State of the Baltic Sea

Background Paper

Havs- och vattenmyndighetens rapport 2013:4
Preface

BalticSTERN (Systems Tools and Ecological-economic evaluation – a Research Network) is an international research network with partners in all countries around the Baltic Sea. The research focuses on costs and benefits of mitigating eutrophication and meeting environmental targets of the HELCOM Baltic Sea Action Plan. Case studies regarding fisheries management, oil spills and invasive species have also been made, as have long-term scenarios regarding the development of the Baltic Sea ecosystem.

The BalticSTERN Secretariat at the Stockholm Resilience Centre has the task to coordinate the network, communicate the results and to write a final report targeted at Governments, Parliaments and other decision makers. This report should also discuss the need for policy instruments and could be based also on results from other available and relevant research.

The final report “The Baltic Sea – Our Common Treasure. Economics of Saving the Sea” was published in March 2013. This Background Paper State of the Baltic Sea is one of eight Background Papers, where methods and results from BalticSTERN research are described more in detail. In some of the papers the BalticSTERN case studies are discussed in a wider perspective based on other relevant research.
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**Reading instructions:** The main purpose of this Background Paper is to describe the Baltic Sea ecosystem and its state. It gives a background to the special characteristics of the Sea and describes the environmental state and the major problems threatening the ecosystem, as well as how they affect the Baltic Sea's ability to provide ecosystem goods and services.
1. Introduction

The Baltic Sea is a complex ecosystem with a multitude of physical, chemical and biological interactions functioning on various temporal and spatial scales. The Baltic Sea is under severe stress as a result of the combination of a large human population in the catchment area, the environmental effects of anthropogenic activities and its special geographical, climatological and oceanographical characteristics. The environmental state is thus influenced by both natural and anthropogenic factors.

The largest environmental problems are eutrophication caused by increasing nutrient loads, overfishing, hazardous substances, risk of chemical and/or oil spills, marine litter and invasive species. These environmental problems, together with current and future climate changes are jeopardizing the Baltic Sea's ability to provide ecosystem goods and services. These goods and services potentially generate benefits (Figure 1), which in turn are coupled to welfare, and thus changes in the ecosystem state can have impacts on human welfare.

Figure 1. Ecosystem services provided by the Baltic Sea. (Illustration: J.Lokrantz/Azote)
2. The Baltic Sea ecosystem

2.1 Ecosystem description

Covering a surface area of 415,000 km², the Baltic Sea is the largest brackish water ecosystems in the world. It is composed of seven sub-basins, with varying surface areas, volume, depth and salinity (Figure 2). They are all connected by straits, through which water flows driven by physical processes. The Sea is however nontidal. The Baltic Sea is characterized by large areas that are less than 25 meter deep, interspersed by a number of deeper basins, with a maximum depth of 459 meter at the Landsort deep. At an average depth of just 52 meters, the Baltic Sea is very shallow, with a volume of only 21,760 km².

Compared to the small water volume, the catchment area is extensive, covering 1.72 million km² and including 14 countries, with a total population of approximately 90 million. Young in geological terms, the Baltic Sea was formed after the last glaciation, approximately 10,000 years ago. It was established as a brackish ecosystem about 6500–10,000 years before present (BP), stabilizing to its present level of salinity approximately 2000 years BP. (E.g. Voipio, 1981; Furman et al., 2004; Zillén et al., 2008, HELCOM, 2010a)
Compared to the average salinity of world oceans (35 practical salinity units, psu), the salinity of the Baltic Sea is low; ranging between 1–20 psu, with an average of 7 psu. Bottom waters are slightly more saline compared to surface waters. Salinity distribution forms a gradient, with very low levels in the Bothnian Bay and in the eastern Gulf of Finland, increasing towards the southern parts of the Baltic Sea and the Danish straits (Figure 3). Water exchange with the North Sea and Atlantic Ocean is very limited by the narrow and shallow Danish Straits. The deep layers of the Baltic Sea are aerated by sporadic intrusions of highly saline and oxygen-rich water originating from the Kattegat. These strong inflows were more frequent prior to the mid 1970s, but in the last decades, only a few major events of inflows have occurred, leading to serious stagnation in the central Baltic deep. Freshwater enters the Baltic Sea from numerous rivers, land runoff and precipitation. In sum there is a positive water balance, meaning that river runoff and precipitation exceed evaporation. (E.g. Voipio, 1981; HELCOM, 2010a)

Because of the restricted water exchange with the ocean and relatively small freshwater input, the water residence time characterizing its renewal is rather long, 25 – 40 years. In addition, the water column in the open Baltic is permanently stratified, with a top layer of brackish water that is separated from the deeper layer of saline water. This so-called halocline limits the transport of oxygen from surface to bottom waters. The depth of this layer varies, but in the Baltic Proper and Gulf of Finland, it is usually formed at a depth of 50–80 meters. (E.g. Larsson et al., 1985; Kautsky & Kautsky, 2000; Furman et al., 2004; HELCOM, 2007, 2010a)

**Marine habitats**

The coastal and offshore zone of the Baltic Sea is in principal comprised of three types of plant and animal habitats: hard and soft bottom and the pelagic community (i.e. open water). Conditions for life in these habitats are shaped by many physical, chemical and geological factors.

Hard bottom communities close to the coast, mainly composed of rocky substratum, are the most species-rich habitats in the Baltic Sea. They are mainly found in the Northern and North-Eastern Baltic (Bothnia, Swedish coast and Gulf of Finland). Typically they are comprised of an upper zone of macroalgae inhabited by a rich fauna. The most common macroalgae is the keystone species' bladder wrack (*Fucus vesiculosus*), but filamentous algae such as *Cladophora glomerata* also thrive, especially in nutrient-rich waters. Fauna include mussels (e.g. blue mussel *Mytilus edulis*), snails, crustaceans and fish such as herring (*Clupea harangus*), sprat (*Sprattus sprattus*), gobies (*Gobius ssp.*) and fresh-water species like common perch (*Perca fluviatilis*). The blue mussel is another keystone species, it dominates the substrate with mussel belts normally starting at a few meters depth and often extending to 30 meters. In the Baltic Proper *Mytilus* represent more than 90 per cent of the

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1 A keystone species is a species that, relative to its abundance, has a disproportionately large effect on its environment. It plays a critical role in maintaining the organization and diversity of its ecological community, and changes in its abundance and distribution thereby affects many other organisms in the food web.
total animal biomass. Blue mussels are not only an important source of food for various animals, including birds such as eider (*Somateria mollissima*), but also filter the water and thus perform important ecosystem services through their water filtrating properties. (Jansson & Kautsky, 1977; Kautsky, 1988, 1995; Furman et al., 2004)

