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Climatic impact on community of filamentous macroalgae in the Neva estuary (eastern Baltic Sea)

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ABSTRACT

In presented study the impact of climatic factors and North Atlantic Oscillation (NAO) on macroalgal community was analysed. Also the factors influencing algal community were defined with help of Principal Component and Classification analysis. It was found that climatic impact may depend on habitat features and that on different sites biomass of macroalgae correlated with different weather factors. Wind and surf may affect biomass of macroalgae adversely on some sites and at the same time on other sites they may accumulate biomass, transferring it is from adjacent areas. High direct correlation with temperature was found on sites which were protected from surf and had no stagnant events. Seasonal biomass inversely significantly correlated with average seasonal wind speed and annual NAO-index.

1. Introduction

In the last 30 years eutrophication of estuaries and coastal waters has become a problem worldwide. The Baltic Sea is also influenced by this phenomenon. According to HELCOM reports, during the last century phosphorus loading to the Baltic Sea has increased fourfold, nitrogen loading – by a factor of seven (HELCOM, 2004).

Such an increase of nutrient loading also resulted in changes in coastal ecosystems (Weckström, 2005). Massive development of fast growing opportunistic macroalgae with simultaneous disappearance of perennial macroalgae and alteration in food webs are main consequences of eutrophication in the shallow zone (Bonsdorff et al., 1997; Bäck et al., 2001). There is an assumption that mass development of macroalgae reflects the global process of eutrophication in the Baltic Sea (Rönnberg and Bonsdorff, 2004).

Besides human mediated impact, the abiotic factors may determine structure and functioning of coastal community and regulate development of macroalgae. Algal communities in the coastal zone are mainly affected by different types of abiotic disturbances: continual disturbances, such as wave action and sedimentation, and periodic disturbances such as ice scouring, changes in light and water level (Kautsky and Kautsky, 1989).

Climate plays an important role for algal communities and can influence its species composition and abundance. On the instance of polar shallow lakes it was shown that climate changes led to a shift in algal communities from planktonic to benthic forms (Smol and Cumming, 2000). Simulation of greenhouse effect in experimental ponds in Finland showed that emerged macrophytes developed earlier and that phosphorus release from decaying plants stimulated the growth of filamentous algae (Kankaala et al., 2000, 2002). Also it was shown that species with opportunistic reproductional strategies gained from heating (Hillebrand et al., 2010).

The climate of the Baltic Sea is influenced by a major air pressure system, the North Atlantic Oscillation, which affects the atmospheric circulation and precipitation in the Baltic Sea basin (HELCOM, 2007). North Atlantic Oscillation (NAO) in winter time determines climatic conditions during the whole following year. The NAO is a good indicator of weather patterns over the eastern Atlantic and Europe (Bolle et al., 2008). When the NAO is positive, the shift in the westerlies causes predominance of warmer air masses over northern Europe and Scandinavia, and leads to increase of precipitation and winter storms. Thus climatic conditions acquire features of wet marine climate and cause warm and ice free winter. When the NAO is negative, the westerlies shift to the south, and northern Europe is colder and less stormy (Hurrell, 1995; Dickson et al., 1996), thus the features of dry continental climate prevail (Hurrell and Deser, 2009). Interannual climate fluctuations may affect communities of aquatic organisms. This was demonstrated in the North Sea where the abundance of *Calanus finmarchius* correlated inversely and highly significantly with the NAO index (Fromentin and Planque, 1996). On the instance of littoral communities of the Baltic Sea it was shown that diversity and dominance of macroalgal species can be related with cold or ice free winters (Kiirikki and Lehvo, 1997). Waern (1952) suggested alternation of so-called "green and brown algal years",

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according to the dominance of green or brown filamentous algae. After ice free winters perennial species (*Fucus vesiculosus*) start to invade filamentous algal zone and control filamentous algae. After cold winters Fucus is eliminated by ice scraping and more scraping-tolerant species, Cladophora, invades free area (Wallentinus, 1979; Kautsky et al., 1986; Kiirikki, 1996; Kiirikki and Lehvo, 1997). Thus according to published literature, it can be suggested that the alteration of warm (ice free) and cold (with ice cover) winters could determine alteration of dominant species in algal community.

After the analysis of long-term climatic data and bottom columns, it was concluded that in case of long-term phase of ice free winters the increase of winter temperature and reduction winter sea-ice in shallow bays of the Baltic Sea (positive phase of NAO) together with human-induced modifications will lead to intense eutrophication that will prevent expansion and survival of perennial species in the littoral zone and will increase the possibility of mass occurrence of opportunistic algae (Cossellu and Nordberg, 2010).

In most coastal areas of the Neva estuary perennial species of algae are absent due to low salinity. Episodic occurrence of brown and red algae is related with inflows of saline waters from the west. In summer time algal communities of the Neva estuary are monodominant and consisted of *Cladophora glomerata* and *Ulva intestinalis* (Gubelit and Kovalchuk, 2010). Possible climate influence on biomass dynamics of opportunistic algae is still unclear. Since climate plays important role for functioning and changes in coastal communities (Cossellu and Nordberg, 2010), the knowledge of the possible influence of climatic changes on coastal ecosystems remains important and can be used for coastal management, especially in areas, which are disturbed by coastal eutrophication phenomena.

