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.

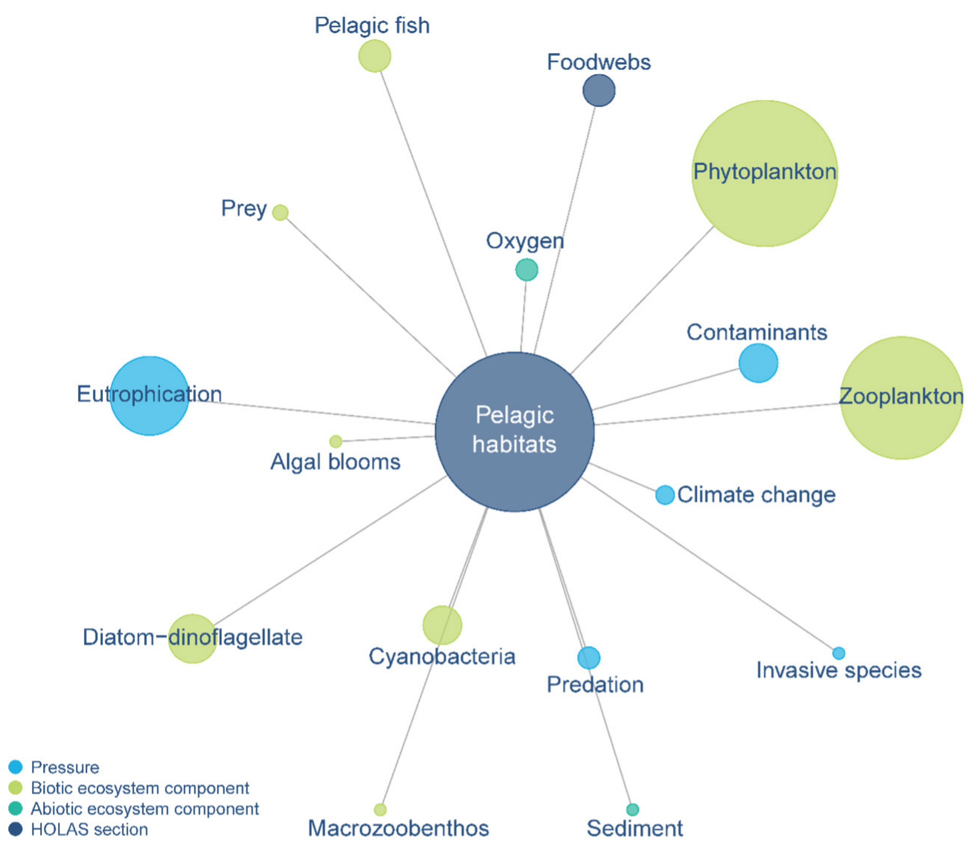

Figure 3.2. An overview of the ecosystem components and pressures descriptively linked to the status of pelagic habitats in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and 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.

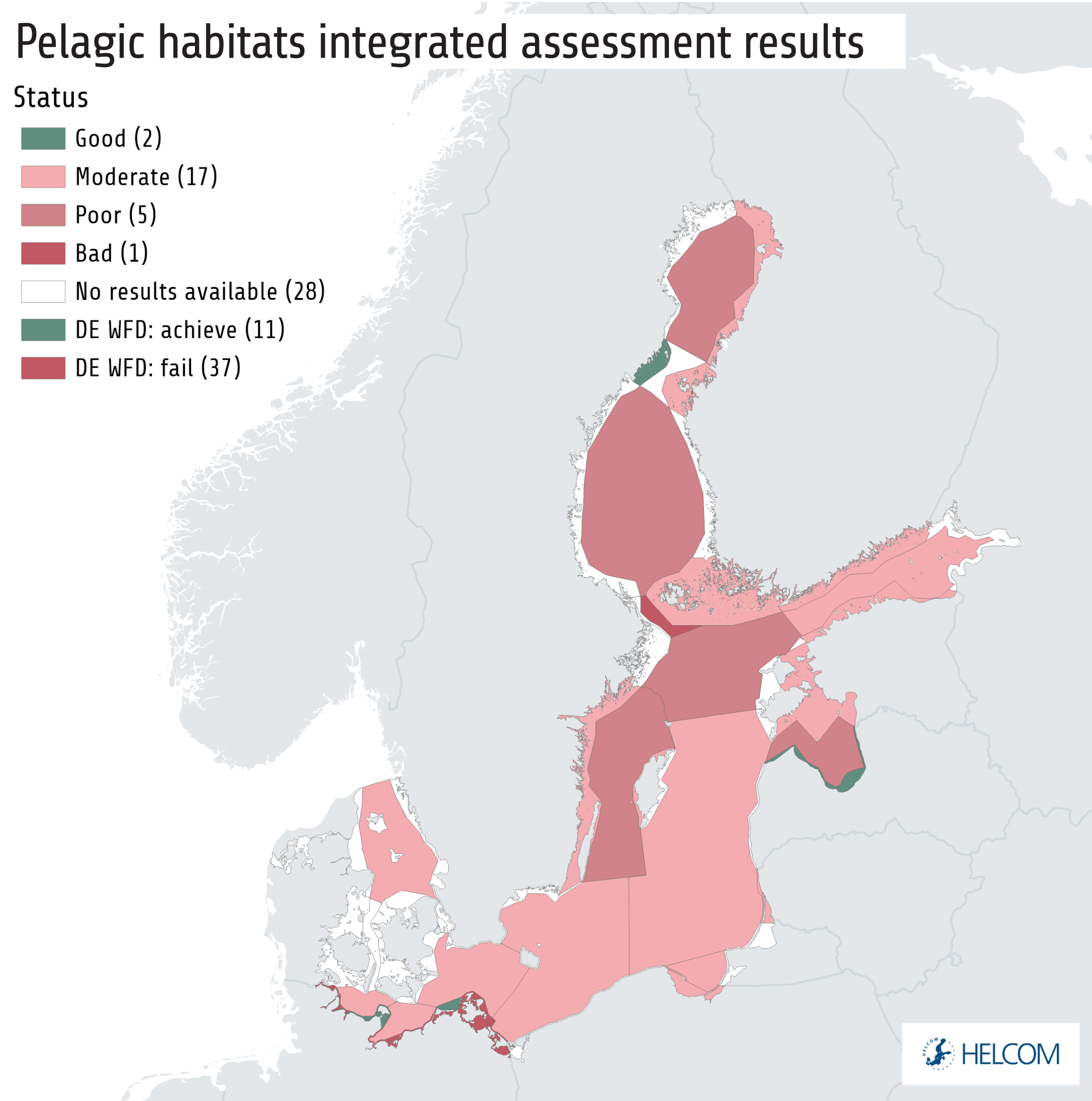

Figure 3.3. Summary of results from the integrated assessment of pelagic habitats. Source: HELCOM 2023a.

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.

