A6.2 Assessment on the effect of spatial scale on biodiversity monitoring results

31.12.2024

LIFE20 IPE/FI/000020 LIFE-IP BIODIVERSEA

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Assessment on the effect of spatial scale on biodiversity monitoring results

Louise Forsblom, Tytti Turkia, Ari Laine, Lasse Kurvinen

Table of Contents

Aims

The aim of action A6 is to deliver a suggestion on monitoring programme for the monitoring of marine biodiversity of shallow photic areas. Deliverable *A6.2 Assessment on the effect of spatial scale on biodiversity monitoring results* supports this aim by investigating the spatial patterns of species richness in the photic zone, mainly focusing on vegetation and sessile infauna. In addition to species richness, we investigate the spatial distribution of species communities. The community distribution was investigated by identifying spatial species clusters, that can support the development of sampling strategies for habitat monitoring. Additionally, we investigated the community composition of marine strategy framework directive (MSFD) monitoring transects on muddy, sandy and gravel substrates.

Introduction

Species richness is only one way to measure biodiversity and many key underwater vegetation habitats can consist of few species that in turn support vast communities of invertebrates and fish. Areas can be identified and classified as national habitat types based on in situ observations (Kotilainen et al. 2018). To support the planning of a monitoring network for biodiversity in the photic zone we investigated the spatial distribution and patterns of both communities as well as species richness.

Material and methods

To support the investigation and to produce seamless maps of species richness as well as species communities we used species distribution maps produced within the Finnish Inventory Programme for Underwater Marine Diversity, Velmu (Virtanen et al. 2018, 2023). We identified areas with high species richness based on thresholded species distribution models. We additionally identified spatially associated clusters of species using spatial clustering (Pang et al. 2023).

Species distribution models

Species distribution models (SDM) are correlative models used to describe the geographical distribution of species. We used 172 models of aquatic vegetation and fauna produced using Boosted Regression Trees (Elith et al. 2008). The modelling approach and the models are described in Virtanen et al. (2018, 2023). Explanatory variables included variables such as depth, substrate, salinity, exposition of the site, as well as variables describing eutrophication. The species observations used for the models were mainly gathered within Velmu (Forsblom et al. 2024). The observations were supplemented by targeted inventories of specific areas, such as the Åland Islands (Kiviluoto 2013; Rinne et al. 2019), monitoring data of benthic fauna from the Pohje data base, and specific species, such as endangered species (LajiGIS 2024). The majority of the species observation data are cover estimates gathered by scuba diving or from underwater videos. Species identification is dependent on the method, and as such the video-data was not used for all species. As diving is mainly used in shallower areas three types of additional absences were considered for deeper areas: 1) by using video observations with no vegetation as absences, 2) by using samples of benthic macrofauna where no vegetation was recorded as absences and 3) by using randomized pseudoabsences from deeper areas than 40 m. The fitted models were used to produce gridded maps for the whole Finnish sea area at a resolution of 20 x 20 metres.

Identifying areas with high species richness

To identify areas with high species richness we converted the continues probability layer to binary layers depicting species presence and absence. For the thresholding we used the value where maximum sensitivity equalled the specificity (Liu et al. 2016). After this, all layers were summed together to produce a gridded map of species richness. To further delineate areas with high species richness we identified areas where the quantiles calculated using the species richness represented 0-90, 90-95, 95-97, 97-99 and 99-

100%. We produced layers for all species, as well as separate layers including only vegetation or fauna. Species lists available in supplementary table 1.

Identifying community clusters

Various association indices are available for the association of species in a community, and these can be used to classify the species into communities using various clustering algorithms (Pang et al 2023). We used the predicted probability map layers to calculate Bray Curtis and Pearson correlation coefficient indices for 172 species (listed in supplementary table 1). Only sessile species were considered. Since the focus is mainly on the photic zone, the gridded maps were cropped using bathymetry, to only include areas less than 40 metres prior to the analysis. We further classified the species into clusters using hierarchical clustering of the resulting indices using Ward's algorithm method. We additionally tested both UPGMA and complete linkages for comparison. To identify the right number of clusters we used the bifurcation approaches suggested and developed by Pang et al. (2023). For calculating the indices, the clustering and to evaluate the results, we used a modified version of the R-code published by Pang et al. (2023).

Community analysis of monitoring data

Ordination for the monitoring data from the existing MSFD monitoring scheme covering mud, sand and gravel bottoms was performed with the function metaMDS in the package "vegan" in R (Oksanen et al. 2022; R Core Team 2022). Abundance data was used instead of presence-absence data, because differences between species communities in the different census sites are more likely to be seen with abundance data. The data was not transformed in any way. Log-transform was tested, but it did not improve the results. Only plants, algae and sessile epifauna were included in the analysis.

Results

Key areas with high species richness

Considering both flora and fauna, the key areas with high species richness are mainly located in shallow coastal areas, including areas close to the mainland, as well as mid-and outer archipelago, estuaries, and some lagoons (Fig. 1A). When considering only the underwater vegetation the emphasis is even closer to shore, with high diversity in coastal lagoons and more emphasis on areas in the Bothnian Bay (Fig 1B). When considering only fauna, the areas highest in species richness are heavily concentrated to the Gulf of Finland and the Archipelago Sea (Fig. 1C).

