Scale-specific effects of environmental variables on benthic macrophyte and invertebrate communities in the Vaindloo area, the central Gulf of Finland

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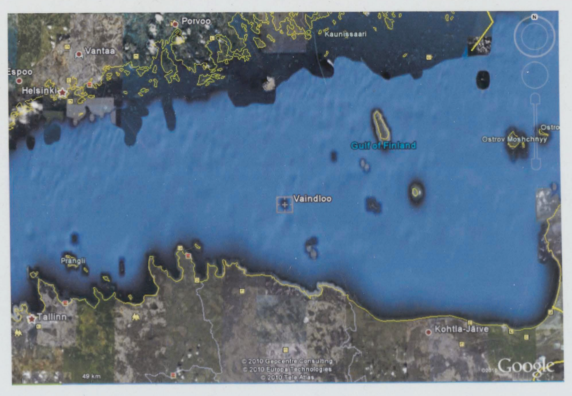
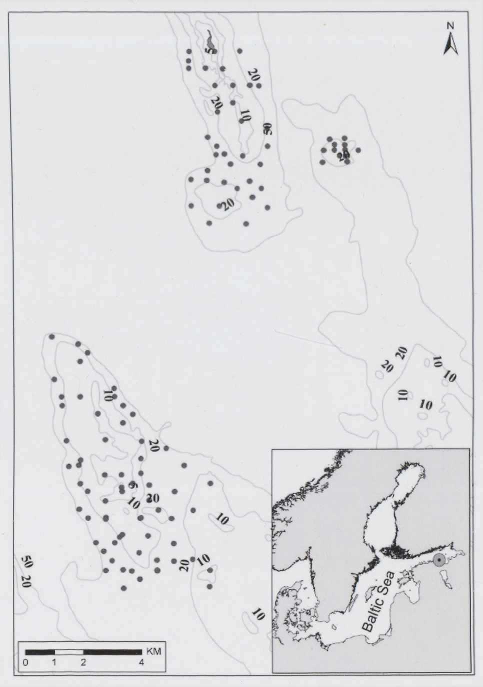
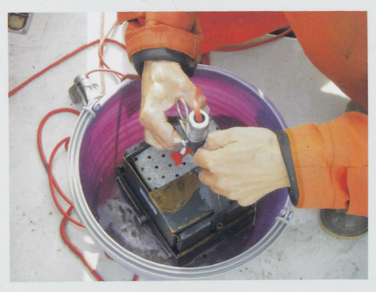
Introduction

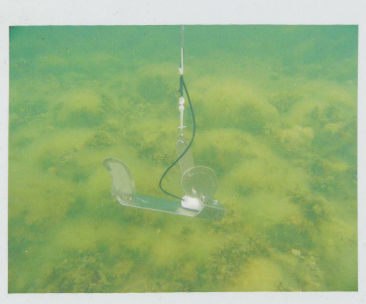
The majority of information on environmental conditions, biodiversity and functioning of aquatic ecosystems has been derived from the studies operated at small spatial scales such as site or habitat scales whereas those performed at landscape or regional scales are much rarer.

In this study we quantified the relative importance of scale-specific variability of macroalgal and benthic invertebrate communities in the Vaindloo area, the central Gulf of Finland.In order to establish the link between scale-specific patterns of abiotic environment and biota, community variability was decomposed into the relative contribution of different abiotic environmental factors.