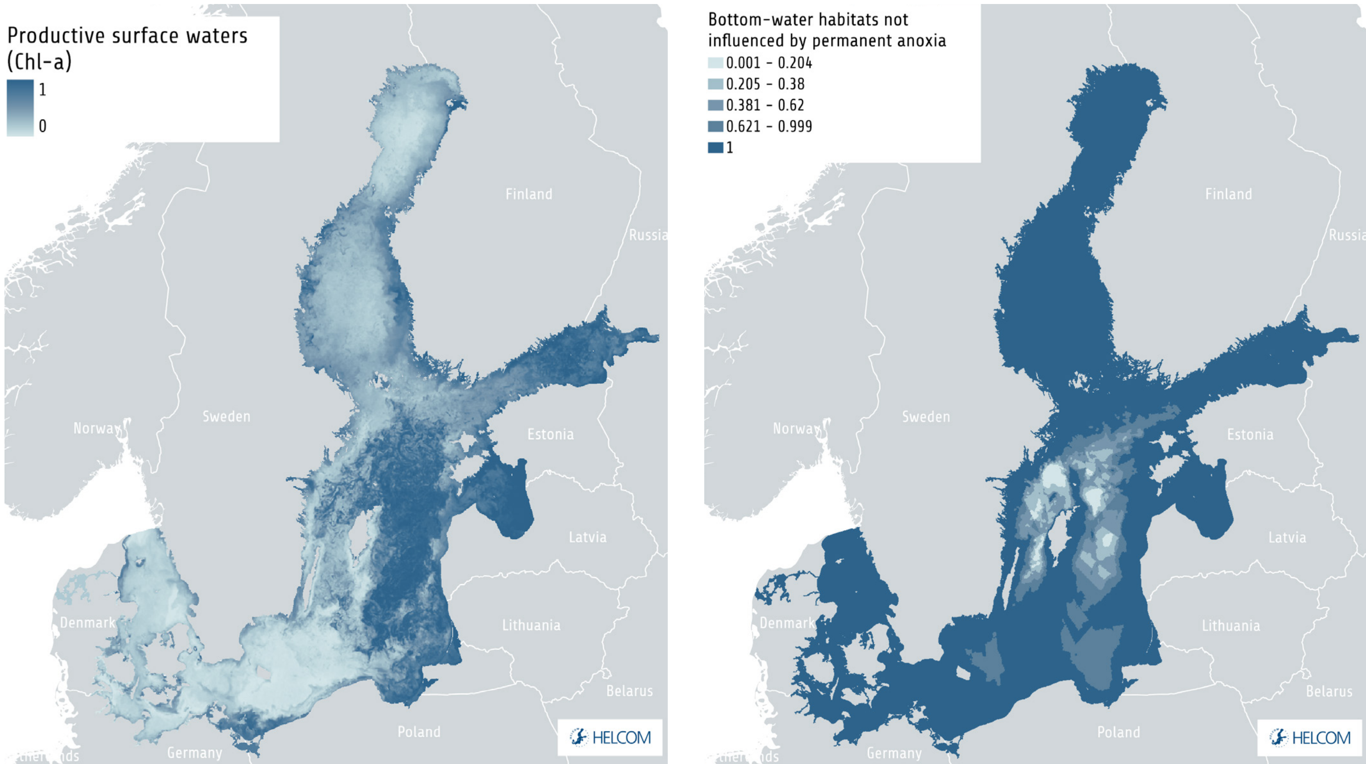

Figure 3.4. Distribution of pelagic habitat. Left: Productive surface waters are represented by the concentration of chlorophyll-a during spring. Higher values indicate areas with more chlorophyll-a in surface waters. The dataset was prepared by the Finnish Environment Institute. Right: Bottom-water 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.

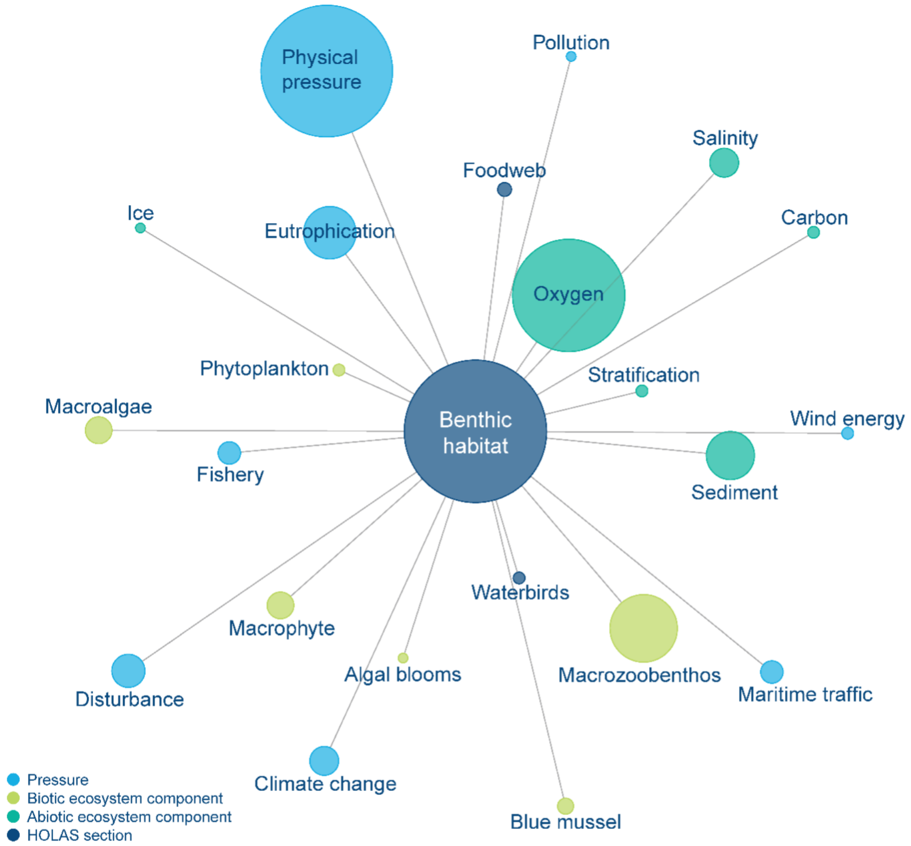

Figure 3.5. An overview of the ecosystem components and pressures descriptively linked to the status of benthic habitats in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and 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.

