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Nutrient and metal pollution of the eastern Gulf of Finland coastline: Sediments, macroalgae, microbiota

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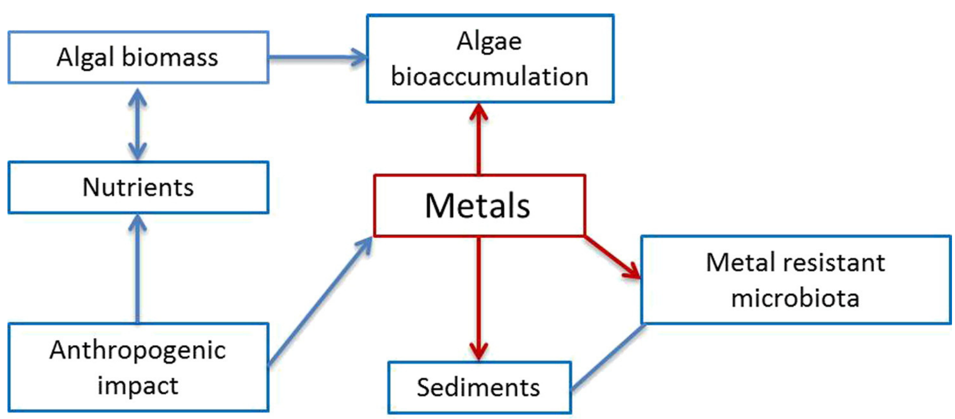
HIGHLIGHTS

- We studied heavy metal pollution in the coastline of the eastern Gulf of Finland.
- Sediments, water, mass macroalgae and microbiota were included into analyses.
- Eutrophication and nutrient loading remain the main problem of the studied area.
- Macroalgae contribute to accumulation of organic matter, nutrient, and heavy metal.
- Pollution in the studied area is caused by a combination of different factors.

GRAPHICAL ABSTRACT



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ABSTRACT

The anthropogenic pollution along the coastline of the eastern Gulf of Finland was studied through a range of methods, including analyses of metal contamination in water, surface sediments, accumulated algal biomass and its correlation with resistant microbiota. According to concentrations, the main pollutants in water were copper and manganese. Influence of Nuclear Power Plant was remarkable in adjacent areas and was expressed in high concentrations of molybdenum, nickel, copper and other elements in the water. Relatively high concentrations of copper, lead and zinc were found in sediments. Microbial tolerance appeared to be correlated with the concentration of the metals in sediments. Higher tolerance levels were found in sediment samples from more polluted stations. Macroalgae, which were massively developed in the coastal zone, had shown high level of metal bioaccumulation. Analyses of carbon, nitrogen and phosphorus content of algal tissues allowed the estimation of additional nutrient loading from accumulated decaying algal biomass on the coastal zone of the eastern Gulf of Finland. Mass development of algae in coastal area may contribute to accumulation of organic matter and associated metals. In our study the highest metal concentrations in sediments were found at the sites with dense and continuous layer of fresh and decaying macroalgal biomass, accompanied by hypoxic conditions.

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Also our study has shown that accumulated biomass may be a significant source of nutrients in the coastal ecosystem.

1. Introduction

The eastern Gulf of Finland is an easternmost part of the Baltic Sea, which is affected by industrial pollution, intensive shipping and wastewater discharges from metropolis Saint Petersburg (Golubkov et al., 2008). High nutrient loading and extensive shallow areas create favorable conditions for development of green opportunistic macroalgae in coastal zone of the eastern Gulf of Finland. Every summer decay of the macroalgal mats leads to mass mortality of benthic animals and fishes (Berezina et al., 2007; Gubelit and Kovalchuk, 2010; Nikulina and Gubelit, 2011). Besides eutrophication, the Gulf of Finland is affected by organic and metal pollution (Rybalko et al., 2007; Vallius, 2012). According to The Baltic Marine Environment Protection Commission (Helsinki Commission, HELCOM) reports, cadmium, cesium-137, copper, DDT, lead, mercury, TBT and zinc are main pollutants in the Gulf of Finland. For example, by 2008, the concentrations of mercury and cadmium in the surface sediments of the eastern Gulf of Finland reached 0.3 and 1.2 mg kg^{-1} DW, respectively (HELCOM, 2010a, 2010b). Despite high anthropogenic pressure on the eastern Gulf of Finland, majority of publications describe distribution of the hazardous substances in its Finnish, i.e. northern, part (Vallius, 2007, 2009, 2011, 2012). Although studies on metal concentration in the bottom sediments of the Russian part of the Gulf of Finland were being conducted since early 1990s, the data published in open sources are fragmentary and sparse (Vallius and Leivuori, 2003; Rybalko et al., 2007, 2009; Fokin and Frumin, 2011; Eglit et al., 2012). In 2006–2007, anthropogenic pressure on eastern Gulf of Finland increased due to dredging and land reclamation in the Neva Bay, resulting in further deterioration of environmental conditions (Rybalko et al., 2007; Rybalko and Fedorova, 2008). After major construction works finished in 2008, high concentrations of cadmium, copper and nickel were recorded in bottom sediments. For instance, concentration of copper increased from 90 mg kg^{-1} DW in 2006–2007 to 200–250 mg kg^{-1} DW in 2008. At the same time, amounts copper and zinc in the water column were above Critical Level of Pollution (CLP) (Rybalko et al., 2009). According to report of state monitoring on water quality, copper, iron and manganese were the main pollutants in the water of the eastern Gulf of Finland (Eglit et al., 2012). Shore zone of the gulf is widely used for recreation, but most of sources mentioned above deal with open sea areas. Data on the coastline of the eastern Gulf of Finland are missing because considerable territory on the southern shore of the eastern Gulf of Finland was closed to public access until early 2000s.

