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Long-term changes in primary production and mineralization of organic matter in the Neva Estuary (Baltic Sea)

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ABSTRACT

The Neva Estuary situated in the eastern part of the Gulf of Finland is one of the largest estuaries of the Baltic Sea. At present, heavy nutrient and organic matter loading, mainly from the Neva River and point sources in the upper estuary are the most serious environmental problem for the Neva Estuary and adjacent parts of the eastern Gulf of Finland. Long-term studies of mid-summer primary production and mineralization of organic matter were conducted in upper and middle parts of the Neva Estuary. A considerable increase of production and biomass of phytoplankton was observed in the middle part of the estuary during the last decades mainly due to an increase in biomass of cyanobacteria. However, they are mostly concentrated in the upper water layers and only a small part of them reached the near bottom water layers and may be used as a food by zoobenthos. The mineralization of organic matter in the water column was twice higher than primary production that indicates the importance of allochthonous organic matter in the carbon budget of the both parts of the estuary. The carbon isotope signature of seston and most of the zoobenthic species in the upper part of the estuary was close to the signature of allochthonous carbon leaking from watershed (−27‰). Higher values of $\delta^{13}C$ of seston in the upper mix layer of the Middle estuary indicate intensive primary production in mid-summer. The carbon isotopic signature of zoobenthos in this part of the estuary was also in general lower than in the Neva Bay reflected higher importance of autochthonous organic matter in food webs of the estuary.

Regional term

Russian Federation
Gulf of Finland
Neva Estuary
Neva River

1. Introduction

Commonly, the term eutrophication is related to the excessive nutrient load of a sea area. A more appropriate definition considers eutrophication as "an increase in the rate of supply of organic matter to an ecosystem" (Nixon, 1995). This definition is based on the fact that organic matter is a major control for the marine food web and oxygen depletion in deeper water layers (Omstedt et al., 2014). Especially important this definition for estuarine ecosystems that are transitional zones between inland and marine environments and their functioning is crucially dependent on allochthonous carbon supply. Indeed, in many estuaries, local primary production is less than the rate of mineralization of organic matter. This heterotrophy is sustained by the upstream and lateral supply of organic matter (often terrestrial) resources in the form of dissolved organic carbon (DOC) and particulate organic carbon (POC). Mass-balance considerations and ecosystem modeling have shown that mesozooplankton in estuaries has to consume detrital carbon in order to obtain sufficient energy (Escaravage and Soetaert, 1995). On the other hand, extensive input of nutrients from rivers often makes them one of the most productive types of marine ecosystems and often leads to high phytoplankton production and intensive cyanobacteria blooms, especially in the Baltic Sea (Conley et al., 2009). Cyanobacteria and other primary producers create a potentially large pool of autochthonous carbon and nutrient sources for estuarine food webs (Karlson et al., 2014, 2015).

The Neva Estuary situated in the eastern part of the Gulf of Finland (Fig. 1) is one of the largest estuaries of the Baltic Sea. It is generally characterized by a number of features common to other major Baltic estuaries. As most of them, Neva Estuary is 1) brackish-water, non-tidal, shallow, 2) strongly affected by wind-mixing, 3) with stochastic water exchange with deep part of the Gulf of Finland, 4) with fluctuations of ecosystem parameters caused mainly by physical factors, 5) with horizontal and vertical gradients of salinity, nutrients and plankton

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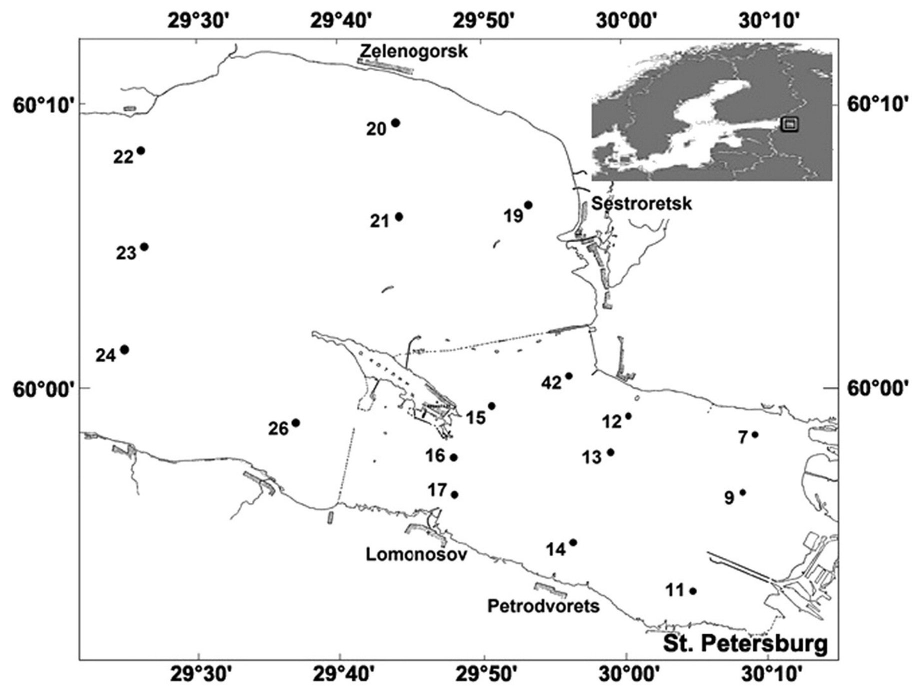

