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Research Article

IMPACT OF INVASIVE BENTHIC CRUSTACEANS ON THE RESUSPENSION OF BOTTOM SEDIMENTS: AN EXPERIMENTAL STUDY APPROACH

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Abstract

The resuspension process caused by the burrowing activity of three Ponto-Caspian amphipod species (*Pontogammarus robustoides, P. crassus* and *Chaetogammarus ischus*) introduced to the Curonian Lagoon, Baltic Sea, was studied in a laboratory. The experimental set-up included aquaria with three types of bottom sediments: 1) sand; 2) sand with pebbles; 3) sand with stones up to 30 cm in diameter. The experimental aquaria contained amphipods in numbers that mimicked their density *in situ*, while control aquaria contained no animals. Water was sampled from three different layers (1, 5, and 9 cm above the sediment surface) from experimental and control aquaria and analyzed with a spectrophotometer at a wavelength of 660 nm in order to estimate the density of suspended material. The burrowing activity of the amphipods in all sediment types increased the amount of suspended material throughout the studied water layer (10 cm). The most visible effect was detected above the sandy bottom with large stones, the least – above the sandy-pebble bottom. The conclusion was drawn that the invasive burrowing amphipods can increase the resuspension of bottom sediments in invaded ecosystems.

INTRODUCTION

The influence of biota on sediment formation through the destruction, modification, and creation of sediment structure has been the subject of scientific interest for quite a long time (Myers 1977). Bioturbation refers to the physical and biological activities occurring at or near the sediment surface which cause the sediment to become mixed (Probert 1984, Bromley 1996, Graf 1999). The resuspension process is a physical aspect of bioturbation (Davey 1991). Burrowing is a lifestyle for most benthic crustaceans. They rework sediments looking for food and building refuges from predators, and this is an energy consuming process (Myers 1977). During different field and laboratory studies, the greatest impact was observed in the upper sediment layer. For example, two of the most abundant Baltic deposit-feeders, *Pontoporeia affinis* and *P. femorata* (Amphipoda), feed only from the upper centimeter. Although they are able to burrow much deeper for quite a long time, this depth is the richest in nutrients, detritus, and microorganisms (Lopez and Elmgren 1989).

Benthic biota affects mostly fine sediment particles that are single or joined into aggregates and are organic or non-organic. This particulate material plays an important role in the functioning of the ecosystem while forming detrital-bacterial complexes and providing substrate for protozoan and bacterial colonies. Microorganisms mineralize organic matter and return it into the trophic chain as nutrients for phytoplankton consumption (Lalli and Parsons 1997, Rubcova 2000). The biogenic reworking of sediments results in the increased depth of the aerobic habitat in the sediment and thus an increase in the surface area available for colonization by microorganisms. Also, as a result of the exchange of sediment pore water with the overlying water, continual bioturbation increases the rate of nutrient mixing within sediments thereby stimulating bacterial growth rates (Probert 1984).

Contributions of different species to rates of turnover of both particles and fluids are dependent upon the burrowing behavior and trophic mode of each (Nickell *et al*. 2001). Bioturbation will, as a general rule, increase in significance as one moves from the deep sea, through the coastal zone, and into estuaries (Davey 1991); therefore, it is suggested that in such a shallow coastal water body as the Curonian Lagoon the role of bioturbation is also important.

The Ponto-Caspian crustaceans of the *Pontogammarus* and *Chaetogammarus* genera, which were intentionally introduced into the Curonian Lagoon in the 1960s, were chosen for the current study (Gasiunas 1964). The population density of these small amphipods can reach thousands of specimens per square meter, and they have become a dominant element in the littoral benthic communities in the lagoon (Daunys and Olenin 1999). It is also known that some amphipods play a great role in matter and energy transformation (Skopcov 1980), and their individual reworking rate while burrowing within the 2.5-10 cm depth may range from 277 to 9900 mg/ind/day (Lee and Swartz 1980).

