Nordic Council of Ministers

Sustainable levels of human activities

in the Nordic marine environment

Authors

Samuli Korpinen[1*], Antti Takolander[1], Zandra Gerdes[2], Jesper H. Andersen[3], Ciaran J. Murray[3], Nathalie B. Zak[3], Antonia Nyström Sandman[2], Pinja Pelkonen[3] & Jacob Carstensen[4]

*) contact email: samuli.korpinen@syke.fi

1) Finnish Environment Institute (Syke)

2) NIRAS Sweden AB

3) Norwegian Institute for Water Research (NIVA)

4) Aarhus University, Department of Ecoscience

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This publication is also available online in a web-accessible version at:
https://pub.norden.org/temanord2024-555

Introduction

Coastal and marine ecosystems are under pressure from various human activities, which exert direct and indirect impacts on underwater biota.[1] To apply relevant management policies on human activities, detailed information on ecological impacts of the activities is urgently needed. Ecological systems are often subject to non-linear dynamics and change points, where an external pressure may lead to abrupt changes in community composition. This poses a challenge for sustainable management of human activities. The European environmental legislation and HELCOM policy objectives aim at environmentally sustainable levels of human activities and uses, which enable good environmental status of the marine environment.

While eutrophication remains the main impact factor on the Nordic coastal areas and the Baltic Sea,[2][3] other human pressures, such as bottom trawling, dredging, shipping, boating and costal land use have significant effects on underwater flora and fauna. Many of these types of pressures typically occur in coastal waters which also host more diverse and productive underwater wildlife than offshore areas.

In the COMA project (Cumulative pressure and impact studies supporting marine management and assessment), the impacts of human activities and pressures on marine ecosystem were analysed from three different viewpoints: (1) What is the evidence of ecosystem responses to single and multiple pressures? (2) How do different human activities impact the marine ecosystem? and (3) What is the evidence of sustainable levels of human activities? These objectives are supported by quantitative analyses and reviews of existing studies in the region.

The ultimate goal of this report is to provide guidance for marine management. It provides evidence of the most impacting activities on marine environment and supports managers in evaluating the impacts of these activities.

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1. Korpinen et al. (2021) Combined effects of human pressures on Europe's marine ecosystems. Ambio 50:1325–1336, https://doi.org/10.1007/s13280-020-01482-x
2. OSPAR (2023) Quality Status Report 2023. https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/
3. HELCOM (2023) HELCOM Thematic assessment of spatial distribution of pressures and impacts 2016- 2021. Baltic Sea Environment Proceedings No. 189

Marine ecosystem responses to cumulative anthropogenic pressures

The state of the marine environment relates negatively to increasing cumulative impacts, as assesed using different cumulative impact assessment (CIA) models. The CIAs made for the Baltic Sea,[4][5][6] to the North Sea[7][8][9] and for Europe's seas[10] indicate indirect evidence of the potential impacts of multiple pressures on marine ecosystems. This is supported by literature reviews and consequent conceptual models.[11][12][13]

There is strong evidence of the power of the CIAs to predict the state of the marine environment (Figure 1). European Environment Agency's Marine Messages II report assessed the state of Europe's seas by the integrated assessment tool BEAT+ and cumulative impacts exerted by 14 anthropogenic pressures on 31 ecosystem components.[14] Even with the poor data availability from many Europe's marine areas, higher values of the cumulative impact assessment (CIA) indicated poorer state of marine ecosystem (Figure 1 filled symbols). A comparison with the ecological status of coastal waters, showed a similar response (Figure 1 empty symbols). The negative relationship is also visible on national scale, as shown for Denmark (Figure 1 (squares) and in the Estonian, Finnish and Swedish marine area.[15]

4. Korpinen et al. (2012) Human pressures and their potential impact on the Baltic Sea ecosystem. Ecological Indicators 15:105–114.
5. Hammar et al. (2020) Cumulative impact assessment for ecosystem-based marine spatial planning. Science of the Total Environment 734: 139024.
6. HELCOM (2023): HELCOM Thematic assessment of spatial distribution of pressures and impacts 2016–2021. Baltic Sea Environment Proceedings No. 189.
7. Andersen et al. (2020) Relative impacts of multiple human stressors in estuaries and coastal waters in the North Sea-Baltic Sea transition zone. Science of The Total Environment 704, https://doi.org/10.1016/j.scitotenv.2019.135316
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10. Korpinen et al. (2021) Combined effects of human pressures on Europe's marine ecosystems. Ambio 50:1325–1336, https://doi.org/10.1007/s13280-020-01482-x
11. OSPAR (2023) Quality Status Report 2023. https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/
12. HELCOM (2023) HELCOM Thematic assessment of spatial distribution of pressures and impacts 2016–2021. Baltic Sea Environment Proceedings No. 189.
13. Laamanen et al. (2021) Impacts on seabed: Approaches for assessment as step towards successful measures. HELCOM ACTION report. Available at: https://helcom.fi/helcom-at-work/projects/action/
14. Reker et al. (2019) Marine messages II – Navigating the course towards clean, healthy and productive seas through implementation of an ecosystem-based approach. EEA Report No 17/2019.
15. Herkül & Martin (2017) Cross-comparison of environmental assessments and pressures. Task 4.2.3 Report of the HELCOM SPICE project. Available at: https://helcom.fi/helcom-at-work/projects/spice/