Soft bottoms are the most dominant bottom type, consisting of muddy and sandy sediment. Covering most of the Baltic Sea seafloor, soft bottoms are vulnerable to the mechanical stress of wind and wave action. Soft bottom communities are typically dominated by the Baltic clam (*Macoma balthica*), but also include reeds (e.g. *Phragmites australis*), muskgrass algae (*Chara ssp.*), and sea grass beds, although faunal biomass typically declines with increasing softness of substrate and with depth. In the Baltic the eelgrass (*Zostera marina*) forms dense beds in shallow protected bays, but is not found north of the Baltic Proper. Sea grass beds are important for sediment deposition, substrate stabilization, as well as through forming habitat for a diversity of fauna, including birds and fish (e.g. cod, *Gadus morhua*), thus providing valuable ecosystem services. (Jansson, 1980; Voipio, 1981; Kautsky, 1988; HELCOM, 2010a)

The pelagic community, that is species living in the open water, contains relatively few species, but forms habitat for the main fish species of the Baltic Sea. The primary producers are different phytoplankton species, which provide food for zooplankton such as copepods (e.g. *Acartia sp*, *Pseudocalanus sp*, *Temora sp*), cladocerans and rotifers. These zooplankton in turn provide food for marine invertebrates and fish species, such as herring and sprat, which in turn are important food sources for larger predatory fish, seabirds and seals. (Möllmann et al., 2009; HELCOM, 2010a)

**Sensitive area**

Due to the slow renewal of water masses, in combination with strong stratification, small water volume and large riverine inputs of different substances, the Baltic Sea is a highly sensitive area. Direct and indirect effects of high nutrient loads, together with hazardous substances remain in the Baltic Sea for many years, exacerbating the problems already faced by its sensitive species. As winters are cold and periods of ice cover long, the physical, chemical and biological decomposition of hazardous substances are slow. The hazardous substances thus remain in the Baltic Sea environment for many years, and therefore there is a possibility that the substances concentrate (i.e. bioaccumulate) in the fauna. (HELCOM, 2010a, b)

Other factors adding to the sensitivity are the relatively low species diversity of Baltic Sea food webs. Low diversity (or simplicity) refers to few ecological interactions in the food web due to low number of species, compared to most other marine ecosystems found worldwide. The simple Baltic Sea food webs are thus more vulnerable to environmental changes. Changes at one end of the chain, such as through the effects of hazardous substances or overfishing affecting top predators, may easily spread through the entire chain (so called cascading effects) and may have unpredictable effects on the other components of the food web and ecosystem. (E.g. Österblom et al.,
Changes in salinity can also have profound effects on organisms that meet their physiological limits in the Baltic Sea. Thus such changes make the Baltic Sea ecosystem and biodiversity sensitive to variations in the environmental conditions, a fact that will be further explained in the sections on overfishing and regime shifts. (HELCOM, 2009, 2010a)

2.2 Biodiversity

Biodiversity (short for biological diversity) is commonly used to describe the number, variety and variability of living organisms, and biodiversity commonly includes genetic diversity, species diversity and ecosystem diversity. Species composition in the brackish Baltic Sea includes species with both freshwater (limnic) and marine origin. The low salinity constitutes a stressful environment, affecting species number and distribution, and the Baltic Sea has generally been thought to have a low biodiversity compared to other oceans. The primary reason being that few species are originally adapted to brackish conditions, but also due to the Sea’s recent geological origin and harsh climate. Species of marine origin invaded the Baltic Sea from the Atlantic approximately 4–8000 years ago (Pereyra et al., 2009, HELCOM 2010a). The sub basins differ regarding species diversity, composition and biomass. Both limnic and marine species meet their physiological limits in the Baltic, manifested in the limited body size and slower growth of many species with marine origin. (HELCOM 2009, 2010a)

In general, Baltic Sea biodiversity have been argued to follow the salinity gradient, as it is the main environmental factor defining structural and functional characteristics of aquatic biota. In the Baltic, biodiversity has been shown to increase towards the south, with a 20–40 times higher biomass of both fauna and flora in the Baltic Proper compared to that of the Bothnian Bay (Figure 3). (E.g. Jansson & Kautsky, 1977; de Jong, 1974) However, recent research (Ojaveer et al., 2010; Telesh et al., 2011) challenges the viewpoint of the Baltic Sea as an ocean with low biodiversity, showing that not only does the Sea hosts some 6000 species1, but furthermore that phyto- and zooplankton in the Baltic exhibit an unexpected high diversity (>4000 taxa), not least in the Gulf of Finland where over 1500 of the 1700 known Baltic species of phytoplankton are found. The diversity of bottom dwelling animals and algae are still comparably low, but pelagic species diversity (dominated by protists) is strikingly high. In addition, these diversity peaks in the horohalinicum, further challenging Remane’s concept. (Ojaveer et al., 2010; Telesh et al., 2011)

Only a handful of species dominate the ecosystem in biomass and abundance, with the consequence that a single or a few species essentially uphold important ecosystem functions. (HELCOM, 2010a; Ojaveer et al., 2010)

1 These include approximately 1,700 species of phytoplankton (e.g. diatoms, dinoflagellates, cyanobacteria, chlorophytes), 440 phytothens (i.e. macroalgae), 1,200 zooplankton (e.g. ciliates and rotifers), 570 meiozoobenthos (e.g. copepods), 1,475 macrozoobenthos (e.g. mollusks and crustacean), 380 vertebrate parasites, about 200 fish, some 80 species of birds, three species of seals and the harbor porpoise, the only cetacean species reproducing in the Baltic Sea. The majority of these are however unknown to the public, and few can be seen by the human eye.
addition to the blue mussel and bladderwrack, additional examples of Baltic key
stone species are the macrophyte eelgrass and Fucus radicans. F. radicans, rela
ted to the bladderwrack Fucus vesiculosus, is a recently described species of brown
macroalga, which has formed in in the Baltic Sea during the last 400 years through rapid
speciation, and is the only known endemic phytobenthic species (Pereyra et al., 2009;
Johannesson, 2011). Despite the relatively low number of species, the Baltic Sea is as
productive as the adjacent North Sea that has about ten times more species (Elmgren &
Hill, 1997).

