HOLAS 3

State of the Baltic Sea 2023

Third HELCOM holistic assessment 2016–2021

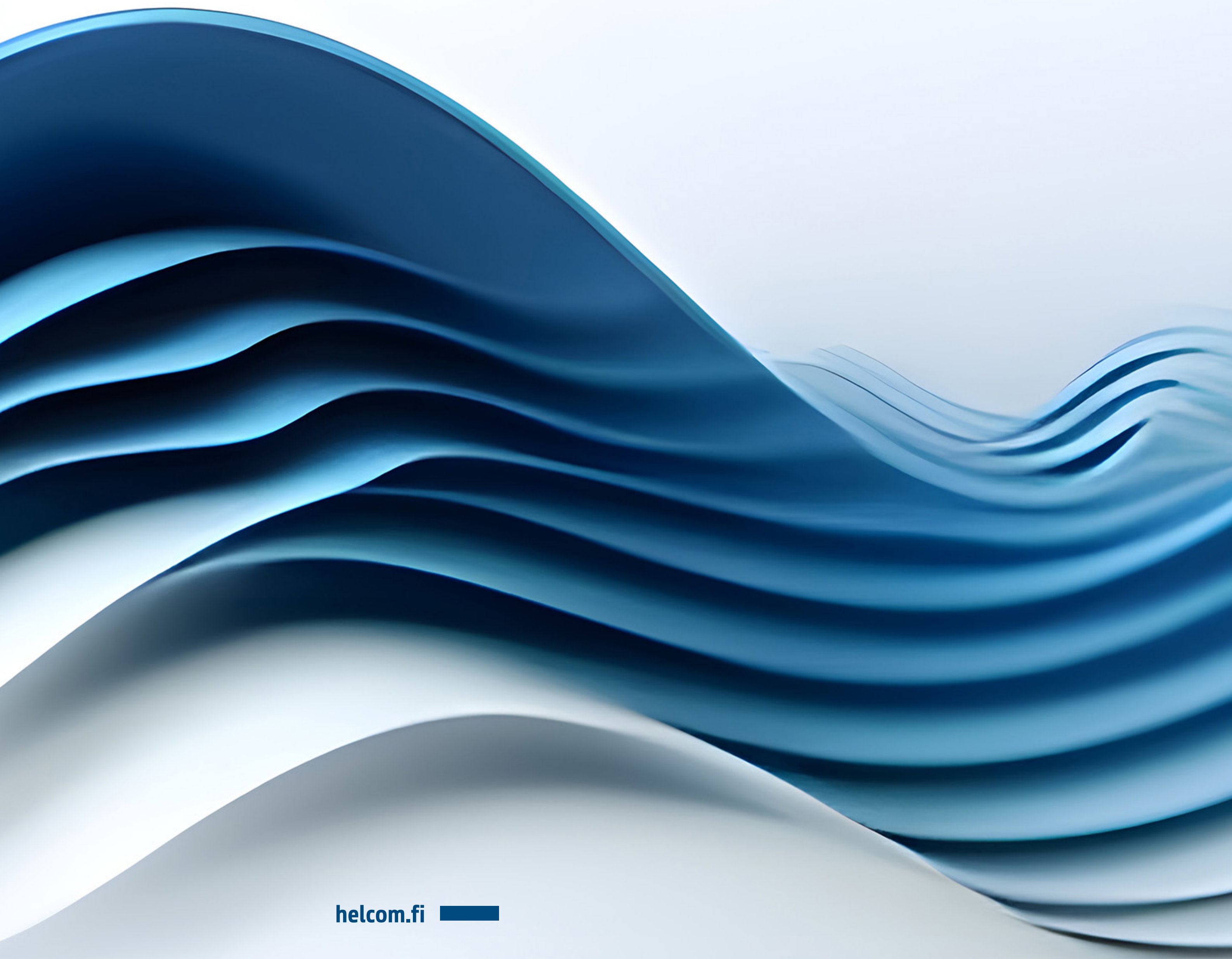
HELCOM

Baltic Marine Environment Protection Commission

HOLAS 3

Monitoring & assessment

Baltic Sea Environment Proceedings 194



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Published by:

Helsinki Commission – HELCOM
Katajanokanlaituri 6 B
00160 Helsinki, Finland

www.helcom.fi

The summary report builds on the results from the HOLAS3 Thematic assessments and HELCOM indicator reports, as available at (indicators.helcom.fi) and at the citations provided in this report. All contributors to these products are highly acknowledged for enabling this summary report. The preparation of this report was also supported by IC HOLAS 3 TT 1-5. Expert comments from the Contracting Parties in the review process provided valuable input. The work overall was supported by input and review from contacts nominated by all Contracting Parties, as well as the HOLAS 3 Correspondence Group.

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For bibliographic purposes, this document should be cited as: HELCOM (2023): State of the Baltic Sea. Third HELCOM holistic assessment 2016-2021. Baltic Sea Environment Proceedings n°194.

Available at: https://helcom.fi/post_type_publ/holas3_sobs

State of the Baltic Sea website: https://stateofthebalticsea.helcom.fi

Layout: Laura Ramos Tirado
Language revision: Sedeer el-Showk

ISSN: 0357-2994

Contents

Preface

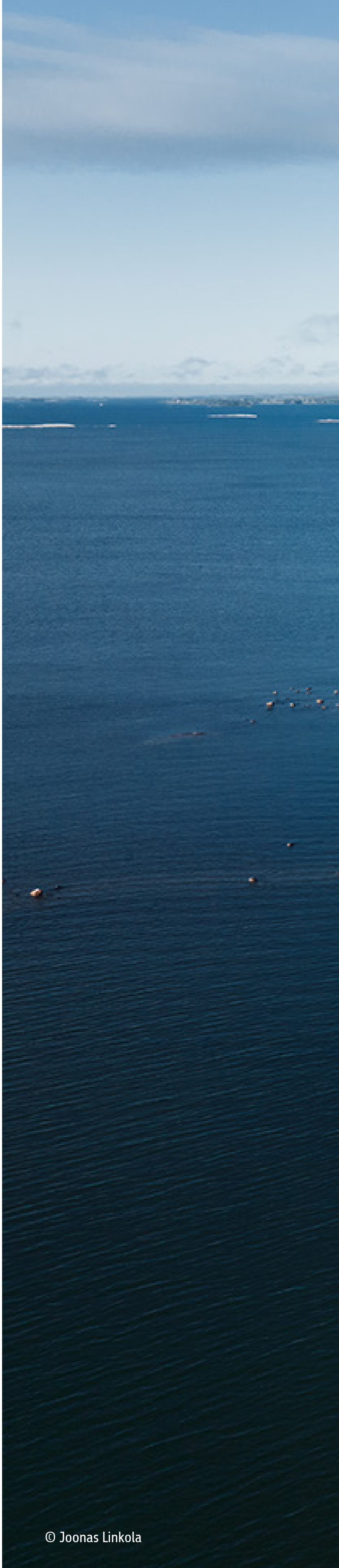
In the Baltic Sea, where the transboundary aspects of environmental problems are highly evident, HELCOM plays a central role in coordinating environmental management objectives and in the implementation of actions and measures.

The HELCOM holistic assessments of the ecosystem health of the Baltic Sea are reoccurring, transboundary, cross-sectoral assessments that look at the effects of our activities and measures on the status of the environment. The knowledge produced through these assessment processes supports environmental policy and is incorporated into the ecosystem-based management of the Baltic Sea, as well as into national, regional and global measures.

These holistic assessments cover a broad range of topics relevant to the state of the ecosystem, environmental pressures, societal drivers and the effects on human well-being. The assessment presented here, the third HELCOM holistic assessment of the state of the Baltic Sea (HOLAS 3), also specifically enables tracking our progress towards the implementation of the 2021 HELCOM Baltic Sea Action Plan goals and objectives. It also functions as a regional contribution to the reporting required under the Marine Strategy Framework Directive for those HELCOM Contracting Parties that are also EU Member States, and it may support achievement of or reporting under other international policy initatives, e.g., the UN Sustainability Development Goals.

The holistic assessments cover 'moments' in time over the dynamic life history of the Baltic Sea, supporting the adaptive development of assessment methods, measures and policies. The third HELCOM holistic assessment focuses on describing the status for the years 2016-2021, contributing to our ambition at HELCOM to develop, update and share knowledge about the state of the Baltic Sea environment.

This summary report builds on, and integrates, results from a wide range of assessment products produced within the third HELCOM holistic assessment. The role of this summary report is to link information from the underpinning assessment products together, thus highlighting the holistic aspects. With this in mind, the summary report focuses on presenting the results and on an in-depth look at why we are seeing these results, providing over-arching context and analysis. The report helps develop a clearer picture of where we are and how things are connected, supporting coordinated and effective measures to strengthen the Baltic Sea environment.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Executive summary

The Baltic Sea has unique biodiversity, and people around the region depend on its ecosystem in ways that are not always directly apparent or appreciated. But in spite of its ecological, economic and cultural importance, biodiversity is continuously being degraded and lost. The importance of functioning ecosystems for human well-being is too often underestimated or not fully recognized in planning and decision-making. Key pressures on the Baltic Sea ecosystem include eutrophication, pollution from hazardous substances, land use and overfishing, but several other pressures also add to the total impact.

Exexutive summary in short

- The Baltic Sea is under increasing impacts from climate change and biodiversity degradation catalysed by eutrophication, pollution, land use and resource extraction. Little to no improvement of the Baltic Sea environment occurred during the assessment period.
- Measures to reduce pressures on the Baltic Sea are working, when they are implemented, and the agreements in the updated Baltic Sea Action Plan remain highly relevant.
- The effects of climate change are expected to increase in the future, increasing the need for measures to enhance ecosystem resilience and mitigate their negative impacts.
- Transformative changes are needed in all socioeconomic sectors interacting with or affecting the Baltic Sea environment. Actions are needed both to stop current negative trends and to protect and restore ecosystems.
- Ecosystem knowledge and policies for the Baltic Sea environment have developed substantially within the past six years.
- Implementing the updated Baltic Sea Action Plan, facilitating ecosystem-based management and minimizing impacts from climate change are focal areas for HELCOM in the coming years.

Countries around the Baltic Sea have agreed to improve the state of its ecosystem

The HELCOM Baltic Sea Action Plan includes measures that countries have agreed on as highly important to halt the deterioration of the Baltic Sea environment, strengthen biodiversity and improve the living conditions of future generations. HELCOM carries out holistic assessments every six years to follow up on how well the agreement is functioning, focusing on how the Baltic Sea ecosystem is doing. These holistic assessments involve several hundred experts on a wide range of topics, from monitoring to system-level evaluations. The third HELCOM holistic assessment focuses on the years 2016-2021 and includes results at various levels of detail, including monitoring data, indicator reports and thematic assessments. This summary report highlights and synthesizes the main findings.

The measures of the Baltic Sea Action Plan also support several other environmental commitments of the Baltic Sea countries, including the United Nations Sustainable Development Goals. The holistic assessment also helps EU countries within HELCOM meet the requirements for coordinated reporting under the EU Marine Strategy Framework Directive.

The state of the Baltic Sea ecosystem has not improved

The knowledge base of this holistic assessment is more comprehensive than that of previous HELCOM assessments. Several uncertainties have been reduced, and assessment approaches improved. Unfortunately, the results show only little or no improvement in the state of the Baltic Sea environment in 2016-2021. Indicator-based assessments show cases of poor status in environmental pressures across the full spatial extent of the Baltic Sea. Across pelagic habitats, benthic habitats, fish, waterbirds and marine mammals, only a few indicators reached their threshold values in parts of the Baltic Sea, and none in all assessed areas. For some species groups, such as marine mammals and fish, the integrated status has worsened compared to the previous assessment. Many commercial fish stocks in the Baltic Sea are in an especially poor state.

This deterioration jeopardizes the sustainable use of species in the Baltic Sea, and it also impacts ecosystem functions that are of central importance for humans. The poor environmental status of the Baltic Sea clearly affects, for example, the profitability of fisheries and tourism, and it also impacts a wide range of ecosystem services on which we depend. Considering the high costs of inaction, achieving a healthy Baltic Sea is also an investment in the sustainable economic and societal development of our region. Achieving good environmental status in national marine waters by 2040 has been estimated to be worth 5.6 billion euros per year to the people around the Baltic Sea.

When implemented, regional measures are working

However, the assessment also shows that measures to reduce pressures on the Baltic marine environment are working, when they are implemented. As a result of regional agreements, inputs of nutrients have reached sustainable levels in some parts of the Baltic Sea, and so have levels of some hazardous substances that were previously problematic. Actions for biodiversity conservation have also increased, and the Baltic Sea region is on track to reach the global target of 30% protected area by the year 2030. Such coordinated measures are essential to enable the recovery of the Baltic ecosystem over time. These are fundamental steps and necessary actions, and it is imperative that we build on them further.

Among current key priorities, lowering the input of nutrients to regionally agreed maximum levels in all sea basins remains a central objective. In addition, strengthening the coordination of management measures to limit the distribution of a wide range of hazardous substances is needed. Transitioning to ecosystem-based management is called for to ensure that fishing does not have negative effects on food web functions or ecosystem resilience. This need is further increased by climate change.

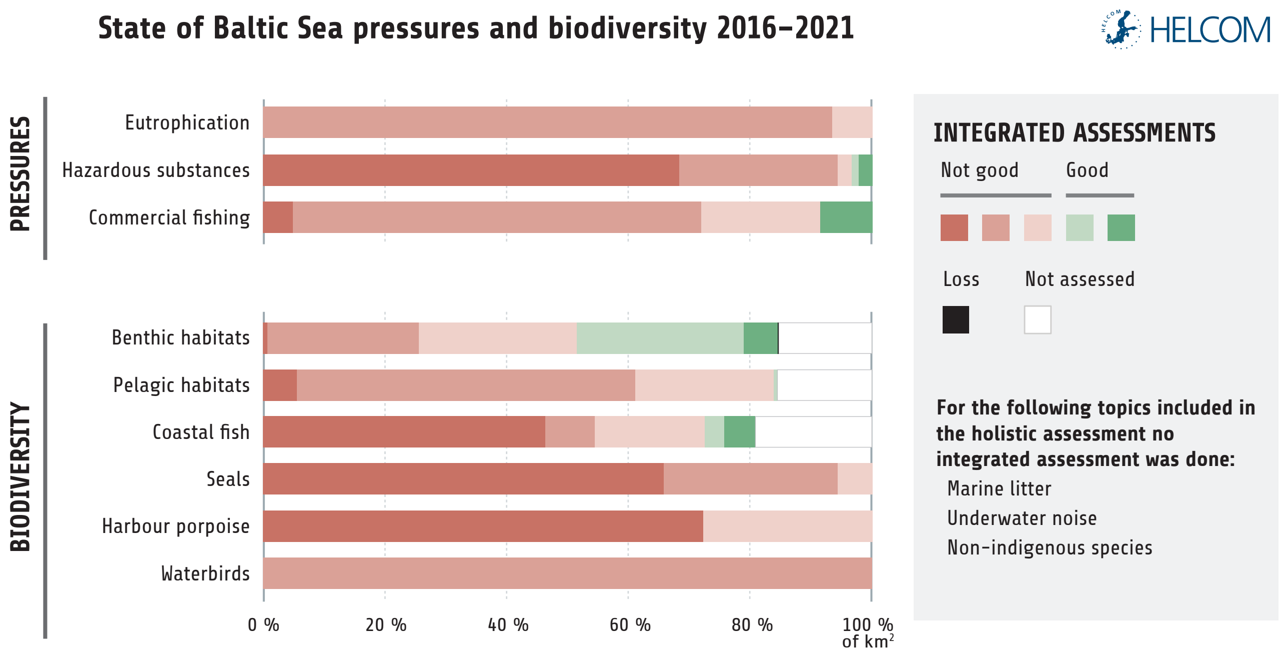

Figure ES1. Summary of the integrated assessment results of pressures and status for the Baltic Sea showing the proportion of the Baltic Sea in the different assessment status categories (based on square kilometres). Integrated assessment results are shown in five categories with three representing degrees of poor status and two representing degrees of good status, as shown in more detail in the different chapters of the report.

The need for stronger measures is accentuated by climate change

Climate change increases the risk of biodiversity loss in the Baltic Sea and aggravates the impact of existing pressures. The impacts of climate change have increased in the Baltic Sea region lately and are predicted to continue doing so in the near future. Assessments show that the water temperature is rising, the ice extent in winter is decreasing and the annual mean precipitation is increasing over the northern part of the region. The increased likelihood of marine heatwaves, climate variability and extreme weather events is of growing concern. These changes affect the abundance and distribution of species in the Baltic Sea, and hence also ecosystem functions and the delivery of ecosystem services. Measures are needed to limit global warming, strengthen the resilience of the natural ecosystem and enhance its potential to mitigate climate change effects.

Ecosystem-based approaches can support environmental measures

The poor status of many species and habitats reflects their response to multiple pressures acting in concert rather than to individual pressures. For example, benthic habitats can be impacted by a combination of physical disturbance, eutrophication and the effects of food web disruptions. Mobile species, including fish, waterbirds and marine mammals, are affected by pressures throughout their distribution area. Several environmental objectives for the Baltic Sea will likely require a combination of measures targeting various pressures and climate change effects in order to be achieved. Transformative changes are called for in all socioeconomic sectors interacting with or affecting the Baltic Sea environment in order to protect and rebuild ecosystems and halt existing negative trends.

Maintaining the natural structure and function of food webs can be expected to strengthen the resilience of the ecosystem against multiple human pressures. Food webs cannot be directly managed, but their structure and function can be improved by proper management of the human activities and pressures that affect the species involved in them. Since all parts of the ecosystem are interconnected, changes in the status of one species in the food web will affect others. Integrating food web knowledge into the design and implementation of management measures (for example, by identifying and coordinating a combination of actions that support key species) is expected to increase the effectiveness of measures to strengthen the species, habitats and food webs of the Baltic Sea.

To this end, ensuring continued, coordinated monitoring, assessment and analysis among Baltic Sea countries, and developing these further, are key to ensuring the coherence and communication needed to support environmental policy towards the ecosystem approach.

Policy statements

- National work in HELCOM countries is at the core of implementing the Baltic Sea Action Plan and improving the health of the Baltic Sea.
- The third HELCOM holistic assessment highlights the importance of measures to strengthen Baltic Sea biodiversity.
- Achieving a healthy Baltic Sea ecosystem requires measures both to limit the extent and intensity of current human-induced pressures and to protect and restore species and habitats.
- An urgent need is to equip our shared Baltic Sea ecosystem with the capacity to withstand the future effects of climate change.
- A central task for HELCOM is to incorporate current knowledge developments in an ecosystem-based management framework that supports, and is supported by, national, regional and global actions that enable a sustainable future for the Baltic Sea region.

Summary of assessment results per assessment element

Status of biodiversity in the Baltic Sea

1. **Pelagic habitats**, including phytoplankton and zooplankton, Pelagic habitats, including phytoplankton and zooplankton, do not have good status in any open sea subbasin. The status is most deteriorated in the central and northern Baltic Sea, and the situation has worsened in the Bothnian Bay. Four out of thirteen assessed coastal areas have good status for phytoplankton. When eutrophication indicators are also included in the assessment, no open sea or coastal pelagic habitats have good integrated status.
2. **Benthic habitats** generally do not have good status in the southern Baltic Sea, while their status is good in open sea areas in the northernmost subbasins. Oxygen conditions are worsening. The oxygen debt below the halocline is increasing in all basins, especially in the Baltic Proper, and the increase between the previous and current assessment periods was very steep. Most coastal areas do not have good status.
3. **For fish,** only four out of fifteen assessed commercial stocks have good status. The status has declined for three stocks, improved for one and remained unchanged for eight stocks that were also assessed in the previous assessment period. The integrated status of coastal fish is good in only two of the twenty-two assessed areas, representing a worsened situation.
4. **Waterbirds** do generally not have good status, although there is variability between groups with different feeding behaviours. The status of benthic feeders and waders is not good in any part of the Baltic Sea. Surface-feeders have good status only in the Gulf of Bothnia. Grazing feeders do not have good status in the Kattegat, the Northern Baltic Proper or the Åland Sea. Pelagic feeders have good status in several subbasins. Many bird species characteristic of the Baltic Sea have decreased in abundance over the past few decades.
5. **Marine mammals** are represented by four species in the Baltic Sea. Grey seals and harbour seals are increasing in some areas, but the indicators for population growth rates, as well as reproductive and nutritional status, do not reach threshold values. Behavioural change in the ringed seal, possibly explained by a warming climate, has impaired the quality of monitoring data to evaluate its status in the Bothnian Bay. The status of the harbour porpoise is not good.
6. **Food web** assessments address the species interactions and energy flows that support ecosystem health. Changes in the status of a food web occur through impacts on its interacting species as these are mediated to other species and trophic guilds. Major changes in the abundance and biomass of species, driven by human pressures, have been associated with changes in the food webs of the Baltic Sea in recent times, and several examples of food web disruptions and putative tipping points are a cause for concern.

How can we protect and restore the Baltic Sea and its biodiversity?

Pollution

Reducing eutrophication is a key measure for improving both pelagic and benthic habitats in the Baltic Sea, and it will also have positive effects on mobile species that depend on these habitats. The increase of areas with poor oxygen conditions in the Baltic Sea is strongly linked to eutrophication. Eutrophication status has shown no signs of recovery since the previous assessment period. Inputs of nutrients have been reduced, but not all basins have achieved the Maximum Allowable Inputs (MAI) targets. Inputs of nitrogen are still too high in the Baltic Proper and the Gulf of Finland, and possibly the Gulf of Riga, while inputs of phosphorus are too high in all subbasins except the Bothnian Bay, Bothnian Sea, Danish Straits and the Kattegat.

Hazardous substances affect the status of several species and habitats. In the past, environmental contaminants decimated marine mammal and bird populations of the Baltic Sea. While many of the substances of the past are now banned, and their impacts relieved, hazardous substances are still the most widespread and impactful pressure in the Baltic, and emerging hazardous substances are a concern. The contamination status of the Baltic Sea has improved to some extent, but it was still assessed as either bad or poor in 80% of the assessed spatial units. The results partly reflect data availability, as units assessed with better status tended to be represented by fewer variables or lower assessment confidence. However, there are trends of improvement for several substances at the level of monitoring stations. Six open sea subbasins have improved their status category, although they are still not in good status. Only a small fraction of potentially hazardous substances is measured and assessed.

Marine litter can have direct effects on animals, as well as on human activities. Eleven out of sixteen assessed sub-basins exceeded the HELCOM threshold value for beach litter, with the highest amounts in the Sound, the Gulf of Riga, and the Eastern Gotland Basin. Most beach litter items are plastic, though the overall occurrence of plastic items has decreased. Litter on the seafloor is monitored through fish trawling surveys. Glass, metal, rubber, natural litter and single-use plastics have not increased in weight or number on the seafloor. Fisheries-related litter has increased in weight but not in number, and seafloor litter in the categories “plastics” and “other litter” have increased.

The introduction of non-indigenous species affects food webs by inducing changes in species interactions (for example, by competing with naturally occurring species). The arrival of non-indigenous or cryptogenic species to the Baltic Sea increased sharply in the second half of the last century and has not shown signs of decline since then. Thirteen non-indigenous or cryptogenic species were recorded for the first time in the Baltic Sea during 2016-2021, meaning the threshold value of zero new introductions was clearly exceeded. Most new non-indigenous species arrive in the Baltic Sea in connection with maritime transport and shipping.

Underwater noise can have harmful effects on species if the levels are too high. The status of underwater noise in the Baltic Sea was evaluated as good with respect to the risk that continuous underwater noise leads to behavioural disturbance of fish or marine mammals. With respect to the risk that human-induced sound masks natural sounds, the status is evaluated as good for marine mammals, but not good for fish in 9 out of 17 assessment units. Noise levels are clearly highest in shipping lanes. Loud impulsive noise can induce a range of effects depending on its intensity. Even if they don’t persist for a long time, activities such as explosions and piling may have effects at vast distances from the source unless mitigation measures are used.

Activities at sea

Fishing has had a significant impact on the Baltic Sea over the past few decades. Over the current assessment period, only four out of fifteen commercial stocks that could be fully evaluated showed good status on average. Eight out of seventeen evaluated stocks failed to achieve their threshold value for the fishing pressure indicator. For the stock size indicator, two pelagic stocks, four demersal stocks and eels failed to reach their threshold values. Fourteen stocks were evaluated with respect to a new indicator for age or size structure. Three of these showed negative trends, while the others showed a positive or no significant trend over time, though in several cases this reflects the indicator remaining at low levels. The deterioration of fish stocks affects not only the prospects of fishing but also of marine mammals and many fish and waterbird species that are dependent on prey fish.

Unintentional by-catch is of concern with regards to marine mammals and sea birds, which mainly drown in gillnets but also in trawls. Based on available data, the highest impact of by-catches likely occurs from the Kattegat to the Eastern Gotland basin. By-catch is a problem for species with poor conservation status, such as the harbour porpoise in the Baltic Sea.

Seafloor disturbance is a pressure that must be reduced for the status of benthic habitats in the Baltic Sea to improve. The effects of bottom trawling in the south-western Baltic Sea and the Kattegat are key concerns, and the risk of cumulative impact from physical pressures is also highest in these areas. In addition, habitat alterations in coastal areas (due to construction and dredging, for example) are a risk to fish and sea bird habitats. Erosion and habitat disturbance from boating and shipping can also have a high impact in some areas.

Seafloor loss is defined as a change of seabed substrate or morphology that has lasted for more than twelve years or is expected to do so. Seafloor loss is estimated to potentially affect less than one% of the total Baltic Sea area. The Sound experiences the highest potential loss, above four%, while loss is clearly below one% in the other the subbasins.

Protection and restoration status of the Baltic Sea

Marine protected areas are spatially defined areas that are selected for protection because they can be particularly useful to safeguard marine ecosystems, processes, functions, habitats and species, and they are managed to support this purpose. Today, the Baltic network of protected areas covers approximately 16.5% of the Baltic Sea, including just above 13% that are HELCOM marine protected areas. The area is expected to increase in the near future as a result of efforts to reach the spatial protection targets of the Baltic Sea Action Plan, the EU Biodiversity Strategy and the Global Biodiversity Targets of the UN Convention on Biological Diversity. For the protection to be effective, it should also be ensured that the MPAs form an ecologically coherent network.

Coastal and marine restoration is still in its infancy in the Baltic Sea, and there is a clear need to build a knowledge base and the capacity to ensure its successful implementation through knowledge-sharing and following up on existing and planned restoration initiatives.

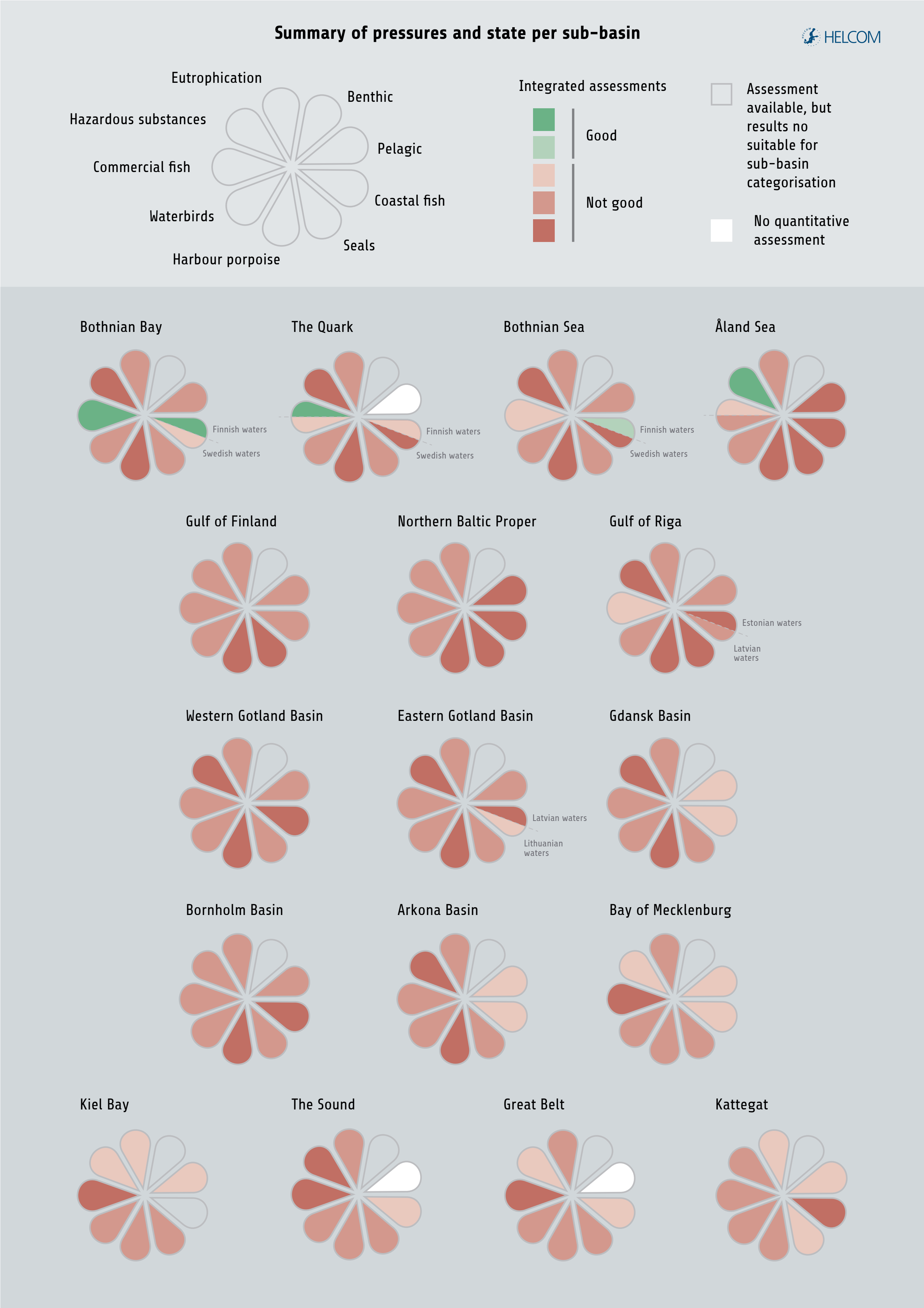

Figure ES2. Summary of the integrated assessment results of pressures and status across topics presented by the sub-basins of the Baltic Sea. For each sub-basin, each petal refers to a pressure or biodiversity ecosystem component according to its position in the flower shape, as shown in the figure legend. White petals are shown when no assessment is available, or when the assessment is currently incomplete. Integrated assessment results are shown in five categories. Further details on the assessment results are shown in the different chapters of this report, which also includes information on the status of marine litter, non-indigenous species, underwater sound, seabed loss and disturbance which are not included here as it is either not possible to aggregate the integrated assessment to sub-basin level, or no integrated assessment was available in HOLAS 3.

1. Introduction

1.1. Why is a holistic assessment of the Baltic Sea needed?

Achieving good ecosystem health is a core area of collaboration among countries bordering the Baltic Sea, which make up the Contracting Parties to HELCOM. Pressures from various human activities have an impact on Baltic Sea ecosystems, affecting the status of species and habitats, as well as human well-being. The close links between different parts of the Baltic Sea mean that actions often have to be coordinated across national borders for environmental measures to be effective. Environmental pressures vary spatially and their importance can change over time, depending on how human activities develop and on how efficiently we are able to manage and minimize negative impacts.

The third HELCOM holistic assessment (HOLAS 3) provides a wide-ranging update on the environmental status of the Baltic Sea for the time period 2016–2021. The holistic assessment helps us understand which pressures are currently of key importance and what areas will require additional measures, assuming current management measures are effective and are sufficient.

This holistic assessment captures a snapshot in time, reflecting the environmental condition and the role contemporary society plays in the dynamic life history of the Baltic Sea. In producing the assessment, researchers and experts around the Baltic Sea share insights into the various aspects that drive changes in its ecosystem. The task is not trivial. Different pressures often interact within the societal, economic and ecological complexity encompassing the Baltic Sea environment, and the effects on species and habitats may occur with a time lag or may be expressed differently between species or areas. It is crucial to produce an overview of the whole system that is as comprehensive and accurate as possible. Together, we want to understand which activities put pressures on the ecosystem and how they do so, how those pressures affect the state of the environment and biodiversity (in other words the species and habitats of the Baltic Sea), how the ecosystem and its functions are altered, and how such changes influence or can be influenced by societal factors. We want to use these insights to define new actions to renew, update and establish more effective measures to ensure a healthy Baltic Sea.

1.2. Policy use

In HELCOM, the holistic assessment provides a shared basis for following up on progress towards the objectives of the Baltic Sea Action Plan, facilitating the adaptive development of measures for the Baltic Sea environment in alignment with the ecosystem approach (Box 1.1).

The results and evaluations can be used to assess the current environmental status of the Baltic Sea and track the progress and effects of existing measures. This work supports several policies of key importance for the marine environment, helping HELCOM countries to come together and agree on the next steps to curb negative impacts and improve the status of the Baltic Sea.

1.2.1 Baltic Sea Action Plan

The Baltic Sea Action Plan (BSAP) is HELCOM's strategic programme of measures and actions for achieving a good environmental status of the sea (HELCOM 2021). The BSAP provides the concrete basis for work in HELCOM by stimulating goal-oriented cooperation among countries in the Baltic Sea region.

The BSAP is guided by the HELCOM vision of "a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable economic and social activities". The 2021 BSAP is divided into four segments, each with specific goals and objectives, which have been jointly agreed amongst the Baltic Sea countries (Figure 1.1).

Each of the four segments contains concrete measures and actions to be implemented by 2030 at the latest.

The *Eutrophication* and *Hazardous substances and litter* segments mainly reflect actions needed to manage pressures stemming from land, while the *Sea-based activities* segment addresses actions needed at sea to curb negative impacts resulting from our marine activities. The segments of the BSAP are intrinsically linked, and accomplishing the goals of these segments has direct importance for securing the status of species and habitats in the Baltic Sea, which is the target of the *Biodiversity* segment. The actions under this segment focus primarily on protection and restoration.

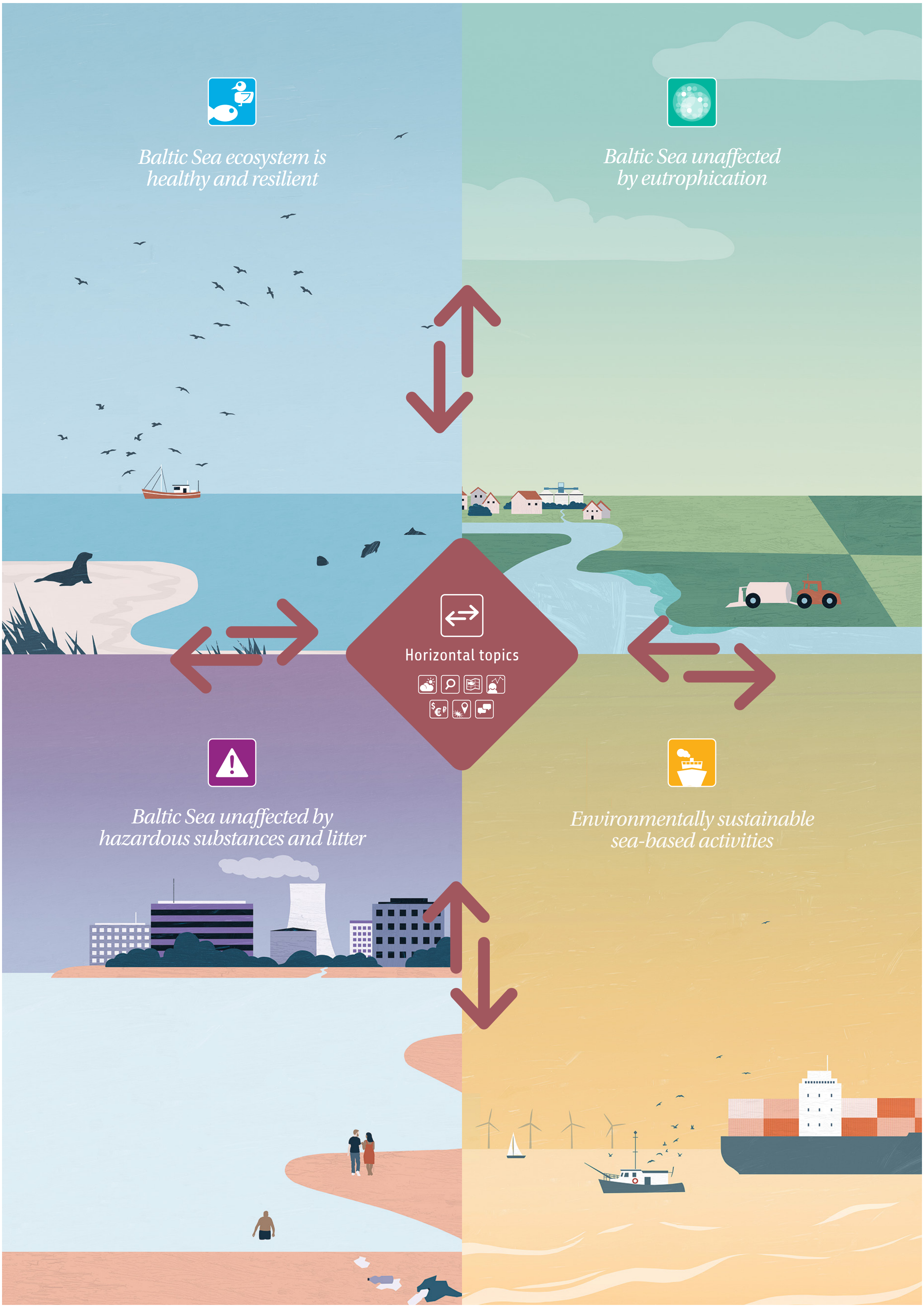

Figure 1.1. The four main segments of the Baltic Sea Action Plan (BSAP) focus on Biodiversity, Eutrophication, Hazardous substances and litter, and Sea-based activities. These segments support each other and share cross-cutting topics. The cross-cutting topic of the BSAP are climate change, monitoring, maritime spatial planning, economic and social analyses, knowledge exchange and awareness raising, hot spots, and financing.

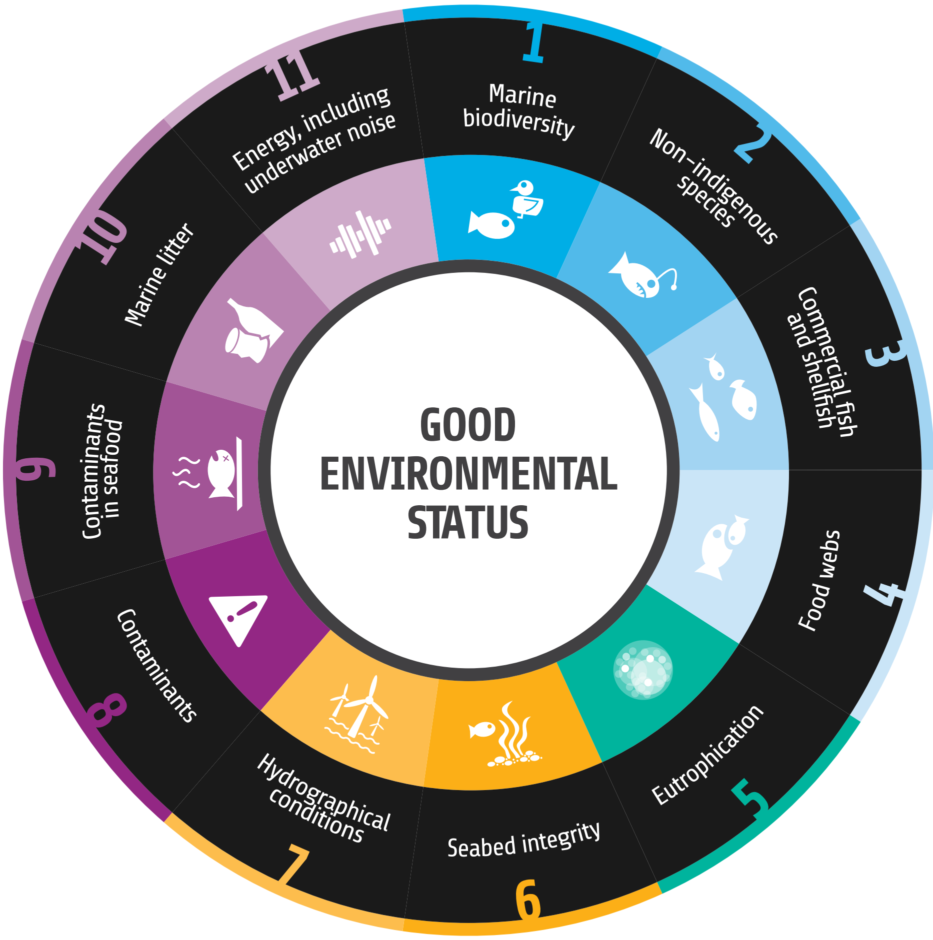

Figure 1.2. The EU Marine Strategy Framework Directive aims for good environmental status based on eleven descriptors covering different aspects of the marine environment

The BSAP also includes a number of horizontal topics. These address cross-cutting issues which have the potential to markedly influence the successful implementation of the BSAP. These include climate change, monitoring, maritime spatial planning, economic and social analyses, knowledge exchange and awareness raising, hot spots and financing.

1.2.2 Marine Strategy Framework Directive and other EU legislation

The Marine Strategy Framework Directive (MSFD) is the legal instrument for the protection of the seas in the European Union. The overarching goal of the MSFD is to achieve a good environmental status of the marine waters within the European Union, which is specified using eleven descriptors (Figure 1.2). EU Member States are required to report on the status of their marine environments (using indicators) in relation to these descriptors in six-year assessment cycles (EC 2017 a,b). While member states define the indicators and their threshold values, they are often required to do so through regional cooperation, and their data collection and assessment approaches need to be as coherent as possible in order to be meaningful, particularly within the same marine region.

The MSFD is an overarching framework that strives to establish an ecosystem-based, adaptive, and integrated approach to the management of all human activities that have an impact on the marine environment. The MSFD does not aim to replace other related EU policies but makes links to them to support harmonised assessment and monitoring. Examples of EU policies of direct relevance for the implementation of the EU MSFD are the Birds and Habitats Directive (EU 1992), the Water Framework Directive (EC 2000), and the EU Common Fisheries Policy (EU 2013).

1.2.3 The Global Sustainable Development Goals

The HELCOM Baltic Sea Action Plan and HELCOM activities are well aligned with the Sustainable Development Goals of the United Nations (Figure 1.3), which provide a global blueprint for peace and prosperity for people and our planet (UN 2015). The seventeen goals were adopted by all United Nations Member States in 2015. Rooted in an urgent call for action by both the Global South and the Global North, the Sustainable Development Goals recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality and spur economic growth while tackling climate change and working to preserve our forests and oceans.

SDG targets addressed

— ***2.4*** *By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.*

— ***6.3*** *By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally*

— ***6.5*** *By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate*

— ***12.2*** *By 2030, achieve the sustainable management and efficient use of natural resources*

— ***12.4*** *By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment*

— ***12.5*** *By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse*

— ***13.2*** *Integrate climate change measures into national policies, strategies and planning*

— ***14.1*** *By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution*

— ***14.2*** *By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans*

— ***14.c*** *Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want*

— ***14.4*** *By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics*

— ***14.5*** *By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information*

— ***15.8*** *By 2020 introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems, and control or eradicate the priority species*

Biodiversity
Eutrophication
Hazardous substances, marine litter, underwater noise, non-indigenous species
Economic and social analyses
Spatial pressures and impacts

Figure 1.3. Sustainable Development Goals and their links with HOLAS 3, based on information in the 2021 HELCOM Baltic Sea Action Plan (BSAP).

1.3. Data and methods underlying the assessment

1.3.1 The HELCOM monitoring programmes

The holistic assessments are based on extensive data collected in a comparable manner throughout the Baltic Sea region to create the most accurate and comprehensive overview of the state of the Baltic Sea.

Maintaining regionally agreed monitoring programmes is a well-established function of HELCOM. Countries around the Baltic Sea carry out the monitoring in line with commonly agreed procedures and collate the data in centralized, open databases (HELCOM 2013a). Monitoring of the physical, chemical and biological variables of the Baltic Sea open sea area started as early as 1979, and monitoring of the input of nutrients and hazardous substances began in 1998. The monitoring programmes are developed continuously. There are now 40 jointly agreed HELCOM monitoring programmes being implemented by the countries around the Baltic Sea. These programmes cover the sources and inputs of human pressures and various variables that reflect the state of the environment. The monitoring data are used in various assessments to evaluate the state of the marine environment and to reveal long-term trends.

Despite recent developments to improve the assessment, several data gaps are still evident and need to be filled in future work. In some cases, data gaps exists because monitoring to support the assessed indicators (see Section 1.3.2) does not cover the full extent of the Baltic Sea region or there is insufficient sampling density. For some elements, regionally coordinated monitoring is still under development or is missing. More details for specific indicators and elements are given in the reports summarized in this report (HELCOM 2023a-e) and the indicator reports.

1.3.2 The HELCOM indicators

The HELCOM indicators are the basis for evaluating progress towards our identified objectives for the marine environment.

The indicators are developed by HELCOM expert groups following a set of key principles that address factors such as ecological relevance, policy relevance, measurability, and connection to human pressures. HELCOM core indicators must be quantitative and their underlying monitoring data and evaluation approaches must be harmonised across the Baltic Sea. The observed status of each core indicator in defined spatial units (see section 1.3.4) is evaluated against a regionally (or sub-regionally) agreed threshold value. Indicators are evaluated as either achieving or failing to achieve their threshold value. The evaluations thus help us understand the current situation in relation to our objectives, what direction we are moving in, and whether we need to take action (HELCOM 2020).

To avoid gaps in the holistic assessment and ensure that available knowledge of key importance is shared, the indicator evaluation results are supplemented with qualitative information for aspects that cannot be addressed quantitatively.

A central part of HELCOM's work is to develop and improve the set of indicators over time to enable better and more comprehensive assessments of the state of the environment and the pressures that affect it. There are currently almost 60 HELCOM indicators in use and reported in this assessment (Table 1.1).

BOX 1.1.

HELCOM policy and work are guided by the ecosystem approach

Marine governance following the ecosystem approach places ecosystem dynamics at the heart of the management of human activities and grounds policymaking in a scientific understanding of the environment. It focuses on the structure and functioning of the ecosystem as a whole, highlights our dependency on the health of the ecosystem, and acknowledges that different parts of the ecosystem are linked to each other. Ecosystem-based management necessitates the development of comprehensive integrated policies reaching across sectors and management levels. With an integrated perspective to the management of human activities, ecosystem-based management aims to ensure successful and sustainable societal and ecological outcomes. HELCOM contributes to the operationalization of ecosystem-based management throughout the implementation of the HELCOM Baltic Sea Action Plan.

Table 1.1. List of HELCOM indicators used in HOLAS 3.

Indicator name	**Indicator category** (Core, Pre-core, Supplementary, Element and Driver)
Distribution of Baltic grey seals	Core
Distribution of Baltic ringed seals	Core
Distribution of Baltic harbour seals	Core
Population trends and abundance of grey seals	Core
Population trends and abundance of ringed seals	Core
Population trends and abundance of harbour seals	Core
Nutritional status of seals	Core
Reproductive status of seals	Core
Harbour porpoise distribution	Pre-core
Harbour porpoise abundance	Pre-core
Abundance of waterbirds in the breeding season	Core
Abundance of waterbirds in the wintering season	Core
Breeding success of waterbirds	Pre-core
Number of drowned mammals and waterbirds in fishing gear	Core
Abundance of coastal fish key functional groups	Core
Abundance of key coastal fish species	Core
Size structure of coastal fish	Core
Abundance of salmon spawners and smolt	Core
Abundance of sea trout spawners and parr	Core
Zooplankton mean size and total stock	Core
Seasonal succession of dominating phytoplankton groups	Pre-core
Diatom/Dinoflagellate index	Pre-core
State of the soft-bottom macrofauna community	Core
Cumulative impact from physical pressures on benthic biotope (CumI)	Core
Baltic Sea acidification	Element
Inputs of nitrogen and phosphorous to the sub-basins	Core
Total nitrogen concentrations	Core
Total phosphorus concentrations	Core
Dissolved inorganic nitrogen (DIN)	Core
Dissolved inorganic phosphorus (DIP)	Core
Chlorophyll a	Core
Cyanobacterial bloom index	Pre-core
Water transparency	Core
Oxygen debt	Core
Shallow-water bottom oxygen	Core
Cadmium	Core
Copper	Core
Lead	Core
Mercury	Core
Hexabromocyclododecane (HBCDD)	Core
Polybrominated biphenyl ethers (PBDE)	State
Perfluorooctane sulphonate (PFOS)	Core
Polychlorinated biphenyls (PCB) and dioxins and furans	Core
Polyaromatic hydrocarbons (PAH) and their metabolites	Core

Table 1.1. (Continued). List of HELCOM indicators used in HOLAS 3.

Indicator name	**Indicator category** (Core, Pre-core, Supplementary, Element and Driver)
TBT and imposex	Core
Diclofenac	Pre-core
Radioactive substances: Cesium-137 in fish and surface waters	Core
White-tailed sea eagle productivity	Core
Reproductive disorders: Malformed amphipod embryos	Supplementary
Oil-spills affecting the marine environment	Core
Beach litter	Core
Litter on the seafloor	Pre-core
Continuous low frequency anthropogenic sound	Pre-core
Distribution in time and space of loud low- and mid-frequency impulsive sounds	Pre-core
Trends in arrival of new non-indigenous species	Core
Driver Indicator name	**Indicator category**
Fishery Operations	Driver
Total Allowable Catch	Driver
Agricultural Nutrient Balance	Driver
Wastewater Treatment	Driver

1.3.3 Integrated and thematic assessments

The integrated assessments combine indicator evaluation results and data to produce more holistic overviews of specific topics.

Different integrated assessment tools have been developed to address several of the themes covered by the holistic assessments. The BEAT tool addresses the biodiversity theme, HEAT addresses eutrophication, and CHASE is designed for the integrated assessment of hazardous substances. These tools all use HELCOM indicators as their basis. The tool outputs show whether the integrated status is good or not in five assessment result categories. The results thus also provide an understanding of how far we are from reaching good status. Two assessment categories represent different levels of good status and three represent different levels of not good status. The tools also produce assessments of confidence in the results, reflecting the spatial and temporal data quality as well as the confidence in the methodology and evaluation.

The SPIA tool, which can be used to show the spatial distribution of pressures and impacts, does not use indicators as a basis for its assessment. Instead, it spatially plots and integrates data on ecosystem components, such as species or habitats, as well as human activities, together with the pressure they can exert and their potential impact on the environment.

The integrated assessment tools are presented in more detail in the thematic assessments on biodiversity (HELCOM 2023a), eutrophication (HELCOM 2023b) and hazardous substances (HELCOM 2023c). Thematic assessments directly supporting this holistic assessment also cover economic and social analyses (HELCOM 2023d) and spatial analyses of pressures and impacts (HELCOM 2023e, see also Table 1.2).