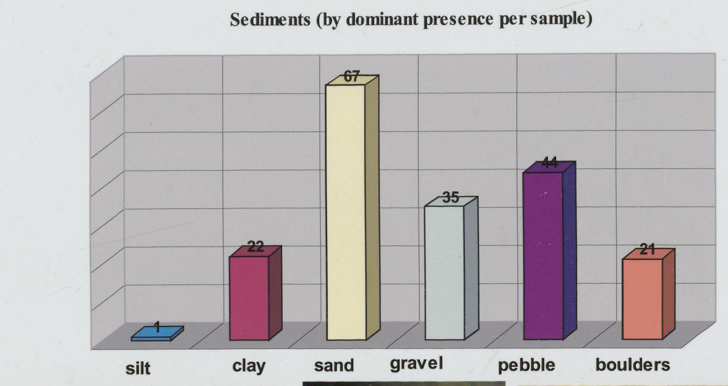


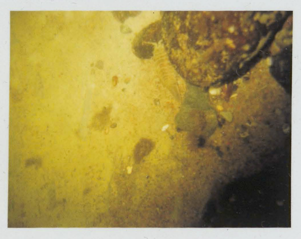


Material and Methods

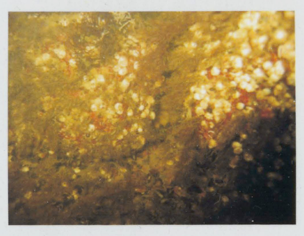
The study was conducted in June 2009 in the frame of the project "Inventory of benthos and habitats in the Vaindloo area" coordinated by the Estonian Fund for Nature. Area salinity ranged between 5 and 7 psu (Database of the Estonian Marine Institute), the average depth was 27 m and maximum 56 m. Sand, pebble and gravel bottoms dominated.

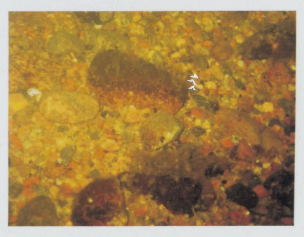
A total of 114 stations were sampled and three replicate samples were taken in each station. On soft bottoms the sampling was performed by an Ekman type bottom grab and on hard bottoms benthic macrophytes and invertebrates were collected by a diver-operated metal frame. In every station the coverage of different substrate types was estimated by a remote video-camera.Wave exposure for mean wind conditions in the study area was calculated for 50, 100, 500, 1000 metre scales. Also inclination of coastal slopes was calculated at 50, 100, 500 and 1,000 m resolutions. We have used stastical programs (PRIMER and relaimpo R package) and colculated the geographical distances between the studied sites. The distance-based mean dissimilarities were used as a proxy of the scale-specific spatial variability of abiotic environment and biota.