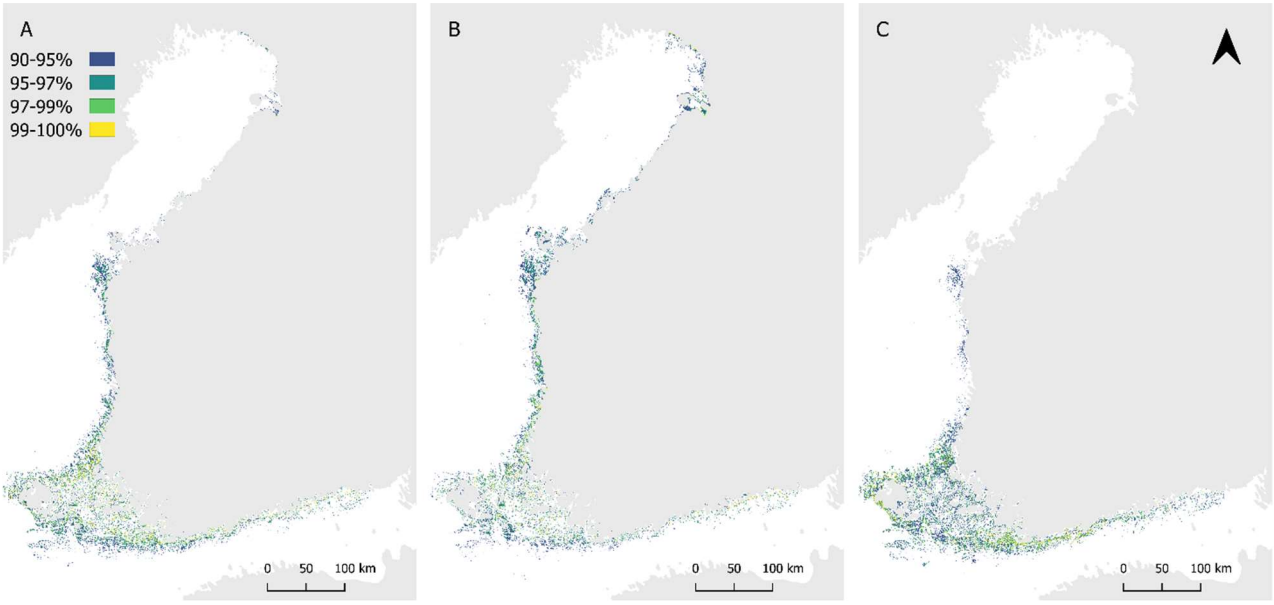

Figure 1. Maps showing the high diversity areas calculated based on species richness quantiles for all species (A), vegetation (B), and fauna (C).

When comparing the areas with highest species richness in terms of flora and fauna, there is some overlap in key areas. However, e.g. for the areas with the top one percentile only 4% of the best grids for vegetation can be found within the top percentile for the fauna (Fig. 2). In addition to mismatches observed in the spatial distribution of key richness areas, the key areas can also occur at different depths, as there are differences in optimal depth distribution for the vegetation and fauna (Fig. 3). The vegetation is mainly expected to occur in the first few metres of depth, with an additional concentration at 10 metres.

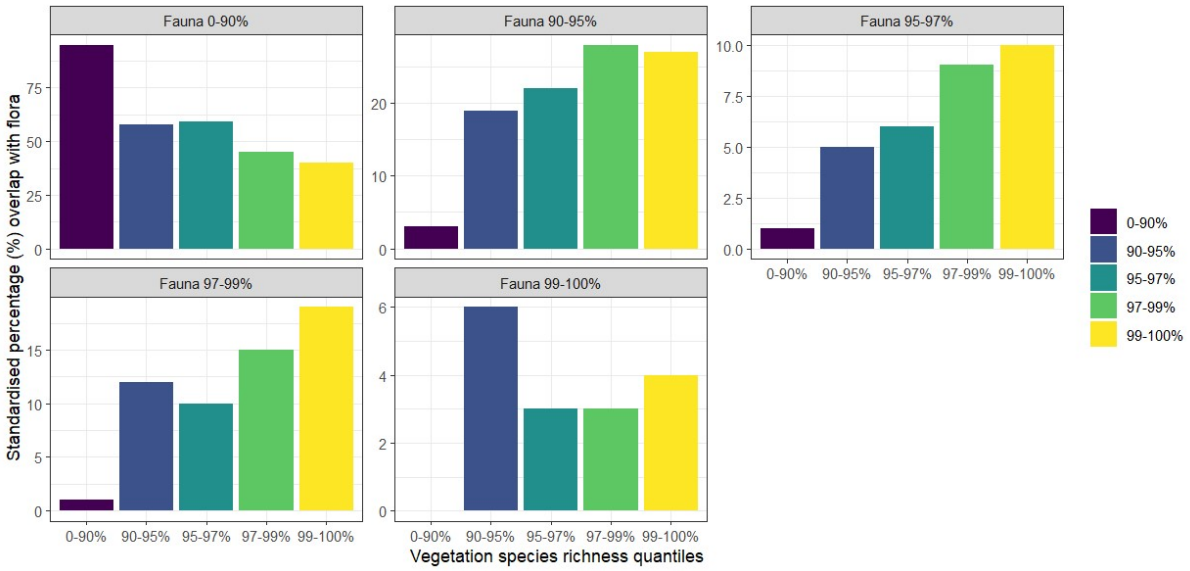

Figure 2. Overlap in quantile classes calculated using species richness of vegetation (x-axis) and fauna (panels). Standardized by the max number of grids in each class for the vegetation i.e., columns sum to 100% per colour. E.g. bottom right panel shows how the fauna biodiversity is distributed for the areas richest in faunal diversity (top one percentage).