1.3.4 HELCOM spatial assessment scales

The HELCOM spatial assessment units divide the Baltic Sea into ecologically relevant divisions with the aim of reporting indicator evaluations and integrated assessment results at their most ecologically relevant scale under a shared and coherent approach (Figure 1.4). The system is nested, which means that spatial assessment units with higher spatial resolution can fit into units with lower spatial resolution (with a few minor exceptions). The applied levels of scale are:

- Level 1. HELCOM Marine area: The whole Baltic Sea, encompassing the entire HELCOM area,
- Level 2. HELCOM Subbasins: Division of the Baltic Sea into 17 subbasins,
- Level 3. HELCOM Subbasins with coastal and offshore divisions (national coastal areas)
- Level 4a. HELCOM Subbasins with coastal water types or water bodies aligned with the Water Framework Directive (WFD)
- Level 4b. HELCOM Subbasins with coastal WFD water types or water bodies with specific subdivisions for eutrophication assessment

In addition, assessments may be evaluated in aggregations of these assessment units where ecologically relevant (e.g., depending on population or species distribution extent).

1.3.5 Assessment period of HOLAS 3

The HELCOM holistic assessments provide recurrent updates on the state of the Baltic Sea over a given time period. Each HEL-

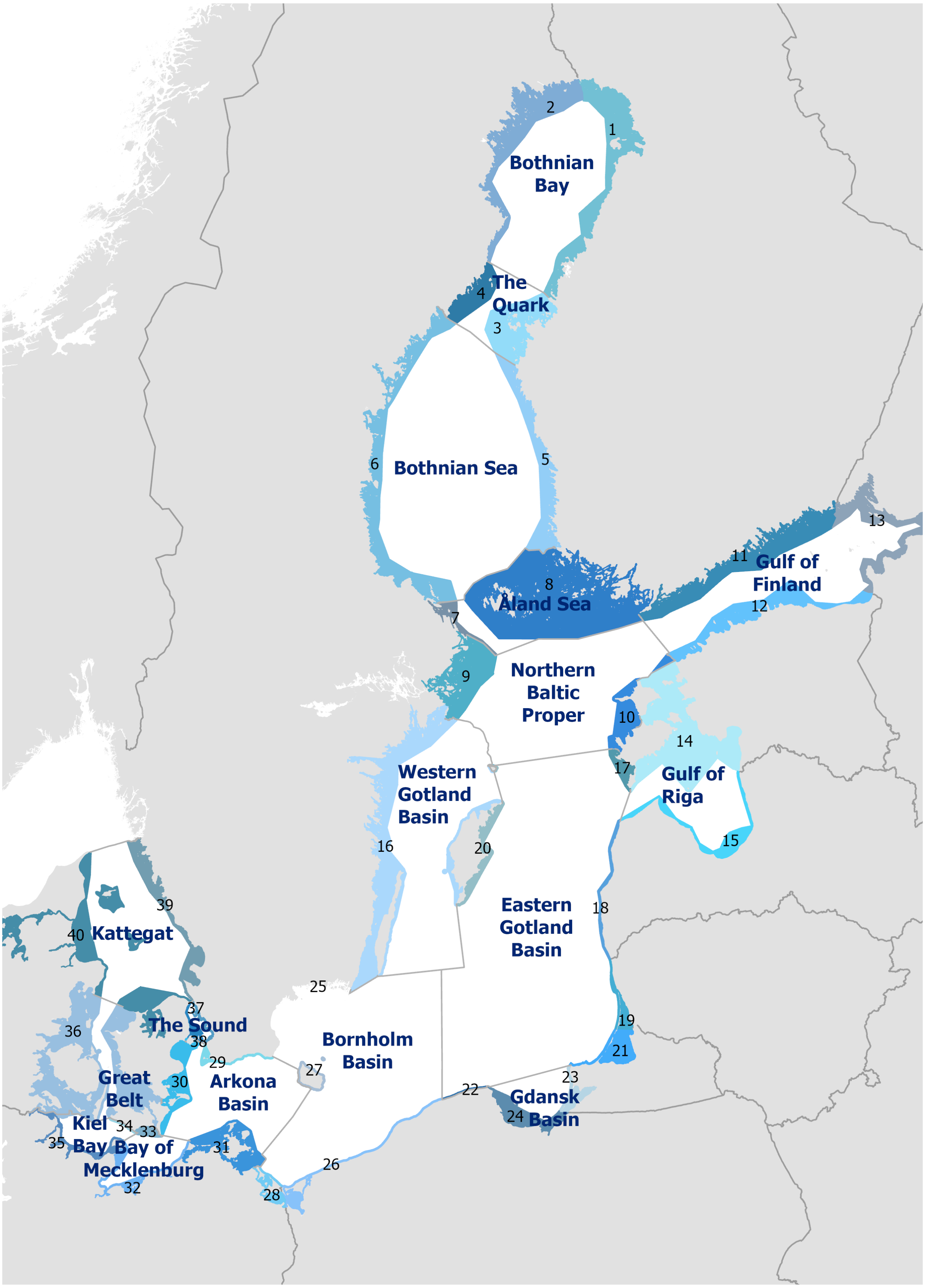

Figure 1.4. The spatial assessment units are a key tool for carrying out regional assessments coherently across the wide variety of topics and features of HOLAS while ensuring that each is assessed at an ecologically relevant scale.

Table 1.2. HOLAS 3 assessment products underpinning this summary report. In addition to these, introductory videos to explain concepts related to the assessments (developed primarily under the BLUES project) and other products to facilitate access to the HOLAS 3 results are available (see the State of the Baltic Sea website).

HOLAS 3 products
Thematic Assessments Reports: — Thematic assessment of biodiversity 2016-2021 — Thematic assessment of eutrophication 2016-2021 — Thematic assessment of hazardous substances, marine litter, underwater noise and non-indigenous species 2016-2021 — Thematic assessment of economic and social analyses 2016-2021 — Thematic assessment on spatial distribution of pressures and impacts 2016-2021
Updated data and data layers (HELCOM Map and Data Services)
59 indicator reports (see also Table 1.1)
HELCOM Metadata catalogue

COM holistic assessment covers a timespan of six years, referred to as the assessment period. The third HELCOM holistic assessment (HOLAS 3) focuses on the years 2016–2021. The HOLAS 3 assessment period partially overlaps with that of HOLAS II, which covered the period 2011-2016 (HELCOM 2018). The first HOLAS (HELCOM 2010) covered the years 2003-2007. These holistic assessments also aim to explore changes in status compared to prior assessment periods. Furthermore, the assessments reflect improvements in our understanding of how the components of the Baltic Sea ecological and societal systems are connected, incorporating enhancements in knowledge into each assessment.

1.4. How to read the summary report

The HELCOM holistic assessment is a multi-layered product representing varying levels of detail for each of the topics covered, and several assessment products underpin this summary report. Detailed data and results generated by national monitoring and regional data collection form the basis of the assessment, contributing to indicator evaluations. These, in turn, contribute to integrated results at overarching levels in the thematic assessments (HELCOM 2023a-e). This approach allows anyone to explore and utilise the results at whatever scale is most relevant while maintaining ecological relevance at the core.

The HELCOM indicator reports and thematic assessments directly underpin the results presented in this summary and offer more detailed and technical information (Table 1.2).

The aim of this summary report is to connect information from the underpinning assessment products to provide a more holistic view of the overall status of the Baltic Sea. The holistic approach strives to acknowledge the variety of roles that different species have in the ecosystems, as well as how they link together. The health and existence of each species in the Baltic Sea depends on interactions with several other species, habitats and environmental conditions, and each species fulfils certain ecological functions, many of which are vital for the ecosystem to function as a whole. An important implication is that the degradation of one element of the ecosystem, or the deterioration of one species, could damage other parts of the ecosystem. As will be evident from further reading, pressures and human-induced impacts can lead to modifications in the entire food web, leading to further reduced stability and resilience.

The summary report strives for a combined view and analysis of where we are today with the protection of the Baltic Sea environment and why the status is as it is. Our activities at sea and on land cause pressures on the marine environment, and these pressures have negative impacts on the species and habitats that we all depend for our survival and well-being. To keep the negative impact of our activities within the bounds that the ecosystem can tolerate, we must understand the effects of our actions and use that information to manage the activities that have a negative impact. This is accomplished by establishing well-founded and ecologically relevant targets and objectives to work towards and taking concrete measures to ensure we reach them. Figure 1.5 shows the management framework HELCOM works in and within which the holistic assessment is made. Observations of deteriorated species and habitats indicate the need for measures to stop the negative trends and restore ecosystems in order to realize sustainable outcomes for the natural environment and ourselves, now and in the future. The summary report aims to support further discussion and analysis of the actions we need to take to ensure a more sustainable future.

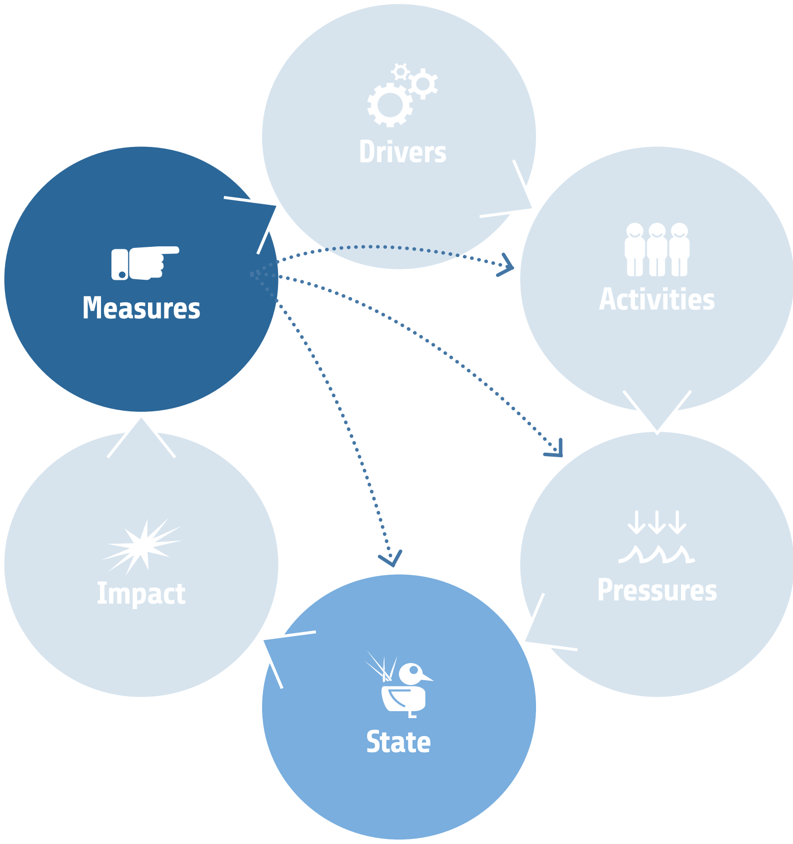

Figure 1.5. The conceptual management framework HELCOM works in and within which the holistic assessment is made. As a basis for further development of the holistic assessment, HELCOM has used a version of the Driver-Activities-Pressures-State-Impacts-Response (DAPSIR) framework, modified to fit the work under HELCOM and address the needs of the holistic assessment. This approach has been taken to strengthen the holistic aspect of the assessment, providing a clearer picture both of what we know across interlinked elements of the framework and of areas where further development or information is needed. In the modified management framework, Response has been replaced with Measures, reflecting the terminology used in the Baltic Sea Action Plan, and the definition of Impact has been expanded to include both perspectives presented in the assessment: impact on the environment and on society. The majority of the assessment work focuses on the environmental perspective (HELCOM 2023a, HELCOM 2023b, HELCOM 2023c, HELCOM 2023e), with the assessments presented under the Thematic Assessment on Economic and Social Analyses (HELCOM 2023d) representing the societal perspective.

2. This is the Baltic Sea

2.1. Biodiversity and the Baltic Sea

The Baltic Sea is one of the largest brackish water areas in the world, with a surface area of 420,000 square kilometres. More than one third of the Baltic Sea is shallower than 30 meters, resulting in a small total water volume in comparison to its surface area. Furthermore, the Baltic Sea has no tides and is relatively isolated from other seas. These distinctive environmental conditions form the setting for the unique biodiversity patterns that prevail in the Baltic Sea region.

The water exchange in the Baltic Sea is slow; it takes approximately thirty years for its waters to be fully exchanged (Stigebrandt 2001). Marine water masses enter the Baltic Sea from the North Sea, predominantly during winter storms, while freshwater runs in from numerous rivers. These flows contribute to the characteristic brackish water gradient of the Baltic Sea, with a gradual decrease in salinity from around 15–18 (psu) at the surface in its entrance in the Sound, to 7–8 in the Baltic Proper and 0–2 in the northern and eastern parts. Salinity also changes with depth, because high salinity water is denser than water of lower salinity. Many Baltic Sea sub-basins are stratified, with higher salinity water in a deeper layer and lower salinity water above (Meier *et al.* 2023).

The salinity conditions of today's Baltic Sea began only around 2,000 years ago (Emeis *et al.* 2003). Before then, the salinity had been decreasing over a period of a few thousands of years. The geological history of the Baltic Sea as we know it started around 12,000 years ago when the Scandinavian ice sheet retreated at the end of the Weichselian glaciation. The sea area went through different configurations characterised by either freshwater or marine/brackish water, depending on how much it was connected to outer seas (Harff *et al.* 2011). The current opening from the Baltic Sea to the North Sea was established between 7,500 and 4,000 years ago. Before this, the connection to the North Sea was wider. Land upheaval has caused the connection to narrow (Leppäranta and Myrberg 2009).

The Baltic Sea also has other distinct characteristics. It is regularly covered by ice in the winter, and even though the sea is shallow, the water at the bottom remains cold during the summer. In general, the water is more turbid than oceanic water. The photic layer, in which photosynthesis is possible, is narrower than in the oceans.

There are clear geographical patterns in biodiversity across the region. The Baltic Sea ecosystem includes both marine and freshwater species, which can tolerate the brackish conditions. In several coastal areas, marine and freshwater species may live side by side and interact within the same food web. However, the brackish water conditions limit the distribution range of many aquatic species. The low salinity limits the distribution into the Baltic Sea of many marine species, while the range of many freshwater species does not extend into waters with too high salinity for them. This creates a salinity-driven gradient in biodiversity (Figure 2.1). The overall number of species decreases from south to north. In total, the Baltic Sea has around 5,000 known species (HELCOM 2017), out of which just over 3,000 are macro-species (species that are visible to the naked eye; HELCOM 2020a). The species form a variety of populations and subpopulations which interact to create the unique ecosystem that is the Baltic Sea. While these numbers may seem high, they are low in comparison with most other sea areas. Because many Baltic Sea species live at the edge of their salinity tolerance, any further changes in their living environment can radically alter their abundance or growth. The structure of the communities could change significantly in response to even a small change in environmental conditions.

In many cases, the species of the Baltic Sea are genetically distinct from their counterparts in other areas. Most Baltic species of marine origin likely originate from a time when this region was saltier. As the salinity has decreased over the past few thousand years, these species have faced the formidable challenge of adapting to the novel conditions or becoming locally extinct (Russell 1985). Modern methods of population structure analysis make it possible to study evolutionary adaptation processes in detail. There are several examples of marine species in the Baltic Sea undergoing genetic diversification and ecological adaptation on a very rapid timescale from an evolutionary perspective (Johannesson and André 2006, Pereyra *et al.* 2009). Two endemic species to the Baltic Sea have been identified, the narrow wrack (*Fucus radicans*; Bergström *et al.* 2005) and the Baltic flounder (*Platichthys solemdali*, Momigliano *et al.* 2018).

A highly varied geomorphology contributes further to creating a mosaic of unique habitats and biodiversity conditions across the region. The southern coasts are often characterized by sand, whereas rocky and moraine shores are a common feature in the north. Overall, these conditions make the Baltic Sea exceptional in terms of its biodiversity (Figure 2.2). There is no other sea like it in the world. The ecosystems of the Baltic Sea are simultaneously very unique and very vulnerable.

We humans are an integral part of the natural world and entirely dependent it for our survival. In the Baltic Sea region, and around the world, we depend on healthy ecosystems in our daily lives, often in ways that are not directly apparent or appreciated. As biodiversity is essential for the natural processes that support all life, biodiversity status is a key indicator of the health of an ecosystem. Maintaining a good state of biodiversity ensures the ecosystems' resilience and productivity, as well as their capacity to adapt to future environmental changes. Each unit and level of biodiversity fulfils a multitude of necessary functions in a complex network. Without healthy populations of a wide range of animals, microorganisms, plants and algae, we cannot have the healthy ecosystems that we rely on. However, despite its ecological, cultural and economic importance, biodiversity is still being degraded and lost in the Baltic Sea region, and the importance of functioning ecosystems for human well-being is too often underestimated or poorly recognized in planning and decision-making.

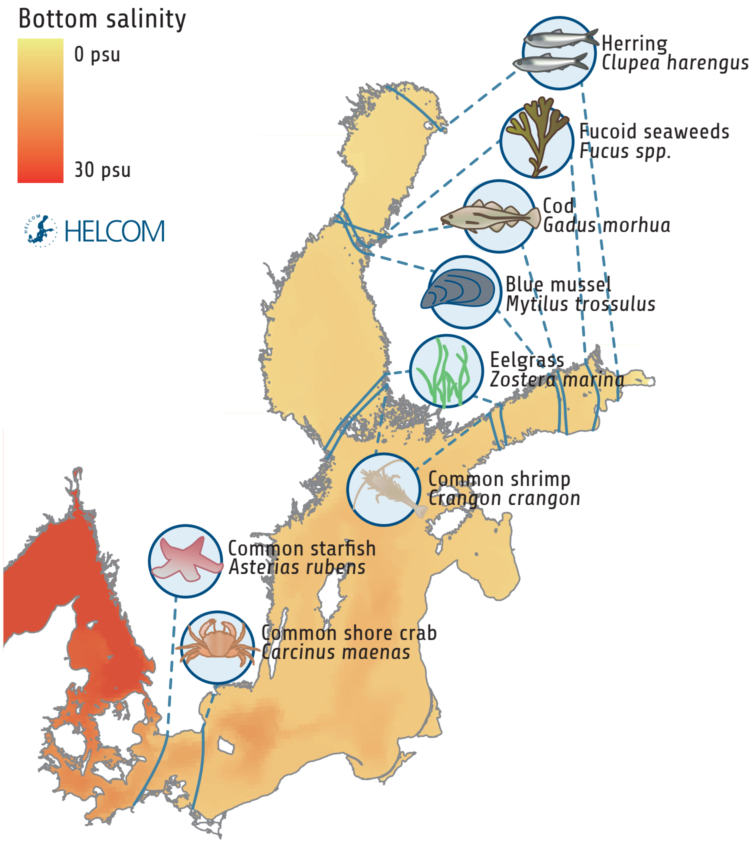

Figure 2.1. The clear majority of the macrospecies in the Baltic Sea are benthic invertebrates. The other main species groups are macrophytes (including algae, vascular plants and bryophytes), followed by fish. Phytoplankton diversity includes the currently known planktonic microalgae and cyanobacteria.

Figure 2.2. Species in all parts of the food web are affected by changes in the Baltic Sea environment.

2.2. How is climate change affecting the Baltic Sea?

Climate change has global impacts on biodiversity and ecosystem health (IPCC 2023), and effects of climate change are also evident in the Baltic Sea today: the water temperature is rising, the ice extent is decreasing, and annual mean precipitation is increasing over the northern part of the region. Ongoing changes in the climate are having significant impacts on the Baltic Sea ecosystem, and this is expected to continue in the near future (HELCOM and Baltic Earth 2021, see also Box 2.1). All these changes affect the sea, its ecosystems and ecosystem services, as well as human activities that depend on these.

The effects of climate change are complex and could differ between parts of the Baltic Sea region (Meier *et al.* 2022). This complexity is further exacerbated by a system of feedbacks between climatic and non-climatic factors, as well as between different parts of the ecosystem (Figure 2.3). Climate change contributes to the cumulative pressure from multiple environmental and human-induced pressures. The effects of climate change can therefore in some cases be difficult to distinguish from certain human pressures (HELCOM/Baltic Earth 2021).

BOX 2.1.

Work on climate change knowledge in HELCOM

The joint HELCOM/Baltic Earth Expert Network on Climate Change (EN Clime) functions as a coordinating platform to connect leading scientists with expertise on the direct and indirect effects of climate change on the Baltic Sea environment. A key role of the platform is to make this expertise available to policymakers and create a space for closer dialogue. The network aims to ensure that new scientific findings on climate change and its impacts on oceans and seas are visible in HELCOM and find their way into HELCOM decision-making and day to day work. Among other things, the Expert Network produces and delivers scientific products on climate change, such as the climate change fact sheet (HELCOM and Baltic Earth 2021) and supporting material.

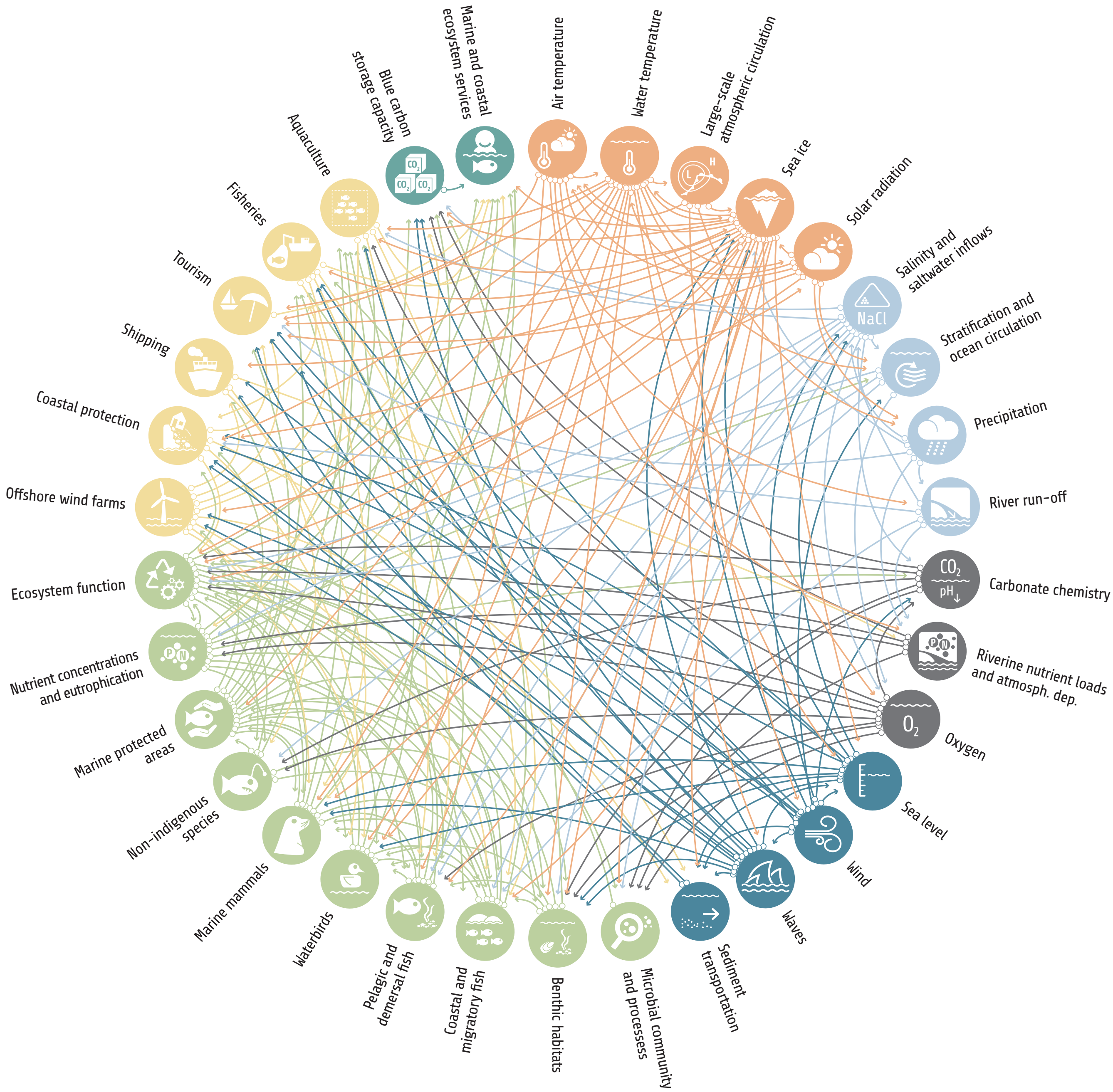

Figure 2.3. The Baltic Sea is facing complex effects and feedbacks between climatic and non-climatic factors, as well as between the effects of climate change on different parts of the ecosystem. Source: HELCOM/Baltic Earth 2021.

The Baltic Sea region is located between two climate zones, the maritime temperate and the continental subarctic climate zones. The opposing effects of moist and relatively mild marine airflows from the North Atlantic Ocean and the Eurasian continent make the climate of the region variable; the prevailing weather regime varies depending on the exact location of the polar front and the strength of the westerlies, and there are considerable seasonal and inter-annual variations (Meier *et al.* 2022).

The future climate projections with the greatest certainty show that the water temperature and sea level will rise, whereas sea ice cover will decrease. Such changes are already occurring in the Baltic Sea environment (Figures 2.3-2.5) and are linked to changes in the Baltic Sea ecosystem in various ways (Figures 2.6-2.7). Model scenarios are still uncertain about future changes in Baltic Sea salinity, although they show a tendency towards reduced salinity. The uncertainties relate to factors such as regional winds, the water cycle and global sea level rise. Increased oxygen deficiency is also expected (Meier *et al.* 2022). The scenario simulations, further, suggest that Baltic Sea water may become more acidic in the future, although these predictions depend on several uncertain factors, such as future emissions of pollutants that contribute to acidification. Changes in oxygen, salinity and acidity are likely to erode the resilience of the Baltic Sea ecosystem and affect the survival or distribution of its species.

How climate-related factors will develop further over time is tightly linked to changes in our society. In order to obtain realistic projections for the Baltic Sea, further work is needed on the scenarios and models that evaluate the relative importance of several drivers together (i.e. multiple or cumulative effects), as opposed to looking at climate change in isolation. This calls for a broad perspective that also considers factors such as changes in emissions, demographic and economic changes, and changes in land use. The evaluation of the effects of climate change on the ecosystem is also dependent on how other environmental drivers and pressures develop (Figure 2.4). Atmospheric and aquatic pollution and eutrophication, overfishing, and changes in land cover are all aspects that interact with climate-related changes to affect the environment (Meier *et al.* 2022).

Figure 2.4. The combination of biodiversity degradation and climate change creates a particularly challenging situation for plant and animals to adapt to changing environmental conditions.

2.2.1 Trends in temperature in the Baltic Sea

Changes in air temperature is the main driver of changes in water temperature (Dutheil *et al.* 2021). Around the globe, marginal seas have warmed faster than the global ocean since the 1980s, and of these, the Baltic Sea has warmed the most (Belkin 2009). The surface water temperature has increased the fastest (Figure 2.5) and the heat spreads downward with time, eventually warming the whole water column (Meier *et al.* 2022). Monitoring data, satellite data and model-based historical reconstructions indicate an increase in the annual mean sea surface temperature of 0.4–0.6 C° per decade (averaged over the Baltic Sea), or around 1–2 Co since the 1980s. Without excluding internal variability, warming trends have recently accelerated tenfold (Meier *et al.* 2022).

In the future, the northern part of the Baltic Sea is expected to have higher water temperatures, a shallower mixed layer with a sharper thermocline during the summer, less sea-ice cover and greater mixing during the winter than today. Both the frequency and duration of marine heat waves will increase significantly in the Baltic Sea, in particular in the coastal zone, except in regions with frequent upwelling (Meier *et al.* 2022).

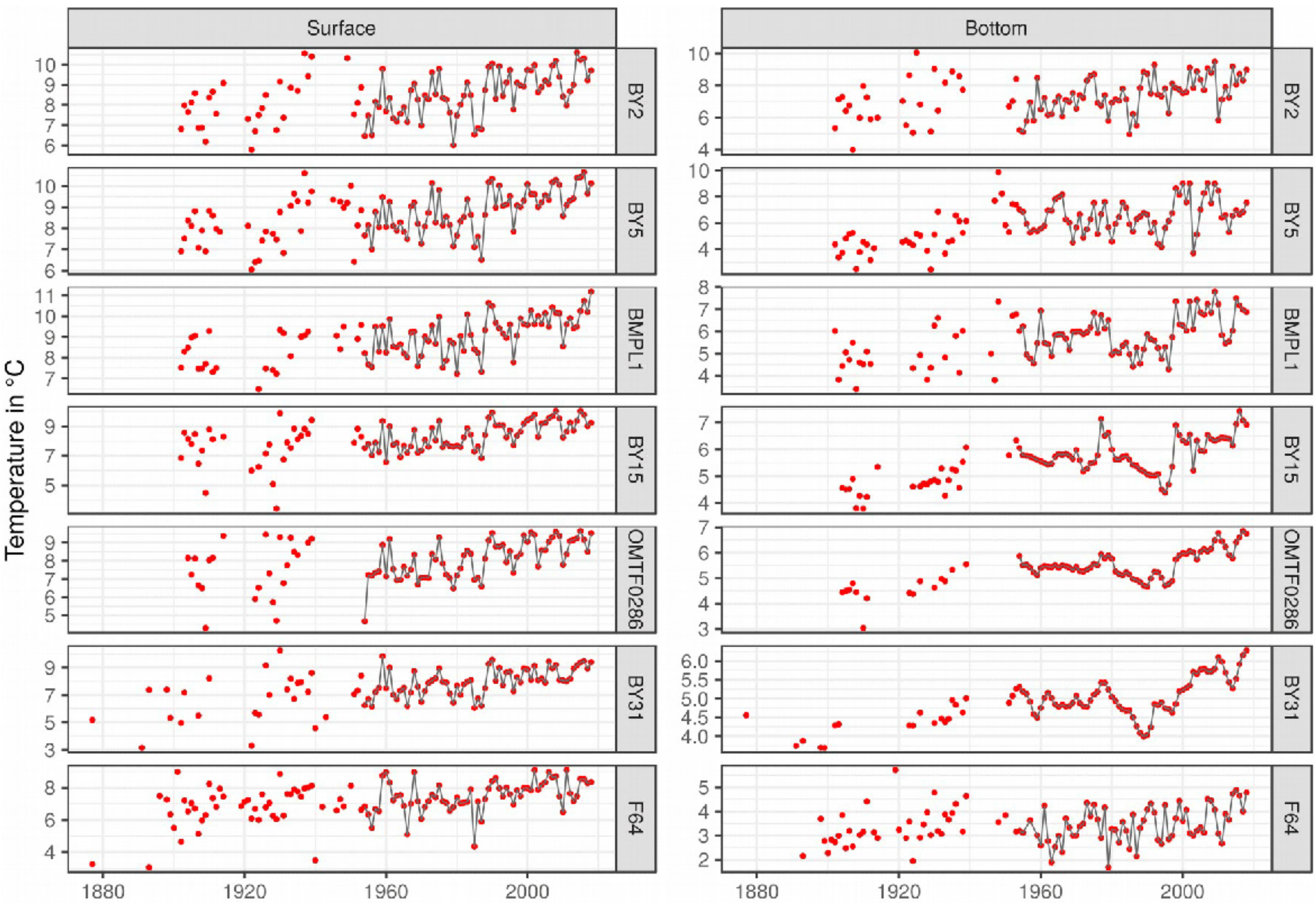

Figure 2.5. Changes in temperature. Annual mean values of daily sea surface temperature (left column) and bottom temperature (right column) at seven monitoring stations in the Baltic Sea during 1877–2018 (red dots). The grey lines indicate the period when every station has data for every year (1954–2018). The data shown has been post-processed to overcome possible seasonal biases due to missing values in the observations. For data sources and more details, see Meier *et al.* (2022).

2.2.2 Trends in ice cover in the Baltic Sea

The maximum extent of sea ice in the winter is an important key indicator of climate change in the Baltic Sea region. On average, around 40 % of the total Baltic Sea area is covered by ice in the winter (including the Kattegat and Skagerrak), which corresponds to about 170,000 square kilometres (Finnish Meteorological Institute 2023). Mild ice winters are defined as having a maximum ice cover of less than 130,000 square kilometres. The frequency of mild ice winters has increased from 7 years within the 30-year period 1950-1979 to 16 years within the 30-year period 1993-2022, whereas the frequency of severe ice winters (at least 270,000 square kilometres of ice) has decreased from 6 years to 1 year during the same periods (Figure 2.6). An extremely mild winter occurred in 2015, during which the Bothnian Bay was not fully covered by ice and the maximum extent in the Baltic Sea was 51,000 square kilometres. In the winter of 2020, the maximum ice extent was only 37,000 km^2, the lowest value since the start of the time series in 1720 (Finnish Meteorological Institute 2023) (Figure 2.7).

The trend of decreasing sea ice extent in the Baltic Sea exceeds natural variability so much that it can only be attributed to global climate change (Meier *et al.* 2022). Baltic Sea ice extent and thickness are projected to continue to shrink significantly. The best estimate of the decrease in maximum ice extent over the 21st century is 640km2/year for a medium emissions scenario (RCP4.5). For a high emissions scenario (RCP8.5), the decrease is estimated to be 1,090km2/year with largely ice-free winters by the end of the century (Luomaranta *et al.* 2015).

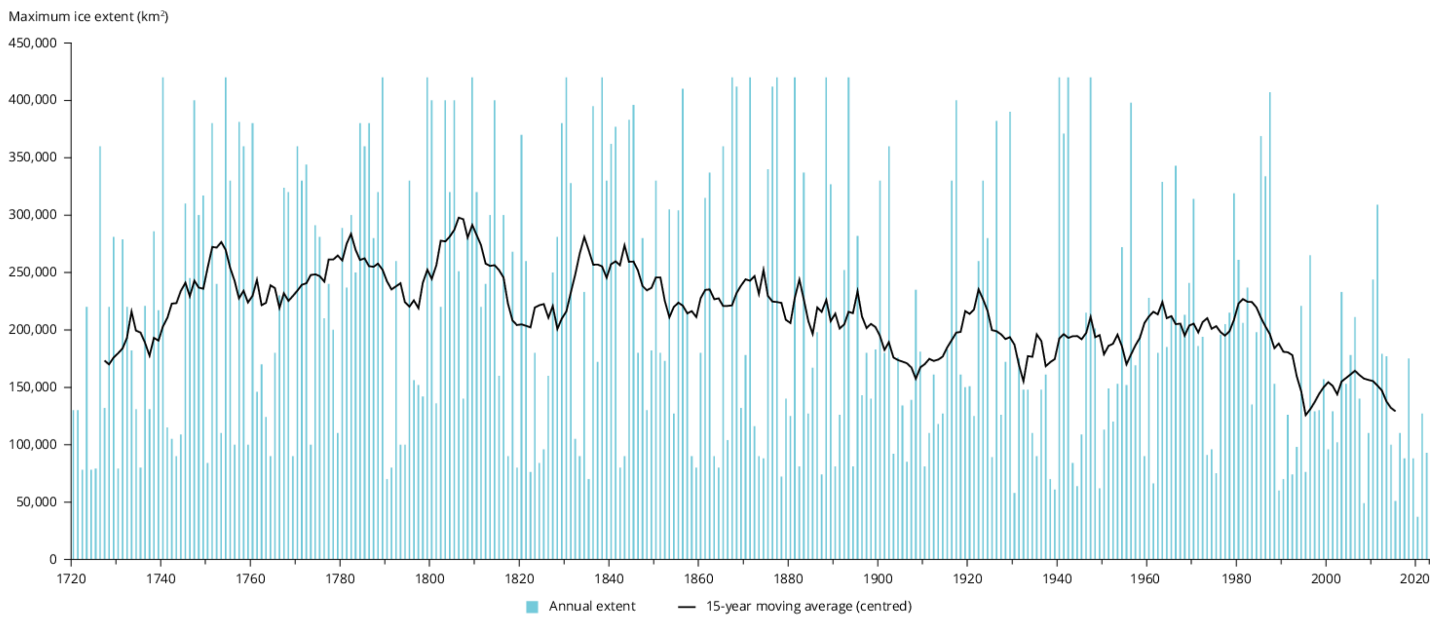

Figure 2.6. Changes in the maximum extent of ice cover in the Baltic Sea in the winter. The line shows a 15-year moving average. Source: EEA 2022.

Figure 2.7. Ice conditions in the winter is an important indicator of climate change in the Baltic Sea

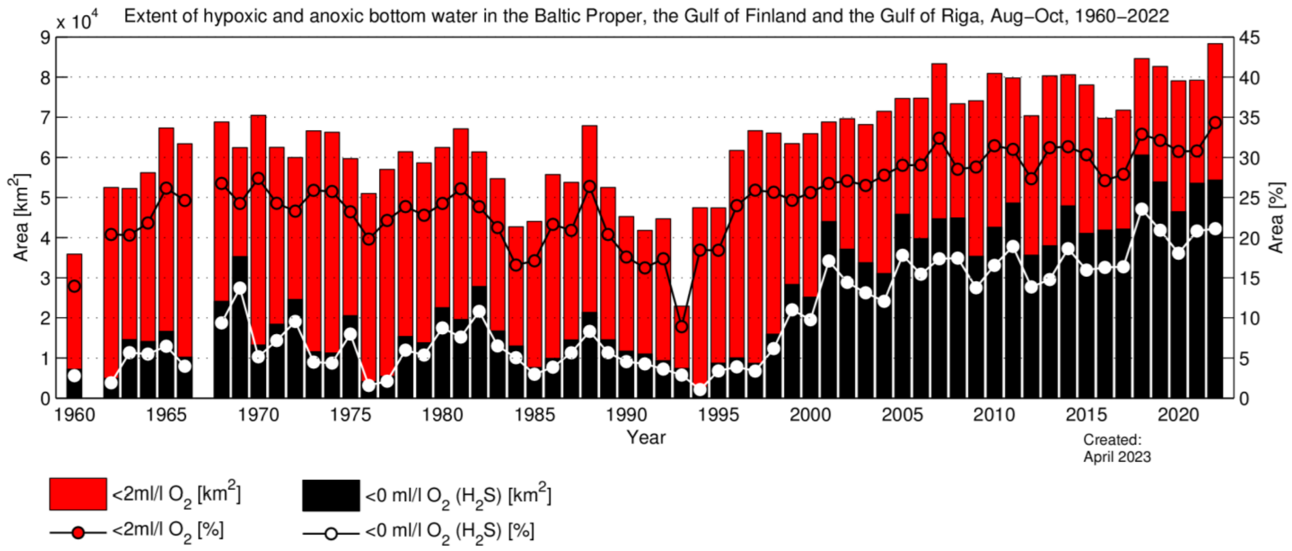

Figure 2.8. The extent of areas with hypoxic (<2 mL O_2 L^{-1}) and anoxic (<0 mL O_2 L^{-1}) bottom water in the Baltic Proper, the Gulf of Finland, and the Gulf of Riga during regular cruises in August–October during 1960–2020. Source: Hansson and Viktorsson 2023.

2.2.3 Effects of climate change on biogeochemical cycling and oxygen conditions

The impact of climate change on biogeochemical cycling is predicted to be considerable, but smaller than the impacts of nutrient inputs, even when recent nutrient reductions are considered.

Even in a future climate, implementing the nutrient reduction targets of the Baltic Sea Action Plan for the entire catchment area is expected to result in a significantly improved environmental status of the Baltic Sea, including a reduced hypoxic area (Figure 2.8). This would also increase the resilience of the Baltic Sea against climate change (Meier *et al.* 2022).

The areal cover of sea bottoms with no oxygen or poor oxygen conditions is considerably higher today compared to when the first oxygen measurements in the Baltic Sea were taken. In 2016, the maximum extent of areas with poor oxygen conditions (hypoxia) in the Baltic Sea was about 70,000 square kilometres, whereas it was presumably very small or even absent 150 years ago (Gustafsson *et al.* 2012, Carstensen *et al.* 2014a, b, Meier *et al.* 2019). Hypoxia is mainly caused by increased nutrient inputs from the land and atmospheric deposition, leading to eutrophication (Chapter 4). Other drivers, such as warming or sea level rise, have a smaller, though still important, impact (Carstensen *et al.* 2014a, Meier *et al.* 2019). On annual to decadal timescales, variations in the halocline also have a considerable influence (Conley *et al.* 2002, Väli *et al.* 2013).

2.3. Human uses of the Baltic Sea

The Baltic Sea countries benefit considerably from their utilization of the Baltic Sea, both economically and socially. Nine countries share the borders of the Baltic Sea, namely Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, Poland and Germany. Another five countries are partly located within its drainage area (Figure 2.9). In total, around 85 million people live within the drainage area of the Baltic Sea. The benefits we receive from the Baltic Sea include jobs, income and natural resources, as well as various contributions to personal well-being. We all depend on biodiversity in our daily lives in ways that are not always directly apparent or appreciated.

Figure 2.9. The Baltic Sea and its drainage area.

As one example, plants and algae take up nutrients from seawater as part of their normal growth, and they in turn serve as food for other species, supporting the production of fish, for example. But the storage of nutrients in tissues of long-lived plants and algae can also contribute to the regulation of excess nutrients stemming from human activities. The nutrients can become bound for a longer period if the organic materials are buried in soft bottom sediments. Such sequestration of nitrogen and phosphorus has an estimated worth of nearly 10.5 billion euros per year in costs saved for the countries surrounding the Baltic Sea (HELCOM 2023d). Some of the nutrients are also removed from the aquatic system by activities such as fishing. Similarly, the marine ecosystem can regulate carbon flows, as carbon is bound in plants and animals or accumulated in bottom sediments (Figure 2.10). The monetary benefits of carbon sequestration range from 622 to 1,554 million euros on average per year in the Baltic Sea region, based on an annual sequestration of 4.23 million tonnes of carbon in total.

A good biodiversity status and ecosystem functions are also essential for human well-being in several other ways. Primary producers and animals at different levels of the food web form the basis as prey for fish, birds and mammals, which could not exist without them. These structures are essential to humans, for food provision, supporting recreation, enabling cultural values, and more. Fishing is among the most traditional livelihoods and is widely distributed globally, including in the Baltic Sea region.

Figure 2.10. The variety of habitats in the Baltic Sea contribute to biodiversity and to a wide range of ecosystem services of importance for humans. © Juuso Haapaniemi

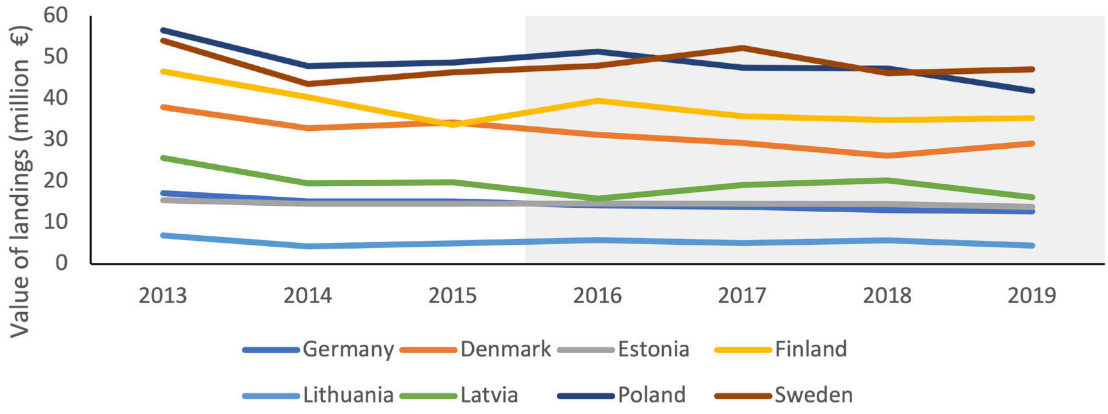

Figure 2.11. Value of landings (million €) 2013 – 2019. Shading indicates the years included in the HOLAS 3 assessment period. Source: STECF 2021b. All monetary values have been adjusted for inflation; constant prices (2015) using Eurostat (2022i). STECF does not report on Russia.

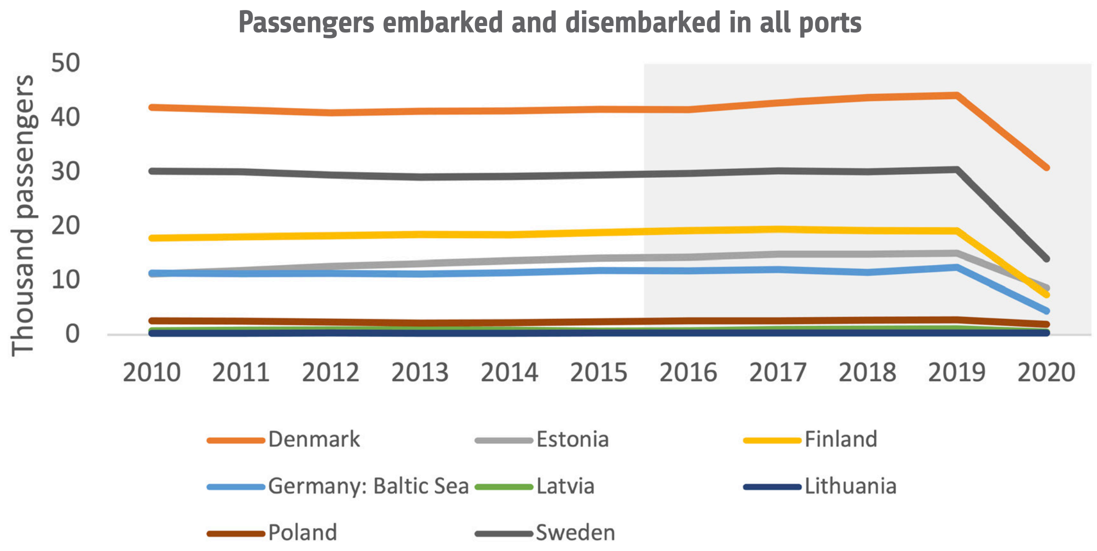

Figure 2.12. Passengers embarked and disembarked at all ports (thousand persons) 2011 – 2019. Shading indicates the years included in the HOLAS 3 assessment period. Source: Eurostat 2022e. Eurostat does not report on Russia.

However, humans use marine waters in a wide variety of ways with different characters. While some activities, such as fishing and most recreational activities, depend on the state of the marine environment, others do not, such as maritime transport and construction (Bryhn *et al.* 2020). Furthermore, activities can rely on the extraction of tangible resources, the use of space, or on intangible resources connected with how we, as humans, experience the sea.

The fishing sector depends on healthy fish stocks of a harvestable size for its well-being and long-term sustainability. Many Baltic fish stocks are currently in an especially bad state and, moreover, have a negative forecast, which affects the profitability of the fishing sector (STECF 2022). The total value of landings in Baltic Sea countries has been unchanged or has slowly declined during the current assessment period (Figure 2.11). Sweden and Poland have had the largest values of landings. Around 4,000 full-time equivalent jobs remain in the Baltic Sea fisheries, of which more than half are in Poland. Overall, the Baltic region's small-scale coastal fishing fleets have negative gross and net profit margins, which differs from other marine regions within the EU (STECF 2022).

Marine transport encompasses both marine transport infrastructure and the shipping sector. The infrastructure sector includes ports and the activities to maintain ports and their services, such as dredging and cargo handling, while shipping includes the transportation of freight or passengers by sea. The gross weight of goods handled by ports in the Baltic Sea countries has been relatively constant over the past decade, with the exception of a notable increase in Poland. Passenger volumes were also relatively unchanged overall, aside from a clear drop in 2020 reflecting the impact of the COVID-19 pandemic (Figure 2.12). Employment in shipping has been relatively stable over the past decade, with only minor fluctuations, while the added value has shown larger changes (HELCOM 2023d).

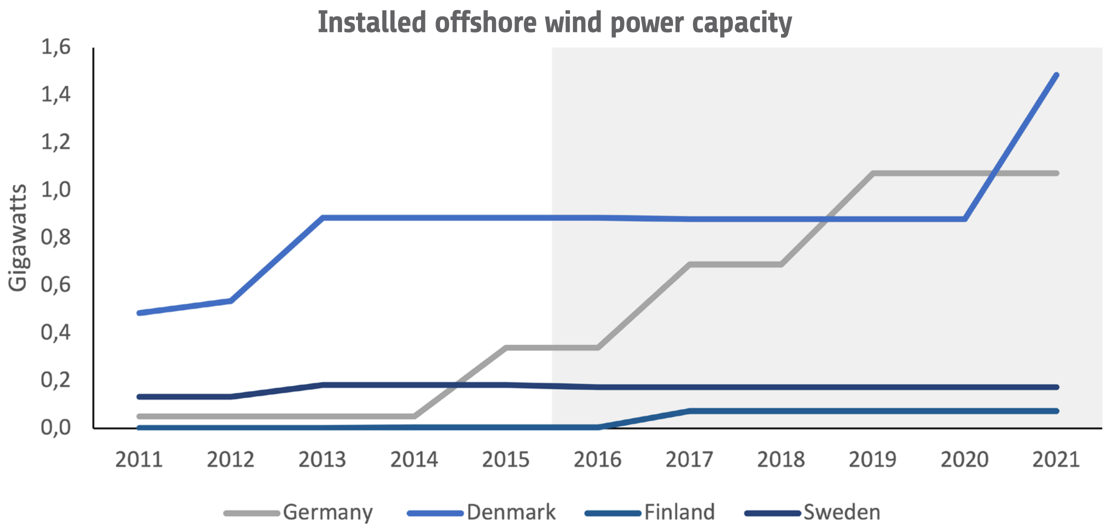

Figure 2.13. Installed offshore wind power capacity 2011 – 2021. Shading indicates the years included in the HOLAS 3 assessment period. Source: Eurostat 2022g, EMODnet 2022a. Eurostat does not report on Russia. See also Figure 5.6.

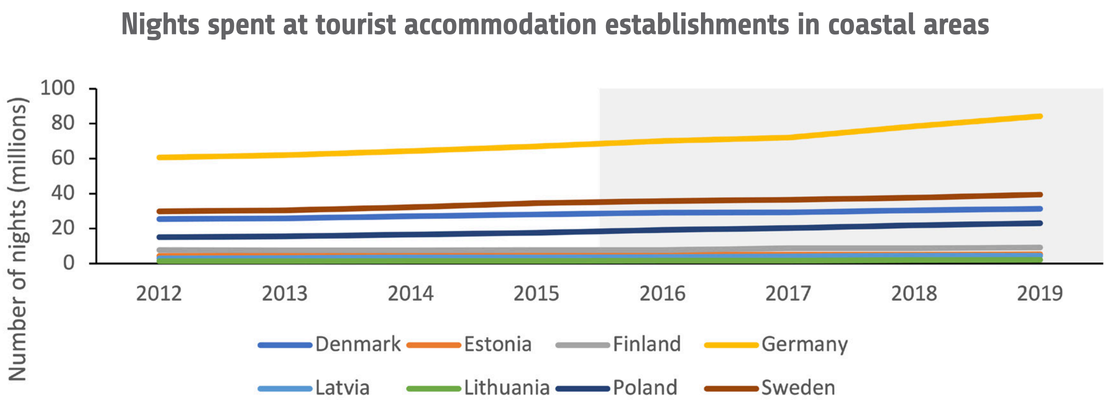

Figure 2.14. Number of nights spent at tourist accommodation establishments in coastal areas (million nights) 2012 – 2019. Shading indicates the years included in the HOLAS 3 assessment period.