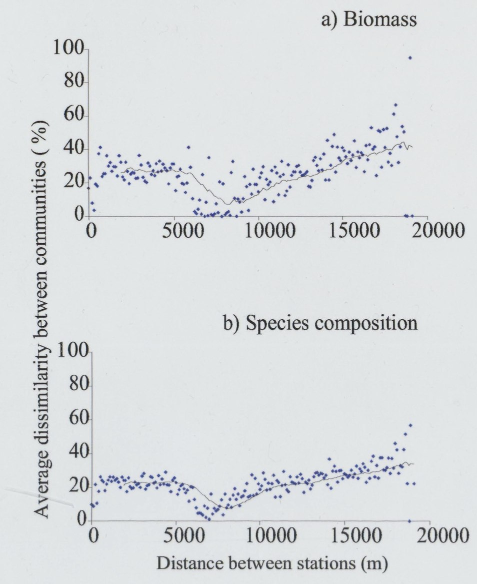


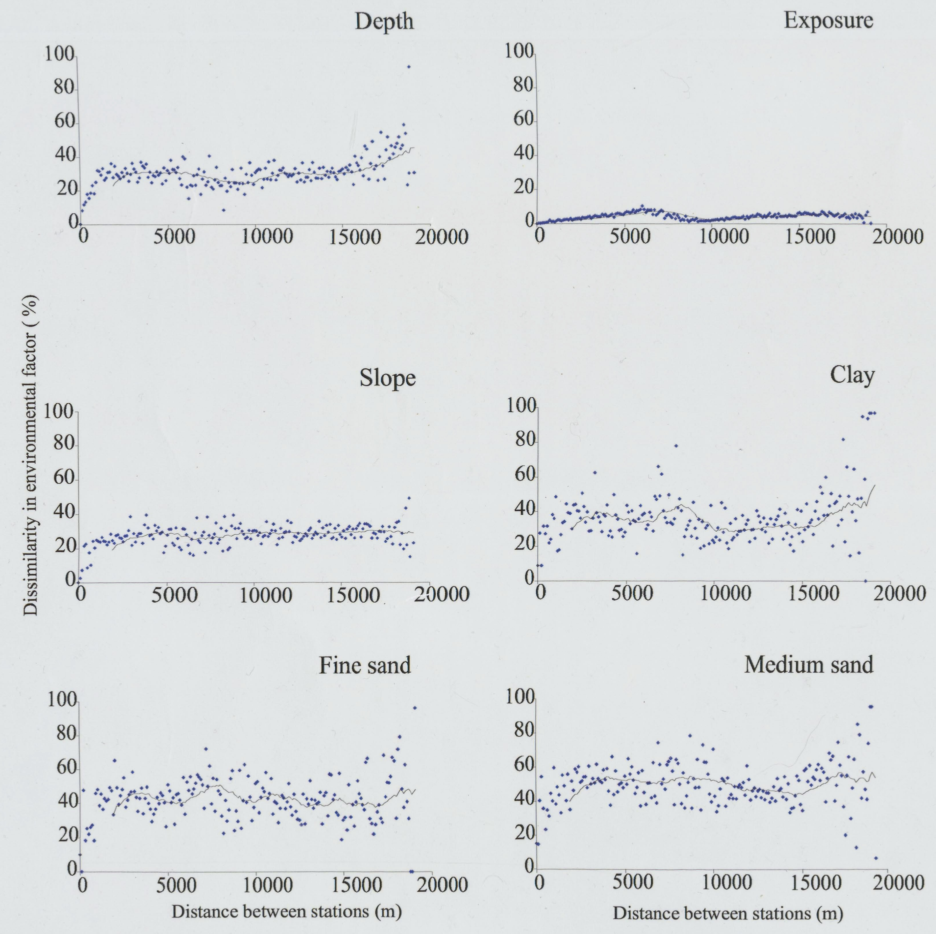


Scale-specific dissimilarity (Bray-Curtis) between phytobenthic communities



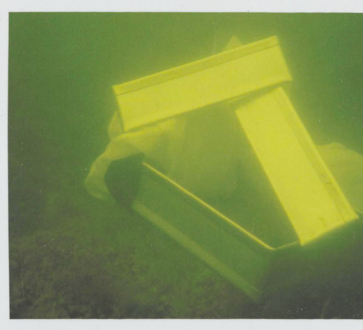


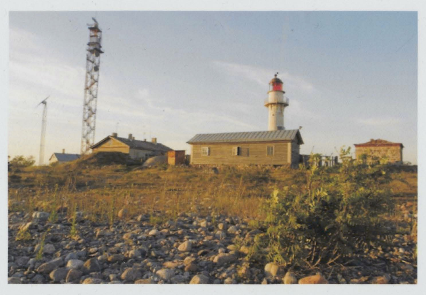


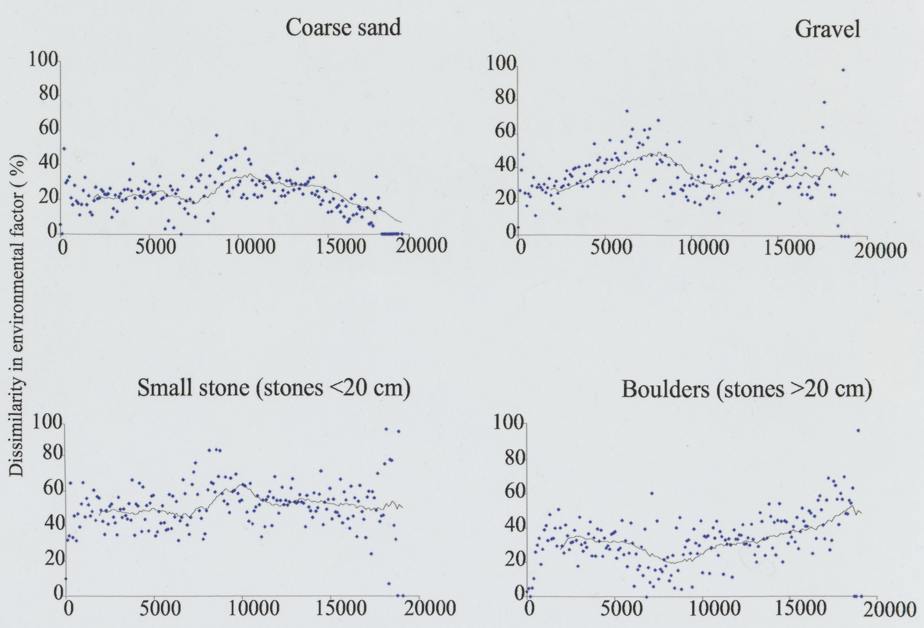


The scale-specific variability of the key environmental factors assessed by the Bray-Curtis dissimilarities of environmental data
Depth was expressed in metres, wave exposure in m2 s-1, inclination of coastal slopes in degrees of grade, and substrate types in percentage cover

Substrate class	Size
silt (fluffy, high in organic content)	< 0.063 mm
clay	< 0.063 mm
fine sand	0.063–0.25 mm
medium sand	0.25–0.5 mm
coarse sand	0.5–2 mm
gravel	2–20 mm
small stones	d < than 20 cm
boulder	d > than 20 cm







Results

Macrophytes were represented by a few species as only 8 species were found in the study area. Altogether 23 benthic invertebrate species were recorded in the study area.

