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Author-formatted document posted on 02/07/2025

Published in a RIO article collection by decision of the collection editors.

DOI: https://doi.org/10.3897/arphapreprints.e163734

Causes and consequences of degrading marine communities in the Archipelago Sea

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Causes and consequences of degrading marine communities in the Archipelago Sea

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Abstract
The Archipelago Sea in the northern Baltic Sea suffers from multistressor perturbations, including ones related to local nutrient loading as well as consequences from global climate change. In this study, we use the bow-tie risk analysis framework to examine and illustrate how these drivers, eutrophication and climate change, contribute to biodiversity loss and associated implications of this in the Archipelago Sea. The bow-tie approach indicates both causes and ecological, economic, and social consequences of a problem as well as measures to prevent and mitigate the identified causes and consequences. For the Archipelago Sea, the bow-tie approach illustrated highly interlinked impacts of agriculture and aquaculture-driven eutrophication and climate change in degrading marine communities in the Northern Baltic Sea. Similarly, the consequences of this biodiversity loss were complex and highly interlinked. Many of the marine communities in the study area are highly connected, and as this may propagate the degradation of biodiversity and ecosystem services, future assessments should aim to include both trophic and non-trophic interactions in the bow-tie risk analysis. The study also highlights the need to prevent and mitigate multiple drivers of biodiversity loss simultaneously in order to reduce and stop the ongoing degradation of marine habitats and the ecosystem services they support.

Keywords: eutrophication, climate change, biodiversity loss, ecosystem services, Baltic Sea

Introduction

The Archipelago Sea is a brackish, non-tidal sea that forms a substantial part of the Finnish Baltic Sea coast (Fig. 1). It forms a complex archipelago and ranges from the mainland and inner archipelago with large, forested islands to the mid archipelago with smaller islands, and the outer archipelago with small skerries to the open sea area. The depth ranges from shallow to deep (0-120 m), and the seabed substrate varies from muddy to sandy, coarse and mixed sediments to rock (Fig. 1). This high geodiversity (Kaskela & Kotilainen 2024) provides habitats for reed, seagrasses, macroalgae and biogenic reefs, among others, supporting high biodiversity.