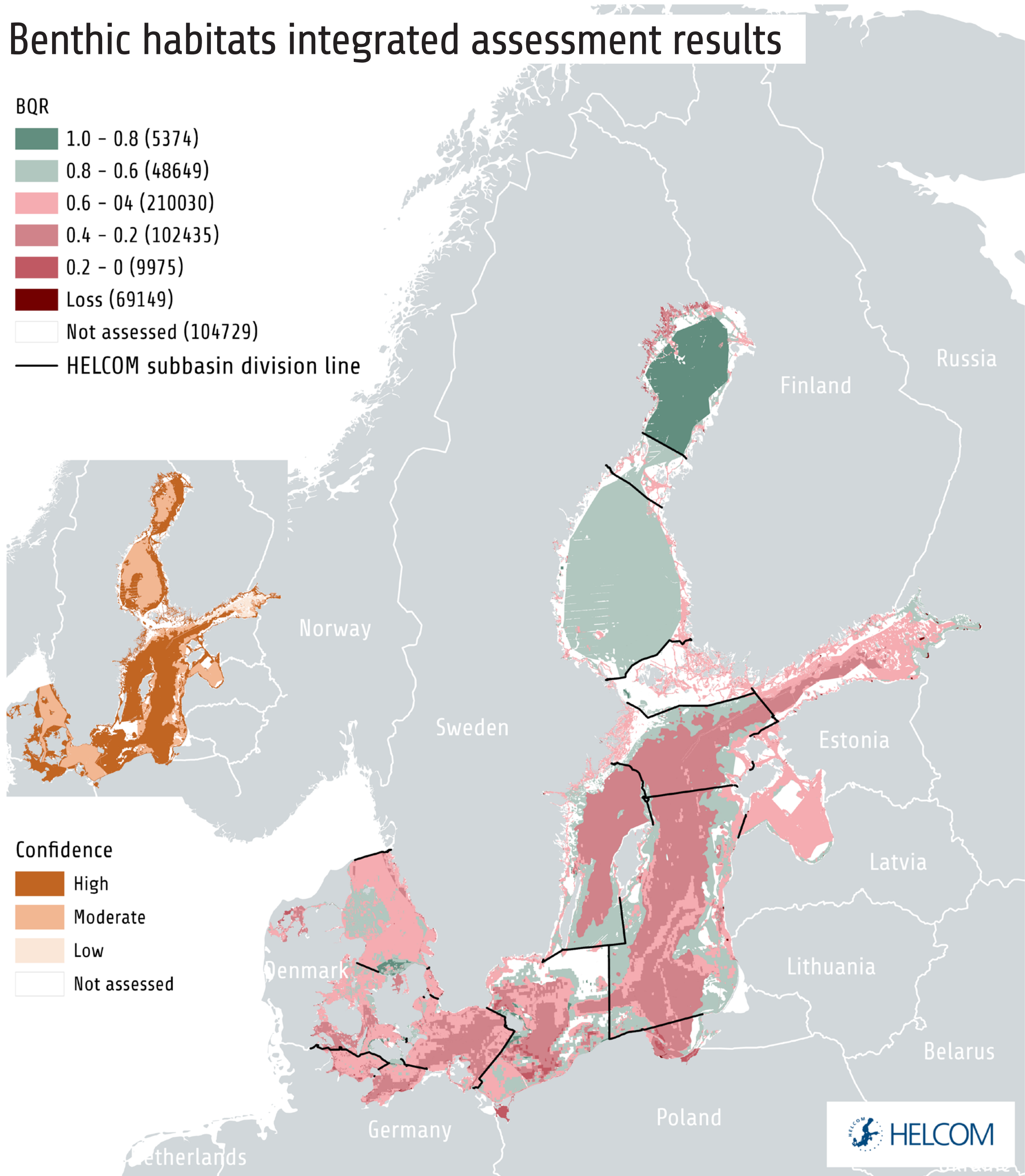

Figure 3.6. Summary of results from the integrated assessment of benthic habitats. Biological quality ratios (BQR) above 0.6 correspond to good status. Assessment confidence is presented in the inset map on the left. Source: HELCOM 2023a.

State of the Baltic Sea
Third HELCOM holistic assessment 2016–2021

State of the Baltic Sea 2023
3. Status of biodiversity

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).

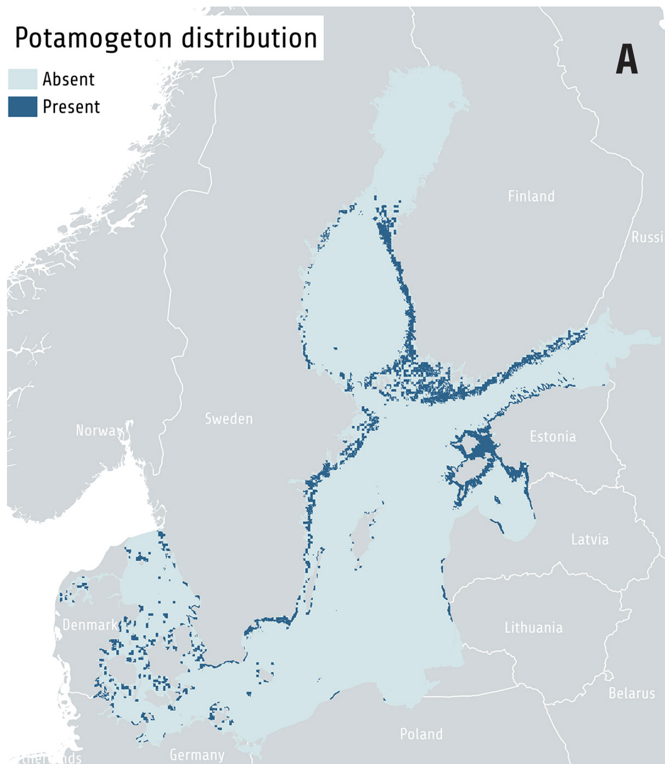

Figure 3.7. Distribution of a) Potamogeton spp, an important freshwater macrophyte in the Baltic Sea, b) Fucus spp, a brown macroalga, and c) the marine macrophyte Zostera marina (eelgrass). Source: HELCOM 2023a.

