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Sectoral Impact Assessments for the Baltic Sea Region

Climate Change Impacts on Biodiversity, Fisheries, Coastal Infrastructure and Tourism

Editors:
O. Krarup Leth, K. Dahl, H. Peltonen,
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BALTADAPT – Baltic Sea Region climate change adaptation strategy

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Visit our project website www.baltadapt.eu to learn more about Baltadapt.

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Preface

Ole Krarup Leth
Danish Meteorological Institute (Lead Partner Baltadapt)

During this century, global average surface temperature rises are likely to exceed 2°C above the preindustrial level. Temperature rises will be greater at higher latitudes. In the Baltic Sea area temperature rises are expected to be most pronounced in the northern half and during winter months. United Nations Intergovernmental Panel on Climate Change (IPCC) intermediate emission scenario labelled "A1B", which is the scenario used to derive most of the projections discussed in this report, predict 3-5°C rises of the Baltic Sea area by year 2100 and with more frequent events of, e.g. heat waves compared to present day. A future climate is expected to also bring larger amounts of precipitation to the Baltic Sea area, more so in winter. Precipitation extremes are expected to increase although with higher degree of uncertainty compared to projected changes in temperature extremes. Average sea level is expected to increase by a meter or so in the Baltic Sea by 2100. The tendency of future changes in wind speed remains unclear and so does the tendency of the strength and frequency of storm surge events. The resulting changes will jeopardize the integrity of the ecosystem and increase risks caused by natural disasters.

The interaction between climate change and sectors, government functions etc. are likely to be rather complex. Identifying which effects are important in terms of responding now may seem to be a rather overwhelming task. However, assessing the effects of climate change may be focused on specific sectors and broken down into manageable steps while risk assessments can be used to guide judgements on where to focus adaptation efforts.

In the EU Interreg project Baltadapt, climate change impact assessment has been focused on the following three sectors: Fish stocks and fisheries, infrastructure and tourism. Besides these sectors, climate change impact on the Baltic Sea marine biodiversity has also been assessed. Results can be found in the following chapters.

Climate change is truly a cross-cutting issue impacting different sectors on macro-regional scales. Our ability to respond to negative effects of climate change in the Baltic Sea Region relies on the generation of reliable and relevant information. Strengthening of scientific and technological capacity is crucial here to help reduce our vulnerability and build resilience in national, local, regional and macro-regional infrastructures. The selection in Baltadapt of the particular sectors is based on the notion that climate change adaptation can gain particularly from region-wide cooperation here because impacts are expected in major parts of the region.

Together the assessments presented in this report form a basis for the development of a Baltic Sea climate change adaptation strategy and action plan, a main output of the Baltadapt project. The strategy and action plans have been developed in the project as a direct response to the EU strategy for the Baltic Sea Region and its wish to provide a framework to strengthen cooperation and information sharing in the region and help to create a coherent set of adaptation policies and actions from the trans-national to the local level. While it is understood that such a strategy cannot be adopted by Baltadapt, the project is aiming to clear the ground for its adaptation.

Other achievements of the project include a knowledge brokerage process between political decision makers and researchers leading to improved institutional capacity and the development of the Baltic Window, a one-stop-shop information portal of the European Environmental Agency's Climate Adapt portal, compiling all available information on climate change in the Baltic Sea Region. This portal shall be the hub for decision makers from the Baltic Sea Region.

Project Partners:

Danish Meteorological Institute – Denmark
Aarhus University, Department of Bioscience – Denmark
University of Tartu, Estonian Marine Institute – Estonia
Finnish Environment Institute – Finland
Federal Environment Agency – Germany
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety – Germany
Leibniz Institute for Baltic Sea Research Warnemünde – Germany
University of Latvia – Latvia
Baltic Environmental Forum, Lithuania – Lithuania
Swedish Meteorological and Hydrological Institute – Sweden
The Secretariat of the Council of the Baltic Sea States – Sweden

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s.Pro – sustainable projects GmbH – Germany

Content

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Climate Change Impacts on Marine Biodiversity and Habitats in the Baltic Sea– and Possible Human Adaptations

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Abstract

Climate change is expected to induce substantial changes in the Baltic Sea ecosystem. The Baltic Sea is generally recognized as a fragile ecosystem characterized by a low number of species that virtually all find their distribution range within the area. This article demonstrates, in a number of case studies, how first of all climate stressors, like increasing temperature, changing precipitation patterns and increasing sea level, are expected to severely affect ecosystem stressors like eutrophication and oxygen depletion. Secondly, the article focuses on how one or several climate or climate driven ecosystem pressures are expected to affect the Baltic Sea ecosystem using examples of expected changes in primary production, biodiversity and key habitats. The findings are based on existing reports as well as new analyses carried out as a part of the Baltadapt project. Finally, possible adaptation measures to secure a healthy Baltic Sea ecosystem in the future climate situation are discussed as well as management implications to existing policies.

1 Introduction and aim

The Baltic Sea is one of the world´s largest brackish inland seas with nine countries bordering its coast, which has a length of around 8,000 km. An additional five countries are included in the Baltic Sea Drainage Basin. Approximately 16 million people live within a distance of 10 km from the coast (Hannerz & Destouni 2006).

The Baltic Sea is still influenced and shaped by on-going postglacial uplift in the northern part whereas the area in the south-western part is slightly sinking. The Baltic Sea has a limited water exchange with the North Sea and is characterized by strong horizontal salinity gradients. As a consequence, the Baltic Sea also exhibits strong horizontal gradients in ecosystem variables, with dominance of marine and warm-water species at lower latitudes and freshwater and cold-water species at higher latitudes.

The Baltic Sea is distinguished by a low number of species inhabiting the sea. This is due to the brackish living conditions and that the Baltic Sea in an evolutionary sense is a young sea with short time for species to invade and adapt to the special living conditions. The fact that most species are living on the very edge of their physiological ability somewhere along the gradients of structuring factors in the Baltic combined with the relatively few number of species, justify the assumptions that the ecosystem in this area is particularly vulnerable for even minor changes in the overall living conditions.

Assessments of climate change impacts on the Baltic ecosystem are available in a number of reports and papers (e.g. the BACC report 2008). The aim of this report, however, is to focus on possible adaptive measures that can be taken either directly to counteract climate change effects on the ecosystem or measures that can be taken in general with regard to management and planning of the future Baltic Sea.

The report will focus on selected case studies including key habitats, species communities and important key species. Potential changes in different climate factors and their impact on the bio-logical diversity in the Baltic Sea will be discussed as well as management implications and adaptive measures.

Some work presented in this report is based on existing knowledge. However, some analyses have been carried out as a part of the Baltadapt project (effects of temperature on distribution of selected macrophytes in Danish waters) or represent an updated analysis of previous studies presented in this report for the first time (temperature effects on nutrient concentrations in Danish Fjords and effects of temperature on oxygen depletion). Projections of future species distributions based on changing salinities have also been carried out as part of the Baltadapt work and the results are presented in this report.

2 Expected and recent climate change in the physical-chemical living condition for the Baltic Sea species

The Baltic Sea water is characterized by large variations in the salinity, both horizontally and vertically. The surface salinity is very low in the Gulf of Bothnia and the Gulf of Finland, due to large river run-off, and increases gradually towards the south and the entrance region. The Kattegat and the Belt Sea area is a transition zone between the brackish Baltic Proper and the more oceanic Skagerrak. The Baltic Sea water is strongly stratified with a permanent halocline (layer where the salinity changes rapidly with depth). In the central part of the Baltic Proper the halocline is usually found at a depth of 60–70 m.

As a consequence of the strong stratification, the water becomes stagnant in the deeper parts of the Baltic Proper and depleted of oxygen. Eutrophication will aggravate the situation in the bottom waters where oxygen is consumed. Irregular Inflows through the Danish straits and the Sound of more saline and oxygen-rich water temporarily improve the conditions.

The Baltic Sea surface temperature shows large seasonal variations, from more than 20°C in summer to freezing conditions in winter. In spring the surface water warms up and a shallow thermo-cline (layer where the temperature changes rapidly with depth) is created. Winter turnover of the water mass will break down the thermocline and in areas with depths less than 60 m, or with weak salinity stratification, the turnover may reach down to the bottom and renew the bottom water.

The Gulf of Bothnia and the Gulf of Finland are normally ice covered during the winter season. The ice cover records show large inter-annual variations in the maximum ice extent.