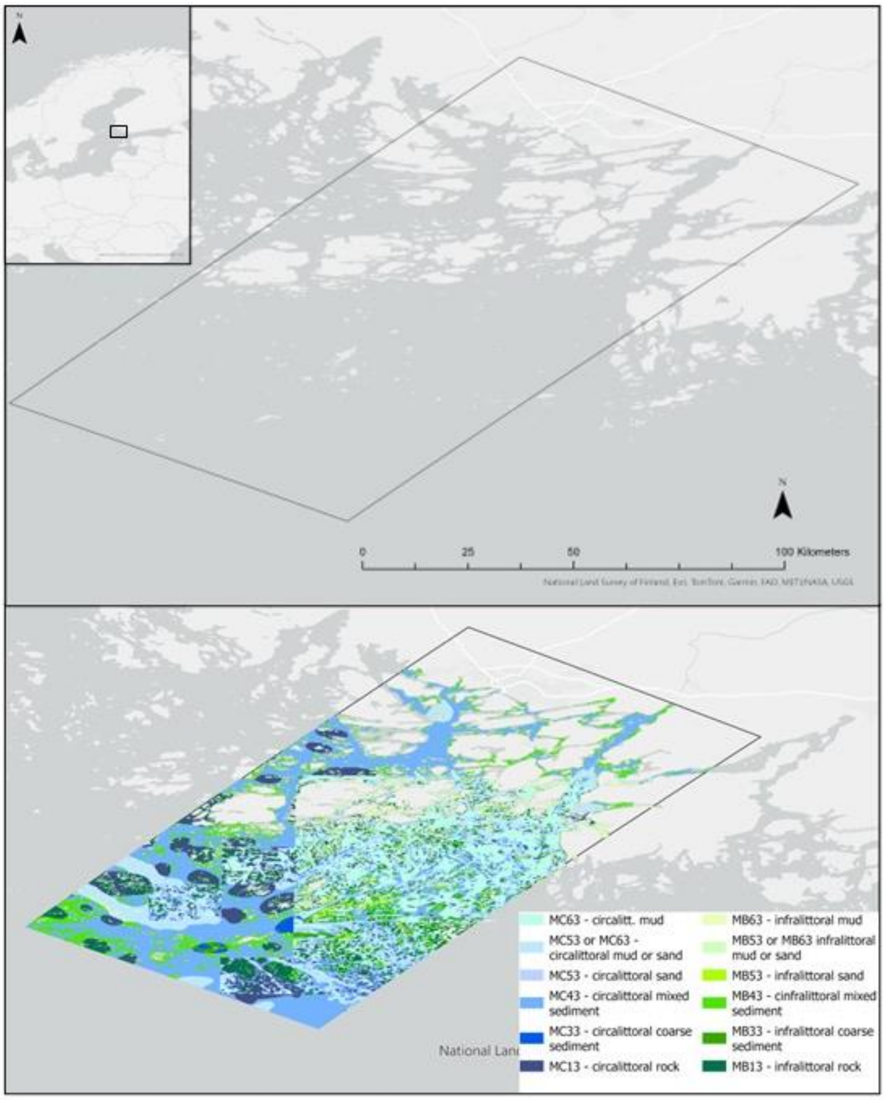

Fig. 1. Map of the study area in the Archipelago Sea, Northern Baltic Sea (top panel), and the seabed substrate types (lower panel). Substrate types are according to the EUNIS level 3 habitat model. The square in the map in the top left corner indicates the placement of the study area in the Baltic Sea.

Due to long-term nutrient pollution, the Archipelago Sea suffers from severe eutrophication, which threatens the environment in the area (HELCOM 2018, 2021). The majority of the nutrients in the Archipelago Sea are transported to the sea from the surrounding land and originate from various anthropogenic sources, such as agriculture (HELCOM 2018). Due to the riverine input of nutrients, the severity of the eutrophication impacts decreases gradually towards the open sea (Salo & Salovius-Laurén 2022). Long-term international governance efforts have succeeded in reducing nutrient input in the Baltic Sea (HELCOM 2023). However, the extensive agricultural run-off to the Archipelago Sea is one of the few remaining HELCOM pollution hot spots in the Baltic Sea (HELCOM 2013). In addition to the riverine input of nutrients, aquaculture contributes to the nutrient pollution with direct releases of nutrients into the sea, with the resulting eutrophication impacts ranging from local to large-scale (Gyllenhammar & Håkanson 2004).

The Baltic Sea is one of the fastest-warming seas in the world (Reusch et al. 2018). In addition to increased annual mean sea surface temperature since 1980s, also sea ice cover has drastically decreased in the past decade. Climate change further increases precipitation in the area, resulting in higher input of nutrients from the drainage area, increases stratification of the water, and impairs oxygen conditions, among others (Meier et al. 2022). Hence, while warming *per se* can have drastic impacts on ecosystems, modifying the structure and functioning of the communities, it simultaneously worsens the eutrophication in the Baltic Sea (HELCOM 2018, Meier et al. 2022).

The Archipelago Sea is a well-studied area, and we here use the bow-tie approach (Elliott et al. 2019) to exemplify the causality between some of the main causes and consequences of degradation of marine communities. We use examples from the literature to illustrate these causal connections. We also identify relevant prevention and mitigation measures to alleviate the loss of biodiversity and related ecosystem services. This approach visualises how drivers of biodiversity loss affect ecosystem services and can aid in identifying how the management of different drivers may benefit humans.

Methodology

In our study area, seven central events linked to degradation of marine communities were identified: 1) loss of *Fucus*-habitats, 2) loss of seagrass habitats, 3) homogenization of benthic fauna, 4) loss of biogenic reefs (*Mytilus*), 5) loss of bird populations, 6) cyanobacteria blooms, and 7) increase in reed (Fig. 2). The major activities and pressures causing the degradation and the identified key consequences of the degradation are listed on the left and right side, respectively, of the central event. The consequences are divided into ecological, economic, and societal consequences. The causality between causes, central events and consequences is indicated with paths (arrows). In addition, key prevention measures that could control the causes and the mitigation measures that may alleviate the consequences are identified for different paths. Prevention measures range from technological improvements to legislative measures to changes in human behaviour. The mitigation measures include knowledge building, protection, restoration and other management aspects (Fig. 2). It should be noted that the bow-tie presented here is not intended to be exhaustive, and that there are relevant central events, activities and pressures, as well as consequences that are not included. Instead, we aim to include major activities and assess central events across multiple trophic levels. To implement the bow-tie approach consistently with parallel efforts across European seas, we apply the standardised vocabulary and classification of each element described by Elliot et al. (*in preparation*).