Figure 2.15. The importance of healthy and functioning ecosystems for human well-being is too often underestimated or poorly recognized in planning and decision-making. To realize the sustainable use of marine ecosystems, we must find a balance between the values we extract from the environment and the negative impact we cause.

The Baltic Sea is a growing source of renewable energy from offshore wind farms. During the HOLAS 3 period, Germany joined Denmark as a major producer of electricity from offshore wind in the Baltic Sea (Figure 2.13). Increased renewable energy is included in the maritime spatial plans of most Baltic Sea countries, with additional capacity currently approved or under construction. At the European level, the EU strategy on offshore renewable energy recognises that Europe is in a unique position to develop offshore renewable energy because of its large maritime space and the variety and complementarity of its sea basins, and the strategy proposes ways forward to support the long-term sustainable development of the wind energy sector (EC 2020a).

Tourism and recreation are important sectors in the Baltic Sea region, although they are not always easy to quantify. For example, the coastal and marine tourism sector includes accommodation, food and drink, but also services, such as boating, water sports, recreational fishing, nature watching and beachside recreation. Though most coastal and marine tourism activities depend at least partly on the quality of the marine environment, the level of dependence varies. Altogether, the value of the recreational benefits for the Baltic Sea countries amounts to at least 33.7 billion euros on average per year, conservatively estimated (HELCOM 2023d, based on Ahtiainen *et al.* 2022). Germany and Poland have the largest total benefit, while the benefit per person is largest in Denmark, Sweden and Finland. The number of nights spent at tourist accommodations in coastal areas is used as a proxy for developments in tourism and recreation over time (Figure 2.14). Over the past decade, the number of accommodation nights has increased in the Baltic Sea countries, increasing by more than 50% in for example Latvia, Lithuania and Poland. The annual value added and the level of employment in the tourism industry also increased during this period.

However, our use of the sea also puts pressure on the marine environment. This can cause environmental degradation which, in turn, reduces human well-being. Pressure on marine ecosystems from human activities can deteriorate their status, affecting biological communities and entire socioeconomic systems locally or at wider geographical scales (Österblom *et al.* 2017). The degradation of environmental conditions reduces the ability of marine ecosystems and food webs to maintain important ecological functions. This also impairs the capacity of these ecosystems to produce services that support human well-being (Beaumont *et al.* 2007, Micheli *et al.* 2013, Bryhn *et al.* 2020). Economic and social analyses linked to the status of the marine environment provide several valuable perspectives on the close relationships between society and ecosystems (Box 2.2).

Ecosystem services is the collective name for the variety of contributions that ecosystems make which could benefit human society (Potschin & Haines-Young 2016b). Functions and processes in ecosystems provide a wide range of goods that are appreciated by humans, such as wild fish and algae for nutrition, along with benefits that are necessary for our well-being, such as carbon sequestration. We also gain considerable non-material benefits from interacting with the ecosystem, like recreation. The concept of ecosystem services supports environmental policy and management by helping us understand and conceptualize the full range of connections between ecosystems and human well-being.

Cost of degradation is a term that refers to benefits that are lost to society because of a failure to achieve good environmental status. The term includes losses related to both the direct use of marine resources and non-use values, which are values people gain from the marine environment even if they do not use it directly, for example value from the existence of marine biodiversity (Figure 2.15). Reaching good environmental status in national marine waters by 2040 is estimated to be collectively worth 5.6 billion euros per year to people around Baltic Sea, based on individuals' stated willingness to pay for improved environmental conditions (HELCOM 2023d). As another example, degraded environmental conditions are estimated to cost the region's population 9 billion euros annually in terms of forgone recreational benefits. In the first example, benefit transfer was required to generate estimates for five of the nine Baltic Sea countries, and in the second example for six of the countries, which increases the estimates' uncertainty. These estimates give overlapping perspectives on the cost of environmental degradation in the Baltic Sea and should therefore not be summed.

BOX 2.2.

Social and economic analyses

The relationship of humans to nature is multifaceted. On the one hand, our well-being and prosperity depend on a healthy and thriving environment that supports our health, our economies and our overall quality of life. At the same time, our activities to derive these benefits often have negative impacts on our environment. This creates a dynamic tension between the desire to preserve the natural world and the need to use it for our own benefit.

Economic and social analyses help navigate this tension by accounting for the environmental and societal impacts and values of different courses of action. The analyses strive to clarify both the ways our society benefits from using the sea and the negative impacts our activities have on the ecosystem. Although there are typically no absolute answers, the analyses support decision-making by clarifying how our actions affect us in the short- and long-term through their impacts on ecosystems.

Developing economic and social analyses at the international scale involves continuous effort to improve the available data and methodologies. Promising tools currently in use and under development for regional work in HELCOM are ecosystem accounting, ecosystem services and cost-benefit analyses (HELCOM 2023d). Together, these can provide a transparent and sound framework for charting a course towards a more sustainable future.

The HELCOM Baltic Sea Action Plan (HELCOM 2021) includes eight actions targeted towards improving the quality and integration of economic and social analyses in decision-making. The broad objective of the UN Sustainable Development Goals is the improvement of economic and social equity, and nearly all EU environmental directives require addressing economic, social and cultural aspects. For instance, the EU Marine Strategy Framework Directive requires Member States to carry out economic and social analyses of the use of marine waters and the cost of degradation, and to consider the social and economic impacts of planned measures for protecting the marine environment (EC 2008). Hence, economic and social analysis plays a crucial role in the practical implementation of environmental protection, and in several policies related to management of the marine environment.

3. The status of biodiversity in the Baltic Sea

3.1. What is at stake for biodiversity?

The triple planetary crisis refers to the three main interlinked issues that humanity currently faces (UNEP 2021) . The climate crisis, the pollution crisis and the biodiversity crisis are three intersecting and global environmental crises, and the first two are exacerbating the third. Addressing these crises will require a transformative change in the relationship between people and ecosystems (EU 2020c). Biodiversity is essential for the processes that support all life on Earth, including humans. Biodiversity loss is thus one of the biggest global threats to humanity today, and marine biodiversity is no exception. On the other hand, restored and properly protected marine ecosystems can bring substantial health, societal and economic benefits.

Updated biodiversity status assessment results for the Baltic Sea clearly show the need for continued and improved coordinated measures for its environment and biodiversity (Box 4). Species and communities at all levels of the food web have at least partially inadequate environmental status across the full spatial extent of the Baltic Sea, as presented in summary here and in full detail in the HELCOM thematic assessment of biodiversity in the Baltic Sea (HELCOM 2023a). Only a few indicators have acceptable levels in parts of the region, and none in all assessed areas. The deteriorated status is of immediate concern for the affected species, but deteriorated status of individual species also leads to impacts on ecosystem processes through the connections among species and populations in the food web. Hence, deteriorated biodiversity status also has implications for the capacity of the Baltic Sea to support our human well-being.

The HELCOM vision is a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in good ecological status and supporting a wide range of sustainable economic and social activities.

In the Baltic Sea Action Plan, a central goal for biodiversity is:

— *A Baltic Sea that is healthy and resilient*

Through the actions in the 2021 Baltic Sea Action Plan, HELCOM countries have declared their firm determination to preserve the ecological balance of the Baltic marine environment, to ensure the possibility for it to self-regenerate, and to take all appropriate measures to conserve and protect the natural habitats, biological diversity and ecological processes of the Baltic Sea by 2030 at the latest.

3.2. The status of biodiversity in the Baltic Sea

The integrated assessment of biodiversity gives an overview of the status of key biodiversity components, namely pelagic habitats, benthic habitats, fish, marine mammals and waterbirds, across the Baltic Sea ecosystem during the assessment period 2016-2021. The results of the assessment are presented in maps showing the status for different areas of the Baltic Sea, which helps identify priority topics and areas for further action. These results can be further explored by examining the indicators which underpin the integrated results and looking into how areas of concern are affected by var-

BOX 3.1.

The HELCOM biodiversity assessment

The thematic assessment of biodiversity in the Baltic Sea (HELCOM 2023a) presents the environmental status of components relating to the biodiversity segment of the 2021 HELCOM Baltic Sea Action Plan. Based on regionally agreed data, indicators and integrated assessment approaches, HELCOM experts have produced evaluation results for five principal ecosystem components of the Baltic Sea, namely pelagic habitats, benthic habitats, fish, marine mammals and waterbirds. Regionally agreed indicators or methods for evaluating the status of food webs are still not available, but the currently available data and knowledge have been used to produce a qualitative assessment and examples of possible ways forward. The thematic assessment of biodiversity also includes an evaluation of the by-catch, threatened species and habitats, spatial protection and restoration measures.

Pelagic habitats are living environments in the open water column, including both coastal areas and the open sea. Pelagic habitats are the main setting for primary productivity in the Baltic Sea. Phytoplankton support the growth of species at higher trophic levels, as they are food for zooplankton and benthic animals. They also contribute to the microbial loop. Zooplankton are food for various species and are the key food source for many fish.

Benthic habitats are the living environments close to the seabed. Species in benthic habitats live attached to, in or very close to the substrate. The primary producers are microalgae, macroalgae and vascular plants. Typical animals in the benthic habitats of the Baltic Sea are mussels, small crustaceans, worms and fish. The primary producers occur only at depths which sunlight can reach, which varies within the Baltic Sea depending on the water transparency. Deeper down, benthic habitats are mainly supported by energy from organic material produced in the pelagic zone that settles down to the seafloor.

Fish are present in all Baltic Sea habitat types. Around 230 fish species occur in the Baltic Sea (HELCOM 2012), including species of both marine and freshwater origin. Different types of assemblages characterize coastal and open sea areas, and many fish have different key habitats in different seasons. For example, they may migrate between coastal and offshore areas for spawning or feeding. Some populations even move between the Baltic Sea and the North Sea. Coastal areas and freshwater tributaries are key habitats for freshwater species.

The sea bird community of the Baltic Sea is highly variable, depending on the season. Some bird species are present throughout the year but many migrate to the Baltic Sea to breed. In all, the Baltic Sea is an important area for around 80 species of seabird. A variety of species groups with different habitat preferences are found in coastal areas during the breeding period. In winter, the birdfauna is dominated by species that breed in arctic freshwater habitats, which use ice-free areas of the Baltic Sea as wintering areas.

Five marine mammal species are residents in the Baltic Sea: the grey seal, harbour seal, ringed seal, harbour porpoise and Eurasian otter. Of the seals, the grey seal lives in the whole region and the harbour seal only in the southwestern Baltic Sea and the Kattegat. The ringed seal is restricted to the eastern and northern Baltic Sea. The harbour porpoise is found throughout the Kattegat, the Belt Sea, the Sound, the southern parts of the Baltic Sea and the Baltic Proper. The harbour porpoise population in the Baltic Proper is listed as Critically Endangered.

ious activities and pressures. More detailed integrated results are also available for several elements in the assessment, for example species or functional groups. A summary of the status of the biodiversity topics included in the assessment is provided in the following sections, and more detailed information is presented in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2013a). Each section also presents an overview figure showing how the biodiversity component in question is linked to other aspects included in the assessment reports, such as other parts of the ecosystem and pressures. The threat status of species and habitats in the Baltic Sea region was evaluated most recently by HELCOM (2013b), and the evaluation is going to be updated in 2024 (Box 3.2).

BOX 3.2.

Threat status of species and habitats in the Baltic Sea

The threat status of species in the Baltic Sea region was evaluated most recently by HELCOM (2013b). About 1,750 of the nearly 2,800 taxa considered at the time were evaluated according to the IUCN Red List criteria. Of these, four per cent were evaluated as being in danger of becoming extinct in the Baltic Sea, meaning that they were classified as vulnerable, endangered or critically endangered. In all, 8 taxa were categorised as critically endangered, 18 as endangered, 43 as vulnerable, 36 as near threatened and 37 as data deficient. Two fish species, namely the American Atlantic sturgeon (Acipenser oxyrinchus) and the common skate (Dipturus batis), and one bird, the gull-billed tern (Gelochelidon nilotica), were listed as regionally extinct in the HELCOM area.

In 2013, the HELCOM Underwater Biotope and Habitat Classification System (HELCOM HUB) defined a total of 328 benthic and pelagic habitats (HELCOM 2013c). A threat assessment was made for 209 of these, of which approximately one quarter were red-listed. The others (73%) were classified as Least Concern, meaning that they were not seen to be at a risk of collapse at the time of the assessment (HELCOM 2013c). Of the HELCOM HUB biotopes that were red-listed, 1 was categorized as Critically Endangered, 11 as Endangered and 5 as Vulnerable. Forty-two biotopes were categorized as Near Threatened. The highest comparative proportion of red-listed biotopes was within the group benthic aphotic biotopes (HELCOM 2013b).

Regularly updating the Red List assessment is an integral part of tracking the progress and effectiveness of HELCOM and other relevant commitments, and it can help increase the effectiveness and efficiency of measures by identifying areas or species to be prioritized. The HELCOM Red List is going to be updated in 2024.

3.2.1 The status of pelagic habitats

Pelagic habitats, including phytoplankton and zooplankton (Figure 3.2), do not have a good status in any of the fourteen open sea sub-basins assessed in 2016-2021 (Figure 3.3). The most deteriorated status occurs from the northern Baltic Proper and northwards, and the situation has worsened in the Bothnian Bay. The functioning of a pelagic habitat depends on its level of productivity, as well as on its species composition and the size structure of the species. The mean size of zooplankton has increased in some of assessed areas, which is a positive development, but the status of phytoplankton is generally not good. Four out of the thirteen assessed coastal areas have good status for phytoplankton. Eutrophication status and the status of pelagic habitats are closely interlinked. When the eutrophication indicators are also taken into account, no open sea or coastal pelagic habitats have good integrated status (HELCOM 2023a). This represents an unchanged situation since the previous assessment (HELCOM 2018).

Why is this important?

Functional pelagic habitats contribute to a wide range of ecosystem services and support the overall productivity of marine systems.

A poor status of pelagic habitats is associated with several ecological and socio-economic losses.

Effects of eutrophication are particularly evident in pelagic habitats, where they can lead to algal blooms and reduced water transparency, for example, with secondary impacts on benthic habitats, mobile species and human activities.

Eutrophication of the pelagic habitat also affect benthic habitats by contributing to poor oxygen conditions.

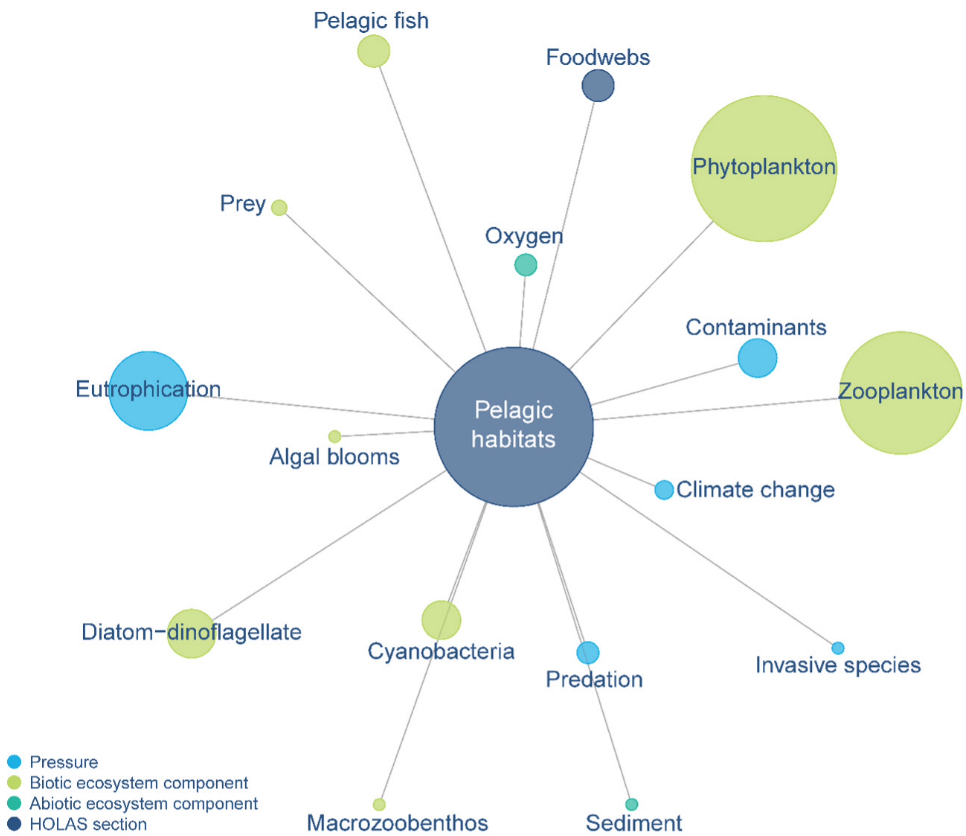

Figure 3.2. An overview of the ecosystem components and pressures descriptively linked to the status of pelagic habitats in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages made. The chapter itself is symbolised by the dark blue circle in the centre, and the other circles represent the key elements (terms) used in the chapter. The size of each circle is based on how often the term is mentioned in the chapter and should only be interpreted in this way. The terms are aggregated, so each circle includes both the term itself and all terms deemed to be synonymous (e.g. "eutrophication" includes "eutrophication" and associated terms such as "nutrient input" or "concentrations"). The width and length of the lines and the placement of the items is arbitrary. The image gives a simple visual representation of the topics covered in the evaluation, while simultaneously providing a gap analysis of where more information may be required in the future to increase the holistic nature of the evaluation (e.g. if an interaction between a certain pressure and an ecosystem component has not been well addressed). The overview was made using igraph.

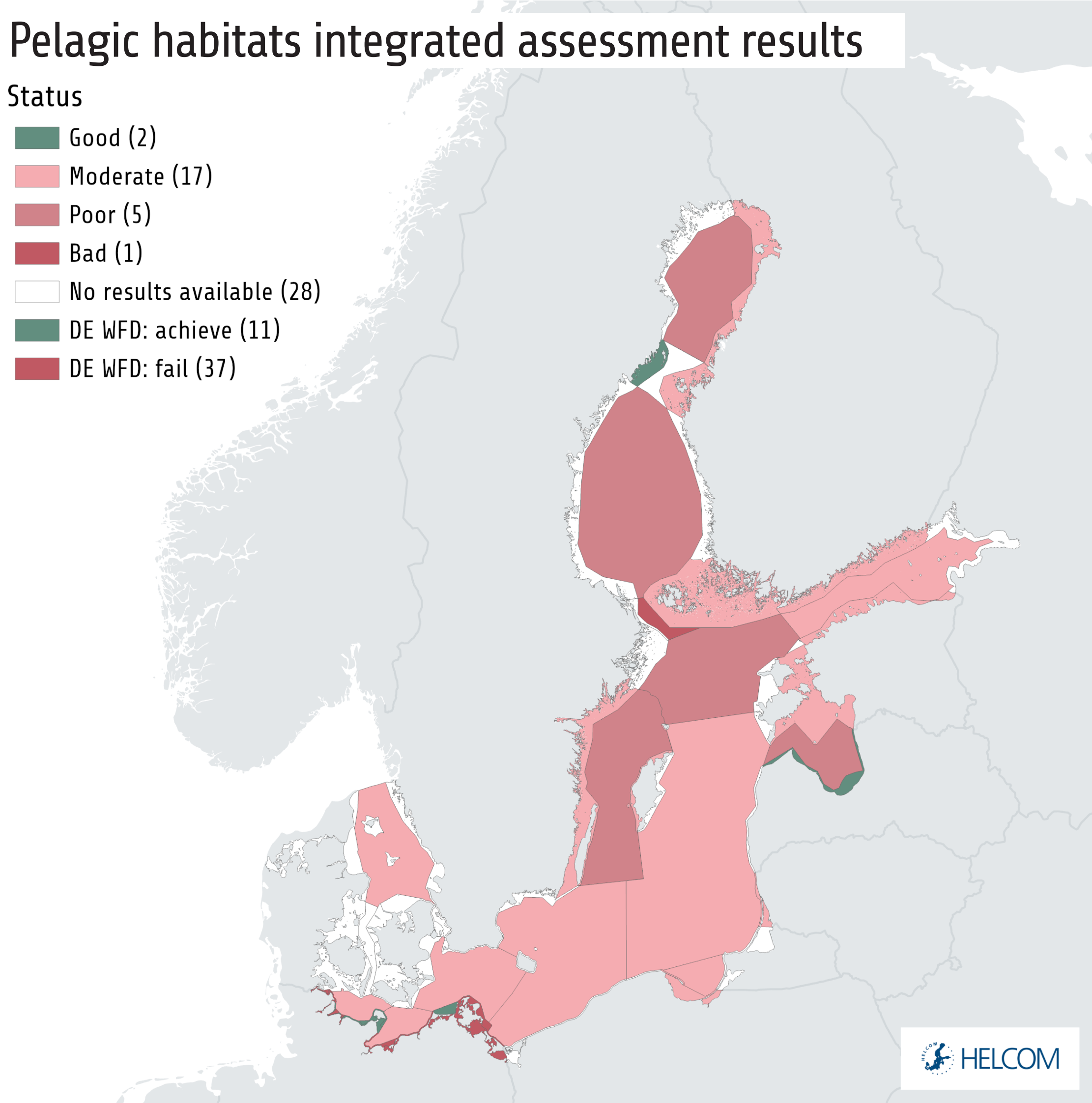

Figure 3.3. Summary of results from the integrated assessment of pelagic habitats. Source: HELCOM 2023a.

What can we do – what is affecting the status of pelagic habtats?

Pelagic habitats are directly affected by eutrophication because high nutrient levels enhance the productivity of phytoplankton. Eutrophication also affects the biodiversity of the phytoplankton community because some species benefit more than others. Zooplankton, which feed on phytoplankton, are affected by eutrophication if changes in the abundance and species composition of phytoplankton affect the availability or quality of their food. Moderate eutrophication is expected to benefit herbivorous zooplankton through increased food availability. However, high eutrophication is associated with algal blooms, which affect other species by decreasing water transparency. Blooms also affect other habitats because the organic materials produced sink down in the water column, decomposing closer to the seafloor and increasing oxygen consumption there (Figure 3.4). Reducing eutrophication is a key measure to improve the status of pelagic habitats in the Baltic Sea, as well as other habitats. The status of pelagic habitats is also affected to some extent by hazardous substances and non-indigenous species (HELCOM 2023a).

Maintaining the natural structure and ecological functions of food webs is expected to enhance the resilience of pelagic food webs to human pressures, including eutrophication. Species in the food web are closely connected, and they interact with each other through their feeding patterns. Thus, if consumer species are in good status, they can contribute to regulating fluctuations in the species that constitute their food. For example, phytoplankton abundance can be controlled through grazing by zooplankton, while the abundance of zooplankton, in turn, can be controlled by predation from higher trophic level species, such as other, larger zooplankton and pelagic fish.

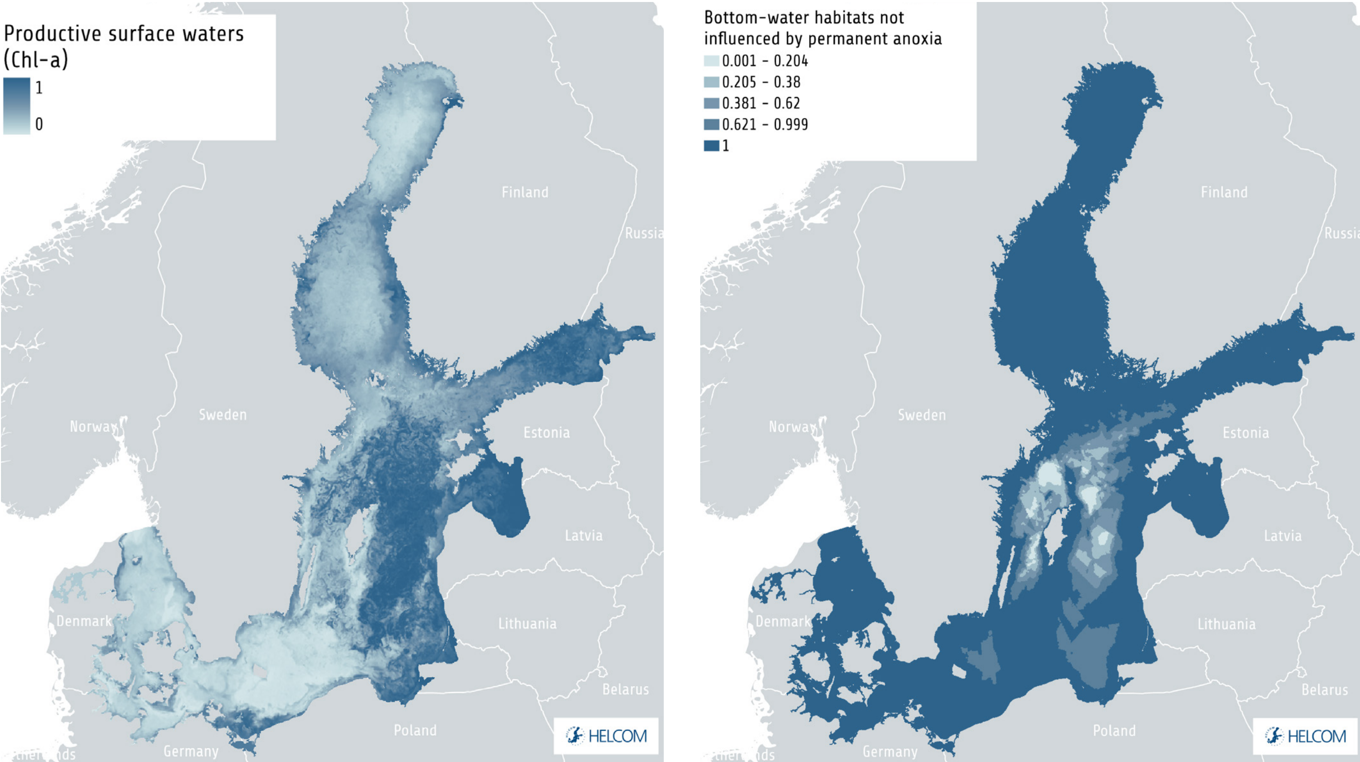

Figure 3.4. Distribution of pelagic habitat. Left: Productive surface waters are represented by the concentration of chlorophyll-a during spring. Higher values indicate areas with more chlorophyll-a in surface waters. The dataset was prepared by the Finnish Environment Institute. Right: Bottom-water habitats not influenced by permanent anoxia. Areas with low values are more influenced by anoxia. High values thus indicate suitable habitats for biota with respect to oxygen condition. The map was prepared based on the occurrence of hydrogen sulphide near the sea bottom. Importantly, the map only shows areas with permanent anoxia, and nformation on this is only available for open sea areas. Additional areas experience various degrees of temporary oxygen deficiency. For example, anoxia in coastal waters is often temporary in nature (HELCOM 2023h). Data were provided by the Leibniz Institute for Baltic Sea Research Warnemünde (IOW) and are based on point measurements and modelling for five periods per year during 2016–2021. Source: HELCOM 2023e.

Effects of climate change on pelagic habitats

Various changes in the species composition and seasonality of pelagic communities are expected in a future climate (HELCOM/ Baltic Earth 2021). For example, dinoflagellate blooms are assumed to increase, and diatom blooms decrease with increasing temperatures, although the associated processes are not yet fully understood. Worldwide, climate change is a significant driver of changes in zooplankton communities. However, what impacts this will have in the Baltic Sea is still uncertain.

Changes in the timing of spring blooms can occur due to changes in ice cover, cloudiness or wind condition (Kahru *et al.* 2014, 2016). This could have consequences for zooplankton and could also affect benthic productivity and fish if there is a mismatch between the time when food is available and the important recruitment periods.

The effects of climate change can also interact with other pressures. For example, increased pelagic primary productivity is mainly attributed to eutrophication (Saraiva *et al.* 2019), but warmer water may increase pelagic and benthic primary production (Kahru *et al.* 2016, Karlson *et al.* 2015, Lindegren *et al.* 2012, Hjerne *et al.* 2019, Suikkanen *et al.* 2013).

3.2.2 The status of benthic habitats

The status of benthic habitats (Figure 3.5) is assessed based on the status of soft-bottom macrofauna, shallow-water oxygen conditions, oxygen debt and the cumulative impact of physical pressures. Large parts of the benthic habitats in the southern Baltic Sea do not have a good integrated status, while the status is good in most of the open sea areas in the northern parts of the region (Figure 3.6). The vast majority of the coastal area, irrespective of its location, exhibits not good status (HELCOM 2023a). Of particular concern is the increasing extant of areas with poor or low oxygen in deep waters of the central Baltic Sea, which limits the populations of benthic fauna and impacts on overall ecosystem processes. The oxygen debt below the halocline has increased in all sub-basins since the early 1900s, especially in the Baltic Proper. The increase has been very steep between the previous and current assessment periods.

Why is this important?

Benthic habitats are widely distributed and contribute to various ecosystem services, including the assimilation, storage and sequestration of carbon and nutrients.

Many benthic animals have important regulatory roles by decomposing organic matter that sinks to the seabed or as grazers in shallow areas.

Benthic species are a fundamental food source for fish and birds and are therefore an important link between food web processes in benthic and pelagic habitats.

Seaweeds and plants in shallow areas are an important environment for many fish species.

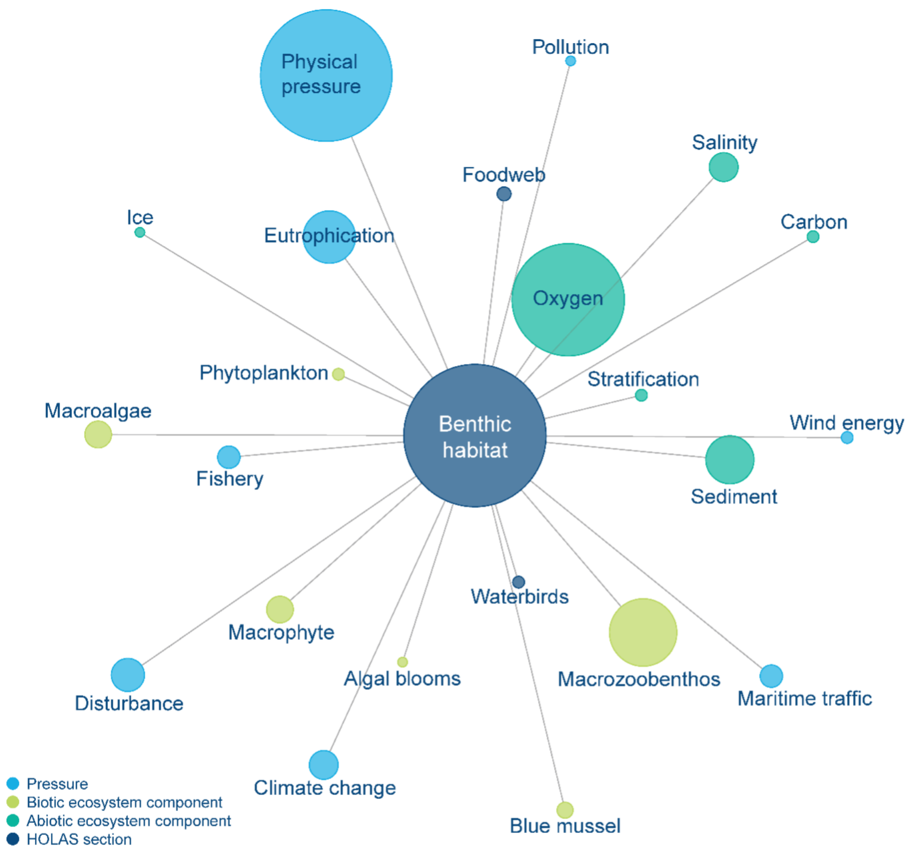

Figure 3.5. An overview of the ecosystem components and pressures descriptively linked to the status of benthic habitats in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages made. The chapter itself is symbolised by the dark blue circle in the centre, and the other circles represent the key elements (terms) used in the chapter. The size of each circle is based on how often the term is mentioned in the chapter and should only be interpreted in this way. The terms are aggregated, so each circle includes both the term itself and all terms deemed to be synonymous (e.g. “eutrophication” includes “eutrophication” and associated terms such as “nutrient input” or “concentrations”). The width and length of the lines and the placement of the items is arbitrary. The image gives a simple visual representation of the topics covered in the evaluation, while simultaneously providing a gap analysis of where more information may be required in the future to increase the holistic nature of the evaluation (e.g. if an interaction between a certain pressure and an ecosystem component has not been well addressed). The overview was made using igraph.

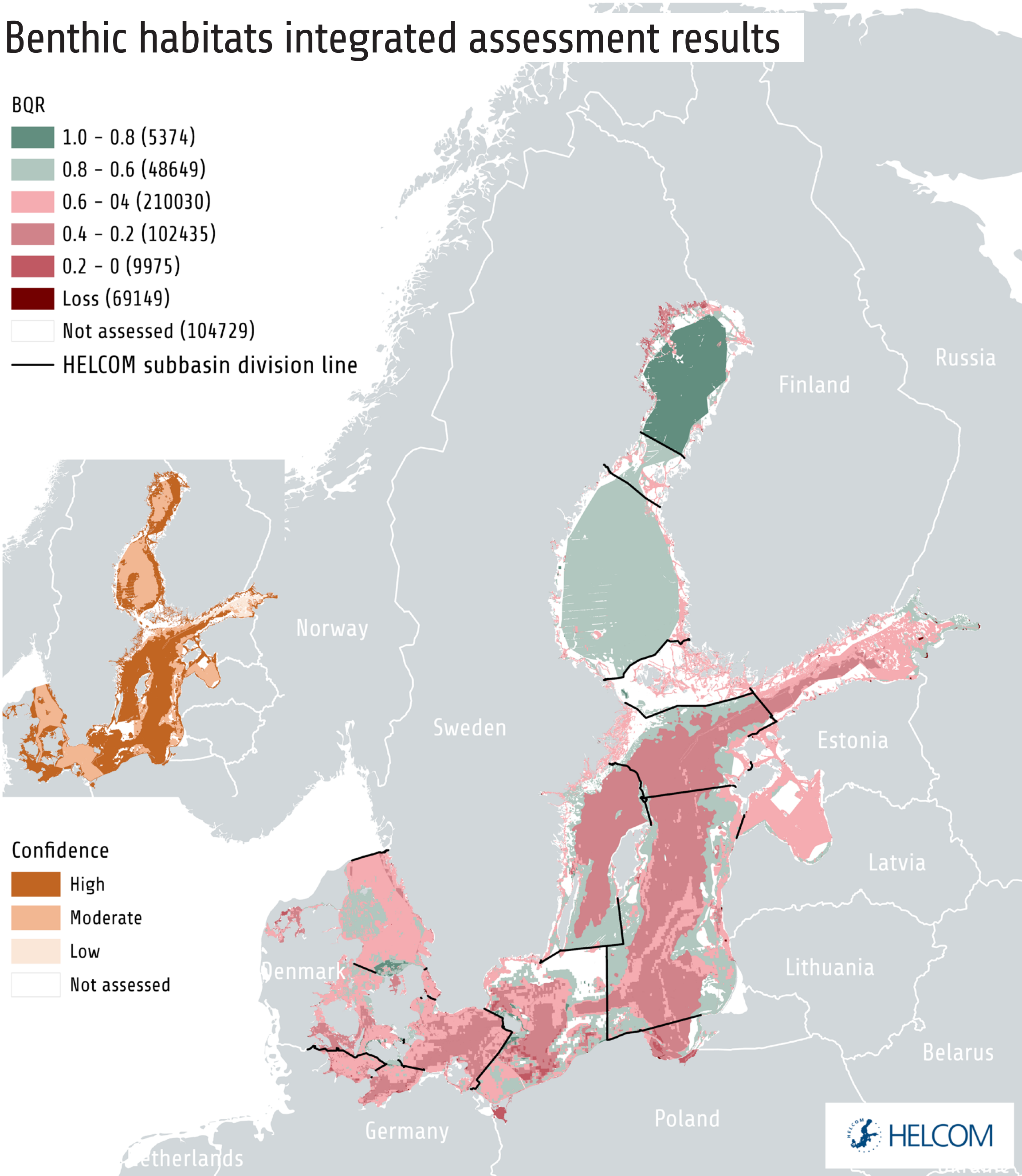

Figure 3.6. Summary of results from the integrated assessment of benthic habitats. Biological quality ratios (BQR) above 0.6 correspond to good status. Assessment confidence is presented in the inset map on the left. Source: HELCOM 2023a.

What can we do – what is affecting the status of benthic habitats?

Benthic habitats are often under impact from several simultaneous pressures, particularly in coastal areas. Typical pressures affecting benthic habitats are eutrophication, alteration of the physical habitat, habitat loss and pollutants.

Oxygen depletion in benthic habitats is influenced by the eutrophication status of the Baltic Sea, as increased productivity in pelagic habitats leads to increased sedimentation of organic matter to the seabed, where oxygen is consumed as the material decomposes (Figure 3.4).

Several human activities also cause physical disturbance to the deeper parts of the seafloor, including bottom trawling fishery, extraction and disposal of sediments, and construction. The cumulative impact-risk from physical pressures is generally highest in the southern Baltic Sea and in the Kattegat, where pressures with a wide spatial extent commonly occur, such as bottom trawling. To improve the status of benthic habitats, nutrient runoff and physical disturbance from human activities such as bottom trawling must be reduced.

Effects of climate change on benthic habitats

In the Baltic Sea, many benthic species live at their distributional limit with regards to high or low salinity (Figure 3.7), and even small fluctuations in climate-related factors can affect their abundance, biomass or spatial distribution (HELCOM/Baltic Earth, 2021).

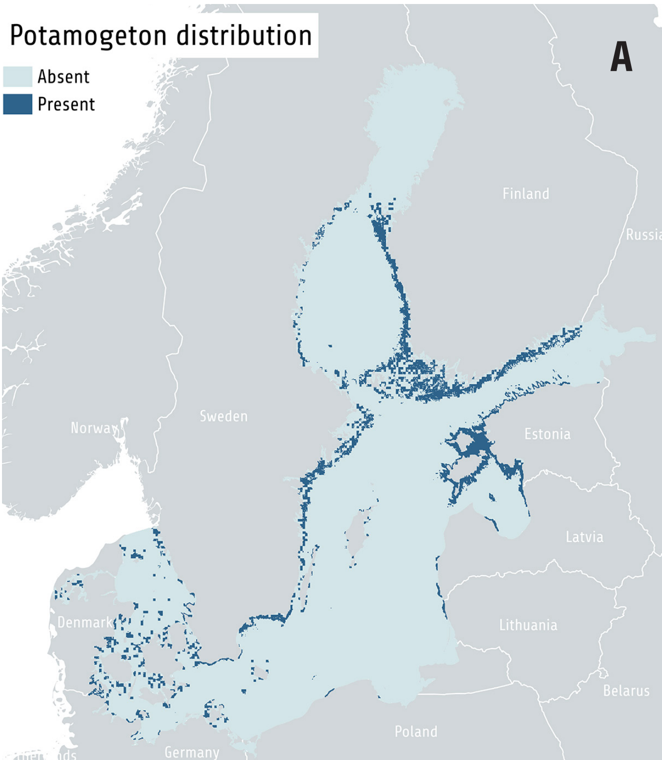

Figure 3.7. Distribution of a) Potamogeton spp, an important freshwater macrophyte in the Baltic Sea, b) Fucus spp, a brown macroalga, and c) the marine macrophyte Zostera marina (eelgrass). Source: HELCOM 2023a.

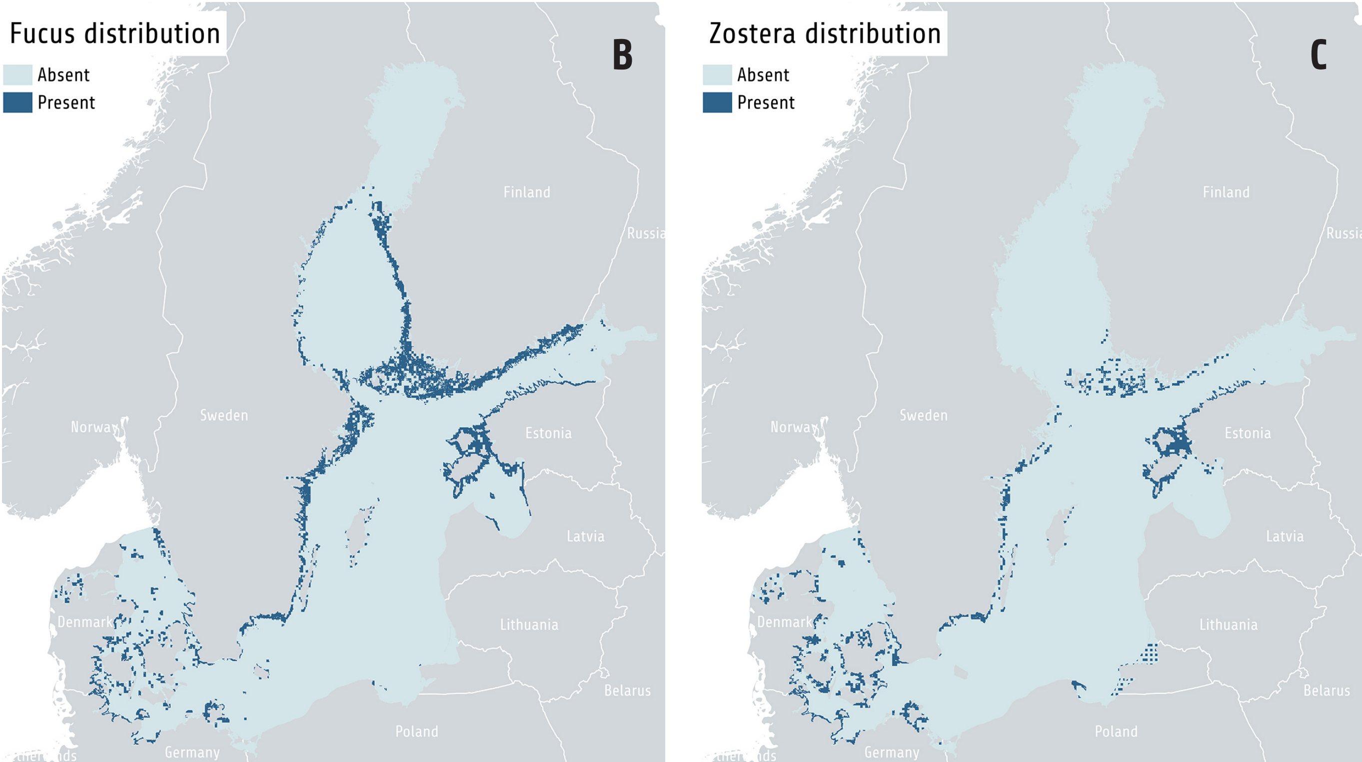

Figure 3.7. (Continued).Distribution of a) Potamogeton spp, an important freshwater macrophyte in the Baltic Sea, b) Fucus spp, a brown macroalga, and c) the marine macrophyte Zostera marina (eelgrass). Source: HELCOM 2023a.

The potential effects of climate change on benthic habitats are closely linked with processes in the pelagic system and on land. If climate change leads to increased freshwater inflows, this could bring more dissolved organic carbon to the sea. This would first affect pelagic primary production, which could either decrease or increase, depending on which species are favoured, and affect benthic habitats via changes in the amounts of organic material that eventually sinks down and reaches the seafloor. Such a scenario could mainly be expected in the northern Baltic Sea (Gulf of Bothnia). In the Baltic Proper, the combined effects of warming and planned nutrient reductions could lead to reduced amounts of carbon reaching the seafloor in the future (HELCOM/Baltic Earth, 2021). However, algal blooms have been observed more frequently during warmer years in recent decades (HELCOM/Baltic Earth 2021). Increased algal blooms may cause increased decomposition and the depletion of oxygen in bottom sediments (Carstensen *et al.* 2014). Warmer seawater in the winter may also increase the energy expenditure of certain species, such as mussels (Waldeck & Larsson 2013).

If climate change leads to lowered production of benthic animals or reduces their quality as prey, this would also have negative effects on the feeding conditions for fish, marine mammals and waterbirds (Hjerne *et al.* 2019, Kahru *et al.* 2014, 2016, 2020, Lindegren *et al.* 2012, Saraiva *et al.* 2019, Waldeck & Larsson 2013).

3.2.3 The status of fish

For fish (Figure 3.8), only four out of fifteen commercial stocks in the Baltic Sea have good status on average during 2016-2021. Compared with the previous assessment period (HELCOM 2018), the status has declined for three stocks, improved for one stock, and remained unchanged for eight stocks assessed in both periods (Figure 3.9a). The integrated status of coastal fish is good in two out of twenty-two assessed coastal areas (Figure 3.9b). For migrating species, salmon (*Salmo salar*) stocks in the northern Baltic rivers have improved, but their status is far from good in many rivers further south. The European eel (*Anguilla anguilla*) remains critically endangered, and efforts to re-introduce the regionally extinct sturgeon (*Acipenser oxyrinchus*) are ongoing.

For the first time, the HOLAS assessment includes evaluation of changes in fish age/size structure (HELCOM 2023a). Regional work should continue to develop these assessments in relation to definitions of good environmental status, to ensure the overall assessment has sufficient confidence (see also section 4.3.1).

Why is this important?

Fish are a key food source for humans, waterbirds, marine mammals, and other fish. Deterioration of fish populations affects fishing opportunities for people as well as food provisioning for many Baltic Sea species. Effects can also be seen in the long term, since depleted stocks are less productive than healthy stocks.

Healthy fish populations contribute to several ecosystem services. The role of piscivores in regulating food webs and maintaining trophic structure is increasingly recognized, in connection to worrying declines in several key piscivores in the Baltic Sea, such as cod and pike.

Deteriorated stocks are more vulnerable to environmental changes. Because of the central role of fish in the food web, this also lowers the overall resilience of the ecosystem.

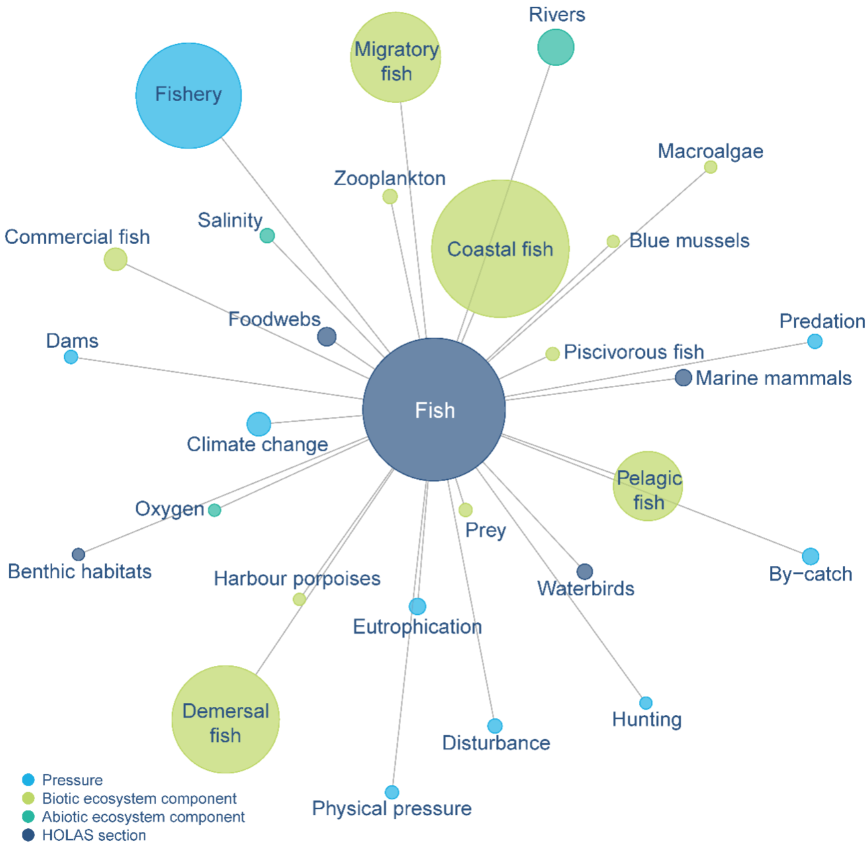

Figure 3.8. An overview of the ecosystem components and pressures descriptively linked to the status of fish in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages made. The chapter itself is symbolised by the dark blue circle in the centre, and the other circles represent the key elements (terms) used in the chapter. The size of each circle is based on how often the term is mentioned in the chapter and should only be interpreted in this way. The terms are aggregated, so each circle includes both the term itself and all terms deemed to be synonymous (e.g. "eutrophication" includes "eutrophication" and associated terms such as "nutrient input" or "concentrations"). The width and length of the lines and the placement of the items is arbitrary. The image gives a simple visual representation of the topics covered in the evaluation, while simultaneously providing a gap analysis of where more information may be required in the future to increase the holistic nature of the evaluation (e.g. if the interaction between a pressure and an ecosystem component has not been well addressed). The overview was made using igraph.

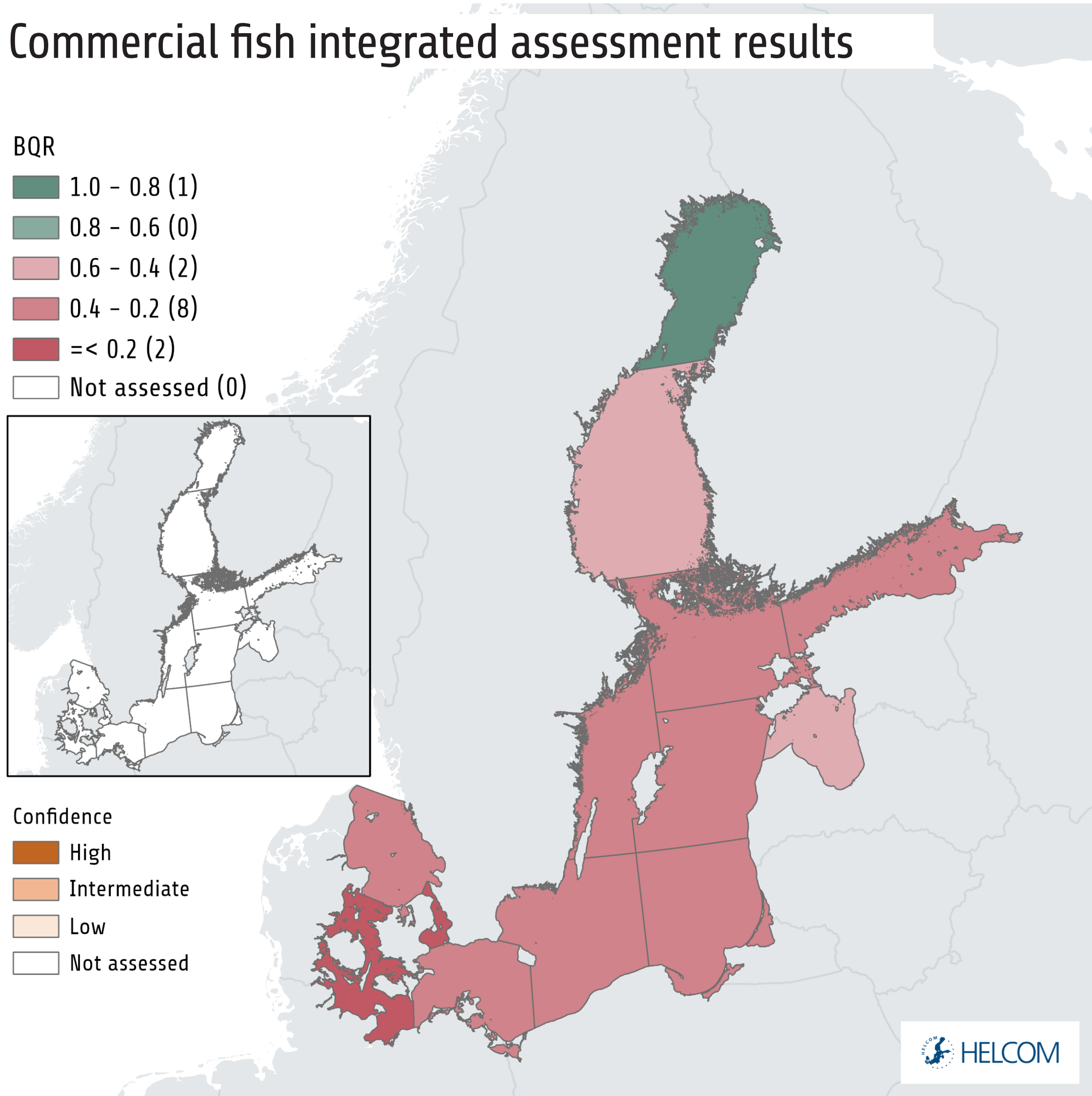

Figure 3.9a. Summary of results from the integrated assessment of commercial fish. Biological quality ratios (BQR) and Ecological Quality Ratio (EQR) above 0.6 correspond to good status. Assessment confidence is presented in the inserted small maps. The spatial assessment units for commercial fish are the ICES sub-divisions. Source: HELCOM 2023a.