The study presented in this paper addressed the resuspension effect of the introduced Ponto-Caspian amphipods on the bottom sediments in laboratory conditions. The principal questions to answer were 1) if the burrowing activity of the amphipods influences the density of suspended material in the water column, and 2) how high in the water layer can this effect be detected.

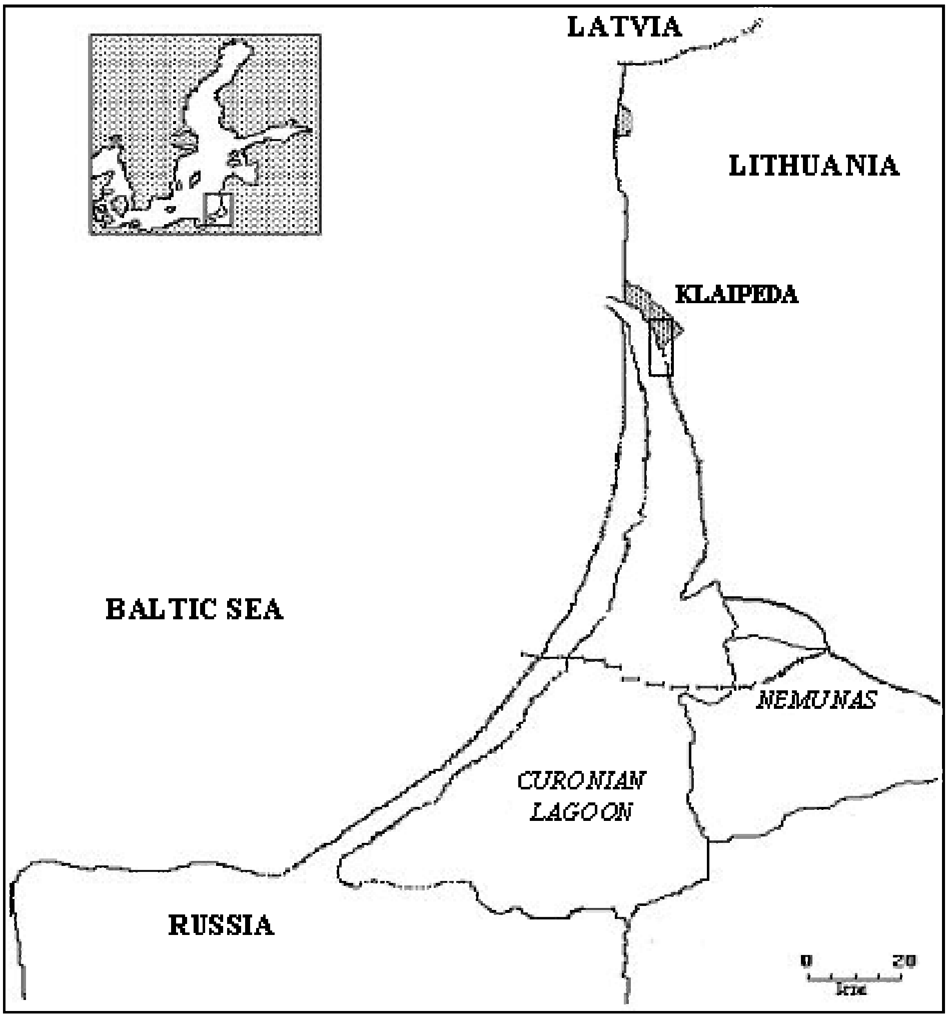

Fig. 1. Location of the sampling site.