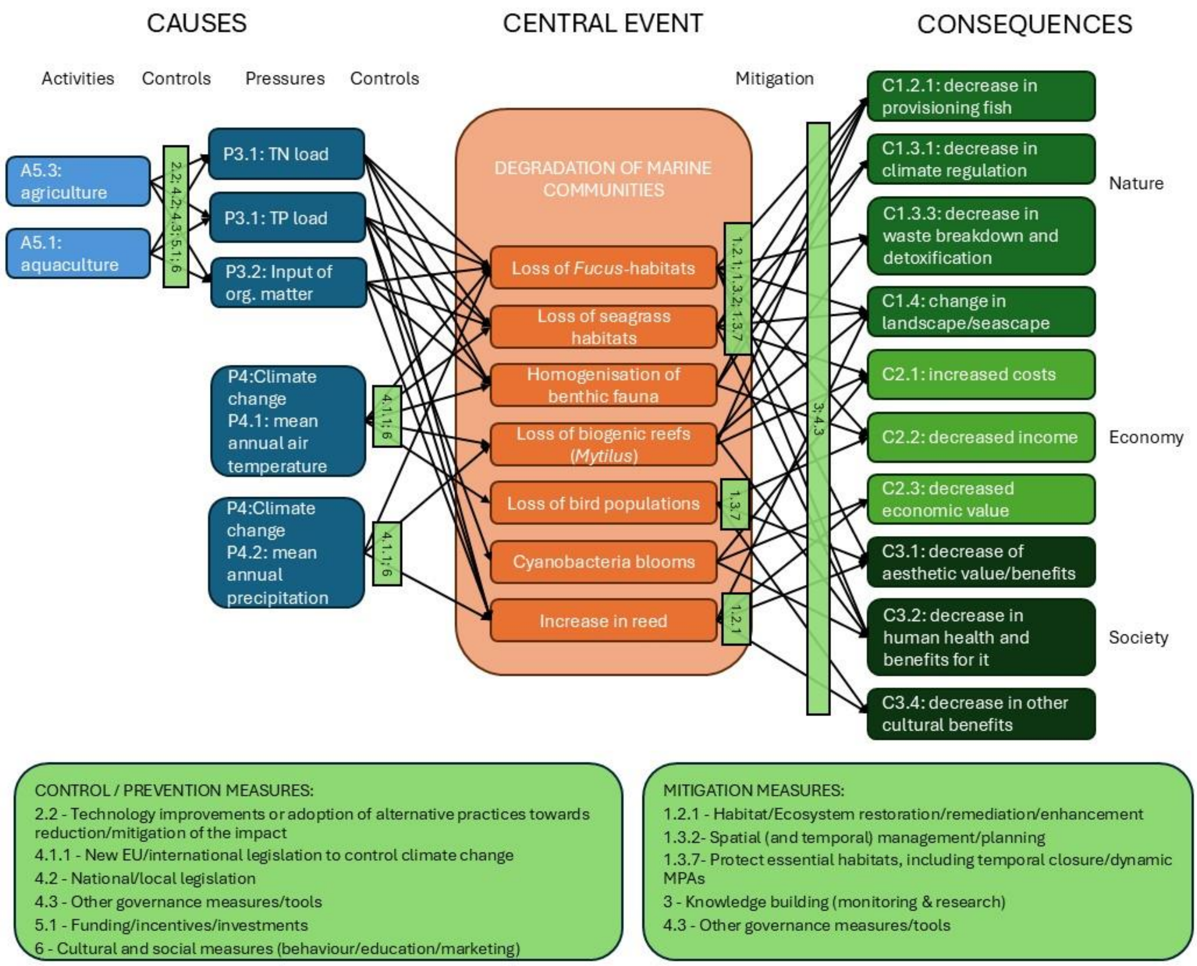

Fig. 2. Bow-tie diagram of the central biodiversity losses, and the causes (left, blue boxes) and consequences (right, green boxes) of these. The consequences on nature, economy and society are marked with different colours. Controls refer to the prevention measures, and mitigation to the mitigation measures listed in the light green boxes below the bow-tie.

Results of bow-tie analysis

The major drivers of degradation of marine communities, eutrophication and climate change, are well known and studied in the area (see introduction). Both drivers have broad impacts on biodiversity, and all identified pressures have negative impacts on several marine communities (Fig. 2, HELCOM 2018, Meier et al. 2022). Similarly, degradation of marine communities contributes to many different consequences, with different degradation events simultaneously contributing to the same consequences. Many of the identified biodiversity degradation events simultaneously link to both ecological, economic, and societal ecosystem services. This emphasises both the importance of marine communities as supporting ecosystem services in the study area and the importance of alleviating the impacts of the causes driving biodiversity loss.

