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RESEARCH ARTICLE

Dynamics of invertebrate communities on the stony littoral of the Neva Estuary (Baltic Sea) under macroalgal blooms and bioinvasions

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Abstract

1 - The Littoral zone of the Neva Estuary is strongly influenced by "macroalgal blooms" (mainly *Cladophora glomerata*). The present paper aims to study species composition, abundance and seasonal dynamics of littoral invertebrate communities in the Neva Estuary in order to assess their current status and the influence of macroalgal blooms on invertebrates.

2 - Littoral communities at three sites in the Neva Estuary were monitored during May to October of 2002, 2004 and 2005. Quantitative sampling of macroinvertebrates at a depth of 0.5 m was carried out with a 0.03 m^2 cylindrical metal frame. Temperature, conductivity, dissolved oxygen and total phosphorus in water were measured at studied sites using a WTW Oxi330 oxygen meter, a DistWP4 conductivity meter and standard analytic techniques.

3 - A list of macroinvertebrate species includes 104 taxa in the freshwater part of the Neva Estuary and considerably fewer in its oligohaline part due to the disappearance of some species of typical freshwater groups (oligochaetes and dipterans). Amphipods *Gmelinoides fasciatus* and *Pontogammarus robustoides*, recent invaders to the Neva Estuary, were abundant species at all studied habitats of the estuary, accounting for 73 % of the total biomass of zoobenthos.

4 - We obtained significant positive correlations between the density of invertebrate groups (oligochaetes, chironomids, ephemeropterans, trichopterans, amphipods) and oxygen content in water. Temporary hypoxia (0.62–2.8 mgl^{-1}) and a 4-10-fold decrease in the density of amphipods, oligochaetes and aquatic insects were recorded in littoral habitats during decomposition of drifting filamentous algae (July-August). We conclude that intensive macroalgal blooms in the littoral zone due to the intense eutrophication of the Neva Estuary can negatively affect the density of intolerant species and groups and the structure of the invertebrate community through deterioration of oxygen conditions and increase of nutrients during intensive decomposition of drifting algae.

Keywords: macroinvertebrates, littoral community, species composition, abundance, eutrophication, macroalgal blooms, introduced species.

Introduction

The Neva Estuary is one of the largest estuaries in the Baltic Sea, consisting of three main parts: the Neva Bay (400 km^2) and the inner and outer estuary (3,200 km^2). Neva Bay is the freshwater part, separated from the other parts of the estuary by a storm-surge barrier since the early 1980s (Fig. 1). The storm-surge barrier has several sluices in the northern part and a broad ship gate in the southern part of the estuary. The Gulf of Finland, including the Neva Estuary, is known to be one of the most eutrophic areas of the Baltic Sea (Lappälainen, Ponni, 2000), annually receiving 7.6 thousand tons of phosphorus and 138 thousand tons of nitrogen (Pitkänen *et al*, 1998). The estuary is impacted by a number of human activities such as discharges of large amounts of waste waters from Sankt-Petersburg and its province, intensive ship traffic, development of new ports and oil terminals, commercial fisheries and recreation.

The littoral zone of the Neva Estuary is dominated by macrophytes proliferating on hard substrates, which together with their epiphytes provide large amounts of organic matter. Increased nutrient inputs from point sources in the Neva River and the upper estuary have stimulated the growth of fast-growing filamentous algae (mainly a green alga *Cladophora glomerata*). The production of *C. glomerata* has been put at 7 g Cm^{-2} per day, or 800-900 g Cm^{-2} per vegetation period, which is at least twice the production of phytoplankton in the open waters of the Neva Estuary (Berezina *et al.*, 2005). This value is similar to the production of rocky shore ecosystems along the Atlantic coasts of Europe and other parts of the Baltic (Bird, Benson, 1987; Bokn *et al.*, 2002). The high primary production of the littoral zone of the Neva Estuary supports complex and highly productive invertebrate communities, including annelids, amphipods, isopods, mussels and aquatic insects that feed on the produced algal matter (Alimov, 1988, Berezina, Panov, 2003, Golubkov *et al.*, 2003 a, 2003 b).

Unfavourable conditions in the littoral zone of the Neva Estuary appear to be the consequence of large *Cladophora* “blooms”, storm activity and fluctuations in the water level induced by the wind, seiches and changes in the Neva River runoff. These phenomena become more frequent around the middle of summer, dramatically affecting the growth of filamentous algae, detaching them from their hard substrates. Great masses of the algae drift into the shallow littoral zone, forming loose-lying algal mats or accumulating on beaches. Occupying different habitats, the drifting algae mats represent a serious threat to the biodiversity of coastal areas (Norkko, Bonsdorff, 1996 a, 1996 b).

The present study focuses on species composition, abundance and seasonal dynamics of littoral invertebrate communities in the Neva estuary in order to assess the current status of invertebrate communities in the littoral ecosystem and clarify whether macroalgal blooms influence negatively the communities in the study area.

Methods

From May to October dynamics of littoral communities were studied at three sites at a depth of 0.5 m at two-week intervals in 2002 and 2004 and monthly in 2005. Species composition, density and the biomass of macroinvertebrate communities were obtained during the intensive surveys. During the sampling, the temperature, dissolved oxygen, total phosphorus and conductivity of the water were also measured.