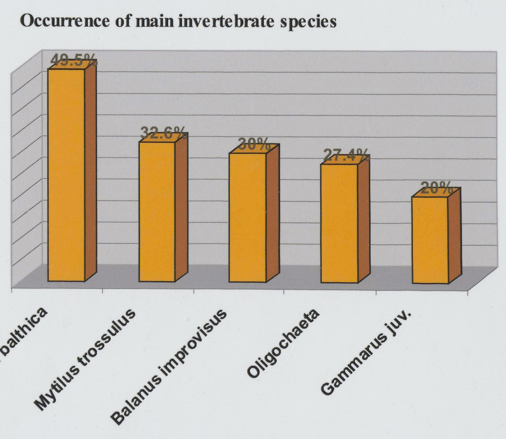
Macrophyte communities had a clear variability minimum at 8 km spatial scale. In contrast to macrophytes, the scale-specific variability of benthic invertebrate communities was small with no clear variability peak or minumim.

Among abiotic variables depth, coastal slope, silt, fine and medium fractionated sands had low scale-specific variability. Gravel coverage and exposure had a variability peak at 8 km scale whereas boulders had a variability minimum at 8 km scale. On the other hand, coarse sand and small stones had a variability peak at 10 km scale.

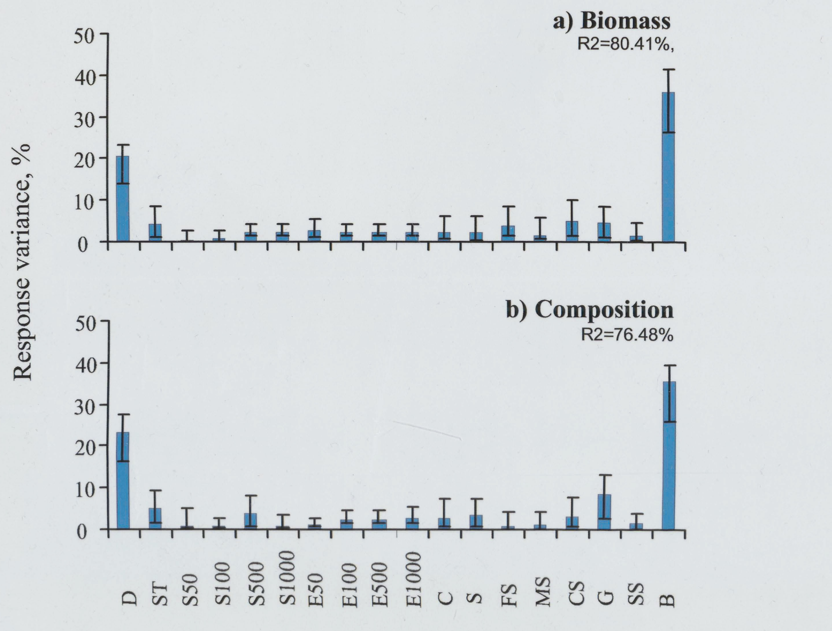
The relaimpo analysis showed that the studied abiotic environmental variables significantly contributed to the distribution patterns of benthic communities. Among environmental variables the coverage of boulders and depth contributed most to the variability of species composition and biomass dominance structure of macrophytes. Similar to macrophytes the coverage of boulders and depth largely described variability in the species composition of benthic invertebrates. In addition to these environmental factors, variability in the abundance and biomass dominance structure of benthic invertebrates was described by coastal slope, exposure and cover of sediment size fractions other than boulders.

Average biomass ± SE (g m^{-2}), occurrence (% of findings), and depth range (m) of macrophyte species in the Vaindloo area.