Preventing degradation linked to agriculture and aquaculture (nutrient load and input of organic matter) would benefit from broad measures including adoption of practices to reduce the impact of agriculture and aquaculture (Control 2.2), national legislation (Control 4.2), other governance measures (Control 4.3), investments (Control 5.1) and changes in behaviour, education and marketing (Control 6), (HELCOM 2021). Climate change-induced degradation of marine communities requires international legislation to control climate change (Control 4.1.1) and funding, and incentives or investments to control climate change (Control 5.1) (IPCC 2014, Reusch et al. 2018, IPBES 2019). Specific mitigation measures were determined for some communities (see examples below), but all consequences would require and benefit from knowledge building (Mitigation 3) and governance measures (Mitigation 4.3) (HELCOM 2021).

Loss of Fucus-habitats. Bladderwrack (*Fucus vesiculosus*, henceforth *Fucus*) is a key habitat-forming species in the area supporting diverse communities of invertebrates and fish (Kautsky et al. 1992, Henseler et al. 2019). *Fucus* is an indicator species, and its distribution reflects the status of the sea area. The drastic decrease in *Fucus* in the area since the 1980s has been linked to the eutrophication development of Baltic waters (Rinne & Salovius-Laurén 2020). The increase in nutrients (P3.1 in Fig. 2) increase competition from fast growing ephemeral algae decreasing the area suitable for *Fucus* (Bonsdorff et al. 1997, Rinne & Salovius-Laurén 2020). Nutrients also increase the growth of phytoplankton, decreasing light penetration, and together with the eutrophication-induced increases in particulate and dissolved organic matter (P3.2) concentrations, reduce light levels in water. This results in a decrease in deeper-growing *Fucus* stands (Rinne & Salovius-Laurén 2020) and impairs the settling of *Fucus* germlings on otherwise suitable substrate. *Fucus* is a cold-water, marine species. Hence, increases in temperature (P4.1) and decreases in salinity due to increased precipitation and river run-off (P4.2) likely impair its growth and threaten the *Fucus* habitats (Takolander et al. 2017). As *Fucus* is such a central habitat in the area providing nurseries and food for many commercial fish species (Wikström & Kautsky 2007, Rinne et al. 2022), decreases in it may have both ecological and economic consequences: Decreases in *Fucus* result in decreases in provisioning fish (C1.2.1), decreases in nutrient cycling (C1.3.3), changes in landscape and seascape (C1.4), as well as decreased income (C2.2). *Fucus* is a well-known species that is important for many community members in the region (Salo et al. 2024). Thus, decreases in *Fucus* have societal impacts as it simultaneously decreases the aesthetic value (C3.1) and human health and benefits for it (C3.2). Mitigation measures include restoration (Mitigation 1.2.1), spatial management and planning (Mitigation 1.3.2) and protecting these habitats (Mitigation 1.3.7).

Loss of seagrass habitats. Seagrasses are foundation species that maintain biodiversity, primary production, stabilise sediments, improve water quality and may act as carbon sinks (Orth et al. 2006, Fourqurean et al. 2012). Similarly to *Fucus*, nutrient-induced (P3.1) increased competition from ephemeral algae and phytoplankton degrade seagrass (*Zostera marina*) habitats (Krause-Jensen et al. 2008, Sand-Jensen & Borum 1991). The eutrophication-induced increases in particulate organic matter (P3.2) reduce light levels in water and increase sedimentation in seagrass meadows, risking anoxic conditions for seagrass. Increased temperatures (P4.1) are harmful for seagrass habitats as they impair the oxygen conditions in the meadows and impair growth of seagrass (Pulido & Borum 2010). Given their contributions to the maintenance of high biodiversity, nutrient removal and carbon storage, reductions in seagrass habitats may have vast ecological, economic, and societal consequences. Decreases in seagrass habitats may result in decreases in provisioning fish (C1.2.1), decrease in climate regulation (C1.3.1), increased costs (C2.1), and decrease in human health and benefits for it (C3.2). Mitigation measures include restoration (Mitigation 1.2.1), spatial management and planning (Mitigation 1.3.2) and protecting these habitats (Mitigation 1.3.7).

Homogenisation of benthic fauna. Pollution and climate change modify marine communities through loss of sensitive species and increases in non-native species, among others (Piola & Johnston 2008, Michaud et al. 2022). This environmental filtering may result in more homogeneous communities in an area or region. Indeed, in the current case study area, nutrient pollution (P3.1) and the resulting increase in organic matter (P3.2) have modified marine communities as opportunistic species benefit more from pollution compared to species with slower life cycles or growth (Salo et al. 2023, 2024). As benthic fauna are important nodes in transporting energy to higher trophic levels, among others, the resulting homogenization of benthic fauna risks decreases in fish catches, among others, (C1.2.1) and hence decreased income (C2.2).