There are several aspects of diversity, including functional diversity and genetic
diversity. Different species differ in attributes, which affect different ecosystem
properties. A functional group can be explained as a group of species characterized
by common traits or roles in the ecosystem, applying to functions such as feeding behavior,
or capacity to conduct certain biogeochemical processes. It could also apply to occupa
tions of a specific niche, where one species for example performs optimally in the tem
perature-interval X–Y degrees, salinity x–y psu, is resistant to climate variability and so
on, while another might have a different optimum, and furthermore be very
sensitive to changes. Therefore, a minor change in species biomass and/or

Figure 3. Distribution limits of some marine (dark blue) and freshwater (light blue) species due to salinity, as well as bottom salinity. (Based on Fuhrman et al. 2004 and HELCOM 2010a)
occurrence may influence the ecosystem function, with the loss of a single species potentially having a higher impact compared to areas with high functional diversity. (HELCOM, 2009; Diaz & Cabido, 2001; Worm et al., 2006)

Due to its permanent low salinity and geographic semi-isolation from the fully marine Atlantic, the Baltic Sea marine habitat is ecologically marginal. Research show that, possibly as a consequence of isolation, bottlenecks and selection on adaptive traits, Baltic populations of dominant marine species are locally adapted, have lost genetic variation and are relatively isolated. Some populations have additionally evolved high degrees of clonality. (Pereyra et al., 2009; Johannesson et al., 2006, 2011) Genetic variations within a species are of importance for an individual species capacity to establish, recover and adapt to new conditions, such as those after a disturbance. Due to the lower genetic diversity of Baltic Sea populations, natural selection and thus adaptation through evolutionary change, is limited, consequently rendering this marginal ecosystem vulnerable to environmental stress. (Johannesson, 2011; Johannesson et al., 2006) The Millennium Ecosystem Assessment (2005) pointed out that environmental changes could lead to extinction of species or species communities. Species having one or more of the following features: limited climatic ranges, restricted habitat requirements, reduced mobility, low genetic diversity, or isolated and/or small populations are vulnerable and more prone to these extinctions. Many Baltic Sea species fulfill these criteria, thus falling into the category of vulnerable species. By housing unique genes, genotypes and populations, Baltic Sea species at the same time constitute important genetic resources. The evolution of F. radicans shows that, although Baltic species are vulnerable, the Baltic Sea has, possibly due to its environmental conditions where selection for adaptation is strong, accommodated rapid speciation (Pereyra et al., 2009). According to the Swedish Environmental Protection Agency (SEPA, 2009) 88 per cent of the biotopes found in the Baltic Sea are listed as endangered, rendering the Baltic Sea as one of the most threatened marine ecosystems worldwide.

**Threats to Baltic Sea biodiversity**

There are numerous disturbances threatening Baltic Sea biodiversity, as it is affected by essentially all human activities at sea, coastline and in the catchment area; for example by fisheries, maritime activities, eutrophication, hazardous substances and climate change. Important to note is that biodiversity is affected by the multitude of these pressures, and by the cumulative and synergistic impact they have. The ecological interactions of the relatively simple food webs render them vulnerable to external pressures. (HELCOM, 2009, 2010a) Some of these pressures are presented in coming sections of this Background Paper. In order to maintain biodiversity, and thus the ecosystem services it provides, it is important to protect not only individual plants and animals, but also their fundamental conditions for growth and evolution.
Linked to climate-driven variations in hydrography, the abundance and distribution of pelagic and littoral species and communities in the Baltic Sea has changed during the past century. These types of changes have also occurred during the last decades due to increased anthropogenic pressures. Classifications of the biodiversity status have shown that large areas have an unacceptable biodiversity status, and that a total of 59 species are considered threatened and/or declining in such a way that their future sustainability depends on protective measures. These include all marine mammals, and many species of fish, as well as key species such as bladderwrack and eelgrass. In recent history there has also been a few cases of extinction, the best-known example being the Atlantic surgeon (*Acipenser oxyrinchus*). (HELCOM, 2009, 2010a,)

In recent years there has been some alarming reports regarding the status of wintering waterbirds. A recent study shows that since the 1990s, the total population size of 11 of 20 investigated species of Baltic waterbirds has decreased substantially. Seven of which have declined seriously; by more than 30 per cent over the last 16 years. The estimated total number of wintering waterbirds for the period 2007–2009 was 4.41 million compared to 7.44 million during 1992–1993; a reduction equivalent to 41 per cent. Naturally there are variations depending on species and habitats occupied, as well as between different parts of the Baltic Sea. Some species, e.g. herbivorous waterbirds such as mallards (also known as Wild Duck, *Anas platyrhynchos*), show a positive status. This is possible related to the general improvement of water quality as a consequence of actions to combat eutrophication. Other species, such as the common eider (*Somateria mollissima*), and the common scoter (*Melanitta nigra*) has decreased with 51 and 47 per cent respectively. The reasons for these declines are not yet fully understood, but possible reasons are decreased quality of food (mainly blue mussels) as well as shortages of vitamin B. (TemaNord, 2011)

Biodiversity plays a vital role in the functioning of the Baltic marine ecosystem, including its role in delivering valuable ecosystem goods and services, and in adding insurance when faced with future changes. Biodiversity of seafloor communities has for example been shown to be vital for healthy marine ecosystems, not least through their role in the food web, through habitat engineering and by affecting nutrient cycles and primary productivity. (Lohrer et al., 2004) A recent study, performed in the northern Baltic Sea, show that hypoxic disturbance degrades the structure and function of seafloor communities and sediment nutrient cycling (Villnäs et al., 2012). The preservation of Baltic Sea biodiversity, both at the genetic level, level of individual species and functional groups, as well as the level of habitats and ecosystems, through proper management and conservation is thus of fundamental importance for successful adaptations to our rapidly changing environments. (Johannesson & André, 2006; Johannesson et al., 2011; Millennium Ecosystem Assessment, 2005)
3. Environmental problems affecting the Baltic Sea

3.1 Eutrophication

Nutrients such as nitrogen and phosphorus are essential for primary production, and directly and indirectly result in higher food availability for all consumers. Eutrophication is defined as an increased input of nutrients causing an accelerated growth of planktonic algae and higher plant forms, thus increasing total primary production of organic matter.

The Baltic Sea drainage area is highly populated, and human activities such as agriculture, municipal sewage, industries and atmospheric deposition, in combination with nitrogen fixation, have resulted in excessive nitrogen and phosphorus loads coming from both within and outside the catchment area. Humans began to influence the coastal ecosystems of the region in prehistoric times, for example with discharge of wastewater into the Baltic Sea.

The establishment of small industries and trade, the development and intensification of agriculture and other changes in land-use, in combination with changing climate, are some factors that permitted a gradual increase in the size of the human population during the 18th and 19th centuries. For a long time, crop growing only had a moderate impact on the marine environment, but as increasing areas of land were used for cultivation, the effects of pollution began to show. The expansion of agriculture led to extensive drainage of wetlands and lakes, which together with growing use of agricultural fertilizers lead to increased transport of nutrients to the Sea. The growing population and industrialization also led to increases in wastewater discharge. Higher loads of nutrients stimulated increased production of phytoplankton and fish. These first signs of marine pollution were observed during the 19th century, but the Baltic Sea remained classified as an oligotrophic sea (i.e. nutrient poor) with clear water, oxygenated deep waters and favorable conditions for cod reproduction during the 19th century. (Wulff et al., 2007; Österblom et al., 2007)

Since the turn of the 20th century, terrestrial loads of nitrogen and phosphorus doubled and tripled, respectively, accentuated after the Second World War as a result of the introduction of artificial fertilizers (Gren et al., 2000; Savchuk et al. 2008). According to recent reconstructions, the Baltic Sea has received about 100 million tonnes of nitrogen and 4.5 million tonnes of phosphorus from the land and atmosphere since the 1850, over half of it during the past fifty years (Savchuk et al., 2012b). In result, nutrient pools in the Baltic Sea basins may have increased two- threefold, while the annual rates of important biogeochemical processes, for instance primary production of organic carbon, increased even more (Emeis et al., 2000 Savchuk et al., 2008; Gustafsson et al., 2012).