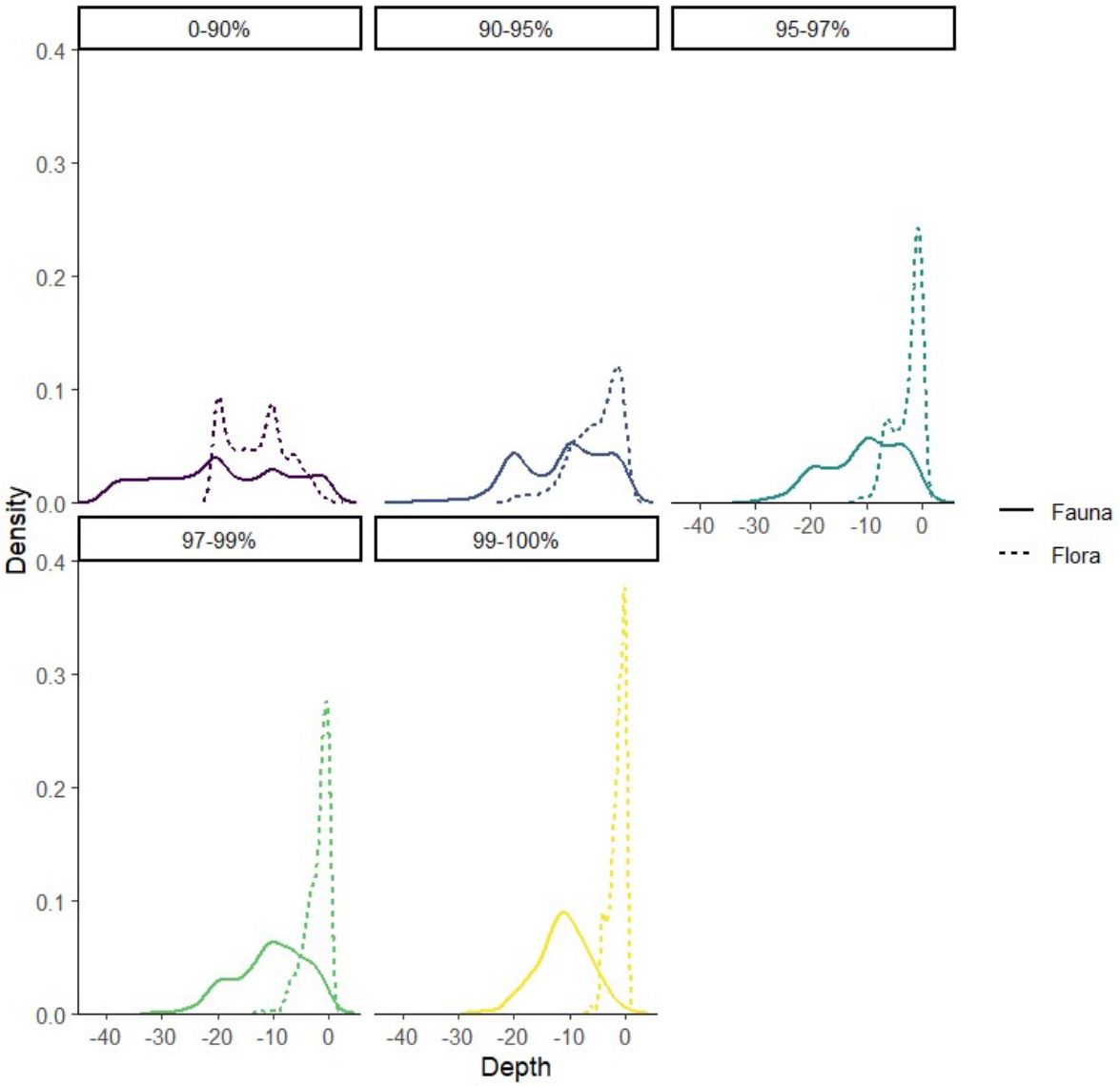

Figure 3. Depth distributions for the high diversity areas calculated based on species richness quantiles for vegetation (Flora) and fauna (Fauna).

Species community clusters

We identified the optimal number of clusters as seven, using the Ward clustering approach on the Pearson correlation coefficients. Whereas Wards yielded more balanced clusters, additional tests with UPGMA and complete linkages only yielded large clusters as selected with the bifurcation method.