Quantitative samples of macroinvertebrates at a depth 0.5 m were gathered with a 0.03 m^2 cylindrical metal frame 0.7 m in height in accordance with a previously proposed approach (Berezina *et al.*, 2005). All samples were taken in three replicates. The samples were preserved in 4 % formaldehyde and transported to the laboratory in plastic bags. In the laboratory, all invertebrates longer than 2 mm (macroinvertebrates) were handpicked. In addition, macroalgae were picked from each sample, rinsed with tap water, dried (at 60 ºC for 96 h) and weighed. The density and biomass of invertebrates were measured as the mean value of all replicates and then re-calculated for 1 m^2 of sea bed. Measurements of temperature and oxygen content in water were conducted with a WTW Oxi 330 oxygen meter. Conductivity (E, µS) was measured with a DistWP4 conductivity meter at 25 ºC. Total dissolved salt concentration (TDS, mgl-1) in water was re-calculated from conductivity using the formula: $TDS = 0.47 \cdot E^{1.08}$. To get total phosphorus concentration (P), the 100-ml samples of water were hydrolyzed with H_2SO_4 according to standard techniques (Golterman, 1969). The measured biological characteristics were expressed as the mean value ± SE (standard error). Possible differences in densities and biomasses between sites and years were analysed by ANOVA. Pearson's correlation coefficient was used to test the relationships between characteristics of key zoobenthic groups and oxygen content.

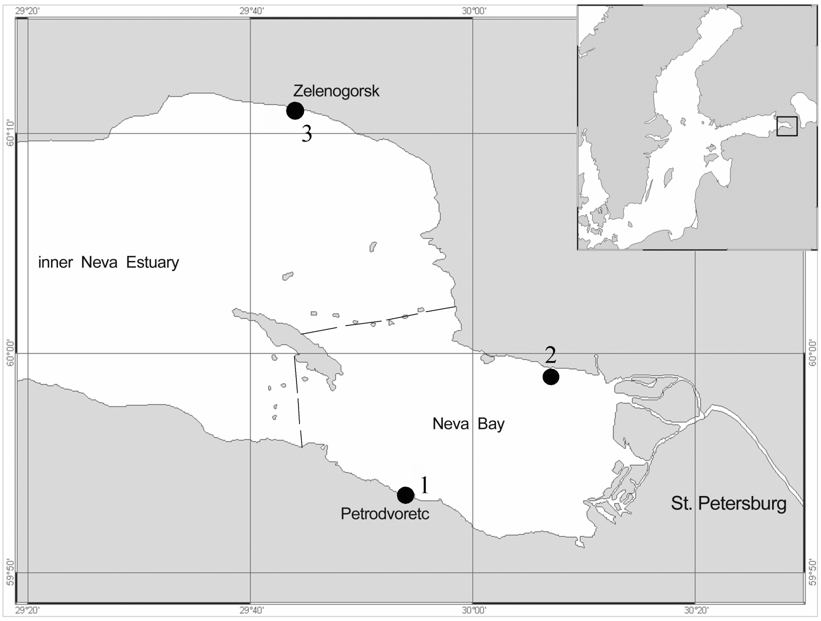

Figure 1. Map of the Neva Estuary with sampling sites. Site 1 – Petrodvorets park, site 2 – Olgino city, site 3 – Zelenogorsk city (Resort District).

Results

Habitat conditions

Table 1 summarizes the results for total dissolved salt content and total phosphorus concentration in the water. The lowest salt content (42-75 mgl^{-1}) was recorded at site 2 due to the strong influence of the Neva River, the major tributary to the eastern Gulf of Finland. Water salinity increased considerably outside the dam in the inner estuary, mixing with mesohaline waters from the open Gulf of Finland. At site 3 TDS often exceeded 1000 mgl^{-1}. Total phosphorus concentration ranged from 23–110 µgl^{-1} and 36-160 µgl^{-1} in the northern and southern Neva Bay respectively. At site 3 this parameter ranged widely, reaching a maximum of 340 µgl^{-1}. All the studied sites can be characterized as "eutrophic zones" with nutrient-rich water.

As a rule, in the eastern Gulf of Finland during December to March, the water temperature is close to 0 ^{o} C. The temperature rapidly increases after the ice-breaking in April-May. The period with temperatures above 10 ^{o} C lasts around 120 days (Savchuk, Davidan 1997). Figure 2 outlines the temperature regime of waters in the littoral zone during the sampling period. By May, the water temperature reached 9-11 °C. The summer daytime temperature varied in the range of 18-23 °C in 2002, 14-25 °C in 2004 and 16-25 °C in 2005. In September the temperature decreased to 8-14 °C. At the end of October it dropped below 3 ^{o} C.

The substrate at the studied locations consists of coarse sand, gravel and stones. Projective coverage of the bottom by hard substrates averages 60% at site 1, 90% at site 2 and 20% at site 3. In different part of the Neva Estuary, macroalgal communities developing on hard substrates consist of green algae *Cladophora glomerata* (L.), *Enteromorpha intestinalis* (L.), brown algae *Pilayella littoralis* (L.), *Ectocarpus* sp. and a red alga *Ceramium rubrum* (Hudson). At the study sites, the communities include mainly a green alga *C. glomerata* proliferating from late May to late September on hard substrates. Macrophyte beds representing mainly *Potamogeton* spp. developed during July to September. The biomass of filamentous algae varied between sites and years, averaging in the range of 13.9 to 76.1 gm^{-2} dry weight (Table 1). It tended to higher growth in the northern inner Neva Estuary (sites 2 and 3).