Baltic Sea eutrophication is thus the result of decades of excessive nutrients loads, and driven by human activities the process is amplified by natural factors such as slow water renewal and strong stratification. In summary, Baltic Sea eutrophication stem from point- and diffuse sources on land, reaching the Baltic Sea through waterways and leakage, as well as from atmospheric deposition.
Effects of eutrophication

Summer blooms of cyanobacteria are a natural phenomenon of the Baltic Sea, and have been recorded as early as 1885, but as the average biomass production has increased by a factor of 2.5, so has the various impacts on the ecosystem. In the 1950s the effects of eutrophication became clearly evident both close to the large cities, but also in offshore areas with blooms and a decrease in summer water transparency. As eutrophication has both ecological and social consequences, it is one of the major environmental problems in the Baltic Sea. It has resulted in a deterioration of the ecosystem, with effects including increase in filamentous algae, withdrawal of perennial fucoid algae, increased frequency of toxic algal blooms and changes in fish population (See figure 4). (Wulff et al., 2001; Larson et al., 1985; HELCOM, 2009)

Figure 4 illustrates changes in the Baltic Sea ecosystem during the 20th Century; increased algal blooms and surface accumulations of plankton has lead to murkier and less transparent waters, followed by increased sedimentation of organic material to the sea floor. Decomposition of the organic matter consumes oxygen, and if the oxygen is not replenished, e.g. through inflow of oxygen-rich water through the Danish straits, ultimately hypoxia or even anoxia (i.e. low concentrations and absence of oxygen respectively) will occur. The oxygen deficit in turn leads to changes in benthic communities; as long-living, deep-burrowing and slow-growing animals no longer survive, they are replaced by small and fast-growing species that live on the sediment surface and can tolerate low concentrations of oxygen. Larger animals such as fish are also sensitive to low oxygen concentrations and, if unable to move to more oxygenated areas, ultimately suffocate. One species severely affected is cod (Gadus morhua), as its spawning requires both high salinity and high oxygen concentrations in order for the cod fry to develop – conditions that in the last decades have been rare in the Baltic Sea. If the state of the ecosystem further deteriorates and oxygen concentrations further decrease, only bacteria and fungi can survive, and the bottom area thus turns into a so-called “dead zone”, void of higher organisms. (Kautsky, 1991; Conley et al., 2011, Savchuk et al., 2008, 2011)

Increase in biomass of phytoplankton and filamentous algae has lead to light deprivation for aquatic vegetation, such as meadows of eelgrass and perennial fucoid algae, reducing their biomass, depth and geographic distribution. As species such as eelgrass and bladder wrack provide substrate for feed, reproduction, and shelter for associated fauna, loss of submerged vegetation is likely to markedly influence the coastal Baltic ecosystem, and thereby coastal fish catches. Eutrophication has also lead to increased frequency and intensity of harmful algal blooms, the most conspicuous composed of potentially toxic cyanobacteria (blue-green algae) that cover large parts of the Baltic Proper in late summer, posing a health risk to humans and domestic animals swimming in the Baltic Sea. When the algae drift ashore they create banks of foul-smelling detritus, limiting recreational and economic use of the beaches and the Sea. (E.g. Kautsky et al., 1986, 1992; Wulff et al., 2008; HELCOM, 2010a)
**Widespread effects of eutrophication**

Eutrophied coastal seas occur worldwide, with a resulting exponential expansion of hypoxia and "dead zones" (Diaz & Rosenberg, 2008). According to HELCOM (2010a) all the open waters of the Baltic Sea, with the exclusion of the Bothnian Bay, are affected by eutrophication. Regarding coastal areas, the only areas not affected by eutrophication are restricted to the Gulf of Bothnia. Although hypoxia is a natural property of the Baltic Sea, its extent and intensity have increased with anthropogenic eutrophication. In the Baltic Proper, hypoxia covered approximately 3000 km² in 1906 and had by the 1930s increased to nearly 19 000 km² (Savchuk et al., 2008 and references therein). Prior to 1950, hypoxia was mostly confined to the spatially restricted deepest areas, but in the two decades following the 1950s, the size and extent of low oxygen regions grew. They expanded into shallower bottoms of the deep basins of the central Baltic Sea, with loss of habitat and spawning areas, elimination of benthic animals and altered food chains as a consequence. These widespread effects of eutrophication and consequent hypoxia has made the Baltic home to the world's largest "dead zone", with large areas affected by long-term hypoxia (i.e. concentrations of oxygen below 2 ml l⁻¹) (e.g. Conley et al., 2009b; Diaz & Rosenberg, 2008; Savchuk et al., 2008). Already in the 1970s, a record area of 70,000 km² (corresponding to an area larger than Lithuania) impacted by hypoxia was reported, as well as increasing occurrence of hypoxia in the coastal areas. (Conley et al., 2011, Savchuk et al., 2008, 2011)
Vicious cycle of hypoxia

During periods of hypoxia, there is not enough oxygen for mineralization of organic matter, and the process of denitrification induces a reduction of nitrate both in the sediments and water column. After the total exhaustion of oxygen, the anoxia settles in, resulting in formation of toxic hydrogen sulphide (H₂S), characterized by the foul odour of rotten eggs. In anoxic environments, phosphorus bound in the sediments is released back into the water as phosphate. This pulse of phosphorus from the sediment to overlying waters is called *internal loading* and, together with denitrification, is a part of a vicious cycle (Vahtera et al., 2007; Savchuk, 2010). With the DIN availability reduced due to denitrification, the excess of released phosphate intensifies blooms of nitrogen-fixing cyanobacteria and other algae benefitting from fixed nitrogen. When the remnants of these blooms sink and decompose, they consume oxygen, thus ultimately expanding the “dead zone” and further contributing to the negative spiral of eutrophication and hypoxia. The amounts of phosphate accumulated in the Baltic Sea, and alternating between its waters and sediments, is an order of magnitude larger than anthropogenic inputs. Therefore the magnitude of plankton blooms is not directly determined by the magnitude of the external loads, but depend also on internal loading (Conley et al., 2009; Savchuk, 2010). The ability to combat and quickly reverse eutrophication is further compromised by the cyanobacterial nitrogen fixation, which to a great degree compensates for nitrogen removal due to both natural denitrification and deliberate nitrogen land load reductions. In addition, a long-term decrease in silicate concentrations is apparent in most parts of the Baltic. Silicate has been shown to limit growth of diatoms in the Gulf of Riga in spring, thus changing the structure of the phytoplankton community rather than limiting the total production. (ICES, 2008; HELCOM 2010a)