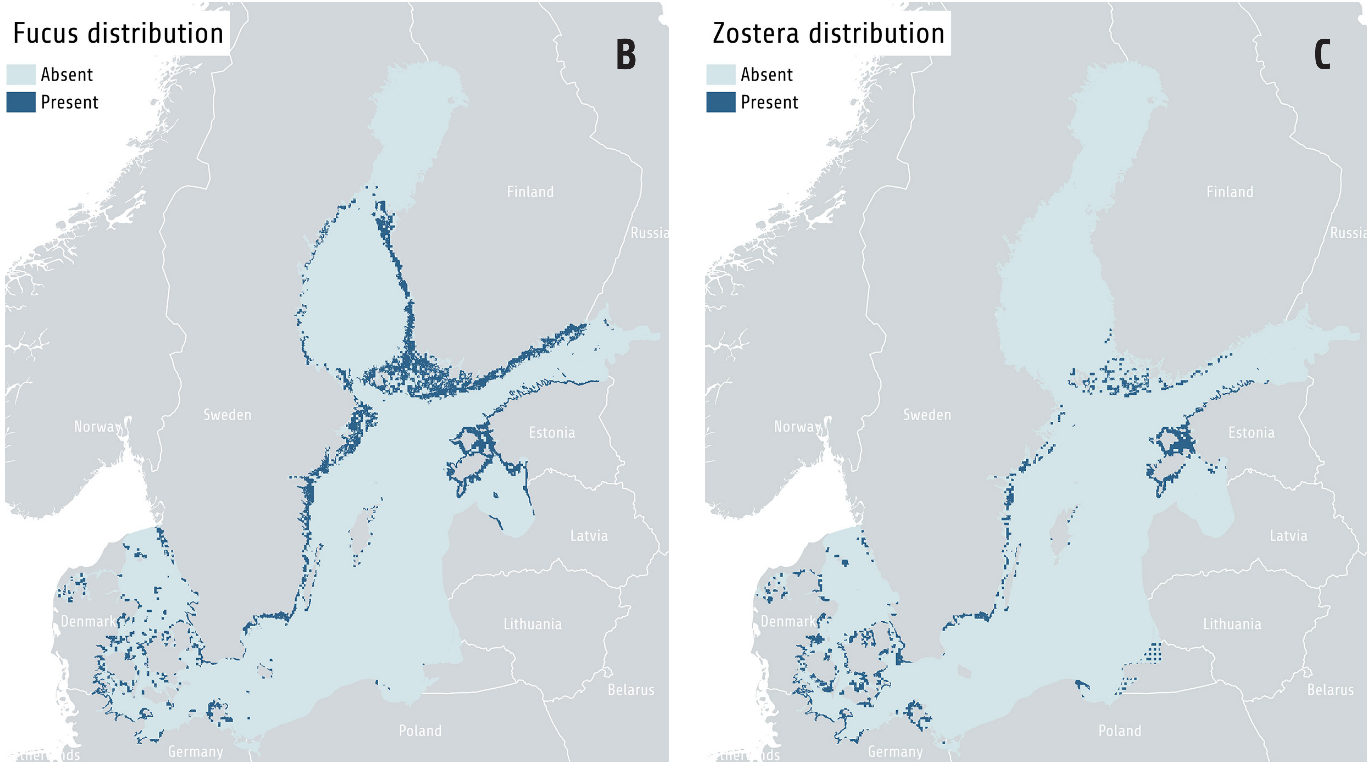

Figure 3.7. (Continued).Distribution of a) Potamogeton spp, an important freshwater macrophyte in the Baltic Sea, b) Fucus spp, a brown macroalga, and c) the marine macrophyte Zostera marina (eelgrass). Source: HELCOM 2023a.

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.

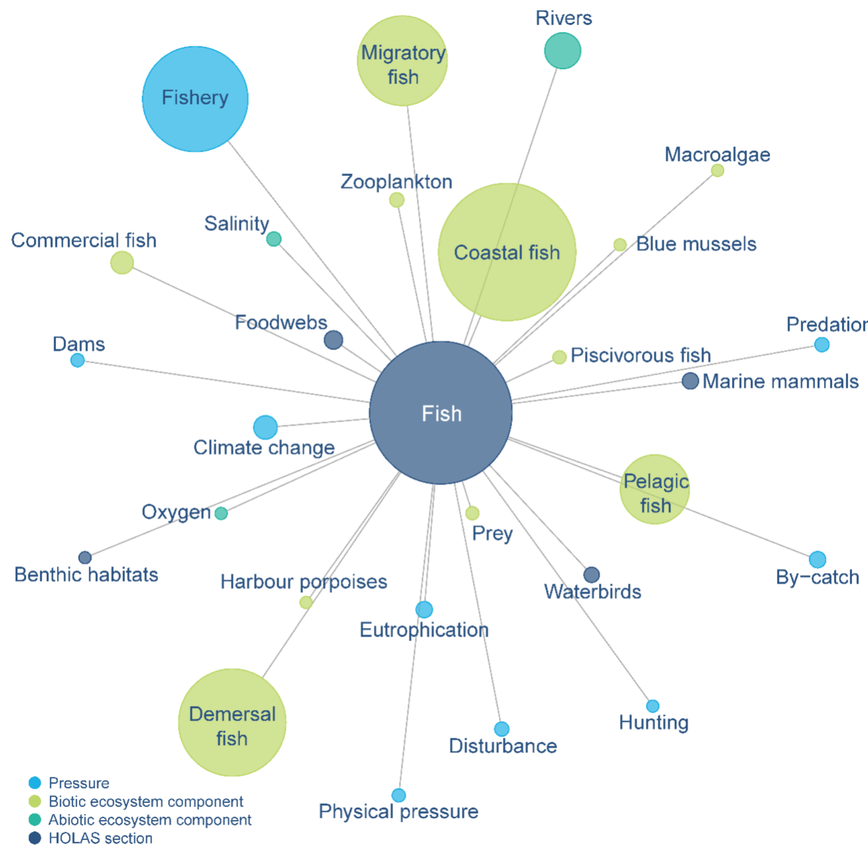

Figure 3.8. An overview of the ecosystem components and pressures descriptively linked to the status of fish in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages 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.

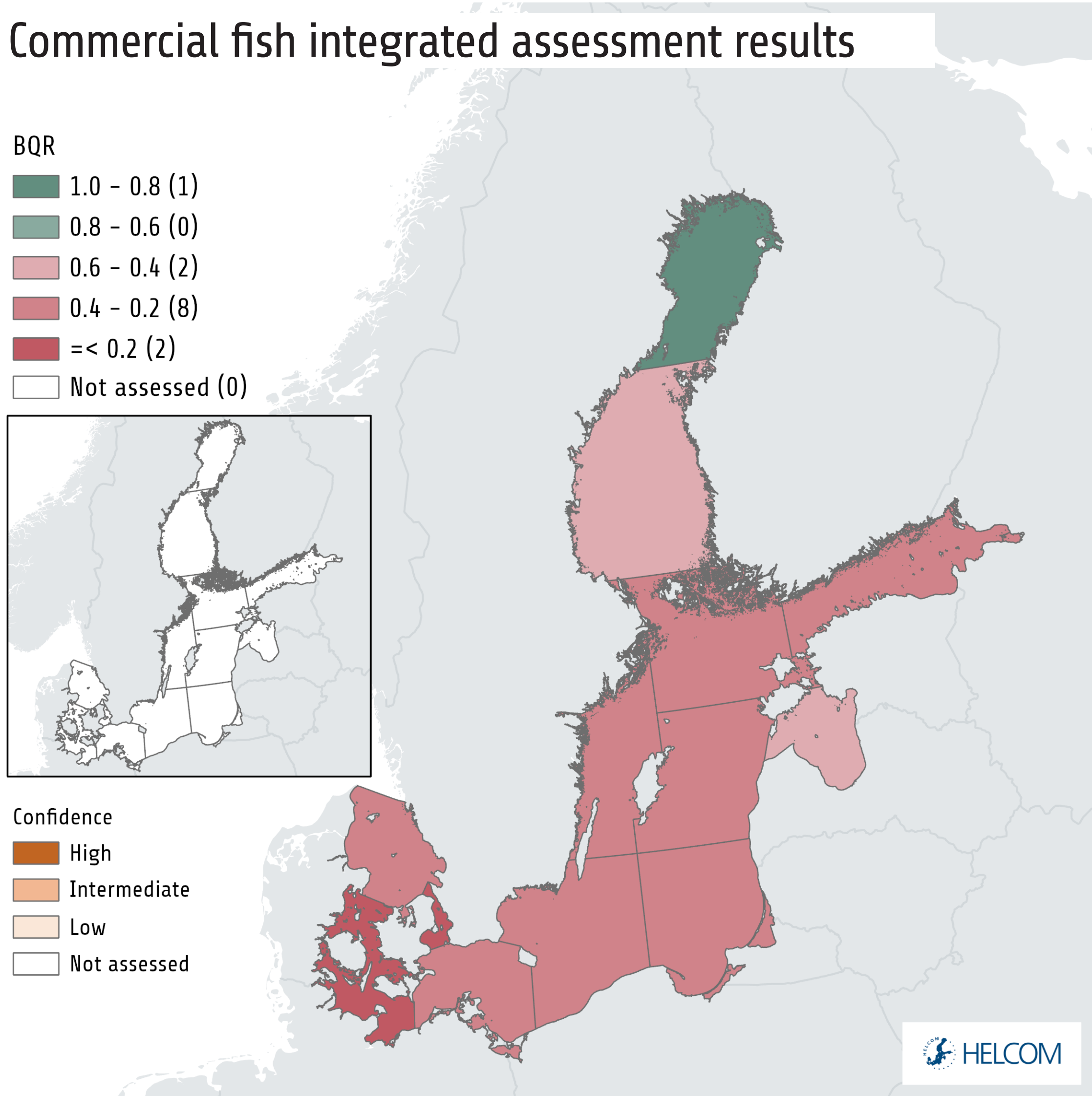

Figure 3.9a. Summary of results from the integrated assessment of commercial fish. Biological quality ratios (BQR) and Ecological Quality Ratio (EQR) above 0.6 correspond to good status. Assessment confidence is presented in the inserted small maps. The spatial assessment units for commercial fish are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