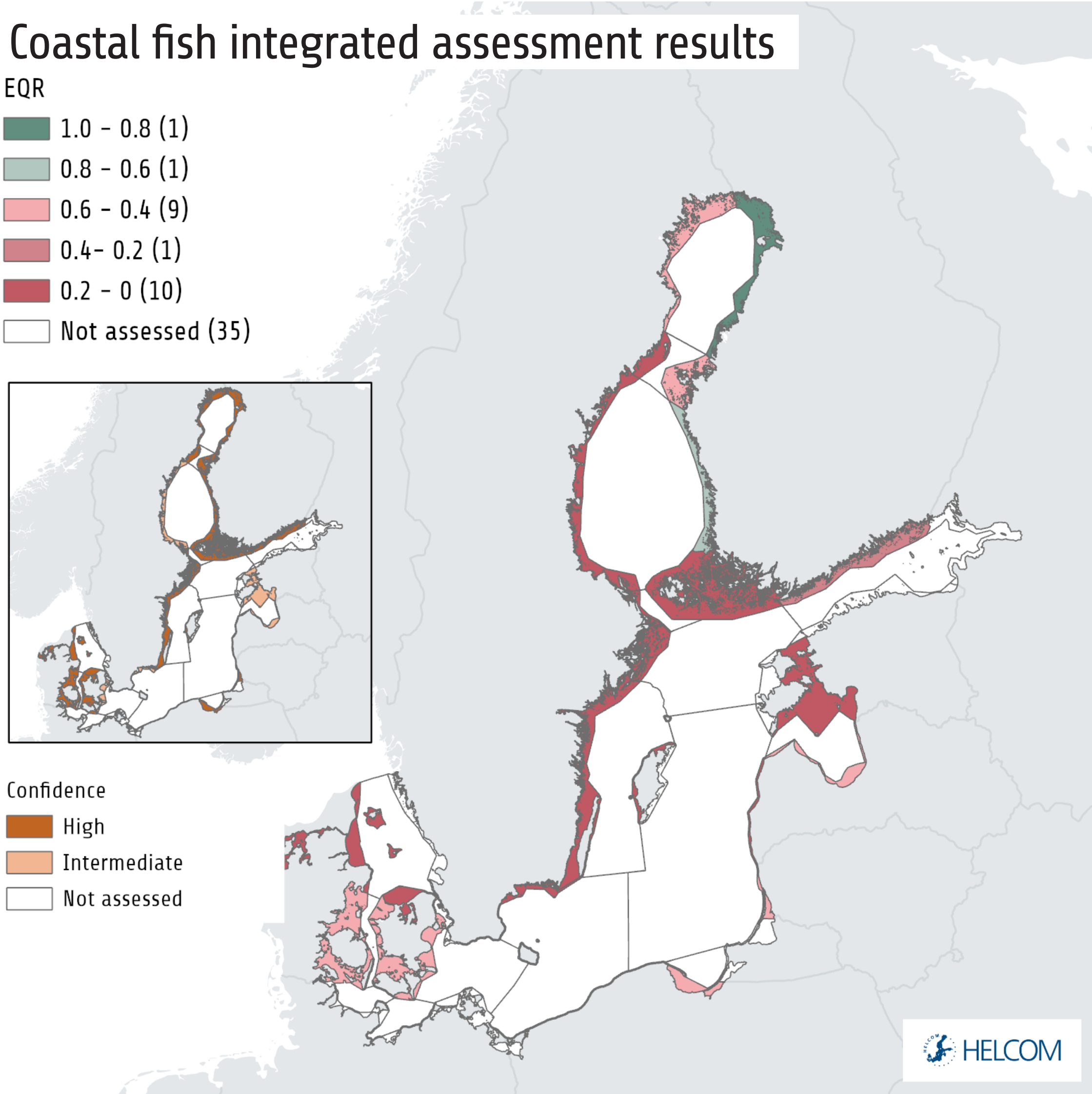

Figure 3.9b. Summary of results from the integrated assessment of coastal fish. Biological quality ratios (BQR) and Ecological Quality Ratio (EQR) above 0.6 correspond to good status. Assessment confidence is presented in the inserted small maps. Source: HELCOM 2023a.

What can we do – what is affecting the status of fish in the Baltic Sea?

Overfishing has had a wide impact on fish stocks in the Baltic Sea. During the current assessment period, fishing mortality was too high for about half of the assessed stocks (HELCOM 2023a, section 4.3.1). Fish are also affected by eutrophication via its effects on habitat quality, prey abundance and feeding behavior.

Several cumulative pressures affect fish in coastal areas, including impacts on spawning areas, feeding and fish populations (Bergström *et al.* 2016, 2018, Moyano *et al.* 2022, Olsson *et al.* 2012, Olsson 2019, Snickars *et al.* 2015). The gradual reduction in the availability of important spawning and recruitment areas is a growing concern, as sheltered coastal areas and river mouths are often preferred areas for development and coastal construction (Seitz *et al.* 2014, Sundblad and Bergström 2014).

In the open sea, the currently most important spawning area for Eastern Baltic cod in the Bornholm Basin is now only a fraction of its historical area, because of oxygen deficiency. The Gdansk Basin and the Gotland Basin have had very limited contribution to cod recruitment since the 1990s (Köster *et al.* 2017).

Effects of climate change on fish

It is very likely that climate change is already affecting fish in the Baltic Sea, and that such effects will increase in the future. Climate change can affect fish directly, through effects on recruitment success and growth (Huss *et al.* 2019, 2021, Lindmark *et al.* 2022, Polte *et al.* 2021, van Dorst *et al.* 2019), or it may influence the distribution range of species, prey availability or the strength of other ecological interactions, for example (MacKenzie *et al.* 2007). Changes in temperature and seasonality may affect the length or onset of the reproductive season of fish, or alter the availability of zooplankton during critical life stages when fish are dependent on these for food (Polte *et al.* 2021). Decreases in surface water salinity could have a strong effect on fish community composition, if marine species in the Baltic Sea are disadvantaged and habitats suitable for freshwater species expand (Olsson *et al.* 2012, Koehler *et al.* 2022). Like any other organism, fish populations are more likely to tolerate external pressures when they are in a good status (Sumaila and Tai 2020). Reaching healthy fish populations in the Baltic Sea in the near future is crucial to build the ecosystem's resilience to future negative impacts of climate.

3.2.4 Status of waterbirds

The overall status of waterbirds (Figure 3.10) is assessed as not good, although there is variability between groups with different feeding behaviour (Figure 3.11). Benthic feeders and waders do not have good status in any part of the region, while surface feeders have good status only in the Gulf of Bothnia. Grazing feeders do not have good status in the Kattegat, the Northern Baltic Proper, or the Åland Sea. Pelagic feeders have good status in several sub-basins. Many bird species characteristic of the Baltic Sea have decreased in abundance over the past decades, such as the pelagic-feeding great black-backed gull (*Larus marinus*) and the velvet scoter (*Melanitta fusca*), while a smaller number of species have increased, such as the greylag goose (*Anser anser*).

Why is this important?

Waterbirds are an integral part of the Baltic marine ecosystem, and their feeding behaviour also plays an important role in linking different parts of the ecosystem.

Waterbirds are a diverse group with various ecosystem functions. For example, they are predators of fish and macroinvertebrates, scavengers and herbivores

Waterbirds are unique in that they connect aquatic ecosystems with terrestrial ecosystems. Their long-distance migrations link the Baltic Sea with other marine regions.

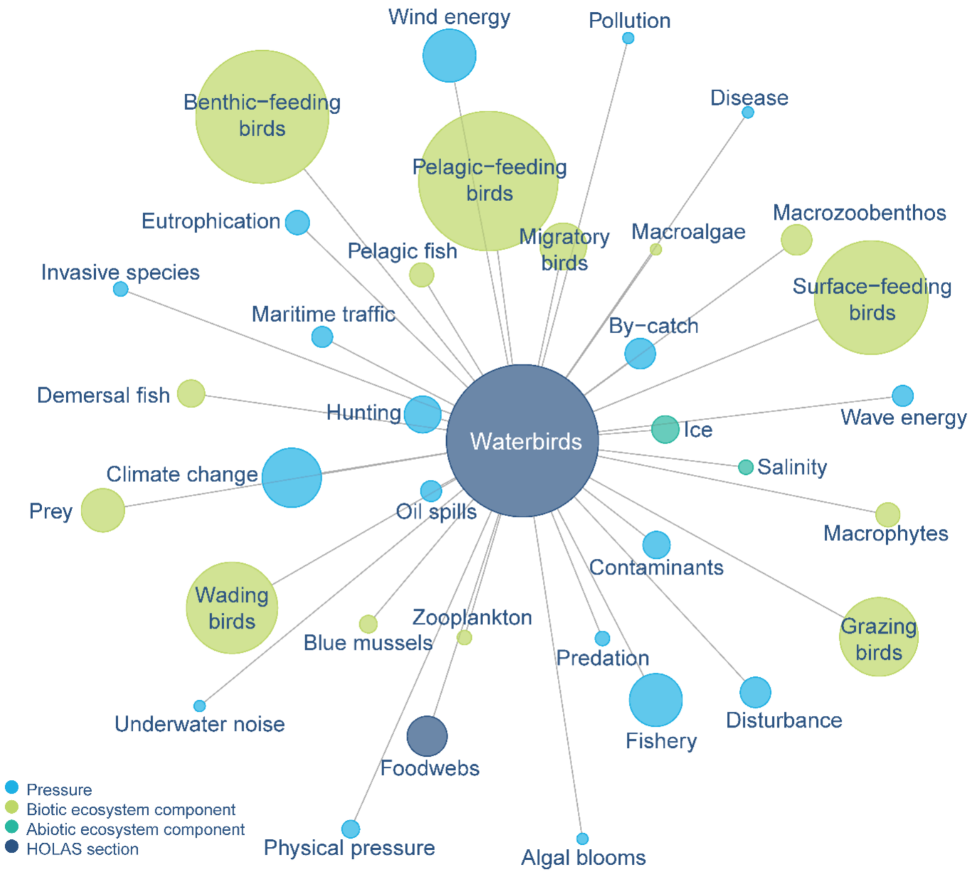

Figure 3.10. An overview of the ecosystem components and pressures descriptively linked to the status of waterbirds in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages made. The chapter itself is symbolised by the dark blue circle in the centre, and the other circles represent the key elements (terms) used in the chapter. The size of each circle is based on how often the term is mentioned in the chapter and should only be interpreted in this way. The terms are aggregated, so each circle includes both the term itself and all terms deemed to be synonymous (e.g. "eutrophication" includes "eutrophication" and associated terms such as "nutrient input" or "concentrations"). The width and length of the lines and the placement of the items is arbitrary. The image gives a simple visual representation of the topics covered in the evaluation, while simultaneously providing a gap analysis of where more information may be required in the future to increase the holistic nature of the evaluation (e.g. if an interaction between a certain pressure and an ecosystem component has not been well addressed). The overview was made using igraph.

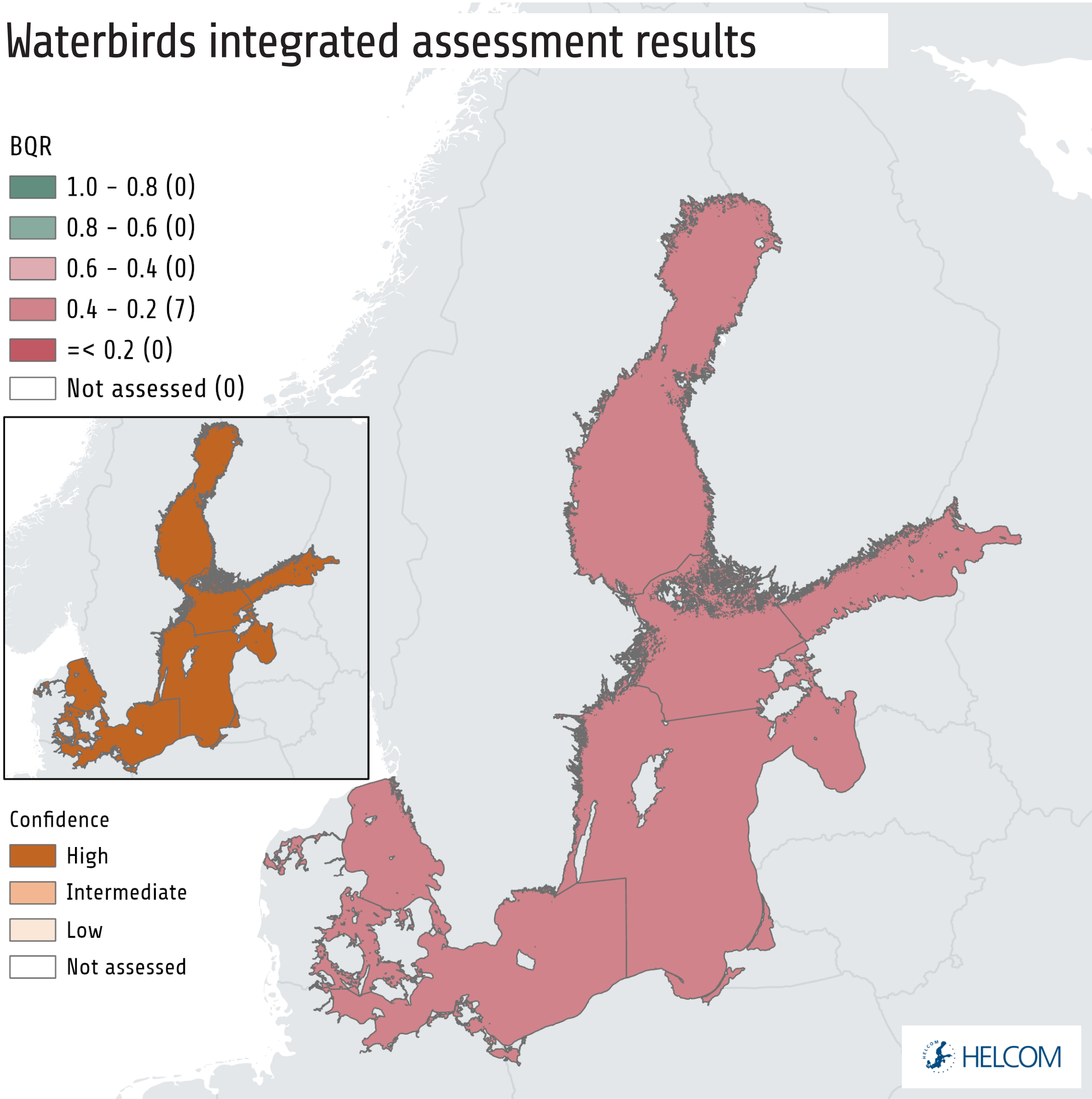

Figure 3.11. Summary of reults from the integrated assessment of waterbirds. Biological quality ratios (BQR) above 0.6 correspond to good status. Assessment confidence is presented in the map inserted to the left. Source: HELCOM 2023a.

What can we do – what is affecting the status of waterbirds in the Baltic Sea?

The status of waterbirds is influenced by several factors, such as disruptions in the food web, habitat alterations, by-catches, hunting, oil spills and climate change. Importantly, the pressures from human activities typically have a cumulative impact on waterbird populations, and impacts on the status of waterbirds during the breeding season carry over to the status during the wintering season and vice versa. The need to address cumulative pressures is amplified by the fact that waterbirds are widely distributed, so impacts from multiple pressures can have an effect at the population level (Dierschke *et al.* 2012, Mercker *et al.* 2021).

Waterbirds respond strongly to food availability and impacts on their food sources readily carry over to effects on bird numbers. Fish-eating birds are sensitive to the depletion of fish populations. On the other hand, in cases where a depletion of large predatory fish has led to increases in the abundance of smaller fish species, through cascade effects, this has shown to improve the food supply for bird species preying on such smaller species. Food availability is also influenced by eutrophication status. While waterbird populations are likely food-limited under oligotrophic conditions, more nutrient-rich conditions can initially benefit them through an increased production of plants and benthic animals which they can feed on. However, extreme eutrophication will again lead to a decrease. The body condition of waterbirds is also affected by the accumulation of contaminants ingested via their food (Broman *et al.* 1990; Rubarth *et al.* 2011, Pilarczyk *et al.* 2012).

Unintentional by-catch in fishing gear is one important pressure of concern for waterbirds in the Baltic Sea. However, current estimates of the number of birds incidentally caught in fisheries are uncertain and are thought to be underestimations (Morkunas *et al.* 2022). Piscivorous birds (such as divers, grebes, mergansers, auks and cormorants) and benthic feeding ducks are particularly susceptible to entanglement and drowning in fishing gear. The by-catch problem is of special relevance when gillnet fishery is practised in areas with high densities of resting, moulting or wintering seabirds. The overlap of gillnet fishing and high bird density usually only occurs during certain periods of the year (e.g. wintering, autumn and spring migration or moulting time; Zydelis *et al.* 2009, Sonntag *et al.* 2012)).

Habitat alterations affect water birds through the draining of coastal meadows, the overgrowth of open areas, agricultural intensification or changes in arable land, for example. Such changes affect the breeding habitats and resting or wintering sites of waterbirds, and they can reduce the carrying capacity of certain wintering sites. Avoidance of offshore wind farms could become a concern for some species in the Baltic Sea in the future, such as divers and long-tailed ducks (Petersen *et al.* 2011, Dierschke *et al.* 2016). Diving ducks also avoid shipping lanes (Bellebaum *et al.* 2006, Schwemmer *et al.* 2011, Fliessbach *et al.* 2019). Benthic feeders are affected by habitat loss associated with physical disturbance of the seafloor (Cook & Burton 2010).

Large numbers of sea ducks are hunted, such as the common eider (*Somateria mollissima*), common goldeneye (*Bucephala clangula*), common long tailed duck (*Clangula hyemalis*) and common scoter (*Melanitta nigra*) (Mooij 2005, Skov *et al.* 2011, Lehikoinen *et al.* 2022).

Oil spills still occur in the Baltic Sea and causes oiled plumage, hypothermia and finally the death of waterbirds (Larsson & Tydén 2005, Žydelis *et al.* 2006).

As the majority of waterbirds in the Baltic Sea are migratory, it is important to note that extra-regional threats can also have a significant impact on their status. Changes in the availability and status of feeding and resting grounds during their migration and wintering periods can have a major influence (e.g. Piersma & Camphuysen 2001, Reneerkens *et al.* 2005).

Effects of climate change on waterbirds

Temperature increases will likely enable a northward expansion of several bird species during both wintering and the breeding season (Pavón-Jordán *et al.*, 2020, Fox *et al.* 2019), as has already been seen in goosander (*Mergus merganser*), the common goldeneye (*Bucephala clangula*) and the tufted duck (*Aythya fuligula*) (Lehikoinen *et al.* 2013), for example.

Some waterbirds that breed along the coasts of the Baltic Sea and formerly wintered further southwest, such as some diving duck species, now remain in the Baltic Sea during the winter (Skov *et al.* 2011, Nilsson & Haas 2016, Pavón-Jordán *et al.* 2020). When the birds' migratory distances shorten, this also reduces their energy demand (Lehikoinen *et al.* 2006, Gunnarsson *et al.* 2012). With milder spring temperatures and the related effects on vegetation and prey, many waterbirds arrive at their breeding area earlier in spring (Rainio *et al.* 2006, Vähätalo *et al.* 2004), and some start breeding earlier (van der Jeugd *et al.* 2009). Furthermore, the earlier loss of sea ice was found to improve the pre-breeding body condition of female common eiders, leading to increasing fledging success in offspring (Lehikoinen *et al.* 2006).

A rise in sea level would reduce the area of saltmarsh available to waders and other waterbirds for breeding and to geese for foraging (Clausen *et al.* 2013), particularly in the southern Baltic Sea. Other coastal habitats could be similarly affected (Clausen and Clausen 2014). Coastal breeding habitats may also undergo physical loss due to erosion. The combination of sea level rise and storms would also affect the breeding success of coastal waterbirds due to flooding of their breeding sites.

Changes in the occurrence pattern of diseases and parasites due to climate change can be expected to affect waterbirds in the Baltic (Fox *et al.* 2015).

Most waterbirds that breed in the region are migratory. The effects of climate change outside the Baltic region, such as in southern Europe and western Africa, thus also affect species that occur in the Baltic Sea (Fox *et al.* 2015).

3.2.5 Status of marine mammals

Marine mammals (Figure 3.12) exhibit not good status in the Baltic Sea (Figure 3.13). While grey seal (*Halichoerus grypus*) and harbour seal (*Phoca vitulina*) are increasing in some areas, overall population growth rates are assessed as too low, and neither the reproductive nor the nutritional status reach their threshold values. The quality of monitoring data to evaluate the status of ringed seals (*Pusa hispida*) in the Bothnian Bay has decreased due to behavioural changes in the population, possibly attributed to a warming climate. The status of the harbour porpoise (*Phocoena phocoena*) in terms of both abundance and distribution is not good for any of the Baltic Sea populations, based on a qualitative evaluation.

Why is this important?

Marine mammals of the Baltic Sea have strong cultural and historical importance, contributing to recreational values and ecosystem appreciation.

As top predators marine mammals regulate the distribution, abundance and health of a variety of prey species.

Because they are highly mobile, marine mammals play an important role in nutrient transfer across different parts of the sea.

The health of marine mammals can be a sensitive signal of broad-scale or diffuse environmental changes.

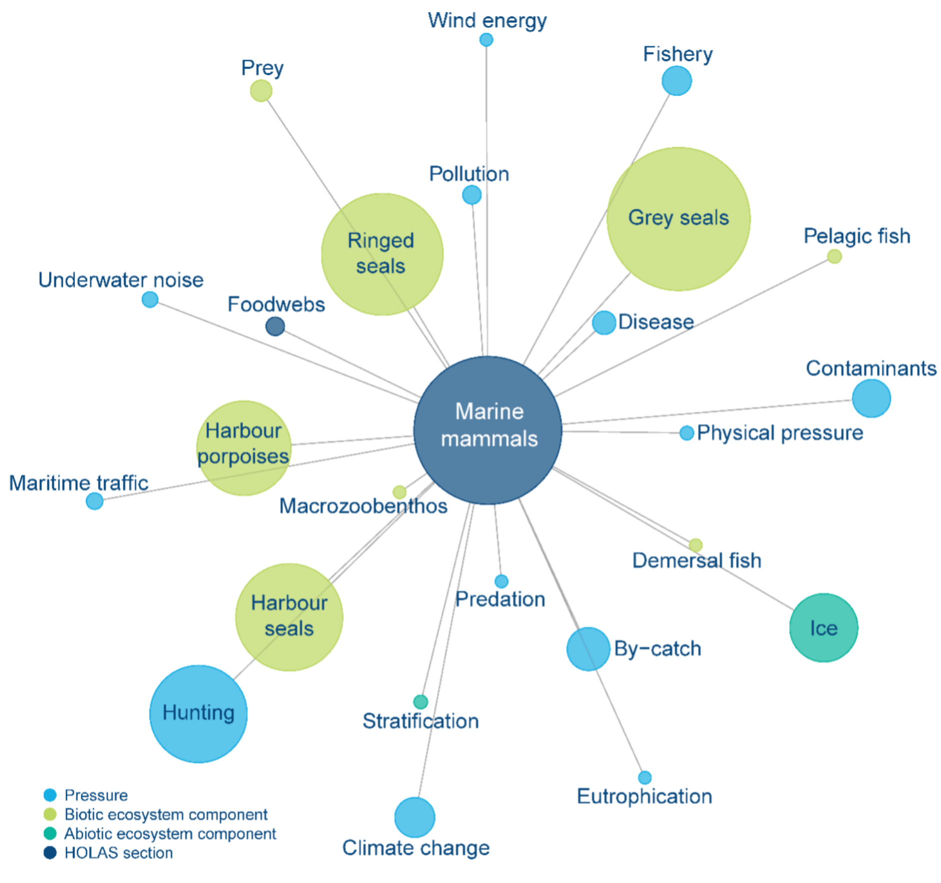

Figure 3.12. An overview of the ecosystem components and pressures descriptively linked to the status of marine mammals in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages made. The chapter itself is symbolised by the dark blue circle in the centre, and the other circles represent the key elements (terms) used in the chapter. The size of each circle is based on how often the term is mentioned in the chapter and should only be interpreted in this way. The terms are aggregated, so each circle includes both the term itself and all terms deemed to be synonymous (e.g. "eutrophication" includes "eutrophication" and associated terms such as "nutrient input" or "concentrations"). The width and length of the lines and the placement of the items is arbitrary. The image gives a simple visual representation of the topics covered in the evaluation, while simultaneously providing a gap analysis of where more information may be required in the future to increase the holistic nature of the evaluation (e.g. if an interaction between a certain pressure and an ecosystem component has not been well addressed). The overview was made using igraph.

What can we do – what is affecting the status of marine mammals in the Baltic Sea?

Marine mammals are top predators in the Baltic Sea food web and are strongly dependent on the availability and quality of their prey, mainly fish.

Drowning in fishing gear is an additional pressure of concern. Unintentional by-catches of marine mammals mainly happen in gillnets but also in trawls (Berggren 1994, Vinther 1999, ASCOBANS 2000, Skóra & Kuklik 2003, NAMMCO & IMR 2019). The status of marine mammals in relation to by-catch is presented in section 4.3.2.

In the past, environmental contaminants decimated marine mammal populations of the Baltic Sea. While many of the substances causing the harm are now banned, hazardous substances remain one of the most widespread and impactful pressures in the Baltic Sea (Slobodnik *et al.* 2022), and emerging substances may be a cause for concern.

Marine mammals are very perceptive of underwater sound. The effects of sound on the animals depend on its properties, such as the intensity, frequency content, amplitude, duration and distance. At lower levels, anthropogenic sounds in the environment can mask natural sounds that species use for communication or to locate prey, while higher levels can lead to behavioural changes or disrupt ongoing behaviour (e.g. feeding or breeding). Very high levels can cause physiological stress or even temporary or permanent changes in hearing sensitivity (HELCOM 2019). Hearing loss can be highly detrimental to the harbour porpoise, a species which uses echolocation to forage.

Hunting has historically put major pressure on marine mammals in the Baltic Sea but is forbidden in most Baltic Sea countries today. However, restricted control hunting of seals is allowed in Denmark, Estonia, Finland and Sweden. In Latvia, a pilot project is being carried out to measure the effects of control hunting of seals, and if results are positive, control hunting will be permitted.

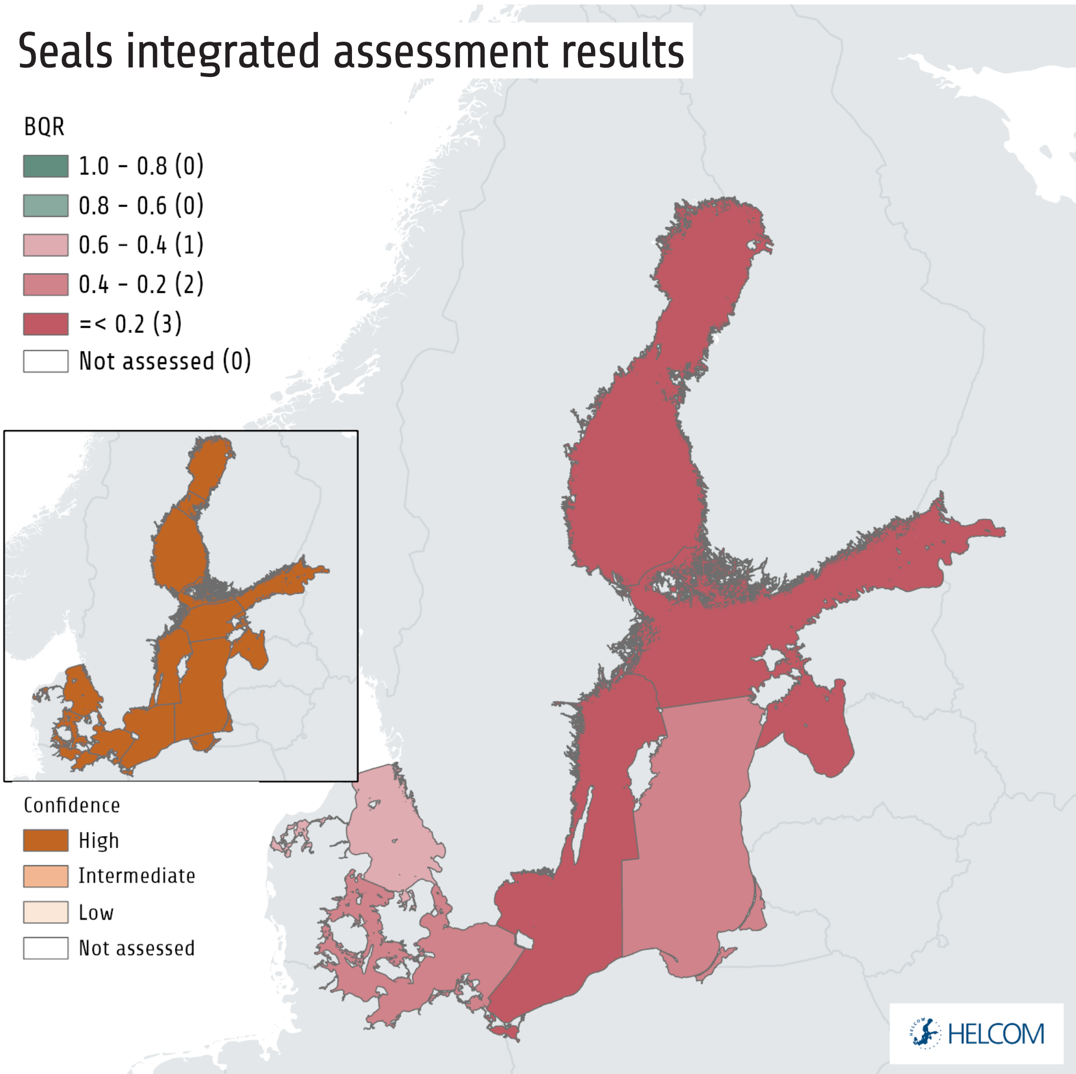

Figure 3.13. Summary of assessment results from the assessment of marine mammals (seals).. Biological quality ratios (BQR) above 0.6 correspond to good status. Assessment confidence is presented in the map inserted on the left-hand side. Source: HELCOM 2023a.

Effects of climate change on marine mammals

The effects of climate change on marine mammals are expected to vary depending on the species' distribution ranges (Figure 3.15). Climate change is an especially important pressure on species which breed on ice, because shorter and warmer winters will lead to more restricted coverage of suitable ice fields (Sundqvist *et al.* 2012, Meier *et al.* 2022). Changes in ice conditions can have strong effects on the reproductive success of ringed seals, which breed in lairs they burrow into snow on the ice. The reduced availability of reproductive areas alone poses a high risk for local extinction to southern subpopulations of ringed seals in the Baltic Sea (Sundqvist *et al.* 2012, Meier *et al.* 2022). Furthermore, early ice break-up may cause pups to enter the water earlier or more often, which affects their thermoregulation. The pups may also be exposed to harsh weather conditions if there is not enough snow and ice for lairs, posing a risk of hypothermia and higher mortality (Stirling & Smith 2004). A shortened ice period has been observed to increase the number of pups with the lanugo fur still present late in the season and to lower growth rates (Harwood *et al.* 2000, Smith & Harwood 2001).

Grey seals are facultative ice breeders, and their breeding success is considerably greater when they breed on ice than on land (Jüssi *et al.* 2008).

A shorter ice season and earlier ice break-up may also facilitate shipping and increase maritime traffic in areas that are usually ice-covered in winter, leading to an increase in underwater noise, disturbance and displacement from habitats.

Environmental changes resulting from a changing climate will likely affect all marine mammals in the Baltic Sea via changes in the food web and ecosystem functions. However, the aggregated effects of changes in prey distribution, quality and quantity on the marine mammals are difficult to predict (HELCOM and Baltic Earth 2021).

Figure 3.14. In the 19th and early 20th centuries, harbour porpoises were widespread throughout the entire Baltic, occurring as far as the inner parts of the Gulf of Bothnia and the Gulf of Finland. The harbour porpoise population in the Baltic Proper has declined dramatically over the past 100 years. Today, harbour porpoise observations are very rare in the Baltic Proper. The number of individuals remaining is estimated to be a few hundred at most (HELCOM 2023a), and there are indications that this population is facing extinction (HELCOM 2013b).

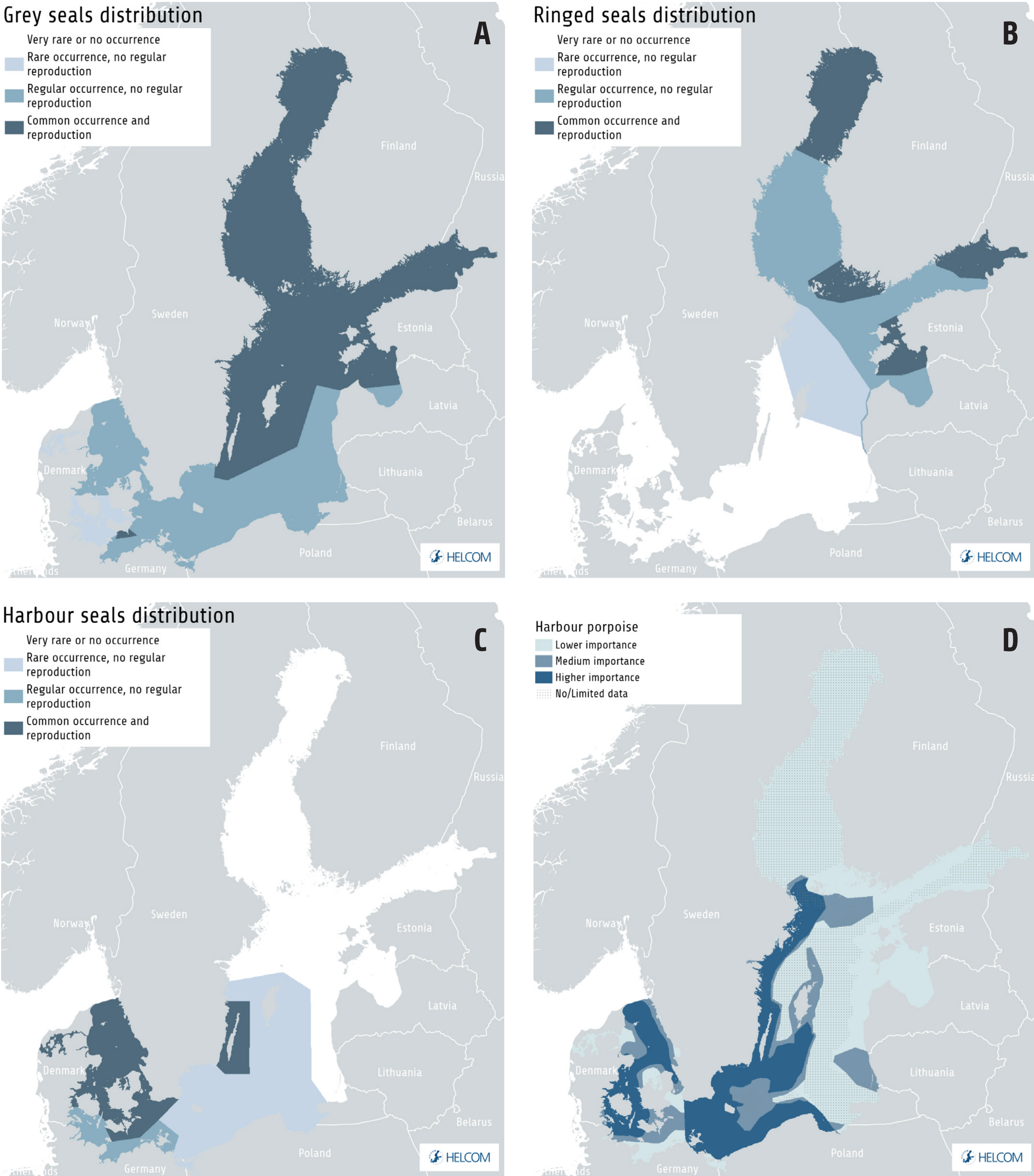

Figure 3.15. Distributional range of A) grey seals, B) ringed seals, C) harbour seals (based on expert input), D) Harbour porpoise. Source: HELCOM 2023e.

3.3. Foodwebs in the Baltic Sea

3.3.1 Status of Baltic Sea foodwebs

Food webs represent the feeding relationships among species and populations (Figure 3.16). Understanding food webs is critical for comprehending key ecosystem interactions and the food/energy flows that underpin ecosystem health and productivity. Impacts on the status of Baltic Sea food webs occur through effects on the species that interact within them, as these effects are mediated to other species and trophic guilds (Eero *et al.* 2021). Alterations in the structure of food webs influence their functions and ecosystem processes, such as ecosystem productivity, stability and resilience against future pressures. Available evidence shows that major changes in the abundance and biomass of species, driven by human pressures, have been associated with changes in the food webs of the Baltic Sea in recent times. Several examples of food web disruption and putative tipping points are cause for concern.

Why is this important?

Healthy food webs are fundamental to the functioning of the Baltic Sea ecosystem and its delivery of ecosystem services.

Food webs ensure the productivity and energy flow in the aquatic system, whereby energy produced by algae and plants is transferred to animals, supporting a diversity of zooplankton, benthic fauna, fish, marine mammals and waterbirds.

Food webs in good status can ensure the stability of ecosystem processes and the ecosystem's resilience against current and future pressures, including climate change.

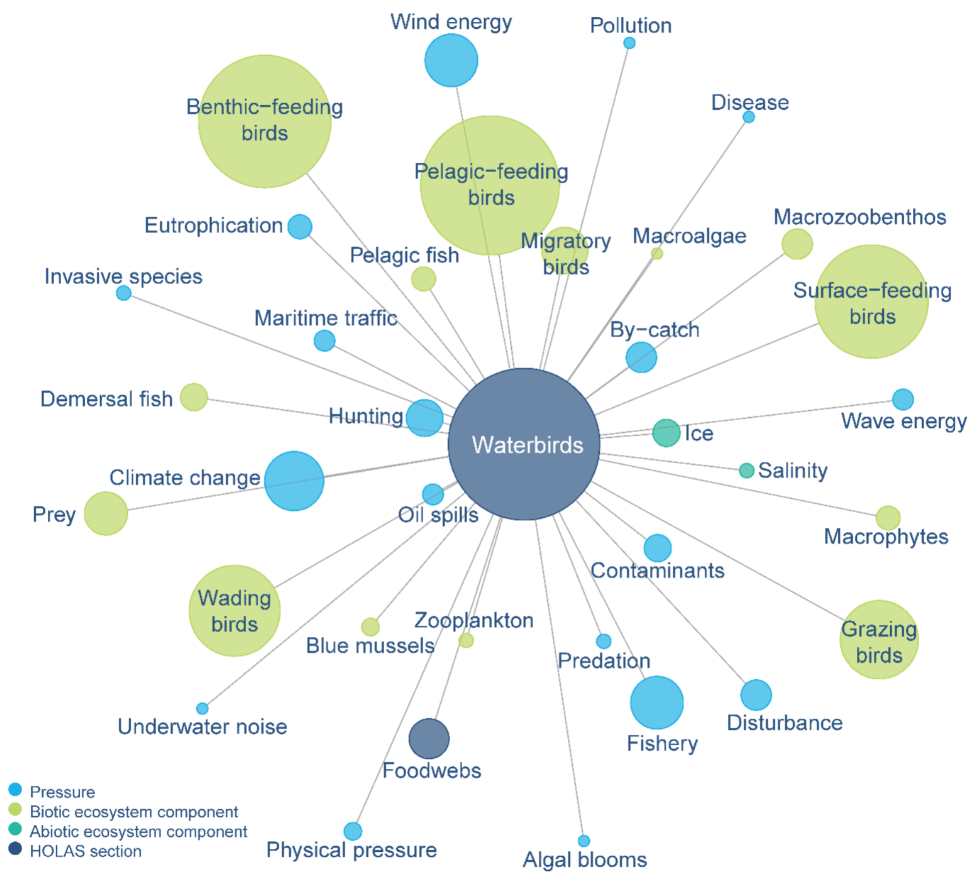

Figure 3.16. An overview of the ecosystem components and pressures descriptively linked to the status of food webs in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages made. The chapter itself is symbolised by the dark blue circle in the centre, and the other circles represent the key elements (terms) used in the chapter. The size of each circle is based on how often the term is mentioned in the chapter and should only be interpreted in this way. The terms are aggregated, so each circle includes both the term itself and all terms deemed to be synonymous (e.g. "eutrophication" includes "eutrophication" and associated terms such as "nutrient input" or "concentrations"). The width and length of the lines and the placement of the items is arbitrary. The image gives a simple visual representation of the topics covered in the evaluation, while simultaneously providing a gap analysis of where more information may be required in the future to increase the holistic nature of the evaluation (e.g. if an interaction between a certain pressure and an ecosystem component has not been well addressed). The overview was made using igraph.

What is affecting the status of food webs in the Baltic Sea?

It is challenging to identify the direct relationship between the status of food webs and any particular pressure. Several pressures often act simultaneously on different parts of the food web. These pressures could have effects through direct or indirect links, and the effects may occur with a time lag. However, pressures that have clearly been associated with an effect on food webs in the Baltic Sea include fishing, eutrophication, contaminants and non-indigenous species.

Fishing has played a key role in driving food web changes in several parts of the Baltic Sea where strong declines in predatory species have led to cascading effects. The most notorious example is the collapse of the eastern Baltic cod stock in the late 1980s and early 1990s, attributed to the combined effects of overfishing, changes in the climate and eutrophication (Möllmann *et al.* 2009). This led to a chain of effects on the offshore food web of the Baltic Proper (Casini *et al.* 2008, Tomczak *et al.* 2012, Blenckner *et al.* 2015). Similar effects were also seen elsewhere, including in the Gulf of Riga (Casini *et al.* 2012). Cod stocks have not yet recovered, and the resulting impacts on Baltic Sea food webs remain present and persistent, indicating that a recovery of the food web will also require addressing several currently ongoing pressures.

Since coastal areas and open sea areas are connected, impacts in the open sea also have implications for coastal areas and vice versa (Eriksson *et al.* 2011, Olsson *et al.* 2015, Tomczak *et al.* 2016). Ongoing regime shifts have recently been observed in coastal areas, relating to the enhanced dominance of stickleback (Eklöf *et al.* 2020) and the role of herring in regulating zooplankton abundance (*Limnocalanus macrurus* in the Gulf of Riga, Einberg *et al.* 2019). The collapse of the western Baltic cod and the western Baltic spring-spawning herring stocks during the current assessment period indicates further deterioration (HELCOM 2023a) which is associated with negative consequences on, for example, harbour porpoises (Scotti *et al.* 2022a).

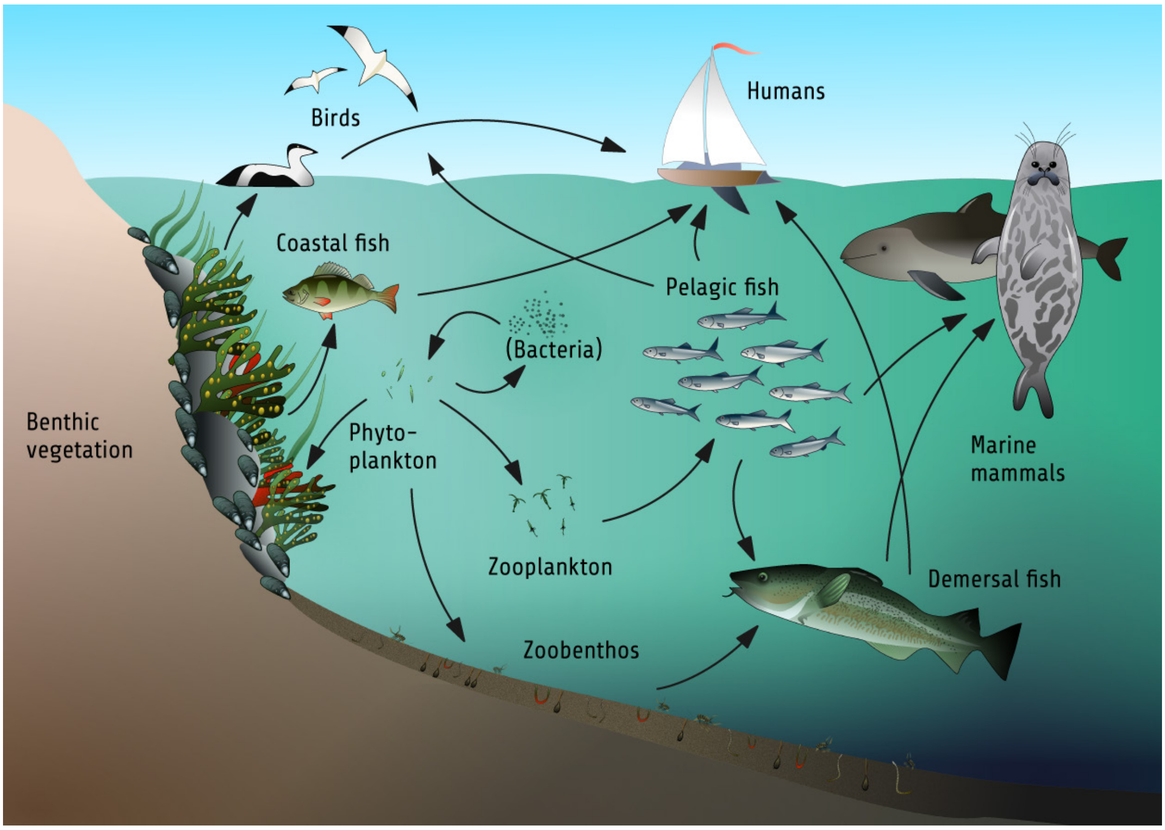

Figure 3.17. The Baltic Sea food web includes primary producers, which make energy and nutrients available to the ecosystem, primary consumers, which feed on the primary producers, and different levels of predators, which feed on lower trophic levels. It also includes species that use dead organic material and contribute to recycling energy and nutrients, and some species function as parasites. Natural food webs are often highly complex, as there are many links between species and a variety of feeding relationships.

Eutrophication is associated with effects on species composition in several key trophic groups in the Baltic Sea, such as pelagic primary producers, benthic fauna, coastal fish and waterbirds (HELCOM 2023a). Eutrophication has had far-reaching direct and indirect impacts on Baltic Sea food webs, not only changing the trophic state of the ecosystem but also affecting higher trophic levels (Tomczak *et al.* 2022). Since the 1920s, the Baltic Sea has transformed from being a typical low productivity aquatic system to a high productivity system in which the presence of insufficient oxygen conditions is a main regulatory driver. Climate change is expected to worsen the negative impacts of eutrophication on food webs through, for example, increased algal blooms and oxygen consumption.

Hazardous substances can have direct toxic effects or damage habitats and accumulate within the tissue of biota. Substances with the potential to accumulate in the food web can affect the health and abundance of species through trophic dynamics. For example, accumulating evidence supports the biomagnification and health consequences of methylmercury (Vainio *et al.* 2022), population declines related to persistent organic pollutants (Sonne *et al.* 2020), and transgenerational effects in Baltic biota (Mauritsson *et al.* 2022). The same contaminant can also have different effects in different types of food webs, and its biomagnification might be affected by how benthic and pelagic habitats are connected (Vainio *et al.* 2022).

Top predators can serve as indicators of persistent harmful substances in the ecosystem. Because persistent chemicals accumulate in the food web, emerging pollutants that are below the detection limits in other biota could be detected in top predators, such as the white-tailed eagle (*Haliaeetus albicilla*) (Helander *et al.* 2008, Badry *et al.* 2022) and marine mammals (UBA 2022).

Several non-indigenous species have been attributed to impacts on biotic properties in the Baltic Sea (Ojaveer *et al.* 2021). Among these, the predatory cladoceran *Cercopagis pengoi* and the zebra mussel (*Dreissena polymorpha*) have been attributed to the highest impacts on food webs. Based on biotic properties, the largest impact has been attributed to non-indigenous species that are a prey for native species. However, the effect varies strongly between species. The polychaete *Marenzelleria* spp., the mud crab *Rhithropanopeus harrisii*, the round goby *Neogobius melanostomus* and the zebra mussel are non-indigenous species that have taken major roles in the Baltic Sea food web, leading to effects at multiple trophic levels and in multiple habitats. There is also evidence that a non-indigenous species (*R. harrisii*) can function as a driver of regime shifts in the Baltic Sea (Kotta *et al.* 2018).

Effects of climate change on food webs

Climate change can influence several processes that affect the status of food webs, such as species interactions, nutrient recycling and ecosystem properties (HELCOM/Baltic Earth 2021). Impacts can occur by direct effects on the physiology or biology of species or through bottom-up and top-down cascading effects, mediated by changes in productivity or predation patterns, for example (e.g. Casini *et al.* 2009, Hjerne *et al.* 2019, Kahru *et al.* 2014, 2016, 2020). Furthermore, climate change is very prone to interacting with other pressures. In the Baltic Sea, changes in climatic conditions in combination with fishing and eutrophication have been attributed to shifts from larger to smaller zooplankton, stronger impacts of nutrients on ecosystem structure, and reduced regulatory capacity of predators (HELCOM/Baltic Earth 2021). Altered inputs of hazardous substances, changes in the how species are exposed to them, and potentially in how they are transferred in food webs may also be relevant.

