BOREAL ENVIRONMENT RESEARCH 5: 235–242 ISSN 1239-6095
Helsinki 25 September 2000

Effect of diffuse and point source nutrient supply on the low diverse macrozoobenthic communities of the northern Baltic Sea

Jonne Kotta[1)], Ilmar Kotta[1)] and Ilkka Viitasalo[2)]

[1)] *Estonian Marine Institute, Marja 4d, 10617 Tallinn, Estonia*
[2)] *City of Helsinki, Environmental Centre, Helsinginkatu 24, FIN-00530, Helsinki, Finland*

Kotta, J., Kotta, I. & Viitasalo, I. 2000. Effect of diffuse and point source nutrient supply on the low diverse macrozoobenthic communities of the northern Baltic Sea. *Boreal Env. Res.* 5: 235–242. ISSN 1239-6095

Soft bottom macrozoobenthic communities from the coastal sea area of Helsinki (south Finland) and Saaremaa Island (west Estonia) were compared in order to evaluate the effects of diffuse and point source nutrient supply. The coastal sea area of Helsinki receives a moderate load of municipal sewage water and the latter is ranked among the most undisturbed ecosystems in the northern Baltic Sea. The species composition and dominance structure were similar in both the studied areas indicating that different sources of eutrophication (i.e. local or basin wide) have similar consequences for the macrozoobenthic communities. However, functional diversity was higher in the Saaremaa area as the higher share of herbivores and suspension feeders were found in the area.

Key words: Baltic Sea, eutrophication, macrozoobenthos, soft bottom

Introduction

Increasing rate of urbanisation results in a higher load of nutrients into adjacent water-bodies. Consequently, phytoplankton blooms and a decrease of light attenuation are expected (Launiainen *et al*. 1989, Nixon 1995). Poor light conditions restrict macroalgal communities to shallower areas (Kautsky *et al.* 1986) creating a severe stress for the benthic fauna relying on a macroalgal belt for shelter, food or reproduction (e.g. Kautsky *et al.* 1992). On the other hand, high phytoplankton biomass supports abundant but low diverse filter- and detritus feeding communities. Further input of nutrients may lead to oxygen deficiency which results in extensive mortality of benthic animals or even dissapearance of entire macrobenthic communities (Larsson *et al.* 1985, Josefson and Widbom 1988, Rosenberg and Loo 1988, Bonsdorff *et al.* 1997, Kotta and Kotta 1997).

Numerous papers have been written about the effects of increased nutrient supply on benthic communities (e.g. Cederwall and Elmgren 1980, Andersin 1986, Brey 1986, Elmgren 1989, Bonsdorff *et al.* 1991, Warwick and Clarke 1991, Żmudzinski and Osowiecki 1991). Benthos studies have led to the development of the concept of indicator species and communities of different trophic zones (Leppäkoski, 1975, Pearson and Rosenberg 1978, Järvekülg 1979). It is summarised that increasing eutrophication leads to an increased biomass of macrozoobenthos above the halocline or a defaunation due to hypoxic or anoxic conditions in deeper waters (Laine *et al.* 1997, Modig and Òlafsson 1998).

Little is known about eutrophication processes in almost unstressed sea areas (e.g. Bonsdorff *et al.* 1997). In these areas the local input of nutrients are considered negligible and the dynamics of the system is mainly driven by the basin-wide processes such as the development of halocline causing long periods of oxygen deficiency (Andersin and Sandler 1991, Laine *et al.* 1997). In the shallower areas of the Baltic the species diversity has remained very high (Bonsdorff *et al.* 1997, Kautsky *et al.* 1999). Similarly to more eutrophied areas, however, the community composition has changed and the number of species has diminished during last decades (Kotta and Kotta 1997).

In this study, we compare the output of diffuse and point source nutrient supply by estimating the structure of benthic communities. The aim of the paper is to analyse whether different sources of eutrophication (i.e. local or basin-wide) lead to different ecological consequences. Due to the relatively stationary life, longevity and broad distribution macrozoobenthos reflects the organic enrichment of the sediment and, hence, is an important tool for the assessment of the state of the marine environment.