Large inputs of nutrients from its vast catchment area enter the Baltic Sea mainly through riverine transport and atmospheric deposition. Internal fluxes of nutrients from the sediments can also be significant. Due to the small volume of water and the limited exchange with the North Sea, the Baltic Sea is very sensitive to excessive nutrient loads. Most parts of the Baltic Sea are affected by eutrophication today (HELCOM 2010).

2.1 Model simulation of future physical-chemical conditions

Climate change will in many ways affect the future conditions in the Baltic Sea. Model simulations indicate a strong increase in air temperature in the Baltic region, especially in winter and most so in the north-eastern part, influencing the sea ice conditions in the area. Cold winter extremes are expected to be unusual while hot summer extremes will become more frequent.

The climate simulations also show an increase in precipitation and, again, the winter will be more affected. The amount of extreme events will also increase according to the scenarios. Although many models indicate an increase in wind speed over the Baltic Sea region, the uncertainty is very great. Consequently, projected sea surface currents, which are wind driven to a large degree, and wind waves will be uncertain as well.

Changes in sea surface level are determined by changes in the global mean sea level, the uplift and future changes in the local wind and pressure patterns. In the IPPC Report (2007) the future global sea level rise was estimated to 18–59 cm. However, ice transport from Greenland and Antarctica was not included and later reports suggest that the rise may be twice as high. Although the size of the global mean level change is under debate, the total effect is anticipated to be larger in the southern and south-eastern part of the Baltic Sea while the northern part will be less affected due to the on-going uplift.

The ocean climate simulations yield a general increase in sea surface temperature, with the largest change found in the Bothnian Bay in summer. In winter a substantial increase is found in the Gulf of Finland. The projected volume averaged temperature will also be higher than today (Meier et al. 2012a).

Although the modelled future averaged river discharge shows an increase in most areas, the largest change is found in the seasonal variations. Hence, it is anticipated that the discharge will in-crease by a large amount in winter but decrease in summer.

Scenario simulations show a future decrease in both surface and bottom salinity (e.g. Meier et al., 2012a, Neumann 2010, Neumann et al. 2012, Friedland et al. 2012). The decrease is mainly due to the expected increase in river run-off and a deepening of the permanent halocline.

A reduction in bottom oxygen concentrations in the deeper parts of the Bothnian Sea and the Baltic Proper may be expected due to climate change (Meier et al. 2011a, Meier et al. 2012b, Neumann 2012), see Figure 1. The decrease is explained by higher temperatures causing lower solubility in the inflowing water and an increased decomposition/oxidation rate of organic matter (Meier et al. 2011b). The total nutrient load from rivers may also increase, due to an increase in river run-off, there-by enhancing the oxygen consumption.

A study of the impact of warming of water masses in the Kattegat and Belt Sea area clearly demonstrates a large effect on oxygen content and duration of hypoxic conditions in bottom waters (Bendtsen & Hansen 2013). The distribution of oxygen has been successfully modelled for three consecutive years 2001–2003 with marked differences with respect to hypoxia. Then the sensitivity to a climate change scenario was simulated by forcing the circulation model with a 3°C increase in air temperature and surrounding water masses but otherwise applying the same climatic conditions in terms of solar radiation, precipitation, wind and humidity as observed in 2001–2003. The outcome of this scenario was oxygen depletion in much larger areas in the Kattegat and the Danish straits and low-oxygen conditions (hypoxia) lasted for a longer period during late summer and autumn and the oxygen deficiency were more severe (Figure 2 and Appendix 2 for further details). An overall reduced export of oxygen in water masses to the central Baltic Sea is then expected.

In the surface layer nutrients and phytoplankton concentrations may increase and the water transparency in the Baltic Proper may be reduced (e.g. Meier et al. 2011a, Meyer et al. 2012b, Friedland et al. 2012). If the Baltic Sea Action Plan (BSAP) is implemented, bottom oxygen concentrations may in-crease along the slopes of the Gotland Sea and in the Gulf of Finland.

However, in a warmer climate the effect of BSAP on the water quality may not be as large as it would in today's climate (e.g. Meier et al. 2011a, Friedland et al. 2012).

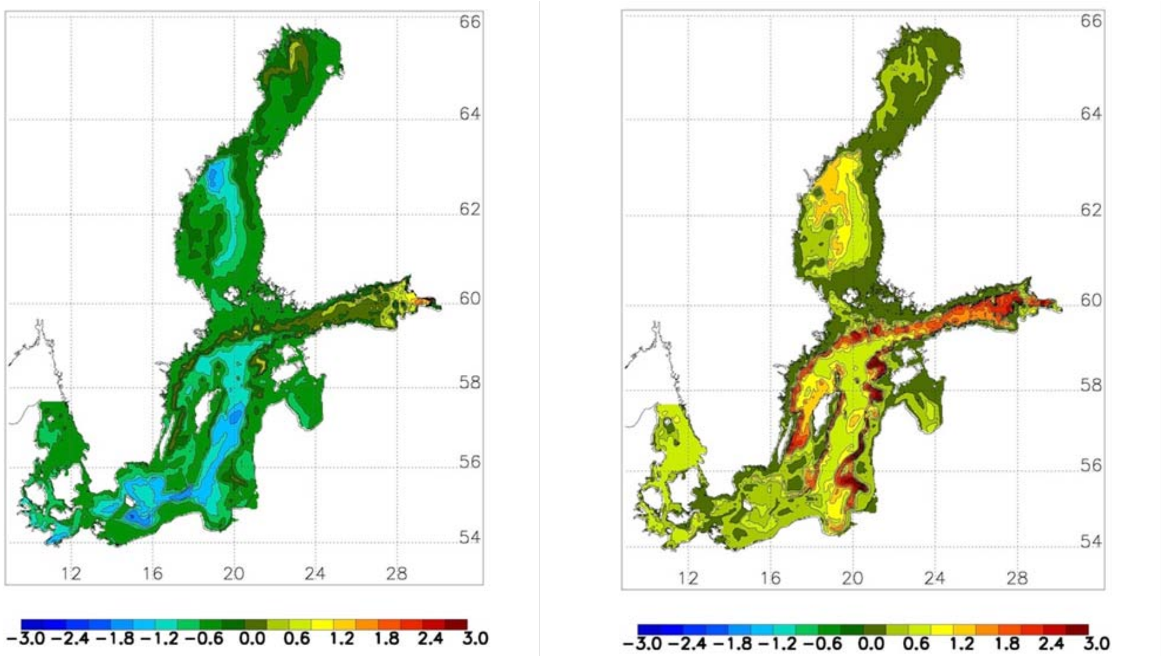

Figure 1: Left panel: The mean change in the annual bottom oxygen concentrations (ml/l) between 2070–2099 and 1969–1998 based on four simulations. The nutrient load scenario is based on current loads from rivers and atmospheric deposition.
Right panel: The range of the changes. (From Meier et al. 2011a).

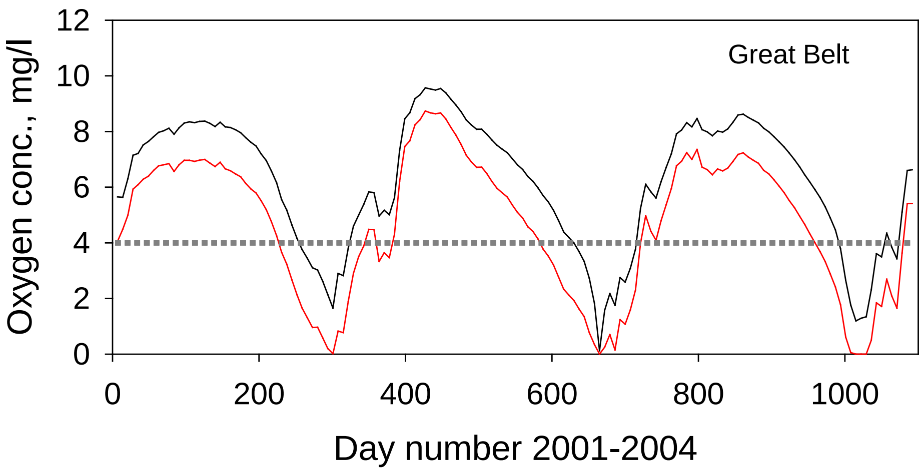

Figure 2: Black line: Temporal distribution of bottom water oxygen during 2001–2003 in the Great Belt. Red line shows the distribution of oxygen in a 3 °C warmer climate change scenario. Dotted line indicates the conventional limit for hypoxia in the area (see Appendix 2 for the situation in central and northern Kattegat as well as for further details).