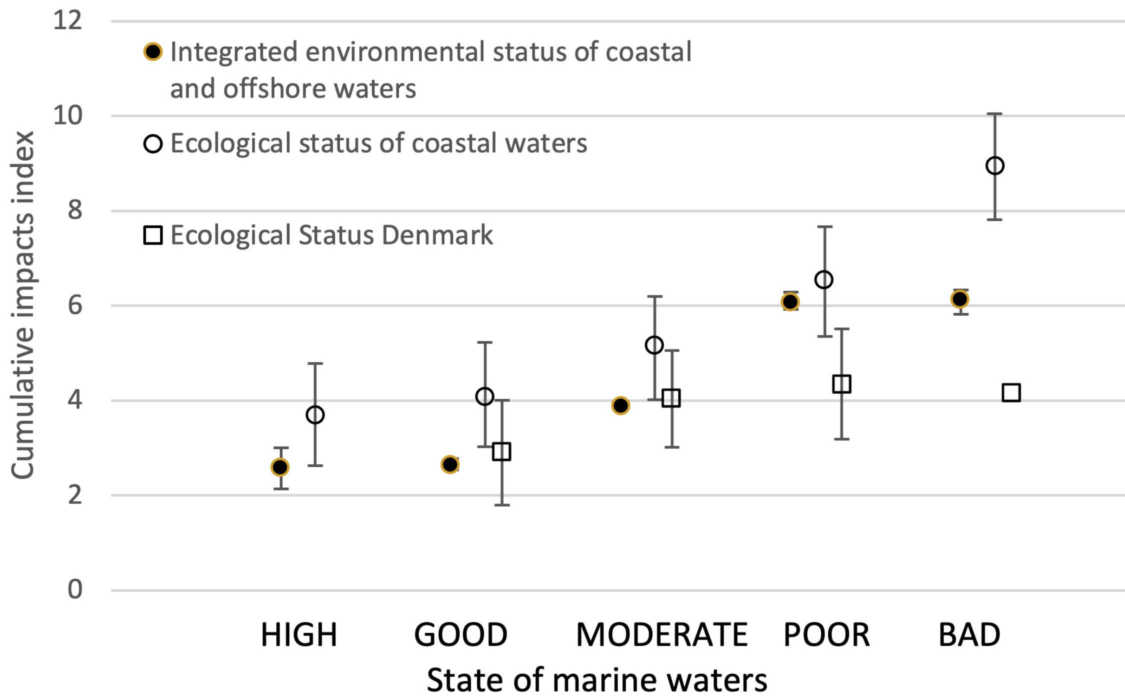

Figure 1. Relationship between cumulative pressures and the state of marine environment. The state classifications follow the ecological status of coastal waters by the EU Water Framework Directive (empty circles for the whole EU and empty squares for Denmark; data source: WISE Freshwater) and the marine assessment by European Environment Agency in 2019 (filled circles). The definition of coastal waters follows EU Water Framework Directive, and the outer boundaries of offshore waters are defined by European Environment Agency. The cumulative impacts index includes 14 anthropogenic pressures impacting the marine ecosystem, as listed in EU Marine Strategy Framework Directive (Annex III). Source: Reker et al. 2019 and COMA project.

Differences in pressures impacting the Nordic seas

Direct evidence of the negative impacts of anthropogenic pressures on marine ecosystems has accumulated over decades of research in the Nordic marine areas. Evidence of the pressure impacts on marine species populations, seabed and plankton communities is strong. The pressures can be divided according to their:

- impact severity, i.e., how strong impacts are found in the core zone and wider,
- spatial extent, i.e., how widely they impact the marine area from the pressure source, and
- duration, i.e., how long the pressure remains in the area after an activity has ended.