Material and methods

Study area

Macrozoobenthos was sampled in two adjacent sea areas of Helsinki, the capital city of Finland (Fig. 1). Samples were collected from soft sediment between a depth of 0.5 and 10 m (Table 1). During sampling the presence of phytobenthos was estimated either visually or using a bottom scraper. The region is highly populated (2 920 inhabitants per km^2) and influenced by the moderate input of municipal wastewater. Daily load of nutrients is in order of magnitude of 0.15 t for phosphorus and 7.5 t for nitrogen (Pesonen *et al.* 1994).

The Seurasaari Bay is situated in the suburban area of Helsinki. It is a wide, shallow area with a narrow and 6–10 m deep strait connecting the bay with the open sea. Prevalent bottom types are silty and silty clay sediments with a small gravel fraction. Average depth of the bay is 2 m. Due to the isolation, Seurasaari is seemingly the most eutrophied among the studied areas.

The Vuosaari sea area is situated about 10 km eastwards from Seurasaari. It is characterised as a relatively open sea-area with few scattered islands. Approximately 1/6 of the nitrogen and phosphorus load from Helsinki is discharged in the vicinity of Vuosaari. There is a strong correlation between depth and the type of substrate as stone bottoms are predominant at the sea level and replaced by gravel bottoms at 1–2 m and by silty or silty clay sediments at 2–2.5 m.

In the isolated and open sea areas of the Saaremaa Island (Fig. 1) samples were taken between a depth of 0.5 and 6 m (Table 1). The coastal sea of the island is characterised as a relatively unstressed environment. The urbanisation level of the island is one of the lowest in Estonia (14 inhabitants per km^2) and less than 7% of the land is cultivated. The load of nutrients may be considered negligible in the coastal sea of Saaremaa. The region is supplied by diffused nutrients from the open part of the Gulf of Riga. However, the gulf as a whole is a relatively eutrophic system with its annual primary production being almost twice as high as in the Baltic Proper (Yurkovskis *et al.* 1993, Mägi and Lips 1998).

Because of comparable soft-bottom macrozoobenthic communities, the coastal sea of Saaremaa is well suited as a reference area to Seurasaari and Vuosaari. Similarly to the Helsinki areas Saaremaa Island has a diverse coastline with more than 600 islets (Ratas and Nilson 1997). Salinity varies around 5–6 PSU in both areas and no oxygen

Fig. 1. Study area. Stars represent the location of the sampling stations. Seurasaari sea area, Arju, Kasti, innermost parts of Tepu and Kõiguste bays constitute isolated group and Vuosaari, Kuressaare, Sepamaa and open parts of Kõiguste and Tepu bays open sea areas, respectively.

Table 1. Description of benthos samples: No. = number of stations, depth = average sampling depth (with maximum and minimum values), sediment = percentage of clay, silt and mixed bottoms in the region.

Region	No.	Depth (m)	Sediment		
			Clay	Silt	Mixed
Saaremaa isolated	12	1.53 (0.5–2.5)	58.3	16.7	25.0
Seurasaari isolated	13	3.96 (1.5–10)	30.8	23.1	46.1
Saaremaa open	8	2.63 (0.5–6)	37.5	12.5	50.0
Vuosaari open	10	5.30 (3–10)	40.0	10.0	50.0

deficiency has been recorded in the study areas.

Benthic samples were collected using a modified Petersen bottom grab (0.017 m^2) in the coastal sea of Saaremaa in 1993 and in Seurasaari in 1995. An Ekman-Lenz bottom sampler (0.04 m^2) was used in Vuosaari in 1996. Sampling was performed during late summer. At each site one sample was taken (Table 1).

Sediments were washed through a nylon net bag of 0.25 mm mesh size and the samples were preserved in 4% buffered formaldehyde solution. In the laboratory, the samples were sorted under a stereo dissecting microscope. Total wet weight for each taxon was weighed to the nearest 0.5 mg.