The projected climate change is linked to uncertainties of various degrees. Results that are based on a large set of simulations are more robust than those based on just a few scenario runs. In general, statements about future conditions in the ocean are based on a more limited set of simulations.

The most robust results are those concerned with the future atmospheric temperature. Since the ocean is heated by the atmosphere, the projected ocean temperatures are also relatively certain.

The future regional precipitation is more uncertain and, consequently, the projected river run-off and salinity. The largest uncertainties concern changes in wind speed which means that statements on future currents and waves, and possibly also mixing, are highly uncertain as well.

The simulated changes generally get stronger with time. However, the high degree of natural variability in the region implies that changes temporarily may be stronger or weaker than what would be expected from a continuous change. Such variability can amplify or weaken the signal on time scales of years to decades.

The emission scenarios that form the basis of the simulations are coupled to different "story lines", describing the future developments on Earth. These developments may be faster or slower, or take another course, than those anticipated.

2.2 Measurements of recent climate change in the Baltic Region

Several studies indicate an increase in the mean sea surface temperature in the Baltic Sea, especially in summer (e.g. Siegel 2006, Belkin 2009).

For the last 40 years, a 1.5°C temperature rise has been observed in the inner Danish surface water and bottom water (Carstensen 2011). However, most of this increase has occurred during the past 25 years and particularly during the late summer where the temperature has increased about 2°C. The seasonal bias in the temperature changes is particularly important for the oxygen conditions during the hypoxic season in late summer. In general, the changes in temperature have occurred concomitantly with the major changes in the eutrophication levels with possible coupled effects on the marine ecosystem.

2.3 Eutrophication – a human effect sensitive to climate change

Nutrients are essential for organisms but can also threaten the ecosystem when excessively available. Eutrophication occurs when high nutrient concentrations stimulate growth of primary production ('algae blooms') leading to alterations in flora and fauna communities and imbalanced functioning of the ecosystem (HELCOM 2009 and HELCOM 2012). Increasing sedimentation of organic material enhances decomposition and oxygen consumption from the water column. This leads to low oxygen conditions (hypoxia) especially in areas where water mixing is restricted, such as in deeper waters below the halocline or in shallower waters affected by thermal stratification during summer (HELCOM 2012). In the worst case, death of benthic organisms and fish is the consequence. Anoxic conditions cause phosphorus release from the sediments ('internal loading'). High phosphorus and low nitrogen concentrations favour cyanobacteria which are able to fix atmospheric nitrogen and thus are not dependent on nitrogen availability in the water. These processes add even more nutrients into the water column.

Due to anthropogenic emissions, nutrient loads from the catchment to the Baltic Sea have in-creased severely during the last century: dissolved inorganic nitrogen (DIN) loads more than doubled and dissolved inorganic phosphorus (DIP) loads nearly tripled (Savchuk et al. 2008, Schernewski and Neumann 2005). The DIP pool more than doubled mainly due to the increased river loads but also due to the internal phosphorus release from the hypoxic sediments in the last 100 years (Gustafsson 2012). However the DIN pool decreased by 50%, due to the increased denitrification in the Baltic Proper in the last 50 years (Gustafsson 2012). The nutrient concentration changes lead to a change of the nutrient composition which is of high importance for phytoplankton communities and primary production.

Following increasing nutrient concentrations, chlorophyll-a concentrations (indicator for primary production) increased and water transparency decreased in the Baltic Sea up to the 1980s. Recent developments vary strongly among regions and include as well improvements, stagnant conditions as deteriorations (HELCOM 2009). According to a HELCOM assessment (2010), only the Bothnian Bay and the Swedish parts of the north-eastern Kattegat are not affected by eutrophication today.

The open waters of all other basins and also most coastal waters are still classified as areas affected by eutrophication. Oxygen depletion and hypoxia are still a major problem in many parts of the Baltic Sea. The relative importance of sources for anthropogenic nutrient emissions have been changing over time, but at present the main pollution source for both nitrogen and phosphorus in the Baltic Sea catchment is the diffuse input with agriculture being the main emitter (60–90% of the diffuse loads). The second largest nutrient emitters are the point sources of municipalities (HELCOM 2011).

Future changes in precipitation will have large effects on discharge and thereby on the nutrient flux between land and the Baltic Sea. Yet different hydrological conditions between years cause varying nutrient loads to the Baltic Sea. The overall projected increase of precipitation and discharge in the Baltic Sea region in the future might lead to increased nutrient loads from the catchments to the Baltic Sea and accelerated eutrophication (HELCOM 2009). The yearly river discharge will mainly increase in the forested northern catchment areas whereas it will decrease in the agriculturally dominated southern and continental areas of the Baltic Sea catchment (HELCOM 2007b). However, a seasonal change in the intensively cultivated south-western area with more precipitation in winter and dryer summer combined with warmer climate is expected to increase the overall nutrient turnover and run-off as nutrient loss from agricultural soils is primarily associated with vegetation free seasons (Jeppesen et al. 2011). Despite the overall trend of precipitation changes, regional projections for discharge are still lacking for most areas of the Baltic Sea region or are very uncertain. Climate change might also influence nutrient inputs to the Baltic Sea by changes in the timing of spring run-off, autumn low flow, ice and snow cover, and by changes in the frequency and severity of extreme events such as floods/erosion and droughts (HELCOM 2007b).

Counteractive pressures and processes complicate the projections of effects on nutrient loads to the Baltic Sea and “there is currently no overall scientific consensus on the influence of climate change on nutrient inputs to the Baltic Sea” (HELCOM 2007b).

Studies conducted on 22 years’ monitoring data from Danish fjords connected to Kattegat and the Belt Sea area as part of the Baltadapt project (for further details see Appendix 1) demonstrate counteracting influences of different climate change effects on the eutrophication. Increased temperature stimulates removal of total nitrogen but increase phosphorous concentrations in the fjords. The removal of nitrogen might level out load expected from the changing precipitation while it adds to the expected run-off of phosphorous (Table 1).

Not only precipitation itself but also the conditions influencing evaporation (e.g. kind of land use) do have an impact on discharge rates. Climate-driven choice of land use and crops, but also irrigation habits, has an impact on discharge (evaporation) and nutrient emissions. Recently, political decisions such as the promotion of renewable energies had serious and very rapid impacts. For example, the German renewable energy act has caused an immense increase in the cultivation of maize which has now become one of the most common crops in the German Baltic catchment area. Maize cultivation can lead to very high nutrient emissions. From such past experiences, it can be expected that political and economic developments and decisions will have a strong impact on nutrient emissions in the future which can be even stronger than climate change impacts.

Table 1: Schematic summary of the predicted change in nutrient loadings in Danish estuaries and rivers due to climate change in the most extreme scenario (SRES A2). A less extreme scenario is expected to give changes in the low end of the predictions. Climate scenario is mainly from the Danish Meteorological Institute (DMI) and riverine changes are derived from literature (Jeppesen et al. 2009, Jeppesen et al. 2011) while estuaries changes are predictions based on own data, empirical modelling and other studies. Some of the same effects are expected for northern and western part of the Baltic region but can deviate locally depending on local climate and land use.

