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Trends and scenarios exemplifying the future of the Baltic Sea and Skagerrak

Ecological impacts of not taking action

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Preface

The Swedish Environmental Protection Agency, by assignment of the Swedish Government, has carried out a project, led by Katrin Zimmer to gather information about the economic impacts of the human influence on the Baltic Sea and the Skagerrak[1] environment. The project, based on already existing material, attempts to compare the situation if no further measures are implemented compared to if further measures are implemented. The countries around the Baltic Sea have been invited to participate in the project and the search for economic marine information has been carried out in every state that borders the Sea.

The goal of the project is to provide decision makers with the information available regarding the economic benefits of ecosystem services, the cost of measures required to protect these services, as well as the estimated costs of non-action.

The assignment was divided into different subprojects which resulted in different reports.

1. Report 5873 Ecosystem services provided by the Baltic Sea and Skagerrak
2. Report 5874 The economic value of ecosystem services provided by the Baltic Sea and Skagerrak - Existing information and gaps of knowledge
3. Report 5875 Trends and scenarios exemplifying the future of the Baltic Sea and Skagerrak - Ecological impacts of not taking action
4. Report 5876 The costs of environmental improvements in the Baltic Sea and Skagerrak - A review of the literature
5. Report 5877 Costs and benefits from nutrient reductions to the Baltic Sea
6. Report 5878 Tourism and recreation industries in the Baltic Sea area - How are they affected by the state of the marine environment? - An interview study
7. Report 5879 Economic information regarding fisheries

Each of the reports 1-5 contains information on knowledge gaps and suggestions of new research or how existing information could be compiled.

All subprojects have been compiled into one synthesis report with the title What´s in the Sea for me – Ecosystem Services of the Baltic Sea and Skagerrak. (Report 5872)

This report is the result of one project within the governmental assignment and describes the possible ecological impacts if no further actions are taken to improve the state of our seas. Future outcomes are exemplified by scenarios and trends and important issues are highlighted in interviews with leading researchers. The work

[1] The project defines the Baltic Sea and the Skagerrak as the waters of the Bothnian Bay, the Bothnian sea, the Gulf of Finland, the Gulf of Riga, the Baltic Proper, the Danish Straits, the Kattegat and the Swedish coast of the Skagerrak.

has been carried out by Martina Kadin, Baltic Nest Institute, Stockholm Resilience Centre.

The report was financed by the Swedish Environmental Protection Agency. Opinions expressed in this report are those of the author and do not necessarily reflect the official view of the Swedish Environmental Protection Agency. However, the views expressed by the experts and the researchers do not necessarily reflect the view of the author. Similarly, the statements made in the text by the author do not necessarily reflect the view of the experts and the researchers.

Stockholm, May 2008

Swedish Environmental Protection Agency

Contents

Summary

Strong anthropogenic influence has shaped the present states of the ecosystems in the Baltic Sea and the Skagerrak. The current driving forces are very likely to be important also in the future, but also emerging pressures, mainly induced by global climate change, will probably have large-scale impacts on the marine environment.

Nutrient inputs resulting in eutrophication are likely to change. Decreased emissions from point sources will probably be seen rather soon, but the development of diffuse sources, mostly dependant on agriculture, is more uncertain. There is a potential for improvements but these must be anticipated in a perspective of several decades. A changing climate will by the end of the century contribute to more severe effects of eutrophication if no improvements have occurred.

Over-exploitation of commercially important fishes poses a threat to the whole ecosystem, but this is the issue with the greatest potential for fast improvements. Fisheries management seems to have implications for the effects of eutrophication and these relationships deserve further attention.

Climate change may induce changes in temperature, salinity and pH towards the end of the century or even sooner and possible cause changes in species composition and interactions. Such changes are also likely results of introductions of harmful alien species, which will occur at an increasing rate. All these drivers have major implications for native biodiversity. In addition, exploitation of coastal areas will lead to competition for space that may be of great importance for our possibility to conserve biodiversity.

Maritime transportation will increase during the next decade whereby the risk of a large oil spill will be higher. Illegal oil discharges results in chronic pollution, which presently severely affects some species, but the future trend for illegal discharges is uncertain. The increase in maritime traffic will also be the major factor behind the future increasing rate in introductions of alien species.

Hazardous substances are likely to be a reason for concern in the future, but the awareness of this issue has improved significantly whereby there is a potential for discovering effects at an earlier stage.

The cumulative effects of these drivers need to be considered, since many smaller long-term impacts may lead to continuous reduction of ecosystem function. This can eventually bring the system to a tipping-point where the system enters a new state. A return to the former state may not be possible. A single large disturbance to a healthy more resilient ecosystem may be less severe, since the system in this case has ability for reorganization and renewal.

Sammanfattning

En intensiv mänsklig påverkan har format det nuvarande tillståndet för ekosystemen i Östersjön och Skagerrak. De krafter som är pådrivande idag kommer sannolikt att vara viktiga även i framtiden, men även kommande krafter, huvudsakligen orsakade av den globala klimatförändringen, kommer sannolikt att innebära en storskalig påverkan på havsmiljön.

Näringstillförseln med övergödningen som resultat kommer sannolikt att förändras. Minskade utsläpp från punktkällor kommer förmodligen att märkas relativt snart, medan utvecklingen för mer spridda källor, väsentligen beroende av jordbruket, är mer osäker. Det finns en potential för förbättringar, men dessa måste man föreställa sig i ett perspektiv som sträcker sig över årtionden. Ett förändrat klimat kommer mot slutet av seklet att ge en mycket svårare övergödning om inga förbättringar har genomförts innan dess.

Överexploatering av de kommersiellt mest intressanta fiskarterna utgör ett hot mot hela ekosystemet. Detta är samtidigt den fråga som har störst potential för snabba förbättringar. Skötsel av fiskodlingar ser ut att ha konsekvenser bland annat när det gäller övergödningens effekter. Därför är det intressant att utveckla detta vidare.

Klimatförändringar kan mot slutet av seklet eller ännu tidigare medföra förändringar avseende temperatur, salthalt och pH-värde och skulle kunna ge förändringar i arters sammansättning och samverkan. Introduktion av skadliga främmande arter, något som sker allt mer, skulle också kunna resultera i sådana förändringar. Alla dessa drivkrafter kan ha betydande konsekvenser för ursprunglig biologisk mångfald. Dessutom kommer en exploatering av kustområden att leda till en konkurrens om utrymme, vilket troligen kommer att vara av stor betydelse när det gäller möjligheter att bevara biologisk mångfald.

Under nästa årtionde kommer transporter till havs att öka i omfattning. Detta kommer att innebära att risken för större oljeutsläpp ökar. Olagliga oljeutsläpp leder till kronisk nedsmutsning, vilket för närvarande ger allvarliga konsekvenser för vissa arter. Framtiden när det gäller de olagliga oljeutsläppen är dock osäker. Ökade transporter till havs kommer också att bli den mest betydande faktorn för en ökning av introduktionen av skadliga främmande arter.

Miljöfarliga ämnen kommer sannolikt att vara ett bekymmer i framtiden, men medvetenheten kring detta har förbättrats avsevärt, varför det finns en potential för att man ska kunna upptäcka effekterna på ett tidigare stadium.

Den samlade effekten av dessa drivkrafter måste tas i beaktande, eftersom mindre, långvariga effekter när de blir många kan leda till en ständig försämring av ekosystemens funktion. Detta kan till slut innebära att systemet kommer till en brytpunkt

där det övergår i ett nytt tillstånd. En återgång till det föregående tillståndet kanske då inte längre är möjlig. En enda större störning på ett friskt och mer motståndskraftigt ekosystem kan vara mindre skadlig, eftersom systemet i det här fallet har kvar förmågan till omorganisation och förnyelse.

Introduction

The Baltic Sea and the Skagerrak are strongly affected by human-induced changes. Global, regional and local human activities have radically changed the environment in the seas. Our extensive use of marine goods and ecosystem services has severely influenced the possibilities for continued utilization today and in the future. Changes in the terrestrial and fresh-water ecosystems have had strong impacts on the environment in the marine system. Global climate change will inevitably also affect the Baltic Sea and the Skagerrak.

The current state of the Baltic Sea and the Skagerrak is a great challenge for our society with both economical and social impacts. Large-scale effects, such as eutrophication and changing sea level, will influence most, if not all, people living along the coasts as well as firms depending on goods and services provided by the marine ecosystems. Other effects, smaller on a geographical scale or restricted to fewer trophic levels[2], are still of large importance for many industries, e.g. tourism, maritime transport and fisheries, and for people whose wellbeing is affected by these factors.

Ecological effects are the bases for the socio-economical impacts. The present situation is the result of the huge anthropogenic influence on our seas and affects all parts of the ecosystems from primary producers to top predators and the trophic interactions. The impacts from previous and current human activities are still emerging and new impacts will continue to appear. This report describes briefly the recent changes but focus on future trends and scenarios.

The assignment and aim of the report

Information about future events and trends is valuable when possible measures are evaluated and decided. The developments of model simulation techniques during the last decades have greatly improved the ability to explore scenarios and make projections about the future. For some aspects of the marine environment, i.e. eutrophication and climate change, several projects to model the present and the future have to a large extent contributed to our understanding of these issues. This study will compile information from these fields of research for the Baltic Sea and the Skagerrak and briefly describe the models involved in producing projections. For other aspects of the marine environment, projections from models are not yet available. Instead, analyses of previous events, in our seas and other oceans, and current trends as well as risk analyses may provide insights to future outcomes. The purpose of the study is to describe the present knowledge in these fields of research concerning the Baltic Sea and the Skagerrak. Cumulative as well as counteracting

[2] The trophic level is the position an organism occupy in a food chain or food web. The first trophic level consists of primary producers; the second is primary consumers (i.e. organisms that feed on primary producers) and so on up the highest trophic level which consists of top predators. The number of trophic levels differs between food webs.

effects of future trends and scenarios are to be expected. The study will exemplify and discuss such effects, with special concern given to the resilience[3] of our seas. Lastly, this assignment also includes summing up knowledge gaps and to suggest areas for further research.

The aim is to identify and describe future trends and scenarios for the Baltic Sea and the Skagerrak as wells as the interaction between impacts and by that provide an overview of the knowledge about the future for our seas. The overall aim is to contribute to an understanding of the large human impact on the marine environment and elucidate the importance of immediate actions to improve the situation.

The structure of the report

The report is structured around the human activities mainly impacting ecosystem services as described by Garpe (2008; Appendix II). The first section concerns models and projections in order to introduce these concepts. The following impact sections include a background description, trends or scenarios to exemplify future outcomes and ecological consequences. A chapter aiming at describing the general situation for marine biodiversity, in relation to the impacts, is included in the end as well as a chapter summarizing knowledge gaps and desirable research.

Delimitations and scope of the report

The report is based on existing material, but interviews with leading researchers have been made to provide a more updated picture. However, to fully capture the range of the ongoing research is not possible within the scope of this report and hence it is likely that new knowledge will soon become available.

Since anything can happen in the future it is not possible to make a fully comprehensive overview of likely and less likely events. The report is therefore focused on published scenarios and analyses and expert opinions of the most important issues for the future, rather than listing all possible outcomes. Scenarios studying the effects of possible actions are more commonly occurring than studies of not taking action, but the first type of scenarios is beyond the scope of this report. The included scenarios concern effects of no action, current trends or likely changes without further action from decision-makers. In some cases decided actions are described when these provide a fuller picture of what to expect.

The aim has been to find scenarios and trends relevant for all countries surrounding the Baltic Sea and Skagerrak. However, my restricted knowledge of the many languages in the region and of the structure of national institutions involved in environmental research and management will inevitably have the consequence that there are aspects that have been overlooked.

[3] Resilience is the capacity of a system to deal with change and continue to develop. A system with low resilience has reduced ability to reorganize after disturbance, which can result in a shift in the state of the system.

What happens right now?

American comb jelly *Mnemiopsis leidyi* – an alien species with potential to alter the Baltic Sea ecosystem

The American comb jelly is a carnivorous ctenophore, native to the eastern coast of North and South America. The American comb jelly was first seen in Kattegat and the Sound in 2006 (Tendal et al. 2007). In March 2007 it occurred with a density of 200 individuals/m^2 in the Landsort deep and in August it was found as far as the western Gulf of Finland and the Bothnian Sea. By December 2007 the comb jelly had reached the eastern Gulf of Finland. The highest densities, almost 700 ind./m^2, occurred in the Åland Sea in September (Lehtiniemi et al. 2007).

In January 2008 the comb jelly was found in even higher densities – 3800 ind./m^2 in the deep waters in Åland Sea (Maiju Lehtiniemi, pers. comm.). The mild winter with low ice coverage and available zooplankton is probably the main reason for this dramatic increase.

Sergej Olenin, professor at the Coastal Research and Planning Institute of Klaipeda University, explains the potential impact of the comb jelly:

– I am deeply concerned about the recent invasion of *Mnemiopsis leidyi* into the Baltic Sea. The situation strikingly reminds of the first phases of its invasion into the Black and Caspian seas. In the Black Sea, it took a few years from the first record of this species in 1982 (in small numbers and in one place) until it occupied the entire sea by 1987 and caused catastrophic shifts in ecosystem functioning and collapse of pelagic fishery in 1988-1989. The same history repeated in the Caspian Sea in 1999-early 2000's. What scares me is the fact that in the Baltic, it took only one (!) year for the comb jelly to invade the entire Baltic Proper, i.e. it was much faster than in the Black and Caspian Seas. This means that we may expect serious consequences already in the nearest future (next summer, or 1-2 years later), especially if the summer is hot and calm. These consequences will include the comb-jelly intensively grazing on zooplankton, redirection of energy flow from pelagic fish (Baltic herring and sprat) and, as a result, a serious decline in pelagic fishery. There might be other consequences which are difficult to foresee now.

– In the Black Sea, the situation was "fixed up" by the unintentional introduction of another comb-jelly, *Beroe ovata*, which feeds exclusively on *Mnemiopsis* and suppresses it abundance. However, in the Baltic, due to its lower salinity, such "rescuer" will hardly survive…

The mild winter of 2007/2008 seems to have allowed the *Mnemiopsis* population to increase and thus consequences throughout the food-web may appear soon. Speculative, but still possible, effects can be more intense algal blooms since grazing pressure on phytoplankton may decrease and reduced reproductive success of birds dependant on sprat. If the sprat population suddenly crashes we may even see starving birds and seals.

How has projections been done?

The future is, by nature, unknown – but for planning and management predictions and assumptions about coming changes are necessary. The shorter the time perspective and the less complex the question predictions about the future will be easier to do and can be more precise. Computer models are essential for providing projections into the future when complex issues or systems are studied. The results are referred to as projections rather than predictions, as the word prediction implies that the result is likely meanwhile in most cases the probability can not be assessed.

This chapter is intended to give a very brief general introduction to models for the reader unfamiliar with this type of tools. More specifically, process-based ocean models applicable to the Baltic Sea and the Skagerrak will be described, since those have been used in several of the studies described in the following chapters. Other types of models will be mentioned in the report, but describing these models too is beyond the scope of this section. In those cases the references included can be used to find additional information.

A range of ocean models describing hydrographic and ecological variables have been developed for the Baltic Sea and the Skagerrak. Meteorological, hydrological and environmental institutes, as well as universities and research centres build and use these models to make short- and long-term forecasts, explore future scenarios and reconstruct past states (hind cast). The models differ in many aspects, for example in their geographical ranges, level of spatial and temporal resolution and in ecological complexity – if biogeochemistry is at all included. The differences are caused by the variety of purposes for which the models originally were developed.

Prerequisites for computer models

To build a model it is necessary to have a good enough understanding of the processes operating in the system. The processes are described by equations and the formulation of equations requires knowledge about which variables to include (i.e. which components determine the behaviour of the system and which components are of negligible importance), mathematical descriptions of variables and how variables are interrelated. Data is necessary in order to provide the model with starting values and boundary conditions. In reality, data from the studied system is also what gives the understanding of the processes in the system.

The quality of the data used is of uttermost importance when results from the model are interpreted. Data sets include a range of errors (e.g. sampling errors, calculation errors and typing errors) that can be either random or systematic. Systematic errors can often be identified and minimised, but random errors can seldom be accounted for. The degree of error is one part of the uncertainty associated with a specific variable, which also includes e.g. how well spatial and temporal variability is captured and the effect of missing data. Strict sampling protocols and schemes, carefully selected sampling sites and high sampling effort will reduce uncertainties and increase data quality. Similarly, or faster, the cost of data collection will increase, whereby perfect data sets do not exist. Since all variables include a degree of uncertainty a rising number of variables in a model lead to inclusion of a greater uncertainty. Therefore a model should contain as few variables as possible while still maintaining its function as a representation of the studied phenomenon.

After the model is first set up it is usually calibrated against a time period for which raw data exists. The model representation of reality is compared to reality as represented by measurements. The behaviour of the model is checked so that the model reproduces trends and events in a realistic way.

Scenario studies

Scenarios are often studied with models and this application of models is the focus of the report. When the results are discussed it is important to consider the assumptions included in the scenario. The assumptions are made by the modelling team and reflect a possibility that are of interest to study. A scenario in this context is a change from the current state that may happen – not something that will happen and it may not even be the most likely change.

Baseline scenarios are uncommon in this context. Baseline scenarios are projections into the future, within a specific time frame, of the current trends and decided actions assuming that no other things will change. Those are commonly used in other types of modelling studies (e.g. economical models), but for ocean modelling baseline scenarios has seldom been developed with the exception of studies of climate change (see section *Global climate change will impact our seas*). This is due to lack of available data or forecasts to construct such scenarios and further that scenarios of this kind have not been requested by policy institutions.

Zero- and one-dimensional models

Zero-dimensional models describe the ocean by using homogenous boxes, for example by describing each sub-basin as a separate box. One-dimensional models also use boxes, which are typically horizontally averaged but highly vertically resolved. These models are used when it is of interest to know if or when a phenomenon will occur and to make quantitative projections. The disadvantage is that the few dimensions make the models rather crude and possibly important geographical differences are not captured.

Hydrodynamic models of these types can include variables like currents, temperature, salinity, alkalinity and concentrations, for example oxygen. The one-dimensional models can be used to simulate vertical processes, like mixing and advection.

A hydrodynamic model can be coupled to a biogeochemical model, thus creating a hydrodynamic biogeochemical model. Since these models are applied to eutrophication issues, they are often referred to as eutrophication models. This kind of model describes transport mechanisms in and between the boxes and biogeochemical fluxes in the water and the sediment. The biogeochemistry can be described with different level of complexity, ranging from biogeochemical cycling and matter fluxes, to inclusion of ecosystem functional aspects for e.g. phytoplankton, zooplankton and sediments. Further descriptions of eutrophication models and examples of models are given in Appendix I.

Three-dimensional models

Three-dimensional (3D) models describe ocean processes both horizontally and vertically, thus being able to provide projections with spatial resolution. 3D models can give insights to *where* the studied phenomenon or event may happen, which is valuable if differences within sub-basins or between localities are to be studied. Such studies may for example concern projections of the extent of ice-cover in a gulf or which near-shore waters that are likely to be affected by cyanobacterial blooms. The disadvantage of 3D models is that these models are data demanding in order to be able to produce relevant projections. A lack of data with sufficient resolution will imply large uncertainties in the results concerning local differences, which was the purpose of using a 3D model.

The resolution differs between models, ranging from about two to twenty kilometers horisontally (Söderkvist 2006) and vertical layers of a few meters to hundreds of meters (SMHI 2007a).

Similar to models of fewer dimensions, hydrodynamic 3D-models simulate currents, temperature, salinity and concentrations of elements. Hydrodynamic 3D-models can be used together with biogeochemical models. These coupled models can be of different complexity in the same way as for zero- and one-dimensional models. Similarly these models are also sometimes called eutrophication models. Examples of models are given in Appendix I.

A hydrodynamic model can also be coupled with an atmospheric model. The advantages of using this approach to study regional climate are described by SMHI (2007b): "The coupled regional climate model is a more realistic representation of the true climate system, than running component models individually with prescribed forcing at the air-sea interface. Atmospheric simulations require information on surface temperature and sea ice, which in turn are affected by the atmosphere. Similarly, ocean simulations require atmospheric forcing, which is locally affected by the sea and ice surface quantities. A coupled regional ocean atmosphere system is a consistent set up for covering these aspects. In climate change, or any sensitivity experiment, the question of feedback processes needs to be explored, i.e. how a change in some part or aspect of the climate system might affect the rest of the system."

One example of a coupled hydrodynamic-atmosphere model applied to the northern European region is the RCAO model developed by the Rossby Centre of SMHI. The projections concerning climate change included in this report (see pp 45f) were made using RCAO or its oceanic part RCO.

Linking models and model results

Models or the result from models can be linked together mainly in two ways: By model coupling or by using results from one model to drive a second one.

Coupled models have been exemplified above. The component models are said to be coupled when (parts of) the output of one model is used within the second model, which then gives feedback to the first model and vice versa.

Results obtained from one model can provide boundary conditions for a second model. Then the result data from the first model simulation is said to be driving data in the second model. This option is chosen when a mutual coupling is inexpedient due to high complexity of the models or poor knowledge of feedback mechanisms between the studied systems. For example, results from watershed models are used as driving data for hydrodynamic models and simulated climate may be input to a hydrodynamic biogeochemical model.

Decision-support model systems

Decision-support systems are designed to provide decision-makers with efficient tools to evaluate different actions that may be taken, whereby the actions usually are related also to cost-effectiveness. A decision-support model system is often made of several models, which can be used separately or together by using results as driving data in the next model.

In the context of environmental aspects in the Baltic Sea and Skagerrak, decision-support model systems have been developed for eutrophication issues. These systems differentiate between various nutrient sources and thereby actions or changes in different sectors can be evaluated.

Examples of decision-support model systems:

- Nest – A web-based decision support system for the Baltic Sea, freely available from http://nest.su.se/nest At present these modules are included:
  - Module **Cost calculation** is an interface to an economic model.
  - Module **Marine model** is an interface to SANBALTS (see Appendix I).
  - Module **Watershed model** is an interface to data describing Baltic Sea drainage basins characteristics and a model, MCSIM, of nutrient load.
  - Module **Fish model** is an interface to modelling results (e.g. the effects on production of zooplankton and fish at different phytoplankton levels), using a model of the Baltic Proper food-web, with 15 functional groups from phytoplankton to seals.

In addition to these modelling modules there are also two interfaces to different databases:

- Module **Riverine and marine data** is an interface to the Baltic Environment Database (BED) containing marine observations as well as water and nutrient inputs from rivers.
- Module **EMEP data** is an interface to atmospheric emissions and nitrogen depositions compiled at EMEP Centre.

Nest was used in the eutrophication modelling exercises preceding the development of the Baltic Sea Action Plan (see page 24) and in several other studies concerning eutrophication described in the section *Eutrophication – are there reasons to be hopeful?*.

- BEVIS - A joint decision support system for effective water protection measures in the archipelagos of Turku, Åland and Stockholm. Documentation is available from http://web.abo.fi/fak/mnf/biol/huso/bevis/english.htm
  - Two 3D hydrodynamic models are used, both can model nutrient concentrations and one also includes an eutrophication module to model phytoplankton. Databases of nutrient sources and emissions and water quality have been developed.
  - Scenarios for changed nutrient input have been studied and an economic evaluation of the scenarios has been conducted to assess cost efficiency.

  The end products and tools are said to form a raw version of a support system for decision making and are available for the regional authorities for further use.

Eutrophication – are there reasons to be hopeful?

Eutrophication is caused by large nutrient input to the marine environment. Nitrogen and phosphorus, the main elements causing eutrophication, are growth limiting nutrients and thus necessary for primary production. In an oligotrophic ecosystem, a system with low nutrient levels and production, extra input of nitrogen and phosphorus causes, through increased primary production, changes throughout the food web. With continued addition of nutrients the system is radically modified and becomes eutrophic.