MATERIAL AND METHODS

Observations *in situ*

Field observations were performed in the littoral zone of the Curonian Lagoon at a depth of 0.2-0.5 m at a site situated 12 km south of the lagoon's outlet to the Baltic Sea (Fig.1). Three main types of bottom sediments inhabited by Ponto-Caspian amphipods were found at the sampling site: 1) fine sand; 2) sand with pebbles and small stones covering up to a half of the bottom surface; 3) sand with large stones up to 30 cm diameter covered with green algae during the vegetation season. Accessory sampling was performed in all habitat types from April to September 2002 to discover the natural densities of the Ponto-Caspian amphipods so that these could be mimicked in the experiment. Bottom samples were collected using a 23 x 25 cm metal frame. Sediments from the 0-4 cm sediment layer were sieved through a 0.5 mm mesh. The animals were fixed with a 4% formaldehyde solution in the field. In the laboratory the amphipods were identified to the species or genus level; all *Pontogammarus* spp and *Chaetogammarus* spp were measured under a binocular microscope at 15x magnification in order to evaluate their size distribution and choose the animals of the most abundant size groups for the experiments. Water temperature and salinity were measured, and the coverage of filamentous green algae was estimated at the time of sampling.

Collection of sediments and experimental animals

Sediments for the experiment were collected in late September 2002 from the same sampling site. At the time of sampling, the water temperature was 15^0 C, and salinity was 0.1 PSU. The macrobenthic animals were removed from the sediments on site. The water used in the experiments was collected from the same area and filtered through a 0.5 μm filter to remove particles. Simultaneously, the amphipods were collected gently and transported to the laboratory in plastic aquaria containing natural surface sediment from the sampling site. In the laboratory the animals were kept for eight weeks prior to the experiments. Half of the water volume in the aquaria was renewed twice weekly.

Experiment design

The experiment was performed with three main sediment types – sand, sand and pebbles and sand with stones, in two replicates each. Two 50 l aquariums, each filled with a 2 cm layer of bottom sediments and 10 cm of water, were used. After the water was poured in, the aquaria were left at rest for three days to allow the roiled sediments to settle. The water temperature during the experiment was about 16^0C. A certain number of active, undamaged amphipods measuring 8-10 mm in length was added to one of the aquaria. The other one, without animals, was used as the control. The number of amphipods added to each sediment type was determined based on the results of field observations: 1) 15 specimens to sand; 2) 33 specimens to sand and gravel; 3) 253 specimens to sand with stones.

Before the addition of the animals, the aquaria contents were mixed thoroughly with a glass stick. The water was sampled simultaneously in both aquaria from three horizontal layers using a 20 ml syringe without a needle (aperture diameter - 3 mm): 1) upper - 1 cm below the water surface; 2) intermediate - 5 cm below the water surface; 3) lower or near-bottom - 1 cm from the sediment surface.

Three 20 ml samples from random spots were taken from each layer. Every water sample was poured into a 25 ml tube and analyzed with the spectrophotometer at a wavelength of 660 nm. This wavelength was chosen as the most appropriate for measuring the concentration of particulate material according to the results of earlier investigations (*e.g.*, Sagan *et al*. 1995, Bermann and Napp 2001). Prior to each analysis, a control measurement was performed using distilled water in order to estimate zero absorption.

The experiment lasted for seven days. The measurements were performed before mixing the contents (to determine the initial concentration of particulate material in the water column) and then 1, 3, 5, 7, 24, and 34 hours following mixing. After the first seven measurements, there was a three-day interval to allow the dredge to settle. Then the observations were continued for three more days (two measurements daily). Altogether, thirteen samplings were performed per experimental series.

Statistical procedures

The Wilcoxon matched-pairs test was applied to verify the null hypothesis that there is no statistically significant difference between the control and experimental measurements; the alternative hypothesis was tested that the difference exists. Using multifactor analysis of variance the variability of the experiment results was decomposed into contributions due to two different factors – sediment type and horizontal measurement layer.

RESULTS

Estimation of amphipod density *in situ*

At the sampling site, the water temperature was 12 °C in April. It reached the maximum (25.7 °C) in August and decreased to 20 °C in September (at the end of observations). Salinity varied slightly from 0 (April) to 0.7 PSU (June).