<table>
<tr><th colspan="2">Scenario</th><th colspan="2">Impact</th><th>Effect</th></tr>
<tr><td colspan="2" rowspan="4">SRES A2</td><td colspan="2">Temperature</td><td>Increase (3-5°C)</td></tr>
<tr><td colspan="2">Winter precipitation</td><td>Increase (>40%)</td></tr>
<tr><td colspan="2">Summer precipitation</td><td>Decrease (3-15%)</td></tr>
<tr><td colspan="2">Sea level</td><td>Increase (0.5-1.5 m)</td></tr>
<tr><th colspan="5">Rivers</th></tr>
<tr><th>Climate change</th><th colspan="2">Impact</th><th>Effect</th><th>Main cause</th></tr>
<tr><td rowspan="2">Increased run-off</td><td colspan="2">Nitrogen concentration</td><td>Increase (7-35%)</td><td>Subsurface and surface run-off</td></tr>
<tr><td colspan="2">Phosphorous concentration</td><td>Increase (3-17%)</td><td>Surface run-off</td></tr>
<tr><th colspan="5">Estuaries</th></tr>
<tr><th>Climate change</th><th colspan="2">Impact</th><th>Effect</th><th>Main cause</th></tr>
<tr><td rowspan="3">Increased temperature</td><td colspan="2">Nitrogen concentration</td><td>Decrease (3-20%)</td><td>Increased denitrification</td></tr>
<tr><td colspan="2" rowspan="2">Phosphorous concentration</td><td rowspan="2">Increase (5-50%)</td><td>Decreasing redoxpotential in sediment</td></tr>
<tr><td>Increased mineralization</td></tr>
</table>

3 Climate change impacts on habitats and biodiversity

3.1 Scenarios on future biogeographic distribution of selected Baltic Sea species

In addition to effects from hypoxia and anoxia, the present distributions of flora and fauna in the Baltic Sea are strongly regulated by salinity. The salinity gradient from fully marine (salinity of 33) in the Kattegat to almost freshwater in the Bothnian Bay and eastern parts of the Gulf of Finland restricts the distribution of marine species resulting in a decrease in numbers of species with marine origin towards less saline living conditions. No species with marine origin that can cope with salinities below 3. At the same time there is an increase in the number of freshwater species able to cope with salinities from 0 to 5 (Remane 1934). Species richness is lowest in the northern Baltic where salinity is less than 5, where only some freshwater and highly euryhaline species occur. Overall this results in the lowest species richness in the coastal regions of the northern Baltic. The effects of the salinity gradient have been documented in several studies (e.g. Remane 1934, Nielsen et al 1995, Bonsdorff & Pearson 1999, Bonsdorff 2006, Zettler et al. 2007, Glockzin & Zettler 2008, Josefson 2009, Ojaveer et al. 2010, Bleich et al. 2011, Villnäs & Norkko 2011).

Global warming will likely be accompanied by increased precipitation and consequently in-creased freshwater run-off to the Baltic Sea. Thus, a likely result of warming will be a lowering of the salinity, and also increased risk of hypoxia formation in the bottom water (e.g. Meier et al. 2011a). A temperature increase will also increase the duration of the ice-free period particularly in the northern parts. It is therefore likely to expect dramatic changes in species distributions in the Baltic Sea as a consequence of global warming.

3.1.1 Species distribution in a future more brackish Baltic Sea

Approximate present geographical distributions in the Baltic for some selected species are depicted in Bonsdorff (2006) and shown in Figure 3A and C. This include the fish species Cod (*Gadus morrhua*) and flounder *Platichthys flesus*, and mussel species like blue mussel (*Mytilus edulis/trossulus*), Baltic tellin (*Macoma balthica*) and Sand gaper (*Mya arenaria*), as well as some crustaceans and poly-chaetes.

Given one of the possible future scenarios for changing the salinity condition in the Baltic presented by Meier et al. 2011a, we predict possible geographic distributions of the same species in approximately 100 years from now (Figure 3B).

At the same time we expect these species to be replaced by species with freshwater orrigin like cyprinid fishes and pike-perch (*Sander lucioperca*). Among invertebrates midges (chironomids) are likely to increase. However, due to higher temperatures some cold water species like the white fish *Coregonus lavaretus* may decrease their distribution ranges (Figure 3D).

The effects of decreased salinity can influence marine species in several ways. The maintenance of turgor pressure is one of the key processes in marine macrophytes at low salinity. When salinity is reduced further, the amount of energy used for turgor pressure maintenance may increase to a level intolerable for an individual and it will die. The examples discussed here include two large brown macroalgal species bladder wrack (*Fucus vesiculosus*) and serrated wrack (*Fucus serratus*) and the red algae *Furcellaria lumbricalis*. Bladder wrack and serrated wrack form important underwater habitats on hard substrates in shallow littoral areas. One of the factors influencing the distribution of macroalgae at low salinities is their reproductive success. Low salinity is e.g. known to reduce spore survival and germination success in bladder wrack.

The red macroalga *Furcellaria lumbricalis* is the most important red algal species in the Northern Baltic Sea forming a red algal belt on rocky shores below the *Fucus* belt. The species is known for its wide tolerance range for salinity and can be found at salinities above 3. However, the sexual reproduction is prohibited below 7 and at this salinity, the population regeneration occurs via asexual reproduction by spores or detached thallus pieces. The genetic effects of asexual population regeneration may reduce the genetic diversity within algal populations and therefore sudden environmental changes can destroy populations existing at the low salinity as the algae cannot acclimate to sudden changes.

As the salinity declines, a larger part of the shallow benthic primary production on hard bottom will be taken over by species tolerating low salinities, such as green algal species like gut weed *(Enteromorpha intestinalis)* and *Cladophora spp.* All of these species can efficiently utilize the increased amount of nutrients in the seawater and also grow epiphytic on other macrophyte species. Thus the competition for light and space on suitable substrate may facilitate the disappearance of perennial, large algae and increase the amount of annual species. The effects of such a changing structure of the macrophytes community are hard to predict in the littoral zone. Increasing amount of filamentous algae may also influence deep sea bottoms as a large part of the biomass often get detached and accumulate at deeper waters where their degradation might cause oxygen deficiency.

It is important to keep in mind that this is just a rough estimate of changes in the spatial distribution of a number of selected species. Combined effects with other possible changes in the physical environment caused by changing climate conditions are likely to interfere with salinity changes. Changed oxygen conditions in bottom waters are predicted (Meier et al. 2011a, Meier et al. 2011b) but the range of change in oxygen is likely depending on the success of implementing the Baltic Sea Action Plan. The future distribution of Baltic cod is an example of a species that might suffer in several ways in a future climate. It can be found in small numbers in the salinity interval between 7 and 11 but prefers higher salinities (Tomkiewicz et al 1998) and its recruitment is already today under pressure because of low oxygen conditions in the former major breeding areas at Bornholm Deep, Gotland Deep and Gdansk Deep (Köster et al. 2005).