Loss of biogenic reefs (Mytilus). Blue mussel (henceforth *Mytilus*) is a key species in the Baltic Sea, and *Mytilus* reefs support high biodiversity (Norling & Kautsky 2008). *Mytilus* is a marine species, and it lives close to its salinity tolerance limit in the study area (HELCOM 2023). *Mytilus* growth decreases with salinity (Maar et al. 2015). Hence, climate change with expected decreases in salinity (P4.2) and increases in water temperature (P4.1) threaten this key species and the ecosystem services it provides. *Mytilus* is a primary consumer, and it filters large amounts of water daily to feed on phytoplankton, among others, simultaneously removing nutrients and pollutants from the water (Dolmer 2000, Petersen et al. 2014). Filtration rate of *Mytilus*, however, decreases with reduced salinity (Riisgård et al. 2014). Hence, in addition to decreased biodiversity, decreased salinity risks also decrease in pollution control (C1.3.3), increased costs (C2.1) and a decrease in human health and benefits for it (C3.2). *Mytilus* is an important prey species for many fishes and birds in the Baltic Sea (Kautsky 1981) and population decreases may result in decreases in provisioning fish (C1.2.1). The measures to prevent loss of *Mytilus* reefs require international legislation to control climate change (Control 4.1.1) and funding, incentives or investments to control climate change (control 5.1).

Loss of bird populations. Climate change is affecting many bird species. Milder winters have led to changes in wintering areas (Fox et al. 2019), migration times and the onset of breeding (Meier et al. 2022). For example, in mallard (*Anas platyrhynchos*), tufted duck (*Aythya fuligula*), and common goldeneye (*Bucephala clangula*), among others, the proportion of resident *vs* migratory individuals has increased drastically (Meller et al. 2016). In addition, climate change may impact the prey of bird species differently, causing temporal or spatial mismatches between the birds and the environment and/or prey (Saino et al. 2010). Changes in temperature (P4.1) are thus expected to affect many bird populations negatively. This may in turn decrease game or tourism and lead to decreased income (C2.2), decrease in aesthetic value or benefits (C3.1) and in other cultural benefits (C3.4). Mitigation measures include protection of essential habitats (Pavón-Jordán et al. 2020), including temporal closure or dynamic MPAs (Mitigation 1.3.7).

Cyanobacteria blooms. Cyanobacteria (e.g., *Aphanizomenon flos-aquae* and *Nodularia spumigena)* are a natural part of the Baltic Sea ecosystem, but decades of eutrophication have resulted in frequently occurring massive blooms of cyanobacteria and other harmful algae (HELCOM 2018). As cyanobacteria can assimilate nitrogen themselves, phosphorus loading (P3.1) contributes to cyanobacteria blooms (HELCOM 2018). These blooms drastically change the landscape/seascape (C1.4). As cyanobacteria can be toxic, the blooms directly decrease human health and benefits for it (C3.2) and decrease the economic value (C2.3) as they prevent the use of recreational areas.

Cyanobacteria blooms also modify the energy fluxes in food webs and may indirectly impact other marine communities and ecosystem services.

Increase in reed. Reed (*Phragmites australis*) is an important habitat in the Northern Baltic Sea for many fishes, invertebrates and birds. However, the long-term eutrophication (P3.1, P3.2) has resulted in drastic increases in reed growth in the study area (Altatouri et al. 2014), which has resulted in a decrease in other important vegetated habitats (Pitkänen et al. 2013). The increase in reed drastically changes the landscape (C1.4), decreases the economic value (C2.3) of the shores, and decreases other cultural benefits in the area (C3.4). Habitat restoration (Mitigation 1.2.1) to remove reed is an important, but very laborious, mitigation measure to restore shores to more open, coastal wetlands (Kose et al. 2021).

The Archipelago Sea consists of a highly mosaic distribution of different habitats, with different habitats next to each other. Connectivity is often high in the marine environment, and many, if not all, of the marine communities discussed in this study are interconnected. As an example, both homogenization of benthic fauna, loss of biogenic reefs, and increase in reed may contribute to losses of bird populations. Such reinforcing interactions are, however, not considered in the bow-tie approach, and future assessments should aim to include diverse trophic and non-trophic links for more holistic cause-impact assessments. We suggest that future steps of bow-tie risk assessment development should include incorporating links among the central events and considering the impact of these interactions and any reinforcing or stabilising impacts of the different central events. Network approaches have been suggested to be included in the planning of marine environmental conservation and management, among others, for a more holistic view on the anthropogenic impacts on ecosystems (Eero et al. 2021).