These three factors cause very different end-results in the marine environment. For instance, the very severe impact from dredging on the benthic flora and fauna is limited to a relatively small area outside the activity and hence its overall significance in a regional scale is not high. In contrast, discharges of nutrients and hazardous substances to the marine environment do not cause acute impacts but their spatial extent is very wide, and the pressure remains in the system for a long time. These two pressures are assessed as the main problems in the Baltic Sea.[16] The pressure duration is a significant factor from a management point of view; pressures that disappear from the system quickly, e.g. underwater noise from human activities, will not pose long-term impacts that are complicated to mitigate in future.

Pressures spread over large areas and long time

The most severe impacts can be expected from pressures that spread wide and last long in the environment. Substance flows – nutrients, organic matter, hazardous substances or microlitter – from the catchment area have the potential to be widespread and longlasting if the receiving sea area is limited by depth or water exchange such as the Baltic Sea or any fjords or bays of similar geography.

16. HELCOM (2023) HELCOM Thematic assessment of spatial distribution of pressures and impacts 2016–2021. Baltic Sea Environment Proceedings No. 189.

The greatest pressures in the Baltic Sea marine environment are inputs of nutrient and organic matter causing eutrophication and hazardous substances[16]. These are also recognized as the main pressures that prevents the good ecological status under the EU Water Framework Directive (WFD) in the Baltic Sea coastal waters.[17]

As the management advice to input of nutrients and hazardous substances is well known in the Baltic Sea, this report does not focus on these. In addition to the HELCOM nutrient reduction targets, other quantitative evidence exists of the adverse effects of eutrophication-related pressures (e.g. oxygen, turbidity, suspended solids).[18]

Pressures causing acute impacts

Severe impacts caused by anthropogenic pressures are also called acute impacts.[19] Table 1 provides a summary of human activities causing severe impacts. The summary is from a review covering 446 impact estimates from130 published studies.[20] Most of the activities listed in Table 1 are spatially limited, but some of the activities are both acute/severe and widely spread. These are towed fishing gears (trawls, seines and longlines) and maritime traffic.

17. Laamanen et al. (2021) Impacts on seabed: Approaches for assessment as step towards successful measures. HELCOM ACTION report. Available at: https://helcom.fi/helcom-at-work/projects/action/
18. Virtanen et al. (2018). Task 4.2.1 Definition of adversely affected habitats. HELCOM SPICE. Available from https://helcom.fi/helcom-at-work/projects/spice/
19. Goodsir et al. (2015) A spatially resolved pressure-based approach to evaluate combined effects of human activities and management in marine ecosystems. ICES Journal of Marine Science72: 2245–2256.
20. Korpinen et al. (2018) Estimating physical disturbance on seabed – Baltic Sea Environment Proceedings No. 164.

Table 1. Human activities causing severe and acute impacts on marine ecosystem. Modified from Korpinen et al. 2018 (Estimating physical disturbance on seabed – Baltic Sea Environment Proceedings No. 164).

Sector	Activity
Fisheries and mariculture	Finfish mariculture, Shellfish mariculture
Energy production	Wind energy production (especially construction), Wave energy production, Cable placement, Pipelines (incl. placement), Oil and gas industry infrastructure (Oil platforms)
Extraction of non-living resources	Extraction of metal ores, Extraction of sand and gravel
Extraction of living resources	All kinds of towed fishing gear (trawls, seines, long-lines, etc), gillnets, recreational rod fishing, pots and traps,
Tourism and recreation	Beach replenishment/nourishment, Tourism and leisure infrastructure (piers, marinas, slipways)
Transport	Ferry and ship traffic, Ferry and ship ports, Fishing harbours, Bunkering points at sea, Oil terminals, Bridges, Causeways, Dredging of shipping lanes; Deposit of dredged material
Other shoreline modifications	Permanent land claim (urban, industrial, agriculture purposes), Large-scale water deviation, Canalisation, Culverting/trenching, Coastal dams, weirs, Sea walls, Breakwaters, Groynes, Flood protection, Tidal barrages
Other seabed modifications	Artificial reefs and islands, Small-scale dredging (Capital/ maintenance)

How specific human activities impact the marine ecosystem

Sea and shore-based human activities preventing good ecosystem state

The pressures *Hydromorphological alteration*, *Physical alteration of bed/shore by navigation* and *Physical alteration of bed/shore by flood protection* are the major physical pressures in the Baltic coastal waters according to the WFD reporting of the EU member states. Dredging for recreational, construction or navigational purposes is the main activity causing this pressure in the region.[21]

The HELCOM holistic assessment indicates that physical disturbance to the seabed is significantly higher in the southern areas. While this geographical difference between areas is clear, more interesting are the activities causing this difference. Re-calculation of the HELCOM data shows that the mobile bottom-contacting fishing gears cause the highest proportion of the physical disturbance in the southern Baltic Sea (south of Gotland), dredging (both small-scale dredging and regulated dredging) is a major contributor in the northern parts, and shipping in shallow areas is a major contributor in all the sea areas.[22]

COMA meta-analysis of seabed impacts from human activities

A meta-analysis of 132 studies of human impacts on the seafloor indicates clear differences in severity of human activities. The database included 1066 observed results of various impacts which are replicated and include control measurements. We analysed separately the responses of marine benthic animals and underwater macrophytes.