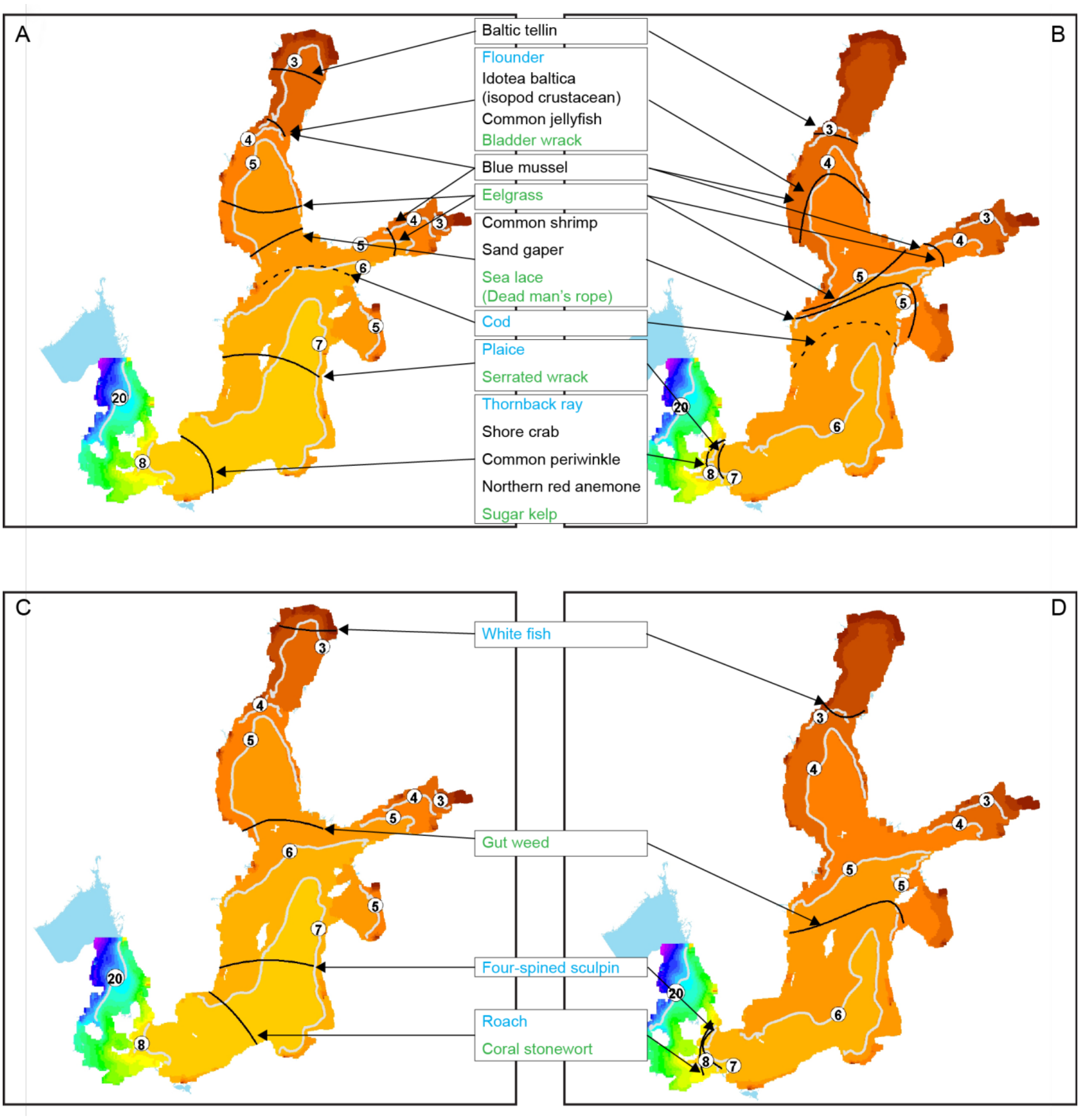

Figure 3: Distribution of selected macrophytes, fish and benthic invertebrate species today (A and C) and predicted based on future climate scenarios (B and D). Surface salinities (top 3 m) in the Baltic Sea modelled by Meier et al. 2011a and the present distribution of species with marine origin in A and with freshwater origin in C are taken from Bonsdorff. 2006. The predicted changes are solely based on simulated salinity changes and not changes in ice cover and oxygen deficiency.

Another example is a scenario predicting that salinity conditions prevailing today in the Gulf of Finland and in the northern Kvark (transition between Bothnian Sea and Bothnian Bay) or the inner Gulf of Finland will dominate in the Archipelago Sea (Åland to Finnish mainland, i.e. the most "marine" part of Finland today) in 100 years from now. However, warmer water and longer ice-free periods may increase the frequency of algal blooms (including harmful algal blooms). This new scenario opens the doors for invasive, non-native species and the bristle worms (Figure 4) of the genus *Marenzelleria* (see below) is no doubt an outstanding recent example (e.g. Maximov 2011). Altogether, non-native species with broad physiological tolerance are likely to increase.

3.1.2 Tolerance against low oxygen – a competitive advantage in hypoxic environments

One plausible/possible consequence of global warming in the Baltic Sea is lowering of oxygen levels in the waters below the haloclines (Meier et al. 2011a). Tolerance towards low oxygen differs between species, and the invasive bristle worms (*Marenzelleria spp.*) are more tolerant (Schiedek 1997) than for instance the native crustacean amphipods *Monoporeia* and *Pontoporeia*. Increased hypoxic conditions in the Baltic Sea will likely promote dominance of the bristle worm *Marenzelleria* in the future, a shift that has already occurred in the Gulf of Finland (Maximov 2011).

Figure 4: A possible future winner in the Baltic Sea system – the invasive bristle worm *Marenzelleria spp.* Photo: Jan-Erik Bruun

3.1.3 Low oxygen conditions and bristle worm feedback mechanism

Invasive species sometimes have a negative impact on the native ecosystem, but this is not always the case as indicated by recent studies of two invasive bristle worm species (*Marenzelleria spp.*). Being recent invaders in the northern and eastern parts of the Baltic Sea, *Marenzelleria neglecta* and *Marenzelleria arctia* apparently have the potential to provide important ecosystem services in the form of mitigating hypoxia in bottom areas earlier populated by native fauna. In a modelling study Norkko et al. (2012) found that bristle worm had the potential, through irrigation of burrows, to bind substantial amounts of phosphorous in the surface sediments. This phosphorous binding is important as it otherwise could have leaked to the water masses, fuelling phytoplankton production and later increased problems with reduced oxygen content in bottom waters. A concomitant correlative field study Josefson et al. (2012) indicated active burial of labile carbon materials by this bristle worm, which eventually also could mitigating hypoxia. By transporting labile organic matter from the oxygenated surface sediment environment down to sediment layers with less oxygen, degradation will likely slow down and consequently oxygen consumption of the near bottom water is decreased. This is because often oxic degradation is faster than anoxic degradation.

While the first mentioned mitigation effect will be effective when phosphorous is the limiting nutrient for primary production, the latter mitigating effect will be effective irrespective of limiting nutrient. Provided that the two mitigation processes do not interfere negatively with each other, we may expect the greatest mitigating effect of bristle worms in areas where phosphorous is limiting, i.e. coastal areas, the Bothnian Bay and the inner parts of the Gulf of Finland.

The effects on carbon cycling and oxygen dynamics by bristle worms are different from effects by several previous residents in soft sediments like the mussel Baltic tellin and the native amphipods *Monoporeia/Pontoporeia*. These species increase degradation rates of organic matter through intensive bioturbation, and thereby likely contribute to increased oxygen consumption in the bottom waters. The phosphorous binding and burial functions exhibited by bristle worms are new to the Baltic Sea system and implies that increased dominance of the worms will have significant effects on carbon cycling and oxygen dynamics in the Baltic Sea (Norkko et al. 2012, Josefson et al. 2012). A likely implication of such a species shift is a build-up of the organic pool in sub-surface sediments and, although microbial activities like sulphate reduction and methanogenesis will increase, overall mineralization rates are likely to decrease and thus mitigate hypoxia in the bottom waters.

3.2 Plankton communities

3.2.1 Impacts of past and present climate change

In the last decades, several profound changes of plankton ecosystem in the Baltic Sea were regarded as long-term trends relevant to climate change. Next to changes of nutrient loads and concentrations (see Chapter 2), a case study for inflowing rivers in the Gulf of Riga confirms an increase in dissolved organic matter (characterised as total or dissolved organic carbon—TOC or DOC) during the last few decades (Kokorite et al. 2011, Klavins et al. 2012).

The oxygen condition has been deteriorating since the 1950s due to increased external nutrient inputs. The oxygen decrease due to increased temperature is also observed in riverine ecosystems flowing into the Baltic Sea (Springe et al. 2012). The total phytoplankton biomass has roughly doubled during the last century (Wasmund et al. 2008). The nutrient concentration changes lead to the change of the nutrient composition, which is responsible for the nutrient limitation to phytoplankton growth. For example, the Gulf of Finland and the Gulf of Riga might show silicate limitation in the future (Danielsson et al. 2008). The likely nutrient limitation change due to N/P ratio change was suggested by Wan et al. (2011 and 2012). Nutrient composition change can lead to the phytoplankton species change. For example, newly appearing bloom-forming species are mostly potentially toxic (*Dictyocha speculum*, *Prorocentrum minimum*, *Pseudo-nitzschia spp.*). Climate change impact on rivers has also caused enlarged phytoplankton biomass, changes in the structure of cyanobacteria communities, increased overgrowth by macrophytes as well as changes of fish communities' structure (Springe et al. 2012).

3.2.2 Some predicted future effects of climate change

Each of the predicted physical changes of climate change would have a different consequence for the ecosystem. However, little is known about the consequences of their interactions or of combined changes. Uncertainties are large in the projection of the Baltic Sea ecosystem.

Temperature has only little direct effect on algal growth because it depends more on the availability of nutrient and light. Global warming will likely lead to increased vertical stratification and water column stability in the Kattegat and the Danish straits. The lacking convective mixing in late winter will prevent resuspension of diatom spores or floating of the vegetative cells. In contrast to diatoms, dinoflagellates prefer stable water columns and are expected to profit from the increase in stratification (Wasmund et al. 1998). The spring bloom in the Baltic Sea is dominated by diatoms and dinoflagellates. Hence, warming may inhibit mostly spring-bloom diatoms and influence phytoplankton composition. Higher temperatures during winter can result in increased metabolic rates for bacteria and a shift in species composition from cold to warm water species. Higher temperatures in summer may enhance blooms of cyanobacteria (BACC 2008) (Figure 5).