Due to these complex interactions, the effects of climate change on higher trophic levels are expected to differ between organism groups (Helenius *et al.* 2017, Lindegren *et al.* 2012, Olsson *et al.* 2012, Niiranen *et al.* 2013, Svensson *et al.* 2017, Pecuchet *et al.* 2013). Current knowledge is limited to what can be observed or deduced about future conditions under current climatic conditions, and there are knowledge gaps on how food web structure, functioning and resilience may change under expected future environmental conditions (HELCOM/Baltic Earth 2021).

Another knowledge gap concerns responses to extreme events, such as heat waves (Humborg *et al.* 2019, HELCOM/Baltic Earth 2021). For example, a mesocosm experiment showed that consecutive heat waves could have different effects on different benthic fauna species in coastal ecosystems of the western Baltic Sea. Positive effects were seen on some species (amphipods) and negative effects on others (tellinid bivalves), highlighting how the same stress factor yields diverse responses that contribute to reshaping the food web (Pansch *et al.* 2018).

What can we do?

Food webs are not possible to manage directly, but the status of food webs benefits from strengthening its key components and from the proper management of the human activities that causes pressures on them, such as eutrophication, fishing pressure, contaminants, and non-indigenous species. The status of food webs also benefits from measures to reduce the effect of climate change. The establishment of a network of strictly protected areas is an important tool to ensure functioning food webs now and in the future.

Furthermore, understanding the structure and function of food webs is helpful for the implementation of measures generally (Eero *et al.* 2021, Nordström *et al.* 2021). Food web knowledge helps us understand the ways in which different species in the Baltic Sea are dependent on each other and how the effects of pressures, and pressure management, might manifest. Information about food webs is therefore key for designing efficient measures to improve and strengthen environmental and marine management, including the development of ecosystem-based management.

4. What is impacting the status? How can we protect and restore the Baltic Sea and its biodiversity?

4.1. Pressures, types of measures and regulations

Measures to improve the Baltic Sea environment are implemented at many levels, from the subregional to the global. Nationally and at more local levels, people around the Baltic Sea carry out important work and take action to reduce pressures, conserve biodiversity or restore degraded ecosystems. The work is relevant to a range of initiatives, from the local scale to global agreements. Regional coordination in HELCOM helps identify key priorities for the Baltic Sea environment and identify actions that benefit from or require regional coordination in order to have the necessary effect.

The segments of the Baltic Sea Action Plan (BSAP) seek to reflect a combination of pressures that both stem from activities on land and relate to activities at sea (HELCOM 2021a). They identify regionally agreed steps required for HELCOM countries to reach shared objectives. Central goals related to the management of human activities and pressures in the plan are:

— *A Baltic Sea unaffected by hazardous substances and litter*

— *Environmentally sustainable sea-based activities*

— *A Baltic Sea unaffected by eutrophication*

Progress towards our shared vision for a healthy Baltic Sea ecosystem relies upon the successful implementation of actions included under all of the pressure-related BSAP segments. Furthermore, the three segments support each other: The interconnectedness of life in aquatic systems means that progress along any segment benefits the other segments, moving towards the same shared objectives.

The updated status assessment results for 2016-2021 highlight the significance of this work. Nutrient loads are decreasing, but most of the Baltic Sea is still affected by eutrophication, which is a key driver of ecosystem changes in many areas. Concentrations of certain hazardous substances are declining because of measures taken, but there are elevated levels of several contaminants, and there is a vast number of emerging substances of potential concern. Overfishing has had widespread impacts on fish stocks in pelagic, demersal and coastal systems, and it has also led to changes in the overall structure and function of the food web. Other pressures affecting the Baltic Sea environment include, inter alia, the introduction of non-indigenous species, marine litter, underwater noise, seafloor loss or disturbance, and the unintentional by-catch of birds and marine mammals. Stopping or reducing the negative impact of all of these pressures arecritical steps to reach a healthy Baltic Sea.

This chapter briefly presents the assessment results regarding pollution-related pressures (eutrophication, hazardous substances, marine litter, non-indigenous species and underwater noise), as well as pressures at sea (related to the extraction of fish, unintentional by-catch of marine mammals and birds, and seafloor loss and disturbance). In addition, the progress of work in HELCOM to develop marine protection and restoration is presented. All results are presented in summary, together with their main points of connection to species or habitats, climate change and the management objectives of the Baltic Sea Action Plan. Assessment results in full detail are presented in the respective thematic assessment reports (HELCOM 2023a-e).

4.2. Pollution

Pollution refers to pressures that spread through the marine ecosystem, where they can have major and widespread impacts. Eutrophication, hazardous substances, marine litter, underwater noise and the introduction of non-indigenous species add to the pressures exerted on the Baltic Sea ecosystem (Figure 4.4 and Box 4.1). These pressures originate from societal and economic activities, both terrestrial and maritime. For most of these pressures, reaching sustainable levels in the Baltic Sea is ultimately dependent on successful actions to restrict and limit their initial inputs, as subsequent remedial action is generally problematic, costly or impossible.

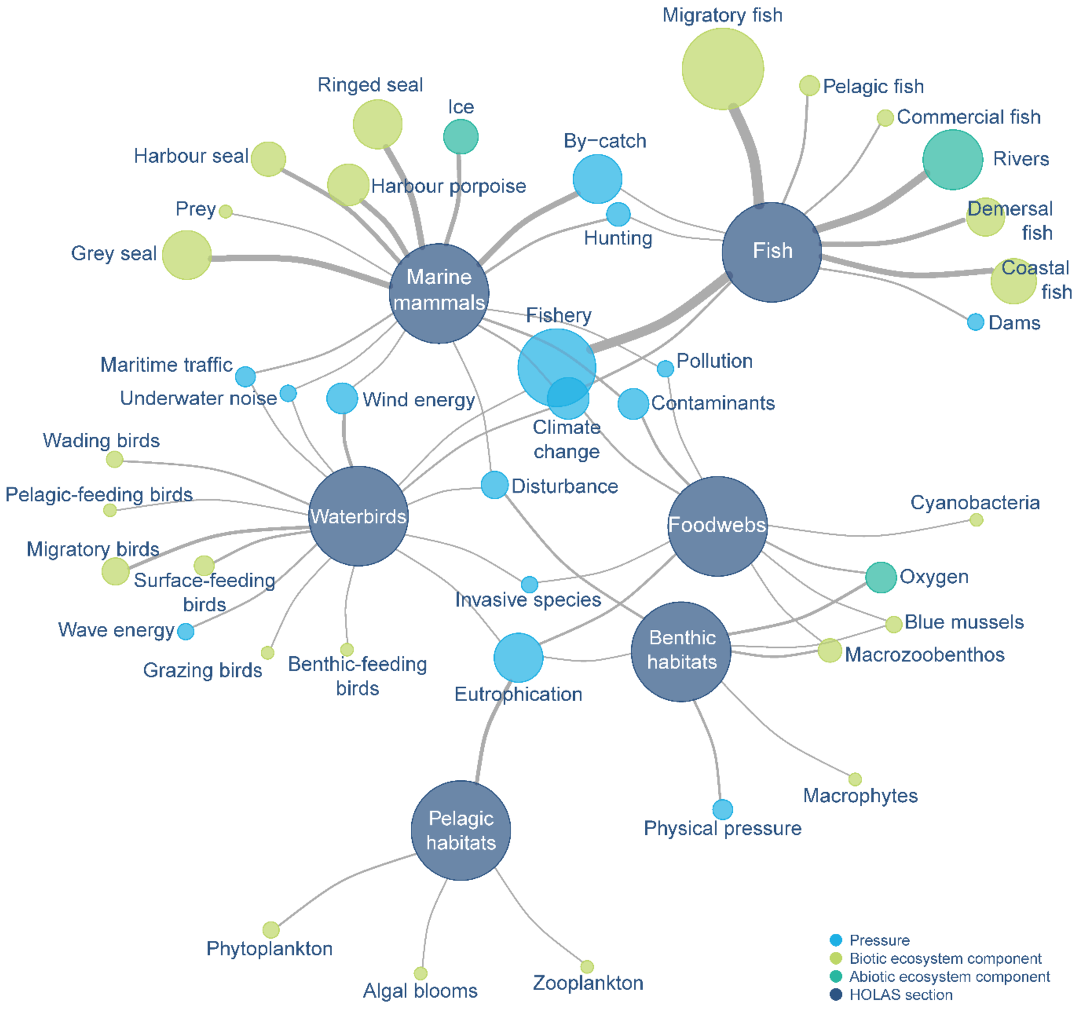

Figure 4.1. An overview of how the different ecosystem components mentioned in Chapter 3 are descriptively linked to different pressures, based on the HOLAS3 thematic assessment report on biodiversity (HELCOM 2023a). Each chapter in the thematic assessment is symbolised by a dark blue circle, and the other circles reflect the key elements (terms) used. The size of each circle loosely reflects how often the term is mentioned and should only be interpreted in this way. Similar terms are aggregated, so each circle includes both the term itself and all terms deemed to be synonymous (e.g. "eutrophication" includes "eutrophication" and associated terms such as "nutrient input" or "concentrations"). The width and length of the lines and the placement of the items is arbitrary. The image provides a simple visual representation of the topics and links covered, while simultaneously providing a gap analysis of where more information may be required in the future to increase the holistic nature of the evaluation (e.g. if the interaction between a certain pressure and an ecosystem component has not been well addressed). The overview was made using igraph.

Figure 4.2. Pollution enters the Baltic Sea from a mix of sources, including direct point sources, freshwater discharges, rivers and the atmosphere.

BOX 4.1.

The HELCOM thematic assessments of eutrophication, hazardous substances and other pollution

The HELCOM thematic assessment of eutrophication in 2016-2021 (HELCOM 2023b) addresses eutrophication in the Baltic Sea. It provides status assessment results for eutrophication indicators and their trends, as well as integrated assessment results using the HELCOM eutrophication assessment tool, HEAT. The results of the assessments are presented in summary in the current report and are given in full detail in the thematic assessment and its associated indicator fact sheets, which also describe the methods used.

The HELCOM thematic assessment of hazardous substances, marine litter, underwater noise and non-indigenous species in 2016-2021 (HELCOM 2023c) addresses other pollution-related pressures, and provides detailed assessment results and method descriptions for these topics. In addition to results based on the integrated HELCOM assessment tool CHASE (for hazardous substances), the report gives summaries of available indicator evaluations and descriptive knowledge of relevance. It also suggests various ways in which HELCOM assessments could be further improved in the future for the covered topics. For hazardous substances, the current assessments do not address all relevant policy requirements or cover all relevant ecological aspects. While a strong evaluation can be made based on the relatively few well-studied and well-monitored hazardous substances currently included in the assessment, there is a vast array of hazardous or potentially hazardous substances for which we have little information about their presence in the marine environment or their impacts.

The topics addressed in both reports are directly and primarily linked to human activities and have the potential to exert significant pressures on the Baltic Sea marine environment. They share the characteristic that the most effective way to address them is to prevent or limit their initial inputs. Once these pressures are in the marine environment, alleviating or remediating them is often very complex, difficult and costly compared with acting earlier. Different pressures have different scales of impact, but all cause or could cause significant negative effects on the ecosystem, and addressing all of them is of high importance for achieving our aim of a healthy Baltic Sea environment.

4.2.1 Eutrophication

The integrated assessment of eutrophication status shows that eutrophication is still a major problem in the Baltic Sea (Figure 4.3). There were no clear signs of recovery during 2016-2021 compared to the previous assessment period. Excess nutrient inputs to the marine environment increases phytoplankton development, which reduces light levels in the water, contributes to depleting oxygen reserves at the bottom, and triggers a series of other ecosystem changes (Box 4.2).

Inputs of nutrients to the Baltic Sea have decreased significantly but the target for maximum allowable inputs has not yet been achieved in all basins (Figures 4.4-4.5). For the whole Baltic Sea, the normalized total input of nitrogen was reduced by 12% and phosphorus by 28% between the reference period (1997-2003) and 2020 (HELCOM 2023f). The maximum allowable input (MAI) target for nitrogen was fulfilled in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat. For the Baltic Proper and the Gulf of Finland, the MAI was exceeded, and results for the Gulf of Riga were statistically uncertain. The target for phosphorus was fulfilled in the Bothnian Bay, Bothnian Sea, Danish Straits and Kattegat. In the remaining sub-basins, the MAI was exceeded also for phosphorus.

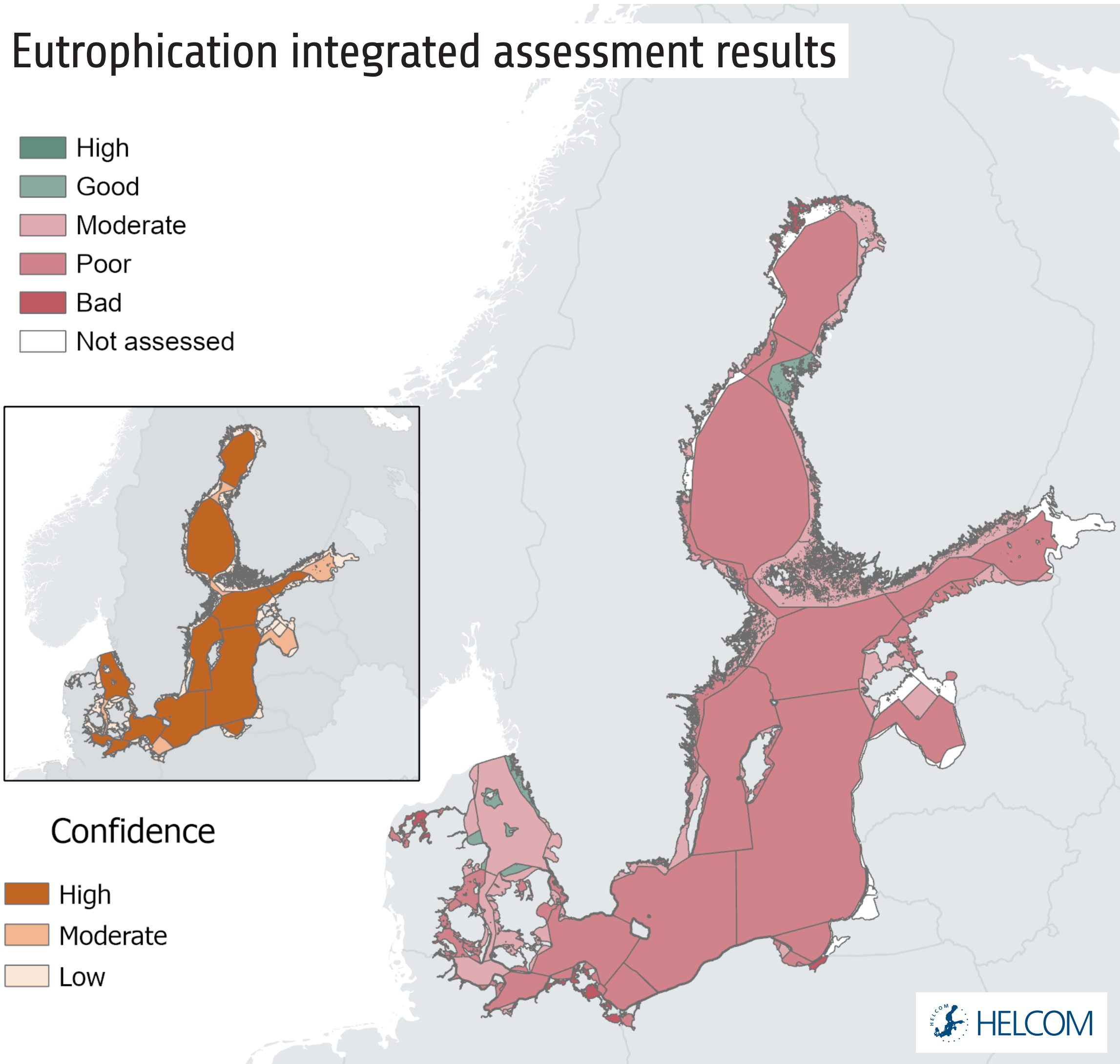

Figure 4.3. Summary of assessment results from the assessment of eutrophication. Source: HELCOM 2023b.

BOX 4.2.

What is eutrophication?

Eutrophication comes from the excessive input of nutrients into the marine system, leading to an increased supply of organic matter. Primary production by algae, plants and cyanobacteria is a key process at the base of the food web, providing energy for organisms higher in the food web. This primary production depends on the availability of nutrients, in particular nitrogen and phosphorus, but too high nutrient levels enhance primary production beyond what grazers in the food web can consume. Early symptoms of eutrophication are increased concentrations of chlorophyll in the water column and the growth of opportunistic algae. These lead to reduced water clarity and increased deposition of organic material to the seabed, which in turn increases oxygen consumption and may cause oxygen depletion. Long-lasting eutrophication can cause changes in species composition, when species that benefit from eutrophic conditions are favoured directly or through food web interactions, and vice versa.

The Baltic Sea Action Plan states the following ecological objective concerning eutrophication:

— **A Baltic Sea unaffected by eutrophication**

Countries around the Baltic Sea have a long-term commitment to reduce eutrophication in the Baltic Sea. A central tool is the Maximum Allowable Input, which gives the maximal inputs of waterborne and airborne nitrogen and phosphorus that can be allowed to Baltic Sea sub-basins while still achieving good status in terms of eutrophication.

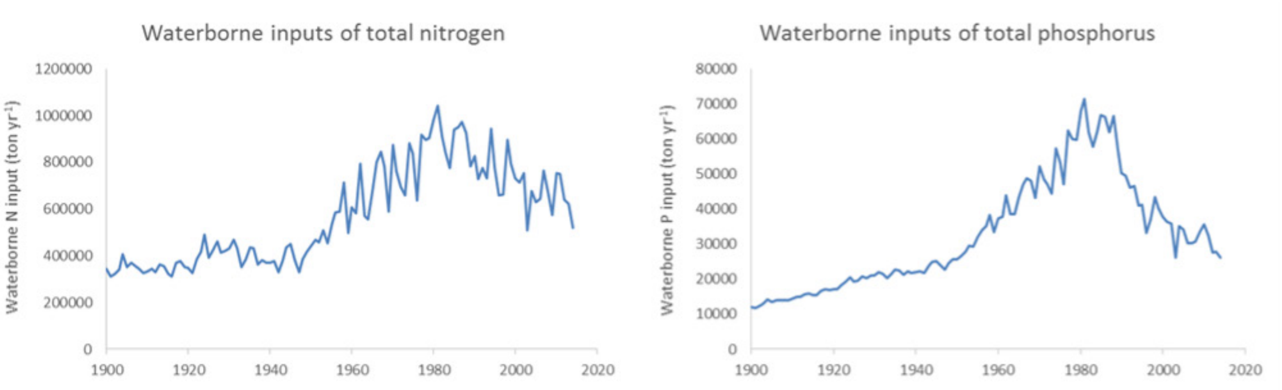

Figure 4.4. Temporal development of waterborne inputs of total nitrogen (left) and total phosphorus (right) to the Baltic Sea Source: HELCOM 2023b.

Figure 4.5. Inputs of nitrogen (left) and phosphorus (right) to the Baltic Sea sub-basins, as these are defined in the HELCOM pollution load compilation. BAS=whole Baltic Sea. The columns show trend-based estimates of total nitrogen and phosphorus inputs in 2020, in tons per year and including statistical uncertainty. The short blue lines show the maximum allowable inputs (MAI). Green indicates that the estimated inputs, including uncertainty, were lower than MAI, while red indicates that they exceeded MAI. Yellow indicates that the statistical uncertainty of the input data makes it not possible to determine whether MAI was fulfilled. Note that the scale of the y-axis differs between charts. Source: HELCOM 2023f.

Impacts of eutrophication in the Baltic Sea ecosystem

Eutrophication initially affects primary producers, and processes in the pelagic system are of key importance for how eutrophication symptoms develop. Widespread and lasting eutrophication can impair ecosystem functions through a combination of direct and indirect impacts on aspects such as species composition, food web dynamics and oxygen conditions (Carstensen *et al.* 2014). These impacts can have widespread effects across a broad range of habitats and species. In the Baltic Sea, eutrophication has been associated with changes in species composition in several key trophic groups, including primary producers, benthic fauna, coastal fish and sea birds. Over time, eutrophication has become a key driver of changes in the trophic state of the Baltic Sea ecosystem. The Baltic Sea has transformed from being a typical low productivity system in the 1920s to a high productivity system today, with the presence of insufficient oxygen conditions becoming a key mechanism and cause for concern (Tomczak *et al.* 2022, Rolff *et al.* 2022).

Eutrophication causes multiple adverse economic and societal effects. Factors such as decreased water clarity, more frequent cyanobacterial blooms, oxygen deficiency in bottom waters, changes in fish stocks and loss of marine biodiversity all decrease the environmental benefits from the Baltic Sea in terms of both use-related values and non-use values (Ahtiainen *et al.* 2016). Examples include increased costs of cleaning, reduced income from tourism, damage to fishing gear and lost fishing possibilities, increased travel costs to reach unaffected areas, and reduced cultural and historical values. Reaching good eutrophication status for the Baltic Sea is foreseen to increase human well-being significantly and bring economic benefits to society.

Sources of nutrient inputs

The majority of nutrient inputs to the Baltic Sea originate from human activities on land and at sea. Waterborne inputs enter via rivers and direct discharge from coastal areas. The main point sources of waterborne inputs are wastewater treatment plants (Figure 4.6), industries and aquaculture. The main diffuse sources are agriculture, managed forestry, scattered dwellings and storm water overflows. In addition, natural background sources contribute to the input.

The main sectors contributing to atmospheric inputs are energy production (combustion) and industry, as well as the transportation of oxidized nitrogen, and agriculture is also a source of reduced nitrogen. A large portion of the atmospheric inputs originate from sources outside the Baltic Sea region. Emissions from shipping in the Baltic and North Seas contribute significantly to atmospheric inputs of nitrogen.

Excess nutrients stored in bottom sediments can re-enter the water column and again enhance primary production. In oxygen-depleted areas, phosphorus can leak out and be used by cyanobacteria that can make use of inert nitrogen. Other habitats have a strong capacity to store and sequester nutrients, such as coastal habitats with rooted plants and long-lived macroalgae (HELCOM 2023d).

Regulations and needs

Minimizing the input of nutrients from human activities is a central management objective of the Baltic Sea Action Plan.

Regional targets for nutrient inputs are defined by the Maximum Allowable Inputs (MAI) and Nutrient Input Ceilings (NIC) in the Baltic Sea Action Plan. Fulfilling these targets for all sub-basins is a key prerequisite for achieving a Baltic Sea unaffected by eutrophication.

Reducing the agreed levels of nutrient inputs is expected to improve eutrophication status at sea, even though the responses at sea may take time (HELCOM ACTION 2021a). Model simulations indicate that significant improvements in eutrophication status can be expected roughly one or two decades after nutrient inputs are reduced to the target levels, and that it could take half a century or more to reach the environmental objectives. In coastal areas, the responses could be faster, if significant direct point sources are removed. This is probably also the case in the eastern part of the Gulf of Finland (HELCOM 2023f).

Measures to restore the natural functioning of Baltic Sea food webs are expected to enhance the natural capacity of the ecosystem to counterbalance eutrophication symptoms. Strengthening trophic control in the food web can curtail the overproduction of fast-growing filamentous algae, for example (see section 3.3).

Measures to strengthen coastal habitats with a strong capacity for nutrient uptake and storage, such as rooted plants and long-lived macroalgae, are expected to strengthen the ecosystem's natural capacity to sequester nutrients at sea.

Climate change is expected to worsen the negative impacts of eutrophication. Climate change effects could enhance algal blooms or oxygen consumption, for example.

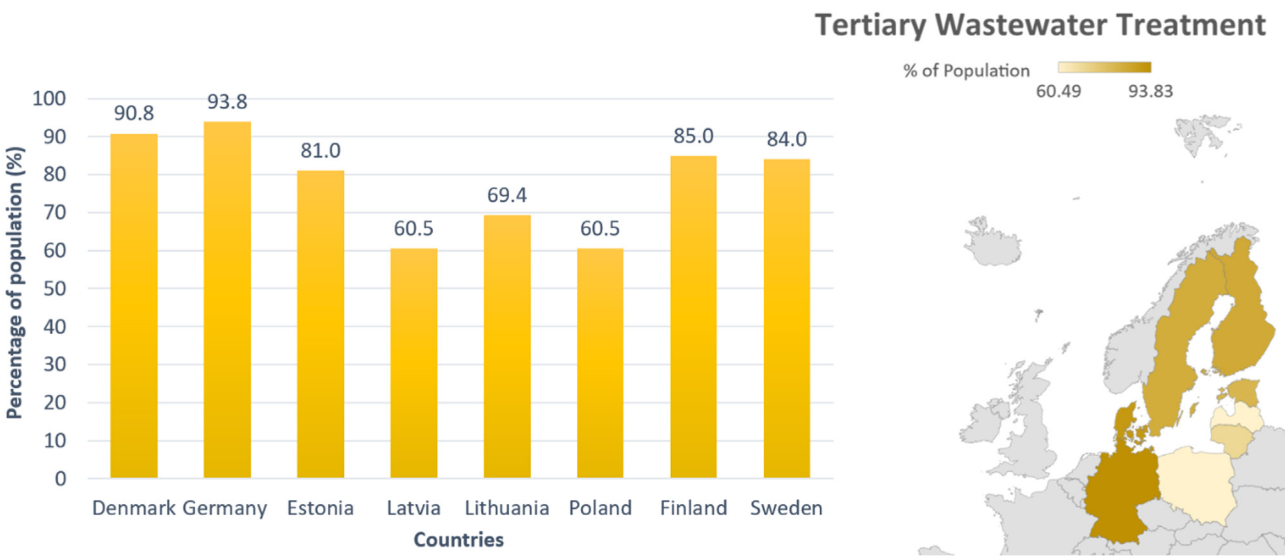

Figure 4.6. Various drivers determine the extent and efficiency of wastewater treatment in the Baltic Sea region, including political will, investment, regulations and the adoption of technology. Overall, 72% of the Baltic Sea catchment area population is connected to tertiary wastewater treatment plants (Eurostat 2022). The bar charts show the percentage of the total population connected to tertiary wastewater treatment plants in Baltic Sea countries in 2020. The chart does not include data from Russia or any non-HELCOM countries. Source: HELCOM 2023d.

4.2.2 Hazardous substances

The status of hazardous substances shows some signs of improvement during the assessment period, however it is still clearly not good (Figure 4.7). The integrated contamination status of the Baltic Sea remained above acceptable minimum levels during 2016-2021. The contamination status was assessed as either bad or poor in roughly 80% of the 57 assessed spatial units, including the majority of the open sea sub-basins. Only one assessment unit in the open sea had good status. The results partly reflect the prevailing monitoring regimes, because units achieving better status tend to be represented by fewer parameters being evaluated or key drivers of the overall status being absent.

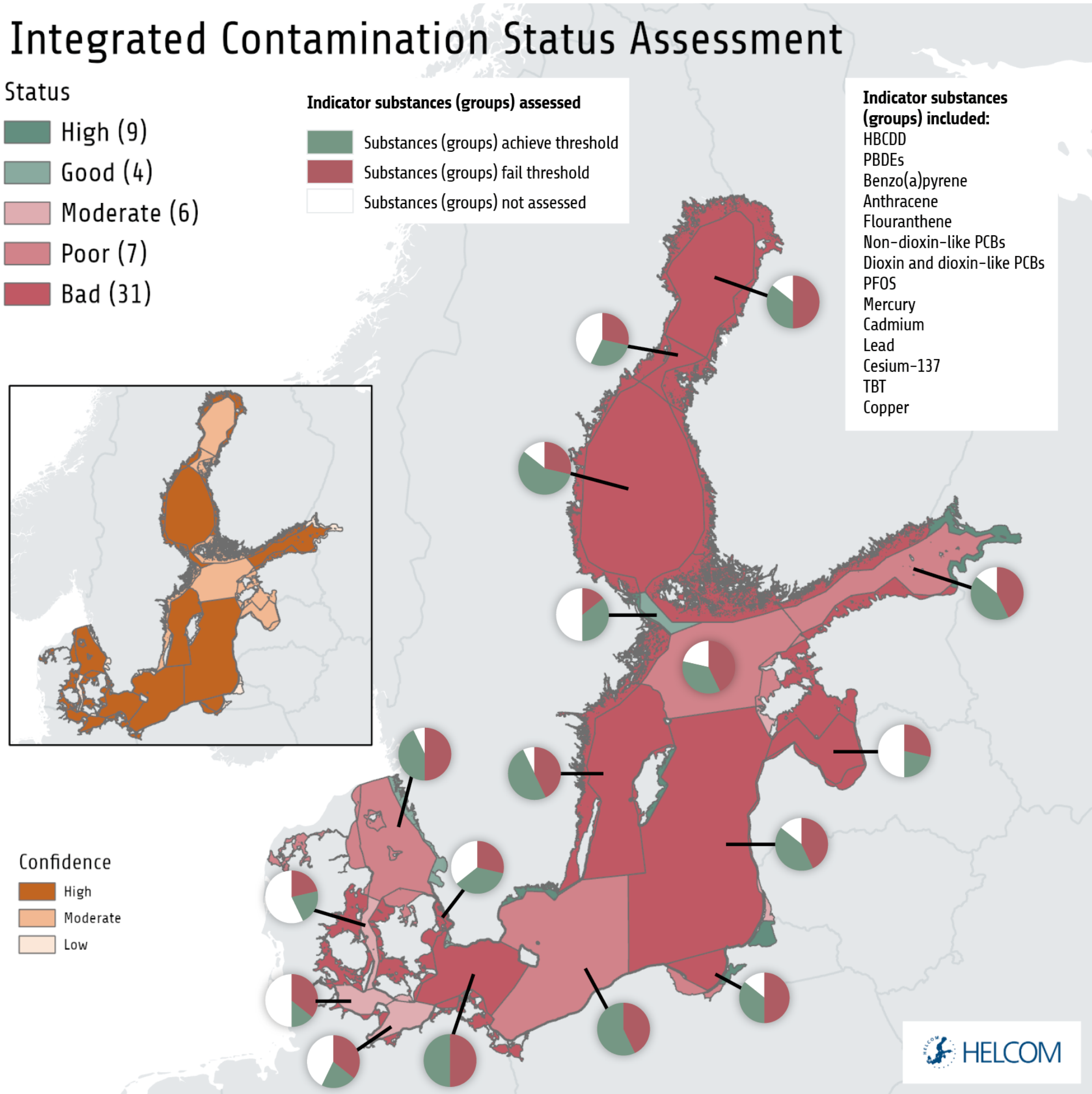

Figure 4.7. The integrated assessment of hazardous substances status in the Baltic Sea, assessed using the CHASE integrated assessment tool. The assessment shows that hazardous substances are a cause for concern in almost all assessed units, and those showing good status generally lack a full and adequate assessment. The integrated assessment is based on 11 core indicators. It integrates concentrations to threshold-derived values (contamination ratios) for fourteen individual hazardous substances or substance groups. The overall assessment is moderated by a parallel assessment of confidence (see inset map on the left) that can be considered an appraisal of the data coverage and assessment quality in any given assessment unit. Source: HELCOM 2023c.

Furthermore, only a small fraction of all potentially hazardous substances is measured and included in the indicator evaluations that make up the integrated assessment (Box 4.3).

There are some encouraging signs, however. Six open sea sub-basins have improved their status category since the previous assessment (HELCOM 2018), although they are still not in good status. Furthermore, at the level of individual monitoring stations, there are more substances with downward concentration trends than upward trends (Figure 4.8).

The assessment results are mostly driven by elevated concentrations of polybrominated diphenyl ethers (PBDEs) in biota, tributyltin (TBT) in sediments, mercury in biota, and copper in sediments. Cadmium concentrations in biota and sediments also contribute, as do lead concentrations in biota (Figure 4.9).

Monitoring and assessment currently focus on a relatively small number of priority substances which are known to have persistent and widespread negative impacts on the Baltic Sea environment. Work to address additional substances and develop a regional strategy for hazardous substances (towards BSAP action HL1) are ongoing in HELCOM. A pilot assessment shows that approaches to detect the biological effects of contaminants (signatures of exposure) and screening a wide array of substances could complement existing methods. An initial regional screening listed roughly 130 substances that regularly occur across the region, of which around 40 exceeded available environmental risk values. These substances include, for example, pharmaceuticals, industrial chemicals, personal-care products and tobacco/coffee-related contaminants, and they may require dedicated follow-up actions.

BOX 4.3.

What are hazardous substances?

Hazardous substances are synthetic or natural substances that enter the Baltic Sea at elevated concentrations because of human activities and can cause various types of damage to species and habitats in the ecosystem. Hazardous substances range from those that are highly visible in the form of oil-spills to others that can remain unnoticed until signs of detrimental impacts on the ecosystem or organisms become apparent. Many contaminants degrade slowly, and their impacts can magnify as they accumulate within aquatic food webs. Because hazardous substances are difficult or impossible to remove once they are in the system, the key measure is to limit the risk of their entry into the environment.

The Baltic Sea Action Plan has the following ecological objectives for hazardous substances:

- **Marine life is healthy**
- **Concentrations of hazardous substances are close to natural levels**
- **All sea food is safe to eat**
- **Minimal risk to humans and the environment from radioactivity**

Impacts of hazardous substances in the Baltic Sea ecosystem

Hazardous substances can have both direct and indirect harmful impacts on species, habitats, and the environment as a whole, and they remain among the most widespread and impactful pressures in the Baltic Sea today (HELCOM 2023c). Hazardous substances are often persistent, bioaccumulative and toxic. They affect the function or viability of biota when they occur at concentrations above safe limits. Many hazardous substances have the potential to interfere with biota even at very low levels. Furthermore, impacts from several contaminants can occur together (multiple mixture effects) or can coincide with other types of pressure, potentially enhancing and increasing the susceptibility of the system. Examples of impacts range from acute pollution events, such as oil spills to the slow accumulation of hazardous substances in top predators via biomagnification in the food web. Hazardous substances also affect the suitability of fish as food for humans and other animals.

Clear examples of hazardous substance leading to reproductive failure occurred recently in the history of the Baltic Sea. Widespread use of persistent organochlorines, such as DDT and PCBs, until the 1980s resulted in their spread into the Baltic Sea environment. They accumulated in the food web and severely reduced the fertility and population growth of ringed and grey seals, as well as the white-tailed eagle, all top predators in Baltic Sea food webs (Helle 1980, Helle *et al.* 1976, Bergmann 1999, Helander *et al.* 2008). There are also indications of a link between elevated organochlorine concentrations and lower pregnancy rates in harbour porpoises (Murphy *et al.* 2010). At the point when impacts are detected on top predators, such as marine mammals, the road to recovery is often long and complex. However, because certain persistent chemicals accumulate in the food web, new emerging pollutants that are below detection limits in other biota may be detected in the tissues of top predators, giving an early warning signal.

Sources of hazardous substances

Hazardous substances enter the Baltic Sea through various pathways. Key sources of hazardous substances include wastewater treatment plants, rivers, atmospheric deposition, redispersal of substances from dredged material (or other dumped material, such as dumped munitions) and discharge from maritime activities. Certain direct inputs also occur (or have occurred), such as in relation to biofouling treatment using TBT or copper. More examples are presented in the HELCOM (2023c).

Wastewater treatment plants are a key point source of contaminants to the Baltic Sea. Households and industries in the Baltic

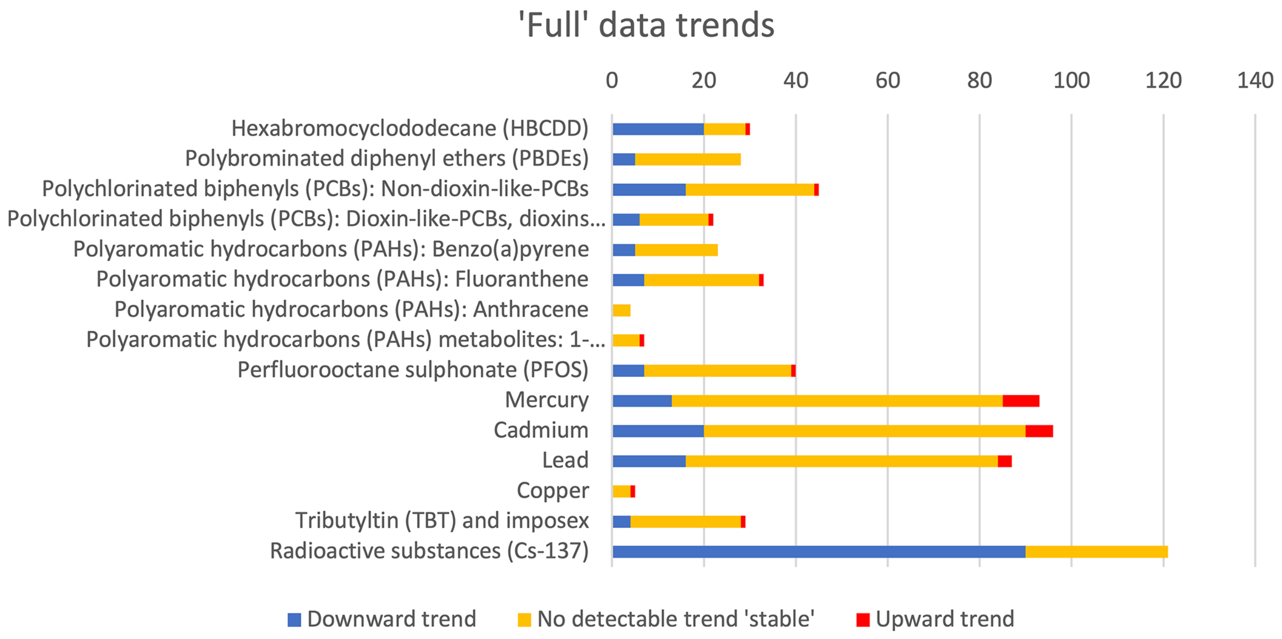

Figure 4.8. Trends in indicator substances or substance groups based on stations where "full" data series were available (i.e. longer-term data series with more than three years of data). The number of stations with suitable time series data available (horizontal axis) is divided into trend categories. Downward trends reflect a decrease in concentrations (i.e. improving status), whereas the opposite is true for upward trends, and other stations show no detectable trend ("stable" concentrations). Source: HELCOM 2023c.

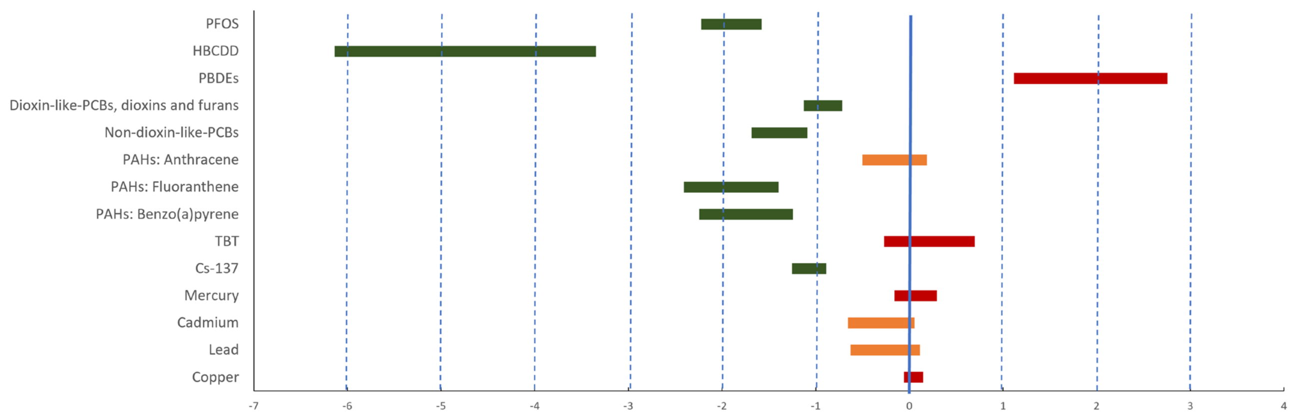

Figure 4.9. The range of contamination ratios of the evaluated hazardous substances. The ratios are the observed concentration value divided by the threshold value, based on the mean concentrations for the assessment period 2016–2021. The horizontal bars show the range of contamination ratios from the 20th to 75th percentile for each substance on a log-transformed scale. Red bars indicate that the median value fails the threshold value, which is indicated by the solid blue line. Orange bars represent a situation where the median value achieves the threshold value but not some of the stations (in the 75th percentile). The figure is based on the coastal and open sea data used in the integrated assessment. Source: HELCOM 2023c.

Sea catchment area are generally well connected to wastewater treatment systems, which results in a large number of hazardous or potentially hazardous substances occurring at elevated concentrations in their sludge and effluent. Some substances are depleted or transformed in the wastewater treatment process, while others remain relatively unaffected (HELCOM 2021). Phenolic substances appear to be frequently occurring, based on available measurements, although they generally are at levels below current environmental quality standards. Polyfluoroalkyl substances (PFASs), in particular PFOS and PFOA, are detected regularly, and many are not removed. Pharmaceuticals have also been shown to remain relatively unaffected by wastewater treatment processes, and levels exceed current environmental quality standards (HELCOM 2021).

Information on riverine and atmospheric sources are available for a few selected priority substances (HELCOM 2021). Data for the period 2015-2017 suggest that inputs of cadmium come mainly through rivers, while mercury and lead are predominantly introduced through atmospheric deposition. The total amount of input differs markedly between the substances, with 27, 5.3 and 356 tonnes per year being recorded for cadmium, mercury and lead, respectively. Only a small amount is estimated to come from point sources. Atmospheric deposition of these substances has generally declined since the 1990s (HELCOM 2020e and HELCOM 2021). The volume and location of dredged material in the Baltic Sea varies between years (e.g. HELCOM 2020b). For example, around nine million tonnes were deposited at 106 sites in 2020, with a little over half of this material being from capital dredging and the rest from maintenance dredging. Around seven million tonnes came from harbours and river estuaries, and most of the dredged material was deposited at locations offshore. Levels of mercury, lead, copper, tributyltin and polycyclic aromatic hydrocarbons in the dredged material were similar to or lower than corresponding values recorded in 2014 or before. However, cadmium levels had increased.

Maritime activities, such as shipping, can emit hazardous substances through spills of oil or other substances. Operational discharges from the cleaning systems of ships are a significant source. With the use of exhaust gas cleaning systems (scrubbers), hazardous substances are released with the discharge of scrubber waters, as well as in grey and bilge waters and through the smokestack. In 2021, the total volume of discharge water from exhaust gas cleaning systems was roughly 286 million cubic metres, mainly from open loop systems. For example, open loop scrubber systems are estimated to generate as much as 8.5% of the total Baltic Sea load of the polyaromatic hydrocarbon anthracene (Ytreberg *et al.*, 2022). Discharges from these activities are increasing.

Regulations and needs

Minimizing the input and impact of hazardous substances from human activities is a key goal of the Baltic Sea Action Plan. Management objectives relating to hazardous substances are to minimize their input from sea-based activities, enforce international regulations, achieve no illegal discharges and have safe maritime traffic without accidental pollution.

Hazardous substances that enter the aquatic environment often remain for a long time, and their impacts accumulate in the food web. Removing a contaminant once it is present at sea is far more complex and costly than preventing its release, and in several cases is impossible. Furthermore, many substances are persistent and have long recovery times even after their input has been stopped.

Finding measures to reduce or prevent the input of hazardous substances at the source is significantly more achievable and cost-effective than dealing with them once they are already present in the environment.

The complexity of human activities and regulatory levels associated with environmental contaminants makes management response and policy implementation for hazardous substances a significant challenge that warrants strategic development in itself.

Climate change is expected to have significant effects on the Baltic Sea, but there is currently no regional overview of how climate change interacts with hazardous substances (HELCOM and Baltic Earth 2021). A number of direct climate change effects are likely to affect hazardous substances, such as water temperature, atmospheric circulation, solar radiation, acidification, stratification, precipitation, river runoff and sediment transportation. Among indirect effects, factors such as changes in oxygen concentration, microbial processes, non-indigenous species and ecosystem functions could affect the presence and impact of hazardous substances in the Baltic Sea ecosystem (HELCOM 2023c).

4.2.3 Marine litter

The status of marine litter in the Baltic Sea is currently evaluated based on beach litter and litter on the seafloor (Figure 4.10, Box 4.4).

The HELCOM threshold value for beach litter is 20 litter items per 100 metres of beach. During 2016-2021, eleven out of the sixteen sub-basins that could be assessed were above this limit and did not reach good status. The subbasins with highest median values were the Sound (313 litter items per 100 m), the Gulf of Riga (156 items) and the Eastern Gotland Basin (96 items). The sub-basins achieving good status for beach litter were Kiel Bay, the Bay of Mecklenburg, the Gdansk Basin and the Western Gotland Basin. The Quark had a median value below the threshold value, but the result was evaluated as uncertain due to limited data. Plastic litter, including single-use items, was the most common litter category, accounting for between 32 and 93% of the total number of litter items (Figure 4.12). Several sub-basins showed a decrease in the total litter count over time, which correlates with a decrease in the count of single-use plastics and plastic litter items.

Data about litter on the seafloor is collected in connection with fish surveys using trawls and is available for some sub-basins (Figure 4.11). Litter in the categories "plastic" and "other" increased during the evaluation period, and these categories thus fail the preliminary threshold value, which is "no significant increase" from 2015 to 2021 in weight, number or probability of catching litter. The category "fisheries-related litter" achieved the threshold when measured in number per square kilometre but not when measured in weight. The remaining categories,

BOX 4.4.

What is marine litter?

Marine litter comes from a vast range of human sources and reaches different marine compartments. Beach litter is monitored worldwide as a proxy of human impacts on the ecosystem. Information on the amount of litter can indicate general levels of potential harm to marine biota and ecosystems, as well as societal losses in the form of aesthetic values, economic costs and hazards to human health. Litter that has accumulated on the seafloor is equally relevant and can have significant impacts on organisms at sea. Evaluation of litter types and categories helps us understand the sources of marine pollution and assess the efficiency of environmental management measures.

The Baltic Sea Action Plan states the following ecological objective for marine litter:

— No harm to marine life from litter.

Figure 4.10. The impact of marine litter on the marine environment is closely linked to human behaviour.

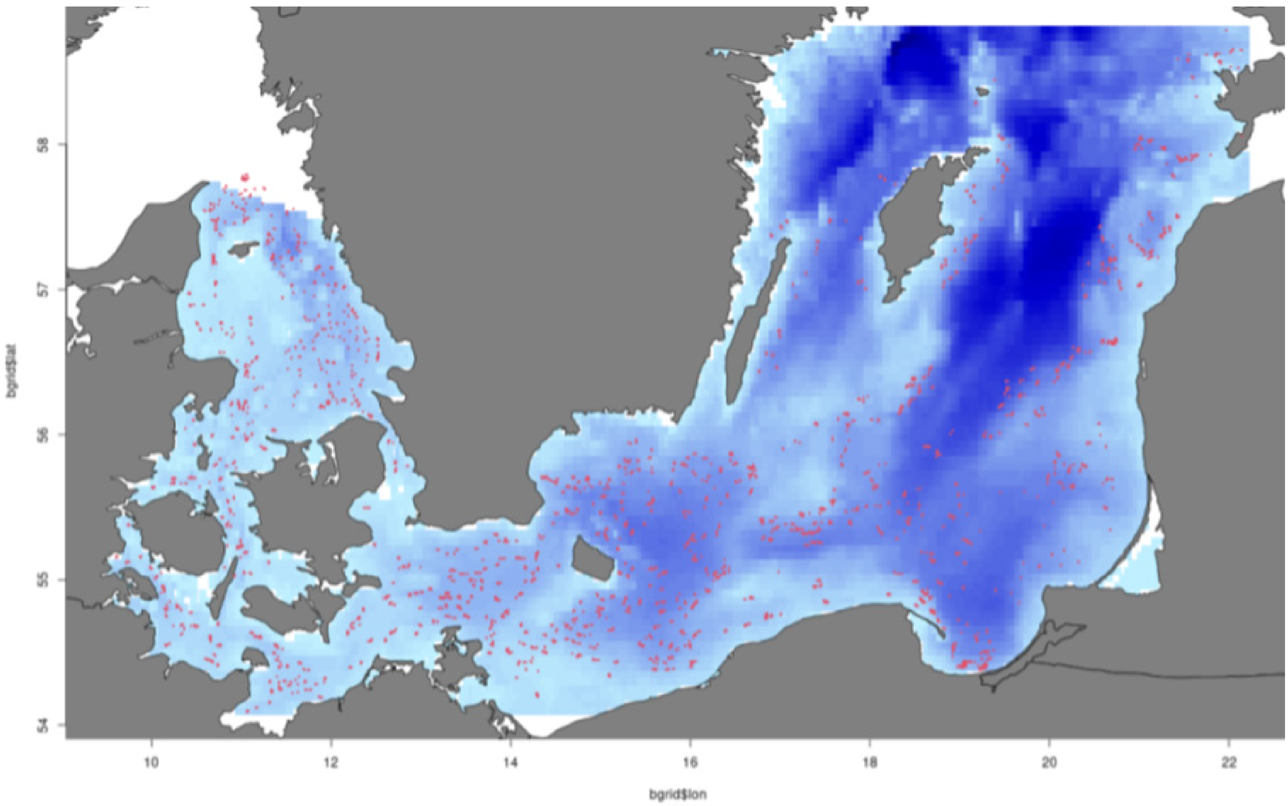

Figure 4.11. Sampling locations of sea-floor litter (red) and depth (shades of blue, darker indicating deeper). Note that deep locations and the north and north-eastern parts of the Baltic are not currently sampled, and that the depth map is not aligned with HELCOM assessment unit borders. Sampling of sea-floor litter was started in 2011, by its inclusion in the Baltic Sea International Trawl Survey, but litter categories and sample codes were not fully standardised until 2015. Source: HELCOM 2023c.

"glass", "metal", "natural", "rubber" and "single use plastics", showed no significant increase in weight or number per square kilometre during the evaluation period.

Work is needed to develop these evaluations further, along with evaluations of microlitter and the impacts of litter on biota (HELCOM 2023c).

Impacts of marine litter in the Baltic Sea ecosystem

Litter may cause harm to animals when they ingest it, either by clogging or injuring their digestive tract or by causing contamination. Another major impact is animals becoming entangled and trapped in lost fishing gear or packaging material. Litter on the seafloor can result in anoxia in the underlying sediments, which alters the biogeochemistry and the benthic community structure (Goldberg 1994). Certain litter types, such as glass bottles and tin cans, may provide substrates for the attachment of sessile biota (Mordecai *et al.* 2011, Moret-Ferguson *et al.* 2010, Pace *et al.* 2007). Heavy plastic items may become colonized by bacteria or loaded with sediments and sink to the seafloor, where they can persist for centuries (Thompson 2006, Derraik 2002, Ye & Andrady 1991). Large plastic items can pose a risk of obstruction or harm to animals, and they leak smaller particles that pose risks to organisms. Litter containing hazardous substances can act as a source of contamination and thereby contribute to chemical impacts on the ecosystem. Marine litter has a socioeconomic impact through the costs associated with cleaning it up, damage to or loss of fishing gear, obstruction of motors and harm to tourism and recreation (Newman *et al.* 2015).