There was no vegetation in April. In June filamentous green algae covered 30% of the sampling site, in May – 50%, July – 60%, and in August – September the coverage was nearly total.

The most abundant group of amphipods was *Pontogammarus* spp (Table 1). They were present in all types of substrate during all sampling times except in the April sample taken on sand and pebbles. The highest abundance (3043 ind/m^2) of them occurred on sand with large stones in July.

The other group of Ponto-Caspian amphipods, *Chaetogammarus* spp., was not found in the sand and pebble sediments. They were found only twice in fine sand, while on sand with stones they were found in five samples out of six. Their highest abundance (161 ind./m^2) was also recorded in July (Table 1).

Other Gammaridae spp. were found in only half of the sand with stones samples taken and were absent in other types of sediments (Table 1).

Table 1

Natural densities of amphipods on three different bottom types according to April-September, 2002 field observations

Sediment type	**Density, ind./m^2**	***Pontogammarus* spp.**	***Chaetogammarus* spp.**	**Gammaridae**
Fine sand	min – max	48 – 209	0-16	0
	mean ± SD	96±60	4±6	0
Sand and pebbles	min – max	0 – 596	0	0
	mean ± SD	199±115	0	0
Sand and stones	min – max	290-3043	0-161	0-48
	mean ± SD	1433±908	75±70	40±42

The size distribution analysis of amphipods showed that the most frequent were individuals measuring 8-10 mm in length. Specimens of this size were chosen for the experiment.

Laboratory experiment on bioresuspension

Visual observation of the bottom sediment after each experiment series indicated that the entire sediment surface in the aquaria containing amphipods was covered with footprints from burrowing and crawling (Fig. 2). The sediment material in the experimental aquaria was more flocculent than in the control without animals. Additionally, numerous bottom microstructures appeared. No dead animals were observed in the aquaria during the experiment.

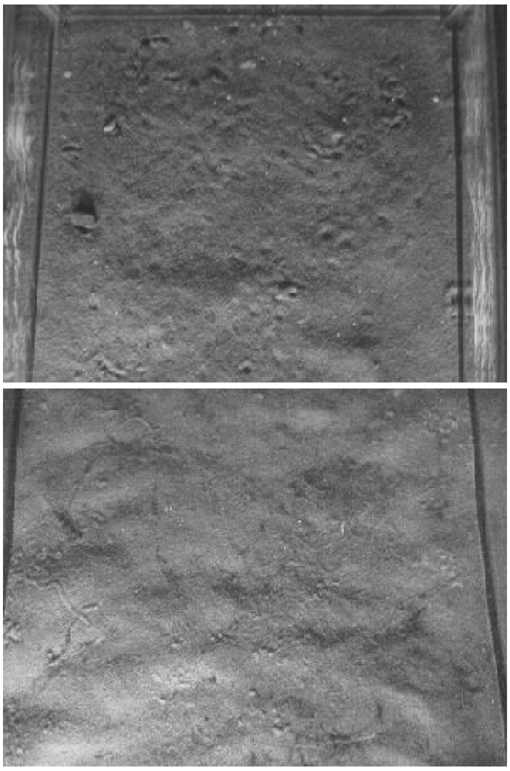

Fig. 2. The surface of aquaria bottoms with (upper photo) and without (lower photo) Ponto-Caspian amphipods after the first experiment session.

Light absorption of water in the experimental aquaria was always higher than in the control (Table 2). Although this tendency was observed in the water column above all three types of substrate, the difference was most pronounced in the aquaria containing sand with large stones. Therefore, the results from the experiment with sandy-stony sediments was subjected to further detailed examination.

The most evident difference between the experiment and control readings was found in the near-bottom layer (about 30%); this dissimilarity was less pronounced in the intermediate (about 25%) and upper (about 19%) layers. This was evidence that the burrowing activity of amphipods prevented the sedimentation of suspended particles in the near-bottom layer. The most significant resuspension impact of amphipods was observed during the first three to seven hours from the beginning of the measurements, but it was still notable within 34 hours after mixing when the contents of the aquaria had not yet stabilized.