Seven out of nine human activities caused predominantly negative impacts on benthic fauna abundance in the northern cool temperate region (Fig. 2). The most impacting activities were maritime traffic, shoreline structures, bottom trawling, dredging and disposal of dredged spoils. Positive impacts on fauna abundance were seen from mariculture and offshore structures. The smaller sample size of the Baltic Sea studies showed comparable results (Fig. 2).

21. HELCOM (2023) HELCOM Thematic assessment of spatial distribution of pressures and impacts 2016–2021. Baltic Sea Environment Proceedings No. 189.
22. Laamanen et al. (2021) Impacts on seabed: Approaches for assessment as step towards successful measures. HELCOM ACTION report. Available at: https://helcom.fi/helcom-at-work/projects/action/

The underwater vegetation in the northern cool temperate region was impacted most strongly by plant removal, bottom-trawling, shoreline structures, mariculture, boat traffic, anchoring and dredging (Fig. 2). The Baltic Sea results showed the same pattern.

The responses are however species-specific and highest for eelgrass (*Zostera marina*), charophytes (*Chara* spp.) and the sea pen *Pennatula phosphorea.*[23]

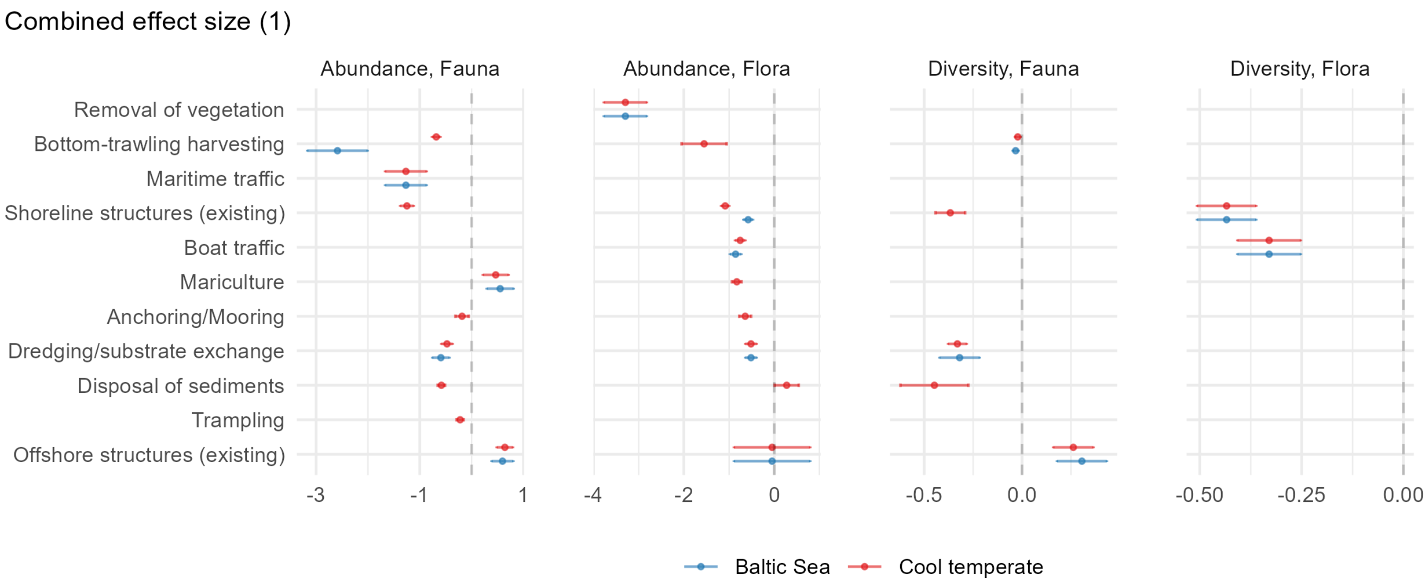

Figure 2. Responses (mean effect size and SD) of fauna and flora abundance and diversity to human activities in the Baltic Sea and the cool temperate region of the northern hemisphere.