Statistical analysis

A significance level of 0.05 was adopted to all statistical tests. After testing for normality of the data (Kolmogorov-Smirnov test for goodness and fit) and homogeneity of variance (Bartlett's, Hartley's tests), two-way analysis of variance (Sokal and Rohlf 1981) of the effects of region and isolation was performed on the abundance and biomass of macrozoobenthos. The comparative plots of the relative proportions of biomass and abundance of each species in the community (k-dominance curves) were drawn. This method has been previously suggested to detect pollution effects on marine macrobenthic communities (Warwick 1986, Warwick *et al*. 1987). The abundance diversity is higher than the biomass diversity under stable unpolluted conditions and vice versa in grossly polluted communities.

Additionally the non-metric multidimensional scaling analysis (Clarke and Warwick 1994) was run to see whether or not there were regional differences in the structure of invertebrate communities, and to evaluate which environmental factor might be responsible for these differences. An untransformed data of abundance and biomass of macrozoobenthic species was used to calculate the difference between the stations. Bray-Curtis similarity measure was used to construct the similarity matrices (Bray and Curtis 1957).

Table 2. Probability intervals of two-way analysis of variance (α = 0.05) for the abundances and biomasses of macrozoobenthos against isolation rank (open, isolated) and region (Saaremaa, Helsinki).

Model	Isolation	Region	Interaction
Biomass			
Total	0.476	**0.035**	0.102
Vermes	0.522	0.205	0.641
Crustacea	0.288	0.286	0.288
Insecta	0.484	0.106	0.700
Mollusca	0.458	**0.041**	0.104
Abundance			
Total	**0.024**	**0.013**	**0.041**
Vermes	**0.031**	**0.004**	**0.017**
Crustacea	0.632	0.095	0.632
Insecta	0.054	0.981	0.782
Mollusca	0.709	**0.000**	0.279

Results

The two-way analysis of variance showed that isolation and region are important in explaining the variance of the total macrozoobenthos abundance but only regional differences were significant for its total biomass (Table 2). The mean abundances were higher in Saaremaa than in Helsinki, and higher in isolated areas than in open areas (308 ind. m^{-2} in Vuosaari, 1 620 ind. m^{-2} in Seurasaari, 1 711 ind. m^{-2} in Saaremaa open sea areas and 1 735 ind. m^{-2} in Saaremaa isolated sea areas). The mean biomasses were higher in Saaremaa (99 g m^{-2}) than in Helsinki (31 g m^{-2}). The differences were mainly attributed to the higher density of phytophilous gastropods (e.g. *Theodoxus fuviatilis* and *Bithynia tentaculata*) in the Saaremaa area. Polychaetes and oligochaetes were more abundant in the coastal sea of Helsinki. Isolation rank and area did not contribute to the variance of the biomass of Annelida, Cructacea, Insecta and Mollusca.

The share of four different trophic groups (herbivores, filter-feeders, omnivores and deposit-feeders) in the benthic community was calculated according to Järvekülg 1979. Deposit feeders dominated in the studied areas, especially in the coastal sea of Helsinki (Fig. 2). However, the areas were functionally different. The coastal sea of Saaremaa had higher proportion of herbivores as compared to Vuosaari and Seurasaari imply-