Extra nutrients enter the marine environment through point sources, such as municipal waste water treatment plants and industries, and through diffuse land-based sources, which is mainly run-off from agricultural areas, and via atmospheric deposition of nitrogen. During the last century the overall load of total nitrogen to the Baltic Sea increased roughly twice, meanwhile the load of total phosphorus increased about three times (Schernewski & Neumann 2005, Savchuk et al. in press). However, during the last 30 years the overall loads have not changed significantly (Stålnacke et al. 1999, HELCOM 2004, Humborg et al. 2007) despite many measures to reduce emissions during the last decades (Bernes 2005, HELCOM 2007a). The lack of general trend is likely due to leaking from previous built-up nutrient pools in agricultural soils and inertia of watersheds, since the major watersheds have groundwater residence of some decades (Humborg et al. 2007). In addition, straightened waterways and deterioration of important wetlands may have decreased the nutrient retention potential further in some areas also in recent years.

Background

Point sources

Biological and chemical treatments of municipal and industrial waste water have successively been implemented in some of the countries surrounding the Baltic Sea and the Skagerrak. Continuous improvements have been achieved since the 1950's, starting in the Nordic countries but later also in the other countries in the catchments of the Baltic and Skagerrak (Elmgren 2001, Ærtebjerg et al. 2003, Bernes 2005, HELCOM 2007a, Humborg et al. 2007, Statistics Sweden 2007a). This development is described more in detail in Appendix II. However, there is still a potential for improvements, especially in Russia, Estonia, Latvia, Lithuania and Poland (Eriksson et al. 2007, HELCOM 2007e, Fredrik Wulff, pers. comm.).

The implementation of effective treatment methods has reduced nutrient input from point sources and in 2000 they constituted about 10 % of waterborne nitrogen loads and 25 % of waterborne phosphorus loads to the Baltic Sea (HELCOM 2004).

Is nitrogen or phosphorus more important?

The increased primary production during eutrophication is the underlying problem resulting in the effects cascading through the food web. To understand the problems it is important to know which factors limit the production.

During winter light conditions reduce photosynthesis capacity and hence production is low. In spring production increases whereby nutrients are used. Nitrogen is generally the limiting nutrient for spring phytoplankton production in Baltic proper and open Danish waters, which was shown through algal growth-potential tests (Waern & Pekkari 1973) and a whole-bay experiment (Granéli et al. 1990) in the 70's and 80's (Elmgren 2001). This was surprising considering the dominance of nitrogen in the nutrient inputs, but a plausible mechanism for nitrogen limitation was found (Larsson et al. 1985) when a huge potential of nitrogen loss through denitrification was shown (Shaffer & Rönner 1984). In the Bothnian Bay phosphorus limitation often controls the production. During summer the nitrogen shortage in the Baltic Proper leads to a competitive advantage for nitrogen fixating cyanobacteria, whereby intensive algal blooms occur and this production peak is thus limited by phosphorus.

Researchers agree on the mechanisms causing the peaks in primary production, but disagree on their relative importance. Cyanobacterial blooms are by many researchers, politicians and by the media regarded as the most severe problem associated with eutrophication. These blooms occur naturally in the Baltic (Bianchi et al. 2000), although the frequency and magnitude probably have increased through eutrophication. A decreased input of phosphorus will reduce this problem, but as internal processes are important for these blooms improvements must be anticipated in a long-term perspective (Vahtera et al. 2007). Reductions of nitrogen are by most researchers viewed as important to reduce other effects of eutrophication.

Farming of predatory fish, one common type of aquaculture, has been much debated as point sources for extra nutrients (e.g. Johansson 2003, Härdmark 2007). The released nutrients from fish farms contribute to the pool of nutrients in the water and will in that way contribute to eutrophication. To what extent farming of predatory fishes contribute to the eutrophied state of the Baltic and the Skagerrak depends on the choice of comparisons. Emissions from aquaculture in marine waters constitute 0.4 - 1.4 % of total anthropogenic nitrogen and phosphorus input in Sweden and Denmark, but compared to the direct point sources aquaculture in coastal areas contributed with 5-9 % of the emissions (Ærtebjerg et al. 2003, Swedish Board of Fisheries 2005, Statistics Sweden 2007a; more information about the calculations and ecological effects of aquaculture is given in the section Aquaculture).

Mussel farming, another form of aquaculture, can be viewed as point sinks for nutrients, especially nitrogen. The mussels filter particles and phytoplankton from

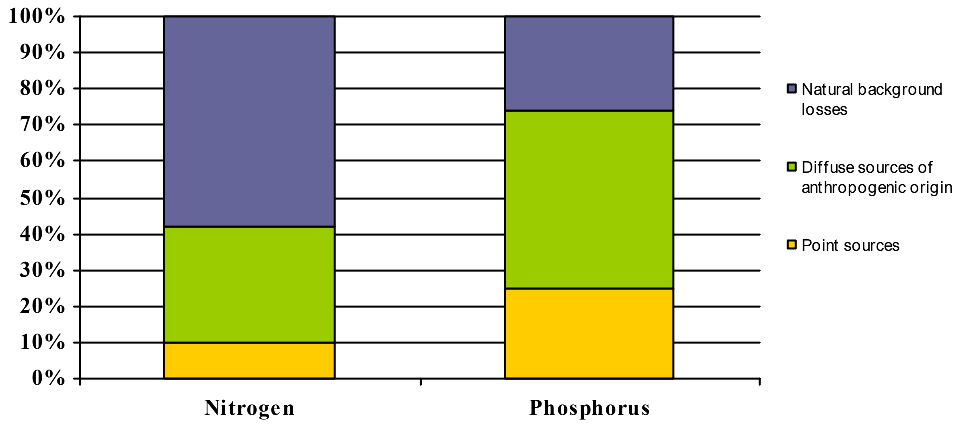

Fig. 1. Sources of nutrient input to the Baltic Sea. Data from HELCOM (2004, 2007a).

the water and when harvested nutrients are removed from the marine system. Mussel farming may be a measure to further increase efficiency of sewage treatment systems, if the farm is placed in the vicinity of the sewage treatment plant (Such a system is currently tested in Lysekil on the west coast of Sweden.) and there is also a large potential in using mussel farming as a point sink for nutrients originating from diffuse sources (e.g. Lindahl et al. 2005). In Skagerrak mussels are mainly cultivated for human consumption but in the Baltic Proper, a similar approach would most likely be better suited for production of poultry fodder, since mussel growth is significantly reduced by the lower salinity there.

Diffuse land-based sources

The major part of nutrients entering the Baltic and the Skagerrak originate from diffuse sources on land. The diffused sources can be divided into:

- Natural background losses, 32 % and 26 % of waterborne N and P loads to the Baltic Sea respectively and;
- Losses caused by human activities, 58 % and 49 % of waterborne N and P loads to the Baltic Sea respectively (HELCOM 2004, 2007a).

Among the human-induced sources runoff from agricultural and managed forest areas dominate for both nitrogen and phosphorus, accounting for almost 80 % of the input (HELCOM 2004). The remaining nitrogen input is caused by atmospheric deposition on inland waters and other diffuse sources. Additional significant diffuse sources of phosphorus are waste-water from scattered settlements and atmospheric deposition on inland waters.

In the Gulf of Bothnia and the Bothnian Sea a significant proportion of nitrogen originates from forest land, since managed forestry is the dominating land use in the northern parts of Sweden and Finland. In the other parts of the Baltic Sea and in Skagerrak, runoff from agricultural areas is the major source of nitrogen and phosphorus. The nutrient loss from agricultural soils, especially concerning nitrogen, depends on practices such as time of fertilizer spreading and ploughing, if fertilizer use is balanced against the uptake of crops and if catch crops are cultivated (Humborg et al. 2007, Swedish Board of Agriculture 2007). Another factor in the contribution from agriculture is livestock. Poland has the largest numbers of cattle and pigs in the Baltic Sea catchment areas, while Denmark has the highest densities. The nutrient input from livestock farming depends for example on storage and handling of manure and to what extent animals are held outdoors (Humborg et al. 2007, Swedish Board of Agriculture 2007).

Atmospheric deposition of nitrogen

Airborne nitrogen constitutes 25 % of the nitrogen entering the Baltic Sea. The nitrogen is emitted to the atmosphere as ammonia or nitrogen oxides (NO_x). Ammonia is almost solely due to agricultural emissions[4] and is mainly related to livestock (Swedish Board of Agriculture 2007). The extent of ammonia emissions from livestock farming depends on storage and handling of manure, type of production – slaughter cattle or milk cows, slaughter pigs or sows, and if animals are held in stables or outdoors (Humborg et al. 2007, Swedish Board of Agriculture 2007).

Nitrogen oxides are mainly emitted from the transport sector – with road transport being the largest contributor, but shipping and other mobile sources are of importance. Combustion for different purposes (e.g. energy, manufacturing) is also a significant source (HELCOM 2007a). More than 40 % of the atmospheric deposition, of both ammonia and NO_x, originates from sources outside the Baltic Sea countries.

Possible future decrease in NO_x emissions from combustion plants – The case of energy production in Sweden

In 1992 a charge on NO_x emissions from energy generation was introduced in Sweden. During the 90's there was a considerable reduction in emission of NO_x in relation to energy output. Therefore the system has been expanded and is now applied to NO_X emissions from electricity and heat-producing boilers, stationary combustion engines and gas turbines with a useful energy production of at least 25 GWh per year.

The total charge amount is returned to the participating plants, with the refund to each plant being proportional to its production. This encourages the plants to reduce their emissions of NO_x per unit of energy to the lowest possible level. Plants with high emissions relative to their energy production are net payers to the system, whilst sources with low relative emissions are net receivers.

At present the plants included in the system emit about 15 000 tonnes of NO_X per year, which represents approximately 8 % of the total Swedish emissions of NO_X[5].

[4] About 90 % of the ammonia emissions originate from agriculture (HELCOM 2007).
[5] Compared to total Swedish NO_x emissions of 175 000 tonnes (Swedish Environmental Objectives http://miljomal.nu/Pub/Indikator.php?MmID=3&InkID=Kva-24-NV&LocType=CC&LocID=SE (last verified 2008-03-14))

The trend in specific emissions is decreasing (see Fig. 2) and for the plants that have been within the system since 1992 the reduction is about 47 % (Swedish Environmental Protection Agency 2007).

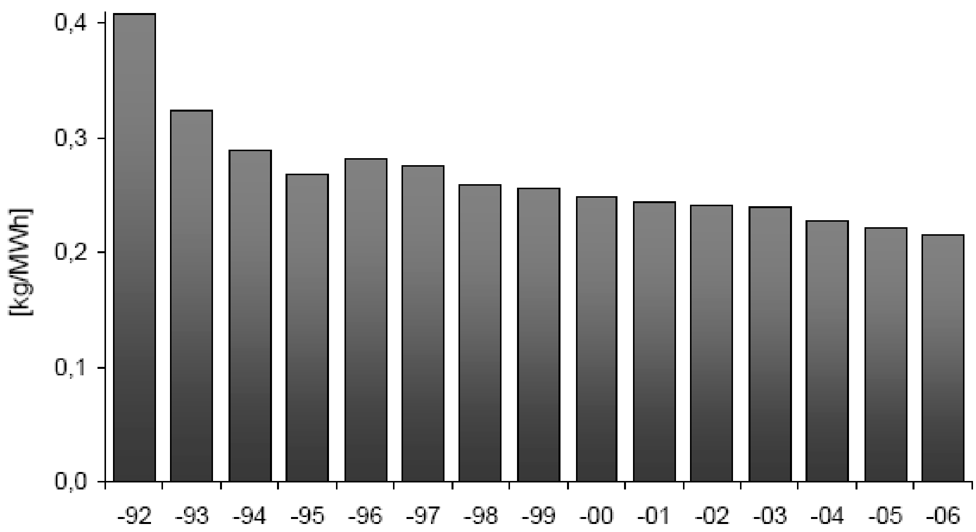

Fig. 2. Decreasing specific emissions of NO_x in Swedish combustion plants 1992-2006. Source: Swedish Environmental Protection Agency (2007).

A continuingly decreasing trend in specific emissions is to be expected. Total NO_x emissions from energy generation have however been rather stable, due to an increasing production of useful energy. There is a clear possibility however that total NO_x emissions from energy generation will decrease in Sweden, since the NO_x charge was raised in 2008, from 40 SEK/ton NO_x to 50 SEK/ton NO_x. It is estimated that total annual emissions will decrease with roughly 3 000 tonnes, based on the energy production in 2001, due to the increase of the charge (Swedish Environmental Protection Agency 2004, 2005). Energy consumption is unlikely to decrease in the near future and instead increased energy production is more likely whereby the actual decrease in total emissions probably will be somewhat lower.

The amount of NO_x not being emitted due to this system can also be illustrated by a simple calculation. If the amount of energy produced today, by the type of plants included in the system since 1992, would cause emissions of the same level as in 1992, an additional 10 000 tonnes of NO_x would have been emitted annually.

Applicability of the trend to other countries
NO_x emissions from land-based sources have in general decreased in Baltic Sea catchment countries since 1980 (HELCOM 2004, 2007a) whereby it is clearly possible that a continued decrease will be observed also in other Baltic Sea and Skagerrak countries. The measures to decrease emissions differ however between countries.

Scenario studies

Scenario: Baltic Sea Action Plan fully implemented

The HELCOM Baltic Sea Action Plan (BSAP) was adopted in November 2007 by all HELCOM countries. Although other environmental issues are addressed, the major achievement was the agreement on significant reductions of nutrient input.

According to the BSAP (HELCOM 2007e) actions will be taken and implemented no later than 2016 whereby the nutrient input will be reduced with:

- 135 000 tonnes of nitrogen
- 15 250 tonnes of phosphorus

The reductions were set after modelling studies, using the decision support system Nest (HELCOM 2007f), of reductions of nutrient input that are necessary to reach the environmental targets within HELCOM. The HELCOM targets can, generally speaking, be viewed as bringing the Baltic Sea to a state similar to that of the mid-1900’s. Country-wise nutrient reductions were also decided, but specific measures and policy instruments needed to reach the ambitious reductions were very briefly mentioned (HELCOM 2007e).

This scenario can be viewed as a best case scenario, since it is based on the best available knowledge on what is needed to reach the HELCOM targets. However, since the road towards these reductions is not specified it is not certain whether these targets will be reached. Therefore it is of interest to study other possible scenarios and trends to see what may happen if the BSAP is not fully implemented.

Time frame of the scenario

The BSAP states that measures will be implemented no later than 2016. The effects in form of actual decreases of nutrient concentrations will however emerge more slowly, in the order of decades. With the assumption that the reduced nutrient inputs take place at once, there is an initial rapid decline in e.g. total nitrogen and primary production and after that a slower decrease. The declines in Kattegat approach a new steady state more rapidly than in the Baltic Proper where the decline continues even after the first 50 years (HELCOM 2007f).

Risk and uncertainty associated with the scenario

The probability that the scenario will happen or the uncertainties associated have not been assessed.

Ecological effects on the scale of the Baltic Sea

If the scenario is realized it will eventually lead to significant improvements of the water quality and eutrophication status of the Baltic Sea. Water transparency will increase and nutrient concentrations as well as phytoplankton production will decrease. See further HELCOM 2007a, e, f.

Scenario: Adaption to current agriculture policies – The case of Swedish agriculture after implementation of the last agriculture reform

The Swedish Board of Agriculture has studied the possible environmental impacts of Swedish agriculture in 2020 based on current and possible future drivers (Swedish Board of Agriculture 2007). Five scenarios were developed by the Swedish Board of Agriculture, of which two concerns decided reforms and changes caused by global factors. The other three are based on possible reforms and a new world trade agreement and are not included here.

The scenarios are formulated as follows:

- Adaption to the decided agricultural policies
  The decided reforms are assumed to be implemented, but no further political changes occur and prices and production technologies remain at the present level.
- Growth of the agricultural sector
  The decided reforms are assumed to be implemented but no further political changes occur. Global prices of agricultural products are assumed to change according to OECD (OECD/FAO 2006). The Swedish agricultural production is assumed to grow with 3 % per year.

The first scenario results in a decreased Swedish production of cereal, milk and beef compared to 2003 level. In the second scenario cereal and beef production will decrease, but less than in the first scenario. Milk production however will increase compared to the production in 2003. Agriculture land with cultivation of energy crops and set-aside areas will increase relative to the areas with other crops in both scenarios compared to the situation in Sweden in 2003.

Nitrogen leakage from agricultural soils is projected to decrease in both scenarios. The reduction at the sources will be roughly 10 000 tonnes and slightly larger in the second scenario. Ammonia emissions are also projected to decrease in both scenarios. The decrease will be about 10 000 tonnes in the first scenario and roughly 5000 tonnes in the second (all figures in relation to the level in 2003).

Time frame of the scenarios

The calculations concerns projected changes until 2020.

Risk and uncertainty associated with the scenario

The Swedish Board of Agriculture (2007) states that price developments are difficult to assess and have a major impact on the results. In addition, the future productivity is also important and difficult to assess in a longer time perspective. The difference between the two described scenarios can be however be said to illustrate this uncertainty, according to the Swedish Board of Agriculture (2007).

After the study was published global market prices of cereal and dairy products have increased (FAO 2008, Wahlberg 2008), which may drive a development towards a larger production than projected in the scenarios.

Ecological effects on the scale of the Baltic Sea and Skagerrak

The projected decrease in nitrogen leakage and ammonia emissions will contribute to a better situation regarding eutrophication in the Baltic Sea and Skagerrak. However, since it is projected that reductions in nutrient input have a delayed response in the marine system, the major benefits will probably not be observable within the time frame of the scenarios (HELCOM 2007f).

Applicability of the scenario to other countries

The scenario is relevant for the situation in Sweden. Similar development is expected in most parts of Finland (Nowicki et al. 2007) but the future agriculture production in the countries that joined the EU in 2004 is more uncertain (Eriksson et al. 2007, Nowicki et al. 2007). The production of biofuels is uncertain when projections up to 2020 are concerned (Nowicki et al. 2007).

Scenario: All countries around the Baltic Sea develop their agriculture to the same state as in Denmark

Baltic Nest Institute at the Stockholm Resilience Centre has developed several scenarios of future nutrient loads to the Baltic Sea. The scenario intensified agriculture is a possible result of current drivers (HELCOM 2007, Humborg et al. 2007, Fredrik Wulff, pers. comm.)[6]. The scenario is included in this report to illustrate the large-scale severe effects that a large increase in agricultural production would have. In addition, the scenario has also been used in projections concerning eutrophication in a changed climate (see further *Future climate has implications for actions to mitigate eutrophication*).

Changes in agricultural practices have greatly increased productivity during the last century. This development has been most apparent in western countries, but similar changes are now seen in Poland, Lithuania, Latvia, Estonia, Belarus and Russia. The EU agricultural subsidies and improved living standards are drivers to these changes, as a higher income is associated with a change of preferences towards increased meat consumption (Humborg et al. 2007).

The scenario assumes that all countries surrounding the Baltic Sea will have the same intensity in their agriculture as the present Danish level. Denmark is the country with the highest number of cattle and pig per agricultural area in the Baltic Sea catchment. Productivity (measured as meat and milk per animal) is among the highest which means that nutrient excretion of animals also is high. Thus the scenario assumes, for all Baltic Sea countries, the same number of milk cows, other cattle, slaughter pigs and sows per ha cultivated area as in Denmark and nutrient excretion per animal at the Danish level.

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[6] A range of other scenarios have been developed, but those scenarios concerns changes that, at least to some extent, require actions from politicians and institutions. Further information is available in: HELCOM (2007a), Humborg et al. (2007) and Wulff et al. (2007).

The described scenario results in an up to fivefold increase in cattle for some areas and a massive increase in pig densities for transitional countries, 4-30 times. The huge increase in livestock will add roughly 340 000 tonnes of total nitrogen and 16 000 tonnes of total phosphorus to the riverine load – corresponding to a 48 % and 43 % increase in nitrogen and phosphorus loads respectively.

Time frame of the scenario
The scenario has no time aspects, but these changes can not occur instantly. If such intensification of Baltic agriculture will occur, it will probably take place in the perspective of decades. However, if meat production is based on imported fodder, development may be fast since establishment of local fodder production will not be a prerequisite (Fredrik Wulff, pers. comm.). The effects will most likely emerge in a decadal perspective (Humborg et al. 2007).

Risk and uncertainty associated with the scenario
The probability that this particular scenario is realized has not been assessed, but in the light of available scenario studies on agricultural development up to 2020 (e.g. Nowicki et al. 2007, Swedish Board of Agriculture 2007) it must be said to be low as projections rather indicate decreased agricultural production in the next decade. However, in the Baltic Sea countries that joined the EU most recent, a development towards more meat consumption, which may increase livestock farming (Humborg et al. 2007), and more intensive agricultural production is possible (Eriksson et al. 2007). In addition, the scenario studies on agricultural development were published before the recent increase in global market prices on agriculture products, whereby the prerequisites have changed (FAO 2008).

Ecological effects on the scale of the Baltic Sea
The large additional nutrient input will lead to extended hypoxic areas, from the present situation with 42 400 km^2 of hypoxic bottoms to almost 64 000 km^2 in future. Cyanobacterial blooms in the Baltic Proper will almost double, compared to the situation today (Fig. 3).

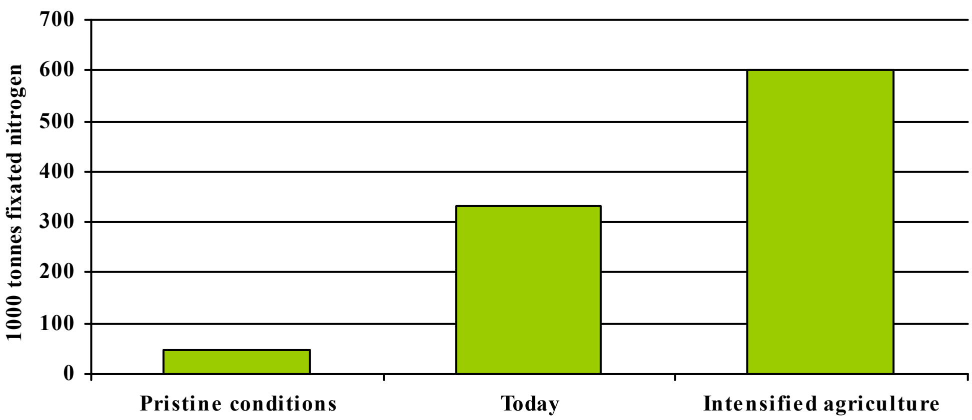

Fig. 3. Cyanobacterial blooms in the Baltic Proper under different levels of eutrophication. Pristine conditions refer to mid-1900’s. Cyanobacteria fixate nitrogen whereby the unit, amount of fixated nitrogen, is propotional to the occurrence of cyanobacteria.

Scenario: Increasing urban populations – The case of N load from the Stockholm county

Researchers at the Beijer International Institute of Ecological Economics have studied the effect on nitrogen load of the projected increase in population in the Stockholm County (Jansson & Colding 2007).

The study examines a population increase of 400 000 - 600 000 new inhabitants in addition to the 1.8 million inhabitants in 2000.

Two alternatives for the projected growth were used: One includes spatial-specific projections of urban development, attempting to include ecological factors in regional planning such as communication efficiency and logistics and functional structure of green areas. The other alternative is when the urban area is assumed to grow in an expanding circular fashion with its centre in the middle of Stockholm city. However, the difference between the two alternatives was only slight, since in both alternatives nitrogen leakage from diffuse sources will decrease as a result of land-use changes. The land-use changes are similar in the alternatives both when regarding amount of transformed land and where it would occur.

The projected population growth will contribute to a 13-20 % increase in nitrogen load from point sources, compared to the present load from the Stockholm County, if the effectiveness of sewage water treatment remains on the present level. The total net N load will increase by 5-10 %. However, the study also compared this result with the effects of an improved sewage treatment[7] whereby the total net load would increase less; 1-6 %.