Finally, warming is expected to increase the negative impacts of eutrophication (HELCOM 2018, Meier et al. 2022). However, for simplicity, we here only indicate the direct impacts of different causes on degradation of marine communities. Including these interactions and the strength of the impact would benefit the management of the ecosystem. A confidence layer to indicate the certainty of the linkages would further benefit the assessment for future use. To conclude, while the bow-tie risk assessment conducted in this study summarises the central links between causes, biodiversity loss and the causes of this, it is important to consider that the realised impacts of the causes on communities and ecosystem services may be more drastic than estimated based on the examples above.

Conclusions

We here summarise the main estimated causes and consequences of eutrophication and climate change on the degradation of marine communities in the Archipelago Sea area. The study illustrates the complexity of the impacts and the interlinkages of biodiversity loss in different communities. This highlights the need for a holistic approach and consistent decision-making at regional, national and international levels to prevent and mitigate the degradation of communities and ecosystem services.

References

Altartouri, A., Nurminen, L., Jolma, A., 2014 Modeling the role of the close-range effect and environmental variables in the occurrence and spread of Phragmites australis in four sites on the Finnish coast of the Gulf of Finland and the Archipelago Sea. Ecology and Evolution 4, 2045-7758. doi.org/10.1002/ece3.986

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 Science 44, 63–72. doi.org/10.1016/S0272-7714 (97)80008-X

Dolmer, P., 2000. Feeding activity of mussels Mytilus edulis related to near-bed currents and phytoplankton biomass. Journal of Sea Research 44, 221-231. doi.org/10.1016/S1385-1101(00)00052-6.

Eero, M., Dierking, J., Humborg, C., Underman, E., MacKenzie, B.R., Ojaveer, H., Salo, T., & Köster, F.W., 2021. Use of food web knowledge in environmental conservation and management of living resources in the Baltic Sea. ICES Journal of Marine Science 78, 2645-2663. doi.org/10.1093/icesjms/fsab145

Elliot, M., Franco, A., & Smyth, K., 2020. Industry- and policy-driven conceptual frameworks of climate change impacts on aquaculture and fisheries. Deliverable 5.1, CERES Project, Report.

Fourqurean, J., Duarte, C., Kennedy, H., Marbà, N., Holmer, M., Mateo, M.A., Apostolaki, E.T., Kendrick, G.A., Krause-Jensen, D., McGlathery, K.J., & Serrano, O., 2012. Seagrass ecosystems as a globally significant carbon stock. Nature Geosci 5, 505–509 . doi.org/10.1038/ngeo1477

Fox, A.D., Nielsen, R.D., & Petersen, I.K., 2019. Climate-change not only threatens bird populations but also challenges our ability to monitor them. Ibis, 161, 467-474. doi.org/10.1111/ibi.12675

Gyllenhammar, A., & Håkanson, L. 2005. Environmental consequence analyses of fish farm emissions related to different scales and exemplified by data from the Baltic – a review. Marine Environmental Research, 60(2), 211–243. doi.org/10.1016/j.marenvres.2004.10.005

HELCOM, 2013. Implementation of hot spots programme, 1992-2013 – Final report.

HELCOM, 2018. HELCOM Thematic assessment of eutrophication 2011-2016. Balt. Sea Environ. Proc. No. 156.

HELCOM, 2021. HELCOM Baltic Sea Action Plan – 2021 Update. HELCOM 2021.

HELCOM, 2023. State of the Baltic Sea – The HELCOM holistic assessment 2016-2021. HELCOM 2023.

Henseler, C., Nordström, M.C., Törnroos, A., Snickars, M., Pecuchet, L., Lindegren, M., & Bonsdorff, E., 2019. Coastal habitats and their importance for the diversity of benthic communities: a species- and trait-based approach. Estuarine, Coastal and Shelf Science, 226, 106272 doi.org/10.1016/j.ecss.2019.106272

IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Díaz, S., Settele, J., et al. (eds.). IPBES secretariat, Bonn, Germany.

IPCC, 2014. Climate Change 2014: impacts, adaptation and vulnerability. Part A: global and sectoral aspects. In: Field, C. B. et al. (eds), Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Kaskela, A.M., & Kotilainen, A.T., 2024. Quantifying seabed geodiversity of the Archipelago Sea, Baltic Sea, Finland. GEUS Bulletin, 52, 8317. doi.org/10.34194/geusb.v52.8317

Kautsky, N., 1981. On the trophic role of the blue mussel (Mytilus edulis L.) in a Baltic coastal ecosystem and the fate of the organic matter produced by the mussels. Kieler Meeresforschungen. Sonderheft 5, 454-461.