Table 1. Coordinates, salinity, phosphorus concentration and biomass of filamentous algae (as dry weight) at study sites in the Neva Estuary during sampling period

	Site	1	2	3
		59º53' N, 29º54' E	59º59' N, 30º05' E	60º11' N, 29º44' E
Total dissolved salts (gl^{-1})	2002	0.24-0.38	0.05-0.07	0.40-1.08
	2004	0.20-0.48	0.05-0.06	0.38-0.93
	2005	0.29-0.56	0.04-0.07	0.63-1.4
Total phosphorus, µgl^{-1}	2002	36-88	30-80	64-114
	2004	84-160	23-110	44-260
	2005	88-140	20-110	65-340
Biomass of algae, gDWm^{-2}	2002	18.8±11.3	24.5±11.9	35.7±10.3
	2004	51.7±11.6	76.1±51.2	42.1±6.8
	2005	14.35±10.9	22.4±12.6	13.9±8.1

Daytime dissolved oxygen levels, arising from photosynthesis of aquatic plants and from the air-water interface, ranged from 68–132% at all studied sites during most of the observation period. However, temporary falls in oxygen concentration were recorded during decomposition of drifting filamentous algae in August of 2004 and 2005 at site 1, and in July of 2004 and in August of all years at site 3 (Fig. 3). During these periods the dissolved oxygen content in water near the bottom reached 5.4-31 % or 0.62–2.8 mgl^{-1}.

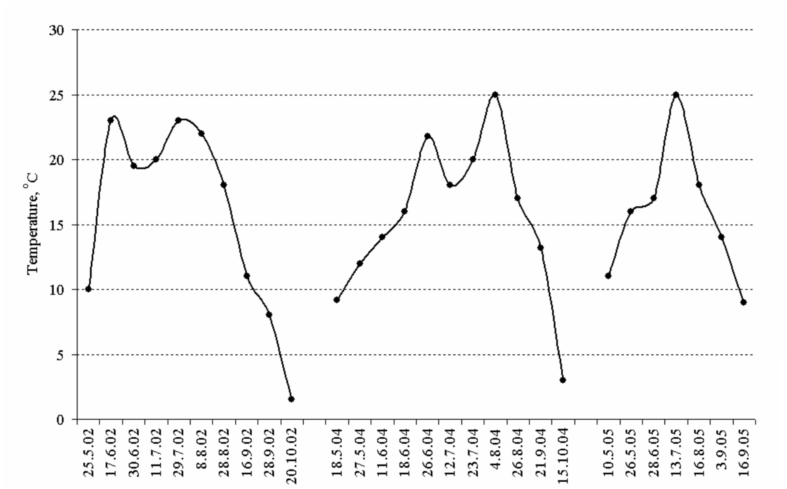

Figure 2. Dynamics of temperature during observation period in the littoral zone of the Neva Estuary

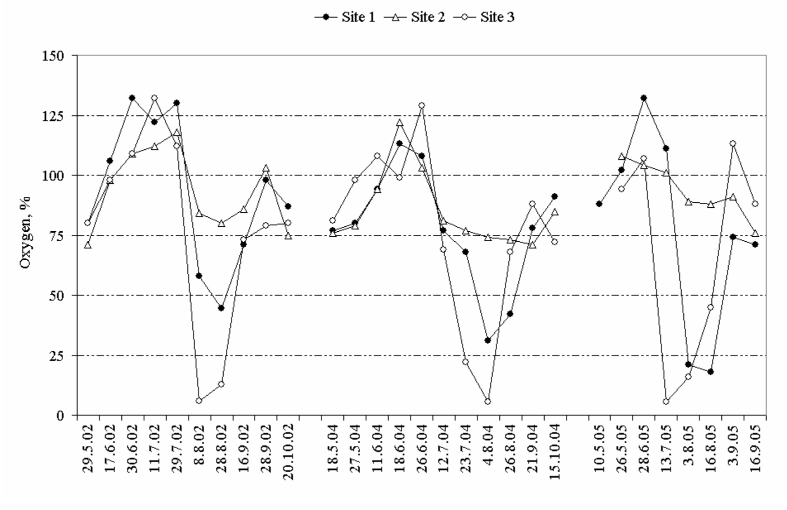

Figure 3. Dynamics of oxygen saturation (%) in water at studied sites during sampling period.

Species composition of the invertebrate community in the littoral zone

The richness of macroinvertebrate species in the littoral communities was high. The list of benthic species includes 116 taxa (Table 2). The highest numbers of species (and group of species) were found for oligochaetes (41) and chironomids (34). Three amphipod species, *Gmelinoides fasciatus*, *Pontogammarus robustoides* and *Chaetogammarus warpachowskyi* and the mollusc *Dreissena polymorpha* on this list are introduced species. In the freshwater Neva Bay, the number of recorded species reached 104. In the oligohaline part of the estuary (site 3) more than 20 % of typical freshwater species disappeared from the community and although some species of oligohaline organisms (amphipods, molluscs and others) were added to the fauna list, the species richness significantly decreased (to 70).