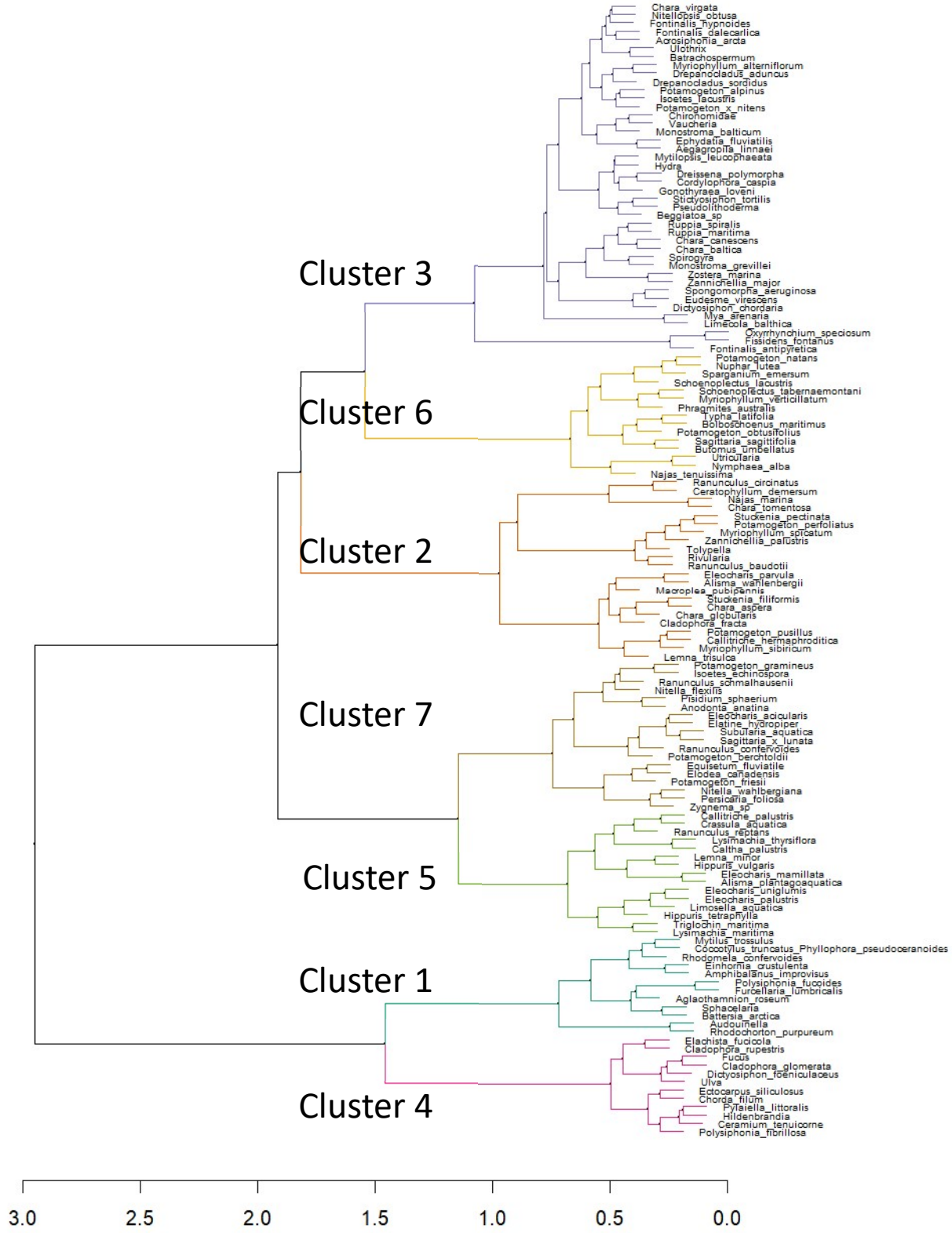

Figure 4. The seven clusters (colours) identified using hierarchical clustering of Pearson correlation coefficients using Ward.