Table 2

Difference (%) between mean light absorption in the control and experimental aquaria

Layer	Experimental series		
	Sand	**Sand and pebbles**	**Sand with stones**
Near-surface	14±11	11±9	19±11
Intermediate	20±10	11±10	25±10
Near-bottom	26±7	16±7	32±11

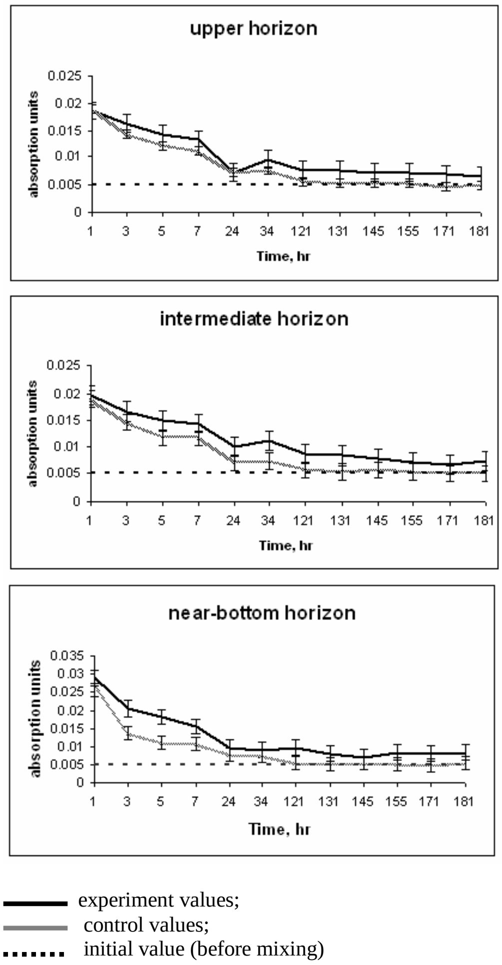

Fig. 3. Results of spectrophotometer analysis in the experiment on sand with stones.

After three days the absorption values in the control aquarium matched the initial value defined before mixing. The results from the experimental aquarium showed that a certain concentration of resuspended particles was maintained constantly by amphipods in the water column up to 10 cm high (Fig.3).

According to the results of the Wilcoxon matched-pairs test, the null hypothesis was rejected at a 95.0% confidence level ($p < 0.001$). Therefore, this suggests that amphipods have a statistically significant impact on the sedimenttation of the suspended particles.

The applied multifactor analysis of variance showed that the p-value of the sediment type factor was less than 0.05, so this factor had a statistically significant effect on the experiment results at a 95.0% confidence level (Table 3). Meanwhile, the data from the different layers had no significant differences ($p > 0.05$). This means that the bioresuspension effect was more or less equally distributed throughout the studied 10 cm of the water column.

Table 3

Analysis of variance for the experiment results

Source	Sum of squares	Df	Mean square	F-ratio	p-value
Factors					
Type of Sediment	0.001	2	0.0003	5.08	0.007
Layer	0.0003	2	0.0001	2.11	0.12
Residual	0.02	346	0.6×10^{-4}		
Total	0.021	350			

DISCUSSION

During the described experimental study the resuspension effect of amphipod activity was observed up to 9 cm above the bottom surface, *i.e.*, within the entire water layer studied. Somewhat higher concentrations of resuspended material in the near-bottom layer can be explained by the extensive burrowing of the animals in the upper 1-2 cm layer of the sediments. It is obvious that some quantities of the resuspended particles are also being raised upwards and kept in the water column by the swimming of the animals.

In this study the natural abundance of the amphipods was mimicked; therefore, their density on different types of experimental bottoms was *a priori* different. This renders the direct comparison of the obtained results impossible.