COMA case study: Depth limit of eelgrass in response to eutrophication and mussel dredging

Eelgrass meadows in shallow coastal waters are under threat from several pressures, including eutrophication, climate change and physical disturbance. Krause-Jensen et al. (2021) conceptualised three main pressures on eelgrass meadows in shallow waters, where deeper eelgrass populations are shaded out by reduced light transparency caused by eutrophication and physically destroyed by bottom trawling while shallower eelgrass populations are vulnerable to warming and heat waves. The COMA case study exemplifies this by data from Nibe-Gjøl Bredning (Limfjorden), an estuarine complex in northern Denmark.

23. Nyström Sandman et al. (2024) Mänsklig påverkan och effekter på bentisk miljö. Metoder för bedömning av havsbottnens integritet i svenska hav. Naturvårdsverket (in preparation).

The depth limits of eelgrass in Nibe-Gjøl Bredning decreased from 1989 to around 2000 as a result of decreased water transparency caused by high nitrogen and phosphorus concentrations in the area (Fig. 3A). While the eutrophication stabilized, the depth limit degraded as a result of mussel harvesting starting in the area (Figure 3B). The mussel dredges caused high physical disturbance and sediment resuspension, which reduced the colonisation depths. Recolonisation at deeper depth occurred approximately 4–5 years after mussel dredging ceased. Eelgrass cover in the nearshore waters did not indicate high sensitivity to warming; neither to a general warm summer with a high average temperature or to shorter heatwaves indicated by high maximum temperature.