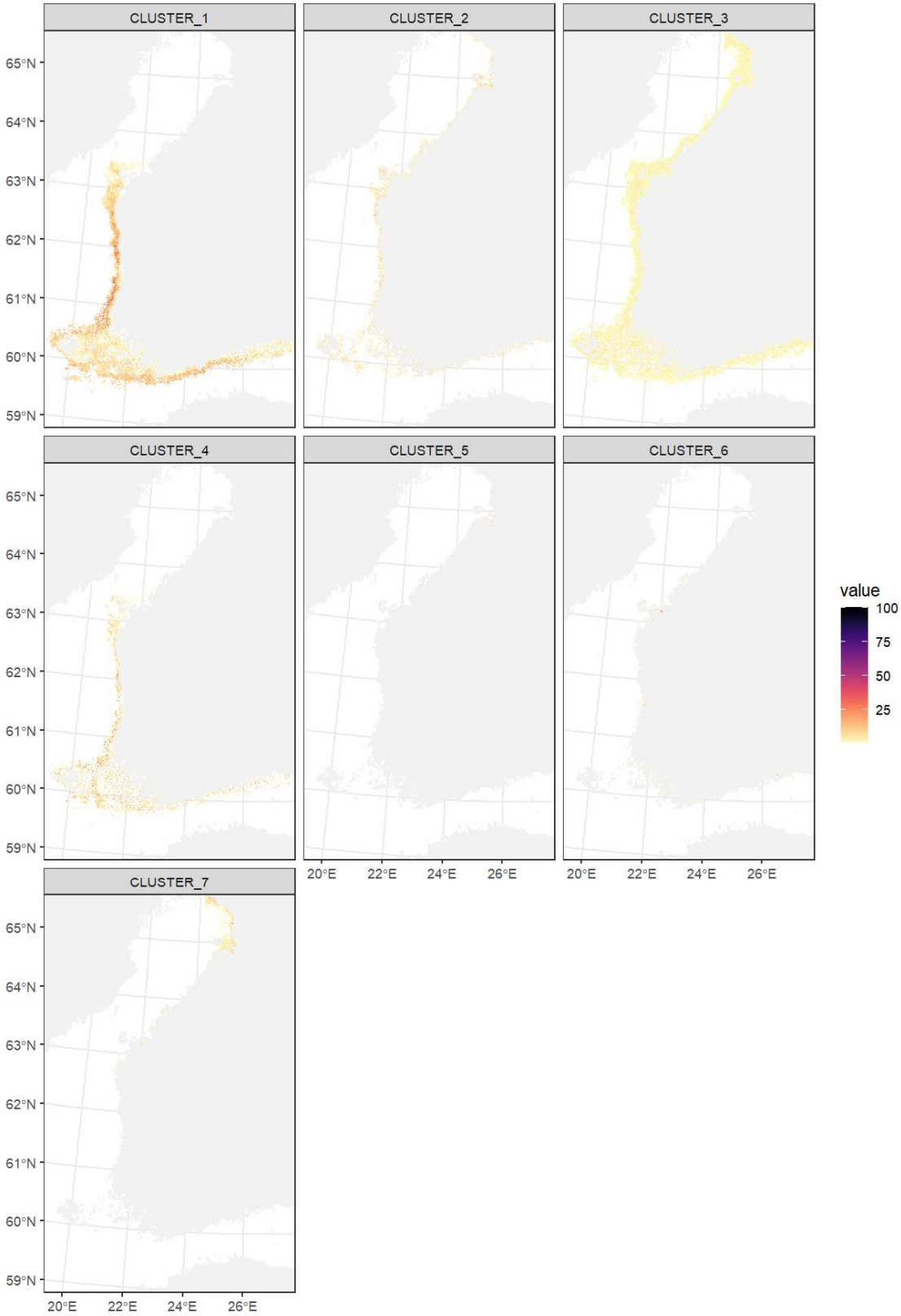

Figure 5. Maps depicting the clusters with the colour scale indicating how many percentages of the species in that specific cluster are present per pixel. Cluster 5 is present patchily in narrow bands in areas such as estuaries, and lagoons with largest distributions in the Bothnian Bay. Cluster 6 is distributed in a similar manner as Cluster 5 but more broadly with highest values in the Quark.

Substrate

Dive transect data from the existing MSFD monitoring scheme covering mud, sand and gravel bottoms shows that species communities differ between the Finnish sea areas even on the same substrate. Especially gravel and sand bottoms in the Gulf of Finland and in the Bothnian Bay differ from those in other sea areas (Figure 6). This is probably caused by the environmental gradients that occur along the Finnish coast, most notably salinity and temperature. Communities on muddy substrates are relatively similar in all sea areas, but also there some census sites stand out from the rest. These are census lines in the Quark, where Nymphaeaceae (lilies etc) occur, which is not typical elsewhere.