Time frame of the scenario

The scenario concerns a 20-30 % population increase, which have been projected to occur by 2030.

Risk and uncertainty associated with the scenario

The projections of population growth and the spatial-specific projections of urban development, to accommodate a larger population, have been developed by the office of regional planning and urban transportation and form the basis for guidance documents that are being used by urban planners in Stockholm. The general direction of the urban development and the magnitude of population increase are therefore likely to be close to the projected.

Ecological effects in the region and on the scale of the Baltic Sea

The projected increase in N load would imply an addition of 320-630 tonnes, if no measures to improve sewage treatment efficiency are taken. Compared to the larger

[7] Minimum 70 % N retention potential in all sewage water treatment plants. The four largest sewage treatment plants in the Stockholm County have at present an average N retention potential of 75 %. The additional human population is assumed to be connected to the four largest plants in all calculations.

changes in inputs resulting from the agriculture scenarios, these additions of nitrogen appear quite small. However, on the regional scale an impact on the eutrophication situation in the archipelago of Stockholm is to expect. The extra nutrients will also contribute to the overall eutrophication of the Baltic Sea.

Applicability of the scenario to other countries

Urbanisation and expansion of urban areas is not a phenomenon that is likely only in Stockholm, but similar development is to be expected in other cities in coastal areas although the pattern will be different in some regions (EEA 2006a, b, Martinez et al. 2007, Nowicki et al. 2007). The effects of urbanisation in other parts of the catchment area will thus be added to this example.

Scenario: Increasing shipping in the Baltic Sea – NO_x emissions from ships

Emissions of NO_x from shipping in the Baltic Sea and possible future emission rates have been calculated by Stipa et al. (2007) within the ShipNODeff program.

They have constructed five scenarios of NO_x emissions based on current and proposed regulations. IMO has a “Three tier approach” to reduce emissions of which Tier I has come into force and regulates emissions from engines manufactured after 1990. Tier II and III have been proposed and are under discussion.

The baseline scenario uses the monthly average amount of ships (3774) and the total NO_x emissions (370 000 tonnes) in the Baltic Sea in 2006. A constant ship renewal rate of 4 % has been assumed and that the emission of NO_x of an old ship left out from the annual emission due to renewal of ships represents a theoretical average of 20-year-old ships corresponding to a 2 % “abatement” until 2011 when functional development of engines is assumed to stop.

The baseline scenario was calculated for two possible rates of increase in Baltic Sea shipping:

- A 2.6 % annual increase in traffic
- A 5.2 % annual increase in traffic

The result show that with a 2.6 % increase in traffic NO_x emissions will reach 531 000 tonnes in 2030 and have an increasing trend. With a 5.2 % traffic increase emissions will be increasing further and reach a level of more than 900 000 tonnes.

Time frame of the scenario

The scenario calculations concern emissions until 2030.

Risk and uncertainty associated with the scenario

The scenario is based on simplifying assumptions and it is possible that ship renewal and “abatement” will be higher. However, the results clearly demonstrate the large effects of rate of traffic increase. At present, shipping is increasing with about

5 % per year in the Baltic Sea (Stipa et al. 2007), whereby the higher estimate of NO_x emissions seems more likely. In this context, it should also be noted that the other four scenarios, concerning implementation of Tier II and III, showed that with such increase in traffic only the most challenging proposal - 19% reduction of emissions from diesel engines to be implemented after 2011 and 80% reduction after 2015 - would reverse the increasing trend of NO_x emissions by 2030 (HELCOM 2008).

Ecological effects on the scale of the Baltic Sea

The transport, turbulent diffusion, chemical transformation and deposition of nitrogen and sulphur compounds in the Baltic Sea region have been modelled (for modelling details see Stipa et al. 2007) by running the model with ship emissions included and without emissions from shipping. The percentage of annual NO_x deposition caused by ship emissions was highest in the northern Baltic Proper, reaching up to 20 %. The relative effect of shipping emissions varies between seasons due to atmospheric conditions. It was found that up to 50 % of NO_x deposition during summer can be caused by shipping in the northern Baltic Proper and the Gulf of Finland.

Since the effect of shipping seems to be most pronounced during summer and production in the ecosystem (i.e. phytoplankton production) is highest during the same period, the consequences of an increased emission of NO_x can be severe. The result may be more frequent and intense algal blooms and a reduction of water transparency.

Fredrik Wulff is the director of Baltic Nest Institute at Stockholm Resilience Centre. He is also a professor in systems ecology at the Stockholm University. His research is focused on eutrophication and nutrient reduction measures in the Baltic Sea. The scenarios used by HELCOM to form the Baltic Sea Action Plan and the reductions included in the adopted plan was developed and calculated by Fredrik Wulff and his colleagues at the Baltic Nest Institute.

Actions to mitigate eutrophication were first initialized in the 1950’s and since then further steps to reduce the problem have been taken in all countries surrounding the Baltic Sea. There are however still several large gaps between the present status and the agreed targets, but the Baltic Sea Action Plan is by many people considered a major step forward in this work.

What can we expect from the Baltic Sea Action Plan? Will the ambitious nutrient reductions be reached?
The decided country-wise reductions in nutrient input are a major achievement. This gives each of the Baltic Sea countries incentives to actually take action, Fredrik says, instead of waiting for other countries to take responsibility for the nutrient emissions.

– This system opens up for nutrient trading, which I believe may be important to reach the decided targets. To reduce nutrient inputs in a cost-effective way such an instrument will be necessary. However, policy instruments were not decided in the action plan and therefore it is not clear how this will work.

– Neither the actual measures to reduce nutrient emission are obvious. This is an important part, because these large reductions require measures in several sectors. I think that building new and improve existing waste water treatment plants will be successful, but this has a major effect only on phosphorus emissions. To reach the targets for nitrogen changed agricultural practices will also be necessary. This is much more difficult to achieve. Technical solutions are discussed, but there is not yet legislation and economical policy instruments to make this work.

– These issues should also be viewed in an international perspective – what will work in Sweden may not work in Poland. The potential for reductions differs also between countries. Take nitrogen reductions in Poland for example – nitrogen leakage from soils is relatively low in Poland, but it is a large country whereby total emissions are large. But how can reductions be made from an already low level? There is at present no solution to such issues, Fredrik says.

The timeframe for improvements is important
It is stated in the Baltic Sea Action Plan that the measures implemented by 2016 are intended to bring the Baltic Sea into "good ecological and environmental status" in 2021. This is not possible, Fredrik says.

Even if we by magic were able to turn off the tap with nutrient-rich water immediately, the effects will not be seen on a larger scale until decades later. There are so large amounts of phosphorus present in the system that even such instant reductions will not change the concentrations until many years have passed, Fredrik states.

Other future trends may counteract the improvements foreseen by the action plan
We must have this long time perspective for effects in the ecosystem and therefore other trends in the Baltic Sea catchment need to be considered. Especially the lifestyle of the Baltic Sea people is important, Fredrik believes, since lifestyle is much more difficult change than for example sewage water treatment.

Improved living standard will most likely lead to increased demand for meat products and will drive a development towards more meat production and more intensive agriculture. Other aspects related to life-style are road transport and energy consumption. Increased world market prices of agricultural products will lead to intensified agriculture in Europe. We can expect an increase of these variables in several countries and they will contribute to more emissions of nitrogen and phosphorus.

Altogether – what do you believe will be the nutrient status of the Baltic Sea in the future?
– I don't believe I will experience reduced eutrophication in the Baltic Sea, Fredrik says. In the best case substantial decreased phosphorus inputs will be observed within 10-15 years. If we find an engineering solution to also decrease the amount of available phosphorus in the sea, we may have fewer problems with cyanobacterial blooms in 15-20 years. Still, we should absolutely take action to reduce eutrophication, but keeping in mind that improvements will not be seen soon.

– My opinion is that at the moment, radical changes in fisheries exploitation are instead the most important measures for a rapid improved environment in the Baltic Sea. For this issue, effects will be seen much sooner – within a few years. It is clearly possible that a larger cod stock may also contribute to reduced effects of eutrophication, Fredrik Wulff concludes.

A summary of the scenario studies

The scenarios give a diverse picture of the future eutrophication situation. The different magnitude of the scenario effects suggest, just like the present sources of nutrients, that the development of agriculture is the most important factor. This development is presently uncertain in the Baltic Sea catchment area, since the published studies have not foreseen the current price increase. However, there is a potential for reduced nutrient input from agriculture land as well as for improvements of sewage water treatment. Land-based NO_x emissions are likely to decrease, but the emissions from shipping appear to increase, possibly to a much larger extent.

The ambitious targets set in the Baltic Sea Action Plan may not be reached in the time frame stated in the plan, but the willingness to commit to the solution to this issue gives reasons to expect improvements in a longer time perspective.

Ecological consequences of eutrophication

Nitrogen and phosphorus are growth limiting nutrients and thus necessary for primary production. Addition of nutrients stimulates primary production leading to a corresponding biomass increase. This causes a series of effects and changes throughout the food web.

- The excess production will increase sedimentation of organic matter, which leads to elevated oxygen demand at the bottom through the enhanced activity of decomposers. This causes oxygen depletion and eventually anoxic conditions with presence of hydrogen sulphide. The consequences are often death of sessile benthic organisms and escape, and sometimes death, of bottom dwelling fish (Bernes 2005). Invertebrate bottom fauna has been found to have decreased substantially at larger depths due to oxygen depletion in the Baltic Sea, whereas the increased primary production appears to have stimulated an increase of bottom fauna at smaller depths (Cederwall & Elmgren 1980).
- Direct input and resuspension of phosphorus from sediments due to prevailing anoxic conditions contribute to high concentrations of available nutrients. The seasonal fluctuations of nutrient concentrations cause algal blooms. Most pronounced are spring blooms and summer cyanobacterial blooms. The nitrogen fixation capability of cyanobacteria may further contribute to increased nutrient levels (Vahtera et al. 2007).
- The species composition and functioning of the food web is often changed - with increasing proportion of small non-siliceous plankton compared to diatoms, grazing by ciliates and dinoflagellates is enhanced compared to grazing by copepods. A larger fraction of the energy will pass through mi-

crobial food webs before entering the linear food web of zooplankton – small fish – top predators. This implies a less efficient energy transfer.

- Light penetration is negatively affected by phytoplankton production. The Secchi depth, a measure of how deep light penetrates through the water column, will be reduced when nutrient input and correspondingly phytoplankton production is increased. There has been a decrease in Secchi depth throughout last century, indicating an increased overall phytoplankton production (Sanden & Håkansson 1996).
- Opportunistic filamentous algae will be favoured at the expense of perennials on shallower bottoms.
- The abundance of seagrasses and perennial makroalgae will be restricted due to the reduced light penetration and overgrowth by filamentous algae.
    - Seagrass meadows are a three-dimensional structured habitat with high production, high species and functional diversity and they are important nursery areas for fishes and crustaceans. Local distribution and abundance of seagrass meadows is variable between years, but in general this habitat has decreased during the last century, especially in Skagerrak and Kattegat (Pihl et al. 1999, Baden et al. 2003). The main cause is likely eutrophication, but construction projects in coastal areas may also significantly impact seagrass meadows.
    - Macroalgal belts also provide protecting structures and are thus important reproduction areas for fish. Studies show decreased depth penetration from the 1940's to the 90's, mostly related to eutrophication effects and in some areas increased isopod grazing (e.g. Kautsky 2000, 2005). Recently, the bladder wrack *Fucus* spp. stands has recovered in some areas, e.g. in the Åland Sea where the improvement is most pronounced, and in the Stockholm archipelago, likely as a result from improved sewage water treatment (Karlsson & Kautsky 2007).

Thus the loss of these habitats cause a reduction of the areas of suitable reproduction habitat for crustaceans and fishes as well as feeding areas for a large numbers of grazers and predatory fishes. The community structure will change leading to reduced biodiversity.

Are there ignored links between fisheries and eutrophication?

Algal blooms and loss of macroalgal belts have so far been attributed to eutrophication, but it possible that a reduced cod stock contribute to this problem. The high sprat stock is a result of the lowered predation pressure from cod. Increased sprat consumption of zooplankton may also be connected to the next level of the ecosystem – phytoplankton, since reduced zooplankton grazing on phytoplankton is a possible result. A decrease of the cod stock could thus lead to more algal blooms.

This hypothesis has a firm scientific base in the substantial research that has been conducted in lake ecosystems, where similar interactions have been documented. There are still only a handful of cases from marine ecosystems that indicate such interactions between fish stocks and algal blooms (Shiomoto et al. 1997, Carscadden et al. 2001, Frank et al. 2005, Scheffer et al. 2005). The cod feeds also on benthic isopods, which in turn eat bladder wrack (*Fucus*). When the cod stock decreases there is a potential for these invertebrates to increase, which may lead to increased consumption of bladder wrack (Bernes 2005, Nilsson et al. 2005).

In addition, eutrophication in itself is connected to cod production. The ecosystem approach is a way of managing these issues together. This new approach to management and the couplings between predatory fishes, fish predators, fisheries and eutrophication are described by Sture Hansson in below.

Sture Hansson is a professor in systems ecology at Stockholm University. His research concerns coastal and pelagic fish and fisheries with a special focus on ecosystem interactions in the Baltic Sea.

The ecosystem approach has during recent years been in focus for management, replacing slowly the earlier perspective with single species or resources being managed separately.

– This approach is in many ways a step forward, Sture says. It allows us to manage for example commercial fish populations in a way where also the impact on other parts of the ecosystem can be taken into account. It is important however not to hide behind this new way of thinking and say that we need to know more before management decisions can be made in cases that are very simple.

– If we talk about cod in the Baltic we do not need an ecosystem approach to identify important actions to reach the major goals. We know that a two-year stop in the cod fishery would allow the cod stock to more than double, which will allow a sustainable yield in the future that is realistic to believe will be twice the current yield. This conclusion can be drawn with confidence from simple single-species models.

– The ecosystem approach is still very valuable for studying more complex situations and I believe that we need to use ecosystem models together with single-species models. A set of tools can give us the necessary insights for effective sustainable management of the whole ecosystem. Intuitively, I would say that 80-90% of all problems associated with ecological effects of fisheries would be solved if managers followed the scientific advices that are based on single species approach.

Interactions between eutrophication, seal numbers and fish populations
Sture has together with colleagues at the Department of Systems Ecology studied how eutrophication impacts fish production in the Baltic Proper.

– We have used “Ecosim” to build an ecosystem model, which is included in the Baltic Nest decision support system, to study the interactions between different management actions. The study simulates effects of different fishing pressure, changed spring and summer phytoplankton production and different seal population size.

– The study highlights the necessity of managing these issues together. It is not possible to reach all goals at the same time. Phytoplankton production seems to influence fish production and now, in a eutrophied situation, the absolute volumes in Baltic Sea fisheries have increased. If we decrease nutrient input the overall production will decrease. Some species, like cod, will however benefit due to improved reproduction with better oxygen conditions. But there is a limit after which the cod will face problems due to decreasing food availability.

– When we look at the period before the 1950's there were no major problems with oxygen depletion in the Baltic, so the conditions for cod reproduction were much better than today. But the cod stock was, despite this, not very large.

– In conclusion, eutrophication has positive and negative impacts. It is positive for total production, but it has negative effects on some species – like cod. In this situation it is important that we accept the prerequisites and strive for a management of the cod population that gives the maximum long-term yield.

– Another conclusion from the study is that we need to realize that seals are competitors with us for fish resources. Again we can not have large populations of all species simultaneously. Still, we can have far more seals than today and get the same yield from fisheries, but then we need to have a different fisheries management.

– These conclusions from the Ecosim model gives one type of advice for an ecosystem based management. But it is important to stress that these results are of relevance only in a long term perspective. For year-to-year management decisions, single species or simple multispecies fisheries models (like VPA) are much more relevant since they are responsive to actual variation in e.g. fish reproduction success.

Can predatory fish be used to reduce the effects of eutrophication?
Biomanipulation, actions to increase densities of predatory fish, are used in lakes to improve water transparency. In marine systems this has not been done. Sture is the project leader for a first attempt to test whether stockings of pikeperch can lead to improved water quality in Himmerfjärden, an area in the southern archipelago of Stockholm.

– During 2008-2010 about 290 000 young-of-the-year pikeperch will be stocked annually in Himmerfjärden. The theory is that this will increase predation on herring, resulting in higher zooplankton abundance and thereby phytoplankton grazing will increase. Reduced phytoplankton level implies clearer water and thereby we will have a mechanism to manage the effects of eutrophication, Sture explains.

– Long time series exist from this area and we will continue these studies, but also make new investigations. It is important to investigate potential negative effects, e.g. reductions in pike and perch populations, as observed in lake experiments. The results will give further insights to how we can manipulate the system, but will also be valuable for decisions on what is possible to achieve at the same time. It is likely also in this situation that we have to make a choice on whether we want to have clear water or a potential for recreational fisheries on pike and perch[8].

– If the biomanipulation works, it will provide a strong argument for a management that would increase the Baltic cod stock. This could be expected to produce a trophic cascade that would result in decreased effects of eutrophication, Sture concludes.

[8] Pikeperch may compete with pike and perch for resources (e.g. food, space) and the stockings of pikeperch can thus lead to reduced stocks of pike and perch.

Knowledge about cyanobacteria and their role in the foodweb is necessary
Blooms of cyanobacteria have been pointed out as one of the major problems during recent years, Sture says. But they may be very important for fish production! At present we do not have any knowledge about this. We can see that cyanobacterial blooms occur at the same time as we have the major production of zooplankton. The zooplankton production forms the basis for fish production. Thus, we need knowledge about how the production based on cyanobacteria flows through the foodweb and how zooplankton would be affected if there was no cyanobacterial blooms.

The factors structuring zooplankton and phytoplankton communities are not well known in marine systems
From studies in fresh water systems we know that there can be top-down effects from predatory fish down to phytoplankton. We do not have the same knowledge in marine systems, Sture says. When cod has been exploited there have been large increases in cod prey species (i.e. sprat in the Baltic, the shrimp *Annulus* in the North-east Atlantic, lobster on the east coast of America). The coupling between these zooplankton predators and zooplankton is poorly understood. In turn we do not know how zooplankton affects phytoplankton.

If we had this knowledge we would be able to understand how much, of what we perceive as eutrophication, in reality is not caused by extra nutrients but caused by human-induced changes in upper trophic levels through fisheries exploitation, Sture states.

Bladder wrack partly overgrown with filamentous algae. Photo: M. Kadin

Excessive fisheries exploitation: The case of the Baltic cod stock – A possible collapse?

The commercially important fishes in the Baltic Sea and the Skagerrak and the use of these resources have received a lot of attention especially during recent years. Cod is the most valuable fish in the Baltic Sea, and a large proportion of the fishermen in the region are dependent on viable cod stocks. The cod stock and catches have been decreasing during recent decades to the present very low level.

A majority of the catch is taken from the eastern stock – the genetically unique Baltic Sea cod – mainly in Hanö Bay and around Bornholm. Cod fisheries in the Baltic Sea are dominated by Poland, Denmark and Sweden, but also Germany, Latvia, Lithuania and Russia land substantial catches (ICES 2007a, b, c). The profitability in commercial fisheries has decreased during several years and today the contribution from fisheries to Danish, Swedish and Polish economies is modest and only constitutes 0.5, 0.2 and 0.005 % of GDP respectively (FAO 2007a, b, c). However, fishery is regionally an important source of employment. About 3 200 fishermen are active from Denmark, fishing in the Baltic and North Seas, and other seas (FAO 2007b). In 2004, Poland had 3 800 fishermen active in the Baltic (FAO 2007a). Sweden had in 2005 slightly more than 1 700 licensed fishermen on the west coast and in the Baltic (Swedish Board of Fisheries 2006). It is unclear how many of these are employed full time as fishermen. The processing industry employs additional people and recreational fishing for cod is a well-established activity in Germany, Denmark and along parts of the Swedish west coast. The absence of large cod stocks thus affects several sectors.

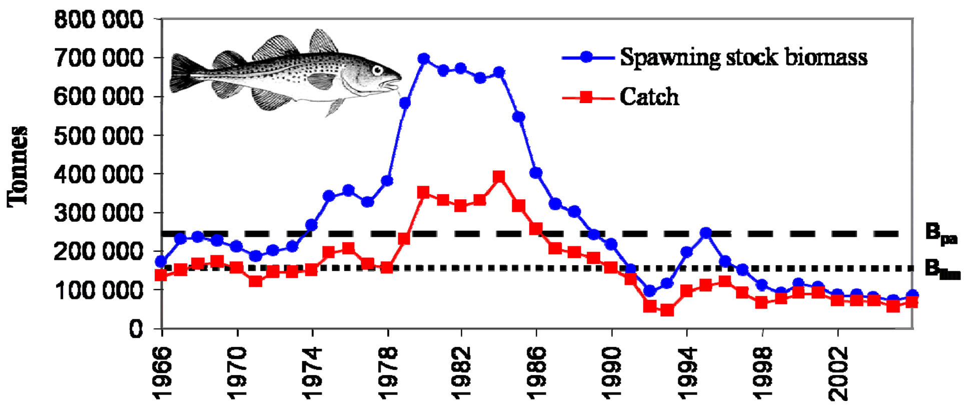

Fig. 4. Spawning stock biomass and annual catches of the eastern Baltic cod stock 1966 – 2006. Data from ICES (2007a) and Olle Hjerne, Stockholm University.

Despite the importance of a viable cod stock, no substantial action has been taken to improve the situation. The International Council for the Exploration of the Seas (ICES) is coordinating fisheries research and producing advice on what fishing pressure the stocks can take. ICES defines a lower limit for the amount of adult fish needed (160 000 tonnes for the eastern stock) to reduce the risks of collapse and generally recommend fishing ban if the stock falls below this level. The stock has been below the critical level during most of the 1990s and during the 2000s (Fig. 4). The risk for collapse is thus very real, but despite this fact, 60 % of all adult cod has been taken from the Baltic annually (Bernes 2005, Sjöstrand 2007).

Possible outcomes in the future

Without actions to change the current situation there are three possible future outcomes: An increase of the cod stock, a continuingly low stock or a collapse. Without actions, an increasing stock seems highly unlikely. Inflow of oxygen-rich saline water from the North Sea may occur and improve reproductive conditions for cod. The projected climate change makes it unfortunately unlikely that favourable reproductive conditions will be more common in the future (HELCOM 2007b, MacKenzie et al. 2007, BACC 2008). Even if they do occur, reproduction is dependant on adult cod which with current fishing practices is to a large extent removed from the system. The potential for growth is thus to a great extent eliminated by the current high fishing pressure.

A cod stock remaining at the present low level is much more likely. During the last decade the cod stock has roughly been of the same size, indicating that the factors regulating the stock altogether have not changed much and that the catch is equal to the production. This may also continue in the future. However, the present size of the cod stock, far below the safety limit, makes the stock vulnerable to stochastic events where a collapse may be the result. Such an event can be failed reproduction due to climatic conditions (MacKenzie et al. 2007). The current exploitation has also resulted in a decreased mean size and age and since smaller females produce fewer eggs with reduced survival in poor oxygen conditions the population is even more sensitive to deep water hypoxia. Another factor with potentially severe consequences is predation on cod eggs and larvae. Sprat larvae can prey on cod eggs (Casini 2006) and although not commonly occurring at present, decreased food availability for the large sprat stock may induce a shift where a significant proportion of the cod eggs are preyed upon. A few consecutive years with no reproduction and the same fishing pressure as today will reduce the cod stock to a level where a recovery would be much more difficult to achieve, if all possible (Casini 2006, Österblom et al. 2007).

Ecological consequences

Sprat is the main prey of the Baltic cod and thus the increase of the sprat stock, mainly during the 1990's, was a result of the lowered predation pressure from cod. The continued low predation pressure on sprat allows the stock to remain at a high level. Top-down regulation impacts also the next trophic level – zooplankton, in which several species likely have decreased due to sprat predation (Möllmann et al. 2004). With an even further reduced cod stock it is possible that the observed cascading ecosystem effects will become more pronounced.

