuaries Beryozovyye Islands and Kurgalskiy is supposed to be very effective in conservation of marine and island wild-life. Therefore, the status of marine protected areas in the lower brackish part of the Neva Estuary may be considered as good.

Much worse situation with protection of marine environment is in Neva Bay, although this part of the eastern Gulf of Finland is also very important for wild-life conservation, e.g. coastal bird populations. Only two very small areas along the southern coast of the bay have the status of natural monuments, where economic activities are restricted. Two large PT are proposed to be established in the north-western part of the bay to preserve coastal bird populations and stop-overs of migratory birds. But at the moment the situation with the Baltic Sea Protected Areas in Neva Bay is very bad.

The main losses and threats to biodiversity in the Neva Estuary. The main losses of biodiversity in Neva Bay include disappearance of considerable part of submerged macrophyte meadows and disappearance of the main spawning areas of fish in the eastern part of the bay. Alien species contribute up to 45% of the total biomass of zoobenthos in the shallow littoral zone. At present, protected areas, which could promote biodiversity conservation in this part of the estuary, are nearly absent.

The main losses of biodiversity in the brackish part of the Neva Estuary include disappearance of more than 90% of ringed seal population, fivefold decrease of commercial fish catch, replacement of native dominant zoobenthic species by aliens in coastal and open waters. Only marine birds may be considered to have good status due to a relatively good situation with the protected areas in this part of the gulf.

DISCUSSION

The role of climatic and anthropogenic factors in biodiversity dynamics. Habitat and community modification, eutrophication and alien species are the main threats to the ecosystem integrity and biodiversity in the Baltic Sea, and in the Gulf of Finland in particular (Schernewski and Schiewer 2002; UNEP 2005, Alimov and Golubkov 2008). At present, phosphorus load from natural sources accounts for approximately 40% and from anthropogenic sources for 60% of the whole load (Frumin and Leonova 2004). Therefore, the most part of primary production in the Neva Estuary, which exceeds 2.0 g C $m^{-2} d^{-1}$ in its eastern brackish part in the 2000s and corresponds to highly eutrophic water (Golubkov et al. 2007), is related to anthropogenic impact. The high level of eutrophication results in intensive development of algae and cyanobacteria, decrease of water transparency and in filamentous algae (mostly *Cladophora glomerata*) blooms in the coastal part of the estuary (Golubkov et al. 2003b). Transparency of the water considerably decreased during the last hundred years in all basins of the Baltic Sea (Sandén and Håkansson 1996), which negatively affects biodiversity of submerged macrophytes and depth of their distribution, by decreasing light penetration into the water column (Berger et al. 2004). In the Gulf of Finland, the Secchi depth decreased from 7–11 to 3–6 m over the past 100 years due to eutrophication (Savchuk et al. 2008). The last values coincide with the contemporary lower limits of depth distribution of perennial algae in the eastern Gulf of Finland. Negative effect of eutrophication on the macrophyte distribution is observed in many parts of the Baltic Sea (e.g. Kautsky et al. 1986; Kruk-Dowgiallo 1991) and in estuaries of the other seas (Valiela et al. 1997).

Cyanobacteria and filamentous algae blooms cause negative community dynamics of macrozoobenthos and fish in the shallow coastal zone due to the release of harmful substances and deterioration of oxygen conditions resulting from decomposition of great amount of organic matter during and after the blooms (Berezina and Golubkov 2008). In its turn, impoverishment of native benthic communities contributes to prosperity of alien species in the coastal zone of the gulf. The exceptional increase of ship traffic in the region also accelerates the rate of new invasions. Alien species are one of the most important threats to biodiversity in the brackish part the Neva Estuary nowadays.

The large-scale digging and dumping of bottom sediments related to construction of new lands, ports and oil terminals also negatively affect biodiversity of macrophytes, macrozoobenthos and fish, especially in Neva Bay. These activities are responsible for direct loss of the fish spawning grounds and bird nesting, foraging and migratory resting places in the eastern part of the bay. A considerable part of fish spawning grounds in the shallow Neva Bay was destroyed during the last decades. Great amounts of suspended matter resulting from dredging activities have also greatly decreased the water transparency and reduced the distribution and biodiversity of submerged vascular plants and perennial macroalgae.

Climatic changes have also contributed to negative community dynamics as in some other European estuaries (Widdows et al. 2007). They were related to the termination of climatic phase of intensive cyclonic activity and renewal of the major Baltic inflows since the middle 1990s (Matthäus and Schinke 1999; Meier 2007). These inflows have led to intrusions of oxygen-poor salt water into the Neva Estuary from the western part of the Gulf of Finland (Averkiyev et al 2004), which is the main natural factor responsible for deterioration of the zoobenthic communities in the western part of the estuary (Maximov 2003). Deterioration of environments leads to decline of native species and prosperity of invasive species. Alien species contribute about 8 per cent of species richness and 60–90 per cent of biomass to the bottom animal communities. The decline of bottom natural communities mostly dominated by crustaceans have led to impairment of food conditions for fish and contributed greatly to a decline of their populations, which, in turn, may be partly responsible for the population decline of ringed seals. The main food item in the diet of this species in the eastern Gulf of Finland is Baltic herring (Rezvov 1977). Therefore, the great decrease in the abundance of herring in the eastern Gulf of Finland during the last decades should result in a decline of the ringed seal population. Another reason is related to the warming of the regional climate (Filatov et al., 2007). This has resulted in milder winters that reduce the period and the area of ice cover in the region (Jaagus, 2006), which decreases breeding success of the ringed seal (Verevkin et al., 2008), because this species needs permanent ice cover to breed (Rezvov 1975). In recent years the situation has become worse due to ice-breakers that clear the ways for tankers coming to the new oil terminals in the northern part of the eastern Gulf of Finland, which is a breeding place of the local population of ringed seals. Therefore, climate-mediated factors should be taken into account for long-term forecasts and measures for the conservation and improving of biological diversity and planned development of the region.

Summary/Recommendations: advices and recommendations to decision-makers for conservation and improvement of biological diversity. The Eastern Gulf of Finland is a complicated natural system, whose biodiversity suffers from diverse anthropogenic impacts: high nutrient and contaminant loads, intensive fisheries, dredging and creation of new lands, intensive ship traffic. To improve biological diversity of the Eastern Gulf of Finland intensity of anthropogenic impacts, such as nutrient and contaminant loads, dredging and creation of new lands, construction of new ports should be reduced. Toughening of the legislation to control ballast waters and deliberate acclimations of new species in the region are highly important. There is a sufficient number of protected areas in the lower brackish part of the Neva Estuary, but they are mostly aimed at protecting birds and land habitats. The status of true marine protected areas (MPA) should be extended to marine parts of the existing and planned protected areas. In Neva Bay, remedial measures should include: restriction of dredging activity in the eastern part of the bay, restoring of fish spawning grounds, further reduction of nutrient load from sewage plants of Saint Petersburg and from point sources at the watershed of the Neva River, establishment of MPA along the northern and southern coasts of the bay.

In the brackish part of the Neva Estuary remedial measures should include: further reduction of nutrient load from different sources, further development of the measures for security of the oil transportation, restriction of construction of new port facilities in the vicinity of protected areas; improvement of the regulation of commercial fisheries in the region; development of preventive measures against overexploitation of the coastal zone by tourists, e.g. prohibition of unregulated pitching of tents and camp-fires, organization of scavenging, etc.

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