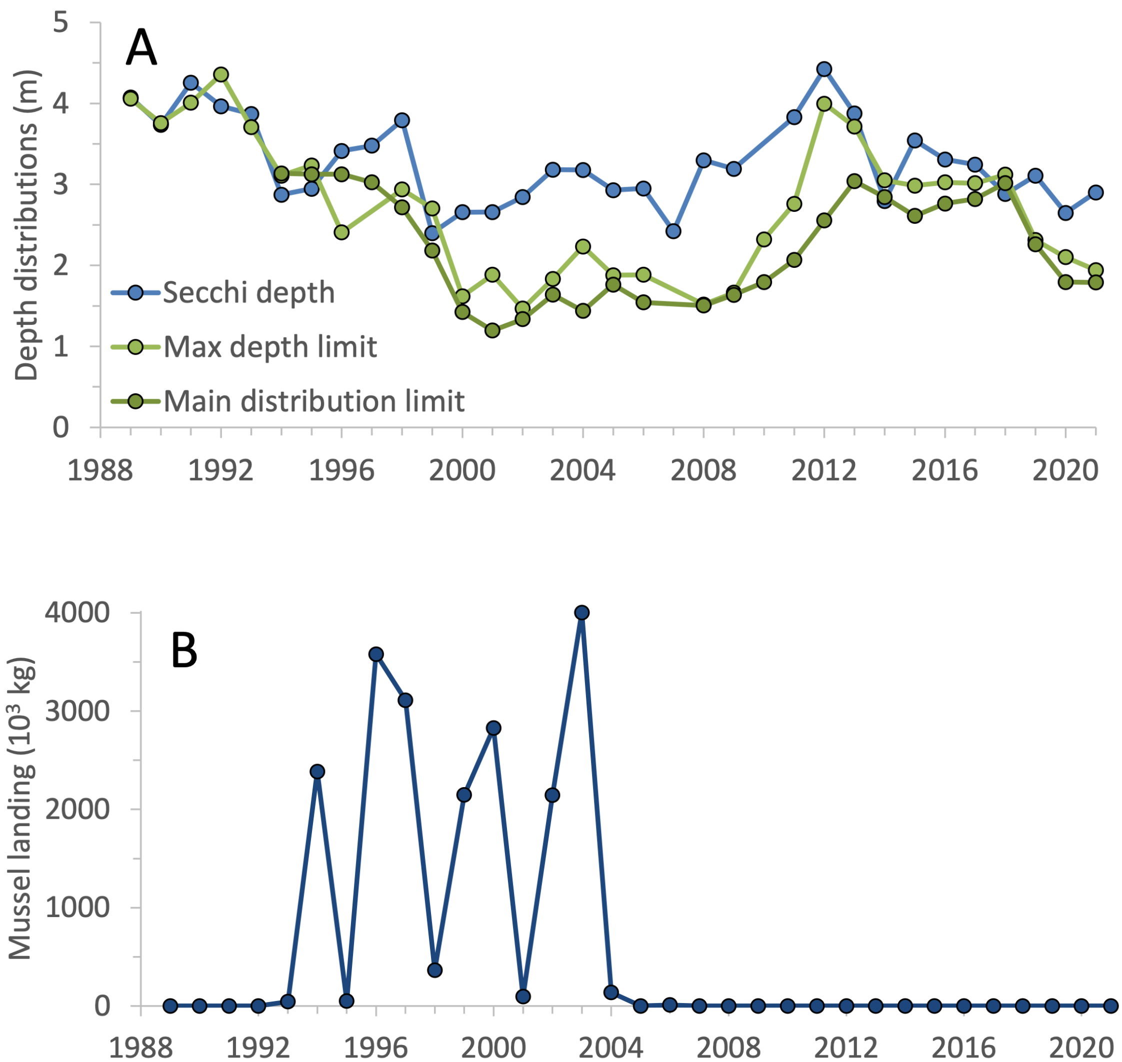

Figure 3. Trends in Nibe-Gjøl Bredning for A) eelgrass depth limits and Secchi depth, B) mussel landings from the area.

COMA case study: Impacts of eutrophication, boating and dredging on Finnish reef and lagoon vegetation

Underwater reefs and lagoons along the Finnish coast host substantial biological diversity, but are at the same time subjected to multiple interacting human pressures. Eutrophication increases sedimentation and reduces photic depth, resulting in reduced macrophyte cover at deeper depths and altered species composition. While eutrophication persists as a regional problem, human activities have local adverse effects on the ecosystem. In this case study, five different vegetation indicators were tested for evaluating impacts of eutrophication, boating and dredging.

In reefs, eutrophication had substantially strongest effect on four vegetation indicators calculated: macroalgal diversity, deepest macrophyte depth, depth of 10% macroalgal cover, and macrophyte quality index. The macroalgae indicators on reefs were positively associated with increasing Secchi depth and negatively with increasing total phosphorus.

In lagoons, both eutrophication and boating had a negative significant effect on macrophyte quality index which also characterises the vulnerable species of underwater flora (Fig 4). Surprisingly, the effects of dredging were non-significant, even though exploratory analyses showed otherwise.

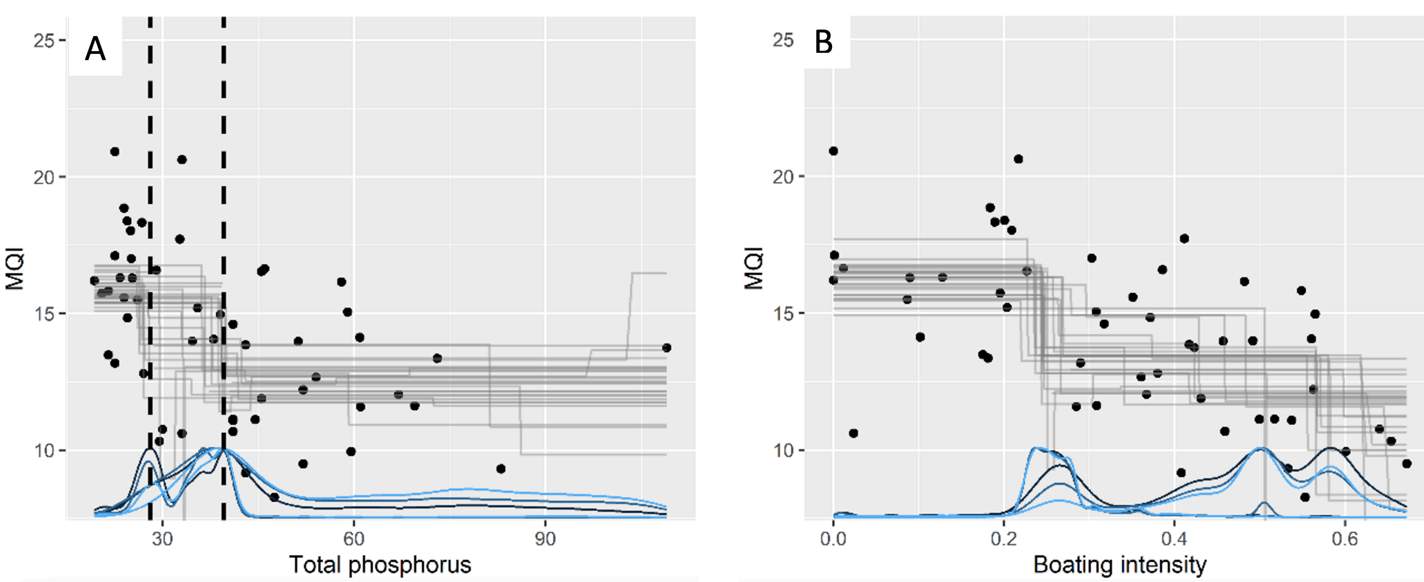

Figure 4. Change points on Macrophyte Quality Index (MQI) in a lagoon along the gradient of June total phosphorus concentration (left) and boating intensity (right). Gray lines are draws from posterior fit and colored density curves represent the posterior densities of the estimated change points. Dashed lines in panel A are modes of estimated first change point posterior density.