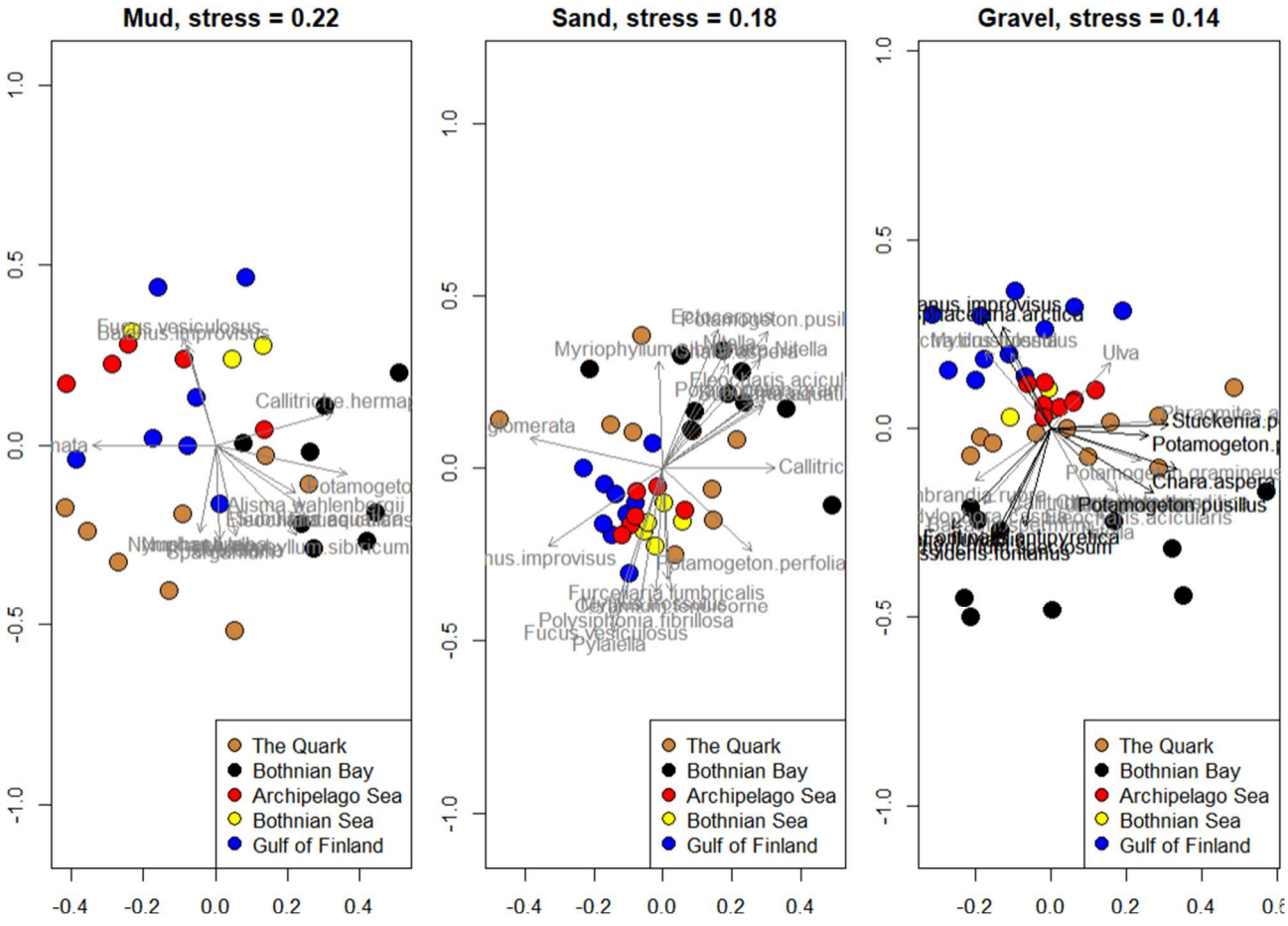

Figure 6. Ordination plots for mud, sand and gravel substrates sampled in different parts of the Finnish coast. Axes are NMDS1 (x) and NMDS2 (y). Vectors of statistically significant species are shown on top of ordination. Light grey: $p < 0.05$, grey: $p < 0.01$, black: $p < 0.001$.

Conclusions

There were marked differences in biodiversity and community distribution between the sea areas, and some species communities were only present in limited areas. Future monitoring efforts need to consider this spatial variability in its design. This can be supported by using the clustered areas identified here.

It is important to include different kinds of communities into the sampling design of any future monitoring efforts to sufficiently cover the biodiversity along the Finnish coast. At the same time, it is also important to take into account in any analysis that some of the census sites differ naturally and may respond differently to environmental changes. This is true especially in the least saline parts, the Quark and the Bothnian Bay, that are already now dominated by freshwater plants and thus may not respond to possible future changes in salinity. These same areas, on the other hand, are predicted to warm more than the southern coast, and changes in the length of growing season or ice conditions might be seen best in these areas.

References

Elith J, Leathwick JR, Hastie T (2008) A working guide to boosted regression trees. Journal of Animal Ecology 77:802–813. doi: 10.1111/j.1365-2656.2008.01390.x

Forsblom L, Virtanen EA, Arponen H, Boman R, Haapamäki J, Hoikkala J, Kallio N, Karvinen V-J, Kaskela A, Keskinen E, Kuismanen L, Kurvinen L, Laine AO, Lanki M, Lampinen E, Lappalainen J, Lehtonen P, Nieminen A, O'Brien K, Riihimäki A, Rinne H, Salovius-Lauren S, Takolander A, Weckström K, Viitasalo M (2024) Finnish inventory data of underwater marine biodiversity. Sci Data 11:1297. doi: 10.1038/s41597-024-04092-4

Kiviluoto S (2013) Rapport nr 135: Kartering och klassificering av undervattensmiljöer samt tillämpning av informationen på den regionala planeringen. NANNUT-projektet på Åland 2010-2012.

Kotilainen A, Kiviluoto S, Kurvinen L, Sahla M, Ehrnsten E, Laine A, Lax HG, Kontula T, Blankett P, Ekebom J (2018) The Baltic Sea. In: Kontula T, Raunio A (eds) Threatened Habitat Types in Finland 2018. Red List of Habitats, Part II: the Habitat Descriptions. The Finnish Environment Institute and the Ministry of the Environment 5/2018, pp 99–183

LajiGIS (2024) Species information management system, species data. Metsähallitus. Uljas-järjestelmä, Metsähallitus, Luontopalvelut.

Liu C, Newell G, White M (2016) On the selection of thresholds for predicting species occurrence with presence-only data. Ecology and Evolution 6:337–348. doi: 10.1002/ece3.1878

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'hara RB, Simpson GL, Solymos P (2022) vegan: Community ecology package (2.6-4).