The large sprat stock has implications for other parts of the food web. Along the Swedish east coast a decrease of pike and perch has been observed. For some reason, neither fry from pike nor perch survive, and the investigations from the Swedish Board of Fisheries illustrate that this effect is most pronounced in areas that are more exposed to the open Baltic. There is a clear absence of zooplankton in these areas, an important food source for pike and perch fry. A probable explanation for the decrease of pike and perch is thus a lack of food caused by a large sprat stock (Bernes 2005, Ljunggren et al. 2005).

A disappearance of the cod will not only mean the loss of an important resource, it will also have consequences throughout the food web. In addition, effects attributed to eutrophication may in part be caused by a low cod stock, which is further discussed in the section *Are there ignored links between fisheries and eutrophication?*. Many of these connections are poorly understood and it is clearly possible that other effects will emerge – effects we are unaware of today.

Aquaculture

Aquaculture is cultivation of algae or aquatic animals in land-based tanks, ponds or in natural water bodies, an industry which on a global scale is considered important, especially in coastal areas. Here aquaculture refers to farming in coastal or marine waters in the Baltic Sea and Skagerrak. Within this context the dominant purpose of aquaculture is production of food for human consumption.

Background

Larger scale aquaculture in the Baltic Sea and in Skagerrak started during the 1970's, with a rapid increase during the 80's before stabilization and in some countries a decline (e.g. Denmark, Sweden, Finland) in the 90's (Official Statistics of Finland 2007, Statistics Sweden 2007b). The industry is of relatively low importance due to unfavourable biological (e.g. temperature, salinity) and economical conditions (Holmer & Håkansson 2008). In Skagerrak aquaculture involves mainly rainbow trout and blue mussels (Eurostat 2006, Statistics Sweden 2007b). In the Baltic Sea the most commonly farmed species is rainbow trout, but whitefish, common carp and other species also occurs (Eurostat 2006, Official Statistics of Finland 2007). Aquaculture production in Estonia, Latvia and Lithuania have been much smaller than in the other Baltic Sea countries and according to statistics from Eurostat (2006) all production takes place in freshwater environments. Poland is a larger producer but also here in freshwater only (Eurostat 2006).

When the environmental aspects of aquaculture are discussed it is important to differentiate between production where nothing or only the cultivated species is added to the system and production where input of food or drugs is necessary. Examples of the first type of production include algae and mussels, where the organisms take up existing nutrients from the water and are being harvested. Artificial substrates may be provided, as in mussel production in Skagerrak where mussels typically grow on ropes hanging from buoys on the surface. Herbivorous fishes can feed on natural vegetation or plankton, but cultivation of predatory fishes requires addition of food.

Aquaculture should also be viewed in the context of utilization of a resource for food production. Harvest of autotrophs, such as algae, is way of using bound solar energy. Similarly, although with largely reduced efficiency in energy transfer, are consumption of aquaculture products from higher trophic levels also use of bound energy and nutrients. When predatory fishes are farmed, the overall fish production in the system may be higher than if only wild-caught fish are consumed or if only farmed fish is consumed (Naylor et al. 2000). Catching a sustainable proportion of the wild predatory fish will allow consumption of the wild fish and an increase of the prey fish population, whereby the prey species can be caught and used to feed predatory fish in fish farms. However, this requires proper selection of species for wild catches, for production of fish meal and for farming, as well as it needs to be balanced within the same ecosystem. Farming of predatory fishes is seldom, if ever, carried out in this way whereby the risk of overfished populations, to produce fish meal, still remains at the same time as local and regional effects of farming of predatory fishes remain.

Possible future aquaculture in the Baltic Sea and Skagerrak

Aquaculture is projected to become more important globally, both in absolute terms and in relation to fisheries (FAO 2006) in order to provide an increasing world population with aquatic food, since global fisheries catches have levelled off. The trend for aquaculture in Skagerrak and Baltic Sea is more uncertain, but the global demand may have an impact.

During the last years farming of rainbow trout for human consumption has increased slightly in marine waters in Sweden, but the production is still lower than in the 1990's (Statistics Sweden 2007b). Mussel production is more variable but was in 2006 the highest since the mid 90's (Statistics Sweden 2007b). In a background report to the Swedish Board of Fisheries Björn Lindblad foresees increased production of rainbow trout along the Swedish coast of Bothnian Sea and Gulf of Bothnia, where he believes large farms will be situated in total producing 6 000 - 8 000 tonnes of rainbow trout (Lindblad 2005). That would correspond to a three- to fourfold increase compared to the current production in marine waters. Lindblad (2005) also foresees a large expansion of mussel farming, three to five times the present production. In addition, Lindblad (2005) expects mussel farming, with the sole purpose of nutrient removal, to take place in the Baltic in the future. The time perspective for these changes is however not mentioned in the report. At present, an evaluation of the prerequisites for future sustainable aquaculture in Sweden is taken place, which was initialized by the Swedish Government and will be reported in December 2008 as a Swedish Government Official Report (Jo 2007:05, see further www.sou.gov.se).

Finnish food fish production in the Baltic has decreased since the early 1990's. A major part of this production takes place in Åland where the authorities have become more restrictive towards farming of predatory fish (mostly rainbow trout) whereby new permits are seldom given, sizes of existing farms have been limited and farms are required to meet higher standards regarding emissions (Lindblad 2005, Åland Parliament 2005.). Thereby it is possible that production will continue to decrease, but information about specific trends or projections into the future has not been found.

Investments in marine aquaculture are made in former eastern European countries and according to Holmer & Håkansson (2008) production in the Baltic Sea is expected to increase during the next decade.

Ecological consequences

In the Baltic Sea and Skagerrak the most controversial impact of aquaculture is eutrophication. Since the major part of aquaculture in this area today, and most likely in the future, concerns farming of predatory fishes the consequences of input of artificial food are of importance.

Locally, food spill and fish excretion products lead to dissolved nutrients and settling particles, which may cause eutrophication events, such as high oxygen demands in sediments and effects on the benthic community (Hall et al. 1990, 1992, Holmer & Håkansson 2008).

Phytoplankton blooms associated with nutrient emissions from single farms have not been observed. Water renewal rate is rather high where most fish farms are situated and hence released nutrients are soon (within hours) diluted to low concentrations (Holmer & Håkansson 2008). Phytoplankton growth rate is slower, with doubling rates of days, and thus high concentrations of nutrients are not available for promoting blooms (Holmer & Håkansson 2008). Such mechanisms may come into play however, if farms with predatory fishes are placed in areas with longer water residence time.

The released nutrients from fish farms contribute to the pool of nutrients in the water and will in that way contribute to eutrophication. To what extent farming of predatory fishes contribute to the eutrophied state of the Baltic and the Skagerrak depends on the choice of comparisons.

Ærtebjerg et al. (2003) estimate that emissions from aquaculture in marine waters to constitute 0.4 % and 1.4 % of nitrogen and phosphorus input to Danish seas respectively. Compared to the direct point sources aquaculture in coastal areas contributed with 9 % of N and 8 % of P (Ærtebjerg et al. 2003). According to the Swedish Board of Fisheries (2005) the input from Swedish aquaculture constitutes 1 % of the total phosphorus emissions of anthropogenic origin. However, the calculated phosphorus emissions of 40 tonnes in 2003 (Swedish Board of Fisheries 2005) can also be compared to emissions from other point sources (municipal and industrial waste water) which together released 702 tonnes of phosphorus in 2004 (Statistics Sweden 2007a), which gives a contribution from aquaculture of about 5.7 % (The Swedish figures include emissions to both fresh and marine waters.).

Large investments have been made and strict regulations have been implemented in many countries to reduce nutrient input from other point sources around the Baltic Sea and Skagerrak (Appendix II). Similar investments and restrictions have not been focused on farming of predatory fishes. Possible measures to reduce nutrient release include closed systems where effluents are collected and treated before release and integrated cultivation of species from multiple trophic levels, including makroalgae and shellfish, which extract nutrients by consuming phytoplankton.

Capture of wild fish for fish meal production locally or regionally would also contribute to a minimization of the impact.

Aquaculture can also be used to remove nutrients from ocean water and thereby reduce eutrophication – through farming of extractive species such as mussels. The mussels filter particles and phytoplankton from the water and when harvested nutrients are removed from the marine system. One tonne of blue mussels contain up to 10 kg nitrogen and 0.6 kg of phosphorus. Mussel farming can thereby be a complement to other measures to mitigate eutrophication (Forum Skagerrak 2004, Lindahl et al. 2005) for example in vicinity of point sources such as sewage treatment plants and farms with predatory fishes.

Another aspect to consider is the origin of the cultivated species. Non-native species may cause undesired ecological impacts (see further *Harmful alien species will be introduced*). The escape of farmed individuals of different genetic origin may lead to hybridization with naturally occurring populations causing depletion of local genetic resources. A different origin of the cultivated species may also bring new diseases that can be transferred to wild populations. The use of drugs, such as antibiotics, to combat and prevent diseases in aquaculture may have negative impacts when emitted into the ecosystem.

However, the knowledge about negative impacts on wild forms of farmed species increases and the Swedish Board of Fisheries has a strategy based on the precautionary approach, which have led to stricter restrictions of if and where specific species and breeds can be farmed (Swedish Board of Fisheries 2005). The available info on use of antibiotics gives a positive picture - in Sweden, the use decreased with roughly 95 % during the last decade (Swedish Board of Fisheries 2005) and in Norway the decrease between 1987 and 2005 was 98 % (Official Statistics of Norway 2007).

Global climate change will impact our seas

There is a strong and growing agreement among scientists that human activities are changing and will continue to change global and regional climate. The Intergovernmental Panel on Climate Change (IPCC) has concluded that global temperature has increased by 0.74 degrees during the last century (IPCC 2007a). Mean temperature will most likely continue to increase during the next century with a global temperature 1.8-4.0 degrees higher in the end of the 21st century compared to 1980-1999 (IPCC 2007a).

Background

Global simulations and emission scenarios

To evaluate the impacts in a specific area of possible global climate change scenarios, a regional model with higher resolution is necessary, where the results of a global climate model provide boundary conditions. Global climate models used to study and simulate the climate system are coupled atmosphere-ocean general circulation models (often referred to as GCMs). To project future climate IPCC has constructed four storylines - possible characteristics of four future worlds (see Fig. 5). The storylines provide basis for several more specific emission scenarios (SRES scenarios [IPCC 2000]), each a plausible representation of a development of emissions of greenhouse gases and aerosol precursors corresponding to the storyline. Each emission scenario can then be used as driving data in a projection of future climate.

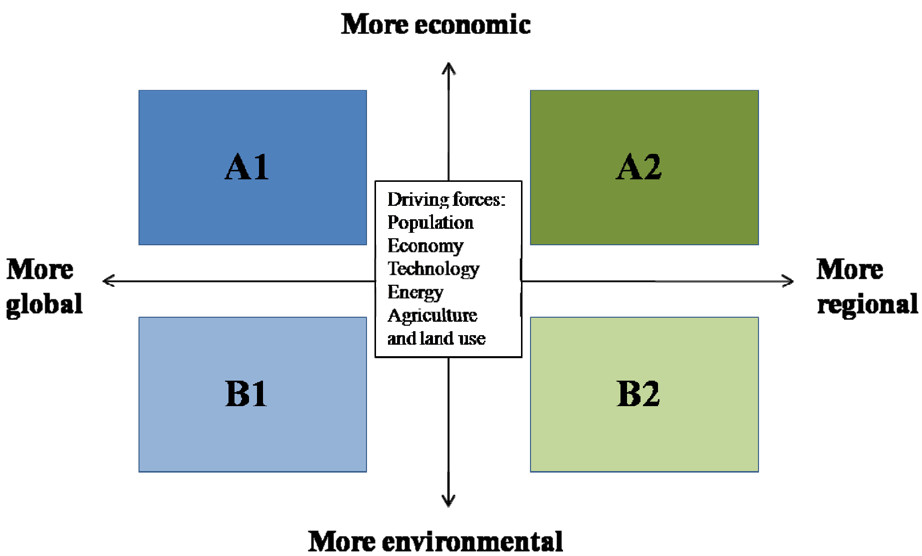

Fig 5. The main characteristics of the four storylines corresponding to emission scenarios. Based on IPCC (2000).

Regional simulations

For the Baltic Sea four regional projections were made using the coupled Rossby Centre Regional Atmosphere-Ocean Model (RCAO) from the Swedish Meteorological and Hydrological Institute (SMHI). Two global models were used to provide boundary conditions: HadAM3H from Hadley Centre, UK, and ECHAM4/OPYC3 from Max Planck Institute for Meteorology, Germany. For each GCM two SRES scenarios; A2 and B2, were used as driving data. More thorough descriptions of model and scenario selection are given in “Assessment of Climate Change for the Baltic Sea Basin” from BACC (2008), from which the marine system sections are summarized in HELCOM Thematic Assessment: “Climate Change in the Baltic Sea Area” (HELCOM 2007b), and in “Sweden facing climate change” from the Swedish Commission on Climate and Vulnerability (SOU 2007:60).

Scenario studies

The relevant factors influencing the rate and the degree of climate change are assumed to have been thoroughly covered by IPCC when the SRES scenarios were developed. Hence it is most likely that the future climate will fall within the range of simulation results based on these scenarios. The regional simulations do not cover an equally wide range of SRES scenarios, but include a medium-high emission scenario (A2) and a medium-low emission scenario (B2).

This section is a compilation of projected changes in the marine environment based on the BACC (2008) assessment and the assessment from the Swedish Commission on Climate and Vulnerability (SOU 2007:60), unless otherwise stated.

Sea temperature

The overall increase in air temperature will cause a rise in sea surface temperature. Based on an average between the regional projections the smallest effect during winter will be in the Gulf of Bothnia, as ice is still expected to cover the northern part of the Gulf and remain along the coasts. In spring, the temperature increase there is still small, but in summer the Gulf of Bothnia is expected to face the largest rise in temperature – more than 4 degrees in most parts. The Baltic Proper will have a similar temperature increase in all seasons, 2-3 degrees. The Danish straits and Kattegat face a sea surface temperature about 2 degrees higher than today throughout the year.

Time frame of the scenario

The global and regional (i.e. Baltic Sea including Kattegat) climate simulations focus on the end of the 21st century. The results presented here concerns the average for the 30-year period 2071 – 2100.

Risk and uncertainty associated with the scenario

The risks of the presented events have not been assessed. There are of course large uncertainties associated with projections on the time scale relevant for climate change. However, since the global and regional studies include a range of emission scenarios and several models it appears rather likely that the actual change will fall within the range of results from the simulations. For further descriptions of the uncertainties read for example the BACC assessment (2008) or the IPCC Fourth Assessment report (available from www.ipcc.ch).

Ecological consequences

For phytoplankton, a general temperature increase will affect species interactions. In mild winters, water temperature does not fall below the point of its highest density (4°C) in the southern parts of the Baltic. Thereby complete vertical mixing does not occur and spring temperature increase leads to immediate stratification of the water. Species that benefit from water turbulence, e.g. diatoms, will have reduced growth potential. In contrast, the stable conditions will enhance growth of dinoflagellates. This pattern has also been observed in the springs following the many mild winters since 1988 (HELCOM 2007b).

Extensive blooms of cyanobacteria have been found to occur only when water temperatures exceed 16°C (among other factors). Therefore the occurrence of summer algal blooms is expected to increase (HELCOM 2007b).

Wintering waterbirds seem to be sensitive to climate variability, with temperature extremes affecting winter survival and winter conditions determining the range of birds in the Baltic Sea area. A northward shift in the distribution of several wintering coastal bird species have been observed in the Baltic during the last decades with many mild winters. This trend suggests a relationship between winter climate and the core of the wintering bird populations. Benthic herbivorous and carnivorous birds constitute the majority of the more than 10 million waterbirds wintering in the Baltic and a shift in distribution may impact benthic vegetation along the coasts and for example stocks of bivalves (Durinck et al. 1994, HELCOM 2007b).

Ice coverage

Ice cover will be drastically reduced, a result which has been obtained regardless of models and simulations used. The reductions regard both the maximum geographical extent of ice and the length of the ice season. By the end of the century, large parts of Gulf of Riga, Gulf of Finland and the Bothnian Sea will, on average, become free of ice. The ice season will be 2-3 months shorter in the central Baltic Sea and 1-2 months shorter in the northern parts. In some simulations occurrence of winters without ice formation is projected.

Time frame, risk and uncertainties of the scenario

See *Sea temperature* above.

Ecological consequences

The Baltic ringed seal is facing difficulties if ice coverage is reduced, since pack ice is their breeding habitat. The pups are born on the ice in February-March, preferably in lairs formed under the snow if enough snow has accumulated on the ice. The projected shorter ice season may drastically reduce the area where pupping is possible and lead to a reduction of and a northward shift in occurrence of the ringed seal. The subpopulations in the Gulf of Riga, Gulf of Finland and Archipelago Sea may go extinct (Meier et al. 2004, HELCOM 2007b).

Grey seals may also be similarly affected by reductions in ice cover, but they have potential to shift to land breeding. However, there are indications of higher mortality when pups are born on skerries. In contrast, winter feeding conditions for grey seals may improve if formerly ice-covered areas become available. The overall impact on the grey seal population is unknown (HELCOM 2007b).

Sea level

Sea level will rise, partly due to global changes in sea level but more westerly winds, as is projected by the global model ECHAM4/OPYC3, may further increase this effect. In a low scenario the continued land elevation will have a much more pronounced effect than sea level rise in the northern Baltic Sea, with a rise in land level up to one metre by the end of the century. Further south the balance between these counteracting factors will shift and in the southernmost parts a few centimetres of sea level rise is expected. In a high scenario the south-eastern Baltic coast face the largest increase, close to one metre, whereas the sea level rise will decline to the north up to the Gulf of Bothnia where sea level will be similar to the present level. Increase in extremes of high water is however more pronounced than sea level rise by the end of the century.

Time frame, risk and uncertainties of the scenario

See *Sea temperature*.

Ecological consequences

Many haul-out and breeding sites for grey seals and harbour seals are low skerries and reefs. In the southern parts of the Baltic, where a sea level rise is most likely, there may be a reduction in available sites which will have a negative impact on these species.

Baltic Sea salinity

Salinity may change and there are primarily two factors that are expected to govern this change. The pattern of salt water inflow through Kattegat and the Sound may change mainly due to changes in wind direction and force. Also, fresh-water input is likely to be higher, as an increase is projected in precipitation in the northern part of the Baltic Sea catchment area.

Salinity changes was studied with the modelling approach described above, giving a projected decrease in salinity of 8-50 % on average. However, there were large uncertainties associated with these results since model biases were not known. Therefore additional simulations were conducted, using a multi-model ensemble approach. In this study the Rossby Centre Ocean Model (RCO – the oceanic part of the coupled model RCAO) was forced with results from sixteen scenario simulations using five GCMs, seven RCMs (regional climate models) and the SRES scenarios A2 and B2 (Meier et al. 2006). The study showed that there is a great uncertainty in future Baltic Sea salinity. In eleven simulations there was no change in salinity or small, not statistically significant, decreases or increases. With ECHAM4 as GCM large decreases in salinity were projected, up to 47 %. These differences between results and how they should be interpreted are explained below by Markus Meier.

Markus Meier is a researcher at the Swedish Meteorological and Hydrological Institute (SMHI), where he is head of the Division of Oceanography at the Research Department. Markus Meier and his colleagues at SMHI conducted most of the climate modelling work included in "Sweden facing climate change" – the final report from the Swedish Commission on Climate and Vulnerability. He is also a contributing author to Assessment of Climate Change for the Baltic Sea Basin (BACC 2008).

The impact of future climate on salinity in the Baltic Sea is uncertain according to the assessments from the Commission on Climate and Vulnerability and BACC. Is it possible to say anything more today?

There has not been any other study on salinity in the Baltic, Markus says. The large uncertainties are caused by differences between global climate models (GCMs). Salinity differences between simulations using a particular RCM driven by different GCMs (and forced by one emission scenario, A2 or B2) are larger than the salinity differences between scenario simulations using different RCMs driven by the same GCM. The uncertainty caused by the emission scenario is also smaller than the uncertainty caused by GCM differences.

– It is difficult to reduce the uncertainty further, since the global models that provide the basis for the simulations have only a few grid cells in this area. The global models produce similar results for larger geographical areas, but there are differences. These, maybe not very large, differences in winds and precipitation have large effects on response of the climate in the Baltic Sea area, Markus explains.

– Still, we should not say that we do not know anything about salinity in the Baltic Sea in a changed climate. The salinity may drop as much as 50 % or it may remain on the same level as today. But it is clear that the Baltic will not become oversalted.

– However, this uncertainty about future salinity is important to include when the results are applied. The biogeochemical system is, of course among other factors, dependant on salinity levels and therefore it should be pointed out which projected climate and associated salinity that is used when discussing a set of consequences, Markus Meier concludes.

In simulations with a large decrease in salinity, the halocline[9] is deeper. This will lead to improvements of oxygen conditions in northern Baltic Proper. However, the increased temperature will imply lower oxygen levels in more shallow parts, such as the southern Baltic Proper. More severe oxygen deficiency is expected in deeper parts of Baltic Proper, the Belt Sea and southern Kattegat (Hansen & Bendtsen 2006).

Time frame, risk and uncertainties of the scenario

See *Sea temperature*.

Ecological consequences

A deeper halocline and corresponding improvements of oxygen conditions will increase the area of oxic sediments. The area of vital seedbeds for phytoplankton will thereby expand. The deeper halocline will allow full winter circulation of water also at the slopes of the basins. In these oxic sediments, phosphorus and silicate would be bound but nitrogen will be released as nitrate. N:P and N:S ratios may increase, which will reduce growth of diatoms and cyanobacteria (HELCOM 2007b, BACC 2008).

Zooplankton is expected to have different distributions due to salinity changes. There is for example a clear relationship between salinity and distribution of marine copepods to the north in the Baltic Sea, whereby a salinity reduction will reduce their distribution further south. A vertical change is also expected, with submergence of marine species, such as *Pseudocalanus acuspes*, as salinity increases with depth (HELCOM 2007b, BACC 2008).

The highly exploited eastern Baltic cod is adapted to reproduce in water of the present salinity. A climate-induced reduction in salinity, combined with possible poorer oxygen conditions, may further reduce the area where salinity and oxygen conditions make successful development of cod eggs possible. The small cod stock has contributed to the present large sprat stock, which may in a changed climate increase the magnitude of the problem. Sprat eggs are less sensitive to (at least small) salinity reductions and higher winter temperatures have been found to increase the reproductive success of sprat. Since sprat larvae compete with cod larvae about food resources (i.e. zooplankton) and sprat larvae also prey on cod eggs, this may become a mechanism with detrimental effects on cod production in the future. Changing fisheries exploitation has however a great potential to diminish such impacts. A recovery of the cod stock will increase predation pressure on sprat and thereby reducing the sprat stock. This will create a positive feedback on cod egg survival, thus enhancing cod reproductive success and contribute to a further increase of the cod stock (MacKenzie et al. 2007).

[9] The halocline is a layer in the water column where a strong vertical salinity gradient is found.

Ocean acidification

Decrease in ocean pH is expected to occur as a consequence of increasing CO_2 concentrations in the atmosphere. Globally there has been an ocean acidification, a decrease of 0.1 pH units, since 1750 (IPCC 2007a). During the 21st century ocean surface pH is projected to decrease with on average 0.14 - 0.35 pH units (IPCC 2007a).

In the Baltic Sea pH has decreased even more than global average. Analyses of measurements 1993-2007 in Skagerrak and the Baltic Sea reveal decreases of 0.06 – 0.44 pH units during this time period, with the largest changes in the Bothnian Sea and southern Baltic Proper (Table 1 and data from SMHI). However, the in recent years sparse measurements in the Bothnian Bay and Gulf of Bothnia make these trends from the northernmost part of the Baltic more uncertain. Data scarcity is the case also for Skagerrak where no significant trend was found.