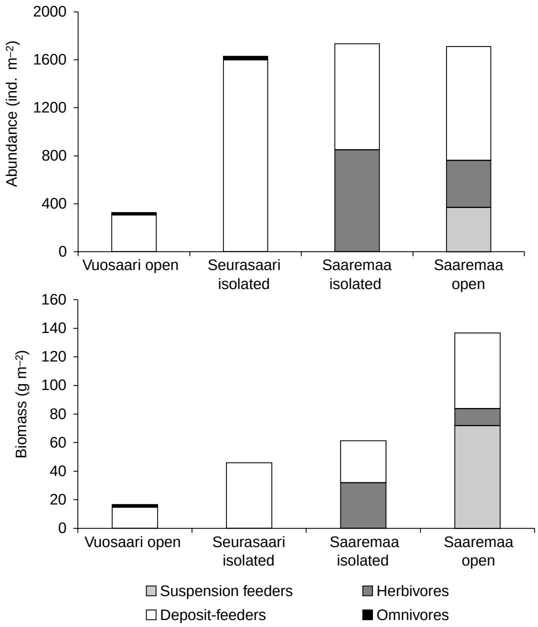

Fig. 2. Share of different trophic groups within zoobenthic communities in the coastal sea of Helsinki and Saaremaa.

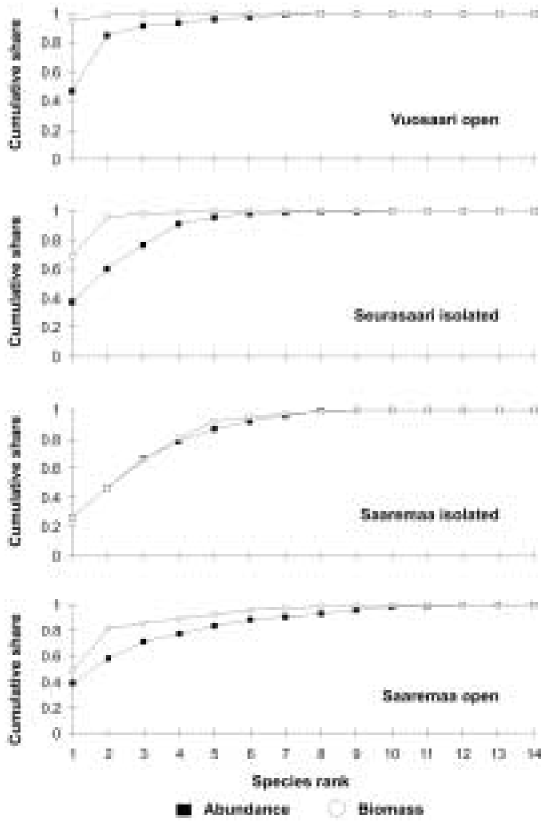

Fig. 3. K-dominance curves of biomass and abundance of zoobenthic communites in the study area.

ing abundant macrovegetation in the region. Suspension feeders comprised about 50% of the total biomass in the open areas of Saaremaa Island being negligible in the other studied areas.

K-dominance curves depict the effect of environmental disturbance (including pollution and eutrophication) on the macrozoobenthos at different studied areas (Fig. 3). The communities of the coastal sea of Helsinki (Vuosaari and Seurasaari) and open areas of Saaremaa Island conform to the model of unpolluted type i.e. the biomass curve is above the abundance curve throughout its entire length. The isolated parts of the coastal sea of Saaremaa represent moderately polluted area.

Taking into account the abundance and biomass, we computed the aggregation pattern of sites with the multidimensional scaling analysis. It showed that the benthic communities of the coastal sea of Helsinki are more uniform than those of Saaremaa Island (Fig. 4). Isolation rank and the presence of macrovegetation contributed most to the variability of macrobenthic communities. The x-axis of Fig. 4 corresponds to the isolation rank of an habitat. Higher values matched the open areas and lower values the isolated areas. Insect larvae, Chironomidae, gastropods such as *Bithynia tentaculata* and partly *Theodoxus fluviatilis*, numerically dominated in the isolated sea areas. The characteristic species of the open sea were the bivalves *Macoma balthica*, *Mya arenaria*, *Mytilus edulis*, and crustaceans *Idothea balthica*, *I. viridis*, *Gammarus salinus* and *G. oceanicus*.