Relative abundance of different species and groups in total biomass

Average absolute and relative biomasses of invertebrates differed significantly between taxonomic groups (F = 3.45, $p < 0.001$) and study sites (F = 3.64, p – 0.034). At sites 1 and 2, the introduced amphipod species accounted for most of the total biomass, ranging from 44 to 73 % (Fig. 4). At site 1 in Neva Bay *G. fasciatus* and *P. robustoides* reached the maximum biomass (13.2 gm^{-2} and 24.8 gm^{-2}, respectively) in the summer of 2004. At site 3 their relative abundance was significantly lower, varying from 8 to 36 % in different years. Chironomids, oligochaetes, molluscs, ephemeropterans and hirudineans were also common in the community, with high relative abundances (> 7 %). Oligochaetes comprised up to 30 % of total biomass at site 1. Molluscs and hirudineans were dominant groups at site 2, reaching 22 and 15%, respectively. The relative biomass of chironomids reached a maximum of 48 % at site 3.

Table 2. Species list of macroinvertebrates in the littoral zone of the Neva Estuary

Group, species name	**Site 1**	**Site 2**	**Site 3**
Class: Aphanoneura			
Aeolosomatidae			
Aeolosoma sp.	+	+	
Class: Clitellata			
Oligochaeta			
Naididae			
Stylaria lacustris (L)	+	+	+
Vejdovskyella intermedia (Bretscher)	+		
Slavina appendiculata (Udekem)		+	
*Piguetiella blanci (*Piguet)		+	
Nais barbata Muller	+	+	+
N. behningi Michaelsen		+	
N. bretscheri Michaelsen	+	+	
N. christinae Kasprzak	+		
N. communis Piguet	+	+	+
N. elinguis Muller	+		+
N. pardalis Piguet	+	+	+
N. pseudobtusa Piguet		+	
N. variabilis Piguet		+	+
Specaria josinae (Vejdovsky)	+	+	
Uncinais uncinata (Oersted)	+	+	+
Paranais botniensis Sperber	+		+
P. litoralis (Muller)	+		+
Amphicyaeta leydigi Tauber	+	+	+
A. sannio Kallstenius	+		
Chaetogaster diaphanus (Gruithuisen)	+	+	+
*C. diastrophus (*Gruithuisen)	+	+	+
C. langi Bretscher	+		
Pristina foreli Piguet	+	+	+
Pristinella bilobata (Bretscher)	+	+	+
P. rosea (Piguet)	+		
Tubificidae			
Rhyacodrilus sp.	+	+	
Aulodrilus limnobius Bretscher		+	

Tubifex tubifex (Muller)	+	+	
Spirosperma ferox Eisen		+	+
Limnodrilus claparedeanus Ratzel	+	+	
L. hoffmeisteri Claparede	+	+	+
L. profundicula (Verrill)	+	+	+
Tubificidae genus sp.	+	+	+
Tubifex tubifex (Muller)	+	+	
Tubificidae genus sp.	+	+	+
Enchytraeidae			
Cernosvitoviella sp.		+	
Cognettia glandulosa (Michaelsen)		+	

Table 2. (cont.)

Group, species name	**Site 1**	**Site 2**	**Site 3**
Lumbricillus lineatus (Muller)	+	+	+
Henlea sp.	+		+
Enchytraeidae genus sp.	+	+	+
Hirudinea			
Helobdella stagnalis (L)	+	+	
Erpobdella octoculata (L)	+	+	+
Glossiphonia complanata (L)	+	+	+
Class: Crustacea			
Amphipoda			
Chaetogammarus warpachowskyi (Sars)			+
Gammarus inaequicauda Stock			+
G. pulex (L)	+		
G. zaddachi Sexton			+
Gmelinoides fasciatus (Stebbing)	+	+	+
Pontogammarus robustoides (Sars)	+		+
Mysidae			
Neomysis integer (Leach)			+
Isopoda			
Asellus aquaticus (L)	+	+	+
Class: Mollusca			
Bivalvia			
Dreissena polymorpha Pallas			+
Pisidium inflatum (Muehlfeld in Poro)	+	+	
Anadonta sp.	+	+	+
Sphaerium corneum (L)	+	+	
Musculium lacustre Mueller		+	
Euglesa spp.	+	+	+
Gastropoda			
Anisus vortex (L)		+	+
Bythinia tentaculata (L)	+		+
Lymnaea glutinosa (Mueller)	+	+	
L. ovata (Draparnaud)	+	+	+
Planorbis planorbis (L)	+		+
Teodoxus fluviatilis (L)			+
Valvata sp.	+		
Viviparus viviparus (L)	+	+	
Class: Insecta			
Ephemeroptera			
Caenis undosa Tiensuu	+	+	+
Ephemerella ignita Poda	+		+
Ephoron virgo (Oliv)	+	+	+

Baetidae gen sp.	+	+	
Siphlonurus lacustris (Eaton)	+	+	
Eurylophella mucronata Bengtsson		+	
Potamanthus luteus L		+	
Trichoptera			
Agraylea multipunctata Curt	+	+	+
Athripsodes cinereus Curt	+	+	
Hydropsyche contubernalis MacLachlan	+	+	+
Holocentropus stagnalis Albarda	+	+	
Limnephilus sp.		+	

Table 2. (cont.)