Pang SEH, Slik JWF, Zurell D, Webb EL (2023) The clustering of spatially associated species unravels patterns in tropical tree species distributions. Ecosphere 14:e4589. doi: 10.1002/ecs2.4589

R Core Team (2022) R: A language and environment for statistical computing. R Foundation for Statistical Computing.

Rinne H, Björklund C, Hämäläinen J, Häggblom M, Salovius-Laurén S (2019) Mapping Marine Natura 2000 habitats in Åland Final report. Åbo Akademi, Husö biologiska station

Virtanen EA, Viitasalo M, Lappalainen J, Moilanen A (2018) Evaluation, Gap Analysis, and Potential Expansion of the Finnish Marine Protected Area Network. Front Mar Sci 5:402. doi: 10.3389/fmars.2018.00402

Virtanen EA, Kallio N, Nurmi M, Jernberg S, Saikkonen L, Forsblom L (2023) Recreational land use contributes to the loss of marine biodiversity. People and Nature pan3.10444. doi: 10.1002/pan3.10444

Supplementary material

Supplementary table 1. List of species included in the calculations for the species richness maps and for the clustering. Columns include species name, classification used for species richness maps (flora or fauna), as well as indication if the model was included in the clustering.

species	***Clustering***	***Community***
Aglaothamnion_roseum	*Included*	*Flora*
Alisma_wahlenbergii	*Included*	*Flora*
Batrachospermum	*Included*	*Flora*
Battersia_arctica	*Included*	*Flora*
Ceramium_tenuicorne	*Included*	*Flora*
Chorda_filum	*Included*	*Flora*
Cladophora_fracta	*Included*	*Flora*
Cladophora_glomerata	*Included*	*Flora*
Cladophora_rupestris	*Included*	*Flora*
Coccotylus_truncatus_Phyllophora_pseudoceranoides	*Included*	*Flora*
Crassula_aquatica	*Included*	*Flora*
Dictyosiphon_chordaria	*Included*	*Flora*
Dictyosiphon_foeniculaceus	*Included*	*Flora*
Ectocarpus_siliculosus	*Included*	*Flora*
Elachista_fucicola	*Included*	*Flora*
Eudesme_virescens	*Included*	*Flora*
Fucus	*Included*	*Flora*
Furcellaria_lumbricalis	*Included*	*Flora*
Hildenbrandia	*Included*	*Flora*
Hippuris_tetraphylla	*Included*	*Flora*
Macroplea_pubipennis	*Included*	*Flora*
Monostroma_balticum	*Included*	*Flora*
Najas_tenuissima	*Included*	*Flora*
Nitellopsis_obtusa	*Included*	*Flora*
Persicaria_foliosa	*Included*	*Flora*
Polysiphonia_fucoides	*Included*	*Flora*
Potamogeton_friesii	*Included*	*Flora*
Pseudolithoderma	*Included*	*Flora*
Pylaiella_littoralis	*Included*	*Flora*
Rhodochorton_purpureum	*Included*	*Flora*
Rhodomela_confervoides	*Included*	*Flora*
Spongomorpha_aeruginosa	*Included*	*Flora*
Stictyosiphon_tortilis	*Included*	*Flora*
Vaucheria	*Included*	*Flora*
Amphibalanus_improvisus	*Included*	*Fauna*
Anodonta_anatina	*Included*	*Fauna*
Bithynia_tentaculata		*Fauna*
Boccardiella_ligerica		*Fauna*
Bylgides_sarsi		*Fauna*

Chironomidae	*Included*	*Fauna*
Cordylophora_caspia	*Included*	*Fauna*
Corophium_volutator		*Fauna*
Cyanophthalma_obscura		*Fauna*
Dreissena_polymorpha	*Included*	*Fauna*
Einhornia_crustulenta	*Included*	*Fauna*
Fabricia_stellaris		*Fauna*
Gammarus_oceanicus		*Fauna*
Gammarus_salinus		*Fauna*
Gammarus_zaddachi		*Fauna*
Gonothyraea_loveni	*Included*	*Fauna*
Halicryptus_spinulosus		*Fauna*
Hediste_diversicolor		*Fauna*
Hydra	*Included*	*Fauna*
Hydrobiidae		*Fauna*
Hydrozoa		*Fauna*
Idotea_balthica		*Fauna*
Idotea_chelipes		*Fauna*
Jaera_albifrons		*Fauna*
Jaera_praehirsuta		*Fauna*
Leptocheirus_pilosus		*Fauna*
Limapontia_capitata		*Fauna*
Limecola_balthica	*Included*	*Fauna*
Lymnaeidae		*Fauna*
Macroplea_pubipennis		*Fauna*
Manayunkia_aestuarina		*Fauna*
Marenzelleria		*Fauna*
Monoporeia_affinis		*Fauna*
Mya_arenaria	*Included*	*Fauna*
Mytilopsis_leucophaeata	*Included*	*Fauna*
Mytilus_trossulus	*Included*	*Fauna*
Neomysis_integer		*Fauna*
Oligochaeta		*Fauna*
Peringa_Ecrobia		*Fauna*
Pisidium_sphaerium	*Included*	*Fauna*
Planorbidae		*Fauna*
Pontoporeia_femorata		*Fauna*
Potamopyrgus_antipodarum		*Fauna*
Pygospio_elegans		*Fauna*
Rhithropanopeus_harrisii		*Fauna*
Saduria_entomon		*Fauna*
Theodoxus_fluviatilis		*Fauna*
Turbellaria		*Fauna*
Valvatidae		*Fauna*
Acrosiphonia_arcta	*Included*	*Flora*
Aegagropila_linnaei	*Included*	*Flora*