The y-axis of Fig. 4 shows the presence of macrovegetation. The lowest values refer to areas without vegetation, the higher values to the communities rich in attached macroalgae such as *Potamogeton pectinatus*, *P. perfoliatus*, *Ruppia maritima* and *Zannichellia palustris*. Rich benthic vegetation supports higher densities of gastropods, hence, the y-axis mainly reflects the changes in the proportion of *B. tentaculata* and *T. fluviatilis* in the community. The factor contributing to the variance along the y-axis of the analysis of the biomass structure is less clear.

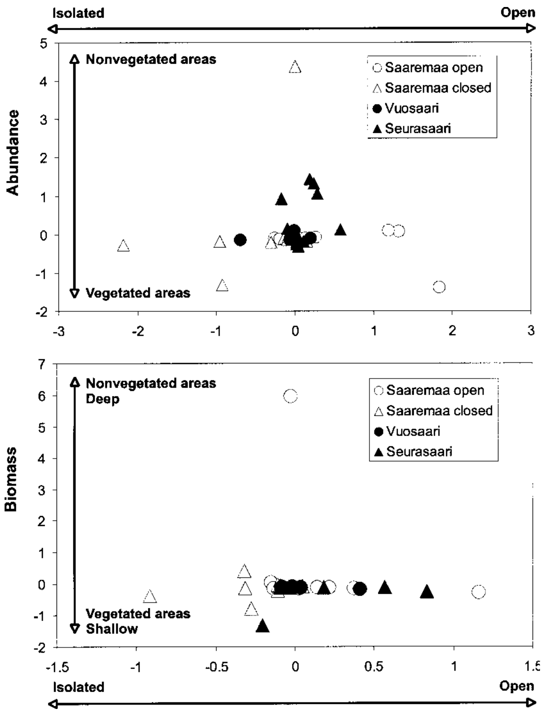

Fig. 4. Multidimensional scaling analysis by sites on the abundances and biomasses of zoobenthos in the coastal sea of Helsinki and Saaremaa.

Discussion

In this study, we compared the soft bottom invertebrate communities at areas subjected to diffused (Saaremaa) and point source nutrient input (Helsinki). The coastal sea of Saarenmaa had a higher trophic diversity than the sea areas adjacent to Helsinki. In the coastal sea of Helsinki, macrozoobenthic communities were dominated only by deposit-feeders. In the coastal areas of Saarenmaa besides deposit-feeders, a significant proportion of filter-feeders and herbivores were found. The higher niche diversity is probably due to the presence of benthic vegetation offering feeding grounds for herbivores and secondary substrate for suspension feeders. Macrophyte beds are known to have a higher abundance of epibenthos and infauna than comparable unvegetated bottoms. This has been attributed to the higher sediment stability, habitat complexity, more diverse food resources and lower predation pressure (Welsh 1980, Barnes and Hughes 1988, Wilson *et al.* 1990).

On the other hand, the k-dominance curves indicated that the environmental disturbance is highest at the isolated areas of the Saaremaa study area. The latter is classified among the most conserved ecosystems in Estonia. However, it may receive nutrients from the Gulf of Riga. Shallow depths and isolation favour light penetration and nutrient accumulation and, therefore, we may expect a higher productivity and a fast eutrophication processes even there.

Multidimensional scaling analysis is considered more sensitive than species independent methods (e.g. ANOVA or similarity indices) in discriminating between sites or times (Warwick and Clarke 1991). The communities of the coastal sea of Saaremaa and Helsinki do not form two distinguished statistical groups as expected from the differences in their urbanisation level. In general, the communities were very homogeneous. *Macoma balthica* was the most common species in the whole study area. Both areas were characterised by relatively high occurrence of insect larvae (mostly *Chironomidae*), oligochaetes and polychaetes. Abundance and biomass values of crustacean were low. Similarly to previous statistical analysis MDS analysis stressed higher benthic diversity in Saaremaa i.e. higher dissimilarities between stations.

It is known that abundance of benthic invertebrates increases with the organic content of the sediment (i.e. eutrophication level) (Bonsdorff *et al.* 1997). We found no evidence of a higher total abundance in presumably more polluted environments. On the contrary, abundances were higher in the coastal sea of Saaremaa in 1990s. Hence, we may say that eutrophication has little effect on the community structure of benthic fauna in silty or clay bottom biotope.