Group, species name	**Site 1**	**Site 2**	**Site 3**
Lepidoptera			
Parapoynx stratiotata L	+	+	
Coleoptera			
Haliplus sp.	+	+	+
Megaloptera			
Sialis sp.	+		+
Diptera			
Chironomidae			
Chironominae			
Chironomus sp.	+	+	+
Cladotanytarsus gr. mancus	+	+	+
Cryptochironomus gr. defectus	+	+	+
Einfeldia carbonaria (Meigen)	+		
Einfeldia sp.		+	+
Endochironomus stakelbergi Goetghebuer	+	+	+
Glyptotendipes barbipes (Staeger)	+		
G. glaucus (Meigen)	+		+
G. gripekoveni (Kieffer)	+		+
G. paripes (Edwards)	+		
Microtendipes gr. pedellus	+	+	+
Paratanytarsus austriacus (Kieffer)		+	+
Paratendipes gr. albimanus	+		
Polypedilum gr. nubeculosum		+	+
Pseudochironomus prasinatus (Staeger)			+
Stictochironomus crassiforceps (Keiffer)			+
Tanytarsus pallidicornis (Walker)	+		
T. verralli Goetghebuer	+	+	+
Orthocladiinae			
Abiskomyia sp.	+		
Corynoneura sp.	+	+	+
Cricotopus gr. festivellus	+	+	+
C. gr. intersektus	+	+	+
C. gr. reversus	+	+	
C. gr. sylvestris			+
C. gr. tremulus	+		
Cricotopus sp.	+	+	+
Paratrihocladius sp.	+		
Psectrocladius barbimanus (Edwards)	+		+
Psectrocladius bisetus (Goetghebuer)	+		+
Psectrocladius sordidellus (Zetterstedt)			+
Psectrocladius sp.	+		+

Synorthocladius semivirens (Kieffer)			+
Tanypodinae			
Ablabesmyia sp.			+
Diamesinae			
Diamesa sp.		+	+
Ceratopogonidae			
Serromyia sp.		+	

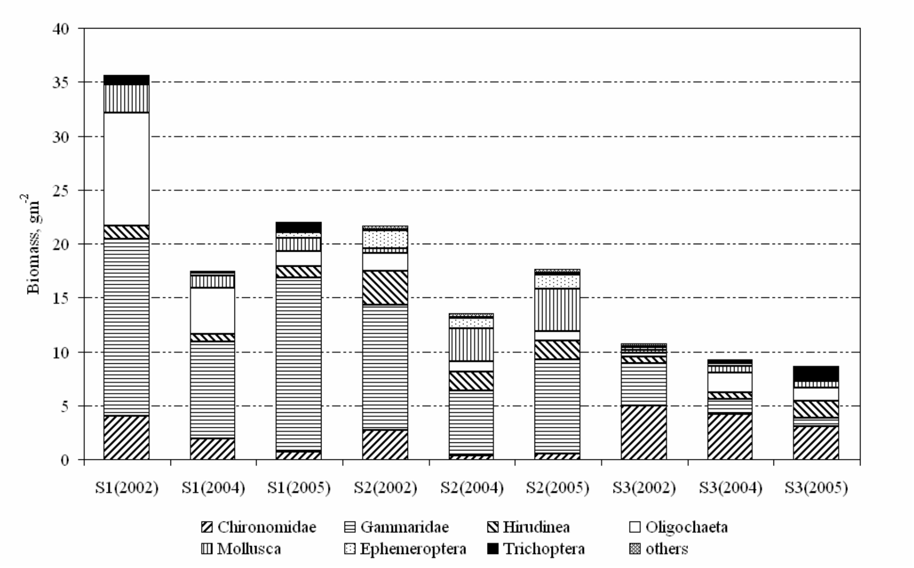

Figure 4. Average biomass (mean for each season) of different invertebrate groups at study sites in the Neva Estuary.

Discussion

The present study showed that deoxygenation of water during decomposition of drifting macroalgae influences macroinvertebrate communities, resulting in a decrease in density of invertebrate groups and structural changes. Decomposition of macroalgae causes periodical hypoxic conditions in the littoral zone of the Neva Estuary during late July-August. Excessive growth of opportunistic macroalgae, called "macroalgal blooms", has become a widely-observed phenomenon in different parts of the Baltic Sea, constituting a major nuisance in shallow coastal zones (Blomster *et al*., 2002, Paalme *et al*., 2002, Cummis *et al*., 2004, Kotwicki *et al*., 2005, Lauringson, Kotta, 2006). The algal mats form in shallow areas and may later accumulate in deeper zones, covering an area of several hectares (Valiela *et al.*, 1997).

It was shown that decomposition of the drifting mats causes modification of nutrient dynamics in the water column and sediments, results in widespread hypoxic and anoxic conditions in littoral habitats and negatively affects communities of invertebrates, seagrass beds and feeding by wading birds (Norkko & Bonsdorff, 1996 a, 1996 b; Peckol, Riviers, 1996; Raffaelli *et al*., 1998; Lehvo, Bäck, 2001; Berglund *et al*., 2003). Decaying macroalgal mats generate low oxygen conditions in the inter-algal water (0–1 mg l^{-1}), corresponding to zones of high and relatively stable phosphate and ammonium concentrations (up to 96 µg l^{-1} and 166 µg l^{-1}, respectively). In addition, this process may often be accompanied by the release of toxic hydrogen sulphide (Lavery, McComb 1991).