Species	Biomass	Occurrence, %	Min. depth	Max. depth
Green algae				
Cladophora glomerata (L.) Kützing	0.11 ± 0.05	2.6	0.7	7
Brown algae				
Dictyosiphon foeniculaceus (Huds.) Grev.	<0.01	0.5	0.7	0.7
Fucus vesiculosus L.	0.58 ± <0.01	0.5		
Pilayella littoralis (L.) Kjellman	20.04 ± 7.69	8.9	0.7	9.4
Sphacelaria arctica Harvey	4.13 ± 0.90	17.4	6	15.3
Red algae				
Ceramium tenuicorne (Kützing) Waern	4.41 ± 2.04	11.6	0.7	14.6
Coccotylus truncatus (Pallas) M.J. Wynne & J.N. Heine	0.02 ± <0.01	0.5		
Furcellaria lumbricalis (Hudson) J. V. Lamouroux	9.06 ± 6.01	3.7	8.5	10.9

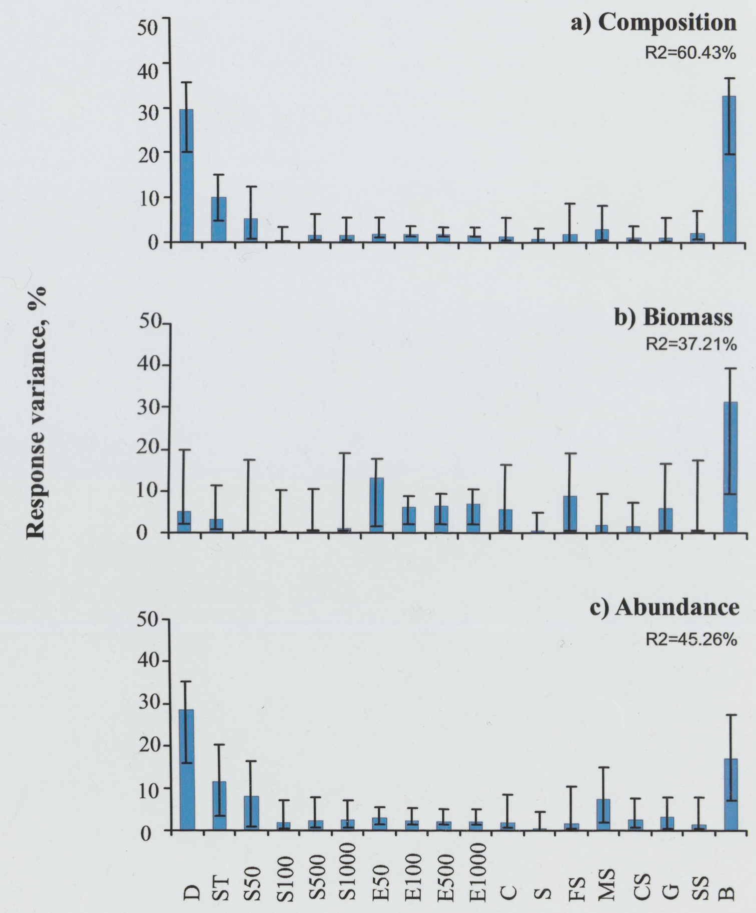


Relative importances of environmental variables for macrophyte communities



D – depth; ST – prevailing sediment type classified into sediment classes shown below; S50, 100, 500, 1000 - coastal slope at the respective spatial scale; E50, 100, 500, 1000 – exposure at the respective spatial scale; coverages of different sediment types: C – clay; S – silt; FS – fine sand; MS – medium sand; CS – coarse sand; G – gravel; SS – stones smaller than 20 cm; B – boulders, stones larger than 20 cm.

Relative importances of environmental variables for benthic invertebrate communities



Conclusions

The results suggest that the scale-specific variability of marine communities is complex and differs considerably among different ecosystem elements. Namely, variability in the species composition and biomass of macrophytes was clearly scale-dependent whereas the patterns of species composition, abundance and biomass of benthic invertebrates were largely scale-independent.

Consequently, the coverage of different sediment types is expected to define the patterns of benthic invertebrates in the study area. Although different sediment fractions showed peaks and depressions at different scales, their cumulative effect resulted in the scale-invariant pattern of benthic invertebrates. Due to strong light and substrate limitation, the distribution of macrophytes is expected to reflect primarily the patterns of depth (i.e. light) and substrate (i.e. boulders).

This suggests that there exist no generic scale-specific pattern of macrophytes and benthic invertebrates.

The methodology shown in our study offers theoretical basis to decompose the effects of different abiotic environment on biota along changing spatial scales. Our study showed that the scale-dependent variability of macrophytes and benthic invertebrates is largely described by abiotic environment operating at multiple spatial scales. With such abiotic data being nowadays widely accessible (e.g. remote sensing data on bathymetry and sediment) the scale-dependent patterns of species composition, abundances and biomasses can be modelled.

Acknowledgements
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