Evidence for the sustainable levels of human activities

Based on the findings of the case studies in this report and the recent scientific studies,[24][25][26] we summarize the existing knowledge of the change points which may represent the level where sustainability can be achieved.

Dredging

Four observations of capital dredging impacts: (1) the core zone impacts are lethal, (2) the pressure increase (i.e. sedimentation and turbidity) is not linear but logarithmic (i.e. high pressures occur already at low activity levels and an increase in activity only marginally effects the pressure), (3) the turbidity pressure decreases away from the 'core zone', and (4) the turbidity pressure is mostly limited to within 2 km distance. A macrofauna community index (BBI) indicates that already low levels of dredging (7–9 mg L^{-1} suspended solids or turbidity of 5–8 NTU) decrease the state of the community, resulting in ecological status less than good. In enclosed and semi-enclosed bays charophyte meadows and number of sensitive species start declining in turbidity >2.5 NTU or >2–3 mg CDOM L^{-1}. Charophyte-dominated enclosed bays exhibit a change-point even at 1–2 NTU. In open coasts, there can be more (5–6 mg L^{-1}) suspended solids in water. In general, it can be stated that dredging leads to loss of sensitive species in enclosed and semi-enclosed bays.

Disposal of dredged matter

A lethal pressure for all biota which are buried, but some thresholds can be presented for sedimentation and turbidity to the nearby impact areas. On naturally hard surfaces even 1–2 cm of sediment cover will kill the sessile macrofauna and 2.4 g dw sediment per dm^2 (3 mm layer) prevents *Fucus serratus* recruitment (healthy *F. serratus* stands had sediment <0.25 mm or 0.2 g dw dm^{-2}). The effects of sedimentation are seen as mortality and changes in the population structure of benthic organisms, e.g. resulting in a *Macoma balthica* population with only large individuals, reduced herring spawning (50% mortality at 1 km distance from disposal site) and reduced coverage and lacking colonization in bladderwrack at a

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24. Laamanen et al. (2021) Impacts on seabed: Approaches for assessment as step towards successful measures. HELCOM ACTION report. Available at: https://helcom.fi/helcom-at-work/projects/action/
25. Virtanen et al. (2018). Task 4.2.1 Definition of adversely affected habitats. HELCOM SPICE. Available at: https://helcom.fi/helcom-at-work/projects/spice/
26. Korpinen et al. (2018) Estimating physical disturbance on seabed – Baltic Sea Environment Proceedings No. 164.

distance of 2 km from the disposal site. Estimates of the time to re-establish the macrozoobenthic community can be a few years or at least 5 years depending on whether condition is determined, respectively, univariate indices or by multivariate analyses of species composition. The magnitude of change in the macrozoobenthic community will depend on how closely the dumped material mounds resemble the natural seafloor in terms of e.g. grain size, organic content and consistency.

Sand and gravel extraction

The mechanism of impact is similar to dredging, but the resuspended material is often heavier and deposits at shorter distances. Half of the macrofauna dies at a distance of 0.4–1 km from the extraction site, but it is also assessed that ecological status of macrofauna community is not impaired over 0.5 km from the sand extraction site. Full recovery of biota takes more than 10 years whilst the topography is permanently impacted.

Shipping and ferry traffic

Impacts of ships and ferries depend on both speed of vessels and frequency of shipping. In shallow areas and inside archipelagos, abrasion stirs up sediment causing concentrations of suspended solids over 8 mg L^{-1}. Impacts of 10 ferries per day can be up to 55% increase in turbidity, circa 31% decrease in plant species richness, 29% decrease in vegetation cover, 38–100% decrease of sensitive plant species coverage and 38–39% increase in coverage of plant species indicating eutrophication. Sensitive macrophyte species are impacted up to 700 m from ferry routes.

Marinas

Marinas of recreational boats cause, on average, a 135% increase in turbidity, 31% decline in vegetation cover, 37% decline in plant species richness, 10–82% decline in coverage of sensitive macrophyte species and 25–29 % increase of plant species promoted by eutrophication. A marina also negatively affects pike recruitment (89% decrease) and increases catches of fish typically observed under eutrophic conditions, such as bleak.