The estimated pH for 2050 indicate that drastic changes in pH may appear in several sub-basins during this century (Table 1).

Table 1. Change in pH 1993-2007, present pH and estimated pH in 2050 based on the trend for 1993-2007 (Data from SMHI, available from shark@smhi.se)

Area	Depth	pH 2007	pH change 1993-2007	pH 2050
Kattegat	0 – 25 m	8.2	**0.06**	**7.96**
	> 30 m	8.0	**0.11**	**7.66**
Southern Baltic Proper	0 – 20 m	8.2	No statistically significant change	
	30 – 60 m	7.9	**0.20**	**7.25**
	> 70 m	7.4	**0.20**	**6.69**
Central and northern Baltic Proper	0 – 20 m	8.2	No statistically significant change	
	30 – 60 m	7.8	**0.14**	**7.35**
	> 70 m	7.2	**0.09**	**6.95**

Time frame of the scenario

The projections made concern an estimate of pH in 2050.

Risk and uncertainty associated with the scenario

The future pH has not been modeled, but SMHI has used linear regression to estimate the possible pH if the observed trend continues. Since data are scarce for several sub-basins and the estimation ignores several important factors (e.g. increased atmospheric CO_2 levels, projected changes in temperature and salinity) the uncertainties are large.

Ecological consequences

Acidification of the seas may have major impacts on calcifying species (i.e. species that take up and use calcium in the form of calcium carbonate ($CaCO_3$) to form shells and skeletons). Biogenic calcified structures are made from calcite or aragonite, of which aragonite is a more soluble $CaCO_3$ crystal structure. Available studies show that aragonite-forming taxa, such as corals and molluscs, are likely to be severely affected (Feely et al. 2004, IPCC 2007b), but there are emerging data for calcite-forming species, such as echinoderms, some crustaceans and molluscs, that indicate potentially catastrophic impacts of small shifts in pH (Dupont et al. in press).

There are very few studies of ocean acidification that are relevant for species occurring in the Skagerrak and the Baltic Sea. Reduced growth of adult blue mussels has been observed, but only at levels of ocean acidification that is expected beyond the year 2400 (Berge et al. 2006, Havenhand submitt.). Earlier life stages may be more severely affected and these effects are likely to be seen within the next 50 years, if the current decrease in pH in the Baltic Sea continues. Laboratory experiments have shown that 0.2 pH unit fall causes rapid 100% mortality of larvae of a common brittlestar, *Ophiothrix fragilis* (Dupont et al. in press) and reduced survival of larvae of another common brittlestar, *Amphiura filiformis*, and the seastar *Asterias rubens* (Dupont et al. in prep.). A decrease of 0.2 pH units lead to increased generation times in the copepod *Acartia tonsa,* but increases survival and growth rates in the tunicates *Ciona intestinalis* and *Ascidiella aspersa* (Dupont et al. in prep.).

Additional results show significant reductions in fertilization success of the sea urchin *Heliocidaris erythrogramma* in response to a 0.4 pH unit fall (Havenhand et al. submitted), decreased calcification and up-regulation of calcification genes in the sea urchin *Strongylocentrotus purpuratus* in response to a 0.5 pH unit fall (Hoffmann et al. unpubl.) and reduced survival of fish larvae (Gagliano et al. unpubl.).

All these results show clear impacts on calcifying species of near-future decreases in pH and confirm predictions made in earlier studies (Feely et al. 2004, Hoegh-Guldberg et al. 2007, IPCC 2007b, Riebesell et al. 2007). Possible consequences for resilience and ecosystem impacts are addressed by Jon Havenhand in the following pages.

Jon Havenhand is a professor in marine ecology at the University of Gothenburg. His research focuses on ocean acidification and its effects in the Skagerrak and the Baltic Sea ecosystems, especially the fertilisation success, larval ecology and settlement of marine invertebrates.

The up-coming results of studies on the impacts of ocean acidification indicate severe effects on several species. Although the knowledge about this issue is still sparse it appears to be of significant importance for the future of marine organisms in the Skagerrak and the Baltic Sea.

What can be the effects of ocean acidification on an ecosystem scale?
Several calcifying species play major roles as ecosystem engineers in the Baltic and Skagerrak, Jon says. Examples of such species are the coccolithophore *Emiliania huxleyi*, the blue mussel *Mytilus edulis*, the barnacle *Balanus improvisus*, the cold-water coral *Lophelia pertusa,* and a number of crustaceans and echinoderms (e.g. *Amphiura filiformis*).

– Given the experimental results obtained to date and the observed trends of declining pH in Swedish coastal waters, it is likely that significant ecosystem-wide effects will be observed within 50 – 100 years, possibly sooner.

– The likelihood of marine ecosystems passing a “tipping-point” and changing to a completely different quasi-stable state will increase with time. Unabated decreases in coastal ocean pH will in time “tip” the current ecological dominance of for example blue mussels in the Baltic proper, change the recruitment patterns of many key marine species (e.g. brittlestars and some fish), and likely cause complete local extinction of the recently-discovered *Lophelia pertusa* biodiversity “hotspots” in the Skagerrak. However, predicting the precise nature and timescale of these effects with any reasonable degree of certainty is presently impossible.

Is it possible to say where the most severe effects will be seen?
Simply put, no, Jon says. A key component of marine ecosystem resilience will be the extent of genetically-based variation in tolerance to ocean acidification within species. This genetic variation will be related to historical levels of pH and pH variation. The Baltic Proper shows far more variable, and generally lower, pH than the Kattegat and Skagerrak. Consequently, it’s likely that species and populations in the Baltic are better adapted, and therefore more resilient, to changes in pH than equivalent populations in the Skagerrak. However, far more understanding of these patterns is required.

To what extent can we be certain of these impacts?
Given that pH in Swedish coastal waters is falling more rapidly than in open ocean systems and that emerging experimental results are consistent with established predictions, it is likely that some level of impact is already occurring. In addition, this will continue and probably accelerate in the coming decades, Jon states.

– Consequently it is less relevant to ask *whether* these impacts will occur, than to ask *which* impacts will occur, and *when*. At present there are insufficient data and understanding to make quantitative estimates of the magnitude and the uncertainty of impacts of ocean acidification on ecosystems in Skagerrak and Baltic Sea.

What are the most important knowledge gaps?
There is an alarming absence of information regarding the effects of near-future levels of ocean acidification on marine organisms in the Skagerrak and the Baltic, Jon says. There is an urgent need for:

- Investigations of the effects of ocean acidification on the early life-history stages (reproduction, fertilization, larval development and recruitment) of key ecosystem-structuring species, and commercially important species of fish and shellfish.
- Assessment of the extent of pre-existing genetic variation (i.e. capacity for adaptation) to ocean acidification in key species and commercially important species.
- Improved regional-scale modelling of acidification mechanisms in coastal waters.
- Testable ecosystem-scale food-web models to articulate with regional acidification models.

Ecological consequences – General and combined effects

Biological processes and biota in the marine environment are to a great extent affected by changes in water temperature, temperature regimes, circulation, salinity and pH – all which are expected to change in a future climate. The species occurring in the Skagerrak and the Baltic Sea today may have changed abundance and distribution in the future and the interactions between species are also likely to be influenced.

An increased water temperature is likely one of the most important factors for the Skagerrak ecosystem. This will favour warm-water marine species and reduce abundance and distribution of temperature-sensitive species as well as species tolerant to cold temperatures, which today give them a competitive advantage. A lower pH is likely to have adverse effects on some species that occur in Skagerrak. There are large uncertainties concerning ocean acidification and its consequences, but the emerging results indicate that it may cause effects throughout the ecosystem.

In the Baltic Sea a similar pattern as in Skagerrak will be seen with increasing temperature. However, salinity reduction may be an even more important factor in the Baltic. The brackish water of the Baltic is a central factor for the unique species composition found there. Also in the Baltic an acidification of the sea may be a significant driver to future changes.

The north-south salinity gradient and decreasing oxygen levels with depth shape the benthic fauna in the Baltic Sea and create a horizontal and vertical zonation. The projected changes in salinity and oxygen content may therefore restructure the benthic community. Since there is often only a single species representing a benthic functional group there is also a risk of changed or reduced ecosystem function in the inner parts of the Baltic Sea if such key species disappear. Effects on biogeochemical cycling, nutrient release, microbes and macrofaunal bioturbation activity may thus appear (HELCOM 2007b, BACC 2008).

The expected changes in abundance of zooplankton may impact higher trophic levels. Herring and sprat have a strong preference for marine copepods (i.e. *Pseudocalanus* and *Temora*) and these prey species have also the highest nutritional value. Since the quality of the available food is a crucial factor for growth and condition of these fish species in the Baltic climate-induced changes in zooplankton dynamics may initiate bottom-up effects in the food-web. Such cascading effects may start with reduced size or fat content in herring and sprat due to reduced availability of high quality food. Prey abundance and quality is important also to top predators. Therefore effects on pelagic fishes may in turn affect their predators such as seabirds and seals (Hedgren 1976, Casini 2006, Österblom et al. 2006, HELCOM 2007b).

Future climate has implications for actions to mitigate eutrophication

The projected future climate is likely to give an increase in nitrogen leakage from agriculture land. This is mostly due to increased water runoff, caused by more precipitation and increased occurrence of heavy rainfalls in most parts of the Baltic Sea drainage basin, especially during autumn and winter. Similarly, there is a possible increase in phosphorus leakage (SOU 2007:60). However, increasing temperatures may increase nutrient retention in rivers and lakes, whereby a smaller fraction of the nutrients reach the marine ecosystem. Timing and extent of ice, snow, spring flood and vegetation period are expected to change in a future climate (SOU 2007:60). These factors affect nutrient inflow to the Baltic Sea. The overall change in nutrient input and dynamics in the Baltic Sea is unknown, but more knowledge is emerging as described by Marcus Meier below.

Markus Meier is a researcher at the Swedish Meteorological and Hydrological Institute (SMHI), where he is head of the Division of Oceanography at the Research Department. Regional modelling of past, present and future climate and its impacts on coastal areas and marine ecosystems is his major field of research. Markus is also affiliated at the Department of Meteorology at Stockholm University as adjoint lecturer.

The projections about the future climate used in “Sweden facing climate change” from the Commission on Climate and Vulnerability were mainly developed by Markus Meier and his colleagues at SMHI. After this work was finished Markus has continued studying the regional effects of climate change. His recent projects have been focused on eutrophication using the results of these climate projections.

- Eutrophication is a major problem in the Baltic Sea today, but the large reductions in nutrient input decided upon in the Baltic Sea Action Plan would be a great improvement. However, we know that it will still take a long time for the sea to recover and therefore it is very valuable to know the impact of a changing climate, Markus says.

- We have studied the effects of changed nutrient loads in future climate. The scenarios have been developed by Baltic Nest Institute at Stockholm University and they have also modelled the effects of the scenarios in terms of nitrogen and phosphorus concentrations in river input to the Baltic Sea[10]. The study covers a reference case with present concentrations and two scenarios where loads are reduced, including the implementation of the Baltic Sea Action Plan. A scenario with increased nutrient input, corresponding to agriculture in all countries around the Baltic Sea developed to the same intensity as in Denmark today, has also been modelled.

Markus points out the importance of keeping in mind the uncertainties in projections when the effects are discussed. Differences in temperature, winds and precipitation from the climate models all affect the outcome of the effect of eutrophication. Therefore the results are not consistent between models and emission scenarios, Markus says.

- First, when regarding the present situation of nutrient input, we can see that in the simulations where the global climate model ECHAM4[11] has been used, the halocline in the Baltic is found at a larger depth. This implies improved oxygen conditions in northern Baltic Proper and thus decreased phosphorus concentrations and a reduction in summer algal blooms there. In the southern Baltic Sea, where the sea is shallower, other factors are more important. There the simulations show more severe problems with cyanobacterial blooms.

- When the global model HadAM3H[11] is used the salinity and halocline depth in the simulations are more similar to the level of today. Then the changes in nutrient concentrations and algal blooms will be less pronounced.

Reduced nutrient concentrations will have important effects in a changed climate
- The two reduction scenarios have quite similar effects in the present climate but also in projected future climate. There are geographical differences – in some areas there will be larger improvements in a changed climate whereas in other parts of the Baltic the effects of reduced inputs will be smaller or the situation might even be worse than today, Markus says.

- Still, the effects of a changed climate could have counteracted the improvements of a reduction in nutrient input, but our simulations show that the decided reductions are so large that the overall situation will be better also in future climate.

A changed climate will show us the severity of the problem with eutrophication
- With a higher lever of nutrients in the water, such as in the scenario with an intensive agriculture in all Baltic Sea countries, the future climate will clearly reveal the consequences of eutrophication. The increased water temperature will allow cyanobacteria to grow faster, as they can use nitrogen fixation and will have large amounts of phosphorus available. This will cause more frequent and more intense summer algal blooms in most parts of the Baltic.

[10] See further the section *Eutrophication – are there reasons to be hopeful?*
[11] The differences resulting from using different global models are induced by the few grid cells global models have in smaller regions such as the Baltic Sea. ECHAM4 gives more westerly winds in the Baltic region. See also page 45.

It is absolutely necessary to account for climate change
The general conclusions can be drawn from all simulations, Markus states, even though, like I mentioned before, there are differences between the projections. The first and most important conclusion is that nutrient load reduction scenarios need to take changing climate into account.

Markus emphasize the time scale as an important issue. It will take a long time – about 40 – 60 years, he says, before we see an effect of the reductions decided upon in the Baltic Sea Action Plan. During that time the climate will change. The effect physical variables have on biogeochemical variables will then change. That means it is of uttermost importance to consider the climate when trying to solve the problem.

Are there aspects we need to understand better?
- Sensitivity of the models is important to consider and there is a lack of knowledge in this field. We have seen differences in sensitivity between model versions and it would be very interesting to further compare models in this aspect. Comparing models to observations would also give valuable insights into how real these sensitivities are. One example is processes in the sediments that are poorly known, at least not to the extent that we know the response to a change in one climate variable such as temperature or salinity, Markus says.

- Another important aspect of this knowledge gap is the uncertainties associated with processes that are not well known and therefore not included in the models. We can be quite sure that the physical processes that will be important in a warmer climate are included in the models, but for biogeochemistry there might be significant processes that we do not model today. For example, microbial food webs are of large importance for the ecosystem in the Bothnian Bay. A reduced salinity in a future climate will probably change the ecosystem in the Baltic Proper to something similar to the present Bothnian ecosystem. The models we have today do not include the microbial food web. Another factor of potential importance is the carbon cycle. An acidification of the sea may impact biogeochemical dynamics but this is left outside today's models.

- Still, even though the biogeochemical models to a large extent simplify the system, I believe that the models are rather robust. The SMHI models have a high level of complexity, which is the main advantage of our models. The models include a large number of processes and we obtain a high degree of spatial resolution by using a three-dimensional model, which means that we can show where changes will occur – not only what might happen. The possibility to include climate modelling further demonstrates the usefulness of this system. Our recent simulations have clearly shown the importance of taking a changing climate into account when eutrophication issues are discussed and decisions are made, Markus Meier says.

Oil pollution from shipping

The Baltic Sea is one of the most intensely trafficked maritime areas in the world. It is estimated that about 15 % of global cargo shipping takes place here (HELCOM 2007c). Consequently the number of vessels passing through Skagerrak on their way to the Baltic is high – about 52 000 AIS-equipped vessels[12] entered or left via the Skaw in 2006 (HELCOM 2007d).

Shipping is generally a relatively environmentally friendly way of transportation, but the intensive shipping put pressure on the environment, with oil pollution of the sea and coasts being the major concern, apart from spreading of alien species and emissions of nitrogen oxides that are described in other sections of the report. Oil pollution can be caused by accidents or operational discharges. Larger oil spills often involve oil tankers, but operational discharges can be made by all types of ships and therefore all shipping activities need to be considered in this context.

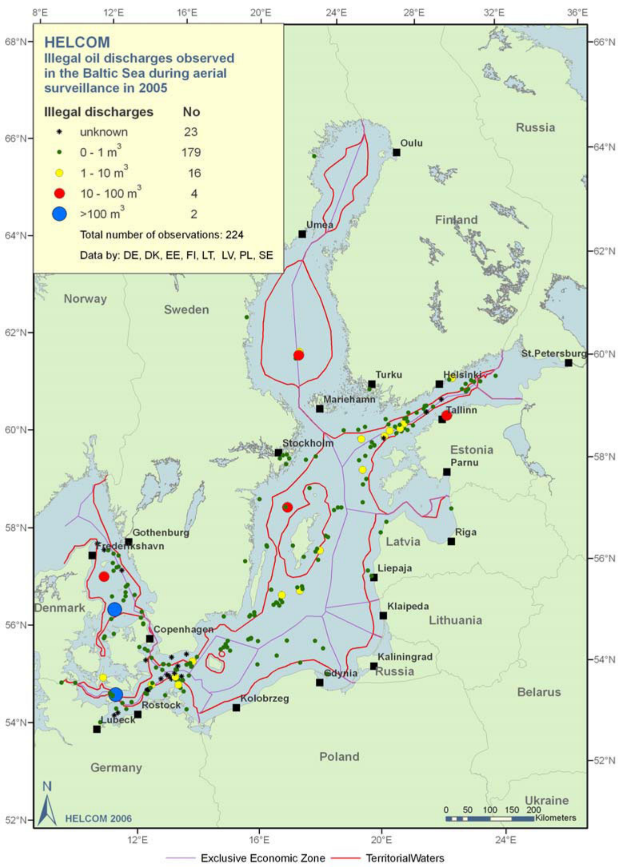

Fig. 6. Spatial distribution of illegal oil discharges in the Baltic Sea 2005. Source: HELCOM 2007c.

[12] The HELCOM states have built a land-based network of AIS stations. AIS is described by HELCOM, 2007a: "The Automatic Identification System is a VHF radio-based system which enables the identification of the name, position, course, speed, draught and cargo of every ship of more than 300 gross tonnes sailing on the Baltic Sea, and displays all available data over a common background map. The system facilitates exchange of information between ships and between ships and shore stations. The whole Baltic Sea area has been covered by land-based AIS stations since mid-2005."

Chronic oil pollution – a more severe threat to marine life than large oil spills?

When ships deliberately discharge oil the amount of oil is almost always small. However, since deliberate discharges occur much more frequently than accidents, the major part of oil pollution is caused by such discharges.

The MARPOL convention about prevention of pollution from ships prohibits discharges of oil and oily mixtures from cargo and ballast tanks in the Baltic Sea and in the North Sea, rendering all such discharges illegal. In stead, the ship-generated waste should be delivered in ports, to special reception facilities (HELCOM 2007c).

Despite these measures, discharges of oil at sea still occur. The Baltic Sea countries survey the sea for potential oil spills (Sweden and Denmark also survey Skagerrak) mostly by aerial surveillance, but satellite images and other methods are also used (Swedish Coast Guard 2006a, HELCOM 2007c). The number of detected illegal discharges is decreasing (see Fig. 7), a trend that is promising as it should be noted that the decrease has happened at the same time as shipping has increased and surveillance has improved (HELCOM 2007c).

Within HELCOM there is a "no-special-fee" policy which means that ships should pay an equal fee in ports whether waste is delivered or not. The purpose is to encourage proper management of waste and a sharing of cost between HELCOM countries. However, at present the implementation of this policy differs between countries (HELCOM 2007c).

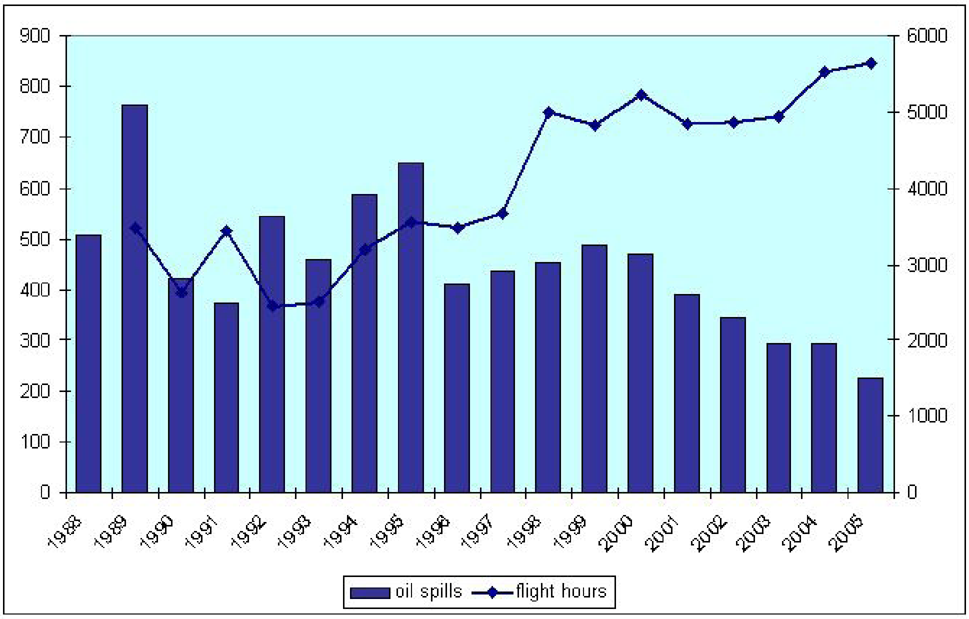

Fig. 7. Number of detected oil spills and surveillance flight hours in the Baltic Sea 1998-2005. Source: HELCOM 2007c.

Possible future illegal oil discharges

Number of detected illegal oil spills in the Baltic Sea is decreasing (Fig. 7). Separate statistics are not available for Skagerrak. However, the trend for all detected illegal discharges in Swedish waters is decreasing (Swedish Coast Guard 2006b, 2007).

It is possible that the current trend will continue and that the number of illegal oil discharges eventually will reach an acceptable level. However, the number of convicted polluters is low (Swedish Coast Guard 2006b, 2007, HELCOM 2007c) and may thus not be sufficient to promote proper handling of oily wastes in shipping activities. Together with the projected increase in shipping the result may be no further decrease or even an increase in the future.

Oil pollution impacts on Baltic long-tailed ducks illustrate that where and when is equally or more important than how much

The long-tailed duck breeds in Arctic areas and spend the winter in open waters at lower latitude. About 90 % of the European population winter in the Baltic Sea and 25 % spend the winter near and in the Natura 2000 site Hoburgs bank south of Gotland (Durinck et al. 1994) where their main food item, blue mussels, are easily accessed (Larsson & Tydén 2005).

A large part of the Natura 2000 site Hoburgs bank, but not the north-eastern part, have been declared "recommended area to be avoided" by IMO. Across the north-eastern part of the bank about 22 000 ships pass annually (Swedish Maritime Safety Inspectorate 2007). Since 1996 the effects of oil pollution on the birds have been studied by Kjell Larsson and Lars Tydén at Gotland University. Weekly counts of birds with oil visible on their plumage are made along the southern coast of Gotland. Since oiled birds are not able to remove the oil from their feathers they will eventually die. The numbers found show that tens of thousands of long-tailed ducks die every winter due to oil pollution (Fig. 8).