The season favouring cyanobacteria blooms can be prolonged, with the spring bloom in the northern Baltic Sea beginning earlier in the season due to the declining sea-ice cover (Neumann 2010).

A warmer hydrographical environment seems to affect the timing of zooplankton blooms (Calewaert et al. 2011). In general, for zooplankton that has their maximum abundance in spring/summer, the pattern is 'earlier when warmer', while species that peak in late summer and autumn the pattern is 'later when warmer'. However, diatom blooms in spring and autumn are free of temperature control and have remained relatively static. This will cause a mismatching of the energy flow from primary to herbivorous secondary producers and appear to be of crucial importance to the dynamics of the whole ecosystem (Edwards & Richardson 2004). Furthermore, warmer water is anticipated to decline the relative importance of *Pseudocalanus sp.* in the Baltic Sea because of an increase in instantaneous mortality rates and a decline of the net growth efficiency with temperatures (Isla et al. 2008). This will have consequences for the food web and ultimately the fish stocks.

Figure 5: Left picture: A rare example of the cyanobacteria bloom observed in Kattegat august 2006 (photo: Karsten Dahl). The bloom dominated by the species Nodularia spumigena covered huge areas in the western Baltic Sea and penetrated into the Danish straits and up into the Kattegat with an outflowing low saline surface water mass.
Right picture (photo: Michael Bo Rasmussen) during a dive in a patch: nearly no light penetrated through the patches just beneath the surface. Blooms of cyanobacteria might be more frequent in the Kattegat in the future.

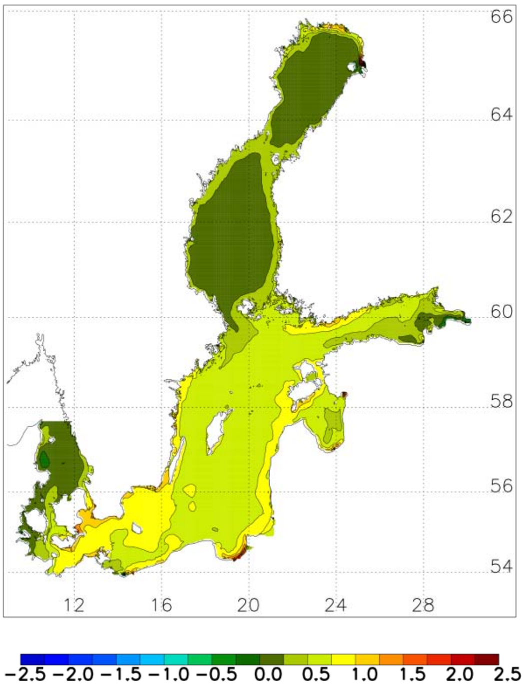

Figure 6: The simulated annual mean phytoplankton production change comparing a 30-year period between 2070-2099 and 1969-1998 for the scenario without implementation of the Baltic Sea Action Plan's nutrient reduction (HELCOM 2007a) (From Meier et al. 2011a).

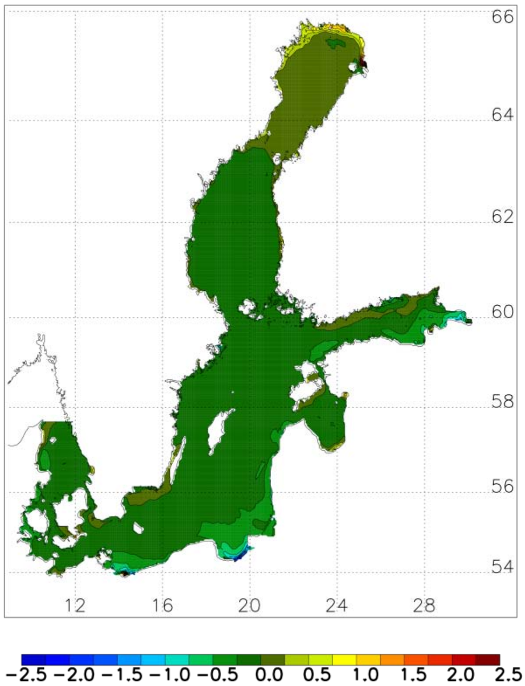

Figure 7: The simulated annual mean phytoplankton production change comparing a 30-year period between 2070-2099 and 1969-1998 for the scenario with the Baltic Sea Action Plan nutrient reduction fully implemented. (From Meier et al. 2011a).

Salinity generally controls the biodiversity of the Baltic Sea. Lower salinities can cause osmotic stress for phyto- and zooplankton and result in a shift in species composition from marine to limnic species. The expected decrease in salinity of the Baltic Sea would result in distribution changes. Freshwater species are expected to enlarge their significance, and invaders from warmer seas are expected to enlarge their distribution area. The lower limit of approximate salinity tolerance for certain species is critical. Decreases in species number due to changes in species distribution areas are expected along the complete range of the Baltic Sea surface salinity (Calewaert et al. 2011).

The climate change impact on phytoplankton in the Baltic Sea has been modelled assuming a change in nutrient loads, increased water temperature and winter wind mixing and a reduction in ice cover. These physical changes tend to increase the nutrient availability for phytoplankton production.

The nutrient loads may have different scenarios depending on the implementation of policy of reducing nutrient loads and land usage. However, a future increase in plankton production can be expected for the scenario without nutrient reduction plan (Figure 6) and the scenario with the Baltic Sea Action Plan (Figure 7).

3.3 Seaweed communities – sensitive for future increasing temperature?

Climate change scenarios indicate that we will face an increasing water temperature in coastal water within the next 100 years. This is expected to influence the geographic distributions of species living in an environment close to their tolerance to warm water temperature.

In the north-western Europe scientific concern has been raised about a possible present effect of global warming on the large sugar kelp, *Saccharina latissima* (Figure 8). This species is also present in the Baltic Sea as far east as Bornholm where it can be found at water depths down to 20 m.

Sugar kelp has a lifecycle with a large stage called sporophyte which forms a leave that can be more than 1 m long and very small male and female plants called gametophytes.

Figure 8: Sugar kelp on a gravel dominated seabed covering part of the Natura 2000 area Hatter Barn. The species is highly productive, has a lifetime of 3–5 years and favour less exposed sites. Photo: Peter Bondo Christensen.

The growths of sporophytes are generally inhibited at 17 to 20°C. For the gametophytes and young sporophytes of *S. latissima*, the upper temperature tolerance is 22–23°C (Lee & Brinkhuis 1988). The sporophyte plants exist for 3–5 years.

A study by Moy et al. (2008) concluded that high surface water temperature in coastal waters in the south-western part of Norway in 1997 was one of the reasons for a regime shift in the seaweed forests along the cost. This regime shift resulted in a major reduction in sugar kelp which was substituted by filamentous algal species. High seawater temperature for *S. Latissima* of more than 19°C was observed over a longer time in the summers of 1997, 2002 and 2006 in the Skagerrak and part of the North Sea coasts. Field studies indicated a reduction in *S. Latissima* after 1997 and 2006 in the same area.

As part of the Baltadapt project we have studied possible temperature sensitivity on sugar kelp and four other algal species: Dulse (*Palmaria palmata*), Sea oak (*Halidrys siliquosa*), Sea beech (*Delesseria sanguinea*) and Carrageen (*Chondrus crispus*). All species are common in the Kattegat and the Danish straits and they play an important role as key species in some seaweed communities or as important primary producers on hard bottom structures in general.

The selection was based on indications from literature studies that they could be potential casualties of global warming in this region.

We have analysed the distribution of the species over a period of 20 years from 1990 to 2010 and their responses to fluctuating water temperatures during the period. The hypothesis was that species close to their physiological heat tolerance would respond to high water temperatures with a reduced distribution in the following year. Algal data were collected as part of the Danish national monitoring programme and they were coupled to the nearest water chemistry station where temperature data were also available. The statistical analyses were done on two data sets, one dealing with algal sampling stations in fjords and the other dealing with algal sampling stations in open waters.

It was not possible to find any effect of temperature on the distribution of the selected species. On the other hand, observations of sugar kelp declined dramatically in Danish fjords in 1993 and 1994. The decline happened just before high temperature observations were observed. In Flensburg Fjord, the *Saccharina* was dramatically reduced in 1993 and the stock collapsed on the monitoring stations between 1995 and 1996 following two very hot summers with measured water temperatures above 22°C (Figure 9). Signs of recovery of sugar kelp were not seen in the fjord until 2010.