3.2 Hazardous substances

Compared to eutrophication, which has a long history of research, information is scarcer on hazardous substances and their effect on the Baltic Sea environment. During the last decades, this area has been identified as important and thus further researched. Presently one of the four segments targeted by the HELCOM BSAP is hazardous substances, with a zero-emission target for all hazardous substances in the whole Baltic Sea catchment by 2021. (HELCOM, 2010a)

Hazardous substances are substances that cause adverse effects on the ecosystem, and include both natural and synthetic compounds. Examples are persistent organic pollutants (POPs), such as PCB, DDT and dioxins, which can be toxic even at low concentrations. Heavy metals such as mercury, lead, and cadmium are generally toxic at higher concentrations. Pollution through hazardous substances constitutes a serious threat to the Baltic Sea environment and contamination by the above-mentioned substances has led to detrimental effects on biodiversity. Some of these substances harm the flora and fauna by affecting the immune and hormone systems, thus impairing the general health and reproduction status. Due to bioaccumulating properties they magnify through the food chain to higher species at higher trophic
levels, and pose a threat also for humans who consume fish caught in the Baltic Sea. The long residence times of hazardous substances, in combination with the introduction of new compounds, pose a grave threat for the state of the future Baltic and health of future generations. (Bignert et al., 1998; HELCOM, 2010a, b, c)

Sources of hazardous substances
Since the late 19th century, when industrialization in the Baltic Sea region began, the Baltic Sea has been exposed to an extensive use of chemicals. Pollution through a range of hazardous substances has continued, and stem from point sources, land-based diffuse sources and atmospheric deposition. These categories include sources from industry, agriculture with its use of pesticides and pharmaceuticals, sludge, marine dump sites and waste deposition in landfills, a range of household consumer products including pharmaceuticals which might be discharged from waste water treatment plants, emissions from traffic, shipping, energy production, incineration of wastes, as well as emissions from buildings and construction materials. In addition, chemical munitions and warfare agents have been found throughout the Baltic Sea as a remnant of World War II (WWII). (HELCOM 1994, 2010a, b)

As emissions can be transported via the atmosphere over long distances, it is important to recognize that although they are deposited over the Baltic Sea and its catchment area, a large fraction originate from sources outside the Baltic Sea region. This is true not only for heavy metals, but also for POPs such as dioxins, which are formed as by-products or impurities of several different industrial processes, as well as from most combustion processes. It is estimated that 60 per cent of cadmium, 84 per cent of lead and 79 per cent of mercury originate from distant sources (mainly the UK, France, Belgium and the Czech Republic). (HELCOM, 2010b, c)

Pollution by DDT, PCB and heavy metals are well-known examples of Baltic Sea contaminants, not least because their negative effects on species such as eagles, seals and guillemots. In the example of the white-tailed eagle (Haliaeetus albicilla), reproduction was reduced by 80 per cent in the 1970s due to impaired reproductive ability as a result of high concentrations of DDTs and PCBs. The population was reduced to one-fifth of pre-1950 levels. In the 1980’s, as a result of increased awareness of their detrimental effects, several POPs including DDT were banned in industrialized countries. This led to improvements in the health of Baltic Sea wildlife, leading to recovery of some top-predators including seals and eagle populations. The eagles reached pre-1950 levels in the mid-1990s and populations have shown increases by an average of 75 per cent annually between 1990–2010. (Helander, 2003; Herrmann et al., 2011, HELCOM 2010b)

Presently, contaminants such as polyaromatic hydrocarbons (PAHs), dioxins, tributyltin (TBT), brominated flame retardants (PBDEs), perfluorinated compounds (e.g. perflourooctane sulfonate, PFOS) and radioactive compounds are also released into and detected in the Baltic Sea. Despite enhanced management and technology, which has led to improvements in the Baltic Sea regarding the status of pollution during the last decades, the
Baltic Sea area is still highly contaminated by hazardous substances. Only a few coastal sites and western Kattegat are presently undisturbed by hazardous substances. Concentrations of heavy metals in the Baltic Sea have been shown to be 20 times higher compared to the North Atlantic. These high levels stem from the fact that the hazardous substances are resistant to natural breakdown processes, making them extremely stable and long-lived. In combination with bioaccumulation in the tissues of animals and humans, hazardous substances constitute a large environmental problem. Levels of dioxins are so high that several fish species (e.g. herring and salmon) exceed the limits determined by the European Union for safe human consumption. (HELCOM, 2010a, b)

After WWII large quantities of chemical munitions and warfare agents were dumped in the Baltic Sea; at least 50 000 tonnes of chemical munitions containing some 13 000 tonnes of warfare agents have been found, mainly southeast of Gotland, east of Bornholm and south of Little Belt (HELCOM, 1994; MERCW, 2005; Fabisial & Olejnik, 2012) The munitions dumped include artillery ammunition, grenades, aerial bombs and barrels with chemical warfare agents (CWA), which are gaseous, liquid or solid substances for anti-personnel use (such as e.g. mustard gas, nerve- and suffocating agents). There is however evidence that CWA is present in many other places due to wild dumping and displacement by sea currents and fishery activities, as well as continued dumping during the Cold War. Some of the material are buried deep in the bottom and remain intact, while some munitions and canisters are corroded, thus releasing CWA to the water. Munitions are regularly netted by Baltic Sea fishermen, leading to both displacement and acute risks; with roughly 700 bombs caught in fishermen nets during the past decades. (HELCOM, 1994, 2012; MERCW, 2005) Almost all warfare agents are broken down at varying rates into less toxic, water-soluble substances. Although knowledge of the ecological effects of CWA to the marine environment is limited, recent studies have shown elevated arsenic concentrations in dumpsites and significantly higher frequencies of histological lesions (i.e. abnormalities in the tissues) in cod and blue mussels, showing that CWA affect Baltic Sea biota and may potentially be carcinogenic. (Sanderson et al., 2009) It is still unclear how large the risks are and further analysis is needed to assess human health risks from eating fish caught in and around dumpsites.