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

Krause-Jensen, D., Sagert, S., Schubert, H., Boström, C., 2008. Empirical relationships linking distribution and abundance of marine vegetation to eutrophication, Ecological Indicators, 8, 515-529. doi.org/10.1016/j.ecolind.2007.06.004.

Kose, M., Heinsoo, K., Kaljund, K., & Tali, K., 2021. Twenty years of Baltic Boreal coastal meadow restoration: has it been long enough?. Restoration Ecology 29, e13266. doi.org/10.1111/rec.13266

Maar, M., Saurel, C., Landes, A., Dolmer, P., & Petersen, J.K., 2015. Growth potential of blue mussels (M. edulis) exposed to different salinities evaluated by a Dynamic Energy Budget model. Journal of Marine Systems 148, 48-55, doi.org/10.1016/j.jmarsys.2015.02.003.

Meier, M.H.E., Kniebusch, M., Dieterich, C., Gröger, M., Zorita, E., Elmgren, R., Myrberg, K., Ahola, M.P., Bartosova, A., Bonsdorff, E., Börgel, F., Capell, R., Carlén, I., Carlund, T., Carstensen, J., Christensen, O.B., Dierschke, V., Frauen, C., Frederiksen, M., Gaget, E., Galatius, A., Haapala, J.J., Halkka, A., Hugelius, G., Hünicke, B., Jaagus, J., Jüssi, M., Käyhkö, J., Kirchner, N., Kjellström, E., Kulinski, K., Lehmann, A., Lindström, G., May, W., Miller, P.A., Mohrholz, V., Müller-Karulis, B., Pavón-Jordán, D., Quante, M., Reckermann, M., Rutgersson, A., Savchuk, O.P., Stendel, M., Tuomi, L., Viitasalo, M., Weisse, R., & Zhang, W., 2022. Climate change in the Baltic Sea region: a summary. Earth System Dynamics, 13, 457-593. doi.org/10.5194/esd-13-457-2022

Meller, K., Vähätalo, A.V., Hokkanen, T., Rintala, J., Piha, M., & Lehikoinen, A., 2016. Interannual variation and long-term trends in proportions of resident individuals in partially migratory birds. Journal of Animal Ecology 85, 570-580. doi.org/10.1111/1365-2656.12486

Michaud, K.M., Reed, D.C., & Miller, R.J., 2022. The Blob marine heatwave transforms California kelp forest ecosystems. Communications Biology 5, 1143. doi.org/10.1038/s42003-022-04107-z

Norling, P., & Kautsky, N., 2008. Patches of the mussel Mytilus sp. are islands of high biodiversity in subtidal sediment habitats in the Baltic Sea. Aquatic Biolofy 4, 75-87. doi.org/10.3354/ab00096

Orth, R.J, Carruthers, T.J.B., Dennison, W.C., Duarte, C.M., Fourqurean, J.W., Heck, K-L., Hughes, A.R., Kendrick, G.A., Kenworthy, W.J., Olyarnik, S., Short, F.T., Waycott, M., & Williams, S.L., 2006. A Global Crisis for Seagrass Ecosystems, BioScience, 56, 987–996. doi.org/10.1641/0006-3568(2006)56[987:AGCFSE]2.0.CO;2

Pavón-Jordán, D., Abdou, W., Azafzaf, H., Balaž, M., Bino, T., Borg, J.J., Božič, L., Butchart, S.H.M, Clausen,P., Sniauksta, L., Dakki, M., Devos, K:., Domsa, C., Encarnaçao, V.,Etayeb, K., Faragó, S., Fox, A.D., Frost, T., Gaudard, C., Georgiev, V. Goratze, I., Hornman, M., Keller, Kostiushyn, V., Langendoen, T., Ławicki, Ł., Ieronymidou, C., Lewis, L.J., Lorentsen, S-H., Luigujoe, L., Meissner,W., Mikuska, T., Molina, B., Musil, P., Musilova, Z., Nagy, S., Natykanets, V., Nilsson, L., Paquet, J.-Y. Portolou, D., Ridzon, J., Santangeli, A., Sayoud, S., Šćiban, M., Stipniece, A., Teufelbauer, N., Topić, G., Uzunova, D., Vizi, A., Wahl, J., Yavuz, K.E., Zenatello, M., & Lehikoinen, A., 2020. Positive impacts of important bird and biodiversity areas on wintering waterbirds under changing temperatures throughout Europe and North Africa. Biological Conservation 246, 108549. doi.org/10.1016/j.biocon.2020.108549