Sources of marine litter

Marine litter comes from both land and sea-based sources. The types of litter from land are often closely linked with consumer behaviour, such as recreational and tourism activities leaving behind plastic bags, left-overs from beach picnics or cigarette butts. Other land-based sources are riverine inputs and inputs from storm-water overflow. Important sea-based sources are ship-generated waste, such as lost or abandoned fishing gear, foamed plastic or lost fish traps. Beach litter monitoring thus reflects both littering trends along the coastline and litter transported over long distances.

The seafloor is a sink for marine litter, and litter items on the seafloor originate from both maritime activities (e.g. fishing or shipping) and land (Galgani *et al.* 2010, Galgani *et al.* 2015, Pham *et al.* 2014). Lost fishing gear, known as ghost nets, continue trapping marine animals for a long time. Both passive fishing gear, such as traps and nets, and trawls are often lost or discarded. The extent of lost fishing gear in the Baltic Sea is not known, but some examples are available. In 2011, WWF Poland, together with fishermen, scientists and divers, retrieved six tonnes of ghost nets from the Baltic seafloor and two wrecks over 24-days. In 2014, a ghost net project conducted on Rügen by the Ozeaneum Stralsund, archeOmare, the Drosos foundation and WWF Germany removed around 4 tonnes of ghost nets from two wrecks (HELCOM 2023c).

Figure 4.12. Lost fishing gear can end up on land, but most often it remains in the sea where it can continue trapping marine animals for a long time.

Regulations and needs

HELCOM countries have agreed in the Baltic Sea Action Plan to prevent the generation of waste and its input to the sea, including microplastics, and to significantly reduce amounts of litter on shorelines and in the sea.

The implementation of the 2021 HELCOM Regional Action Plan on Marine Litter should enable the achievement of the management objectives for marine litter in the Baltic Sea Action Plan. However, there is a need for better geographical coverage in monitoring to evaluate the effect of current actions on marine litter and to define additional ones, if necessary.

Researchers in the fields of climate and marine litter have put forward that commitments against plastic littering in the sea can also increase interest in solving issues related to climate change (Ford *et al.* 2022). The connections between climate change and plastic pollution in the oceans include the fact that plastic contributes to greenhouse gas emissions both throughout its life cycle and as litter in the sea, and that climate change and plastic pollution both occur in all environments. Climate change could worsen the spread of plastic pollution, because litter abundance on coastlines is influenced by water currents and prevailing wind conditions, and rivers are pathways for litter from inland. Changes in precipitation and floods, as well as oceanographic changes, could thus alter litter abundance and the deposition of litter.

4.2.4 Non-indigenous species

Thirteen non-indigenous or cryptogenic species appeared for the first time in the Baltic Sea during the assessment period 2016-2021 (Figure 4.14, Box 4.5). The threshold value for good environmental status is no new introductions of non-indigenous species through human activities at the scale of the whole Baltic Sea during the assessment period. Good status for non-indigenous species was therefore not achieved.

The new introductions were recorded in the Kattegat, the Great Belt, Kiel Bay, the Bay of Mecklenburg, the Bornholm Basin, the Gulf of Gdansk, the Archipelago Sea and the Gulf of Finland.

The indicator only considers new human-mediated introductions. Spreading within the Baltic Sea by natural means, such as by migration or aided by water currents, is not part of this indicator.

The trend in the arrival of new non-indigenous or cryptogenic species increased sharply in the second half of the last century and has not shown any signs of decreasing since then (Figure 4.13).

The number of new introductions was higher during the current assessment period (13) than in the previous one (12 introductions in 2011-2016). However, this comparison is complicated by the fact there were significant additional reports provided for the previous assessment period that were not directly included in the that assessment.

BOX 4.5.

What are non-indigenous species?

Non-indigenous species are species that have spread or been transferred as a result of human activities, reaching environments in which they previously did not naturally occur. Non-indigenous species have the potential to cause harm in their new environments through their interactions with naturally occurring species or human activities.

The Baltic Sea Action Plan states the following ecological objective for non-indigenous species:

— No introductions of non-indigenous species

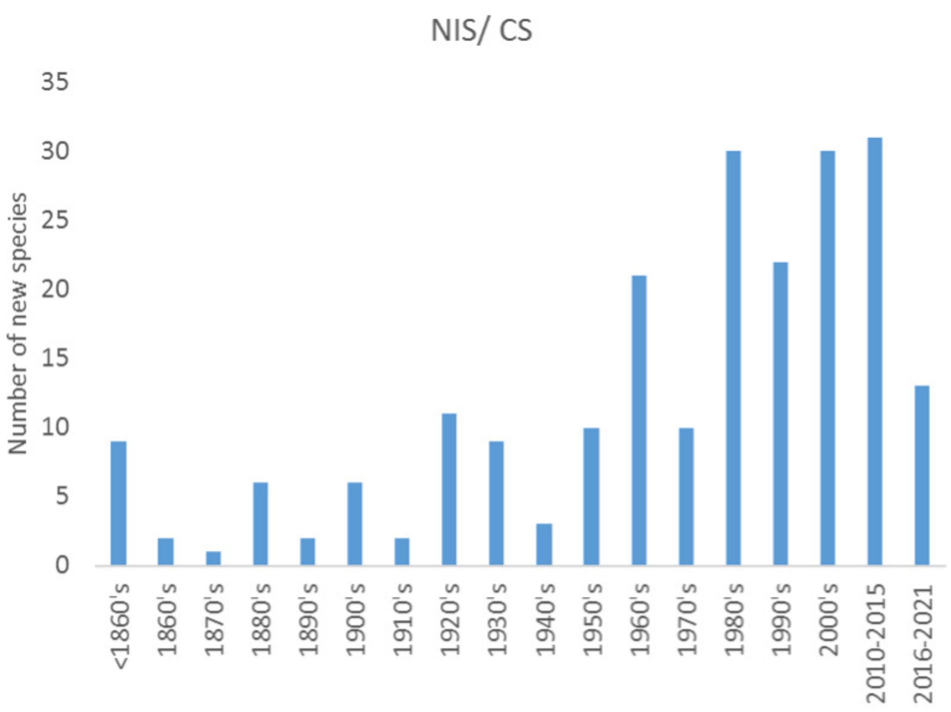

Figure 4.13. The number of non-indigenous species (NIS) introduced to the Baltic Sea over time. The bars indicate the number of new introduced species per time period. Note that the lengths of the last two time periods differ from the others, covering intervals of six instead of ten years. There is a discrepancy between the statistics presented in this figure and the assessment results presented in the text because of retrospective reporting of many new non-indigenous species after the publication of the previous holistic assessment (HELCOM 2018). The threshold value for good status is 0 new introductions. Data are from the Information system on aquatic non-indigenous and cryptogenic species (AquaNIS). Source: HELCOM 2023c.

Impacts of non-indigenous species in the Baltic Sea ecosystem

Non-indigenous species that spread into and become established in the Baltic Sea may harm the natural marine environment. For example, the round goby (*Neogobius melanostomus*), a bottom-dwelling invasive fish originating from the Black Sea and the Caspian Sea, was first observed in the Baltic Sea in 1990. After a few years of low abundance, the species increased dramatically and is now a dominant species in many areas of the Baltic Sea, with the capacity to change interactions in the benthic food web (Kotta *et al.* 2016), and it is still expanding its range in the Baltic Sea.

Overall, non-indigenous species have caused ecological, economic and public health impacts globally (Ruiz *et al.*, 1997, Mack *et al.* 2000, Lockwood *et al.* 2007, Ojaveer and Kotta 2015). Non-indigenous species can induce considerable changes in the structure and dynamics of marine ecosystems. Economic impacts range from financial losses in fisheries to expenses to industries for cleaning intake or outflow pipes and structures from fouling (Black 2001, Williams *et al.* 2010). Public health impacts may also arise from the introduction of pathogens or toxic algae.

The impacts of non-indigenous species can be unpredictable and may be large, especially when they co-occur with other pressures. However, not all non-indigenous species are invasive, spread widely or become abundant. Established non-indigenous species may influence biodiversity and the ecosystem in different ways, and their effects are often difficult to foresee. Risk assessments are important to guide the management of non-indigenous species and to help implement measures at an early stage (Katsanevakis *et al.* 2014). An evaluation of current cumulative negative impacts on marine biodiversity caused by non-indigenous species in the Baltic Sea, based on the Cumulative IMPact of ALien species (CIMPAL) index, is depicted in Figure 4.15. However, our knowledge is very limited for the majority (60%) of wide-spread non-indigenous species in the Baltic Sea (Ojaveer *et al.* 2021).

Sources for the introduction of new non-indigenous species

Maritime transport is the main pathway for the introduction of new non-indigenous species. Harbours and ports are hotspots for both the new introduction of non-indigenous species and their establishment, as they are sites where ships are stationary for extended periods. Harbours and ports also offer suitable places for species to settle, in shallow water or modified habitats (Lehtiniemi *et al.* 2015).

Figure 4.14. The round goby (Neogobius melanostomus) is an example of a non-indigenous species that has taken a major role in the Baltic Sea food web, leading to impacts on several other species.

Regulations and needs

The management objective for non-indigenous species under the Baltic Sea Action Plan is "no introductions of non-indigenous species".

Preventative measures are key to limiting non-indigenous species, as the eradication of already established non-indigenous species is difficult and cost-intensive and has generally proven not to be feasible in aquatic environments (Sambrook *et al.* 2014). There are no records of the eradication of established non-indigenous species in the Baltic Sea. Management should therefore primarily aim to prevent further introductions and to minimize the negative effects of the non-indigenous species that have already been introduced. Further monitoring and evaluation of the establishment, risk and potential harm caused by non-indigenous species in the Baltic Sea is also needed.

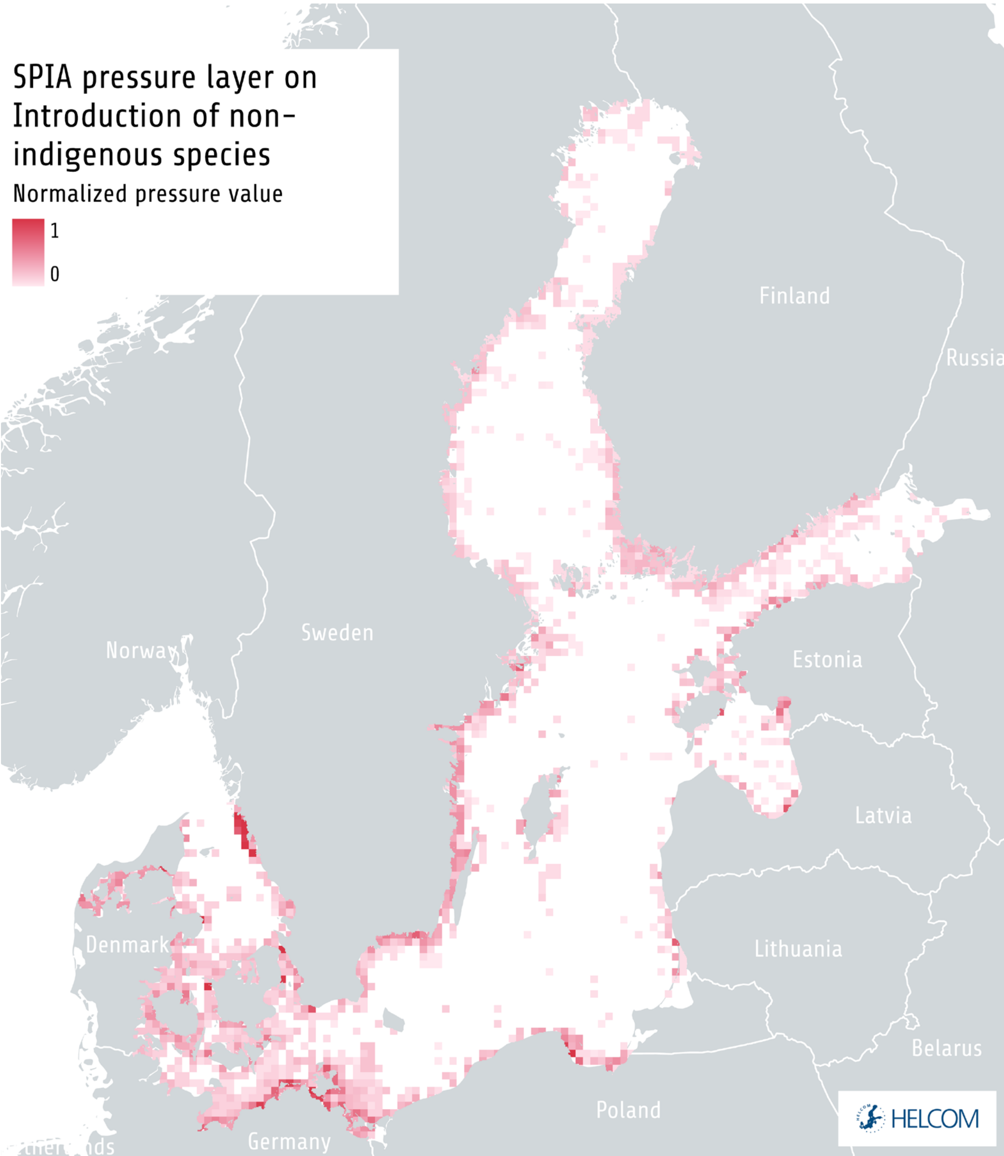

Figure 4.15. Non-indigenous species impacts in the Baltic Sea, as presented in HELCOM (2023e). The layer indicates the cumulative negative impacts on marine biodiversity caused by non-indigenous species based on the index CIMPAL (Cumulative IMPact of ALien species (Katsanevakis et al. 2016). The map shows the normalized pressure values, with increased colour intensity indicating higher pressure. Source: HELCOM 2023e.

4.2.5 Underwater noise

Continuous noise was evaluated for the first time in HELCOM during the current assessment period, by addressing the proportion of the Baltic Sea area exceeding noise levels that may cause adverse biological effects (Box 4.6). The evaluation results indicate a good status of continuous underwater noise in all areas of the Baltic Sea with respect to the risk of behavioural disturbance in fish or marine mammals (Figure 4.19). With respect to the risk that human-induced noise masks natural sounds, the evaluation indicates good status for marine mammals in all of the Baltic Sea but not good status for fish in 9 out of 17 assessment units. Several aspects of the evaluation method are still under development.

Continuous underwater noise shows considerable variation in space and time (Figure 4.16). Noise levels are clearly higher in shipping lanes than elsewhere in the Baltic Sea, and noise is more widespread in winter than in summer.

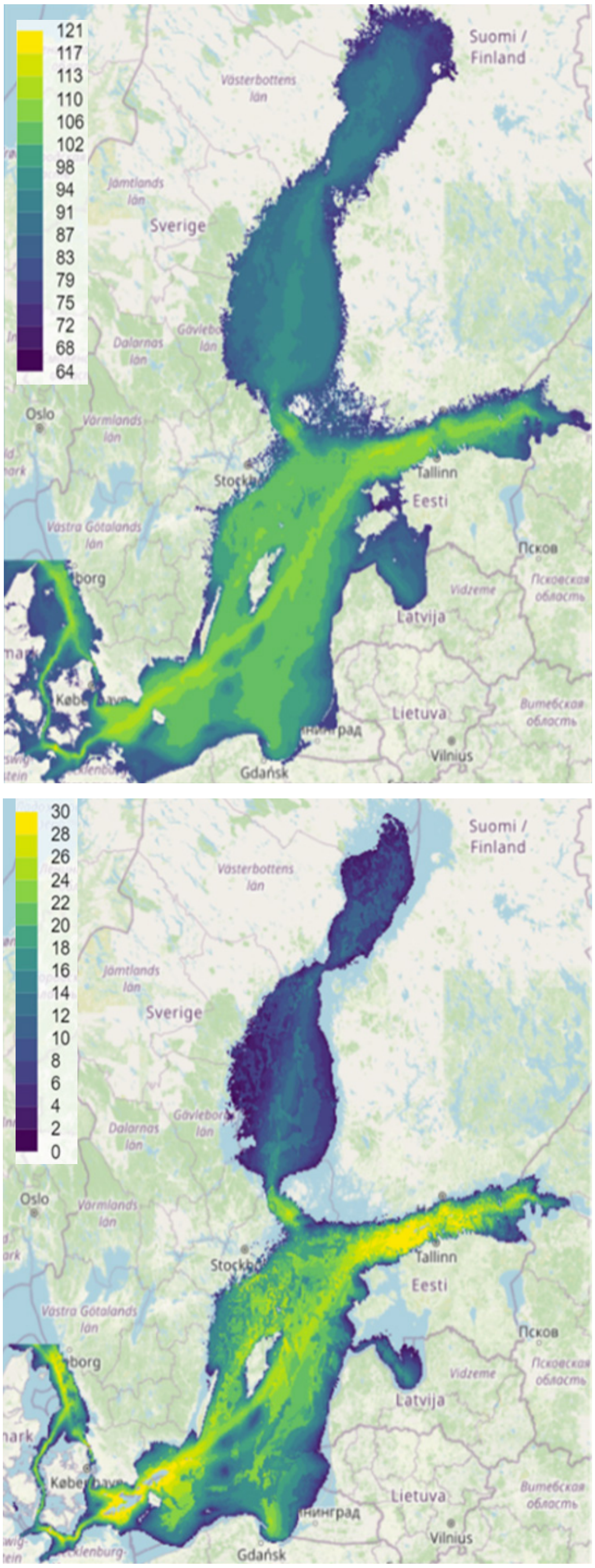

Figure 4.16. Illustration of continuous underwater noise in the Baltic Sea. The upper map shows the median sound pressure level for the third octave band 125 Hz in March 2028, and the map below shows the median excess level for the same. The maps represents the time of the year with the most favourable conditions for the transmission of anthropogenic noise in the Baltic Sea. Source: HELCOM 2023c.

BOX 4.6.

What is underwater noise?

Underwater noise measures the contribution of human activities to the sound environment under the sea surface. Both continuous and impulsive noise occur, and the two types vary in their properties and in how they affect aquatic animals. Continuous noise is constant, fluctuating or varying slowly over time, while impulsive noise has a short duration and a fast pulse rise time.

The Baltic Sea Action Plan states the following ecological objective for underwater noise:

— **No or minimal harm to marine life from man-made noise.**

The status of continuous noise is evaluated in relation to the hearing frequencies of fish and marine mammals, at 125 and 500 Hz decidecade bands, respectively. The risk of behavioural disturbance is evaluated based on the median total sound pressure level, and the risk of masking natural sounds is evaluated based on the median excess of a species-specific level. Impulsive noise is evaluated based on the occurrence of impulsive noise-producing events, such as explosions, reported to the regional HELCOM/OSPAR noise registry hosted by ICES (ICES 2015). The distribution of sound was compared to the distribution of harbour porpoises in the Baltic Sea to get a preliminary view of the overlap between sound and the occurrence of harbour porpoises.

Additionally, the potential effect of continuous noise on mobile species was addressed by combining the HELCOM SPIA pressure layer representing input of continuous noise with information on the distribution of fifteenmobile species and their habitats (HELCOM 2023e). According to the obtained results, the highest average potential effect of continuous underwater noise occurs in the south-western Baltic Sea, where all ships entering or leaving the inner parts of the sea pass through a rather narrow area, compressing the traffic. The Arkona basin is also a hotspot for the occurrence of mobile species, intensifying the impact of this area (Figure 4.17).

Preliminary evaluations of reported impulsive noise indicate that there was enough undisturbed habitat for harbour porpoises in the Baltic Sea to avoid the impacts of low- and mid-frequency impulsive sounds during the assessment period. The area of habitat exposed and disturbed remained clearly below 10% of its HELCOM area habitat per day, based on the occurrence of impulsive noise-producing activities reported by Contracting Parties (Figure 4.18).

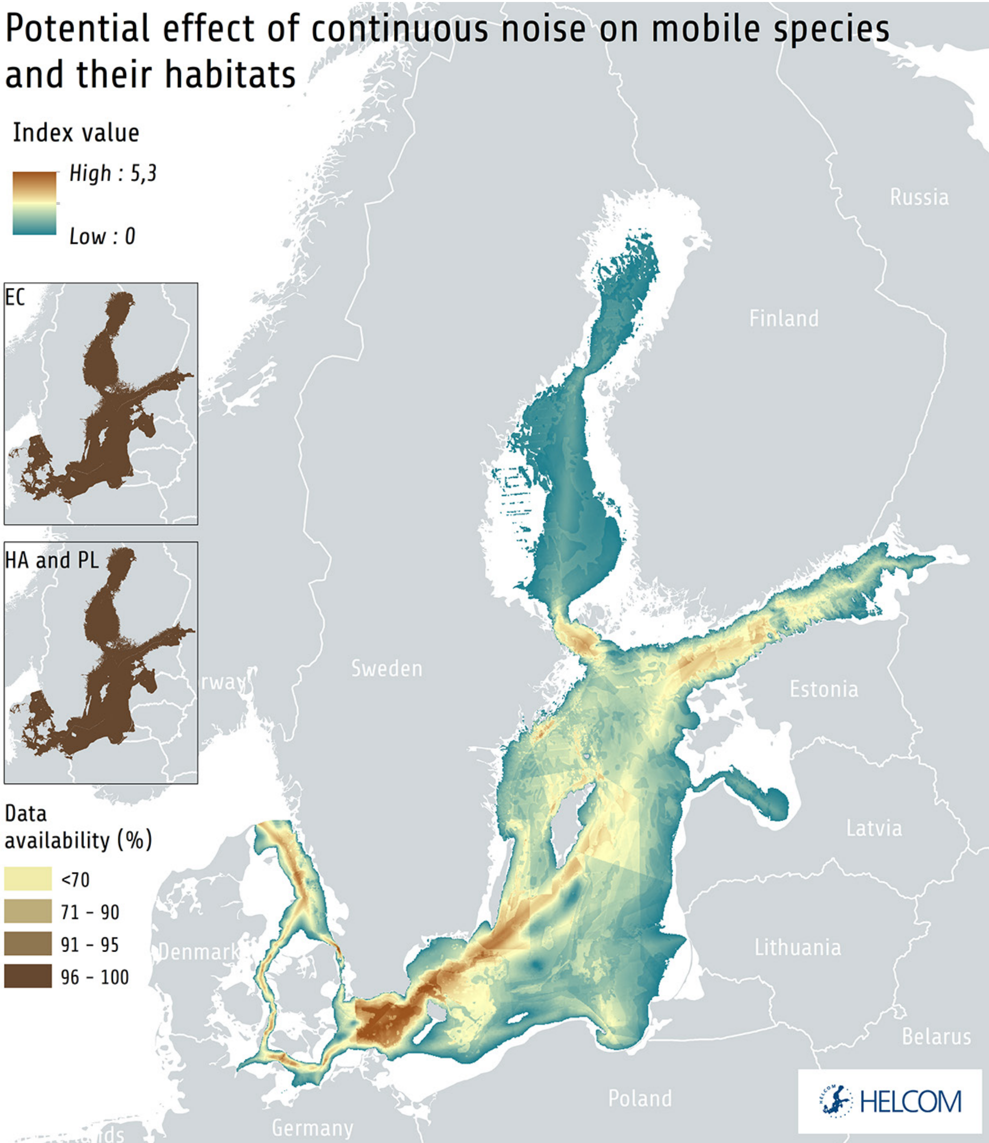

Figure 4.17. Areas with potentially highest impact from continuous underwater noise on mobile species. The map is based on the HELCOM pressure layer on inputs of continuous noise combined with information on the distribution of fifteen mobile species and their habitats (HELCOM 2023e). The highest average potential impact occurs in the south-western Baltic Sea, where all ships entering or leaving the Baltic Sea pass through a rather narrow area. The Arkona basin is also a hotspot for the occurrence of mobile species, which increases the potential impact. Source: HELCOM 2023e.

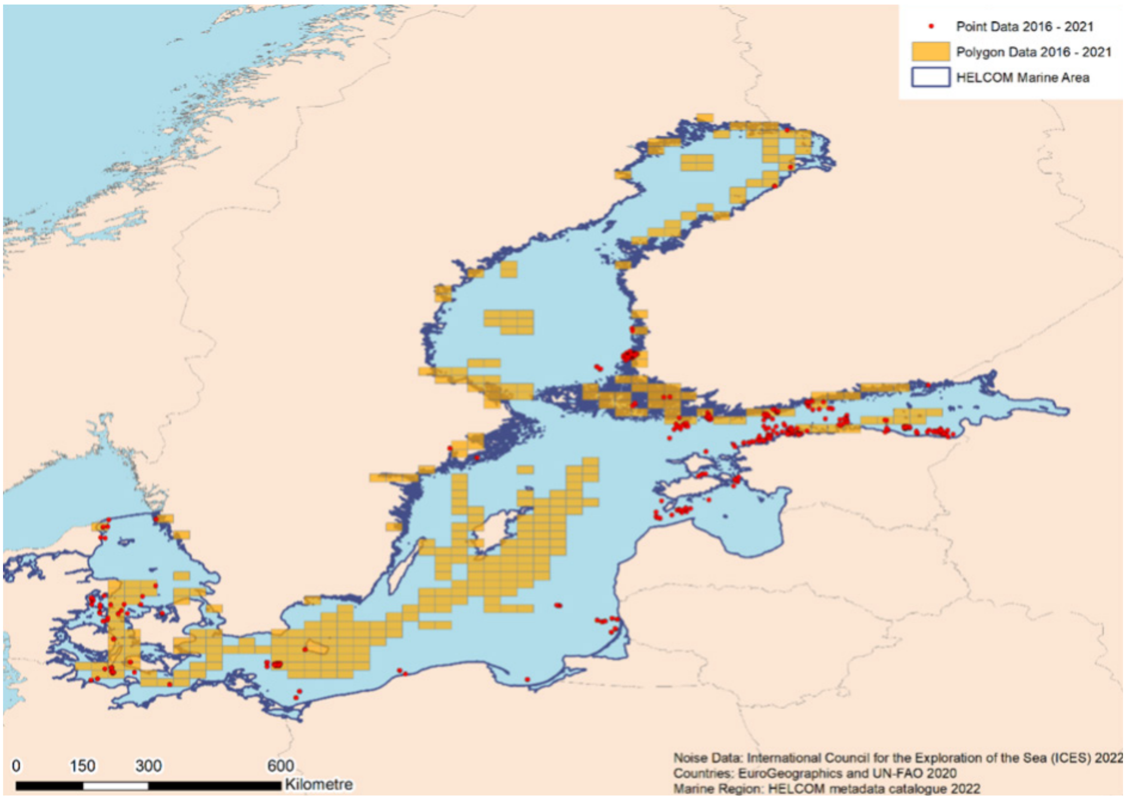

Figure 4.18. Impulsive noise activities reported for the period 2016 – 2021 in the HELCOM area. Data are from the HELCOM noise registry (ICES 2015). Source: HELCOM 2023c..

Impacts of underwater noise in the Baltic Sea ecosystem

Noise can affect aquatic life in several ways. Continuous noise at certain frequencies and high intensity can mask the natural acoustic communication of animals and decrease their ability to hear biologically relevant sounds, such as sounds involved in locating prey. It can also disturb their natural behaviour.

Although loud impulsive noises do not persist, they can nevertheless induce a range of impacts depending on their intensity. Certain levels of impulsive noise can cause biological disturbance by inducing stress and behavioural changes in, for example, fish and marine mammals (Wysocki *et al.* 2006, Santully *et al.* 1999), particularly in harbour porpoises (e.g. Madsen *et al.* 2006, Brandt *et al.* 2009, Tougaard *et al.* 2009, Tougaard *et al.* 2012, Dähne *et al.* 2013) but also in harbour seals (e.g. Jacobs and Terhune 2002, Gordon *et al.* 2015, Kastelein *et al.* 2015). Such disturbances may deter animals from an area or prevent them from carrying out normal feeding or reproductive behaviour. At higher levels, noise can have an impact on an animal's auditory system, leading to temporarily or permanently impaired hearing (Lucke *et al.* 2009, Finneran 2015). Very high levels of impulsive noise can lead to further physiological injury or death.

Sources of underwater noise in the Baltic Sea

Continuous noise in the Baltic Sea comes mainly from maritime transport. Other sources of continuous noise include fishing vessels, energy installations, leisure boats and dredging. Noise from ships sailing at service speed is primarily from their engine and propeller, with secondary components being machinery and the movement of the hull through the water. Sound waves propagate efficiently in water, so sounds from point sources are heard much farther away than in air.

The most intense sources of loud impulsive noise are explosions, pile driving, seismic exploration and low frequency sonar. Unless mitigation measures are used to reduce the propagation of impulsive noise, activities such as explosions and piling may have effects at vast distances from the source. For example, impulsive noise input from pile driving activities was shown to induce avoidance reactions and thus disturbance to harbour porpoises at a distance of 25 km (Dähne *et al.* 2013). Effective mitigation measures exist to significantly reduce the effect distance and to temporarily deter animals from the remaining impacted area.

Regulations and needs

Reducing noise to levels that do not adversely affect marine life is a key management objective of the Baltic Sea Action Plan.

The envisaged revised International Maritime Organization Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life and the HELCOM Regional Action Plan on Underwater Noise are expected to lead to the achievement of this objective. However, compulsory regulations will likely be needed to achieve a significant reduction in underwater noise from shipping.

Furthermore, as spatial and temporal threshold values for underwater noise have just been adopted at the EU level, formal discussions and agreements are still needed about how these should be applied with respect to, for example, spatial assessment units, habitat size and sound levels that result in biologically adverse negative effects.

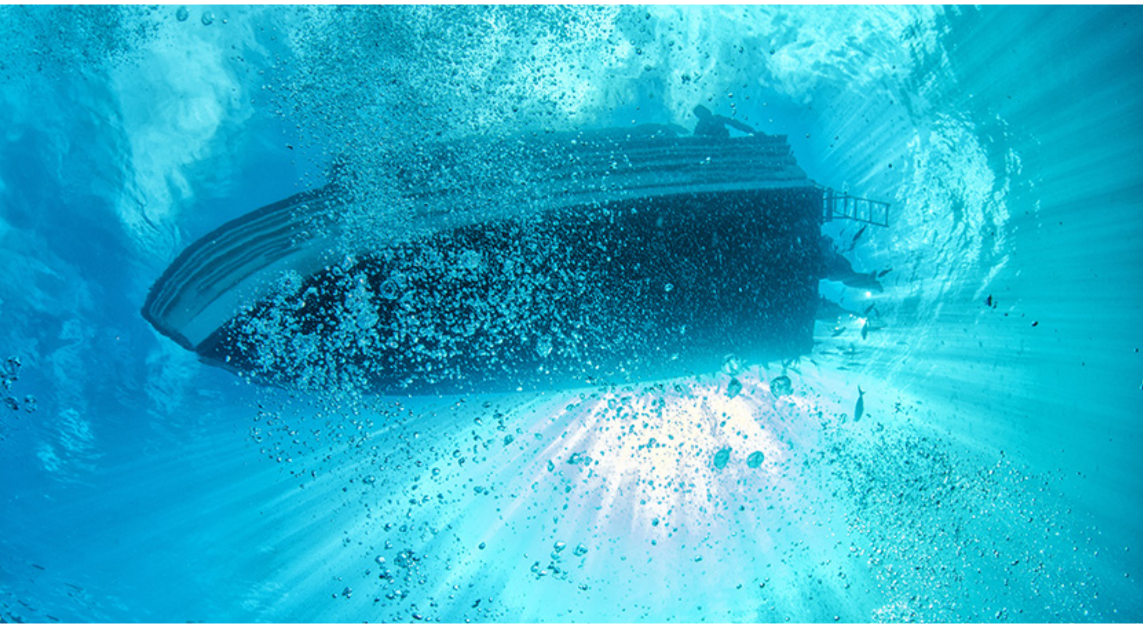

Figure 4.19. Contoinuous noise comes from boats and vessels of all sizes.

4.3. Pressures from activities at sea

Several pressures on the Baltic Sea derive from our direct use of the sea and its resources. Extractive pressures are associated with fishing, hunting and the extraction of materials from the seabed, such as sand and minerals. Physical pressures come from activities such as dredging, bottom trawling and marine construction.

The assessment results for pressures stemming from sea-based activities are presented here for the extraction of fish, unintentional by-catches, hunting of birds and mammals, and sea-floor loss and disturbance. More detailed results can be found in the HELCOM thematic assessment of biodiversity status (HELCOM 2023a) and its underlying indicator reports.

As these pressures are extractive or lead to physical alterations of the seabed, they have direct impacts on the affected species and habitats. Careful planning and regulation of the activities is needed to ensure sustainable use.

4.3.1 Extraction of fish

The status assessment of fish presented in Chapter 3 integrates the status of fishing pressure in the evaluation of commercially important fish stocks (Box 4.7). Out of fifteen commercial stocks that could be fully evaluated, only four showed good status on average during 2016-2021 (Figures 4.20-4.21). Stocks showing good status with respect to both fishing pressure and stock size were plaice in the Baltic Sea, herring in the Gulf of Riga and the Gulf of Bothnia, and vendace in the Swedish part of the Bothnian Bay, although the latter two stocks showed a decreasing trend in stock size.

Looking specifically at fishing pressure, threshold values were not achieved for eight of the seventeen stocks that could be evaluated for this indicator; these were four pelagic and four demersal stocks. Threshold values for stock size was not achieved for two pelagic stocks, four demersal stocks and eel (Table 4.1).

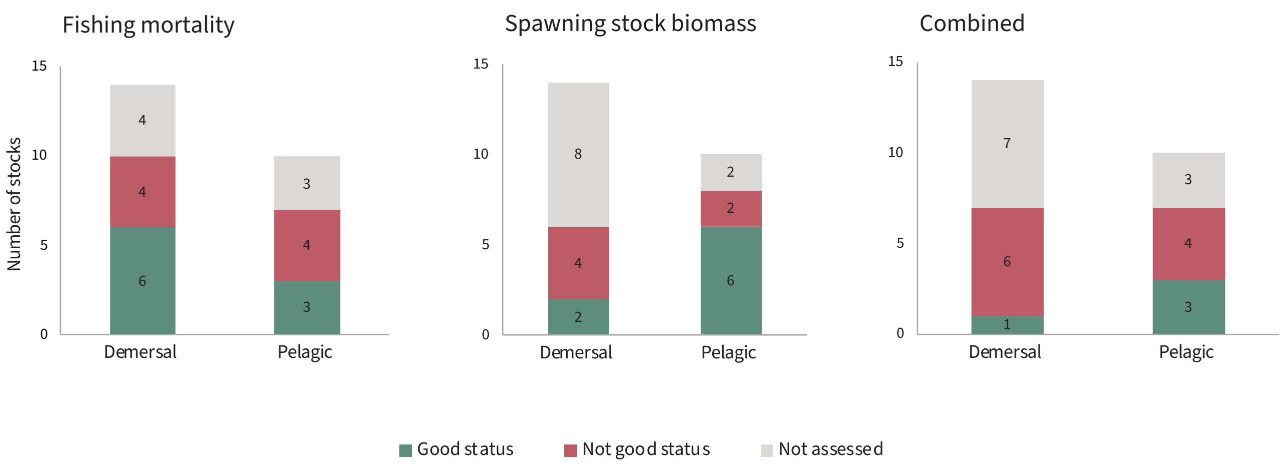

Figure 4.20. Number of pelagic and demersal commercial fish stocks in good and not good status with respect to fishing mortality (left), stock size (spawning stock biomass, middle), and both aspects combined (right). The colours denote whether the average value during 2016–2021 achieved (green) or failed (red) the 2021 threshold value. The number of fish stocks not assessed in each case is indicated in grey.

BOX 4.7.

What is commercial fishing and how is the status assessed?

Twenty-three fish and shellfish species are listed as commercially important in the Baltic Sea, based on that they together contributed to 98% of the accumulated landings in terms of weight or value during 2015-2019 (HELCOM 2021, see also ICES 2022a). Several of the species are divided into different stocks for fisheries management.

One of the central management objectives of the Baltic Sea Action Plan is that:

— **human-induced mortality, including hunting, fishing and incidental by-catch, does not threaten the viability of marine life**

The International Council for the Exploration of the Sea (ICES) provides advice on stock status and fishing opportunities on those commercial stocks that are internationally managed. These represent the largest part of all commercial landings in the Baltic Sea. Where data and models allow for an analytical assessment, individual stocks are assessed in relation to the management objective of reaching a Maximum Sustainable Yield. Assessment results are given with regard to the status of fishing mortality and spawning stock biomass (stock size). Where an analytical assessment is not possible, proxies are sometimes used. Nationally managed species are assessed by each country.

Based on stock assessment data, the status of fish stocks during 2016-2021 is evaluated against the condition that the average assessment ratio within the assessment period should achieve the reference values for indicators of both fishing mortality and stock size. Trends in age or size structure are included as supporting information but should be further developed in order to achieve full confidence in the assessment results.

Figure 4.21. Commercial fish photo.
© Juuso Haapaniemi

Table 4.1. Summary of status evaluation for commercial fish in the Baltic Sea region. Status of internationally managed fish stocks in the Baltic Sea during 2016–2021. Commercial fish species are assessed by stocks, which are named by their areal distribution. The numbers give the corresponding ICES assessment units (Subdivisions, SD). Total status is assessed by the condition that indicators of fishing mortality and stock size should both achieve their reference points, on average during 2016–2021. The symbols denote if each stock achieves (green) or fails (red) the set conditions. In addition, trends over the last ten years are indicated by arrows. The applied assessment approach is indicated as: MSY = analytical stock assessment, evaluated in relation to the MSY objective, PA = precautionary approach. Size or age structure was not evaluated in relation to a threshold value, but changes over the last ten years are indicated based on available data (1 = age structure 2 = length structure, 3 = qualitative assessment based on ICES advice). The evaluations of salmon and sea trout are based on many stocks, which show variable status. White circles denote that no status evaluation is available. The final column gives red list status according to HELCOM (2013c), which is the currently most recent HELCOM red list assessment but which does not match the HOLAS3 assessment period.

Species name (23)	Scientific name	Stocks (33)	Assessment approach	Fishing pressure: Status	Fishing pressure: Trend	Stock size: Status	Stock size: Trend	Age/Size structure: Trend	Total	HELCOM Red List Status
Pelagic species										
Atlantic herring*	*Clupea harengus*	Skagerrak, Kattegat, W Baltic Spring spawners (SD 20-24)	MSY	🔴	→	🔴	↓	↑1	🔴	LC
		Central Baltic Sea (SD25-29 & SD32)	MSY	🔴	↑	🟢	↓	→1	🔴	
		Gulf of Riga (SD28)	MSY	🟢	→	🟢	↑	→1	🟢	
		Gulf of Bothnia (SD30-31)	MSY	🟢	→	🟢	↓	→1	🟢	
Sprat*	*Sprattus sprattus*	Baltic Sea (SD22-32)	MSY	🔴	→	🟢	→	→1	🔴	NA
Vendace**	*Coregonus albula*	Bothnian Bay (SWE, SD30)	MSY	🟢	↓	🟢	↓	↑2	🟢	-
		Bothnian Bay (FIN, SD30)	-	⚪	-	⚪	-	⚪	⚪	
Salmon*	*Salmo salar*	Baltic Sea, excl. Gulf of Finland (SD22-31)	MSY+PA	🔴	↓	🔴	↑	-	🔴	VU
		Gulf of Finland (SD32)	PA	⚪	-	🟢	-	-	⚪	
Sandeels (=Sandlances)*	*Ammodytes spp + Gymnoammodytes spp*	Skagerrak, Kattegat and Belt Sea (SD21-22)	PA	⚪	-	⚪	-	-	⚪	
Smelt	*Osmerus eperlanus*		-	⚪	-	⚪	-	-	⚪	NA
Demersal species										
Atlantic cod*	*Gadus morhua*	Kattegat (SD21)	PA	⚪	↑	🔴	↓	-	🔴	VU
		Western Baltic (SD22-24)	MSY	🔴	↓	🔴	↓	→1	🔴	
		Eastern Baltic (SD24-32)	PA	🔴	↓	🔴	↓	↓3	🔴	
Sole*	*Coregonus albula*	Skagerrak, Kattegat, and W Baltic Sea (SD20-24)	MSY	🟢	→	🔴	↑	-	🔴	NA
Dab*	*Limanda limanda*	Baltic Sea (SD22-32)	PA	🟢	-	⚪	→	→2	⚪	NA
Turbot*	*Scophthalmus maximus*	Baltic Sea (SD22-32)	PA	⚪	-	⚪	→	-	⚪	NT
Brill*	*Scophthalmus rhombus*	Baltic Sea (SD22-32)	PA	⚪	-	⚪	↑	-	⚪	
Plaice*	*Pleuronectes platessa*	Kattegat, Belt Sea, and the Sound (SD21-23)	MSY	🔴	↓	🟢	↑	↑1	🔴	NA
		Baltic Sea excl. Sound and Belt Sea (SD24-32)	MSY	🟢	→	🟢	↑	→2	🟢	
Baltic flounder*	*Platichthys solemdalii*	N Central and Northern Baltic Sea (SD 27, 29–32)	PA	🔴	-	⚪	→	-	🔴	
Flounders (European and Baltic)*	*Platichthys flesus + P.solemdalii*	Belt Sea and Sound (SD 22, 23)	PA	🟢	-	⚪	→	↓2	⚪	NA
		West of Bornholm, S Central Baltic (SD 24-25)	PA	🟢	-	⚪	→	→2	⚪	
		East of Gotland, Gulf of Gdansk (SD 26, 28)	PA	🟢	-	⚪	→	↓2	⚪	
Coastal species										
Eel*	*Anguilla anguilla*	Baltic Sea (SD22-32)	PA	⚪	-	🔴	-	-	🔴	CR
Sea trout*	*Salmo trutta*	Baltic Sea (SD22-32)	PA	⚪	-	⚪	-	-	⚪	VU
Whitefish	*Coregonus maraena*	-	-	⚪	-	⚪	-	-	⚪	EN
Perch	*Perca fluviatilis*	-	-	⚪	-	⚪	-	-	⚪	-
Roach	*Rutilus rutilus*	-	-	⚪	-	⚪	-	-	⚪	NA
Pikeperch	*Sander lucioperca*	-	-	⚪	-	⚪	-	-	⚪	NA
Pike	*Esox lucius*	-	-	⚪	-	⚪	-	-	⚪	NA
Bream	*Abramis brama*	-	-	⚪	-	⚪	-	-	⚪	NA
Blue mussel	*Mytilus edulis*	-	-	⚪	-	⚪	-	-	⚪	-

* Included in ICES advice, ** national data from Sweden

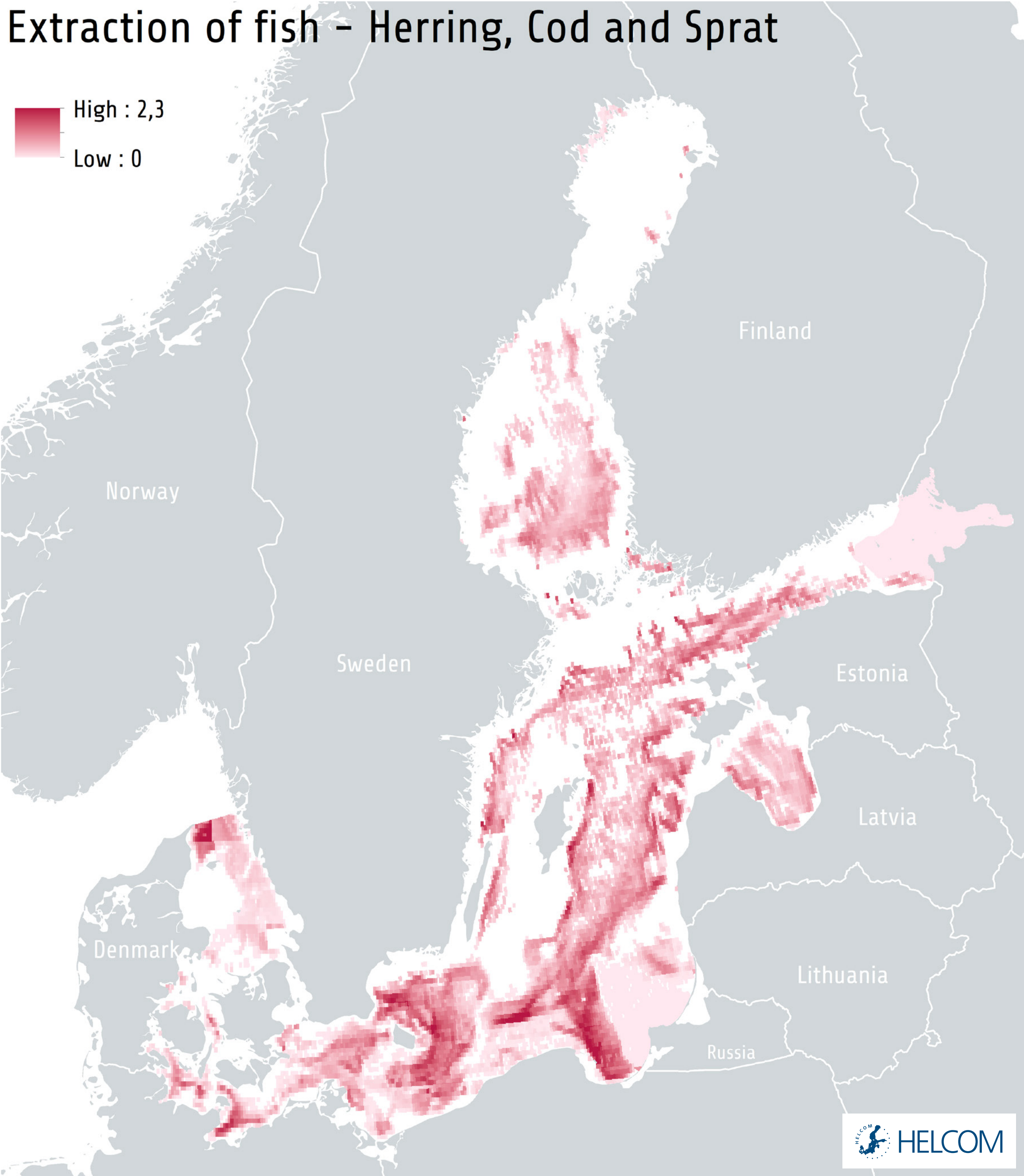

Figure 4.22. Spatial distribution and intensity of fishing efforts for the three main commercial fish species in the Baltic Sea, namely herring, sprat and cod, using all gear types, in 2016–2021. The layer is based on data on commercial fishing during 2016–2020, available at the spatial scale of ICES statistical rectangles from the EU Joint Research Centre's data collection framework for fisheries data, for Contracting Parties which are part of the European Union. Source: HELCOM 2023e.

The age/size structure of fish was evaluated for changes over time without applying threshold values. Three out of the fourteen stocks that could be evaluated showed a decreasing age or size structure, namely Eastern Baltic cod, flounder in the Belt Seas and the Sound, and flounder east of Gotland and in the Gulf of Gdansk. The other stocks showed an increase or no significant trend over time, though in several cases this reflected the fact that they were constantly at low levels.

The pelagic species sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) clearly make up the largest share of landings in the Baltic Sea, contributing to over 80% of the landings by weight. Pelagic commercial fishery is widespread, while demersal open sea fish are mainly caught in the southern parts of the region (ICES 2022, Figure 4.22). Fisheries for other species mainly occur along the coast. In some areas, the volume of landings in recreational and subsistence fisheries is higher than in commercial fisheries, especially for freshwater species, such as pikeperch, pike, perch and whitefish along the coast. The main target species for recreational and subsistence fisheries varies between sub-basins, depending on which species occur in the area (HELCOM 2020c).

The total value of landings has been constant or slowly declining in Baltic Sea countries and has decreased in recent years (Chapter 2).

Impacts of fish extraction in the Baltic Sea ecosystem

Overfishing has been connected with declined fish stocks and a worsened age and size structure of several fish stocks in the Baltic Sea as well as adjacent seas (ICES 2022, HELCOM 2023a, HELCOM 2023d, Cardinale *et al.* 2009, Eero *et al.* 2008, Svedäng and Hornborg 2014).

Changes in fish stocks have also been attributed to changes in overall species composition, leading to structural changes in the food web (Chapter 3, HELCOM 2023a, Möllmann *et al.* 2009, Casini *et al.* 2008, Tomczak *et al.* 2012, Blenckner *et al.* 2015, Casini *et al.* 2012, Eriksson *et al.* 2011, Olsson *et al.* 2015, Tomczak *et al.* 2016, Eklöf *et al.* 2020, Einberg *et al.* 2019, Scotti *et al.*, 2022a).

Unintentional by-catch of birds and mammals, as well as the effects of physical disturbance from fishing gear, are addressed in the sections below.

Sources of pressure from fishing

Fish are a key source of livelihood for humans, but overfishing is connected with detrimental effects on the marine environment and on longer-term prosperity.

The main part of commercial catches in the Baltic Sea are from stocks that are managed internationally within the framework of the EU Common Fisheries Policy. The International Council for the Exploration of the Sea (ICES) provides advice on stock status and fishing opportunities for internationally managed fish stocks (e.g. ICES 2022). Alignment with scientific advice is vital for decisions on fishing quotas to be in line with the environmental, ecological and social sustainability needs of the marine environment. However, the scientific advice has generally not been followed by policymakers in earlier years (HELCOM 2023d). Although countries appear to recognize the hazards of exceeding the biological limits for fish extraction, there seem to be certain reasons to maintain some fish quotas above scientifically advised levels. This likely highlights short-term conflicts between environmental and socioeconomic concerns, though there has been a reduction in the difference between total allowable catches and scientific advice over the past twenty years (Figure 56). Coastal fisheries are managed nationally, where management implementation typically faces challenges related to data deficiency on the spatial and temporal patterns of commercial as well as recreational fisheries. Insufficient regulation or compliance issues may also commonly occur (HELCOM 2020c).

Regulations and needs

The Baltic Sea Action Plan stresses that achieving good environmental status for the Baltic Sea will require major effort and transformational changes in all sectors of the economy affecting the sea, including fisheries. A central target of the UN Sustainable Development Goals, embraced by HELCOM, is to effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing, and destructive fishing practices, as well as to implement science-based management plans and to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yields as determined by their biological characteristics (SDG 14.4).

Ensuring the implementation of fisheries management in line with scientific advice is vital for the long-term sustainable use of marine resources.

Furthermore, several stocks in the Baltic Sea are currently in need of dedicated restoration efforts after long-term deterioration.

Climate change considerations and ecosystem changes leading to changes in food web processes and productivity are expected to affect the productivity of fish stocks and the distribution ranges of fish stocks, and to create new demands for ecosystem-based fisheries advice (ICES 2023).