3.3 Shipping and oil spills

The Baltic Sea is one of the most heavily trafficked seas in the world as a result of intensifying international co-operation and economic growth. Today the Baltic hosts approximately 15 per cent of the world's total maritime transports, with around 2000 ships (mainly cargo ships) at Sea at any one time. A steady increase during the last decades is expected to continue, with both larger numbers and sizes of ships, and shipping traffic is expected to double in the next 20 years. 20 per cent of ships are tankers, carrying as much as 166 million tonnes of oil. (HELCOM, 2010a, d) Alongside heavy emissions, leading to atmospheric deposition and thereby adding to the before mentioned problems with eutrophication and related issues, the increased risk
of accidental alien species introduction and accidents involving oil and other substances poses a serious risk to the Baltic Sea environment. Some experts consider this only second to eutrophication in terms of current issues important for the protection of the Baltic Sea. Each year, there are 120–140 shipping accidents, the majority due to groundings and collisions. Of these, some seven per cent result in some type of pollution, and each year the Baltic experience one major shipping accident resulting in an oil spill larger than 100 tonnes. Heavy shipping results in a number of additional negative effects on the marine environment, including underwater noise and the release of anti-fouling chemicals. Some of the main shipping routes in the Baltic pass through sensitive areas, where seabirds such as razorbills (Alca torda), lesser black-backed gulls (Larus fuscus) and common murre/guillermot (Uria aalge) breed and feed. (E.g. HELCOM, 2010c, d; Huhtala et al., 2009; WWF, 2011)

Oil spills can damage the environment in numerous ways, including harming wildlife. Birds and marine mammals are harmed in a number of ways; when oil coat their feathers and furs they experience problems moving and thus become easy prey, and since the oil also reduces or destroys the ability to insulate and waterproof it also leads to hypothermia, difficulties to keep buoyant and consequently risks of sinking or drowning. Additionally oil contaminates food and water, thereby affecting long- and short-term aspects of health, including reproduction and egg mortality. As oil also disguise scent, marine mammals, such as seals relying on scent to identify their pups, might not be able to identify each other, and thus oil spills can also lead to rejection, abandonment and starvation of seal pups. Oil spills can further cause reductions in phyto- and zooplankton biomass, thus reducing food availability for species in higher trophic levels, thus inducing cascading effects on the food web. (HELCOM, 2010c, d; UNEP, 2012)

It is important to keep in mind that there are no clear relationships between the amount of spilled oil and the impact on wildlife, as even smaller spills at the wrong time/season can cause much more harm in a sensitive area compared to another, or even the same area, at another time of the year. As described above, oil spills can have numerous harmful effects, affecting ecosystem services including primary production, food web dynamics, habitat and biodiversity, and thus ecosystem resilience. These services provide food and aesthetic values, which is the base for some recreational activities, as people value the mere existence of the ecosystem and species as such (see BG Paper Oil spills management). Another consideration is that the appreciation of affected waterfront properties and summerhouses will diminish as a consequence of oiled shorelines. In summary, oil spills might jeopardize a large range of benefits derived from the Sea, and thus the wellbeing of people around the Baltic.
3.4 Energy-related activities

Apart from shipping, and the closely related developments in harbors, a number of energy-related activities take place in the Baltic Sea region. Although there are currently only a few large wind farms in operation in the Baltic Sea, wind power, including offshore wind farms, is the most rapidly expanding field for energy production in and around the Baltic Sea. Although not a source of direct chemical and biological pollution, there are discussions about the environmental and aesthetical effects of wind farms, including competition for space.

Two Baltic oil platforms operate today (in Polish and Russian exclusive economical zones, respectively). In addition there are several gas pipelines being built in the Baltic Sea (e.g. Nord Stream from Russia to Germany). Although there has not been any report of significant environmental problems coupled with these activities, possible growth in oil and gas extraction activities may be a potential source of environmental concern.

3.5 Overfishing

Baltic Sea fisheries have been conducted along the Baltic coast since well before the Middle Ages, forming an essential complement to game caught by hunter-gatherers. Since the 1500s, fishing has been an important economic and social activity, and species such as cod (*Gadus morhua*), herring (*Clupea harengus*), sprat (*Sprattus sprattus*), salmon (*Salmo salar*) and sea trout (*Salmo trutta*) have been valuable catch ever since. (MacKenzie et al., 2002)

As the Baltic Sea drainage area is highly populated, humans have naturally influenced fish stocks through their fishing activities. Until the middle of the 20th century, fishing was carried out on a fairly small scale, but construction of hydroelectric power stations, reservoirs and regulation of the main Baltic watercourses negatively affected natural reproduction of migratory fish, including salmon, sea trout and eel (*Anguilla anguilla*). At the same time, technical advances in fishing methods and materials, including open sea fishery and trawling, paved the way for substantial increases in landings. Baltic Sea fisheries gradually increased, with higher numbers and sizes of trawlers, as well as developments in the handling and transportation of fish. (MacKenzie et al., 2002; SLU, 1973) According to statistics, some 850 000–990 000 tonnes of fish (all species included) were caught yearly in the Baltic between 1974–1984. Landings of cod, the most important species economically, peaked in the middle of the 1980s, reaching extremely high levels, with 344 000 – 442 000 tonnes caught per year. These extreme levels are explained by a combination of favourable hydrographical conditions (favouring successful reproduction and survival, as well as a large biological production of food), and the low predation pressure exerted by seals (as populations were reduced due to hunting and hazardous substances). The cod stocks collapsed in the 1980s (see Figure 4 and section on regime shifts), leading to economic difficulties for the fishing community and the refining industry. Recording of cod landings started in the 1950s, and saw its lowest levels in 2000 – 2007, with 63 000–105 000 tonnes yearly, far below previous landings. (MacKenzie et al., 2012; Casini et al., 2008; ICES, 2008; HELCOM, 2010c)
Today, the stocks of cod and many other fish species are small compared to 20th century levels, and some remain low and unsustainable. The stocks are negatively impacted by a combination of factors, including indirect pressures such as eutrophication, contamination from hazardous substances, oil spills, invasive species and climate change. High fishing pressure and damaging fishing practices in combination with high-levels of by-catch and illegal, unregulated and unreported fishing (referred to as IUU) exert more direct pressure, and the synergistic effects of these pressures have led to present-day overexploitation of many commercially valuable fish stocks. For some species, such as cod, the populations have even been considered outside biologically safe limits (Österblom et al., 2007; ICES, 2008). However, there are some indications that the cod stock increased in the last years due to low exploitation rates and increased recruitment (Eero et al., 2012). Another important factor that has affected commercially important fish communities is the so-called regime shift that took place in the late 1980s (see section 3.X on regime shifts). High fishing pressure by cod in combination with climate change, eutrophication and the lack of salt- and oxygen-rich water inflows from the North Sea reduced the water volume suitable for cod reproduction, led to large-scale changes in the fish community; decreases in the biomass of cod (a high trophic level, commercially high valued and favoured fish), which was replaced by a low trophic level and commercially low valued fish (sprat). (Österblom et al., 2007; Casini et al. 2008, 2009)

The realization that poor political management has exacerbated the poor status of fish stocks has led countries around the Baltic Sea, as well as the European Union, to initiate discussions regarding the reforms of several policies, including the EU Common Fishery Policy (CFP). Reaching new agreements can hopefully help safeguard sustainable management of EU and Baltic Sea fish communities. If fish stocks were allowed to recover, it would not only strengthen the environment, but also boost the fishing economy. It is estimated that recovered European fish stocks would make fisheries dependent on them five times more profitable. (WWF, 2012)