Petersen, J.K., Hasler, B., Timmermann, K., Nielsen, P., Tørring, D.B., Larsen, M.M., & Holmer, M., 2014.Mussels as a tool for mitigation of nutrients in the marine environment. Marine Pollution Bulletin 82, 137-143. doi.org/10.1016/j.marpolbul.2014.03.006

Piola, R.F., & Johnston, E.L., 2008. Pollution reduces native diversity and increases invader dominance in marine hard-substrate communities. Diversity and Distributions, 14, 329-342. doi.org/10.1111/j.1472-4642.2007.00430.x

Pitkänen, H., Peuraniemi, M., Westerbom, M., Kilpi, M., & von Numers, M., 2013. Long-term changes in distribution and frequency of aquatic vascular plants and charophytes in an estuary in the Baltic Sea. Annales Botanici Fennici 50, 1–54.

Pulido, C., & Borum, J., 2010. Eelgrass (Zostera marina) tolerance to anoxia. Journal of Ecperimental Marine Biology and Ecology 385, 8-13. doi.org/10.1016/j.jembe.2010.01.014

Reusch, T.B.H., Dierking, J., Andersson, H.C., Bonsdorff, E., Carstensen, J., Casini, M., Czajkowski, M., Hasler, B., Hinsby, K., Hyytiäinen, K., Johannesson, K., Jomaa, S., Jormalainen, V., Kuosa, H., Kurland, S., Laikre, L., MacKenzie, B.R., Margonski, P., Melzner, F., Oesterwind, D., Ojaveer, H., Refsgaard, J.C., Sandström, A., Scwarz, G., Tonderski, K., Winder, M., & Zandersen, M., 2018. The Baltic Sea as a time machine for the future coastal ocean. Science Advances, 4, eaar8195. doi.org/10.1126/sciadv.aar8195

Riisgård, H., Mulot, M., Merino, L., Pleissner, D., 2014. Effect of Salinity-Changing Rates on Filtration Activity of Mussels from Two Sites within the Baltic Mytilus Hybrid Zone: The Brackish Great Belt (Denmark) and the Low Saline Central Baltic Sea. Open Journal of Marine Science, ***4****, 101-109. doi: 10.4236/ojms.2014.42011.*

Rinne, H., & Salovius-Laurén, S., 2020. The status of brown macroalgae Fucus spp. and its relation to environmental variation in the Finnish marine area, northern Baltic Sea. Ambio 49, 118–129. doi.org/10.1007/s13280-019-01175-0

Rinne, H., Blanc, J.F., Salo, T., Nordström, M.C., Salmela, N., & Salovius-Laurén, S., 2022. Variation in Fucus vesiculosus associated fauna along a eutrophication gradient. Estuarine, Coastal and Shelf Science 275, 107976. doi.org/10.1016/j.ecss.2022.107976.

Saino, N., Rubolini, D., Lehikoinen, E., Sokolov, L. V., Bonisoli-Alquati, A., Ambrosini, R., Boncoraglio, G., & Møller, A.P., 2009. Climate change effects on migration phenology may mismatch brood parasitic cuckoos and their hosts. Biology Letters 5, 539–541. doi.org/10.1098/rsbl.2009.0312

Salo, T., Nieminen, A., Salovius-Laurén, S., & Rinne, H., 2024. Community science approach reveals temporal and eutrophication-related patterns in bladderwrack-associated invertebrate fauna. Extuarine, Coastal and Shelf Science 304, 108822. doi.org/10.1016/j.ecss.2024.108822

Sand-Jensen, K., & Borum J., 1991. Interactions among phytoplankton, periphyton, and macrophytes in temperate freshwaters and estuaries. Aquatic Botany 41, 137-175. doi.org/10.1016/0304-3770(91)90042-4

Takolander, A., Cabeza, M., & Leskinen, E., 2018. Climate change can cause complex responses in Baltic Sea macroalgae: A systematic review. Journal of Sea Research 5, 4. doi.org/10.1016/j.seares.2017.03.007.

Wikström, S., & Kautsky, L., 2007. Structure and diversity of invertebrate communities in the presence and absence of canopyforming Fucus vesiculosus in the Baltic Sea. Estuarine, Coastal and Shelf Science 72, 168–176. doi.org/10.1016/j.ecss.2006.10.009