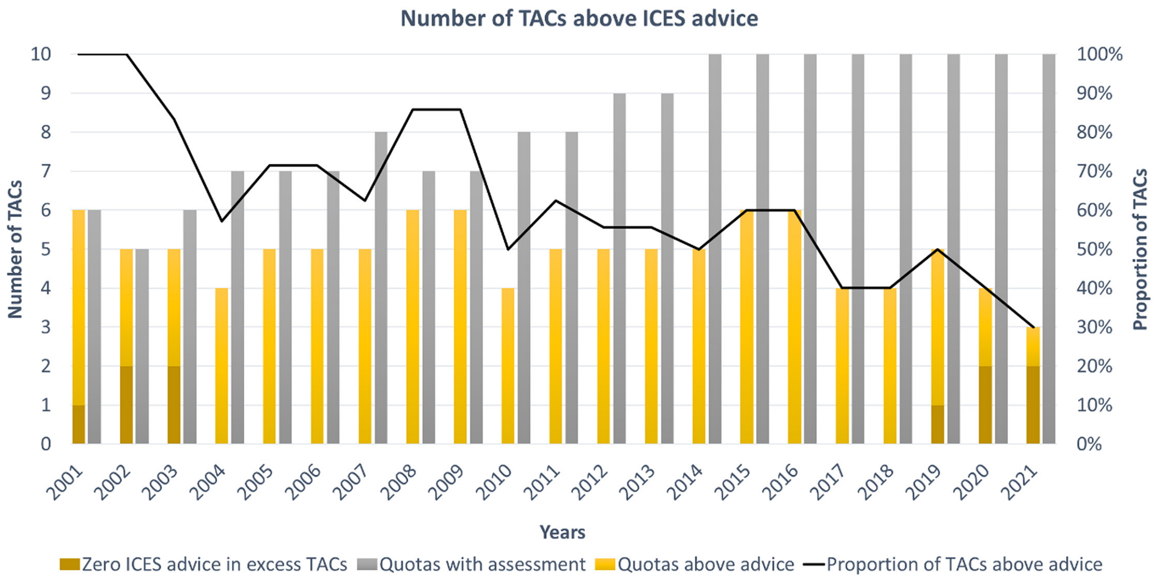

Figure 4.23. Number of cases with Total Allowable Catch (TAC) set above ICES advice for internationally managed fish stocks in the Baltic Sea during 2001–2021. The chart does not include data from Russia. The stocks included are salmon (ICES subdivisions 22–31, subdivision 32), cod (subdivisions 22–24, subdivisions 25–32), herring (subdivision 28.1, subdivisions 25–27, 28.2, 29, 32, subdivisions 30–31, subdivisions 22–24), plaice (subdivisions 22–32), and sprat (subdivisions 22–32). Cases in which ICES has advised zero catches (cod subdivisions 24–32 and herring subdivisions 22–24) are highlighted in dark yellow. Source: HELCOM 2023d.

4.3.2 Unintentional by-catches

Fisheries by-catches have an impact on pelagic- and benthic-feeding waterbirds in the Baltic Sea, as well as marine mammals (Box 4.8). The impacts occur widely, although they can differ between species groups (depending on their feeding mode, for example). Based on available data, the highest impacts are generally in the Great Belt, the Sound, the Bornholm Basin and the Arkona Basin, reflecting both higher fisheries activity in these areas and access to better data on by-catch. However, by-catch affects animals in all parts of the region. The problem of by-catch is particularly important for species with poor conservation status , such as the harbour porpoise in the Baltic Sea.

For pelagic- and benthic-feeding waterbirds, all sub-basins from the Kattegat to the Eastern Gotland Basin fail to achieve good status with regard to by-catch. The impacts of by-catch are also too high on all marine mammal populations. For more results on the integrated status assessments of biodiversity including the by-catch aspect, please see Chapter 9 in HELCOM (2023a).

A quantitative assessment of by-catches has not been carried out before in HELCOM, but available evidence suggests that the status is unchanged since the previous assessment period.

The impacts of unintentional by-catch in the ecosystem

Unintentional by-catch occurs widely in the Baltic Sea, but the risk varies for different species of waterbirds and marine mammals, depending on their feeding behaviour. There are also seasonal trends that influence by-catch levels. For example, fish-eating birds, such as divers, grebes, mergansers, auks and cormorants, and benthic-feeding birds (ducks) are highly susceptible to entanglement and

BOX 4.8.

What are unintentional by-catches?

Unintentional by-catch in fishing gear occurs in many fisheries worldwide and is among the most significant causes of human-induced mortality in a large number of marine mammal and waterbird species (Read et al. 2006, Lewison et al. 2014, Dias et al. 2019). Mammals and waterbirds easily become entangled in various types of fishing gear and subsequently die by drowning. Scientific studies have indicated that the number of waterbirds actually caught in by-catch in the Baltic Sea is considerably higher than number stated in official reports (Morkūnas et al. 2022).

Minimizing by-catch of marine mammals and water birds is included in the management objective:

- **human-induced mortality, including hunting, fishing, and incidental by-catch, does not threaten the viability of marine life" in the Baltic Sea Action Plan.**

drowning in fishing gear. However, due to a lack of monitoring, it is not possible to quantify the consequences for either bird or marine mammal populations.

Sources of unintentional by-catch

Gillnets and fish traps in commercial and recreational fisheries are the main causes of by-catch of marine mammals and waterbirds in the Baltic Sea, but by-catch also occurs in trawls (Figure 4.24). By-catch of waterbirds is also common in longline fishing, but this gear is not widely used in the Baltic Sea. Gillnets are particularly problematic, as they are nearly invisible to birds, which become entangled when they are diving for food. Estimates are uncertain, but studies on birds have shown that gillnet fishery causes the death of up to 100,000-200,000 birds annually in the Baltic Sea and North Sea combined (Žydelis *et al.* 2009).

For birds, the by-catch problem is more severe when gillnet fishery is practised in areas with high concentrations of resting, moulting or wintering seabirds. In the Baltic Sea, gillnet fishery often takes place in shallow coastal areas or on shallow offshore grounds, which are also the most important habitats for birds. The overlap of gillnet fishing and high concentrations of birds usually occurs only during certain periods of the year, such as the wintering, autumn and spring migration or moulting time (Zydelis *et al.* 2009, Sonntag *et al.* 2012). In such instances, the risk and occurrence of by-catch is high.

Marine mammals are also impacted and data limitations are problematic. In the Belt Sea, estimates of harbour porpoise by-catch are in the high hundreds per year (Glemarec *et al.* 2022), and available data for the Baltic Proper population indicate that on average three animals are caught in by-catch per year (HELCOM 2023i). In both cases, these values exceed the relevant threshold values. The threshold value is set to zero for the highly sensitive Baltic Proper population, reflecting its Critically Endangered status. The quality of data from direct monitoring of by-catch is also a limiting factor for seals. However, available estimates commonly indicate that by-catches exceed threshold values; for example, grey seals are caught in by-catch by the thousands (Vanhatalo *et al.* 2014).

Regulations and needs

HELCOM countries actively work to share information on topics related to by-catch, identify additional measures and agree on joint actions to reduce by-catch. Potential measures include changes in what fishing gears are used and temporal or permanent spatial closures of fisheries using certain gear, as well as the use of acoustic deterrents.

Climate change could affect the risk of by-catch in certain areas, as the spatial distribution of fish can be expected to change with a warming climate, and the fisheries, as well as the waterbirds and mammals feeding on the fish, would be expected to follow.

Figure 4.24. PFish-eating birds, such as mergansers, are susceptible to entaglement and drowning in fishing gear.

4.3.3 Hunting of birds and mammals

Hunting of marine mammals is forbidden in Germany, Latvia, Lithuania and Poland. Control hunting of seals is allowed in Estonia (only grey seals), Finland and Sweden. In Denmark, regulation of seals is allowed with the purpose to mitigate conflicts with local fisheries (Figure 4.25, Box 4.9, HELCOM 2023a).

The large majority of grey seal hunting occurs in Sweden and Finland. The total number allowed has increased from around 500 seals in the early 2000s to around 3,500 in 2022. A total of 6,598 grey seals were hunted during 2016-2021.

Hunting of ringed seals has also increased, taking place only in the Bothnian Bay management unit. A total of 2,463 ringed seals were hunted during 2016-2021.

In total, 1,690 harbour seals were hunted during 2016-2021 on the west coast of Sweden and in Denmark.

Most of the hunted waterbirds are sea ducks. For the common eider (*Somateria mollissima*), hunting bag statistics give a total of 135,656 individuals across the Baltic Sea during 2016-2021, with hunting taking place in Denmark, Estonia, Finland and Sweden (Figure 4.26). Other waterbird species with relatively large hunting bags are the common long-tailed duck (*Clangula hyemalis*), common goldeneye (*Bucephala clangula*) and common scooter (*Melanitta nigra*), coming to 31,422, 33,098 and 13,222 individuals, respectively.

Pest control hunting of cormorants occurs in Estonia, Finland and Sweden and is estimated to have numbered 38,716 cormorants in total during 2016-2021.

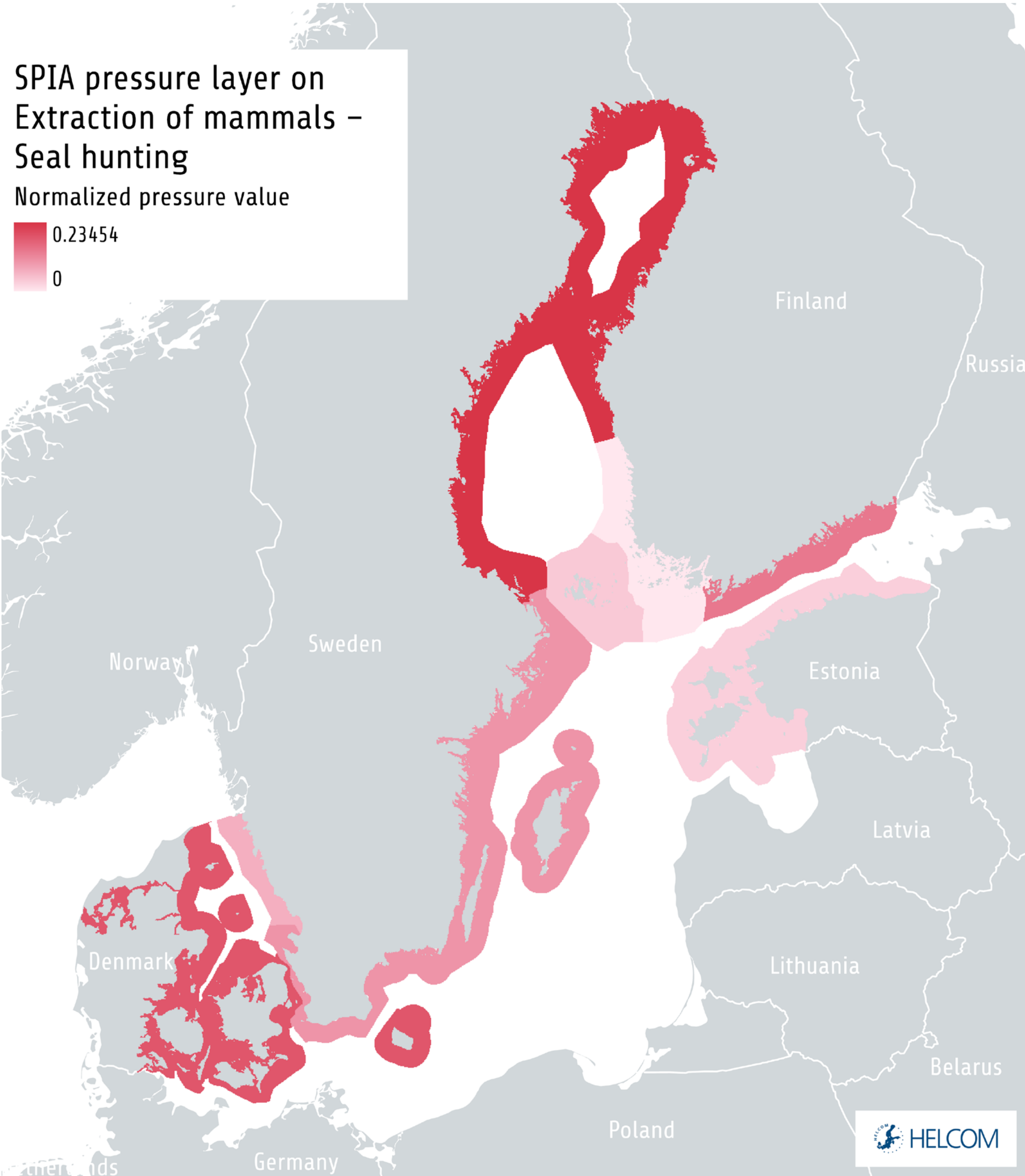

Figure 4.25. Spatial distribution and relative intensity of seal hunting in the Baltic Sea during 2016–2021. Source: HELCOM 2023e.

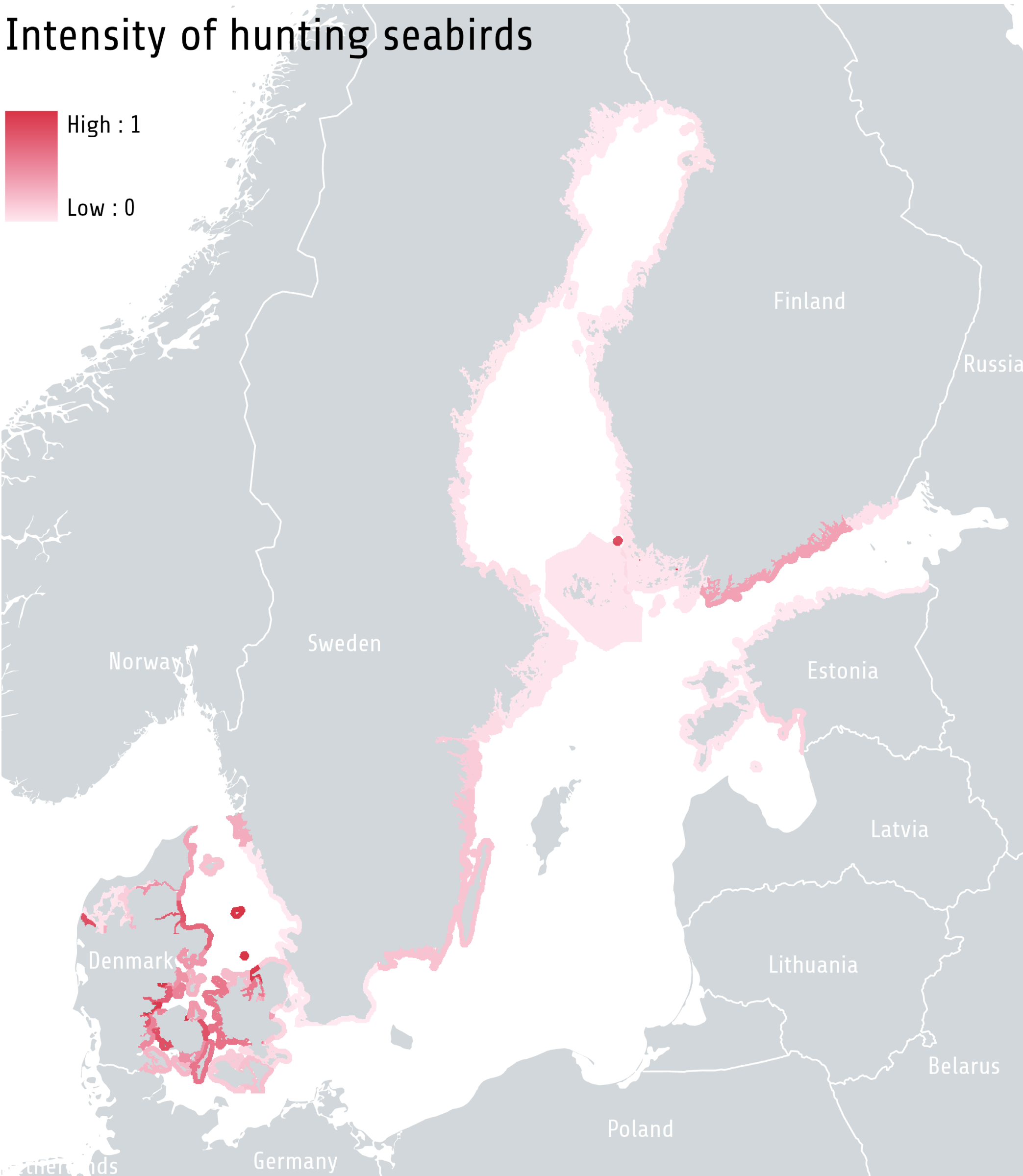

Figure 4.26. Spatial distribution and relative intensity of waterbird hunting in the Baltic Sea during 2016–2021. Total numbers include both game hunting for game and control hunting. Source: HELCOM 2023e.

Impacts of hunting in the Baltic Sea ecosystem

In addition to removing individuals from the population, hunting can affect the behaviour of a species through biological disturbance. The effects of hunting on the behaviour of grey seals were observed in the Stockholm archipelago in Sweden. The number of grey seals observed in moulting time surveys dropped dramatically in recent years, along with increased hunting in the area. At the same time, increased numbers were observed in the archipelago of south-west Finland, suggesting a range shift. However, this change does not fully explain the decrease in the Stockholm archipelago and other explanations may exist. For example, if hunting leads to changes in the spatial occurrence, this canalso increase other risks, such as risks of unintentional by-catches.

Key sources of the pressure

Licensed hunting of grey seals was introduced in Sweden in 2020, and grey seal hunting has been run by regional quota in Finland since 2014. Estonia has licensed grey seal hunting since 2015, but the annual hunting quota in Estonia is comparatively low (between 37-55 animals).

The combined annual quota for ringed seals in Sweden and Finland is around 700 individuals.

Sweden has allowed protective hunting of harbour seals in relation to fisheries since the early 2000s, and licensed hunting was introduced in 2022, with a current quota of 730. No hunting of the Kalmarsund harbour seal population is allowed.

BOX 4.9.

Hunting of marine mammals in the Baltic Sea

Hunting has historically been a major pressure on marine mammals in the Baltic Sea. All seal species in the Baltic Sea were severely reduced at the beginning of the twentieth century as the result of a coordinated international campaign to exterminate seals (Anon 1895). Bounty systems were used in Denmark, Finland and Sweden over the period 1889-1912, and very detailed bounty statistics provide detailed information on the hunting pressure.

Hunting resulted in the local extinction of grey seal and harbour seal in Germany and Poland in 1912 and of grey seals from the Kattegat by the 1930s. Baltic grey seals were reduced to about 20,000 in the 1940s (Harding & Härkönen 1999). Harbour seals went down to around 2,500 in the Kattegat and Skagerrak in the late 1970s, and the hunting pressure caused a rapid decline in the Kalmarsund harbour seal population. Only around 200 seals remained in the Kalmarsund harbour seal population in the 1960s (Heide-Jørgensen & Härkönen 1988; Härkönen & Isakson 2011). Hunting of seals became prohibited in the 1960s and 1970s.

Historically there have also been large catches of harbour porpoises in the Baltic region, with around 2,000 individuals taken annually in Danish waters in the late nineteenth century and possibly larger catches in the Baltic Proper (Kinze 1995).

4.3.4 Seafloor loss and disturbance

The seafloor is negatively affected by several human activities, including bottom trawling fishery, mariculture, extraction and disposal of sediments (e. g. dredging and dumping) and shipping, as well as coastal protection and the construction and operation of pipelines and cables, platforms and wind farms. Assessing single pressures in isolation does not provide representative results about seafloor integrity because multiple pressures typically act on the environment simultaneously. For the purposes of the holistic assessment, information about activities known to result in physical pressures on the environment was combined, providing an overview of the spatial distribution and intensity of disturbances to seabed habitats (Figure 4.27) and their loss (Figure 4.28).

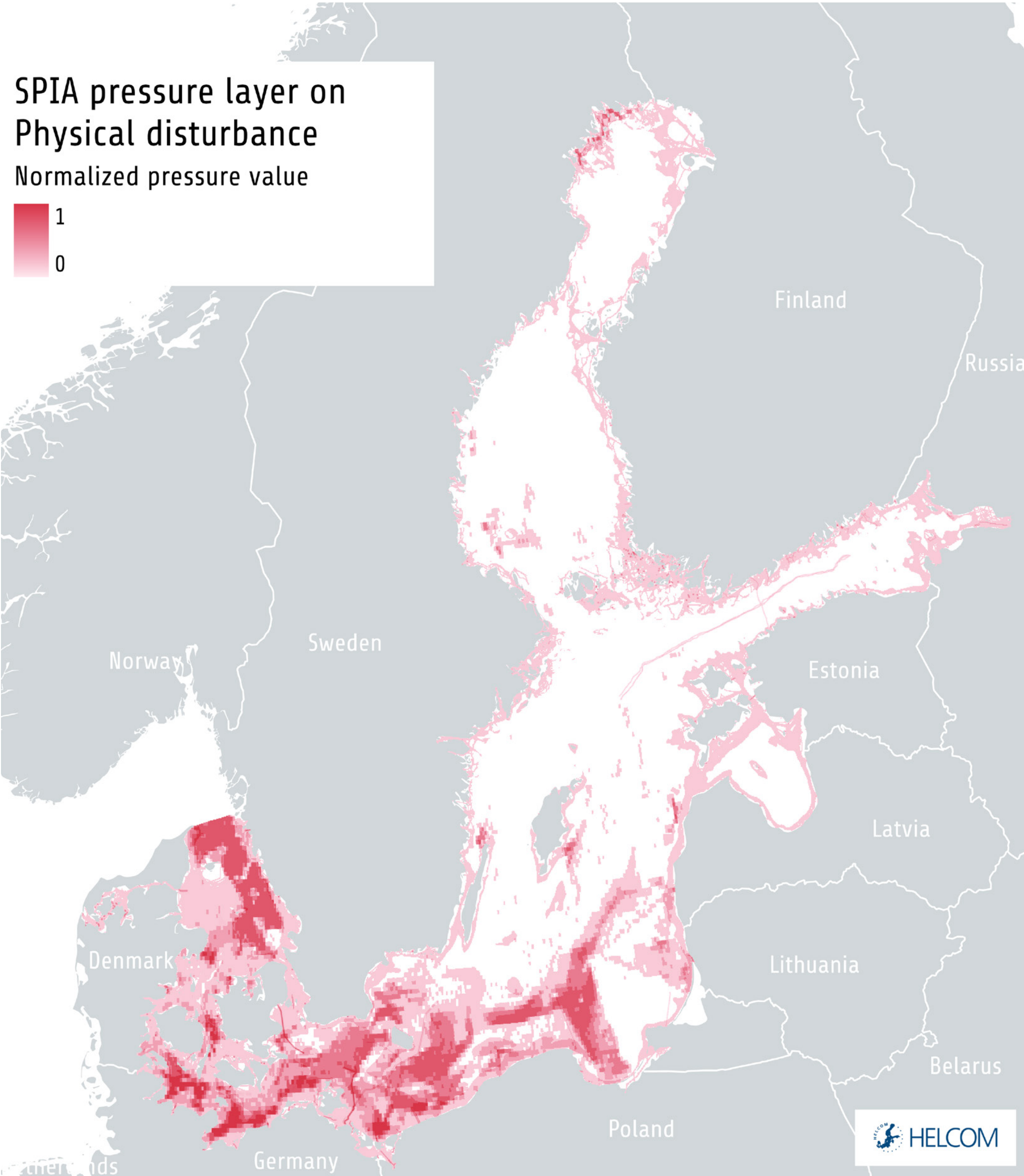

Figure 4.27. Assessment results from the assessment of seafloor disturbance. Source: HELCOM 2023d.

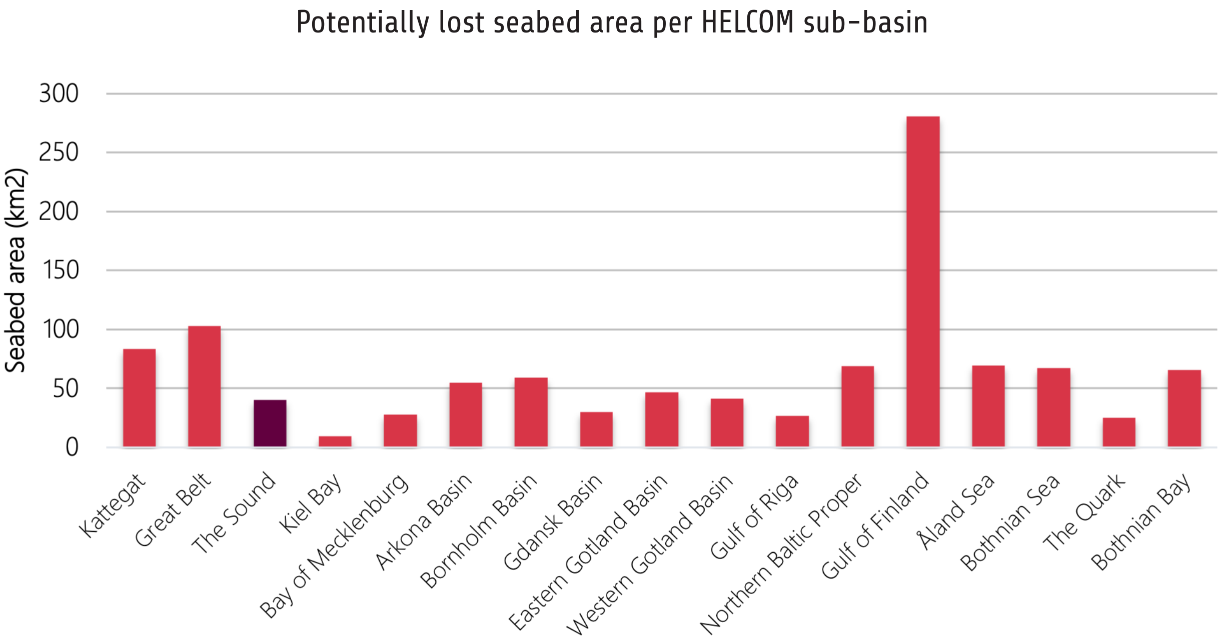

Figure 4.28. Estimated seabed area potentially lost due to human activity for each Baltic Sea sub-basin, given as square kilometres. Values were estimated from spatial data on human activities identified as causing physical loss. Dark red indicates sub-basins where up to 1–10% of the total area could be lost. For the other sub-basins, the potentially lost seabed area was estimated to cover less than 1% of the total area. Source: HELCOM 2023d.

While seabed disturbance is more widespread, less than 1% of the total area of the Baltic Sea is estimated to suffer from potential long-term physical loss of the seabed (Box 4.10). When comparing estimates for different sub-basins, the Sound has the highest potential loss relative to its area, estimated to be above 4% (Figure 4.28). In the majority of the sub-basins, the estimated potential loss of seabed area is clearly below 1%, based on data reported for the assessment period.

There are some differences between the loss values generated under the SPIA assessment (HELCOM 2023e) and the benthic habitat integration process (HELCOM 2023a) because of differences in the application of certain buffer areas or spatial interpretation of structures (e.g. harbours). Although these differences are minor on the scale of a subbasin, further harmonization to eliminate discrepancies is needed.

BOX 4.10.

What is physical loss and disturbance, and how is the status of seabeds assessed?

Physical disturbance is defined as a change to the seabed that can be reverted if the activity that causes the disturbance ceases, while physical loss is defined as a permanent change of seabed substrate or morphology. In this context, “loss” implies that the change to the seabed has lasted (or is expected to last) for more than twelve years (EC 2017a).

The Baltic Sea Action plan addresses seafloor loss and disturbance in the ecological objective

— **natural distribution, occurrence and quality of habitats and associated communities.**

In HELCOM, the indicator “Cumulative impact from physical pressures on benthic biotopes” (CumI) evaluates the aggregated potential impact from physical pressures attributed to several human activities taken together, using a spatial categorical predictive approach (HELCOM 2023a, 2023g). Activities considered in the current evaluation are bottom trawling, aquaculture, extraction, dredging and dumping, coastal protection, shipping, and the construction and operation of pipelines and cables, platforms and wind farms.

An overall evaluation of the condition of benthic habitats is derived based on an integration of the relatively few assessment components of relevance to benthic habitats (currently CumI, State of the soft-bottom macrofauna community, and oxygen). This makes it possible to apply the spatial assessment at the level of broad-scale benthic habitats (as developed under EUSeamap 2021 for the Marine Strategy Framework Directive).

By combining information about the distribution of physical pressures and of the underlying benthic habitats, and their sensitivity to the pressures, it is possible to estimate the potential environmental impact from physical pressures. This evaluation indicated that the risk for cumulative impacts from physical pressures is clearly higher in the southern Baltic Sea and in the Kattegat than in other parts of the Baltic Sea region (Figure 4.29). Pressures distributed over a wide area, such as fishing using bottom trawling, contribute most to the risk for impact. In archipelago areas, and especially in coastal fairways, erosion from shipping can have a high impact on seafloor sediments. Coastal protection is constrained to very narrow stretches or points in the Baltic Sea region.

Sources and impacts of seafloor loss and disturbance in the Baltic Sea ecosystem

Physical loss and disturbance have direct effects on the affected habitat. Physical disturbance of the seafloor occurs when bottom-contacting fishing gear scrapes the surface of the seabed. During such activities, sediments are mobilised and dispersed. The gear can also reach deeper into the sediment, causing sub-surface abrasion. This temporary disturbance results in bottom-dwelling species being removed from the habitat or relocated (Dayton *et al.* 1995). It has a particularly strong impact on slow-growing sessile species, biogenic structure-forming organisms and rare or localised species, which may be eradicated. Since bottom trawling is typically repeated in the same location, even more resilient organisms may have little chance of recovery, leading to changes in species composition over time (Kaiser *et al.* 2006, Olsgaard *et al.* 2008). In addition, sediments are mobilised into the water and may be transported to other areas, causing smothering of other substrates or habitats or the release of hazardous substances that have been previously buried in the seabed (Jones 1992, Wikström *et al.* 2016). Other human activities leading to physical disturbance act in the same way. The severity of the impact depends on factors such as the depth of the disturbed sediment layer, the total area affected, whether the activity is repeated regularly and the sensitivity of species in the affected habitat.

The indicator for cumulative impact from physical pressures on benthic biotopes is structured around human activities known to impact on benthic biotopes through physical disturbance, especially those with a large spatial extent, such as bottom trawling. Activities causing more local disturbance include tourism, leisure activities and infrastructure. Activities resulting in physical loss are commonly linked with construction or infrastructure development, such as wind farms, port infrastructure or coastal defence. While the actual footprint of such structures may be small, their presence can also alter conditions in the surrounding areas and generate localised disturbance. It is also possible thatactivities catalyse functional loss, if the resident biota are unable to flourish.

Regulations and needs

HELCOM countries have agreed to jointly develop a common approach to address and minimize the loss and disturbance of seabed habitats caused by human activities wherever possible, including through the identification of further measures to reduce adverse effects.

The upcoming EU restoration law is expected to require the implementation of measures to reduce adverse effect and restore impacted habitats.

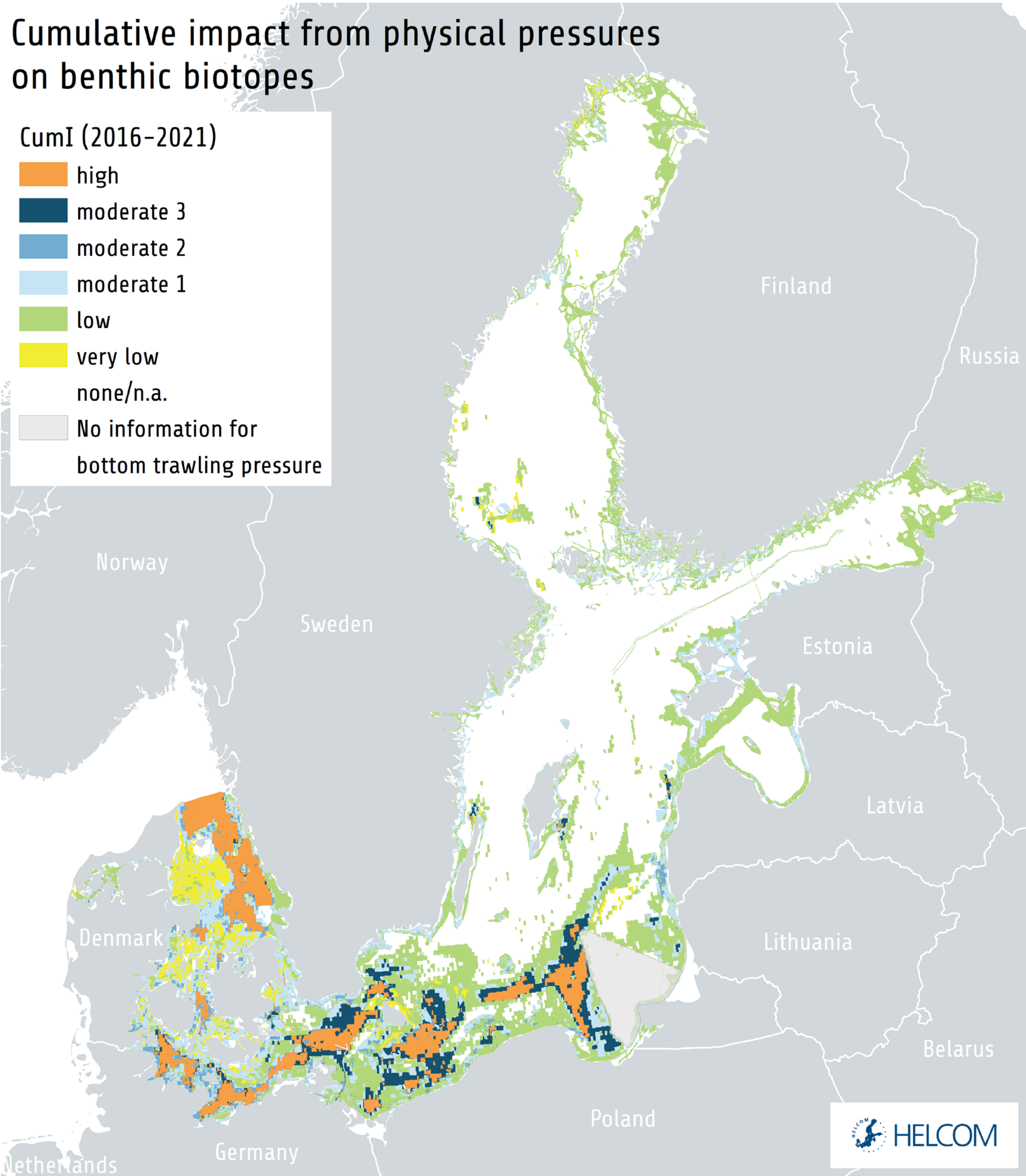

Figure 4.29. Evaluation result of the indicator for cumulative impacts of physical pressures on benthic biotopes in the Baltic Sea, based on reported data for 2016–2021. The map indicates the combined potential impact of physical disturbance (see Box 15). Information on physical pressures from bottom trawling fishery is missing for the area off the coast of Oblast Kaliningrad, marked with a semi-transparent grey triangle. White areas within the Baltic Sea area represent regions with no impact . Source: HELCOM 2023a.

4.4. Protection and restoration

While reducing or preventing harmful inputs and minimizing pressures from human activities at sea are of key importance to ensure the broad recovery of species and habitats in the Baltic Sea, spatial protection supports biodiversity by ensuring sustainable limits to human exploitation or activities in defined areas.

Marine protected areas are the most common form of spatial protection in the Baltic Sea. Other measures that contribute to effective area-based conservation can also be included in the concept of spatial protection.

However, in cases where the natural ecosystem has been degraded, damaged or destroyed, restoration measures may be needed to assist recovery, and these are increasingly being used in HELCOM countries (Box 4.11).

Figure 4.30. Marine protected areas are spatially defined areas that are selected for protection because they can be particularly useful to safeguard marine ecosystems, processes, functions, habitats and species.
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BOX 4.11.

Spatial protection and restoration as tools in conservation

Marine protected areas
Marine protected areas are spatially defined areas that are selected for protection because they can be particularly useful to safeguard marine ecosystems, processes, functions, habitats and species, and that are managed to support this purpose. By providing protection from adverse human activities, marine protected areas can support both ecological values and the social, economic, and cultural values depending on these (e.g. Reuchlin-Hugenholtz & McKenzie 2015). The main purpose of the HELCOM marine protected areas (HELCOM MPAs) is to protect valuable marine and coastal habitats in the Baltic Sea. This is achieved by designating suitable areas which have particular natural values as protected areas and by effectively managing human activities within those areas (HELCOM 2021, HELCOM ACTION 2021b). These sites should form an ecologically coherent network – that is, a network of protected sites which together deliver more benefits than individual protected areas.

Other effective area-based conservation measures
While the network of marine protected areas is the backbone and primary focus of area-based protection efforts in HELCOM, other effective area-based conservation measures (OECM) can complement this network to support biodiversity. For example, other effective area-based conservation measures can be designed to improve the status of key biodiversity attributes or to support key ecosystem aspects in cases where the designation of fully protected areas is not an option. The identification and recognition of other effective area-based conservation measures can also provide an opportunity to engage with and support a range of new partners and sectors in conservation efforts.

Restoration
Different types of restoration exist with differing aims and levels of interference. Passive restoration refers to removing or significantly reducing the source of a disturbance (the pressure), allowing the disturbed habitat to recover naturally through ecological succession. In other cases, the disturbed site may have become so degraded that it is not able to recover on its own within a reasonable time frame. In these cases, the removal of the pressure is only the first step, and recovery must be actively assisted through restoration measures. Active restoration may involve, for example, the removal of artificial objects from the marine environment, the reconstruction of habitats or the reintroduction of species. Active restoration is considered an effective supplement to conservation and management actions when the natural recovery of ecosystems is precluded, but it is often possible only at a comparatively small scale and can be resource intensive (HELCOM ACTION 2021c).

4.4.1 Marine protected areas in the Baltic Sea

Today, the Baltic network of marine protected areas (MPAs) covers approximately 16.5% of the Baltic Sea, including just above 13% that are HELCOM marine protected areas (Figure 4.31). The coverage of the MPA network is expected to increase substantially in the near future as a result of efforts to reach the spatial protection targets agreed upon by HELCOM countries in the BSAP, the EU Biodiversity Strategy and the Global Biodiversity Targets of the UN Convention on Biological Diversity (CBD).

The first HELCOM MPA was designated in 1994. After the adoption of the 2007 Baltic Sea Action Plan, the Baltic Sea became the first marine region in the world to reach the target of conserving at least 10% of its coastal and marine areas, a goal set by the CBD in 2010. Current targets for spatial protection agreed in HELCOM stem from the 2021 BSAP and state that, by 2030 at the latest, countries are to establish a resilient, regionally coherent, effectively and equitably managed, ecologically representative and well-connected system of marine protected areas, supported by other spatial conservation measures (under alternative regimes for marine protection) that can contribute to the coherence of the network. Where scientifically justified, special attention should be given to offshore areas beyond territorial waters.

The network of marine protected areas will:

- cover at least 30% of the marine area of the Baltic Sea, of which at least one third will be strictly protected. Other Effective Area-based Conservation Measures (OECMs) can be counted towards the 30% target only if they, as a minimum, comply with the OECM criteria agreed by the Convention on Biological Diversity (CBD).
- where scientifically justified, consider including no-use zones within marine protected areas, which can also serve as scientific reference areas.
- expand conservation efforts to include areas of particular importance for biodiversity and ecosystem resilience, including important ecosystem elements such as species or areas recognized to be ecologically significant based on their function for the ecosystem or the provisioning of ecosystem services, and broad habitat types which may not necessarily be rare or threatened.

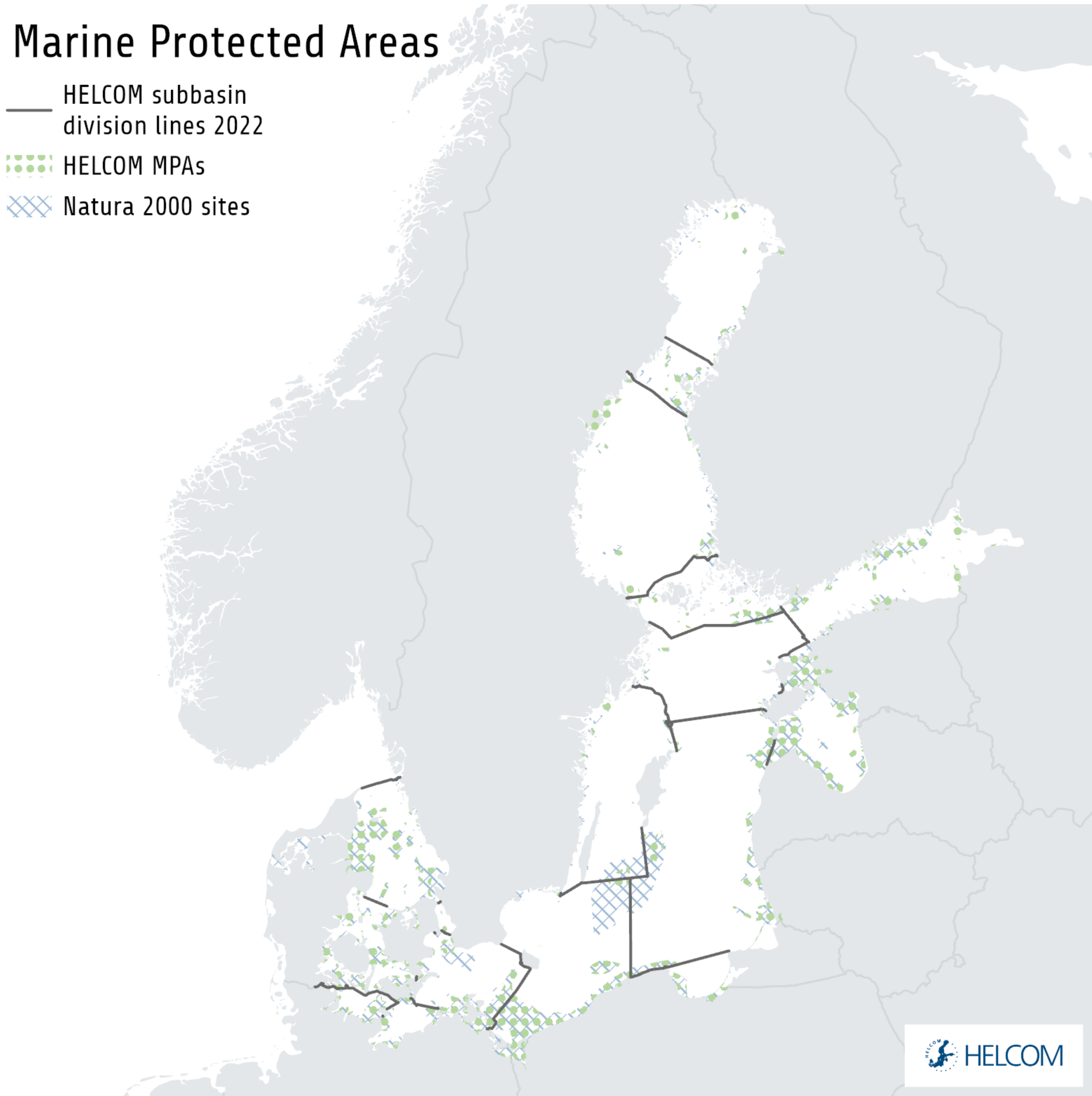

Figure 4.31. Current HELCOM marine protected areas 2016–2021.

Effects of marine protected areas on Baltic Sea ecosystems

Improving the spatial coverage and connectivity of the network of marine protected areas while taking into account natural biodiversity and conditions is expected to strengthen the overall resilience of the Baltic Sea ecosystem and enhance its general capacity to maintain functional ecosystem processes under environmental pressures and, importantly, under future climate-related changes. By enhancing the capacity of the natural system to provide ecosystem functions and services, biodiversity conservation can also support the resilience of the ecosystem, which would ensure economic benefits for many sectors that benefit from improved environmental conditions in both the short- and long-term. Marine protected areas are expected to support and enhance material and non-material ecosystem services, consumptive and non-consumptive goods, and benefits for humans (Marcos *et al.* 2021). Studies on marine systems have estimated that each euro invested in marine protected areas would generate a return of at least three euros (Brander *et al.* 2015). IPBES (2019) recognises that expanding and effectively managing the current global network of marine protected areas is important for safeguarding biodiversity, particularly in the context of climate change. Properly designed and managed MPAs have been shown to have a positive impact on a far broader scale than the protected areas alone, and such zones are thus vital for the overall health of the ecosystem.

Regulations and needs

The target of achieving a spatial coverage of 30% protected areas by 2030, including 10% that will be strictly protected, will require that countries come together and protect roughly another 15% of the Baltic Sea area. Effective management plans also need to be developed and implemented for all designated MPAs.

However, the ultimate aim of all the conservation initiatives is not to reach the percentage coverage target but to strengthen biodiversity. In order for spatial protection measures to be effective, planning should account for what happens both within and outside of the protected area, considering ecological as well as societal aspects. The connectivity of the network, as well as the activities and pressures in its vicinity, are also key to evaluate. To fully benefit from increased spatial protection, the protected areas should be designated in a strategic way, taking into consideration what is protected, for what purpose and in what way. Collaboration between providers of ecosystem knowledge and spatial planners is key, as the implementation should be done at ecologically relevant and meaningful scales.

Furthermore, the implementation must be supported by functional governance, effective and efficient management plans and the capacity for monitoring and adaptive management.

There is currently neither a sufficient framework nor the necessary prerequisites to ensure ecosystem-based strategic decision-making for the conservation of biodiversity and ecosystem services across local, regional and national management levels. Effective policy and management on a broad scale are needed to prevent MPAs from becoming isolated islands of protection in a larger sea of degradation. Such isolated systems offer marginal benefits to overall status and are, by nature, more susceptible to small changes or increases in pressure. While governance bodies and institutions with the necessary mandates and aspirations to protect the marine environment exist, there is a challenge in ensuring sufficient integration across them, including improved interaction between actors across the marine biogeographical region.

4.4.2 Restoration as a measure in HELCOM

Restoration of the marine environment is still an emerging topic in the Baltic Sea. Spatially restricted development work is ongoing in some areas, such as the restoration of eel-grass meadows in the Kattegat and the restoration of coastal lagoons in the Bothnian Bay (SwAM 2021, HELCOM ACTION 2021b, Saarinen 2019). Activities have consisted of transplanting flora and fauna, creating artificial habitats to promote range expansion and recolonization, and inducing changes in hydrological and physical settings, for example (Fraschetti *et al.* 2021). As yet, there is no consistent source of information on efforts, success rates or trends in restoration in the Baltic Sea region. The importance of restoration is likely to increase in response to ecological, management and policy-related needs.

Impacts of restoration in the Baltic Sea ecosystem

The primary goals of restoration are often to re-establish ecological functions and ecosystem services and to revert the system to a previous condition that is self-sustaining and resilient against disturbance. The ultimate aim is to bring diverse and resilient nature back to marine ecosystems (HELCOM ACTION 2021b). This means reducing pressures on habitats and species, and ensuring that all uses of the ecosystem are sustainable. It also means supporting the recovery of ecosystems and tackling inputs of pollution and invasive alien species (EC 2020b).

Restoration can be an effective way to accelerate the recovery of biological communities at the local scale. It can also be used in protected areas to enable the quicker realization of biodiversity benefits. For example, recruitment areas for fish, biogenic reefs and vegetated seabeds are threatened in the Baltic Sea by many human activities and could benefit from restoration measures (Kraufvelin *et al.* 2018, 2020). When successful, restoration of coastal and marine systems can signifcantly enhance benefits relating to mitigation of climate change effects, biodiversity values, economic growth and physical and mental well-being (Aronson and Alexander 2013). Across Europe, increased restoration efforts are expected to create jobs, reconcile economic activity with natural growth, and help ensure the long-term productivity and value of the natural capital of European seas, including the Baltic Sea (EC 2020b).

Regulations and needs

Coastal and marine restoration is still in its infancy in the Baltic Sea, and there is a clear need to build a knowledge base and the capacity to ensure the successful implementation of restoration through knowledge-sharing and following up on existing and planned restoration initiatives.

In addition to the choice of method, successful restoration depends on the focal species/ecosystem (Montero-Serra *et al.* 2018), the duration of the restoration activity (Bayraktarov *et al.* 2016), the geographical location (Darwiche-Criado *et al.* 2017) and local factors, such as pressures present and conservation levels (Keenleyside *et al.* 2012).

A fundamental prerequisite for successful restoration is that the factors initially causing the pressure or damage to the habitat or ecosystem have disappeared or can be kept at a level which is known not to cause detrimental impacts.

Restoration should be undertaken with an awareness of climate change, taking into consideration whether the restored systems will be sufficiently resilient to changing conditions and potentially whether they could be adapted to facilitate mitigation and dampen the negative effects of climate change.

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5. Spatial distributions of ecosystem components, human activities, pressures, impacts and ecosystem services

The Baltic Sea is influenced by a range of pressures from human activities. In order improve its environmental status in an efficient and adequate way, it is of key importance to map activities which affect the marine environment, analyse what effects they have and how strong the effects are, and assess what this means for the ecosystem. Furthermore, while some activities and pressures might seem of little importance individually, their summed impact can be considerable when they occur in the same place, particularly in areas with sensitive species or habitats.

The HELCOM Spatial Distribution of Pressure and Impact Assessment (SPIA) analyses data on the distribution of ecosystem components (such as species or habitats), pressures and human activities, thus linking human activities with the pressure (or pressures) they cause. It links spatial information on ecosystem components with spatial information about pressures, identifying where they overlap and how sensitive a given ecosystem component is to a particular pressure. This provides an overview of the potential impact of a given pressure or subset of pressures on one or more ecosystem components, allowing us to trace which activity underpins the pressure(s) causing an impact. Each of these assessment steps can provide valuable contextual information to the results of the other assessments included in the holistic assessment of the state of the Baltic Sea.

The SPIA is an effective tool for deepening our understanding of how different pressures act on the Baltic Sea ecosystem, where they are most common, and in what areas different pressures co-occur (Box 5.1). This information can be important for management and planning purposes.

BOX 5.1.

Spatial analyses of pressures and impacts in HELCOM

The thematic assessment report on the spatial distribution of pressures and impacts analysis (HELCOM 2023e) clarifies the methodology of the HELCOM spatial pressures and impacts analysis (SPIA) for the years 2016-2021. The comprehensive approach of the SPIA differs from the other thematic assessments, which address topics in a more sectoral manner. It also differs by not comparing results against a threshold value but rather analysing where the cumulative pressure is likely higher or lower. The SPIA examines the spatial distribution and intensity of different human activities and pressures and uses the best available knowledge to quantify their combined effects. The maps are evaluated together with information on the sensitivity of each ecosystem component to each pressure in order to produce information about their potential impact on the environment.

5.1. Spatial analyses of pressures and impacts

The SPIA tool used to assess the spatial distribution of pressures and impacts is highly versatile and can analyse any combination of pressures and ecosystem components to provide information about both the potential distribution and the potential impact. By combining all available information on pressures and impacts, the tool can also address the cumulative burden on the environment caused by human activities in the Baltic Sea region. The results are presented as two indices.

— The Baltic Sea Pressure Index gives information about which areas are likely to have the greatest pressure from human activities.
— The Baltic Sea Impact Index shows the distribution of the potential cumulative impact of these pressures on the environment. This is accomplished by considering the spatial distribution of species and habitats, as well as how sensitive these ecosystem components are to the different pressures.