3.6 Invasive species

There is evidence of a rapid expansion of invasive (also called alien or non-indigenous) species in the Baltic Sea since the 1990s. These terms are used for species that, often due to human activity, intentionally or accidentally have spread across a major geographical barrier. The brackish water of the Sea provides a possibility for both fresh and salt-water invasions (Paavola et al., 2005). Between the 19th and 20th century, approximately 120 such species have been recorded in the Baltic Sea and roughly 80 of these have reproductive populations. Species new to the Baltic Sea ecosystem include mussels (e.g. *Mytilopsis leuco-phaeata*), barnacles (*Balanus improvisus*), polyps (*Cordylophora caspia*) and water fleas (*Cercopagis pengoi*). Potential harmful invaders such as toxic dinoflagellates (*Pfiesteria piscicida*), American comb jelly (*Mnemiopsis leidyi*) and Asian clam (*Corbicula fluminea*) have also been identified (see Main report Chapter 8 for more information about the case study on the Asian clam). The dominant vectors of invasion in the aquatic
environment include introductions via ballast water, hull fouling and aquaculture. The survival of the introduced species depends on the biological characteristics of the species and of the environmental conditions faced. High biodiversity is known to enhance invasion resistance and as the Baltic Sea ecosystem has a relatively low biodiversity, this could perhaps explain the high invasion success of many invasive species. (Leppäkoski et al., 2002; Leppäkoski, 2005; Baltic Sea Alien Species Database, 2012)

Invasive species are increasingly recognized as serious threats to aquatic ecosystem and biodiversity. As invasive species have been claimed to be the second biggest factor of biodiversity loss in general (Vitousek et al., 1997; UNEP, 2006), it is reasonable to expect that biodiversity-related ecosystem services of the Baltic Sea will also be affected. These species can have deleterious effects on native species by for example exerting predation pressure, compete for food or space, hybridize or spread diseases and parasites. These changes often lead to negative consequences on human economy as these species can damage fisheries, tourism and aquaculture (Ojaveer et al., 2002; Almqvist, 2006). Some invasive “engineering” species may also change the habitat itself, leading to larger shifts in the ecosystem. Examples of invasive “engineering” species include the Bay barnacle (Balanus improvisus) and Conrad’s false mussel (Mytilopsis leucophaeata), which both cause biofouling in addition to changes in regulating and supporting services of the Baltic Sea. On the other hand, the invasive American polychaete worm Marenzelleria, which invaded the Baltic Sea in 1985, seem to enhance the denitrification cycle and improve bottom-water oxygen conditions due to its bioirrigation, thus helping to counteract eutrophication-related problems. (Wallentinus & Nyberg, 2007; Norkko et al., 2011).

3.7 Marine litter

The United Nations Environmental Program (UNEP) describes marine litter as “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment” (UNEP, 2012). The problem of marine litter is recognized and considered to be one of the major threats to oceans worldwide, with estimations showing that the total input of marine litter into the worlds oceans are approximately 6.4 million tonnes annually. This litter causes a wide spectrum of environmental, economic, safety, health and cultural impacts. (UNEP, 2012) Items such as plastics (e.g. bags, bottles and toys), fishing gears, paper and cardboard (e.g. paper and tetra packs), glass, clothes, metals (e.g. cans, caps and spray cans), or any other item made by, or used by people, find their way to the Baltic Sea via beaches, sewage, coastal urban areas and rivers, or through storms or wind. The very slow rate of degradation of most marine litter items, mainly plastics, together with the continuously growing quantity of the litter and debris disposed, is leading to a gradual increase in marine litter found at sea and on the shores. Generally, up to 70 per cent of marine litter that enters the sea sinks to the bottom, whereas 15 per cent is found on beaches and the remaining 15 per cent floats on the water surface. (UNEP, 2006; HELCOM, 2007b)
Marine litter can range from large or medium-sized particles visible to the human eye, to invisible microscopic particles that form when the litter degrades. Microparticles also derive from other sources such as plastic pellets used as raw material, different kind of scrubbers for cosmetic use and cleaning or wearing of roads and rubber tire. The problems of marine litter in the Baltic Sea are not comprehensively studied, but existing studies show that the amount of litter varies between countries, although generally plastic items were the most common type (50–63 per cent) of all litter found. Some studies show that the amount of marine litter found on the coastline ranges between 700 and 1200 pieces per 100 m coast. However, in most cases the average amount of litter found on the coast varied between 6 and 16 pieces of litter per 100 m of coast. Other studies show that each cubic meter of water can contain hundreds of thousands of pieces of microscopic plastic particles (e.g. 104 000 pieces per m³ in the Gulf of Bothnia). (Norén et al., 2009; HELCOM, 2007b)

Effects of marine litter
Harm to the marine environment as a result of marine littering includes ingestion and entanglement of marine fauna such as seals, fish and seabirds. Marine litter can resemble food such as jellyfish or fish egg, and when digested get caught in the animals feeding appendices, causing a slow death through injuries and famine. Microscopic particles are in the same size range as the food for many marine filter and detritus feeders, and when digested these particles can probably lead to physical injuries. As some hazardous substances may adsorb to these particles, they may enhance accumulation of toxic substances in the food web. Larger objects can cause habitat destruction by affecting water quality and causing physical damage, for example when dragged along the seabed by currents, thus scraping and tearing up fragile and vital habitats, as well as smothering seabed animals. Besides this, marine debris can contribute to the transfer and movement of invasive species. Marine litter can also damage marine industries and the aesthetic quality of coastal environments through contamination of beaches and harbors, damages to fishing boats and gears, fouled propellers and broken engines affecting the shipping industry, clogging of cooling water intakes of industries, as well as potentially injuring humans, pets and grazing cattle. These effects naturally cause serious economic losses to various sectors and authorities. Examples from Sweden and Poland show that merely cleaning beaches and removing litter from harbor waters can cost millions of Euro annually. (HELCOM, 2007a, b; UNEP, 2006; SEPA, 2010; Barnes, 2002)

3.8 Climate Change
Another concern when considering the status of the Baltic Sea ecosystem is climate change, identified as one of the dominant drivers of change globally. Measurements show that between the years 1900–2005, the global temperature rose with 0.78 °C and scenarios of climate change, developed by the Intergovernmental Panel on Climate Change (IPCC), project an increase in global mean surface temperature of 2.4 – 6.4 °C above preindustrial levels by 2100. Generally, increases in frequency of intense rainfall and rising sea levels,
decreases in snow cover and sea ice, more frequent and intense heat waves as well as widespread ocean acidification are considered to be associated with global warming and climate changes. (IPCC, 2007)