Coastal sediments are sites of intense biogeochemical cycling regulated by microorganisms. Anthropogenic pollution plays an important role modulating the adaptation of sediment microbial communities to environmental conditions. Microorganisms adapt to the presence of pollutants by developing resistance mechanisms (Mergeay, 1995; Nies, 1999). The tolerance of bacteria to metals has been proposed as an indicator of the potential toxicity of metals to other forms of biota (Hassen et al., 1998). Microbial bioindicators are known to play a major role in detecting ecosystem change in response to environmental perturbations (Paerl et al., 2003). However, relatively little is known about what happens to sediment microbiota in the presence of organic and inorganic contamination (Nogales et al., 2011; Sun et al., 2013). Coastal sediments of the eastern Gulf of Finland, an estuarine filter to incoming anthropogenic pollution, provide an appropriate model system for studying interactions between contaminants and microorganisms.

Biogeochemical processes at the sediment–water interface are likely to be considerably affected by the degradation of macroalgal detritus (Garcia-Robledo et al., 2008). As mentioned above, green opportunistic algae *Cladophora glomerata* (L) Kutz. and *Ulva intestinalis* (L) grow in vast masses in the eastern Gulf of Finland. Macroalgae have the ability to uptake metals from aquatic environments and species such as *C. glomerata* and *U. intestinalis* are considered as effective bioindicators of metals (Vymazal, 1987; Whitton and Kelly, 1995; Chmielewská and Medved', 2001; Zbikowski et al., 2007). A number of articles on metal content in some algae from southern and northern Baltic Sea were published in recent years (Zbikowski et al., 2007; Lill et al., 2012). However, despite their extensive distribution in the eastern Gulf of Finland, accumulation of metals in *Cladophora* and *Ulva* from the eastern Baltic Sea has not been addressed.

The aim of our study was to determine concentration and distribution of metals in surface sediments along the eastern Gulf of Finland coastline and look for possible relationships with macroalgae and microorganisms. Our study is intended to fill the gap in the data on metal contamination of the eastern Gulf of Finland coastline and reveal the possible influence of the Nuclear Power Plant in this area. Considering complexity of the gulf ecosystem and coastal eutrophication in this area we had proposed that massive accumulation of green macroalgal biomass may be an additional source of nutrient loading and also may reinforce contamination of sediments due to algal bioaccumulative properties and hypoxic conditions under algal layer. Accordingly, we expected to find a shift in the composition of heterotrophic organisms that regulate biogeochemical cycles towards the metal-tolerant forms within contaminated sediments.

2. Material and methods

2.1. Study area

The Neva estuary is an easternmost part of the Gulf of Finland. It is divided by artificial and natural bars into an upper part (the Neva Bay) and a lower part (inner and outer estuary). In turn, inner and outer parts of estuary include several distinct areas: shallow eastern part, deeper central region, Vyborg Bay in the north and Koporskaya and Luga Bays in the south (Fig. 1). The Neva estuary is a transition zone from fresh to brackish waters and salinity increases from east to west (Frumin and Basova, 2008). City of St. Petersburg, laying at the estuarine coast brings high levels of anthropogenic pressure and eutrophication. Atmospheric emissions and intense discharge of municipal and industrial wastewater lead to high pollution of the Neva estuary (Rybalko and Fedorova, 2008). Current population of St. Petersburg is to five million people, resulting in about 3500 t of phosphorus per year in the Neva River runoff (Frumin, 2008). In 2000s the total phosphorus concentration in estuarine waters differed widely between years and various parts of the estuary. In 2003 concentration of total phosphorus did not exceed 48.6 mg m^{-3}, but after beginning of dredging, in 2007, it surged to 300–619 mg m^{-3} in different parts of the estuary (Golubkov et al., 2008).

2.2. Sampling

We chose ten sampling sites located on the northern and southern coasts of the Neva Bay and inner and outer parts of the Neva estuary (Fig. 1). Samples of both surface sediments and macroalgae were taken at a depth of 0.5 m. Sediments were collected with a plastic cylinder and placed in polyethylene bags. We obtained tree replicates of the samples from each site for metal detection. Macroalgae were collected