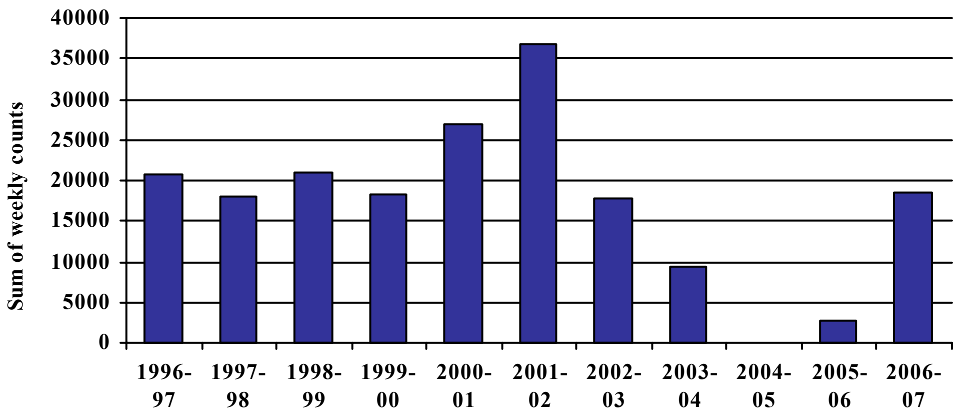

Fig. 8. Number of oiled Long-tailed Ducks observed close to the shore at the southern coast of Gotland during the winters 1996/1997 to 2006/2007. Bars represent the sum of weekly counts per winter. Data is missing for the winter 2004/2005. For details see Larsson & Tydén (2005) and Larsson (2007).

However, all birds affected by oil may not reach the coast and an analysis of nearly a thousand long-tailed ducks caught in fishing-gear at Hoburgs bank in the winters 2000/01 to 2003/04 showed that about 11.8 % was oiled at the bank (Larsson & Tydén 2005). Despite a likely significant decrease in population size since surveys in 1992/93, when the number of wintering birds were estimated to 1.2 millions (Durinck et al. 1994, Kjell Larsson, pers. comm.), the high proportion oiled birds show that at least several tens of thousands long-tailed ducks are still hit by oil every winter . Thus, the analysis of birds caught in fishing nets showed independently from the previous analysis similar results and confirm the severity of this type of pollution.

These figures can be compared with the numbers of birds killed in the Prestige oil spill. About 22 000 oiled birds were found dead (Cedre 2003) and it was estimated that the Prestige oil spill in total caused the death of 100 000 – 200 000 birds (Camphuysen et al. 2005). This reveals that although large accidental oil spills may and do have severe effects on birds, the chronic oil pollution in the Baltic Sea, that is the result of many small illegal oil discharges, has similar impacts.

The unfortunate co-occurrence of one of the main Baltic Sea shipping routes and an important area for wintering birds shows that it is where and when oil pollution occurs that determines the environmental impacts, not necessarily the amount of spilled oil.

Ecological effects of chronic oil pollution

The ecological effects of intentional discharges of small amounts of oil are similar to the consequences of major oil spills. The chronic pollution of intentional oil discharges is however in many cases a more severe problem than single accidents. This is well exemplified by seabirds, which are often one of the major concerns when large oil spills occur. However, the still too many intentional oil spills are for most seabird species a larger threat. Birds are particularly sensitive to this type of pollution, since even with a small oil stain, corresponding to the size of a coin, the plumage will no longer be water resistant. The bird will suffer from hypothermia and starvation due to reduced foraging capacity. In Skagerrak and near-shore parts of Kattegat this type of oil pollution has shown a decreasing trend, but in the open waters of Kattegat the situation has become worse in recent years (Larsen et al. 2007, Tommy Järås, pers.comm.). The situation in the Baltic Proper is exemplified by the long-tailed duck above. Although the behaviour and the wintering areas of the long-tailed duck make it particularly affected by operational oil discharges, it should be noted that many other species may also be affected by these illegal activities, but this is less well known.

Increasing risk of a large oil spill

The intensive shipping activity in the Skagerrak and Baltic Sea implies a risk of a large oil spill occurring in this area. About 18 % of the Baltic Sea registered vessel movements concern tankers and the transportation of oil has increased significantly during recent years, with an increase in both numbers and size of tankers (HELCOM 2007c, d).

There has been an increase in both groundings and collisions during the last years and the number of accidents is about 150 per year in the Baltic Sea area, but in 2006 the number of reported accidents decreased (HELCOM 2007c). For an overview of accidents in 2006, see Fig. 9. Luckily, most accidents do not render any pollution – slightly less than 7 % of the accidents in 2004-2006 resulted in pollution (HELCOM 2007c).

Measures to improve maritime safety are for example taken by HELCOM. The HELCOM Copenhagen Declaration has resulted in the Baltic Sea AIS system, improved navigation tools and contributed to the phase-out of single hull oil tankers and the establishment of the Baltic Sea by the International Maritime Organisation (IMO) as a Particularly Sensitive Sea Area, which requires ships to take special care when passing through important ecological, economical, cultural or scientific areas (HELCOM 2007c).

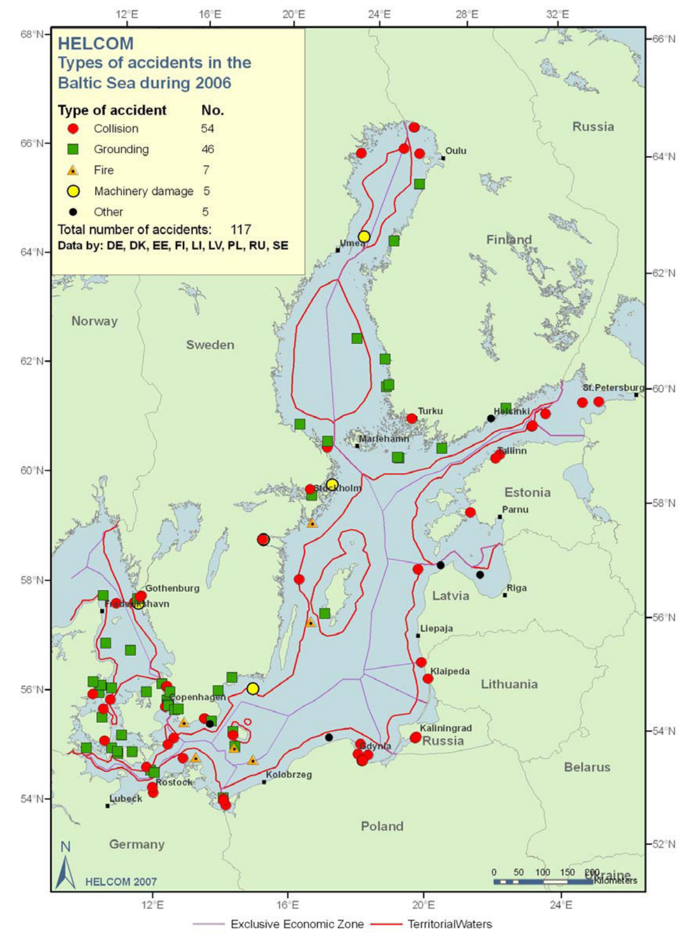

Fig. 9. Spatial distribution and types of accidents in the Baltic Sea 2006. Source: HELCOM (2007d)

Larger oil spills and their impacts

When pollution occurs, the result may be small or large amounts of oil being released into the environment, but so far the Skagerrak and the Baltic Sea have been saved from large spills. However, the recent accidents in European waters with large-scale oil pollution highlights the risk of something similar, or worse, happening here.

The oil tanker Prestige sank outside the Galician coast of Spain in 2002 after being charged with oil in Latvia and passing through the Baltic Sea. The Prestige accident resulted in 17 000 tonnes of oil being released immediately and a continued leakage from the sunken ship, reaching 59 000 tonnes in 2005 (Garza-Gil et al. 2006a). The social and economical damages have been huge with an estimated minimum cost of 770 million euro (Loureiro et al. 2006), resulting from cleaning

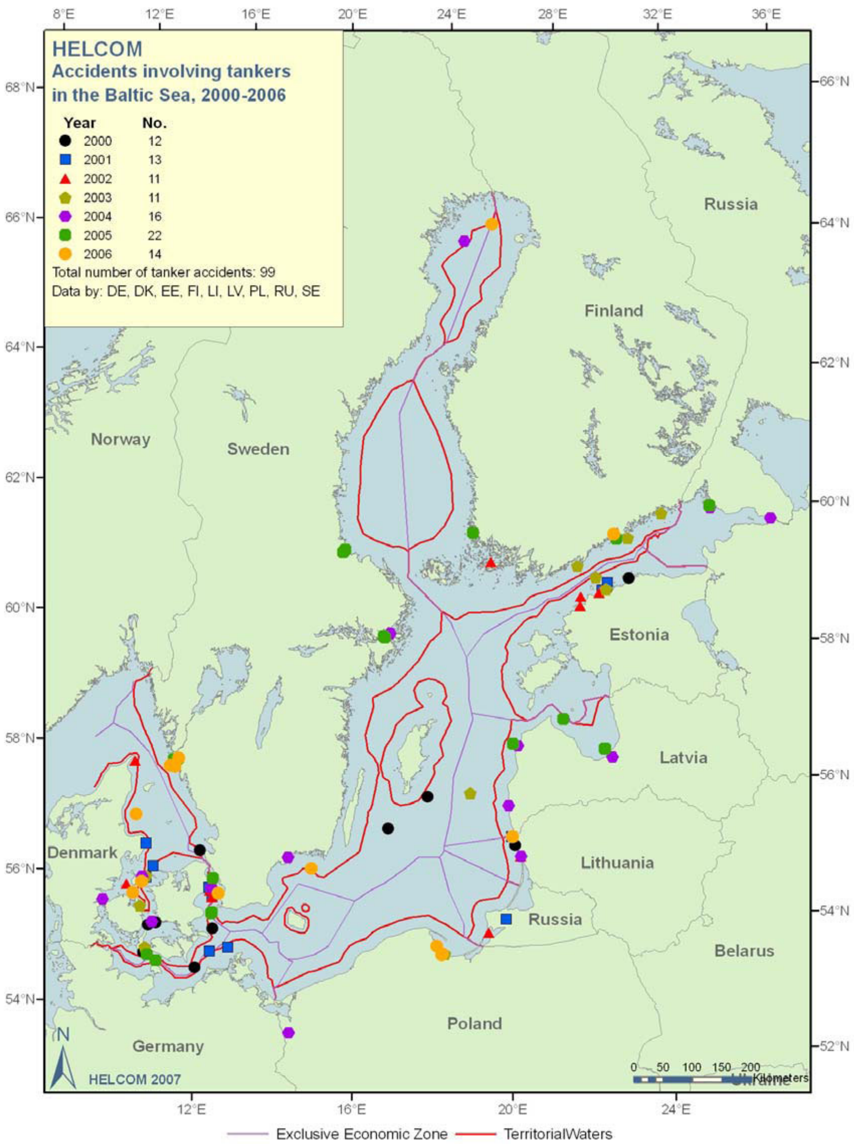

Fig. 10. Tanker accidents in the Baltic Sea and the Skagerrak 2000-2006. Source: HELCOM (2007d)

and recovery costs as well as economic damages on tourism, fisheries and aquaculture (Garza-Gil et al. 2006a, b, Loureiro et al. 2006). The ecological impacts resulting from the spill include more than 22 000 seabirds found dead (Cedre 2003).

In the Baltic Sea and Skagerrak one of the more severe and well-studied oil spills has been the Tsesis spill in the archipelago of Stockholm in 1977, where an estimated 1000 tonnes of fuel oil was released. The pelagic ecosystem was affected immediately after the spill, but after one month all measured parameters were essentially normal. The littoral macrofauna was affected but one year later the fauna had started to recover. The soft-bottom community showed drastic effects on fauna with no signs of recovery one year later, indicating that this system is more vulnerable to oil pollution (Lindén et al. 1979).

More recent major spills include the collision between Baltic Carrier and Tern in the south-western Baltic Sea in 2001 where 2700 tonnes of oil was released of which about half was recovered at sea. The spill affected pebble beaches and marchlands on Danish islands, of which many were important bird habitats. The documented ecological impacts concerned mainly physical deterioration of sensitive banks due to use of heavy machinery during clean-up and up to 4500 birds infected by oil (HELCOM 2002, Cedre 2006). In 2003 Fu Shan Hai sank outside Bornholm, but most of the 1200 tonnes of oil released was recovered at sea whereby no major ecological effects were found.

Projected growth in maritime oil transport

The general trend in tanker accidents relates to the increased shipping intensity. Therefore are future risks of accidental oil pollution connected to the projected increase in oil transportation.

Presently overall shipping is increasing with about 5 % annually in the Baltic Sea (Stipa et al. 2007). Oil transportation is also increasing, but it is projected that this increase will be lower, with an annual increase during the next decade of 2-3 % on the scale of the Baltic Sea (Rytkönen et al. 2002). In some parts of the Baltic a higher increase is likely, which is exemplified by the Gulf of Finland (next page).

Ecological effects of large oil spills

Ecological impacts of larger oil spills receive much attention, but although seabird and mammal populations are affected and pollution of the seabed occur, most oil spills do not render severe long-term impacts, but instead inappropriate clean-up methods have often been found to be the cause of severe impacts (e.g. Baker 1999, Vandermeulen & Ross 1995, Cedre 2006). In most cases where proper or no clean-up operations have been made the affected ecosystems have returned to the state before the oil spill after some years (e.g. Sell et al. 1995) indicating that most ecosystems have a capacity of self-remediation. Still, there are ecological and not least socio-economic impacts resulting from oil spills and thus efforts to avoid them are of great importance.

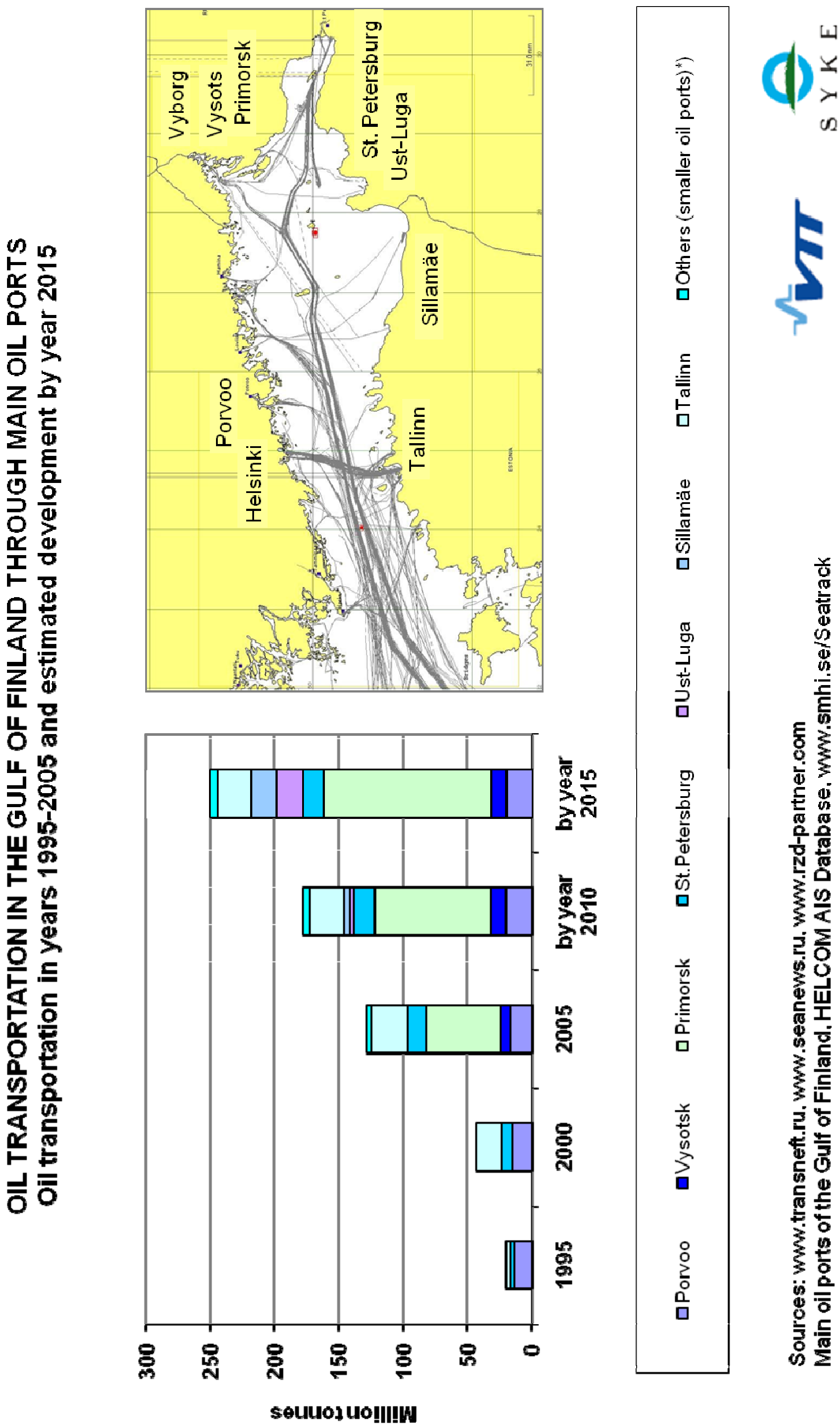

Fig. 11. Projected oil transportation in the Gulf of Finland by 2015. With kind access from Jorma Rytkönen, Kymenlaakso University of Applied Sciences.

Scenario studies

Scenario: A large oil spill north-east of Gotland

A scenario concerning a large oil spill affecting the archipelago of Stockholm has been developed by Björn Forsman, SSPA Sweden (Forsman 2007). The scenario is formulated as follows:

A ten years old double-hull tanker, loaded with 90 000 tonnes of Russian crude oil of high viscosity, collides with a smaller cargo ship east-north-east of Gotska Sandön in late winter. Three tanks in the tanker are ripped open and about 30 000 tonnes of oil is released almost simultaneously. The tanker remains stable whereby no additional significant spills occur.

When the accident happens there are strong winds from southeast and east and wind-generated currents cause the oil to drift towards the Swedish coast. The first oil slicks reach land four days after the accident.

About 10 000 tonnes of oil is recovered at sea whereby 20 000 tonnes remain. The drifting oil is broken up in smaller belts, accumulates water whereby about 40 000 tonnes of oil emulsion reach the island shores in the outer and middle parts of the Stockholm archipelago. The concentration of oil is highest along coasts first struck by oil and in bays open to the wind direction.

A total of 2728 kilometres of coast is affected by the spill. About one third of the shores are classified as important to protect since they constitute sensitive types of shore or are parts of nature reserves, Natura 2000 sites or national park.

Risk and uncertainty associated with the scenario

The risk has not been assessed, but Forsman (2007) concludes that based on the projected increase in oil shipping and other European accidents involving oil tankers the scenario represents a real risk. However, he states a risk analysis may identify other scenarios that are associated with larger risk.

The assumptions concerning wind direction are of importance for the effects and the assumed south-eastern and eastern winds can be said to be particularly unfavourable. The type of oil involved is a major factor. The assumed type of heavy crude oil that forms emulsions with water cause severe damage, but is also representative for a large fraction of the Russian export (Forsman 2007).

Ecological effects

Islands in the outer part of the archipelago often have cliff beaches and sparse vegetation, which make them less vulnerable to oil pollution (Forsman 2007). Inside the outermost islands the shores are of more sensitive types, with reed belts, coastal meadows and fine sediment beaches.

The impacts of the oil spill may resemble the effects seen after the Tsesis spill in the archipelago 1977 (see Lindén et al. 1979), where studies found that the pelagic ecosystem in the area was affected immediately after the spill. Increased phytoplankton biomass and production was observed, which was attributed to decreased zooplankton grazing, since zooplankton was found to be contaminated by oil droplets. After one month all measured parameters were essentially normal. Oil analyses of sediments indicated that about 10 % of the oil remaining after the clean-up settled to the bottom. The littoral community was affected by the oil spill, with major damage to most macrofaunal species, although no severe effects were seen on macroalgae. After one year of immigration from unaffected areas and reproduction of survivors the fauna had started to recover however not completely. The soft-bottom community showed drastic effects on fauna with no signs of recovery one year later, indicating that this system is more vulnerable to oil pollution (Lindén et al. 1979).

However, the Tsesis spill was much smaller than the scenario spill – about 1000 tonnes of fuel oil was released. The greater area affected by the scenario spill and the larger amount of oil may reduce the possibilities of successful immigration from unaffected areas. The heavier fractions of the crude oil persist in the environment for a long time, up to years in sediments wherefrom resuspension may occur. This may contribute to more severe effects.

The timing of the scenario spill creates a risk that birds wintering in the area will be affected, for example tufted ducks, long-tailed ducks and great cormorants among others.

There are a large number of near-shore nature reserves in the area where oil will reach the shores. In addition the shores in the national park Ängsö may be struck by oil, although the area is somewhat protected by other islands (Forsman 2007). The valuable nature in these protected areas may thus be negatively affected by the oil spill.

Applicability of the scenario to other countries

A large oil spill may occur anywhere where oil is transported or handled and the scenario may thus be of relevance for all Baltic Sea and Skagerrak countries. The ecological impacts of a spill of the same amount and type of oil vary however between different sites.

Other scenarios concerning large oil spills

Similar scenarios concerning large oil spills can be developed and studied in the same way. Björn Forsman at SSPA Sweden has conducted such studies for the Gothenburg area, the southern part of the Swedish west coast (Halland) and in the Baltic Proper (three different spills affecting southern or south-eastern coasts of Sweden: Scania, Blekinge and Småland including Öland) to evaluate socio-economic impacts. These studies are described in Forsman 2004a, b and 2006.

Harmful alien species will be introduced

Alien species has been present in northern European waters during a long time. Transplantations of fish probably occurred in north-western European lakes already during the Stone Age (Leppäkoski et al. 2002). The soft-shelled clam is the first known introduction of an American species to this area, probably made by the Vikings (Baltic Sea Alien Species Database 2007). Since the early 1800's about 120 alien species have been recorded in the Baltic Sea (Gollasch & Leppäkoski 2007) of which almost 80 are established with reproducing populations (Baltic Sea Alien Species Database 2007). About half of the alien species in the Baltic Sea have been introduced during the last 50 years. Some alien species and diseases have been shown to be harmful to human health, to affect the environment or to cause socio-economic impacts (Leppäkoski et al. 2002, Reinhardt et al. 2003, Gren et al. 2007).

Background

The Baltic Sea is susceptible to invasions of alien species, since the brackish water and temperature gradient do not protect the sea, but in stead provide a range of conditions suitable for freshwater, brackish and marine organisms of different bio-geographical origin (Gollasch & Leppäkoski 2007). The number of alien species is lowest in the northern Baltic Sea and the highest numbers have been recorded in coastal lagoons in the southern part and in Kattegat. A comprehensive review of the invasion status of the Baltic Sea and its sub-basins, including descriptions of species and their impacts, is given by Leppäkoski et al. (2002).

The main vector of introduction to marine systems is shipping activities, including ballast water, tank sediments, hull fouling and artificial waterways connecting previously separated water bodies (Leppäkoski & Olenin 2001, Leppäkoski et al. 2002, Gollasch & Leppäkoski 2007). Another important vector is active translocation of species by humans, either for intentional introduction, often to provide additional resources for food and recreational activities (e.g. hunting and fishing), or through escapes from captive populations such as fur farms or aquaculture (Leppäkoski & Olenin 2001, Leppäkoski et al. 2002, Birnbaum 2006). Analyses of the NOBANIS (North European and Baltic Network on Invasive Alien Species) database (available from www.nobanis.org) reveal that for harmful alien species occurring in Swedish aquatic environments the most common vector is ballast water and sediments followed by aquaculture and hull fouling (Ullrika Sahlin, pers. comm.).

Rates of within-basin spread for alien species have been estimated from first findings in the Baltic Sea. The range is wide, from 20-30 km/year (e.g. the barnacle *Balanus improvisus* and the gastropod *Potamopyrgus antipodarum*) to 480 km/year for the polychaete *Marenzelleria neglecta* (Previously referred to as *M. viridis*) (Leppäkoski & Olenin 2000). This secondary spread is either the result of natural colonization abilities or further mediated by human activities, i.e. shipping. The intense shipping activity in the Baltic facilitates not only within-basin secondary spread, but is also the cause of secondary introductions for example in the North American Great Lakes. The cladoceran *Cercopagis pengoi* invaded the Baltic Sea before 1992 and its introduction to the Great Lakes in 1998 was very likely the result of secondary introduction from the eastern Baltic (Cristescu et al. 2001 in Leppäkoski et al. 2002).