The Baltic Sea Pressure and Impact indices for the years 2016-2021 are based on nationally reported spatial data sets for 28 human activities occurring in the Baltic Sea and 6 data sets of pres-

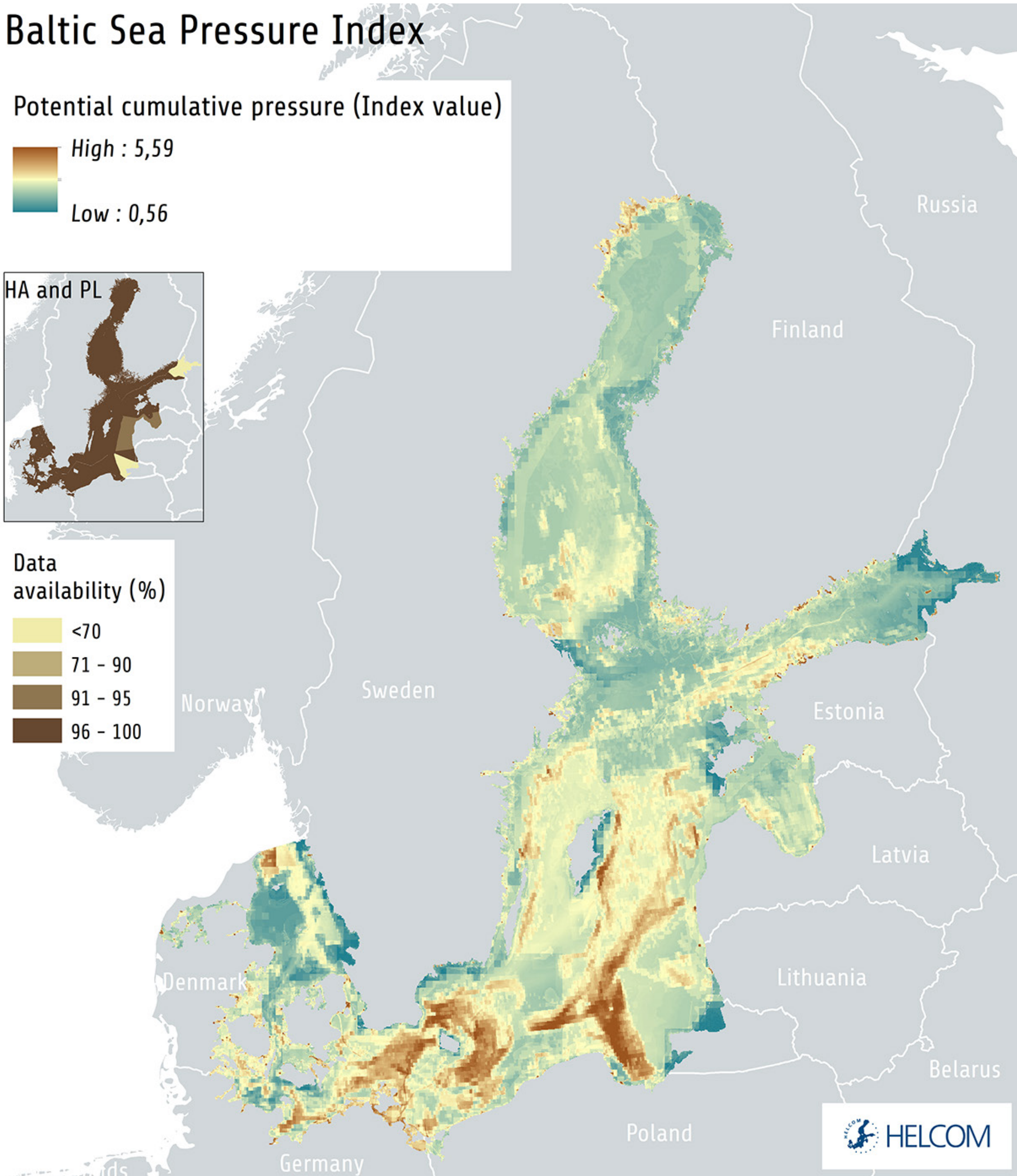

Figure 5.1. The Baltic Sea Pressure Index shows the spatial variation in the potential cumulative pressure on the Baltic Sea by combining data on several pressures. The index is based on the currently best available regional data, but spatial gaps may occur in some underlying data sets. The inset data availability map shows data availability for human activities (HA) and pressures (PL). Source: HELCOM 2023e.

sures estimated by direct measurements at sea. These data were compiled into 17 aggregated pressure layers which were used in the assessment. In addition, 57 spatial data sets representing different ecosystem components were included in the assessment. The thematic assessment report (HELCOM 2023e) gives a detailed description of the method and a complete account of all data layers, their sources and how they were developed.

The results show that hazardous substances and eutrophication are the two most influential pressures in terms of both potential cumulative pressures and impacts. When the cumulative pressure was estimated without including the spatial overlap with ecosystem components, the highest level of pressure was found in open sea areas (Figure 5.1).

The cumulative impact index indicated that there are potential cumulative impacts on the environment from human activities throughout the Baltic Sea, but there were some clear spatial differences. Shallow coastal areas are generally subject to the highest levels of cumulative impact, as these are areas where a high number of human activities and ecosystem components occur together (Figure 5.2).

The SPIA tool also enables dedicated analyses of combinations of pressures and ecosystem components. When the analysis was narrowed to only consider the combined potential impact of hazardous substances and eutrophication, the result was largely similar to the potential cumulative impact of all pressures together, demonstrating that these pressures are the main con-

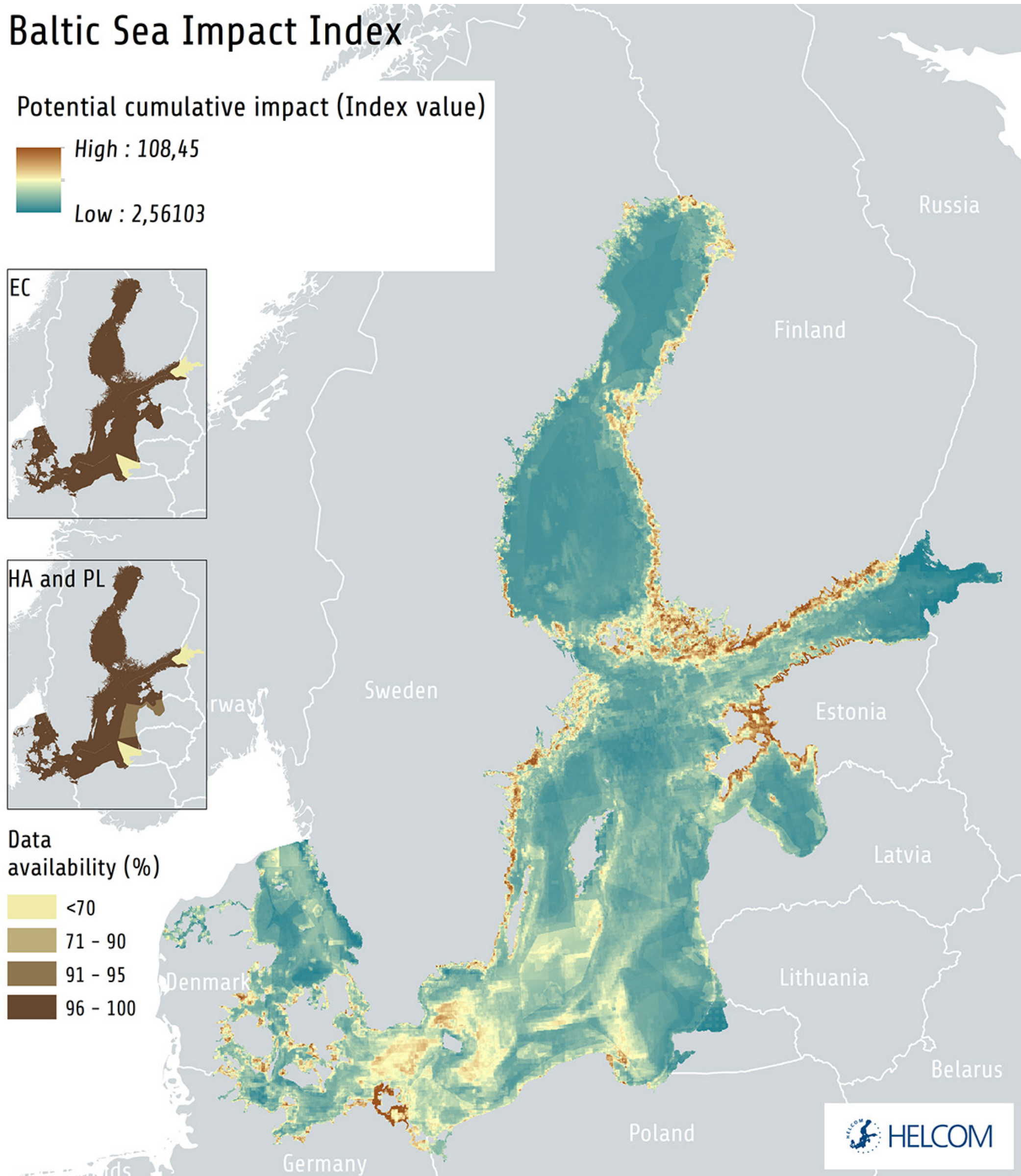

Figure 5.2. The distribution of the potential cumulative impact from human activities on the Baltic Sea environment, based on the Baltic Sea Impact Index. The analysis is based on the currently best available regional data, but spatial gaps may occur in some underlying datasets. The inset data availability maps show data availability for human activities (HA), pressures (PL) and ecosystem components (EC). Source: HELCOM 2023e.

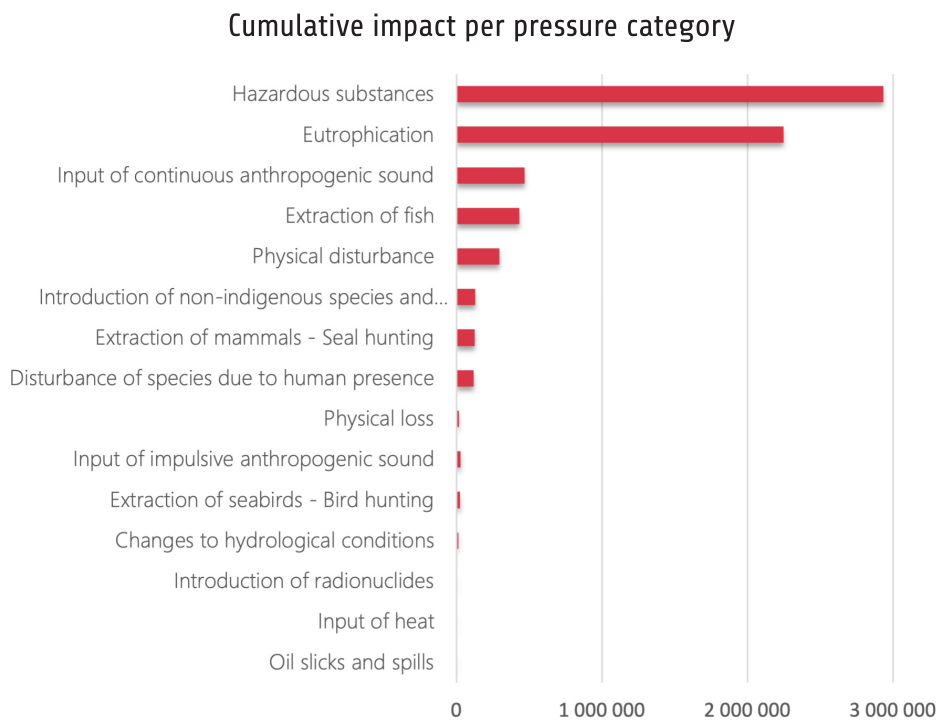

Figure 5.3. Ranking of pressures based on their potential cumulative impact measured by the Baltic Sea Impact Index. The values in the figure represent the sum of the impact index values for the whole assessment area. For details, see HELCOM (2023e).

tributors to the total impact. Both eutrophication and hazardous substances have a wide distribution throughout the Baltic Sea.

The results of these analyses clarify the spatial patterns and relative intensities of the potential cumulative pressures and impacts in the Baltic Sea. They do not provide information on the absolute magnitudes of potential pressures or impacts but instead evaluate their relative levels in different parts of the region. Hence, the indices that are produced are not status assessments in the same way as the HELCOM indicator-based evaluations. They are best used as a means to describe and communicate relative patterns and intensities of pressures and impacts in different parts of the Baltic region. They can highlight areas that are facing the highest relative potential cumulative pressures and impacts, based on the currently best available regional data. Spatial gaps occurring in some underlying datasets are indicated in the results with separate data availability maps.

5.2. Top pressures causing impacts on the Baltic Sea environment

Further analyses of the Baltic Sea Impact Index showed that “hazardous substances” and “eutrophication” were the pressures that contributed most to the total impact, comprising more than three quarters of the total impact (Figure 5.3). This reflects the fact that these pressures have the widest spatial distributions, and many species and habitats are highly sensitive to them. Other pressures that ranked high in the analyses were “input of continuous anthropogenic sound”, “extraction of fish” and “physical disturbance”. These pressures also have a wide distribution, but they were found to occur closer to the related human activities than hazardous substances and eutrophication. Furthermore, the number of ecosystem components (species and habitats) that are sensitive to these pressures is somewhat lower. Other pressures had a more limited distribution and a lower contribution to the total impact. However, many species and habitats in the Baltic Sea are also highly sensitive to such lower-ranking pressures, “physical loss” being a clear example. Even though they have limited contribution to the total potential cumulative impact at the scale of the whole Baltic region, their impact on a local scale can be high. Grey seals (*Halichoerus grypus*) and bottom-water habitats not influenced by permanent anoxia are the ecosystem components most affected by potential cumulative impacts, partly due to the large extent of these ecosystem layers compared to other layers.

The accumulation of impacts in shallow areas can also be analysed by looking at the average impact per square kilometre within HELCOM subbasins (Figure 5.4). Many of the subbasins facing the greatest potential impact have a large share of relatively shallow areas. This is particularly true for the Åland Sea, the Sound and the Great Belt. However, there are also subbasins with broad open sea areas that rank relatively high, mainly because of the pressure from commercial fishing with bottom-contacting fishing gear. The lowest average impact was found in basins with vast open sea areas compared with their coastal regions, such as the Bothnian Sea and Bothnian Bay. These are also areas where widely distributed and high-ranking pressures, such as bottom trawling, eutrophication and inputs of sound, are generally lower.

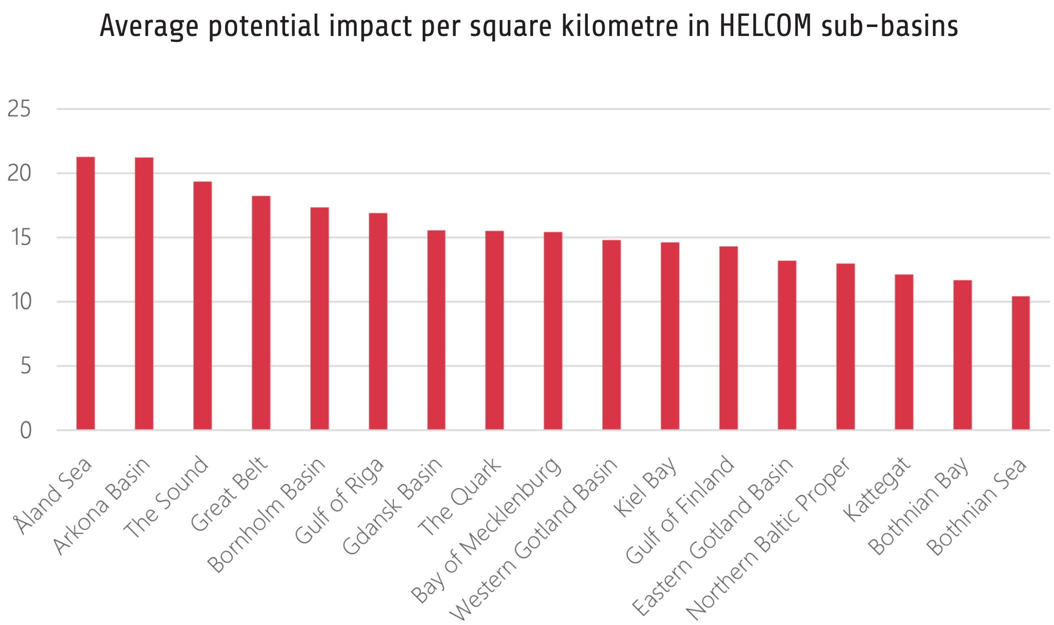

Figure 5.4. Average potential cumulative impact per square kilometre by HELCOM subbasin according to the Baltic Sea Impact Index 2016–2012. For details, see HELCOM (2023e).

BOX 5.2.

The SPIA tool

The increasing use of sea areas leads to complex patterns of interactions between human activities, pressures and ecosystem components. Tools to assess the spatial distribution of pressures and impacts are helpful for evaluating the spatial distribution of human activities and pressures and the combined and cumulative impact of human-induced pressures on the environment, as well as for identifying potential key areas of concern and in need of enhanced management efforts.

The HELCOM SPIA tool is an open-source tool which is free for everyone to use. Users can analyse the spatial distribution of pressures and impacts in the Baltic Sea using HELCOM datasets as the input. The SPIA tool is available as an ArcGIS Pro desktop toolbox and as a web-based online tool, with functionalities that can be used to present and explore the results in various ways The user can select which layers to explore and include in the calculation. The assessment can be run for the whole Baltic Sea or separately for an individual HELCOM subbasin. Results appear in the tool's map viewer, where it is possible to explore and download the map together with a statistics matrix of the result. In the interactive map viewer, the results can be compared with any pressure or ecosystem layer used in the calculation. The map viewer can also be used to explore the contribution of pressure and ecosystem layers to the total impact in a selected location.

5.3. Spatial analyses of ecosystem services

The status of the environment is directly linked to our use of the sea, which provides us with both direct and indirect benefits. Having a marine environment in good status offers several benefits that are currently not fully provided across the Baltic Sea, such as clear and oxygen-rich waters, healthy fish stocks, safe fish and seafood for human consumption, good quality coasts and beaches, and healthy marine biodiversity. Reaching good environmental status in national marine waters by 2040 is collectively estimated to be worth 5.6 billion euros per year to society (HELCOM 2023d). Not achieving good status of the marine environment affects different groups of society by, for example, decreasing the opportunities for fishing or causing impacts on human health, including for future generations (HELCOM 2023d).

Ecosystem services is a collective term for all the direct and indirect contributions that healthy ecosystems make to human well-being, as a result of functions and processes in the ecosystem (Potschin & Haines-Young 2016b). The ecosystem services

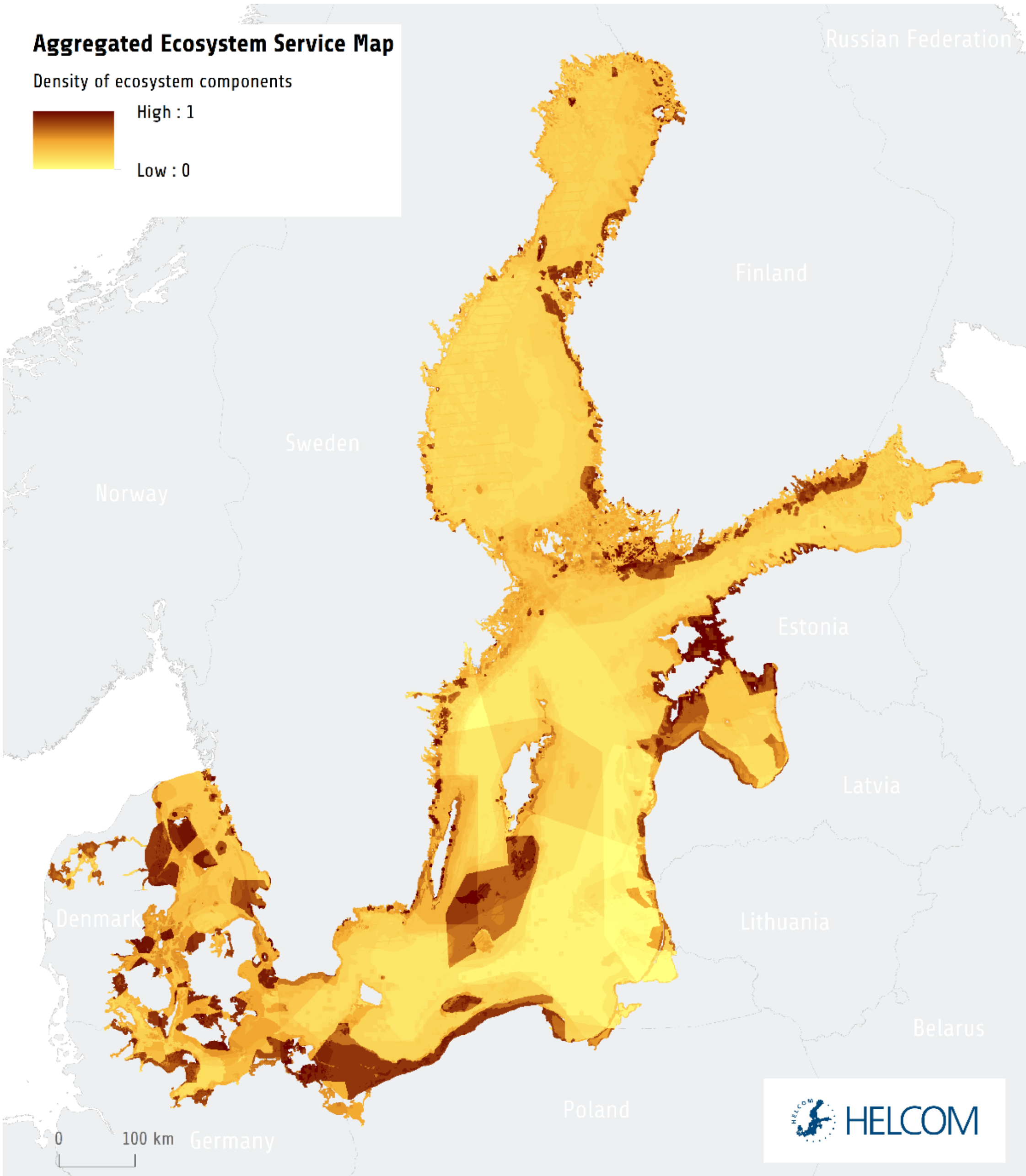

Figure 5.5. Illustration of areas with high potential to contribute to ecosystem services in the Baltic Sea. The map is made from 54 different ecosystem component layers based on their respective contribution to specific ecosystem services. For a more detailed description of the data and analyses, see HELCOM (2013d–e) and Ruskule *et al.* (2023).

concept covers aspects of the environment that are fundamental to human survival. The ecosystem produces goods that we value, such as wild fish and algae for nutrition. It also contributes to the regulation and maintenance of the ecosystem that we live in, through processes like carbon sequestration. Interacting with nature also provides non-material benefits, like recreation and cultural values. Analysing the environment using an ecosystem services approach is helpful for understanding and clarifying the connections between ecosystems and human well-being. The ecosystem services approach can thus support decisions and policy-making to ensure the sustainable use of resources (Martin-Ortega *et al.* 2015). Analyses of ecosystem services can help clarify potentially complex relationships between nature and society. As ecosystem services link the state of the ecosystem with societal well-being, such analyses are an effective tool for evaluating the trade-offs between alternative sea uses, and between different management and protection options. However, both the ecosystem services approach and its branch, ecosystem accounting, are fairly new concepts in comparison established environmental assessment tools. Further development of their knowledge base, information base and appropriate application is needed.

A mapping approach building on the data layers developed for use in the assessment of the spatial distribution of pressures and impacts demonstrates the potential contribution of ecosystem services in the Baltic Sea region (Figure 5.5). An aggregated map of ecosystem service potential was created using an extension of the Baltic Sea Impact Index calculation tool (Ruskule *et al.* 2023). This updated evaluation used 54 different ecosystem component layers, including benthic habitats, pelagic species, habitat-building species, mobile species and their key habitats. The tool aggregates the spatial extent of the ecosystem components contributing to the provision of a particular ecosystem service and combines the results for all the layers. The precision of the resulting map is still comparatively low because it only considers the presence or absence of ecosystem components, not their quantity or quality, and it only reflects the ecosystem services that were included in the exercise. Nevertheless, it provides a rough illustration of potential key areas for ecosystem services in the Baltic Sea, thus supporting key management actions, such as protection and the determination of acceptable levels or locations of pressures to achieve good environmental status.

5.4. How can maritime spatial planning support the Baltic Sea environment?

Maritime spatial planning (MSP) is the spatial planning of activities at sea. The processes used in MSP involve a holistic, multisectoral effort at national scales and can serve as a key component in the implementation of several shared environmental objectives for the Baltic Sea. Maritime spatial planning is thus becoming an increasingly important instrument for the development of ecosystem-based management, facilitating or enabling work towards reaching a good environmental status of the Baltic Sea environment (Box 5.3).

The current state of maritime spatial planning in the Baltic Sea

All Baltic countries that are also members of the European Union have implemented their first (or, in some cases, second) generation of maritime spatial plans, in alignment with the EU Maritime Spatial Planning Directive (EC 2014). Important topics for future iterations of the plans are dealing with climate change, meeting the visions of the European Green Deal (EC 2019), monitoring and evaluating the existing plans, and the cooperative development of coherent plans to better support an ecosystem-based approach towards reaching good environmental status.

BOX 5.3.

What is maritime spatial planning?

Maritime spatial planning (MSP) is spatial planning at sea using a holistic, multisectoral effort. A key aim of MSP is to delineate human uses in such a way that sensitive environmental areas are not significantly negatively affected. Furthermore, the MSP process should serve as a platform for the involvement of all relevant stakeholders in determining how society should use the sea.

The Baltic Sea Action Plan includes MSP as a horizontal topic. Through the Baltic Sea Action Plan, HELCOM countries have agreed to:

— **Utilize maritime spatial planning (MSP) applying an ecosystem-based approach to support BSAP objectives and targets and contributing to sustainable sea-based activities**

The maritime spatial plans are implemented nationally. Thus, the inclusion of coastal areas or related sectors, and the formal status of the plans, varies between countries in HELCOM.International cooperation between neighbouring countries and within regional seas is of high importance in MSP and is a cornerstone of the formation of a coherent framework. In HELCOM, the HELCOM-VASAB MSP working group addresses a number of joint challenges for MSP in the Baltic Sea with its regional MSP roadmap for 2021-2030, including knowledge development, regional collaboration, environmental considerations, a sustainable blue economy and climate change (EC 2022).

How can MSP make a difference for ecosystems and societies?

Maritime spatial planning can potentially have positive or negative effects on the marine environment, depending on where and how space is allocated for different uses. It is essential that knowledge about how different human activities may affect both the local and the broader ecosystem are included in the planning process in order to ensure long term sustainability.

Because planning considers social, economic, cultural and other relevant aspects while also aiming to enhance marine nature values, it can help countries integrate key environmental considerations into their planning in a holistic way. When applied optimally, MSP can make a difference for Baltic Sea ecosystems and society by guiding or directing the locations of different types of human uses of the sea in a way that maximizes the possibility for a positive sustainable future. For example, planning efforts can enhance nature conservation by facilitating a Baltic Sea network of marine protected areas or can improve marine ecosystem services by securing space for different sea uses in a manner that protects and improves long-lasting ecosystem functions and the provisioning of key ecosystem services.

Figure 5.6. Operational wind farms in the Baltic Sea during 2016–2021. Several more offshore wind farms are currently in planning. The expansion of offshore wind is a key topic for sustainable environmental management, in which MSP plays a central role. Please note that the symbols in the map are enlarged to make them visible at this scale. Source: HELCOM 2023e.

Figure 5.7. Several human activities coexist within the Baltic Sea, interacting with or affecting the marine environment.

The role of maritime spatial planning in HELCOM

HELCOM plays an important role as a regional anchor that can help countries around the Baltic Sea harmonize their national MSP processes. This is important because most fundamental aspects of MSP are actually transboundary, including the distribution of human activities, as well as environmental pressures and biodiversity. The regional perspective on the Baltic Sea provided in HELCOM, its data coordination, resources and the institutionalized knowledge of its community all support maritime spatial planning.

Successful planning in alignment with the ecosystem approach is vital to our prospects of reaching a healthy and long-term sustainable Baltic Sea environment. The development of ecosystem-based approaches in MSP can also support the implementation of ecosystem-based management efforts more widely.

The Baltic Sea Action Plan includes measures to be implemented by countries by 2030, at the latest, to support our shared objectives for the Baltic Sea environment. The BSAP gives an important role to maritime spatial planning and outlines both the direct and indirect ways that Baltic countries should carry out planning towards this aim (HELCOM 2021).

Key topics where work in HELCOM could support regionally harmonized maritime spatial planning include the development of cumulative impact assessments of the plans on a regional scale, which would supplement the national coverage of impact assessments by countries, facilitating their coherence. Work in HELCOM should also contribute to the general development and exchange of knowledge about cumulative impact assessment in relation to strategic environmental objectives. In this regard, HELCOM also serves as a common point for collaborations with other regional seas by actively sharing information and knowledge. Dedicated projects shared by countries around the Baltic Sea to support MSP have been instrumental in strengthening regional coordination in recent years and in opening connection points between marine protection, regional development and maritime spatial planning.

Joint efforts to increase the resilience of our aquatic ecosystems to climate change is a cornerstone question for maritime spatial planning in countries around the Baltic Sea, as well as globally. This runs in parallel with necessary actions to reduce the loss of biodiversity and reach environmental protection targets (see Chapter 4), and needs to be harmonized with them. Current key challenges to which maritime spatial planning can contribute are to take areas vulnerable to climate change into consideration in spatial planning, facilitate management of coastal areas to minimize damages caused by extreme weather events, identify areas for renewable energy, and make sure that environmental pressures caused by human activities are minimized (Figure 5.6-5.8). All of these challenges will benefit from regional work in HELCOM.

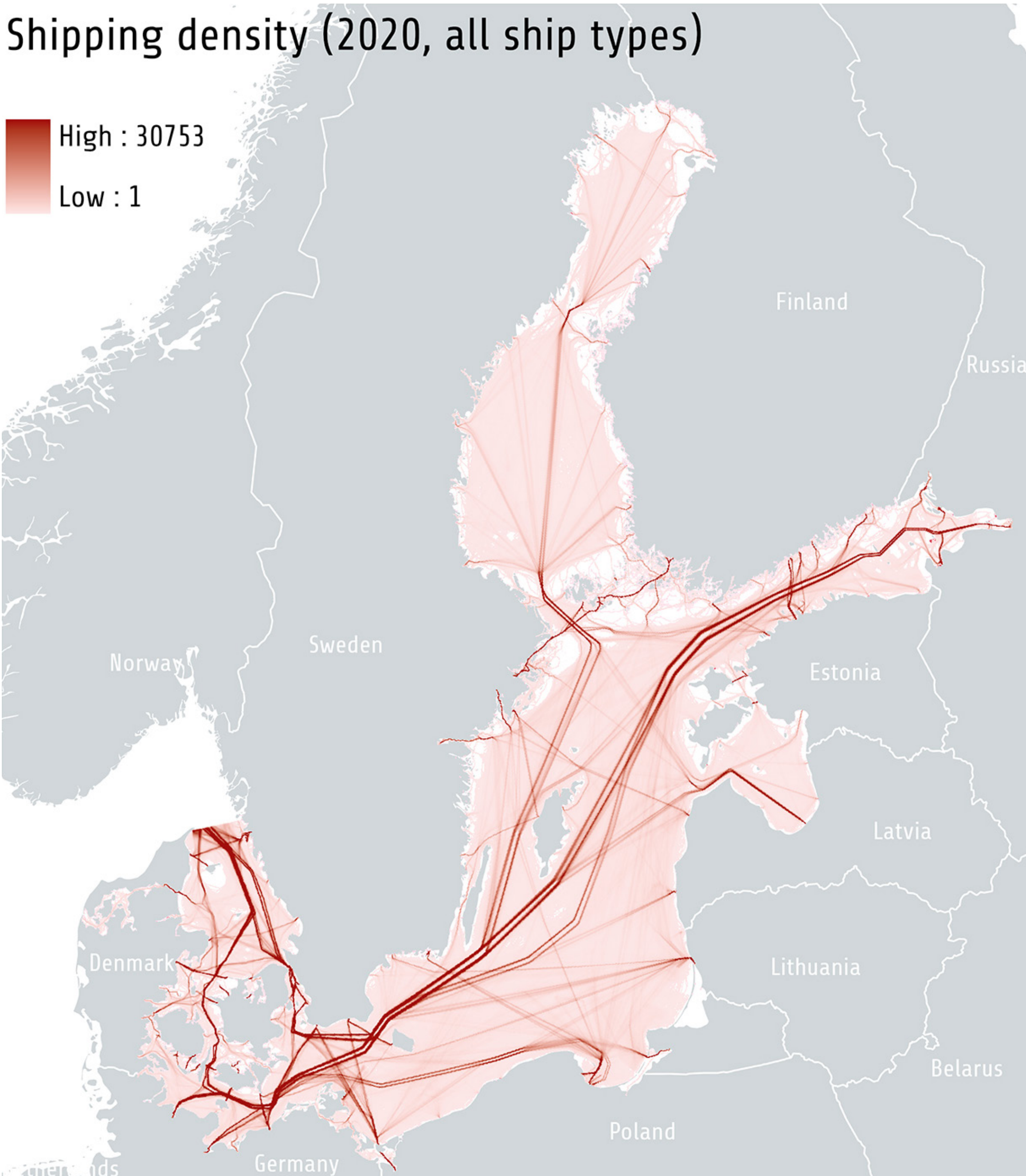

Figure 5.8. Key shipping lanes in the Baltic Sea.

6. Conclusions and future outlook

The health of the Baltic Sea ecosystem is under threat from the increasing effects of climate change and biodiversity degradation, catalysed by pollution, demands on land use, resource extraction and other pressures. At the same time, knowledge about the Baltic Sea ecosystem and policies to support its environment have developed substantially in the past six years. Such advancements are of key importance in enabling a sustainable future, although much work remains. Implementing the updated Baltic Sea Action Plan and mitigating the pressures and impacts, including from climate change, are focal areas for HELCOM in the coming years.

6.1. Conclusions of the summary report

The third HELCOM holistic assessment of the ecosystem health of the Baltic Sea is a milestone in the HELCOM monitoring and assessment system (Figure 6.1). This assessment provides us with an opportunity to reflect on how our current actions affect the Baltic Sea environment and assess the need for new or improved measures. Societal and ecosystem processes are complex, and we need to consider both how well measures that were agreed have actually been undertaken and whether they have had the intended effect. In line with the principles of adaptive management, the assessment also enables us to tune our management efforts as needed in order to ensure that our actions are relevant in relation to the current state of knowledge and environmental conditions.

The third holistic assessment, focusing on the years 2016-2021, provides a benchmark for the updated Baltic Sea Action Plan adopted by all HELCOM Contracting Parties in 2021. The Baltic Sea Action Plan (HELCOM 2021) specifies our shared objectives and agreed actions and measures for the Baltic Sea environment, building on the vast knowledge and experiences developed among HELCOM countries over several decades. Compared to the preceding Baltic Sea Action Plan (HELCOM 2007), the 2021 BSAP integrates management efforts for the Baltic Sea environment more clearly into an ecosystem approach and into the global setting. It thus takes a more holistic approach to management and governance, with the ecosystem at the centre of the process.

Both the Baltic Sea Action Plan and the results of this third HELCOM holistic assessment make it clear that achieving good environmental status of Baltic Sea ecosystems requires direct actions to support marine biodiversity along with transformative change, in all sectors, of the processes or economy affecting the sea. Measures across many domains are needed to rebuild ecosystems and stop negative trends. Strengthening and expanding protection efforts, as well as reducing current negative impacts on biodiversity from pollution and sea-based activities, are all cornerstones of conservation and of reinforcing deteriorated ecosystems.

The third holistic assessment shows that there are cases of inadequate status in biodiversity and pressure-related indicators across the full extent of the Baltic Sea and in most ecosystem components. Only a few biodiversity indicators have acceptable levels in parts of the region, and none in all evaluated spatial units. In cases where the deterioration is first noted for certain species or parts of the ecosystem, it can then spread to other parts through links within the food web. Persistent negative trends threaten populations, habitats and the functioning of the ecosystem. Importantly, a poor status for biodiversity also increases the risk of further degradation, since it re-

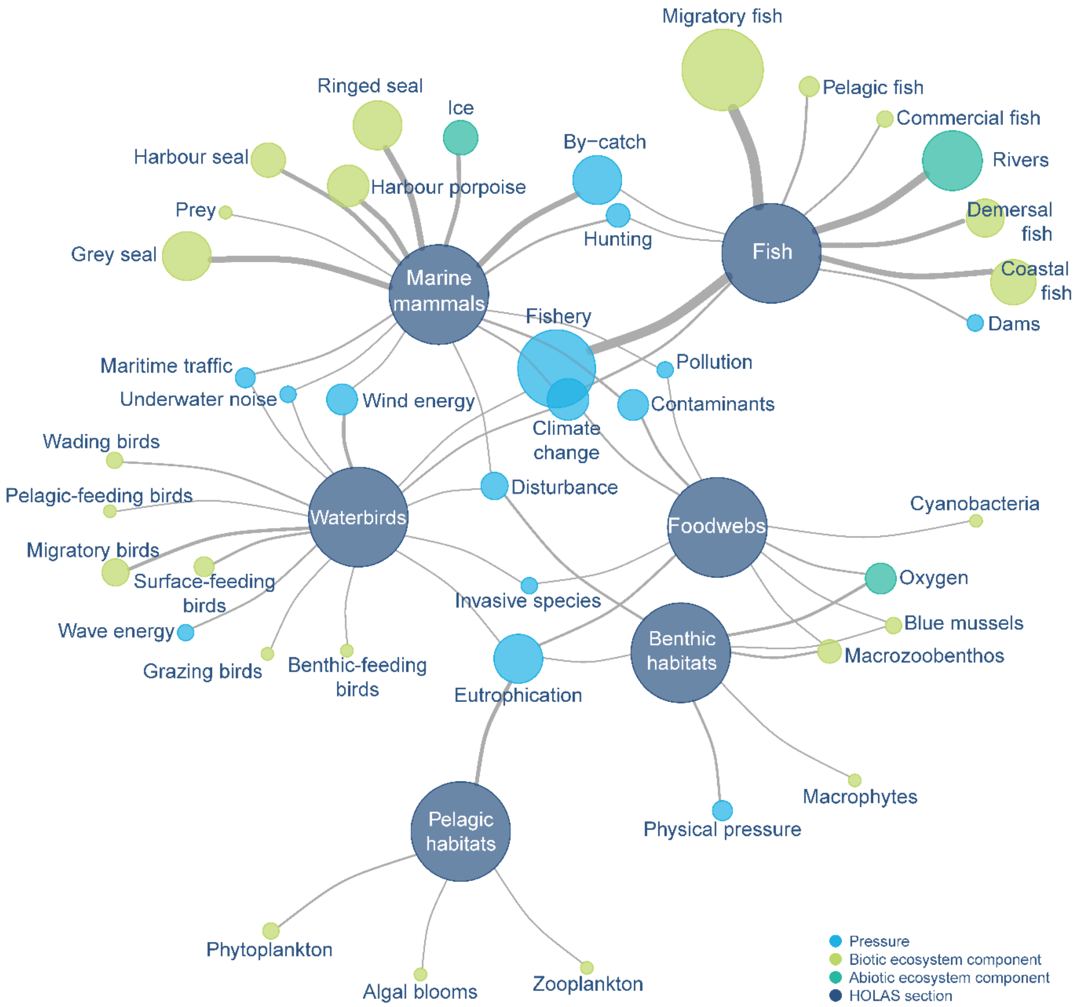

Figure 6.1. An illustration of the components of the Baltic Sea ecosystem encompassed in this summary report for the third holistic assessment of the ecosystem health of the Baltic Sea, together with their multiple connections. The figure shows a network graph of the aspects (pressures, components of the ecosystem, and ecosystem services) covered in this report. Each of the key ecosystem components covered in a section of this report is symbolised by a dark blue circle, and the other circles reflect key elements (terms) mentioned in the sections. The size of the circles is based on how often the term is mentioned and should only be interpreted in this way. Similar terms are aggregated, so each circle includes both the term itself and all terms deemed to be synonymous (e.g. "eutrophication" includes "eutrophication" and associated terms such as "nutrient input" or "concentrations"). The width and length of the lines and the placement of the items are arbitrary. The image gives a simple visual overview of which topics may interact (e.g. a pressure and certain ecosystem components) while simultaneously providing a gap analysis of where more information may be required in the future to increase the holistic nature of the evaluation (e.g. if the interaction between a pressure and an ecosystem component has not been well addressed). The overview was made using igraph.

duces the resilience of the ecosystem against further environmental changes. Pressures on the environment, including hazardous substances, eutrophication, fishing and the introduction of non-indigenous species, remained above sustainable levels during 2016-2021, and the effects of climate change are increasing.

The degradation of the marine ecosystem also reduces its ability to produce goods and services for the benefit of society, with effects on our well-being. Considering the cost of inaction, achieving a healthy Baltic Sea is an investment in our region's sustainable economic and social development.

6.2. What is needed next?

The poor status of many species and habitats in the Baltic Sea reflects their response to multiple environmental pressures acting in combination rather than to individual pressures. Several environmental objectives for the Baltic Sea require a combination of measures in order to be accomplished. Importantly, with the exception of a few measures, such as habitat restoration, the only viable action to improve the status is to alleviate the pressures by managing our activities so that they are within the limits the ecosystem can tolerate. This calls for the engagement of all sectors impacting on or dependent on the sea. Reaching the nutrient input reduction targets continues to be a priority in HELCOM work, with measures needed in all countries to implement the agreements of the Baltic Sea Action Plan. Coordinated and innovative management is needed to address the wide range of sources from which hazardous substances reach the Baltic Sea, which is part of ongoing work under action HL1 of the BSAP (2021). The impacts of fishing continue to affect fish stocks and the productivity and resilience of food webs. Together, measures to relieve such pressures are key to strengthening the ability of the Baltic Sea to recover and to respond to future challenges.

Even if the third holistic assessment only touches upon a fraction of the complexity of the ecosystems of the Baltic, the large amount of information provided gives us a good understanding of the main pressures on the Baltic Sea, where they primarily occur and the status of key ecosystem components (Box 6.1). A key aim for us now is to incorporate this new knowledge into an operational ecosystem-based management , and into national, regional and global actions for a sustainable future.

The results of the third holistic assessment, including this summary report and all its underpinning products, can support policymakers in determining the decisions and priorities to ultimately secure a healthy ecosystem and a sustainable future for the Baltic Sea. National work in HELCOM countries is at the core of implementing the agreements of the Baltic Sea Action Plan. The third holistic assessment also helps EU countries within HELCOM meet the requirements for the marine environment under the EU Marine Strategy Framework Directive. Actions to support the Baltic Sea environment also support various national, regional and global commitments, such as commitments towards the United Nations Sustainable Development Goals (SDGs). Ultimately, a key factor at all levels of governance is our ability as a society to adapt to an environmentally sustainable way of living around the Baltic Sea and its catchment.

6.3. Climate change will increasingly impact the Baltic Sea in the near future

The need for stronger actions and more integrated management of human activities is enhanced by climate change, which increases the risks of biodiversity loss in marine and coastal ecosystems. Climate change effects are already evident in the Baltic Sea, and global warming is expected to lead to further hydrological and ecological changes in the near future. For example, climate change is expected to lead to considerable changes in the occurrence and abundance of species due to the effects of increasing temperatures, a decreasing ice cover and possible changes in salinity. This can lead to direct effects on the functions of food webs and ecosystems, such as changes in productivity and resilience. Climate change effects can also interact with other pressures or lead to changes in human activities affecting the sea. The effects of climate change therefore need to be considered in all aspects of management and policy.

Although further research and understanding is strongly needed, this should not function as a barrier to action, as the vast existing knowledge should be used to plan and implement measures. Along with actions to mitigate climate change, priority areas for the Baltic Sea include meeting the nutrient reduction targets of the BSAP, ensuring a sufficient network of marine protected areas and strengthening the natural capacity of Baltic Sea food webs to regulate and resist the negative effects of climate change.

6.4. How can work in HELCOM contribute?

The results of the third holistic assessment show that much work is still needed to improve the status of the Baltic Sea environment. However, the progress that countries around the Baltic Sea have achieved so far clearly shows that the regional collaboration in HELCOM gives results. It is helpful to recall what the state of the Baltic Sea environment could have been like without the measures implemented to date. Inputs of nutrients and hazardous substances have, in fact, reached sustainable levels in some areas and for some substances, biodiversity conservation has increased, and regional monitoring and assessment has considerably improved. These are all necessary and fundamental actions that we want to sustain and build upon. For many processes in the ecosystem, models show that it will take a long time before recovery can be seen in species and habitats. Pressures that have been acting on the Baltic Sea for a long time have legacies and can cause unacceptable status for species and habitats long after they have ceased. However, in some cases, the recovery trend for biodiversity today is still too slow or even absent.

The Baltic Sea Action Plan, together with the increased capacity for knowledge-sharing developed among countries in HELCOM, forms a basis for further ecological understanding, learning, technical improvement and societal innovation that will facilitate future benefits and further improve our actions (HELCOM 2021a). We want to continue our tradition for cooperation and interaction between institutes, organisations and local initiatives around the Baltic Sea, contributing to sustainable human activities and achieving a healthy Baltic Sea environment together.

Continued efforts to improve the environmental status of biodiversity are of key importance. If we successfully limit the amount of pressure our activities put on the environment, we foresee that biodiversity will show signs of improvement and support a sustainable marine region. The results presented in this report clearly show that in order to ensure that the Baltic Sea ecosystem maintains and improves its functions, we need to both limit the extent and intensity of pressures on biodiversity and enhance the resilience of the natural ecosystem. Ultimately, the recovery of Baltic Sea biodiversity is entirely dependent on how well we can manage our activities to ensure that they are truly sustainable, both in the near future and in the long term.

BOX 6.1.

Assessment advance in HOLAS 3

The third HELCOM holistic assessment has increased our knowledge of the state of the Baltic Sea environment and has substantially improved our shared understanding of its current status. It has also explored how different parts of the ecosystem are connected and evaluated what needs to be done for the Baltic Sea environment. In order to provide these updated assessment results, experts around the Baltic Sea have contributed several improvements to the HELCOM assessment system. It is important to acknowledge this work and to ensure its continued development.

The holistic assessment encompasses a wide range of evaluations in order to give as comprehensive an assessment as possible, based on currently available knowledge and data. The list below offers some examples of improvements achieved within the third holistic assessment, while more extended information is provided in HELCOM (2023a-e), as well as in the indicator reports.

- The evaluation of pelagic habitat status has a wider geographical extent than before and applies an integrated approach using key indicators.
- Loss and disturbance of the sea floor is assessed via an integrated assessment based on an initial selection of available indicators and includes the newly developed CumI indicator that evaluates predicted impact.
- The benthic habitats and SPIA assessments encompass a wider range of data on ecosystem components, giving them improved ecological relevance, especially in the northern parts of the Baltic Sea.
- The assessment of fish has developed a regionally agreed list of commercial species and, for the first time, provided suggestions for the evaluation of changes in the age and size structure of fish.
- The assessment of marine mammals now includes an evaluation of the harbour porpoise.
- Assessments of unintentional by-catch of waterbirds and marine mammals against regionally agreed threshold values is included for the first time, and these are also provided as part of an integrated assessment.
- The eutrophication assessment was carried out using an improved version of the integrated assessment tool in which the confidence is reported better and more ecologically appropriate assessment unit divisions are applied.
- The integrated assessment of hazardous substances makes use of more available data, includes new indicators and has an improved evaluation of confidence.
- The first regionally coordinated wide-scope screening of hazardous substances in the Baltic Sea has been completed, and follow-up actions are underway. Pilot evaluations of the biological effects of contaminants have also been carried out, and this will be the focus of future work.
- Assessment protocols for underwater noise and marine litter have been developed and improved, with preliminary or regionally agreed threshold values being applied, respectively.
- A new collaboration for improved and harmonized evaluation of non-indigenous species in HELCOM and OSPAR has been initiated.
- The spatial pressures and impact assessment tool provides an interactive way for users to assess, visualize and evaluate the potential impacts of human activities and pressures on different parts of the Baltic Sea environment.
- Several new and improved approaches for evaluating economic and social aspects have been developed.
- Four driver indicators have been developed, exploring possible trends in human activities that may have impacts on status.
- Substantial amounts of data on human activities, pressures, ecosystem components (species and habitats) and drivers are needed to carry out the HELCOM holistic assessments, and the publication of these data sets provides a unique, region-wide and harmonized data resource to support management.

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Acknowledgements

The contributors to the HOLAS 3 Thematic assessments and other materials underlying or enabling this summary report are highly acknowledged.

Markus Ahola, Heini Ahtiainen, Gastón Alurralde, Matilda L Andersson, Janne Artel, Philipp Arndt, Philip Axe, Torsten Berg, Eva Blidberg, Mats Blomqvist, Elisabeth Bolund, Berit Brockmeyer, Anja Carlsson, Julia Carlström, Jacob Carstensen, Anne Munch Christensen, Jan Dierking, Volker Dierschke, Luke Dodd, Pia Eriksson, Carolyn Faithfull, Ana Filipa Faria Lopes, Vivi Fleming, Rob Fryer, Anders Galatius, Anita Gilles, Elena Gorokhova, Johan Gustafsson, Juuso Haapaniemi, Fredrik Haas, Axel Haldin, Birgit Heyden, Theda Hinrichs, Laura Hoikkala, Theodor Hüttel, Antti Iho, Andres Jaanus, Hans Mose Jensen, Marie Johansen, Sarah Josefsson, Ville Junttila, Susanna Kaasinen, Laura Kaikkonen, Joni Kaitaranta, Katarzyna Kaminska, Aleksander Klauson, Natalja Kolesova, Sven Koschinski, Vasileios Kouloumpos, Axel Kreutle, Petra Kääriä, Martin M. Larsen, Maiju Lehtiniemi, Wera Leujak, Andreas Lindén, Urmas Lips, Stiig Markager, Markku Mikkola-Roos, Rasa Morkūnė, Ciaràn Murray, Rahmat Naddafi, Lasse Tor Nielsen, Florent Nicolas, Henrik Nygård, Antonia Nyström Sandman, Eeva Nyyssönen, Johan Näslund, Henn Ojaveer, Jens Olsson, Kylie Owen, Anna Osypchuk, Kristine Pakalnīete, Hjalte Parner, Sara Persson, Sonja Peterson, Ksenia Pazdro, Kemal Pinarbasi, Rita Poikane, Markus Raudkivi, Anna Rindorf, Owen Rowe, Marta Ruiz, Hans Sanderson, Jan Schmidtbauer-Crona, Marco Scotti, Daiva Semenienė, Deborah Shinoda, Jaroslav Slobodnik, Anne Soerensen, Stella-Theresa Stoicescu, Peter Stæhr, Jakob Strand, Isabelle Taubner, Jakob Tougaard, Riikka Venesjärvi, Max Vretborn, Emmi Vähä, Jana Wolf, Erik Ytreberg, Tamara Zalewska, Örjan Östman.

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