The goal of this study was to define the possible effect of climatic conditions and fluctuations on the community of opportunistic macroalgae in the Neva estuary on the basis of long-term data from 2003–2011.

2. Matherial and methods

2.1. Study site

The Neva estuary, the easternmost part of the Gulf of Finland, is known as one of the eutrophied areas of the Baltic Sea. Phosphorus input from the Neva river to the estuary reaches 3500 t per year (Frumin, 2008). Anthropogenic impact and extensive shallow area result in phenomena of coastal eutrophication and intensive development of green filamentous macroalgae (mainly *Cladophora glomerata* (L.) Kütz. and *Ulva intestinalis* L.) (Gubelit and Kovalchuk, 2010). Besides of nutrient loading from the catchment area, in the coastal zone sediments may often be an additional source of phosphorus pulses that could influence the growth of macroalgae. In the Neva estuary the stony substrate and sand prevail on the bottom in most of the studied sites. According to published data on seasonal dynamics of total phosphorus in semi-closed sites of the Neva estuary, sharp rise of phosphorus concentration (up to 160–340 $\mu g\,L^{-1}$) was registered only after main peak of biomass, when masses of decaying algae accumulated on the coast and phosphorus was released from algal tissues (Berezina et al., 2007; Gubelit, 2011). In seasonal aspect it was found that development of the second peak of biomass depended on favorable weather conditions and the stormy weather was an important factor which affected the biomass of macroalgae (Gubelit, 2009).

Thus there is a reason to believe that in opened and semi-closed sites of the Neva estuary in comparison with weather conditions, phosphorus release from sediments does not play any significant role in the formation of the main peak biomass, which was taken into account in farther analysis.

In the coastal zone of the Neva estuary wind direction causes water level changes, western wind leads to onset of water, eastern wind leads to set-down of water and drying in the coastal zone. In addition, the eastern wind could induce upwelling in the Neva estuary. (Preobrazhensky, 2007). Upwelling results in nutrient enrichment of upper water layers that create additional source of available nutrients (Eremina and Karlin, 2008). Usually algae use incoming nutrients immediately and as a result, the difference of phosphorus concentrations in upper water layers cannot be registered (Kiirikki and Blomster, 1996; Eremina and Karlin, 2008). There is no available open data on inter annual number of upwellings in the Neva estuary, however it is known that upwelling in the Baltic Sea and in the Neva estuary is a result of wind-induced water circulation (Haapala, 1994; Mikhailov and Chernysheva, 1997) and may be considered as a consequence of atmospheric processes, which in Baltic region is determined by North Atlantic Oscillation. It was shown that in the Baltic Sea the number of upwellings depends of NAO phase (Lehmann et al., 2002).

2.2. Sampling and data calculation

Samples of macroalgae were collected on 8 sites on northern and southern coasts of the Neva estuary on the depth 0.5 m (Fig. 1).

According to presence or absence of natural and artificial bars and shape of coastal line the sampling sites were determined as exposed, closed and semi-closed (Table 1).

Samples were taken during first two weeks of July in 2004–2011 on sites 1–4 (Northern coast), 5–8 (Southern coast). Seasonal sampling was conducted monthly during end of May – beginning of September of 2003–2010 on the site 1 and in 2004–2010 on the site 5. Attached filamentous algae on hard substrata were sampled in triplicate, using a cylindrical metal frame with area of 0.03 m^2, according to the previously proposed approach (Berezina et al., 2005). The algae were washed by fresh water and all animals were removed. The samples of algae were then dried to a constant weight in laboratory and weighed to 0.01 g precision. The biomass of the algae was estimated as an arithmetic mean of dry weight (DW) ± SE (standard error) for each date and then recalculated per 1 m^2 of stony substrate.

Data on the weather conditions (daily temperature and wind conditions) were taken from the official open site of meteorological service Gismeteo.ru (www.gismeteo.ru), means of NAO index were taken from the official open site Hurrell James & National Center for Atmospheric Research Staff (Eds) ''The **Climate Data Guide**'' (Hurrell and National Center for Atmospheric Research Staff (2014). https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based).

Whereas storms and wave activity depend on the windy weather, for assess the impact of this factors the average wind speed was used. In case of seasonal effect the average wind speed and average temperature for the season were used (end of May-beginning of September). For evaluation of wind effect on summer biomass the average wind speed observed within one week before sampling was used. In the Neva estuary the field observations showed that filamentous macroalgae requires two weeks to achieve maximum summer biomass (Gubelit, 2009). So, in order to determine the effect of temperature conditions on the biomass, the average air temperature within two weeks before sampling was used. Since sampling was conducted in different days for southern and northern shores, means of temperature and wind were calculated for every date. For data calculation and revelation of the link between weather conditions, NAO and macroalgal biomass, the Correlation and Principal Components & Classification analysis were used.