As is known, the algal mats can substantially modify nutrient dynamics in the water column and sediments. Large amounts of tissue phosphorus (to 65 %) are released by decaying mats of *C. glomerata* during the decomposition process (Paalme *et al*., 2002). In photosynthetically inactive portions of the algal mats, annual carbon release was estimated from tissue-loss measurements for *Cladophora* *vagabunda*. It is around 20% of annual net mat production (Peckol, Rivers, 1996).

Rapid decomposition provides an additional supply of organic and inorganic compounds to be potentially recycled in the water, increasing eutrophication. At the same time, the increase in nutrients due to the decomposition of drifting and loose–lying algal mats is not likely to have a direct influence on the density and structure of macroinvertebrate communities. In some mesocosms, experiments have shown that the majority of invertebrate groups change only slightly in response to nutrient treatment, but a significant increase in the density of the common periwinkle *Littorina littorea* in response to nutrient loading has been observed (Kraufvelin *et al.*, 2002).

Our results show that an abrupt decline in the density of many invertebrate groups coincided with oxygen deficiency in the water during periods of decaying algae decomposition, confirmed by the correlation analysis.

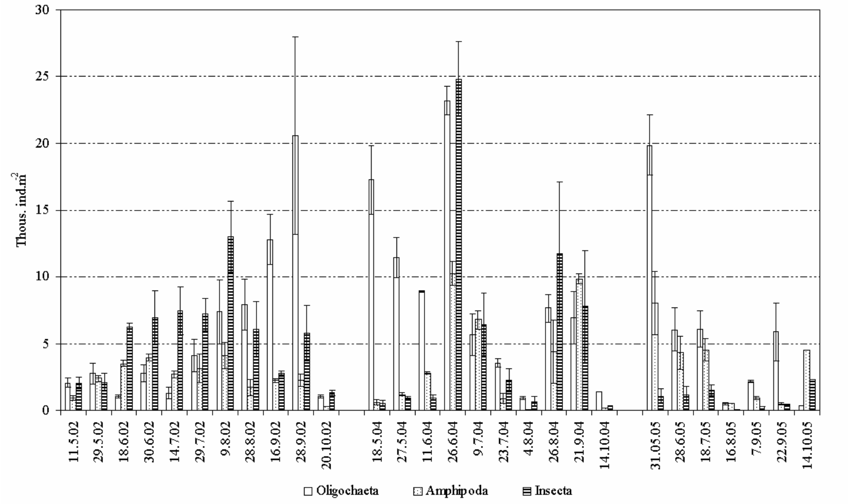

Figure 5. Dynamics of abundant invertebrate groups (oligochaetes, amphipods and insects) at site 1 in the Neva Estuary.

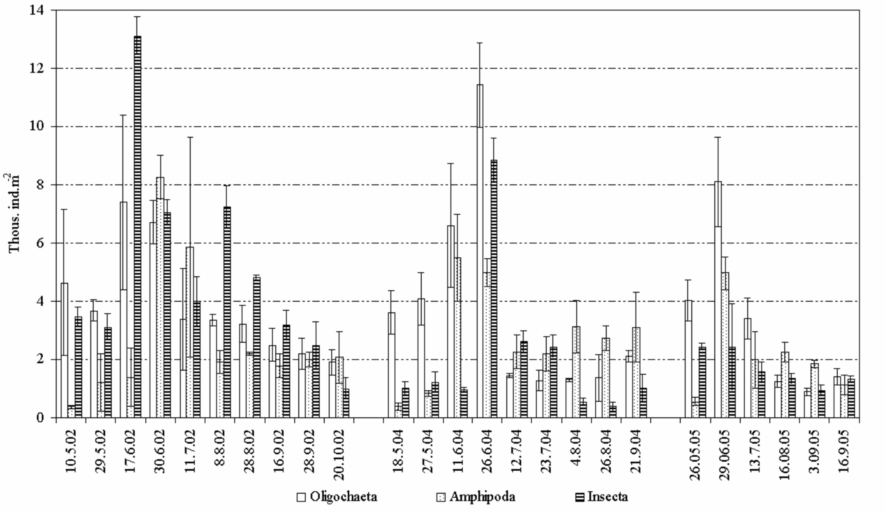

Figure 6. Dynamics of abundant invertebrate groups (oligochaetes, amphipods and insects) at site 2 in the Neva Estuary