Changes have already been detected concerning the increase in sea surface temperature (SST) in the Baltic Sea. The Baltic Sea’s annual mean SST has increased approximately 0.7 °C during the last 20 years. (BACC, 2008) In addition, model studies indicate increases in air temperature of 3–5 °C by 2100 (e.g. Meier et al., 2012, Neumann et al., 2012). The sea surface salinity has decreased during the last two decades due to low inflow of marine salt water through the Sound and Belt areas. Changes in precipitation are also expected, affecting the freshwater load to the Baltic and thus salinity. Projections for the Baltic Sea during the 21st century suggest that, compared to present climate, higher water temperatures, spatial changes in precipitation, lower sea surface salinity and oxygen concentrations and reduced ice-cover is probable. Temperature will be higher and salinity lower than any time since 1850 (BACC, 2008; Meier et al., 2012; Gustafsson et al., 2012), with salinity decreasing in the order of 2–2.5 psu by the end of the 21st century (Neumann et al., 2012). These changes are likely to have significant impacts on the marine ecosystem, and (despite high uncertainties) climate change can be expected to increase phytoplankton biomass and eutrophication, reduce water transparency and reinforce oxygen depletion, although that these problems are largely depending on the future nutrient loads. Projections show that, as a result of the increase in net precipitation over certain parts of the catchment area, river runoff will increase between 15 and 22 per cent. (Neumann et al., 2012; Meier et al., 2012) Although cod biomass is mainly controlled by fishing mortality, new research indicates that in the latter part of the 21st century, a combination of climate change and eutrophication may result in decline of cod biomass. (MacKenzie et al., 2012; Niiranen et al., 2012) Changes in factors such as salinity and temperature are important abiotic parameters structuring the species composition of food webs and biodiversity in the Baltic Sea. Future climate change and its interactions with multiple anthropogenic forcing are thus likely to have major impacts on the ecosystem structure and function.

3.9 Regime shifts

Elevated nutrient concentrations have, in combination with a large inflow of salt water in the 1950s, which mobilized accumulated phosphorus from the deep sediments, led to an increased organic production. Österblom et al. (2007) suggested that this regime shift, from an oligotrophic to a more eutrophic state was triggered in 1951. An ecosystem regime shift is an infrequent, large-scale reorganization, marking an abrupt transition between different states of a complex system, affecting ecosystem structure and function and occurring at multiple trophic levels (e.g. Scheffer & Carpenter, 2003; Collie et al., 2004). In the late 1980s, the Baltic subsequently underwent ecological regime shifts (see Figure 4); in the Central Baltic Sea the food web structure changed from a cod- to a sprat-dominated state, induced among other things by overfishing, eutrophication and changes in climate leading to hydrographic changes. (Österblom et al., 2007, 2008; Möllmann et al., 2008, 2009; Casini et al., 2008)
The ecological background to the latter regime shift is that, due to increased hunting of seals (as these were considered competitors to commercial fisheries) the predation pressure from seals on cod decreased, and the seals no longer controlled the cod population. In combination with increases in primary productions and thus food (as explained earlier in the section on eutrophication), the conditions for cod were very favourable, leading to large increases in the cod populations and a cod dominated state. The fishing industry markedly intensified its cod fishing in the mid 1970s, and a decade later, the cod stocks collapsed. The reduced cod stocks in turn led to lowered predation of its main prey, the clupeid fish sprat (*Sprattus sprattus*). As a consequence, sprat populations increased dramatically, leading to a sprat-dominated state. This has been suggested to stabilize the cod stock at a low level, as sprat predate on cod eggs and larvae and compete with juvenile cod for phytoplankton-eating zooplankton. Besides changes in temperature and salinity, through so-called *trophic cascades*, the increased sprat stock has thus changed the quantity and quality of zooplankton. In the 1980s a sub-shift in zooplankton species occurred, with a shift in dominance of different copepods: from *Pseudocalanus* ssp, the main food supply for cod larvae, to *Acartia* and *Temora* ssp, which besides *Pseudocalanus* is food for sprat (Österblom et al., 2007, 2008; Möllmann et al., 2008, 2009; Casini et al., 2008; ICES, 2008).

Recent research suggests that these shifts have changed the Baltic Sea ecosystem from being mainly regulated by bottom-up control, to presently being partly regulated by top-down control, and have been viewed as a third regime shift in the Baltic Sea ecosystem. Sprat also competes with herring (*Clupea harengus*) for zooplankton, and the increased competition for food has led to herring and sprat becoming smaller and leaner, that is containing less calories. Research has shown that these changes in food quality have affected the condition of certain sea birds, such as guillemots (*Uria aalge*). (Österblom et al., 2008) Although there is more sprat available, they provide less nutrition, and some researchers are suggesting existence of “junk-food” in marine ecosystems. Furthermore, when sprat (a low trophic level and low value fish mainly used for fishmeal and fish oil production) replaced cod (a commercially high valued and favored table fish fetching high market prices) it naturally had effects on the profitability of Baltic Sea fisheries. (Alheit et al., 2005; Österblom et al., 2007, 2008; ICES, 2008)

Thus natural changes in combination with human exploitation in the Baltic Sea has led to large-scale changes, so called regime-shifts, altering not only ecosystem functioning, as changes in the interactions strengths between species in different levels of the food-change change are suggested to occur, but also social-economic aspects for the countries surrounding the Baltic Sea.
4. Conclusions

The Baltic Sea is a complex ecosystem influenced by both natural and anthropogenic factors. It is under severe stress as a result of environmental problems such as eutrophication, hazardous substances, overfishing, risk of oil spills, marine litter and invasive species. In combination with current and future climate changes, the Baltic Sea’s ability to provide ecosystem goods and services are jeopardized. Research show that by the end of the 21st century, abiotic conditions will change; with an increases in water temperature, precipitation and thus runoff, lower salinity and reduced oxygen concentrations. These changes will cause physiological stress for organisms and may thus change the distribution and abundance of species inhabiting the Baltic, including increased phytoplankton concentrations. Future climate change and its interactions with multiple anthropogenic forcing are thus likely to have major impacts on ecosystem structure and function.

The Baltic Sea provides a number of ecosystem goods and services, generating benefits, which in turn are coupled to welfare. Deterioration of the ecosystems and their provisioning of benefits might thus have negative impacts on human welfare by negatively affecting the socio-economy in the countries surrounding the Baltic Sea.
References


BACC Author Team, 2008. *Assessment of Climate Change for the Baltic Sea Basin* (BACC), Regional Climate Studies. Springer Verlag, Heidelberg


Byström, C. 1872. ”Berättelser om fisket i åtskilliga sjöar och vattendrag inom Medelpad och Ångermanland af Westernorrlands län”. Published 1973 in “Information från Sötvattenslaboratoriet Drottningholm” (Swedish University of Agricultural Sciences, Department of Aquatic Resources), No. 5.


HELCOM. 2007A. *HELCOM Baltic Sea Action Plan* (adopted by the HELCOM Ministerial meeting, Krakow, Poland 15th November 2007)