Motor boating

The primary impact of motor boating is sediment resuspension and the consequent turbidity. This has been reported to cause loss of vegetation along the busiest boating routes. A 10 hp engine causes resuspension at 1.5 m depth, while a 50 hp engine affects the seabed at 4.5 m depth. Sensitive macrophyte species start disappearing if there are 2–5 actively used piers per hectare in a bay. The best mitigation measures are (1) to establish boating routes away from shallow-water areas and (2) set speed limits.

Wind turbine construction and operation

The impact is lethal where the turbine and its base are located on the natural seabed (circa 30 m diameter). Similar impacts are expected when a turbine is deconstructed after its use.

Placement of cables and pipelines

Cables are dug into a trench on a seabed which is then covered by the sediment again. On hard surfaces, the cables can be protected by concrete casings. Pipeline placements follow the similar principles on a larger scale. The impacts are highest at the construction period.

Fishing

Bottom-trawling gears cause significant negative impacts on seabed.[27][28]

Safe distances from pressure impacts

The impacts of pressures decline with distance from the core zone. As shown above, some impacts decline sharply after a change-point. Table 2 shows review results for impact distances beyond which impacts can be assumed negligible. Note, however, that these are maximum (safe) distances and good status of marine ecosystem can be found closer to a pressure core zone.

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27. Hiddink et al. (2017) Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. PNAS 114 (31) 8301-8306, https://doi.org/10.1073/pnas.161885811
28. Hinz et al. (2009) Trawl disturbance on benthic communities: chronic effects and experimental predictions. Ecol Appl 19:761–773.

Table 2. Impact distances from a pressure core zone. Over the impact distance, impacts on the mentioned species or parameters can be estimated as negligible.

Activity	Distance (km)
Capital dredging	4 km (fish), 4 km (charophytes), 4 km (mussels), 3 km (benthos), 3 km (vegetation), 3 km (water turbidity)
Maintenance dredging	4 km (fish), 3 km (benthos), 3 km (vegetation), 3 km (water turbidity)
Sand extraction	5 km (water turbidity), 4 km (fish), 3 km (vegetation), 2 km (benthos)
Disposal of dredged matter	4 km (fish), 3 km (benthos), 2–3 km (vegetation), 2 km (water turbidity), 1–2 km (mussels)
Shipping and ferry traffic	1 km (fish), 1 km (water turbidity, 30 m in depth), 0.7 km (vegetation), 0.3 km abrasion (substrate change)
Boating	0.7 km (macroalgae), 0.5 km (water turbidity, 4 m in depth), 0.5 km (sensitive lant species)
Marinas	1 km (charophytes), 0.5 km (fish), 0.5 km (vegetation)
Benthic trawling	0.1 km (siltation)
Wind turbines (operational)	0.1 km (abrasion effect around a turbine)

Conclusions

There is growing evidence that current levels of pressures and human activities cause adverse effects on marine ecosystem. This report has compiled information from previous summaries and made supporting analyses to bring this evidence to a single report.

Management of human activities impacting the marine environment could follow a tiered approach, where:

1. areas of high cumulative impacts in CIAs are hot spots for management (e.g. HELCOM[29])
2. spatio-temporal characteristics of the pressures in the area are estimated (e.g. acute and spatially limited, long-lasting and widespread; see Table 1),
3. severity of the activity is assessed in relation to other activities (e.g. Figure 2),
4. known change points for impacts are assessed (e.g. Figures 3 and 4 and summaries in this report),
5. impact distances are noted (see Table 2).

It may be possible to observe thresholds or change points in ecosystem responses to specific adverse effects of human activities. Using these to determine "safe levels" or "sustainable levels" of human activities is not straightforward since they are associated with great uncertainty, arising from variation in local conditions and in the recipient ecosystem components. Hence, setting a "safe" level for an activity depends on how much risk one is willing to accept.

29. HELCOM (2023) HELCOM Thematic assessment of spatial distribution of pressures and impacts 2016–2021. Baltic Sea Environment Proceedings No. 189.

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TemaNord 2024:555

ISBN 978-92-893-8117-8 (PDF)
ISBN 978-92-893-8118-5 (ONLINE)
http://dx.doi.org/10.6027/temanord2024-555

Cover photo: Florian Rebmann/Unsplash
Published:

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The Nordic Council of Ministers
Nordens Hus
Ved Stranden 18
DK-1061 Copenhagen
pub@norden.org

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