As a conclusion, the structure of the zoobenthos communities of the Saaremaa and Helsinki areas are alike. It suggests that both communities are affected by similar disturbance. That is different sources of eutrophication (local vs. basin-wide) have the same impact on soft sediments in terms of macrozoobenthos. However, the zoobenthos of the coastal sea of Saaremaa Island is more diverse which refers to its higher functional diversity.

Acknowledgements: Authors are grateful to Mrs Tiia Rosenberg. This study was funded by Helsinki City Centre of Environment and Estonian Governmental Programmes no. 0200792s98 and 0200797s98.

References

Andersin A.-B. 1986. The question of eutrophication in the Baltic Sea — results from a long-term study of the macrozoobenthos in the Gulf of Bothnia. *Vesientutkimuslait. Julk., Helsinki/Publ. Water Res. Inst., Helsinki* 68: 102–106.

Andersin A.-B. & Sandler H. 1991. Macrobenthic fauna and oxygen deficiency in the Gulf of Finland. *Memoranda Societas Fauna Flora Fennica* 67: 3–10.

Barnes R.S.K. & Hughes R.N. 1988. *An introduction to marine ecology*, Second edition, Blackwell Scientific publications, Oxford, 305 pp.

Bonsdorff E., Aarnio K. & Sandberg E. 1991. Temporal and spatial variability of zoobenthic communities in the archipelago waters of the northern Baltic Sea — consequences of eutrohication? *Int. Revue ges. Hydrobiol.* 76: 433–449.

Bonsdorff E., Blomqvist E.M., Mattila J. & Norkko A. 1997. Coastal eutrophication: causes, consequences and perspectives in the archipelago areas of the northern Baltic Sea. *Estuarine, Coastal and Shelf Sci.* 44 (Supplement A): 63–72.

Bray J.B. & Curtis J.T. 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecol. Monogr*. 27: 325–349.

Brey T. 1986. Increase in macrozoobenthos above the halocline in Kiel Bay comparing the 1960s with the 1980s. *Mar. Ecol. Prog. Ser.* 28: 299–302.

Cederwall H. & Elmgren R. 1980. Biomass increase of benthic macrofauna demonstrates eutrophication of the Baltic Sea. *Ophelia* (Suppl. 1): 31–48.

Clarke K.R. & Warwick R.M. 1994. *Changes in marine communities: an approach to statistical analysis and interpretation*, Plymouth Marine Laboratory, Plymouth.

Elmgren R. 1989. Mans impact on the ecosystem of the Baltic Sea. Energy flows today and at the turn of the century. *Ambio* 18: 326–332.

Järvekülg A. [Ярвекюльг А.]1979. *Benthic fauna in the eastern part of the Baltic Sea,* Valgus Tallinn, 382 pp. [In Russian].

Josefson A.B. & Widbom B. 1988. Differential response of benthic macrofauna and meiofauna to hypoxia in the Gullmar Fjord basin. *Mar. Biol.* 100: 31–40.

Kautsky H., Kautski L., Kautski N., Kautski U. & Lindblad C. 1992. Studies on the *Fucus vesiculosus* community in the Baltic Sea. *Acta Phytogeogr. Suec.* 78: 33–48.

Kautsky H., Martin G., Mäkinen A., Borgiel M., Vahteri P. & Rissanen J. 1999. Structure of phytobenthic and associated animal communities in the Gulf of Riga. *Hydrobiologia* 393: 191–200.

Kautsky N., Kautski H., Kautski U. & Waern M. 1986. Decreased depth penetration of *Fucus vesiculosus* L. since the 1940's indicates eutrophication of the Baltic Sea. *Mar. Ecol. Prog. Ser.* 28: 1–8.