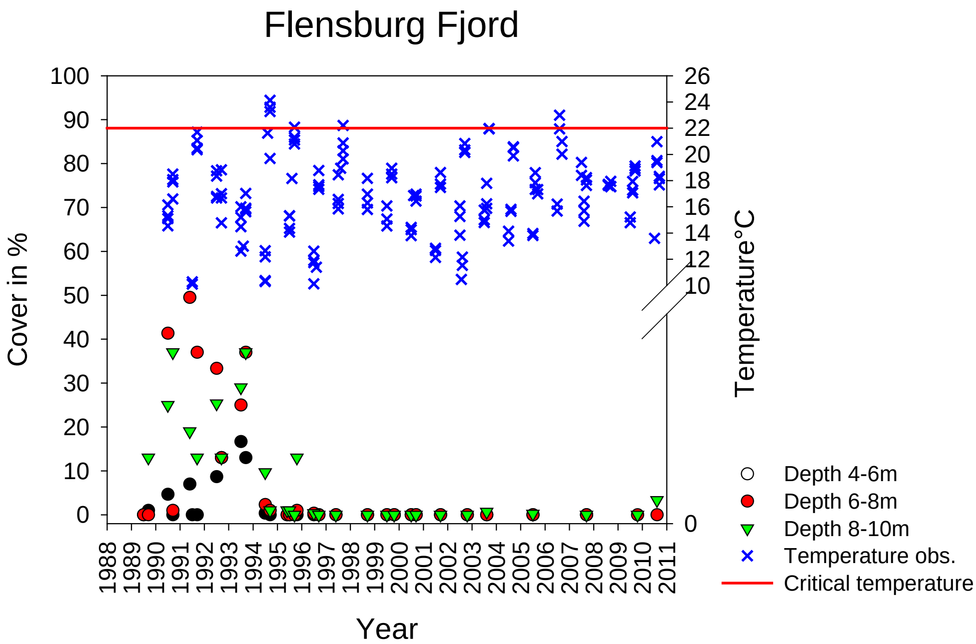

Figure 9: *Saccharina latissima* cover on hard substrate from three depth intervals in Flensburg Fjord and water temperature from the water chemistry station in the fjord. Data from the Danish MADS database.

The question is then what caused the effect on sugar kelp? Observations done by divers reported in the yearly national assessment of the marine environment in 1994 pointed out that massive settlement of blue mussels and observation of intensive snail grassing on kelp combined with exceptionally bad water quality were responsible for a major reduction in the benthic vegetation this year (Dahl et al. 1995). Sugar kelp is known as a species with a relatively quick recolonization response in experiments with harvesting (Kain 1979), however, the observed very high temperatures in 1994 after the vegetation monitoring in June in 1995, 2003 and 2006 may have prevented the recolonization in a 15-year period. No effects on sugar kelp were observed on reefs in the open part of the Kattegat.

In the last 40 years a 1.5° C temperature rise has been observed in the inner Danish surface and bottom water (Carstensen 2011). If this trend continues as expected, the pressure on species like sugar kelp might be too high to sustain populations in the fjord system. Even though there might be years with conditions below temperature tolerance values, the re-colonization might be hampered by lack of a standing stock within the range of distribution spores.

In these days there are huge interests in cultivating sugar kelp. Several research projects are investigating the potential use of this highly productive species as a measure to mitigate nutrient loss from e.g. aquaculture and the species is highly interesting as a future resource for production of biofuel and feed for livestock.

3.4 Seaweed forests on hard bottom – sensitive to eutrophication and sea level rise

The seaweed forests on reef areas are very important and productive habitats hosting a large number of algal and bottom fauna species. They are also an important habitat for a large number of fish species. The macroalgal species depend first of all on available hard substrate where they can settle but also on sufficient light penetrating to the bottom.

As light disappears with increasing depth, hard bottom fauna species will gradually dominate the surface of the hard substrate (Figure 10). Eutrophication does also play an important role for the distribution of seaweed forests. Nutrients stimulate phytoplankton growth and biomasses in the water column and by that decrease the level of light reaching the seabed.

Figure 10: *Fucus* community on shallow water (left) and fauna community at 20 m depth in the central Kattegat (right). Photos Karsten Dahl.

Along the southern Baltic coastline and in Danish waters, the seabed in more shallow waters is made up by glacial deposits and hard substrate is in general rare and made up by boulders “washed out” of glacial deposits. In those parts of the Baltic Sea and the transitional waters, algal forests are “hot spots” for biodiversity.

The depth distribution and development of algal vegetation are also used as an important element assessing the quality of the Baltic Sea in accordance with criteria set up by the three EU Directives; Habitats Directive, Water Framework Directive and Marine Strategy Framework Directive.

3.4.1 Effects of nutrients and salinity

Effects of nutrient load on the development of macro algal vegetation have been investigated and statistical well-founded empirical models have been developed for NATURA 2000 reef sites in the open part of Kattegat. The models describe the overall vegetation cover (total vegetation cover) and the cover of all added species specific covers (cumulative vegetation cover) as a function of locality, solar radiation, depth, grassing pressure of sea urchins and total load of nitrogen to Kattegat from Denmark and Sweden (Dahl & Carstensen 2008). Both algal indicators responded clearly on observed year to year changes in nitrogen load from January-June prior to the algal monitoring in the late summer.

In the context of the Baltadapt project, a climate scenario was run using the same model setup as described in Dahl & Carstensen 2008. Total nitrogen load in the baseline was set to approx. 78,000 tonnes equal to the average of the investigated 20-year period. A regional model for Danish areas (Jeppesen et al. 2011) estimated a possible increase in nitrogen load to marine areas of 19% in the first 6 months of the year based on the A2 climate projection over a 100-year period. A potential future load of nitrogen of approx. 92,000 tonnes was used as the other input to the model. The difference between the two scenarios in terms of changing total macroalgal vegetation cover is shown for the reef Kim’s Top in the central Kattegat (Figure 11). This reef shows the clearest response to changes in nutrient load.

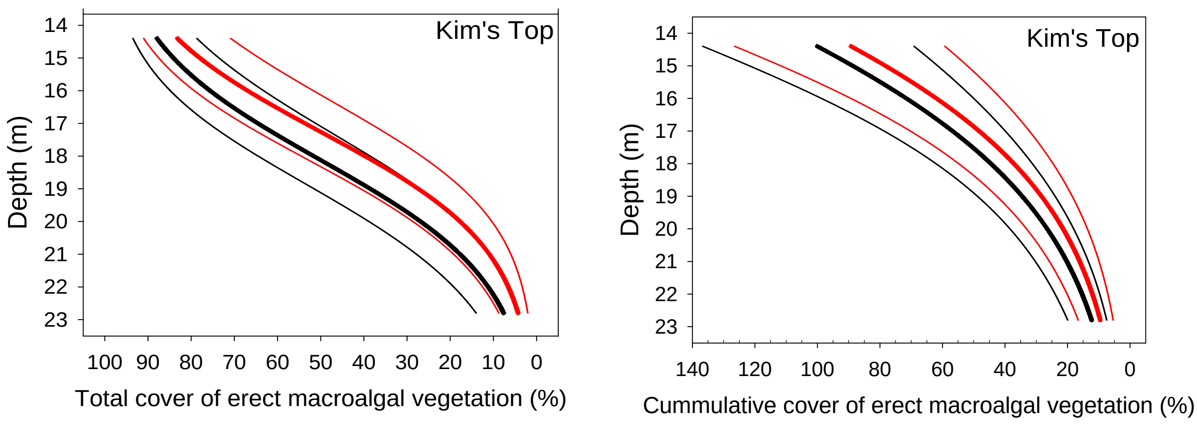

Figure 11: Total cover (left) and cumulative cover (right) of erect macroalgal vegetation at different depths and at different nutrient load scenarios at the reef Kim’s Top in the central part of Kattegat. The thick black lines describe the average load scenario with approx. 78,000 tonnes from rivers and point sources in January-June from the past 20 years. The thick red line describes an average load scenario equal to 91,000 tonnes in the same 6 months based on a regional A2 climate projection (Jeppesen 2009). The thinner red and black lines describe the upper and lower 95% confidence intervals on the estimated covers.