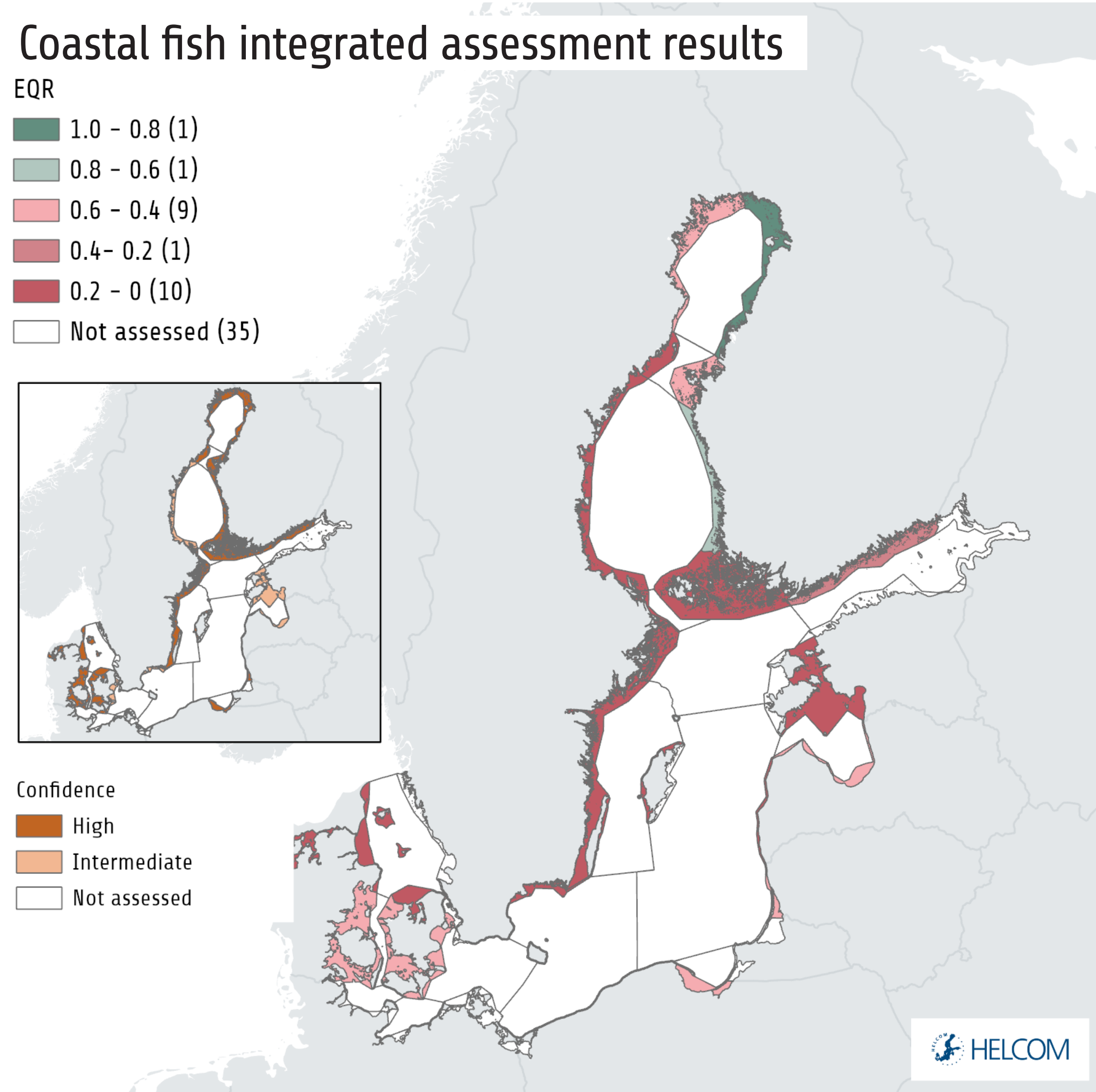

Figure 3.9b. Summary of results from the integrated assessment of coastal fish. Biological quality ratios (BQR) and Ecological Quality Ratio (EQR) above 0.6 correspond to good status. Assessment confidence is presented in the inserted small maps. Source: HELCOM 2023a.

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.

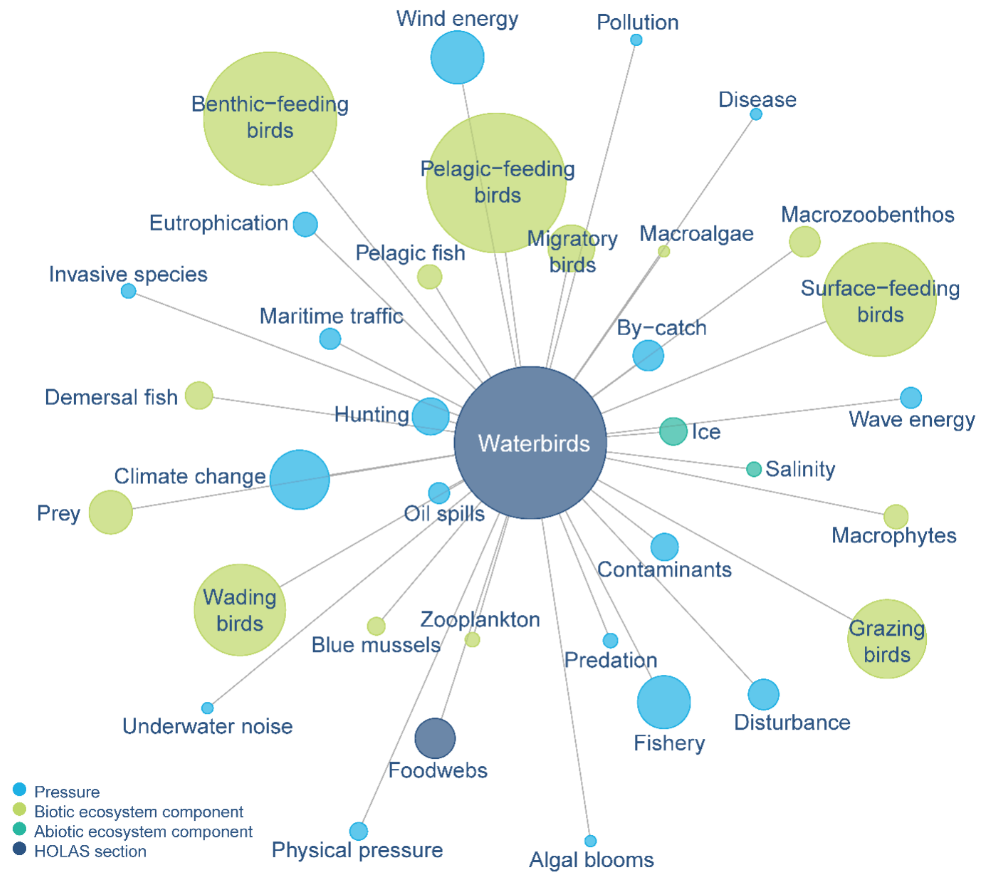

Figure 3.10. An overview of the ecosystem components and pressures descriptively linked to the status of waterbirds in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages 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.