The International Convention for the Control and Management of Ships' Ballast Water and Sediments of IMO, 2004, is an effort to reduce the impact and prevent spreading of alien aquatic organisms. When the convention enters into force, ships will be required to manage ballast water and sediments according to a given standard. The proposed options include ballast water exchange and technical solutions (IMO 2004). The convention will be an important step towards a reduced spreading of species globally, but it does not differentiate between semi-enclosed seas, like the Baltic, and open oceans. Options applicable to the Baltic Sea are discussed by Gollasch and Leppäkoski in "Risk Assessment of Ballast Water Mediated Species Introductions – a Baltic Sea Approach" (2006).

Risk analysis

Risk estimations have been provided by Ullrika Sahlin at Lund University. She describes the concept of risk analyses further on the next page.

In a retrospective analysis based on the NOBANIS database Sahlin has estimated the predicted time until next introduction of a harmful alien species in Sweden. Risk is thus defined as the number of species introduced during a specific time period and as introduction intensity. Based on all environments no increasing trend in introduction rate can be found, but for aquatic environments (fresh-water and marine environments combined) there is an increasing intensity in introductions. When taking the increasing intensity into account the expected time until next introduction of a harmful aquatic species is 1.5-2.5 years.

There are uncertainties associated with this estimate, but 2.5 years should be viewed as a conservative estimate of risk, since it is based only on species that are known as harmful species. By using the using a larger set of species that are known or could be harmful, the shorter estimate on 1.5 years is obtained. Since these estimates have been calculated for Sweden, the risk in a larger area, such as the Baltic Sea, is higher.

Since the analysis is retrospective, the estimates will not be valid if the prerequisites change drastically. But, if no actions are taken to improve the situation, it is likely that this is the actual risk in the near future.

Ullrika Sahlin is a researcher at Department of Ecology, Lund University. She studies extreme events associated with introduction of species and populations. Her work includes also risk analysis and methods for such analysis.

Risk is a word that is often used in the context of possible future events. In this report it refers to the possibility that an undesired event will happen.

– That definition is also what is most often used, Ullrika says. In addition, it usually includes the consequences of the event and that it occurs within a specific time and place. For alien species the undesired event may be the introduction of one species with a specific vector and the consequences that the species survives and is able to reproduce in the area where it is introduced. The consequence may also be that the species become a problem in the new area. Thus there are several ways to define the risk event and therefore it is necessary to clearly state what events that are included.

– A risk analysis can be retrospective or predictive. A retrospective risk analysis may be a direct estimate of the risk – a measure of how often a risk event has occurred or how large the effects were, or it finds factors that explain differences in risk. A predictive analysis is often focused on specific parts of the chain of events in an invasion, for example the possible rate of spread for an introduced population. Both quantitative and qualitative models are used. In addition, it is possible to use "semi-quantitative" models, which for example can include an index of factors of importance for the risk, which is calibrated with well-known cases and used for projection of future risks.

– A keyword in risk analysis is uncertainty. Uncertainty can be caused by incomplete information or be associated with reality – variability in the system. Incomplete information can be described with e.g. confidence intervals or standard errors, and improved measurements can reduce this uncertainty. A biological parameter, on the other hand, can actually vary between individuals or years and this uncertainty can not be reduced – it can only be described. It is of great importance in risk analysis that the existing uncertainties are described and how they were treated.

Biological invasions are uncertain risks – we have only limited knowledge about the factors that affect the risk and the outcome of an introduction is uncertain, since the new species does not necessarily become a problem, Ullrika states. However, the uncertainties should not restrain us from doing these analyses, but we should improve our methods to deal with the uncertainties in a better way.

Knowledge gaps

Today the knowledge is too limited to identify harmful species before they enter a new area, Ullrika says. The knowledge about risk analysis needs to be improved including also how uncertainties are dealt with. There is also need for trans-disciplinary research studying the connections between human behaviour and introduction of alien species.

We should also include alien species in conservation issues, she continues. How do conservation efforts affect the introduction and spread of alien species? How do alien species affect the possibilities to succeed with species conservation?

Alien species is a large threat whereby proper risk analyses are important

Introduction of alien species is a large threat that needs to be taken seriously, Ullrika says. In the future harmful species will appear at an increasing rate[13].

[13] Provided that no actions are taken that change the prerequisites for introductions. See also page 68.

– The society need to become more aware of the risks associated with alien species. We should demonstrate the magnitude of the risks more clearly and make risk analyses that are adequate foundations for decisions.

– Since deterioration of the marine environment and climate change make it impossible to go back to a pristine state, all alien species can not be viewed as something wrong as such. It would be better to identify and prevent introduction of species that constitute large threats and leave the others, Ullrika concludes.

Ecological consequences

Invasive alien species have potential to modify abiotic and biotic conditions for native species. Leppäkoski et al. (2002) have compiled examples of ecological impacts caused by alien species in the Baltic Sea. In many cases, they state, alien species represent a new function or even a new trophic level, thus the introduction will lead to restructuring of the native community.

- Increased local density and diversity of benthic invertebrates can occur. This was observed in coastal lagoons and freshwaters after introduction of the zebra mussel (*Dreissena polymorpha*). The mussels offer protection from predators for other invertebrates and their shell deposits have changed former soft bottoms to shell gravel, creating hard substrates for sessile species (Leppäkoski et al. 2002).
- Energy transfer links may be the result of introduced species. Introduced mysids and amphipods, which spend part of their life in the water column and also dwell within or on the bottom, transfer energy between pelagic and benthic subsystems. Another example is *C. pengoi*, which probably preys on the small cladoceran *Bosmina* sp. Since *C. pengoi* is consumed by herring and other planktivorous fishes its introduction may enhance utilization of mesozooplankton and transfer of zooplankton biomass to fish (Leppäkoski et al. 2002).
- Competition for food and subsequent displacement of native species may happen. This has been suggested to be the result of the introduction of the round goby to the Gulf of Gdansk (Skora & Rzeznik 2001, Karlson et al. 2007). In addition, the round goby may be more favourable food for piscivores (e.g. great cormorant) thus weakening the predation pressure on native prey species such as small sandeel and sprat (Skora & Rzeznik 2001).
- Local decline of native species can occur. For example *Bosmina* sp. declined in the Gulf of Riga following the invasion of the larger cladoceran *C. pengoi* (Ojaveer et al. 1999).
- In general, local species richness increases with additional species, as long as invasions by alien species not lead to species extinction. In the Baltic invasions have not, yet, resulted in loss of native species. A subtle long-term consequence is however the increasing homogenization of aquatic ecosystems.

Leppäkoski et al. (2002) conclude: "It becomes clear from these examples that invasive species are able to modify abiotic and biotic conditions for other species, alter composition of both pelagic and benthic communities, and affect organic matter and energy transfer pathways in a variety of food webs, thus acting as habitat and ecosystem engineers in the Baltic Sea."

Large-scale dramatic ecosystem changes caused by alien species have not happened either in the Skagerrak or in the Baltic Sea. The possibility exists – such events have occurred in other seas similar to the Baltic, with the invasion of the Black Sea by the ctenophore *Mnemiopsis leidyi* being perhaps the most serious. Recent observations of this species in Skagerrak and Baltic Sea raise the question whether similar effects can be seen here. This issue is further described on page 13.

Present stressors in the marine system may facilitate invasion of alien species

The current state of the Baltic Sea ecosystem may facilitate establishment of alien species. Most of the successful benthic species of alien origin in the Baltic Sea are suspension feeders, which benefit from at least moderate eutrophication of the coastal systems (Sergej Olenin, pers. comm.). Thus the present level of eutrophication may give these species a competitive advantage in relation to native species.

Overexploitation of marine resources may push the ecosystem towards a more simplified state, since biodiversity in part is lost when a population to a great extent is removed from the system. When species from upper trophic levels are excessively exploited, like in intense fishery focused on predatory species such as cod, the ecosystem is also pushed towards lower trophic levels. These processes reduce the resilience of the system and make it more vulnerable to invasions of alien species (e.g. Folke et al. 2004).

Sergej Olenin is a professor at the Coastal Research and Planning Institute of Klaipeda University. He is an expert on alien species in the Baltic Sea, with special interest in pathways of introduction and invasion corridors and ecological functions of introduced species.

The number of alien species in the Baltic Sea will be constantly increasing, Sergej believes. There are several reasons for that, he says:

• Increase in global trade (more goods are being transferred within shorter time). This in turn is related to increase in cargo turnover via the Caspian-Volga-Baltic water way, which opens new opportunities for the Ponto-Caspian species to arrive. These species are perfectly pre-adapted for the Baltic conditions. Moreover, there are plans to renovate waterways (or create new) directly from the Black Sea to the Baltic (Ukraine – Poland, or Ukraine – Belarus – Lithuania).
• Also overseas trade shows a clear increasing trend in the Baltic and therefore new species arrivals from America and Asia may be expected.
• Other vectors, such as live organism trade (for aquarium, for food, for sport fishing, etc) will increase in the Baltic area as the living standard of the eastern Baltic countries will increase.

However, the alien species are not likely to be the cause of extinction for any native species in the future.

– No, I do not think that any native species may be extirpated by an alien on the scale of the entire Baltic Sea. We do not have any example of total disappearance of any native aquatic species in Europe (solely or mostly) due to alien species. However, a severe decline in abundance and distribution range of native species may be expected due to introduction of devastating diseases or especially harmful parasites. I am mostly concerned about so called habitat-forming species like *Fucus*, *Zostera* and *Furcellaria*.

What does our perfect sea look like?
Alien species are sometimes described like all introductions are negative. Even though it is not true that all alien species cause severe impacts, before saying that an alien species is positive, a clear definition of “positive” is necessary. We need to decide what state we want our seas to be in.

– Is a higher number of species in the Baltic, which is naturally poor in species, good? Sergej asks. The alien species are known to occupy empty niches and bring unusual functions to the ecosystem. In many cases, this means faster turnover of organic matter and even more dense “packing” of niches. Is that better than in previous centuries when there were no human-mediated biological invasions into the Baltic? I really do not know. The answer depends on how we imagine “the ideal Baltic”.

Hazardous substances

Hazardous substances refer to all substances having adverse effects on biota, including both substances of anthropogenic origin and natural substances, if the observed level exceeds natural concentrations.

There are a vast number of hazardous substances and this report can only include a few examples. A more thorough coverage of major classes of hazardous substances, effects and environmental fate is provided by, for example, “Principles of Ecotoxicology” by Walker et al. (2005).

Background

Monitoring of hazardous substances in the Baltic Sea shows that many of the classic pollutants have decreased significantly during recent decades (Bignert et al. 2007). This has been important for piscivorous species, of which many were severely affected by these substances. There are indications that mercury levels in marine biota have been halved since the 1970’s and most monitoring sites show low levels. Lead has decreased significantly since the ban against leaded fuel. Cadmium increased dramatically during the 1990’s, but this trend has been reversed although levels in Baltic localities are still higher than on the Swedish west coast (Bignert et al. 2007).

The decrease of some persistent organic pollutants, such as PCB and DDT, have positively influenced populations of marine top predators of which several suffered from reproductive disorders due to these substances (Helander et al. 2002, Karlsson et al. 2007), the most well-known example being the white-tailed eagle (see also page 78). However, although PCB show a decreasing trend elevated levels are still observed in the Baltic Proper (Bignert et al. 2007).

Other substances do not seem to have the same positive trend. Dioxins, which are unintentionally produced, and dibensofurans occur at concentrations higher than the background level. Among brominated flame retardants the high-brominated compounds (e.g. polybrominated diphenyl ethers, PBDE, and hexabromocyclododecane, HBCDD) are still produced and the concentrations of HBCDD in guillemot eggs from Stora Karlsö in the Baltic Sea increases with on average 3 % per year (Bignert et al. 2007). Perflourinated compounds (e.g. perfluorooctane sulfonic acid, PFOS) are fat- and water-repelling substances and they are often very stable. The concentration in guillemot eggs has increased almost 30-fold since the 70’s (Holmström et al. 2005, Bignert et al. 2007).

Tributyle tin (TBT) has been widely used in anti-fouling paints and is considered to be one of the most toxic substances with anthropogenic origin. Regulations concerning its use have been implemented – it was banned for use on smaller boats during the 80's and 90's and since 2008 an IMO convention prohibits the use also on large ships. The Geological Survey of Sweden (SGU) has mapped the concentration and distribution of TBT in sediments in Swedish waters in a research project 2002-2006. The results show that TBT occur in sediments throughout the entire coast and in the open sea. The highest concentrations (more than 100 000 times higher than the Ecotoxicological Assessment Criteria (EAC-value) set up by OSPAR in 2000) were found in several harbours, marinas and nearby shipyards, but strongly elevated concentrations were also measured in many other places along the coast (Cato et al. 2007).

Possible future trends and examples of ecological impacts

The substances with increasing concentrations may continuingly occur at elevated levels. For example PFOS is still being produced. The previously largest manufactor stopped using the substance in 2000, but other companies still use PFOS. The water-repelling capacity of PFOS made it a popular impregnation substance for paper, fabrics and leather. Consumer disposal of PFOS-containing products may lead to continued release of PFOS into the environment.

At present the PFOS concentrations found in guillemot eggs are well below the level where effects on reproduction in birds have been seen (Holmström et al. 2005 and references therein). However, the guillemots take up PFOS through their food, which in the Baltic Sea consists almost entirely of sprat (Hedgren 1976, Österblom et al. 2006) and it is possible, although speculative, that other species dependant on sprat and sprat predators, such as the grey seal, can take up PFOS so that the effect level will be reached. Similar chains of events are possible for other substances with increasing concentrations.

The high concentrations of TBT in sediments pose a risk in the future, which is further addressed by Ingemar Cato on the following pages. Already at TBT concentrations of only 1 ng/l water effects on gastropods have been observed. TBT is an endocrine disruptive substance and exposed gastropods develop imposex (male characteristics in females) which impacts reproduction and in several species causes sterility. Gastropods are the most well-known example of organisms affected, but effects on other organisms (e.g. blue mussels) have been seen (Cato et al. 2007). Significant declines in gastropod populations have occurred due to TBT exposure. If such severe consequences affect species with key functions in the ecosystem, like the blue mussel, effects cascading through the system may appear.

However, most substances that are regulated and no longer in use or production are in general decreasing in biota. It is likely that that trend will continue in the future. The awareness of environmental impacts of anthropogenic substances is much higher today than in the decades when many severe problems were discovered. In addition, monitoring of known hazardous substances and screening for potential new ones have been improved during the last decades. Thereby it is likely that we will be able to discover and mitigate the impact of hazardous substances in a better way today (Dag Broman, pers. comm.).

Ingemar Cato is a researcher at the Geological Survey of Sweden (SGU) and professor in Applied Marine Geology at Gothenburg University. He is responsible for the environmental monitoring in sediments and has focused on the presence of heavy metals and persistant organic pollutants.

The surveys of sediments in Swedish coastal waters reveal high concentrations of hazardous substances. The findings of high levels of TBT highlight this problem.

– TBT is clearly a severe problem in many areas, Ingemar says. We have not only found very high concentrations, but also indications of that there have been recent additions of this substance. The ratios of TBT:DBT and TBT:MBT, where DBT and MBT are breakdown products of TBT, are high, which suggests that the release was recent. Despite the ban against use of TBT, anti-fouling paints containing the substance seem to still be used by Swedish boat-owners. Apparently have the actions taken so far not been enough – the authorities need to take further actions if we do not want to face even more severe consequences.

The high concentrations raise the question of the stability of the sediments. Is it possible that more TBT will be released from the sediments and become available for biota?

– Yes, the land elevation will affect the sediments. When the land and the sea bottom are lifted due to isostatic rebound of the earth crust, sediment bottoms not previously exposed to the wave base will be affected by erosion caused by the waves. By this mechanism substances previously bound in the sediments will be rinsed out and resuspended to the water column. The substances bound in the sediments are not broken down due to lack of oxygen, thus the sediments have to be considered as a secondary source of TBT.

– There are also other persistant and hazardous substances found in the sediments (e.g. dioxins, PCBs, PAHs). Similar effects may be seen for these substances due to land elevation, Ingemar adds.

A possible sea level rise is a cause of concern

– Apart from land elevation there is another mechanism with potential to affect sediments – climate change with possible sea level rise. This is much less known, but it is possible that a sea level rise will affect sediments in archipelago areas. In archipelagos, land elevation made new islands appear which gave protection to previously open bays whereby sedimentation started. A sea level rise may reverse this chain of events and expose these sediments to erosion.

– Sea level rise may also result in flooding of near-shore areas where today boat storage facilities are found. From our studies we have seen that hazardous substances, with TBT as the obvious example, often occur at high concentrations near such facilities.

There are also many sites along the coasts where former industries were placed. Do they give rise to concerns in this context?

– This is a potential problem that we do not know the extent of today, but I believe that it may be of significant magnitude, Ingemar says. Abandoned sites, fibre banks from former wood industries and deposit areas for example are found close to shores and in the future those are may be under water.

More knowledge is necessary
Ingemar believe that a survey of dangerous objects and contaminated sites is important.

– We need to know how many there are and where they are situated to be prepared to deal with this issue in the future he says.

He also emphasises the necessity of investigations of more harbours and marinas to detect and measure TBT concentrations.

– TBT is already a major problem in the aquatic environment. Large-scale remediation of contaminated sites may be required. Otherwise, in the light of land elevation and sea level rise the impacts of this widely spread toxic substance may be of severe magnitude.

Hazardous substances reduce organisms' capacity to handle stress and thereby the resilience of the system

Impacts of hazardous substances are not restricted to increased mortality and reduced reproduction, but other effects on biota may be the consequence. Organisms affected by hazardous substances are under chronic stress and this reduces their capacity to handle other types of stressors. Such stressors may be the projected change in temperature, salinity or pH resulting from global climate change. Another stressor, already present in the ecosystem, is food shortage which is the case for several species dependant on zooplankton as a consequence of the high sprat stock (see further *A collapse of the Baltic cod stock?*). Food shortage may also be the result of competition with alien species (e.g. Leppäkoski et al. 2002, Karlson et al. 2007). Thus chronic stress caused by hazardous substances reduces the ability of marine organisms to deal with projected changes. If hazardous substances are present in organisms of several trophic levels or in organisms maintaining important functions in the system, the resilience of the ecosystem is reduced.

Construction and development

The coasts of the Baltic Sea and Skagerrak are under strong pressure from human activities (EEA 2006a). The coasts are becoming increasingly popular locations for housing and development projects at the same time as both coast and open sea are more intensively used to provide us with energy (e.g. wind mill parks, offshore oil platforms, gas- and oil pipelines).

Transformations from natural to artificial

One of the major factors is transformation of natural habitats to artificial surfaces, through the expansion of cities (i.e. urban sprawl) and residential development in previously undisturbed areas (EEA 2006a, b). Residental development includes both permanent and holiday houses and has increased on a large scale in several areas (e.g. the Finnish coast [EEA 2006a], the Stockholm archipelago [Kindström 2006]). This has major implications for many coastal species and communities, since their habitats become more fragmented and decrease in size.

Local or regional effects may appear as the result of ongoing construction projects. Noise can disturb or deter animals from the site and the surroundings. Construction work may cause sedimentation of particles which can adversely affect valuable habitats like seagrass meadows (Baden et al. 2003, Pihl et al. 2006).

Wind mill parks

The concern about climate change has increased the demand for wind power and large-scale expansion of wind power is currently being planned for in e.g. Sweden (Vindval 2008). Near-shore and ocean-based wind mill parks may affect fauna in several ways. Migrating and foraging birds and bats may be affected by increased mortality if the wind mills are not avoided. If the wind mills deter resident animals, areas of available habitat will be reduced. Sounds and vibrations from wind mills may affect invertebrates and fishes, but preliminary results indicate that there are no or small effects (Vindval 2008). The wind mill foundations may also act as artificial reefs and thus attract fauna. Research is currently conducted to assess possible effects and find feasible measures to reduce impacts (Vindval 2008).

The white-tailed eagle – a species with defeated and new threats

During the 1960's it was discovered that fewer white-tailed eagles were born. Monitoring was initialized which confirmed the poor reproductive success and during the 70's demonstrated a continuingly decreasing trend. Hazardous substances were soon suspected to be the cause of the decline. DDT was already in focus and the discovery of PCB in biota in 1966 was through high concentrations in a white-tailed eagle. Supplementary feeding with non-polluted meat was one of the measures used and that greatly increased the survival of the few eagles that were born.

Björn Helander is a researcher at the Department of Contaminant Research at the Swedish Museum of Natural History and the project leader of "Project White-tailed eagle" run by the Swedish Society for Nature Conservation (SNF) since 1971.

– We saw that the concentrations of DDT and PCB in eggs and birds decreased after the ban of these substances in the 1970s, but the reproductive success remained at a very low level into the 1980s. After 1985 the reproduction slowly improved but it was not until 2000 that it was back to normal. Through retrospective analysis I have found that the decrease in brood size started already in the early 1950's, so it actually took 50 years before reproduction returned to the normal level.

– We have not completely reached normal brood sizes, since the eagles in the southern Bothnian Sea still have a lowered reproduction. In this area we analyze dead eggs to try to find out what kind of hazardous substances can be involved. We know now that it is not DDT, PCB or flame retardants.

– The population is now increasing and this is not only in Sweden. The situation has been similar in other Baltic Sea countries and also there the eagle populations are expanding. We can only hope now that we will not see hazardous substances having large impacts in the future. I believe that competition for space will soon be an important issue, Björn says. Exploitation of coastal areas, for housing and wind mill parks, would affect the number of suitable breeding areas and even the survival of eagles. And forestry affects the eagle, since they breed in old trees large enough to support the heavy nest. If potential nest trees are not left to grow further, to a greater extent than is done today, there will soon be a shortage of suitable trees for nesting at the breeding sites. Many of the old nest trees will soon be gone and must be replaced! I believe this is one of the most important issues for the future of the white-tailed eagle, Björn says.

The white-tailed eagle is an example of the possibility to reverse negative trends. The fact that 50 years was necessary before reproduction returned to normal illustrates that efforts during a long time may be required. However, with the current level of monitoring it would have been possible to discover the changes before the situation had become so severe. The work during 40 years of monitoring of reproduction and supplementary feeding has to a large extent been conducted by hundreds of volunteers. If similar efforts are required to save species that are less appealing to people, whereby volunteers is not an available option, the costs for society would be much larger. Therefore discovery of negative trends and actions in an early stage are of uttermost importance in issues concerning biodiversity conservation.

Combined impacts on biodiversity

Biological diversity refers to the variability among living organisms, including the diversity within species, between species and of ecosystems (UN 1993). A high degree of biodiversity within an ecosystem, at the level of genetical diversity, species diversity and biotope diversity, appears to increase the resilience of the system – the capacity of the system to deal with change and continue to develop (e.g. Chapin et al. 1998, Bellwood et al. 2004, Worm et al. 2006). Reduced biodiversity will imply decreased ability to fill specialization niches and a lower buffering capacity against the effects of variability and stochastic events – both naturally occurring and human-induced.

The species in the Baltic Sea and Skagerrak are almost exclusively post-glacial immigrants and the ecosystems are thus quite young (Bernes 2005). The pronounced vertical and horizontal gradients in salinity and temperature shape biodiversity (Stigebrandt 2001, Leppäkoski et al. 2002 and references therein). In Skagerrak, the structure and diversity are very similar to what is found in the North Sea and the northeast Atlantic. Continuing through Kattegat and further into the Baltic Sea the number of marine species decreases while freshwater species appear and become more abundant further north. Relatively few species have been able to adapt to the special salinity of the Baltic whereby overall species diversity is low. Nonetheless the combination of marine and freshwater species is unique and several Baltic Sea species have formed populations that are genetically distinct from their source populations.