Alisma_plantagoaquatica	*Included*	*Flora*
Audouinella	*Included*	*Flora*
Beggiatoa_sp	*Included*	*Fauna*
Bolboschoenus_maritimus	*Included*	*Flora*
Butomus_umbellatus	*Included*	*Flora*
Callitriche_hermaphroditica	*Included*	*Flora*
Callitriche_palustris	*Included*	*Flora*
Caltha_palustris	*Included*	*Flora*
Ceratophyllum_demersum	*Included*	*Flora*
Chara_aspera	*Included*	*Flora*
Chara_baltica	*Included*	*Flora*
Chara_canescens	*Included*	*Flora*
Chara_globularis	*Included*	*Flora*
Chara_tomentosa	*Included*	*Flora*
Chara_virgata	*Included*	*Flora*
Drepanocladus_aduncus	*Included*	*Flora*
Drepanocladus_sordidus	*Included*	*Flora*
Elatine_hydropiper	*Included*	*Flora*
Eleocharis_acicularis	*Included*	*Flora*
Eleocharis_mamillata	*Included*	*Flora*
Eleocharis_palustris	*Included*	*Flora*
Eleocharis_parvula	*Included*	*Flora*
Eleocharis_uniglumis	*Included*	*Flora*
Elodea_canadensis	*Included*	*Flora*
Ephydatia_fluviatilis	*Included*	*Flora*
Equisetum_fluviatile	*Included*	*Flora*
Fissidens_fontanus	*Included*	*Flora*
Fontinalis_antipyretica	*Included*	*Flora*
Fontinalis_dalecarlica	*Included*	*Flora*
Fontinalis_hypnoides	*Included*	*Flora*
Hippuris_vulgaris	*Included*	*Flora*
Isoetes_echinospora	*Included*	*Flora*
Isoetes_lacustris	*Included*	*Flora*
Lemna_minor	*Included*	*Flora*
Lemna_trisulca	*Included*	*Flora*
Limosella_aquatica	*Included*	*Flora*
Lysimachia_maritima	*Included*	*Flora*
Lysimachia_thyrsiflora	*Included*	*Flora*
Monostroma_grevillei	*Included*	*Flora*
Myriophyllum_alterniflorum	*Included*	*Flora*
Myriophyllum_sibiricum	*Included*	*Flora*
Myriophyllum_spicatum	*Included*	*Flora*
Myriophyllum_verticillatum	*Included*	*Flora*
Najas_marina	*Included*	*Flora*
Nitella_flexilis	*Included*	*Flora*
Nitella_wahlbergiana	*Included*	*Flora*

Nuphar_lutea	*Included*	*Flora*
Nymphaea_alba	*Included*	*Flora*
Oxyrrhynchium_speciosum	*Included*	*Flora*
Phragmites_australis	*Included*	*Flora*
Polysiphonia_fibrillosa	*Included*	*Flora*
Potamogeton_alpinus	*Included*	*Flora*
Potamogeton_berchtoldii	*Included*	*Flora*
Potamogeton_gramineus	*Included*	*Flora*
Potamogeton_natans	*Included*	*Flora*
Potamogeton_obtusifolius	*Included*	*Flora*
Potamogeton_perfoliatus	*Included*	*Flora*
Potamogeton_pusillus	*Included*	*Flora*
Potamogeton_x_nitens	*Included*	*Flora*
Ranunculus_baudotii	*Included*	*Flora*
Ranunculus_circinatus	*Included*	*Flora*
Ranunculus_confervoides	*Included*	*Flora*
Ranunculus_reptans	*Included*	*Flora*
Ranunculus_schmalhausenii	*Included*	*Flora*
Rivularia	*Included*	*Fauna*
Ruppia_maritima	*Included*	*Flora*
Ruppia_spiralis	*Included*	*Flora*
Sagittaria_sagittifolia	*Included*	*Flora*
Sagittaria_x_lunata	*Included*	*Flora*
Schoenoplectus_lacustris	*Included*	*Flora*
Schoenoplectus_tabernaemontani	*Included*	*Flora*
Sparganium_emersum	*Included*	*Flora*
Sphacelaria	*Included*	*Flora*
Spirogyra	*Included*	*Flora*
Stuckenia_filiformis	*Included*	*Flora*
Stuckenia_pectinata	*Included*	*Flora*
Subularia_aquatica	*Included*	*Flora*
Tolypella	*Included*	*Flora*
Triglochin_maritima	*Included*	*Flora*
Typha_latifolia	*Included*	*Flora*
Ulothrix	*Included*	*Flora*
Ulva	*Included*	*Flora*
Utricularia	*Included*	*Flora*
Zannichellia_major	*Included*	*Flora*
Zannichellia_palustris	*Included*	*Flora*
Zostera_marina	*Included*	*Flora*
Zygnema_sp	*Included*	*Flora*