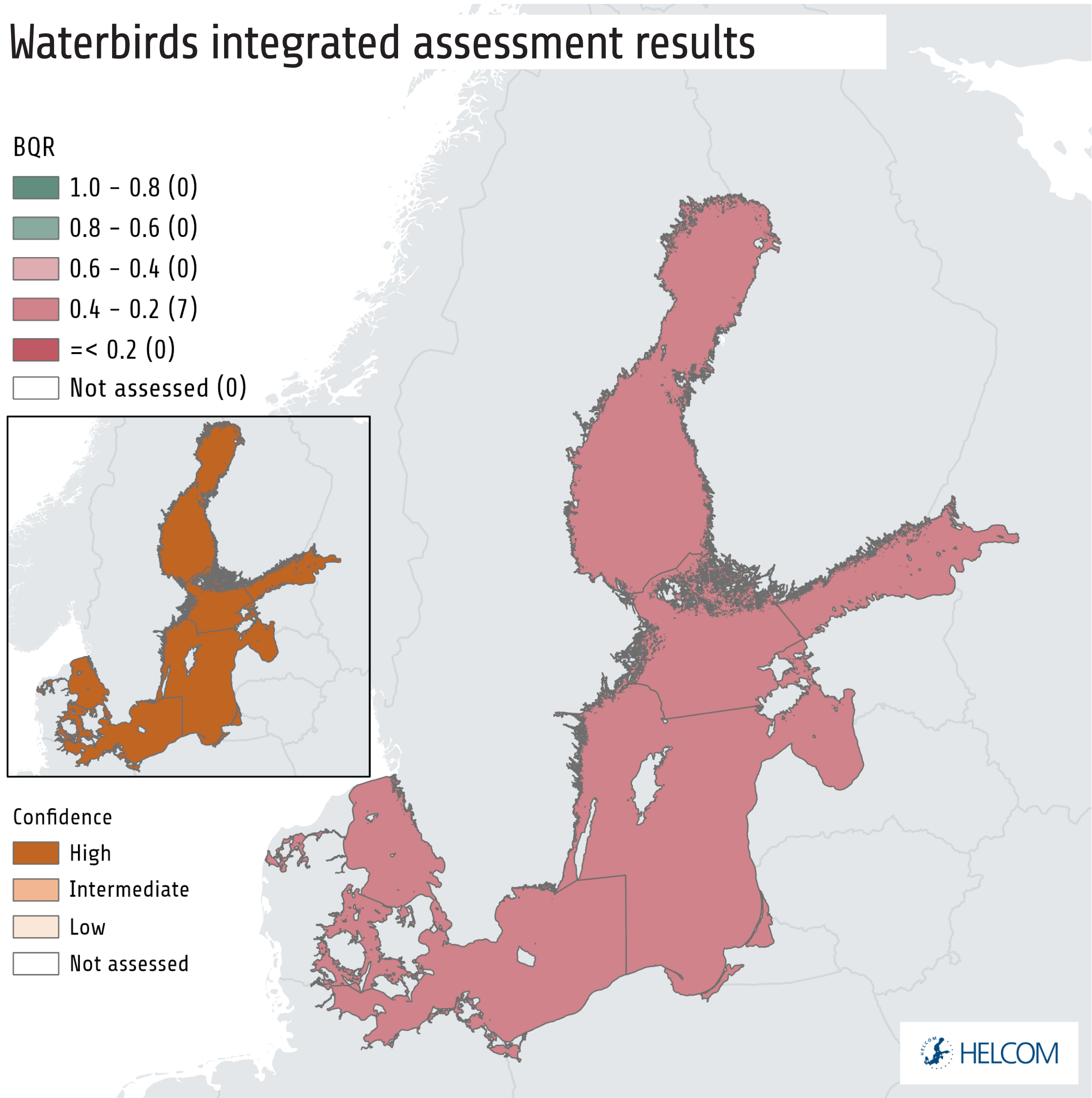

Figure 3.11. Summary of reults from the integrated assessment of waterbirds. Biological quality ratios (BQR) above 0.6 correspond to good status. Assessment confidence is presented in the map inserted to the left. Source: HELCOM 2023a.

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.

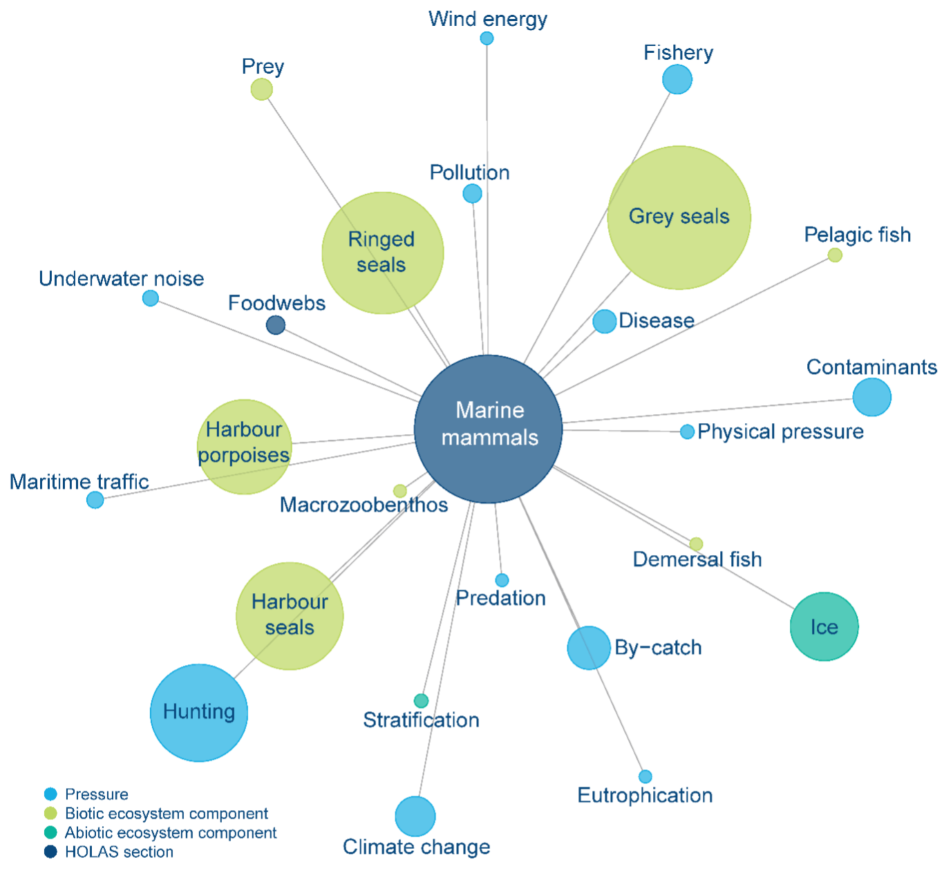

Figure 3.12. An overview of the ecosystem components and pressures descriptively linked to the status of marine mammals in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and 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.