Kotta I. & Kotta J. 1997. Changes in zoobenthic communities in Estonian waters between the 1970's and 1990's. An example from the southern coast of Saaremaa and Muuga Bay. In: Ojaveer E. (ed.), *Proceedings of the 14th Baltic Marine Biologists Symposium*, Estonian Academy Publishers, Tallinn, pp. 70–79.

Laine A.O., Sandler H., Andersin A.-B. & Stigzelius, J. 1997. Long-term changes of macrozoobenthos in the Eastern Gotland Basin and the Gulf of Finland (Baltic Sea) in relation to the hydrographical regime. *J. Sea Res.* 38: 135–159.

Larsson U., Elmgren R. & Wulff F. 1985. Eutrophication and the Baltic Sea: Causes and consequences. *Ambio* 14: 9–14.

Launiainen J., Pokki J., Vainio J., Niemimaa I. & Voipio A. 1989. Long-term changes in the Secchi depth in the northern Baltic Sea. *XIV Geofiisikan päivät Helsinki*, pp. 117–121. [In Finnish with English abstract].

Leppäkoski, E. 1975. Assessment of the degree of pollution on the basis of macrozoobenthos in marine and brackish-water environments. *Acta Academiae Aboensis, Ser B, Matematic, naturvetenskaper, teknik* 35: 1–90.

Mägi L. & Lips U. 1998. Budget components of water, salt, and nutrients in the Gulf of Riga in 1993–95. *Proc. Estonian Acad. Sci. Biol. Ecol.* 47: 14.31.

Modig H. & Òlafsson E. 1998. Responses of Baltic benthic invertebrates to hypoxic events. *J. Exp. Mar. Biol. Ecol.* 229: 133–148.

Nixon, S.W. 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. *Ophelia* 41: 199–219.

Pearson T.H. & Rosenberg R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology. An Annual Review* 16: 229–311.

Pesonen L., Norha, T., Rinne, I., Viljamaa, H. 1994. Helsingin ja Espoon merialueiden velvoitetarkkailu vuonna 1993. *Helsingin Kaupungin Ympäristökeskuksen Julkaisuja* 6: 1–115.

Ratas U. & Nilson E. 1997. *Small islands of Estonia*, Institute of Ecology, Tallinn, 232 pp.

Rosenberg R. & Loo L.-O. 1988. Marine eutrophication induced oxygen deficiency: effects on soft bottom fauna, western Sweden. *Ophelia* 29: 213–225.

Sokal R.R. & Rohlf F.J. 1981. Biometry. The principles and practice of statistics in biological research. Second edition. W.H. Freeman, San Francisco, 859 pp.

Warwick R.M. 1986. A new method for detecting pollution effects on marine macrobenthic communities. *Mar. Biol.* 92: 557–562.

Warwick R.M. & Clarke K.R. 1991. A comparison of some methods for analysing changes in benthic community structure. *J. mar. biol. Ass. U.K.* 71: 225–244.

Warwick R.M., Pearson T.H. & Ruswahyuni 1987. Detection of pollution effects on marine macrobenthos: further evaluation of the species abundance/biomass method. *Mar. Biol.* 95: 193–200.

Welsh B.L. 1980. Comparative nutrient dynamics of a marsh-mudflat ecosystem. *Estuarine Coastal Mar. Sci.* 10: 143–164.

Wilson K.A., Able K.W. & Heck J.K.L. 1990. Predation rates on juvenile blue crabs in estuarine nursery habitats: evidence for the importance of macroalgae (*Ulva lactuca*). *Mar. Ecol. Prog. Ser*. 58: 243–251.

Yurkovskis A., Wulff F., Rahm L., Andrushaitis, A. & Rodrigues-Medina M. 1993. A nutrient budget of the Gulf of Riga, Baltic Sea. *Estuarine, Coastal and Shelf Sci.* 37: 113–127.

Żmudzinski L. & Osowiecki A. 1991. Long-term changes in macrozoobenthos of the Gdańsk Deep. *Int. Revue ges. Hydrobiol.* 76: 465–471.

Received 10 February 1999, accepted 2 June 2000