General future trend

Overviews of possible future development for marine biodiversity have not been found. In stead, experts within the field have been contacted to provide a picture of likely trends and changes in the future. In conclusion, the knowledge about marine biodiversity is limited, but there is probably a large number of species and communities in the Baltic Sea and Skagerrak that face difficulties in the future. There are many threats to biodiversity, which in concert are likely to continuingly drive the current trend with a depletion of native marine biodiversity.

Anna Karlsson and Martin Tjernberg work at the Swedish Species Information Centre. Anna Karlsson is an expert on marine invertebrates and leads an inventory of invertebrates in Swedish coastal waters. Martin Tjernberg is responsible for work related to bird and mammal species and has previously worked with fish.

It is difficult to properly assess status for many marine species due to lack of data, Anna says. When speaking in general terms, we can say that it is very likely that a large fraction of the marine invertebrates has been negatively affected, meanwhile only a small number has benefited from the present situation with eutrophication and large-scale bottom-trawling in the Baltic Sea and the Skagerrak. To sum up, there has been a general decrease in marine biodiversity.

For fish, the situation is poor with many decreasing species, Martin says. This is true especially for commercial species but also for other fishes. Many former important reproduction areas have disappeared. In the Baltic Sea however, the eutrophied state of the ecosystem is beneficial for some species, e.g. sprat. This in turn has been the basis for increases in some bird populations, such as the great cormorant, and has probably been advantageous also for seals.

Lack of knowledge at present
We have a big gap in knowledge when it comes to baseline data for many species, Anna says. Except for commercial fish, there are no long time series available. We have a poor understanding of species composition and the functioning of species in the marine ecosystems. The lack of knowledge is the reason why we are lacking a relevant target for most species. We simply do not know how the situation was before the large-scale human interference.

Are there any particular species groups that are under threat?
The large lack of knowledge combined with large-scale problems makes it difficult to point out specific groups or species, Anna says. But at least on the Swedish west coast we have seen that the coastal fauna is depleted because of eutrophication and that trawling on soft bottoms creates rough conditions for macrofauna. In addition sessile species, like macroalgae and filter-feeders are sensitive to sedimentation caused by human activities.

Martin adds:
– Commercially exploited fish species is the obvious example, for which the situation is the same in the Baltic and in Skagerrak. I believe that long-lived species with low reproduction rate are most threatened, an example being cartilaginous fishes[14].

– Bycatch in fisheries is also a problem for cartilaginous fishes and for other non-target fish species. This is also a threat to some bird species and mammals especially harbour porpoises.

Can you make any forecasts for the future?
Forecasts are not possible to do at this point, as we still struggle to understand what is happening today. But we can guess that if we do nothing to improve the situation we have to get used to eutrophied coasts where we rarely see any fishes or other signs of marine life, Anna and Martin says.

[14] Cartilaginous fishes have skeletons made of cartilage. This class includes e.g. sharks, rays and skates.

Both Anna and Martin believe that climate change will become an important factor for many species.

– Changing currents may lead to different migration patterns for pelagic plankton. A higher water temperature can increase fragmentation of sensitive areas, such as the southern part of Kattegat with water colder than surrounding areas where a rather isolated fauna of many cold water species exist today. It is possible that acidification of oceans will occur which may lead to corals and mollusks facing difficulties absorbing and using calcium, Anna states.

– The projected decrease in ice cover in a changed climate is probably detrimental for the Baltic ringed seal population, Martin says, as this species is dependant on ice.

Martin and Anna think that invasive alien species will probably become increasingly important. We may see aliens replacing native species in the future, they say.

Suggestions for further research
Actions to improve the situation, for example establishment of marine protected areas and areas closed for fisheries, need thorough follow-up to answer whether these measures help species and the ecosystem to recover and if it enhances resilience, Martin and Anna agree.

– Since studies in marine areas are expensive it is important to use existing data, Anna emphasizes. There are for example data from monitoring programs that need to be digitalized to be available for researchers. At present it is difficult to identify relevant data.

– There is a strong need for more research targeted on species, as species and species groups are essential tools in nature conservation. At the same time it should be combined with ecosystem analysis, so we can identify marine keystone species and indicator species. This will allow more efficient work in the future and will help to provide relevant targets, Anna states.

Anda Ikauniece is a researcher at the Institute of Aquatic Ecology at University of Latvia.

The scene in Latvia is similar to the overall picture in the Baltic Sea for marine biodiversity. The main drivers are exists also in Latvian waters with all the following biological consequences, Anda says. There are local differences on e.g. species level, but the processes and functional settings are not unique to Latvia.

– During the last decade we have seen an increase in grey seals numbers, but they are still in the Red Book of Latvia as the other seal species and the harbour porpoise, Anda says. Seals are impacted by bycatch which is also true for birds. We have also a constant influence of eutrophication and construction projects on macroalgal communities.

Forecasts for biodiversity will be produced in Latvia
– The national research programme KALME, ”Climate change impact on the water environment in Latvia”, was launched in late 2006. One of its tasks is to provide a forecast for future marine biodiversity dynamics. As the outcome is planned in 2009 and the analysis is performed currently, I can not say anything more at the moment.

Drivers for future change
Climate and human activities, e.g. fishing, shipping and input of nutrients, will probably be the most powerful drivers also in future. The climatic change is out of scope of regulations and the number of people will not decrease close to medieval time levels, Anda states.

The implementation of the Baltic Sea Action Plan is a way to stop further deterioration of the marine environment and improve it in certain areas like macroalgal habitats and breeding sites for birds and seals. Still, it will not solve the problem of e.g. alien species already inhabiting the Baltic Sea and causing changes in local populations, Anda concludes.

Pasi Laihonen is a senior researcher at the Finnish Environment Institute (SYKE). He works within the research programme for the Protection of the Baltic Sea.

The biodiversity in the Finnish waters is clearly affected by eutrophication, Pasi says. The structure of populations and communities is shifting towards that typical of eutrophied aquatic ecosystems. The change is gradual and proceeds from the Gulf of Finland towards west and north along the Finnish coastline. However, the Gulf of Bothnia remains a relatively unaffected area and has some potential to keep that status in the future. This is due to low local nutrient discharges as well as isolation of the area from the Baltic Proper.

Projections about the future for marine biodiversity are not available in Finland, Pasi says. No reliable scientific forecasts on biodiversity have been made so far. One scenario presented is reduction of salinity due to climate change and alteration of species composition as a consequence, but that has not been verified in any manner.

– What we can expect is that eutrophication will advance at least to some extent during the next 5-10 years. This will continue to change the structure of some benthic ecosystems along the Finnish coastline.

Concerns as well as possible improvements in the future
Increasing maritime traffic and the corresponding risk of extensive oil spills in the Gulf of Finland poses the most serious threat in the future, Pasi believes. In addition, the low level of environmental awareness especially in Russian political decision-making is a serious issue. A corresponding lack of awareness can be found in the decision-making regarding Finnish agricultural policy. However, there are also reasons to be hopeful. The HELCOM Baltic Sea Action Plan has significant potential in improving Baltic Sea protection measures, Pasi Laihonen says.

Knowledge gaps and suggestions for future research

There are many environmental issues which in concert affect the ecosystems in the Baltic Sea and the Skagerrak. Some fields are well-studied and thereby a thorough knowledge has been gained. Other aspects are less well known and cumulative impacts of several stressors to the ecosystems are difficult to assess. This section is a summary of knowledge gaps that have been highlighted by researchers and experts and the gaps of information that have appeared during the compilation of this report. It should however not be viewed as a complete list of important fields for further research.

Socio-economic effects of the projected changes and scenarios included in this report would be desirable information, but such studies have rarely been made (with the exception of oil spill scenarios [e.g. Forsman 2004a, b, 2006, 2007]), whereby the cost of not taking action is not possible to assess in these cases. Information about costs of action exists for several fields (e.g. reductions in nutrient inputs and hazardous substances, oil spill abatement, alien species introduction, changes in fisheries [e.g. Elofsson 2008, Gren 2008, Swedish Board of Fisheries 2007]). In Hasselström and Söderqvist (2008), the present knowledge about economic values of an improved Baltic Sea environment is summarized. Still, more research on the cost of not taking action appears necessary, especially regarding probable scenarios for which the cost (of non-action) can not be derived from studies of benefits of taking action.

For regional impacts of climate change projections have been made concerning several aspects of physical changes. The effects on the ecosystem have been assessed based upon the knowledge about responses to prevailing variations in climatic variables. Modelling exercises might give further insights to possible future development.

Ocean acidification is one aspect of climate change which is poorly known. A lower pH may have implications for biogeochemical cycling and thereby for eutrophication, but this have not yet been studied. Neither have regional modelling studies concerning ocean acidification been made whereby the future trend in the Skagerrak and the Baltic Sea is uncertain. Considering the potential severe impacts of lowered pH such studies would be desirable. Knowledge about the effects of ocean acidification on some species is emerging, but research on more species, including commercially important fishes and shellfish, and ecosystem impacts appear necessary.

Eutrophication is one of the more well-known issues in marine ecology where both local and basin-wide studies have been conducted and the most of the necessary steps to mitigate eutrophication are known. There are however some aspects for which more research would be desirable. The links between cyanobacterial blooms and overall production in the system are not well known. In addition, how changes in upper trophic levels affects zooplankton communities and thereby phytoplankton is a field where possible relationships have been observed, but more studies in marine systems are necessary, since the firm evidence for such relationships in lake systems may not be possible to translate to marine systems. The studies should preferably include several piscivorous predators, e.g. seals, seabirds and predatory fishes, especially those where a large increase in numbers have been seen during the last decades. Their role in these processes (e.g. interactions between species and cascading effects) are still poorly known.

The ecosystems' capacity to deliver ecosystem services is of large importance for society and individuals (Garpe 2008), but the knowledge about which parts of the ecosystem that maintain these functions are still limited. Further research in this field is thus important, especially in regard to the most desired ecosystem services.

For conservation of biodiversity the knowledge seems patchy with commercially important fishes being well-known but for many groups of species there is a lack of knowledge. Targeted research on poorly known groups would be desirable, especially in combination with ecosystem studies so that keystone species and indicator species can be identified. National efforts to conserve biodiversity seem to be a priority for many countries, but more concerted monitoring and measures on a basin-wide scale (i.e. the Baltic Sea) appear beneficial.

Established alien species have been observed to cause ecological impacts, but the knowledge about possible impacts of alien species on native communities, habitats and ecosystem functioning is still sparse. Improved identification of potentially harmful species is necessary as well as inclusion of alien species in programs to conserve biodiversity.

Arctic Tern at Stora Karlsö, Baltic Sea. Photo: M. Kadin.

Conclusions

The Baltic Sea and the Skagerrak are strongly affected by anthropogenic activities. This influence will be equally strong or even stronger in the future, but the relative importance of the driving factors is likely to shift.

Introduction of alien species will probably become a very important issue. The risks of harmful alien species being introduced are large and species already present in the Baltic Sea and Skagerrak can potentially alter the state of the ecosystem. Establishment of harmful alien species is likely to be a large-scale driver of change with fast as well as long-term effects. The effects may cascade through the food-web or directly impact the whole ecosystem. The knowledge about alien species is rather poor, especially as far as risk identification and awareness is concerned.

Excessive nutrient input has occurred during more than half a century and the effects of this input - eutrophication, are slow and long-term. Eutrophication is at present a major concern, since it is a large-scale problem with effects throughout the ecosystem. Significant general improvements can unfortunately not be foreseen within the next decades. Still, in a longer time frame – towards the end of the century, there are reasons to be more optimistic.

Overexploitation of commercially important fishes is a serious threat. The present exploitation has severe effects on some species, such as cod, but in addition the effects cascade through the food-web whereby the ecosystems in the Baltic Sea and the Skagerrak have been pushed into new states. The new states are not irreversible, but instead a fast response to measures can be expected. If proper actions are taken – and these are well known – this problem will soon diminish. In the case of no action there is a risk of passing thresholds whereby the new states become more permanent and much larger efforts will be needed to move the system towards earlier states, if at all possible.

Ocean acidification is a likely result of global climate change with slow and long-term effects. A lowered pH will have large-scale impacts and ecosystem effects may be the result. The knowledge about this issue is very poor and the possibility to reverse the trend appears small at the moment.

Chronic oil pollution is the result of illegal discharges from ships. The consequence is fast and short-term direct effects, but for some species the effects seem severe and in these cases longer-term impacts as a consequence of decreasing populations may be seen. The direct effects are local, but potential indirect effects may occur at a larger scale. At present, illegal oil discharges are decreasing but the projected growth of shipping in the Baltic Sea and Skagerrak may lead to a worse situation. The available knowledge suggests that for some affected populations the effects of chronic oil pollution are equally or even more important than potential effects of a large oil spill. Thus this aspect of maritime activities deserves more attention.

The future salinity in the Baltic Sea is uncertain, but a changing climate may reduce the salinity significantly. The effects will emerge slowly, but are long-term and projected to affect several key species in the ecosystem whereby radical changes may be the result. An increase of sea surface temperature is somewhat more certain and this will affect organisms in the Baltic Sea as well as Skagerrak. A competitive advantage for warm-water tolerant species may appear and cause shifts in dominance between species. New states of the ecosystems may be the consequence and a possibility to reverse this development may not be in our hands.

Hazardous substances are mostly well known and there is a general awareness of their impacts. The effects of hazardous substances usually emerge slowly and on a large scale. When adequate actions are taken medium-term impacts have been the case. The direct consequences of hazardous substances in the Baltic Sea and the Skagerrak have not caused ecosystem effects, but sub-lethal effects may, when widespread in the system, reduce the capacity to absorb and deal with change – the resilience of the system. Thus present and future hazardous substances may contribute to shifts in the ecosystems into less desired states and reduce the possibility of the marine systems to deliver ecosystem services.

Effects of larger oil spills are quite well studied as well as the risk associated with oil transportation. It seems clear that the risk of a large oil spill in the Baltic Sea or in Skagerrak will continue to increase. Most likely, the ecological effects of a large spill will appear fast, but be short-term at a local scale. Unfortunate circumstances may however lead to larger scale effects whereby a return to the pre-spill state of the system also can take a longer time.

Biodiversity is changing both at a local and a basin-wide scale, but the knowledge about marine biodiversity in general and the magnitude and pace of the changes is limited. A changing climate, eutrophication, overexploitation of commercially important species, oil pollution and hazardous substances, competition and predation from alien species – all these drivers change the prerequisites for species, communities and biotopes and their interactions, thus making decreasing “native” biodiversity is a likely trend in the future. In addition, competition for space, caused by exploitation of coastal areas for construction and development (e.g. housing and wind mill parks), will become increasingly important in the future and may on a large scale favour species and communities that are resilient to habitat fragmentation. These trends are likely to be slow and both short-term and long-term impacts may be the result. Introduction of alien species may lead to an overall increase in biodiversity. Since the ecosystems of the Baltic Sea and Skagerrak are young this a natural trend, but whether the human-induced enhancement of this development is positive is a subjective opinion.

The strong anthropogenic pressure on the Baltic Sea and the Skagerrak are not unique examples but marine systems have been modified by humans on a global scale. Jackson et al. (2001) describe how human over-exploitation of marine top-predators during at least many centuries has led to structural and functional changes in ecosystems globally. Subsequent shifts in functional dominance between species contributed to further losses of ecosystem functions when some populations died from diseases related to overcrowding and continued exploitation drove additional species towards extinction. Such development pushes the system towards lower trophic levels and makes it more vulnerable to other types of disturbance.

This type of human impact on an ecosystem may, especially in combination with other influences such as addition of nutrients and hazardous substances as well as a changing climate, increase the likelihood of a regime shift (Folke et al. 2004), a sudden shift of the ecosystem from one state to another.

The cumulative and sometimes synergistic effects of human pressures are thus of obvious importance, since many smaller long-term impacts can lead to continuous reduction of ecosystem function and lower resilience of the system. This can eventually bring the system to a tipping-point where the system enters a new state – a regime shift. A return to the former state may not be possible. The new state may be less desirable, since the capacity of the system to generate ecosystem services may be reduced (Folke et al. 2004).

In conclusion, our long-term change of the ecosystems in the Baltic Sea and the Skagerrak has severe implications for their future ability to maintain the highly appreciated functions of large importance to society and individuals. Continued pressure on the marine environment may lead to consequences that are devastating for all people depending on or enjoying the Baltic Sea and the Skagerrak.

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Appendix I.
Descriptions of eutrophication models

A hydrodynamic model can be coupled to a biogeochemical model, thus creating a hydrodynamic biogeochemical model. Since these models are applied to eutrophication issues, they are often referred to as eutrophication models. This kind of model describes transport mechanisms in the water column and biogeochemical fluxes in the water and the sediment.

The biogeochemistry can be described with different level of complexity, ranging from biogeochemical cycling and matter fluxes, with variables such as concentration of nitrogen (N) and phosphorus (P) in different forms and compartments, to inclusion of ecosystem functional aspects. More complex models describe fluxes like nutrient uptake through primary production, grazing and nutrient excretion by zooplankton, plankton mortality, sedimentation of particulate nutrients, nitrogen fixation and denitrification. Variables included may be (groups of) phytoplankton and zooplankton, detritus, ammonium, nitrate, phosphate, silicate, oxygen (O_2) and nutrient pools in sediments.

The list of models below is not complete, since several other local and regional models have been developed. The models mentioned in the text are included as well as a few of the models used in other studies to illustrate the difference between models and to provide the interested reader with information on how to obtain further documentation.

Examples of zero- and one-dimensional eutrophication models

- SANBALTS – A zero-dimensional model with eight boxes covering the Baltic Sea sub-basins starting from Kattegat. Baltic Proper is represented by an upper layer and a deep layer box. Boxes are interconnected by transport mechanisms due to advection and mixing. Included state variables represent annual averages of N and P in the dissolved inorganic, labile organic, refractory organic and benthic forms. Additionally, average O_2 concentration is included in the deep Baltic Proper box. Developed by Baltic Nest Institute, Stockholm University (e.g. Savchuk 2006, Savchuk & Wulff 2007).
- BALTSEM – A one-dimensional model with 13 boxes covering the Baltic including Kattegat. Pelagic state variables are diatoms, cyanobacteria, small summer phytoplankton, zooplankton, detritus N, P and Si, ammonium, nitrate, phosphate, silicate and dissolved oxygen. Additional state variables are bioavailable pools of N, P and Si in the top active layer of sediments. Developed by Gothenburg University and Baltic Nest Institute, Stockholm University (e.g. Gustafsson 2000a, b, 2003).

- The Swedish coastal zone model system – based on PROBE (a one-dimensional model hydrologic model) and SCOBI (biogeochemical model). Coverage of the Swedish coastal areas from the Bothnian Bay to Skagerrak. Developed by Swedish Meteorological and Hydrological Institute (SMHI). Documentation information is available through www.smhi.se
- Information about other models used to study eutrophication in the Baltic Sea is available from BALTEX: http://www.gkss.de/baltex/projects/survey_bgcm.html

Examples of three-dimensional eutrophication models for the Baltic Sea

- RCO-SCOBI – Rossby Centre Regional Climate Model (RCO) is the hydrodynamic part which is coupled to the biogeochemical model SCOBI. It is developed by SMHI to be used for "investigations of the Baltic Sea response to climate variations and anthropogenic activities on long time scales (100 years)".
- SPBEM – The model has a hydrodynamic module with a sea-ice model coupled to an ocean model and the same biogeochemical module as BALTSEM. SPBEM is developed by Arctic and Antarctic Research Institute in Russia and Baltic Nest Institute, Stockholm University.
- ERGOM – "Biogeochemical model to describe explicitly the nitrogen cycle, truncated at the level of zooplankton". Developed by the Institute for Baltic Sea Research in Germany.
- Information about the above and other models used to study eutrophication in the Baltic Sea is available from BALTEX: http://www.gkss.de/baltex/projects/survey_bgcm.html

Examples of hydrodynamic biogeochemical three-dimensional models for the Skagerrak

- COHERENS - State variables included are microplankton carbon (C) and N, detrital C and N, nitrate, ammonium, O_2, zooplankton and inorganic sediment. Used and developed by National Environment Institute in Denmark among others.
- NORWECOM – State variables included are diatoms, flagellates, detritus, particulate matter, nitrate, ammonium, dissolved inorganic N, total N, phosphate, silicon, O_2 and C. Developed by the Institute of Marine Research in Norway.
- The above and other examples are described in an overview published by Forum Skagerrak (Söderkvist 2006).

Appendix II.
Point sources of eutrophication

The first signs of eutrophication were observed in the waters near larger municipalities and industries early in the 20th century (Bernes 2005). Untreated waste water, containing high levels of nutrients, was discharged directly into lakes, rivers and coastal waters. Especially in archipelago areas and narrow bays – water bodies of small volume and long water residence time – the problem of hypoxia and anoxia became prominent. However, oxygen depletion in urban waters was only partly due to addition of nutrients. The waste water also delivered large amounts of organic material, which when decomposing, increased the demand for oxygen. Although municipal waste water was an important source, industrial effluents have accounted for the major part of the organic material released along the Swedish coasts (Bernes 2005) with pulp mills and paper factories being the main contributors to this pollution.

In the 1950's biological treatment of municipal and industrial waste water was introduced in Sweden which in the 1970's had improved oxygen conditions significantly. However, the technique has no major effect on nutrient content and at the same time the contribution from households increased through the introduction of phosphate-containing detergents. To reduce the problem, chemical treatment to remove phosphorus was introduced during the 1970's (Bernes 2005). This proved successful for remediation of previously eutrophied inland waters, but in the Baltic Sea and the Skagerrak the importance of phosphorus was soon questioned (for a review see Elmgren [2001]). Therefore nitrogen removal was eventually required in waste water treatment plants in sensitive areas. Today, the major part of the municipal waste water released along the Swedish coast undergoes treatment to remove nitrogen (Bernes 2005, Statistics Sweden 2007a)[15]. The water from smaller industries is in most cases treated by municipal treatment plants, but larger industries run their own treatment facilities whose effectiveness have improved greatly during recent decades[16].

Development of waste water treatment in Finland and Germany have generally mirrored the Swedish improvements (Bernes 2005), meanwhile Denmark first focused on nitrogen removal and improved coastal waste water treatment plants with techniques to remove more phosphorus later on (Ærtebjerg et al. 2003). In

[15] Nitrogen was removed from 71 % of the waste water released from coastal Swedish waste water treatment plants in 2004. The technique used removes on average 69 % of TN. Statistics Sweden (SCB) 2007a.

[16] Industrial waste water releases similar amounts of phosphorus as municipal waste water (384 and 318 tonnes TP respectively in 2004) and for nitrogen the contribution from industries is less than a third of the releases from municipal waste water (4 796 and 17 779 tonnes TN respectively in 2004). Statistics Sweden (SCB) 2007a.

Poland large investments were made in modern waste water treatment during the 1990's, which resulted in more than a third of the population connected to municipal waste water treatment plants with biological-chemical cleaning today (Humborg et al. 2007). Recent improvements of municipal plants have also been taken place in Estonia, Latvia and Lithuania (HELCOM 2007a).

The implementation of effective treatment methods has reduced nutrient input from point sources and in 2000 they constituted about 10 % of waterborne nitrogen loads and 25 % of waterborne phosphorus loads to the Baltic Sea (HELCOM 2004).

Aquaculture, in this case farming of predatory fish, has been much debated as point sources for extra nutrients (e.g. Johansson 2003, Härdmark 2007). Their contribution is described in the section *Aquaculture*.

Trends and scenarios exemplifying the future of the Baltic Sea and Skagerrak

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Ecological impacts of not taking action

What will happen if no further action are taken to improve the state of our seas? This report describes possible ecological impacts due to climate change, eutrophication, over-exploitation of commercially important fish, maritime transportation, hazardous substances and the cumulative effects of all these drivers if no action are taken. Future outcomes are exemplified by scenarios and trends and important issues are highlighted in interviews with leading researchers.

The report is part of the project Economic Marine Information assigned by the Swedish Government.

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