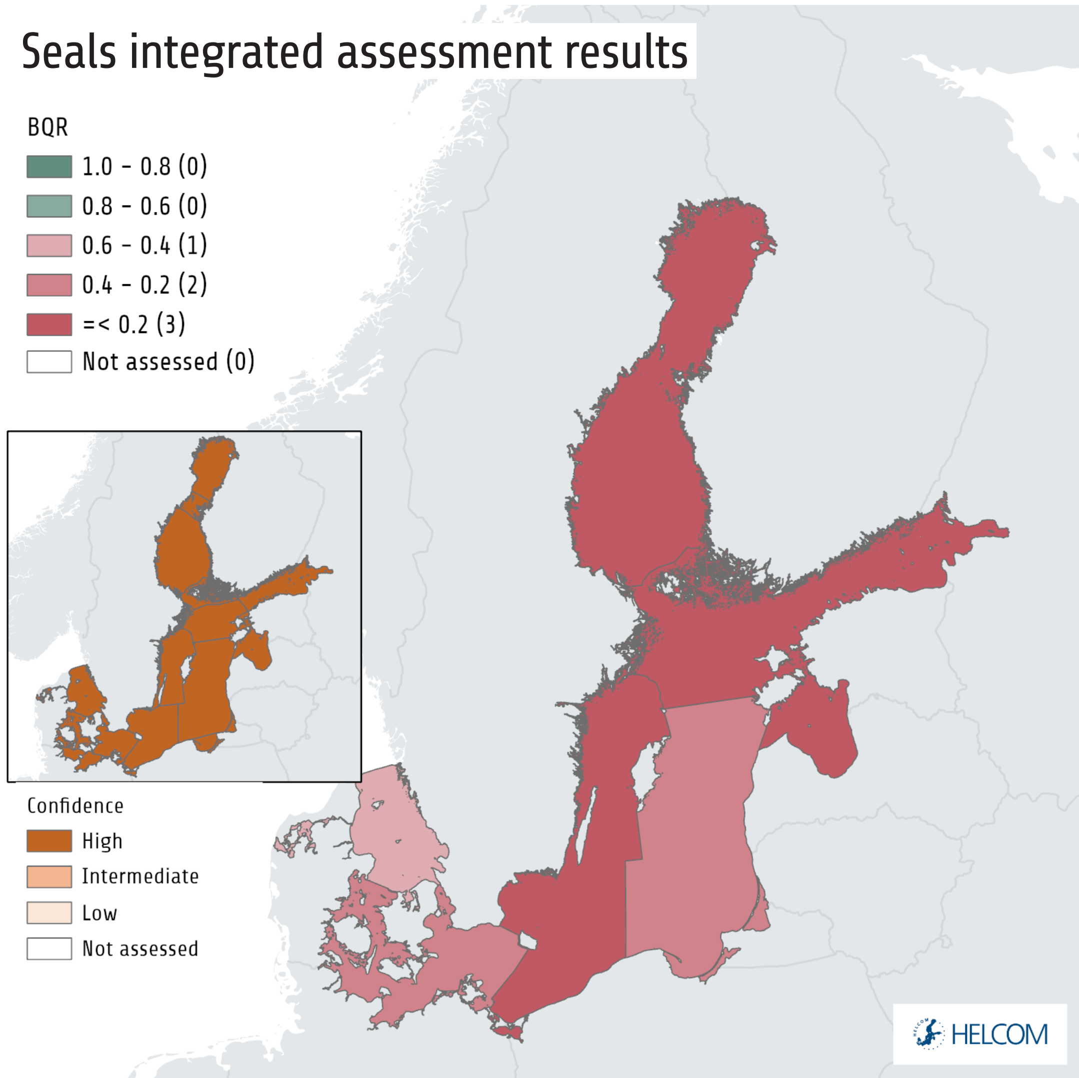

Figure 3.13. Summary of assessment results from the assessment of marine mammals (seals).. Biological quality ratios (BQR) above 0.6 correspond to good status. Assessment confidence is presented in the map inserted on the left-hand side. Source: HELCOM 2023a.

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).

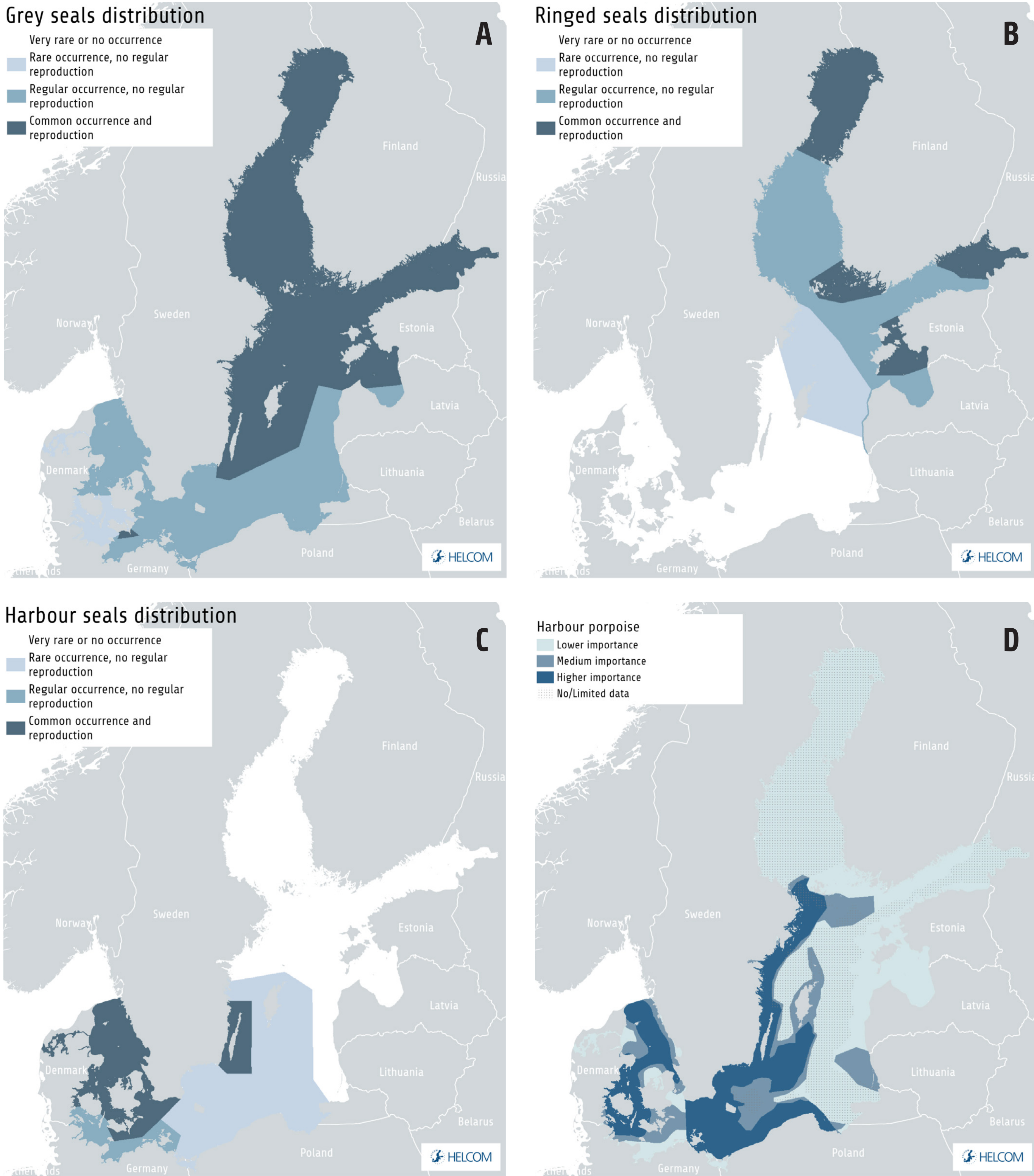

Figure 3.15. Distributional range of A) grey seals, B) ringed seals, C) harbour seals (based on expert input), D) Harbour porpoise. Source: HELCOM 2023e.