The fact that the clearest impact was observed on the sandy bottom with large stones could be explained by the higher natural densities of amphipods on these substrates. Since the large stones provide perfect shelter, the burrowing of crustaceans on such bottom types appears to be caused mostly by their feeding activity. The animals do not need to burrow deep into the sediment for shelter. On the sandy bottom their burrowing activity increases because of the lack of bottom structures that are favorable for hiding (they probably also dig deeper into the sediment here). The least effect on resuspension was found on the sandy – pebble bottom where pebbles provide ample shelter. A similar situation can be expected in natural densities as well, all the more so that the natural density of amphipods on such substrates does not exceed 600 individuals per square meter.

The present study shows that the burrowing activity of the non-indigenous amphipods can modify the structure of the sediment surface and cause the resuspension of sedimented material. This, in turn, may have further implications for the ecosystem. For instance, it is known that there is extensive accumulation of different pollutants in silty and sandy sediments (particle size from 0.001 to 1 mm) (Rubcova 2000). Organic material from primary production as well as contaminants of different origins in the form of suspended particles congregate in the upper sediment layer. Here, different sedimentation processes determine their future, *e.g.*, bioturbation and biochemical cycles. Then nutrients regenerate and pollutants decay in the sediments (Gray *et al.* 1999).

In earlier works it was shown that burrowing organisms built tubes and furrows on the bottom surface thus increasing the aeration of sediments and influencing the hydrodynamic processes of the water body (Schaffner *et al.* 1992; Graf 1999). This process may cause the erosion and resuspension of the upper bottom layer and increase its homogenization (Lee and Swartz 1980, Schaffner *et a*l. 1992, Graf 1999). When burrow structures are extensive, one of the most important consequences is the effective increase in the total surface area of the sediment/water interface across which chemical exchange processes can take place (Davey 1991). Some secondary after-effects may also take place, *e.g.*, increased eutrophication caused by nutrients arising from sediments (Graf 1987). The resuspension of dangerous contaminants (Lee and Swartz 1980, Graf 1987, Gray *et al*. 1999, Rubcova 2000) can further migrate through the trophic chain and accumulate in the bodies of higher animals (Forbes 1999).

It would be premature to interpolate the laboratory results obtained in this study for budget calculations of resuspension material in the entire littoral zone of the Curonian Lagoon. However, the current results provide insight for further research on the functional role of invasive species in coastal aquatic ecosystems, which, in the opinion of the authors, is still largely underestimated in Baltic ecosystem studies.

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REFERENCES

Alimov A.F., Panov V.J., Krylov P.I., Telesh I.V., Bychenkov D.J., Zimin V.L., Maksimov A.A., Filatova L.A., 1998. *Problem of the alien species introduction into the water bodies of the Gulf of Finland* [in:] Frolov A.K. (ed.), *Ecological situation of Saint-Petersburg and Leningrad area in 1997.* Analitical-informational review, St.-Petersburg, 243-248 (in Russian).

Berman M., Napp J., 2001. *Biomass and abundance estimation working group,* http:// cbl.umces.edu/usglobec/reports/optics/optics.insituproc.html.

Bromley R.G., 1996. *I. Neoichnology*. *Trace fossils – biology, taphonomy and applications.* Second edition, Chapman & Hall, London, 361p.

Daunys D., Olenin S., 1999. *The macrofauna communities of the eastern coastal zone of the northern part of the Curonian lagoon*, Ekologija, 2: 19-27 (in Lithuanian).

Davey J., 1991. *Problems of modelling bioturbation* [in:] *Modelling the benthos,* COST 647 workshop Yerseke 20-22 March 1991, 57-62.

Forbes T.L., 1999. *Understanding small-scale processes controlling the bioavailability of organic contaminants to deposit-feeding benthos* [in:]

Gray J.S., Ambrose W. Jr., Sraniawska A. (eds.), Biogeochemical Cycling and Sediment Ecology, 59: 153-159.