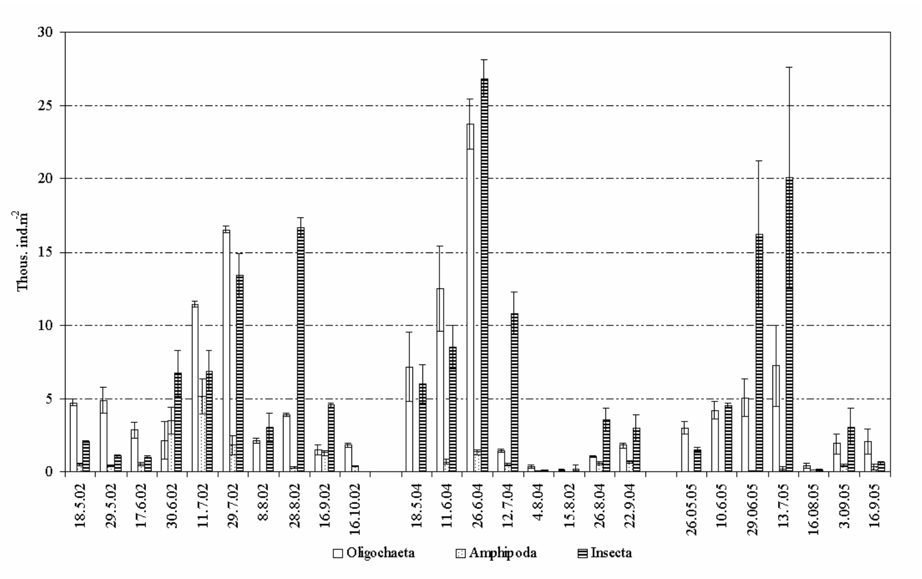

Figure 7. Dynamics of abundant invertebrate groups (oligochaetes, amphipods and insects) at site 3 in the Neva Estuary.

The decline in density is a result of migration of mobile invertebrates and/or large-scale death of many invertebrates under low oxygen conditions which occurred below the critical threshold of their survival. Survival of many invertebrates (amphipods and aquatic insects) is limited in nature by oxygen concentration in water around 2 mgl^{-1}. It may decrease sharply under hypoxic conditions in the shallow zone of the Neva Estuary. Experimentally measured lethal concentrations of oxygen at 20 ºC were 0.5 mg Ol^{-1} for amphipod *G. fasciatus* and 0.3-0.4 mg Ol^{-1} for amphipod *P. robustoides* (Berezina *et al*., 2005).

The high density of different groups of invertebrates including introduced amphipods *P. robustoides* and *G. fasciatus* in the littoral zone of the Neva Estuary excluding the periods of temporarily lower oxygen content testify to the favourable food conditions in the studied habitats. We also assume that the high biomass of introduced amphipods might be one of possible causes of low biomass of chironomids in some locations of the Neva Estuary, as was observed at sites 1 and 2. Similar phenomena have been recorded in other studies (Kelly *et al*., 2003; Kelly, Dick 2005 a, 2005 b, Orlova et al., 2006), when introduced amphipods dramatically altered invertebrate communities (mainly aquatic insects) and fish through strong predatory and competitive interactions. However, disturbance factors such as eutrophication, macroalgal blooms and oxygen deficiency may facilitate the success of opportunistic species including the introduced amphipod and the alterations in macroinvertebrate communities. In many cases it is difficult to determine if the changes in a community are due solely to the effects of the invader or other factors. In the case of Neva Estuary we conclude that macroalgal blooms resulting in deoxygenation of bottom habitats is the main environmental reason for changes in the structure and dynamics of invertebrate communities.

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References

Alimov AF (ed) 1988. Communities of the Freswater invertebrates among macrophytes associations. Proceedings of the Zoological Institute **186**: 1-198 (in Russian).

Berglund J, Mattila J, Ronnberg O, Heikkilä J, Bonsdorff E 2003. Seasonal and inter-annual variation in occurence and biomass of rooted macrophytes and drift algae in shallow bays. *Estuarine, Coastal and Shelf Science* **56**: 1167-1175. DOI: 10.1016/S0272-7714(02)00326-8.

Berezina NA, Golubkov SM, Gubelit JI 2005. Grazing effects of alien amphipods on macroalgae in the littoral zone of the Neva Estuary (eastern Gulf of Finland, Baltic Sea*). Oceanological and Hydrobiological studies* **34** (**S1**): 63-82.

Berezina NA, Panov VE 2003. Establishment of new gammarid species in the eastern Gulf of Finland (Baltic Sea) and their effects on littoral communities *Proceedings of Estonian Academy Sciences. Biology. Ecology*. **52** (**S3**) 284-304.

Bird KT, Benson PH (eds) 1987. *Seaweed cultivation for renewable resources.* Elsevier Press, New York.

Bokn TL, Moy FE, Christie H, Engelbert S, Karez R, Kersting K, Kraufvelin P, Lindblad C, Marba N, Pedersen MF, Sorensen K 2002. Are rocky shore ecosystems affected by nutrient-enriched seawater? Some preliminary results from a mesocosm experiment. *Hydrobiologia* **484**: 167–175. DOI: 10.1023/A:1021365307438

Blomster J, Bäck S, Fewer DP, Kiirikki M, Lehvo A., Maggs CA, Stanhope MJ 2002. Novel morphology in *Enteromorpha* (Ulvophyceae) forming green tides *American Journal of Botany* **89**:1756-1763

Cummins SP, Roberts DE, Zimmerman KD 2004. Effects of the green macroalga *Enteromorpha intestinalis* on macrobenthic and seagrass assemblages in a shallow coastal estuary. Marine Ecology Progress Series **266**: 77-87.

Golubkov SM, Alimov AF, Telesh IV, Anokhina LE, Maximov AA, Nikulina VN, Pavel’eva EB, Panov VE 2003 a. Functional response of midsummer planktonic and benthic communities in the Neva Estuary (eastern Gulf of Finland) to anthropogenic stress. *Oceanologia* **45 (S1)**: 53-66.