Fig. 1. Upper and the middle part of the Neva Estuary with indication of the sample stations.

abundance, 6) with intensive benthic-pelagic coupling, 7) sensitive to nutrient loads (eutrophication), 8) characterized by intensive accumulation of humic substances, 9) with dominance of eurytopic species, and 10) with high biological diversity and productivity (Telesh et al., 2008). 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, are the most serious environmental problem for the Neva Estuary and adjacent parts of the eastern Gulf of Finland. The primary productivity and biomasses of autotrophic and heterotrophic organisms in the estuary are among the highest in the Baltic (Golubkov et al., 2003; Telesh et al., 2008), mainly due to eutrophic effects of the high nutrient inflow from the Neva River, the most affluent river of the Baltic Region. Annually about 3000 t of total phosphorus and 57,000 t of nitrogen enter the eastern part of the gulf, i.e. approximately 8% of macronutrients entering the Baltic Sea with rivers flow (HELCOM, 2004). Periodic hypoxia and intrusions of nutrient rich near bottom waters from deep western parts of the Gulf of Finland also contribute to high eutrophication of this part of the Gulf (Golubkov and Alimov, 2010).

The relative importance of allochthonous vs. autochthonous carbon resources for lacustrine food webs was shown using stable isotopes at natural abundance (Grey et al., 2001; Karlson et al., 2014, 2015) as well as isotopic tracers (Pace et al., 2004). These studies revealed major but variable terrestrial support of lake and estuarine food webs (Middelburg and Herman, 2007; Van den Meersche et al., 2009). For instance, the role of allochthonous carbon in lake metabolism and food webs can be negligible in eutrophic waters (e.g., Jones, 1992).

Long-term data on seasonal dynamics of phytoplankton in the middle part of the Neva Estuary show that since the late 1990s – early 2000s mean seasonal biomasses of phytoplankton increased approximately twofold as compared with the 1980s (Nikulina and Gubelit, 2011). The present high degree of eutrophication in the estuary is also shown by the intensive development of cyanobacteria. Before the late 1990s, when waters of the middle part of the estuary were mesotrophic, the dominant group of phytoplankton was diatoms (Bacillariophyta) (Nikulina, 2003). Cyanobacteria were an important group only in late July and August. In the early 2000s, cyanobacteria biomass and the period of their predominance in plankton has increased considerably (Nikulina, 2003; Nikulina and Gubelit, 2011). Frequent short-term cyanobacteria blooms were observed in mid-summer time.

The increase of phytoplankton biomass may result in a change of community metabolism of the Neva Estuary and considerable decrease the importance of allochthonous carbon in estuarine food webs. The aim of this paper is to evaluate long-term trends in the intensity of primary production and mineralization of organic matter in mid-summer time during the last decades. We also tested the hypothesis that a recent increase of midsummer cyanobacteria biomasses in the middle part of the estuary decreased the importance of allochthonous carbon in zoobenthic food webs. This goal was attained by using stable isotope analysis (SIA) of tissues of zoobenthos and suspended organic matter (seston) consisting of phytoplankton and detritus, both brought by Neva River waters and formed in the estuary.

2. Material and methods

2.1. Study site and sampling

The Neva Estuary receives water from the Neva River, a relatively short canal (74 km) between Lake Ladoga and the Gulf of Finland. The catchment area of the Neva River exceeds 280,000 km^2, and its water discharge averages 2490 m^3 s^{-1} (78.6 km^3 year^{-1}). The Neva Estuary consists of three parts: the upper freshwater – upper estuary (Neva Bay), the brackish Middle estuary, and the Lower (Outer) estuary. The surface area of the Neva Bay (Fig. 1) is about 400 km^2, the salinity – 0.07–0.2 PSU, with the exception of short-term intrusions of brackish-water from the middle part of the estuary during surge events when brackish waters from the Middle estuary come to the Neva Bay and mix there with fresh waters. The depth of the bay is 3.5–5 m. At the end of 1980s, the Neva Bay was separated from the lower part of the estuary by the flood protection barrier (Dam). The flood protection barrier has several sluices in its northern part and a broad ship lock in the southern part. There is no temperature stratification in this part of the estuary. Low water transparency, which does not exceed 1.8 m of Secchi depth in summer time, constrains the distribution of bottom vegetation

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