Gasiunas I. 1964. *Acclimatisation of forage crustaceans into the Kaunas waterpower plant reservoir and possibility of their migration into other waters of Lithuania*. Trudy Ak.Nauk Lit.SSR, Serija B, 1 (30) (in Russian).

Graf G., 1987. *Benthic response to the annual sedimentation patterns. Lecture Notes on Coastal and Estuarine Studies* [in:] Rumohr J., Walger E., Zeitzschel B. (eds.), *Seawater-sediment Interactions in Coastal Waters/ An Interdisciplinary Approach,* Springer-Verlag, Berlin, 13: 84-85.

Graf G., 1999. Do benthic animals control the particle exchange between bioturbated sediments and benthic turbidity zones? [in:] Gray J.S., Ambrose W. Jr., Sraniawska A. (eds.), Biogeochemical Cycling and Sediment Ecology, Kluwer Academic Publishers, Netherlands, 59: 153-159.

Gray J.S., Ambrose W. Jr., Sraniawska A. (eds.), 1999. *Preface, Biogeochmical Cycling and Sediment ecology*. Kluwer Academic Publishers, Netherlands, 59: 236p.

Lalli C.M., Parsons T.R., 1997. *Biological Oceanography. An Introduction.* Thomson Litho Ltd., East Kilbrige, Scotland, 314p.

Lee H., Swartz R.C., 1980. *Biological processes affecting the distribution of pollutants in marine sediments. Part II. Biodeposition and bioturbation* [in:] *Contaminants and Sediments*, 2. Ann Arbor Science Publ., Ann Arbor, Michigan, USA: 555-606.

Lopez G., Elmgren R., 1989. *Feeding depth and organic absorption for the deposit-feeding benthic amphipods Pontoporeia affinis and Pontoporeia femorata, Limnol. Oceanogr*., 34 (6), 982-991.

Myers A.C., 1977. *Sediment processing in a marine subtidal sandy bottom community: II. Biological consequences, Journal of Marine Research*, 35 (3), 633-647.

Nickell L.A., Hughes D.J., Atkinson R.J.A., 2001. *Megafaunal bioturbation in organically enriched Scottish sea lochs,* http://www.imbc.gr/biblio_serv/embs/X0029_40.html.

Probert P.K.,1984. *Disturbance in sediment stability, and trophic structure of soft-bottom communities*, Journal of Marine Research, 42, 893-921.

Pustelnikov O.S., 1983. *Curonian lagoon as a sediment-accumulating environment* [in:] *The Curonian lagoon biogeochemistry* Lit SSR Academy of Science, Geography department, Vilnius, 1, 18-23. (in Russian).

Rubcova S.I., 2000. *On the methods of the experimental estimation of the bottom sediment silty particles sedimentation. Ekologiya Morya,* Institute of the Southern Seas Biology NANU, Sevastopol, 50, 109-110. (in Russian), Sagan S., Weeks A.R., Robinson I.S., Moore G., Aitken J., 1995. *The relationship between beam attenuation and chlorophyll concentration and reflectance ratio in Antarctic waters* [in:] *JGOFS: Southern Oceans. The UK "Sterna" studies in the Bellinghausen Sea, Deep Sea Res.*, Part II, Vol. 42(4), 983-996.

Schaffner L.C., Jonsson P., Diaz R.J., Rosenberg R., Gapcynski P., 1992. *Benthic communities and bioturbation history of estuarine and coastal systems: effects of hypoxia and anoxia, Science of the Total Environment:* 1001-1017.

Skopcov V.G., 1980. *Feeding of Gammarus lacustris* Sars *in different environments* [in:] *Trophic connections of the freshwater invertebrates*. USSR Academy of Science, Institute of Zoology, Leningrad, 94-97 (in Russian).