Golubkov SM, Back S, Nikulina VN, Orlova MI, Anokhina LE, Umnova LP, 2003 b. Effects of eutrophication and invasion of *Dreissena polymorpha* in the coastal zone of the eastern Gulf of Finland. *Proceedings of Estonian Academy Sciences. Biology. Ecology*. **52** (**S3**): 284-304.

Golterman HL (ed.) 1969. *Methods for chemical analysis of freshwaters,* IBP Handbook, 8. Blackwell Scientific Publ., Oxford and Edinburgh.

Kelly DW, Dick JTA 2005 a. Effect of environment and an introduced invertebrate species on the structure of bentic macroinvertebrate species at the catchment level. *Archuv fur Hydrobiologie* **164 (1)**: 69-88. DOI: 10.1127/0003-9136/2005/0164-0069.

Kelly DW, Dick JTA 2005 b.Introduction of the non-ingigenous amphipod Gammarus pulex alters population dynamics and diet of juvenile trout *Salmo trutta*. *Freshwater Biology* **50**: 127-140. DOI: 10.1111/ j.1365-2427.2004.01315

Kelly DW, Dick JTA, Mortgomery WI, MacNeil C 2003. Differences in composition of macroinvertebrate communities with invasive and native *Gammarus* spp. (Crustacea: Amphipoda). *Freshwater Biology* **48**: 306-315. DOI: 10.1046/j.1365-2427.2003.00977

Kraufvelin P, Christie H, Olsen M 2002. Littoral macrofauna (secondary) responses to experimental nutrient addition to rocky shore mesocosms and a coastal lagoon. *Hydrobiologia 484/ Developments of Hydrobiology* **167**: 149–166. DOI: 10.1023/A:1021313323367

Kotwicki L, Weslawski JM, Szaltynis A, Raczynska A, Kupiec A 2005. Deposition of large organic particles (macrodetritus) in a sandy beach system (Puck Bay, Baltic Sea). *Oceanologia* **47(S2)**: 181-199

Lappälainen A, Ponni J, 2000. Eutrophication and recreational fishing on the Finnish coast of the Gulf of Finland: a mail survey. *Fisheries Management and Ecology* **7**: 323-335

Lauringson V, Kotta J 2006. Influence of the thin drift algal mats on the distribution of macrozoobenthos in Koiguste Bay, NE Baltic Sea. *Hydrobiologia* **554**: 97-105. DOI 10.1007/s10750-005-1009-4

Lavery PS, McComb AJ 1991, Macroalgal-sediment nutrient interactions and their importance to macroalgal nutrition in a eutrophic estuary. *Estuarine, Coastal and Shelf Science*: **32**: 281-295. DOI: 10.1016/0272-7714(91)90021-3

Lehvo A, Back S 2001. Survey of macroalgal mats in the Gulf of Finland, Baltic Sea. *Aquatic conservation-marine and freshwater ecosystems* **11 (S1)**: 11–18. DOI: 0.1002/aqc.428.

Norkko A, Bonsdorff E 1996 a. Rapid zoobenthic community responses to accumulations of drifting algae. *Marine Ecology Progress Series* **131**: 143-157.

Norkko A, Bonsdorff E 1996 b. Population responses of coastal zoobenthos to stress induced by drifting algal mats. *Marine Ecology Progress Series* **140**: 141-151.

Orlova MI, Telesh IV, Berezina NA, Antsulevich AE, Maximov AA, Litvinchuk LF 2006. Effects of nonindigenous species on diversity and community functioning in the eastern Gulf of Finland (Baltic Sea) *Helgoland Marine Research* **2**: 98-105. DOI: 10.1007/s10152-006-0026-7

Paalme T, Kukk H, Kotta J, Orav H 2002. “In vitro” and “in situ” decomposition of nuisance macroalgal *Cladophora glomerata* and *Pilayella littoralis*. Hydrobiologia **475/479**: 469-476. DOI: 10.1023/A:1020364114603

Peskol P., Rivers J.S., 1996, Contribution by macroalgal mats to primary production of a shallow embayment under high and low nitrogen-loading rates. *Estuarine, Coastal and Shelf Science* **43**: 311-325. DOI:10.1006/ecss.1996.0072

Pitkänen H, Kondratyev S, Lääne A, Gran V, Kauppila P, Loigu E, Markovets I, Pachel K, Rumyantsev V 1998. Pollution load on the Gulf of Finland from Estonia, Finland and Russia in 1985-1995. Summary report of the working group. In Sarkkula J (ed) *Proccedings of the Final seminar of the Gulf of Finland Year 1996*: 9-18.

Raffaelli DG, Raven JA, Poole LJ 1998. Ecological impact of green macroalgal blooms. *Oceanography and Marine Biology: an annual review* **36**: 97-125.

Savchuk OP, Davidan IN (eds.) 1997. Ecosystem models. Assessment of the contemporary state of the Gulf of Finland. Part 2. Hydrometeorological, hydrochemical, hydrobiological, geological conditions and water dynamics of the Gulf of Finland. Gidrometeoizdat, St-Petersburg (in Russian).

Valiela I, McClelland J, Hauxwell J, Behr P, Hersh D, Foreman K 1997. Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem consequences. *Limnology and Oceanography* **42**: 1105–1118.