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.

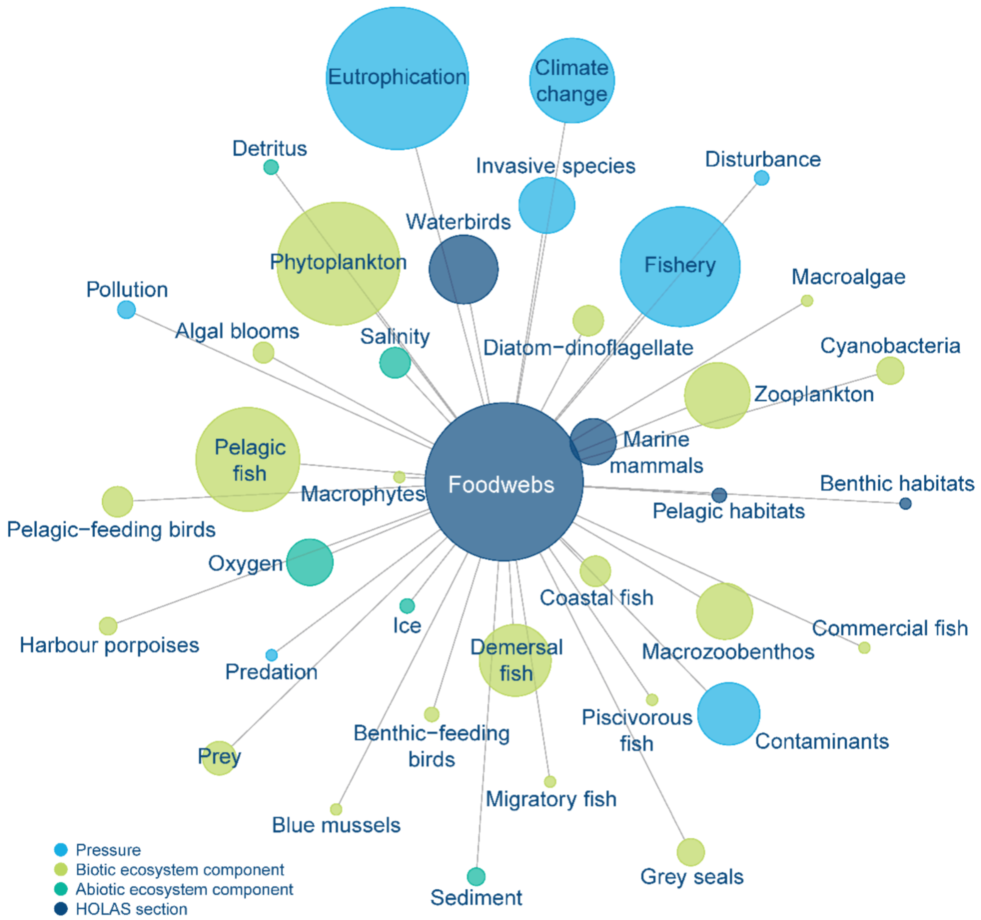

Figure 3.16. An overview of the ecosystem components and pressures descriptively linked to the status of food webs in HOLAS 3. The figure reflects aspects highlighted in the chapter on this topic in the HOLAS 3 thematic assessment report on biodiversity (HELCOM 2023a), based on the terms used and interlinkages 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).

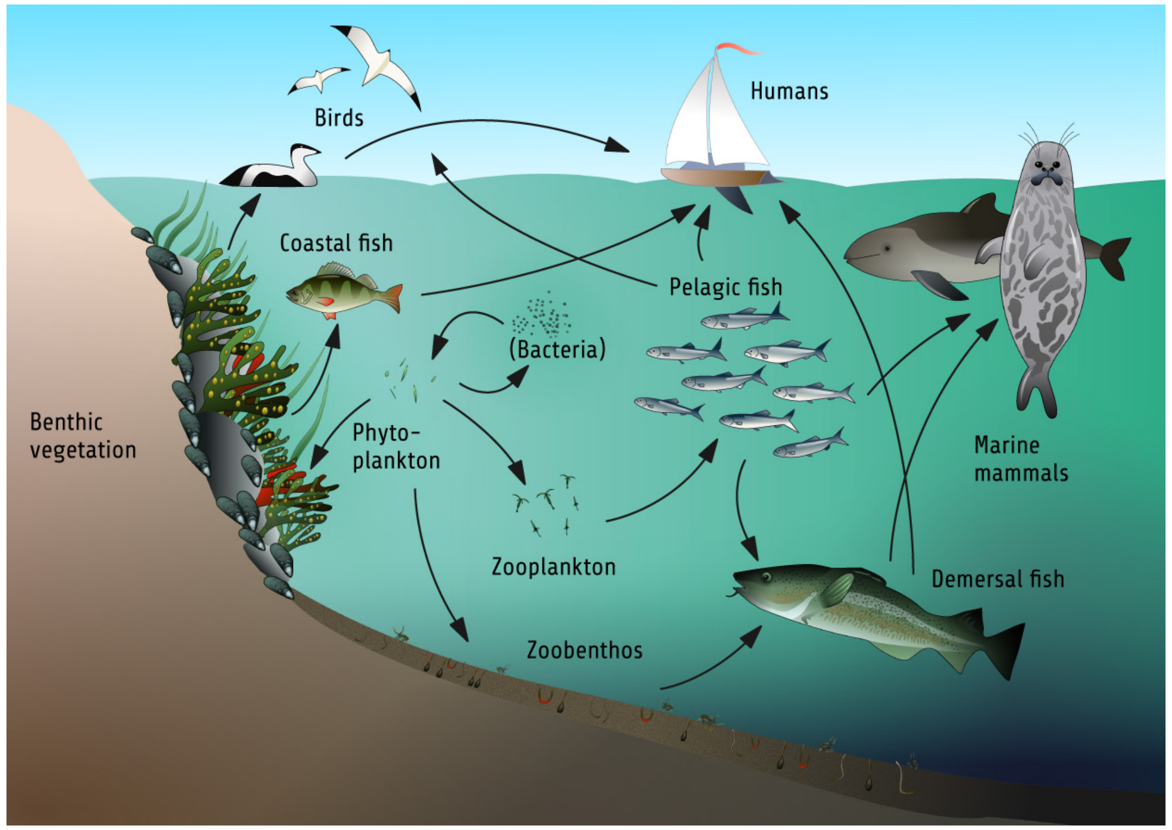

Figure 3.17. The Baltic Sea food web includes primary producers, which make energy and nutrients available to the ecosystem, primary consumers, which feed on the primary producers, and different levels of predators, which feed on lower trophic levels. It also includes species that use dead organic material 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.
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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.