Empirical modelling of algal data sets collected on hard, stable substrate in fjords and shallow coastal areas of Denmark has also been done recently (Carstensen et al. 2008). More or less all data sets collected as part of the Danish national monitoring programme in 2001, 2003 and 2005 have been included in the work. Six different algal indicators were tested and important structuring factors identified and quantified. All macro algal variables were found to respond statistically significantly to a combination of changes in total nitrogen and salinity. Increase in nitrogen concentration in the coastal water resulted in a reduced vegetation cover and the vegetation cover was more developed at high salinities compared to more brackish waters.

The strongest responses to changes in nitrogen concentration and the least variability were found for the indicators ‘total algal cover’, ‘number of late-successional species’ and ‘fraction of opportunists’ in less saline waters.

3.4.2 Impact of sea level rise

The productivity and biodiversity on hard bottom habitats originating from glacial and post glacial processes will be directly impacted by increasing sea level rise. An increase in sea level will affect the level of light available for the seaweed forests on the seabed. Unlike the rocky shores characteristic along the Swedish and Finnish coastline, the algal vegetation will only in some coastal areas be able to adapt by upward movement of the vegetation belt due to lack of substrate. In very shallow water the light level might exceed the need for optimal macrophyte production but in most areas available light is the limiting factor for algal production given a suitable hard substrate.

The average Secchi depth (a simple way to measure the light penetration in surface waters) in the open part of the Kattegat and the Danish straits is approx. 7 m. In Danish coastal and fjord areas the light penetration is reduced to 4.1 m due to higher phytoplankton production and more frequent re-suspension of particulate matter (Figure 12).

An increase in the water level by 1 m in the coming 100 years, as suggested by some studies, will result in an average loss of light for the seaweed forests of approx. 20% in coastal areas and 13% in open inner waters.

The effect on macroalgal vegetation cover of reduced light on the seabed was also tested in the context of the Baltadapt project. In this case the Secchi depth was set to describe year to year changes in vegetation cover and then subtract 1 m as a possible climate change scenario for sea level rise. In this case the vegetation was reduced by 1.5–9% at 18 m depth for reefs in Kattegat and Danish straits. However, the estimated cover was subjected to a relatively high variation in all scenarios.

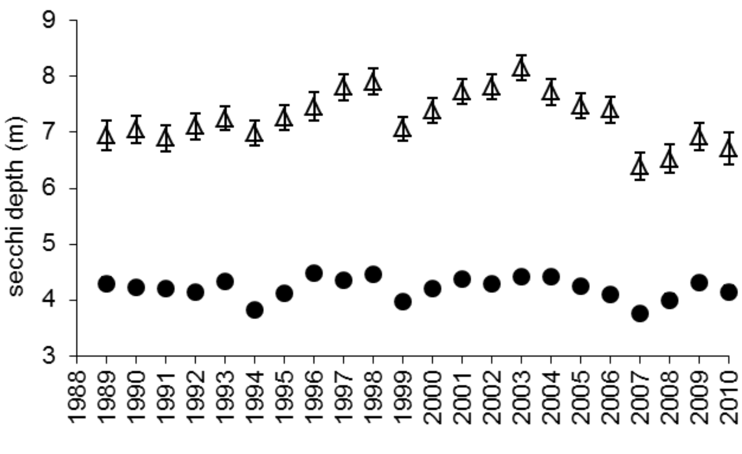

Figure 12: Development in the yearly average values and ± 95 % confidence intervals of Secchi depths in open parts of the Kattegat and the Danish straits (△) and in fjords/coastal waters (●). From Henriksen et al. 2011.

3.4.3 Overall potential climate effects on seaweed habitats

The outcome of vegetation models indicated that there will be a reduction in algal cover if nutrient load in the spring increases or if sea level rise occurs in the future. The models describe changes in the cover of algal vegetation on hard substrate which is a measure given in two dimensions. In terms of biomasses the differences are considerably larger as the vegetation grows higher both in terms of individual plants but also in terms of number of vegetation layers when the vegetation cover increases.

Impact of water clarity and nutrients on the vegetation cover is also proven on a larger data set covering a large part of the Baltic (Skov et al. 2012).

3.5 Eelgrass meadows in a future Baltic Sea

Eelgrass (*Zostera marina*) forms biologically diverse underwater meadows in the Baltic Sea. Its current distribution ranges from the Kattegat in the south to the Archipelago Sea and the mid part of the Gulf of Finland in the north (Figure 13). Eelgrass grows on sandy seabeds in relatively sheltered areas with a depth distribution of 0.7 to 8 m in the Kattegat and the Danish straits and 1 to 7 m in the rest of the Baltic Sea.

Eelgrass meadows host biologically diverse communities of flora and fauna and act as nursery grounds for several commercially important fish species. The eelgrass beds also recycle nutrients and protect the seabed against erosion.

Figure 13: Eelgrass meadow in the Finnish archipelago. Snails (such as river nerites, *Theodoxus fluviatilis*) sitting on the leaves are common in-habitants of the eelgrass communities in the northern Baltic Sea. Photo: Metsähallitus NHS Finland.

Eelgrass can tolerate salinities down to approx. 5. The temperature optimum of the species is wide, varying from 5 to 30°C, and the species can tolerate near-freezing temperatures and survive under ice-cover for four months. On the other hand, reproduction is limited to much higher temperatures, and since the species also suffers from eutrophication, eelgrass is in its northern distribution area classified as “near threatened”.

A sea level rise of 100 cm as presently discussed in the south-western part of the Baltic will most likely be counteracted by intensive diking in areas where it is needed and feasible. Diking also causes increased water turbidity, and it is probable that eelgrass meadows will not be able to adapt to the lowered light conditions. Therefore eelgrass meadows today present on deep waters will probably disappear in the future if the water quality is not improved to counteract the loss of light.

The low persistence of the northern eelgrass populations against environmental changes has been attributed to their low genotypic and genetic diversity (Montalvo et al. 1997). In the northern Baltic Sea, flowering or fruit production of eelgrass is very rare (Boström 1995) and most of the genetic variability is due to clonal competition over long time (Eriksson 1993). In the northern Baltic Sea most of the population consists of the same genotype, which has been estimated to be 800-1600 years old (Reusch et al. 1999). Clonal growth and low genetic diversity may reduce the acclimation capacity and survival of the species in rapidly changing environmental conditions.

Persisting eutrophication and lowering of salinity will probably diminish the areal coverage of the eelgrass beds in the northern Baltic Sea. What happens to the associated ecosystem after disappearance of the eelgrass is not known. Sandy seabeds are also preferred habitats for other marine vascular plants and Charophytes, which tolerate lower salinities than eelgrass, so sandy areas may be taken over by these taxa. Some of the invertebrates and fish associated with eelgrasses may find refuge from vascular plants and Charophytes, too, but only if they survive lower salinities. In case the functional groups inhabiting eelgrass meadows will be replaced by freshwater species, the functions of the ecosystem may change, and living conditions for many species, including commercially important fish, will also change. Knowledge of such ecosystem processes will be necessary for designing adaptation measures for coastal fisheries.

4 Adaptive measures to secure the Baltic Sea ecosystem services in a future climate

The four major potential climate stressors in a future global change scenario are a general warming of water masses, a reduction in the Baltic Sea salinity, increasing sea level rise and an increasing precipitation especially in winter season.

The influence of climate change on the fate of hazardous substances might also be of importance because several factors like rise in temperature, decrease in oxygen, flooding and increased run-off can alter and modify the distribution, partitioning and degradation of such pollutants in the aquatic environments. In addition, also other indirect effects on the fate of hazardous substances can be linked to climate change, e.g. increased use of agricultural pesticides due to more plant diseases, erosion of coastal areas and altered growth conditions and prey-predator interactions in the food webs. All these factors have the potential to enhance the bioavailability of pollutants and with an increasing risk of transfer of bio-accumulative toxic pollutants in the food web. However, there is still a major knowledge gab on how such changes in the fate and bioavailability of toxic pollutants can result in actual effects on species, population and community levels.

Climate change can have various effects on the nutrient status and eutrophication processes in the Baltic Sea as outlined in Figure 14. Although first studies and model simulations exist, research needs to continue and more precise regional projections are necessary. Besides, numerous interaction feedback mechanisms and complex cause effect chains make it difficult to draw simple conclusions and large uncertainties exist.

Agreed strategies to obtain a good ecological status of the Baltic Sea and its coastal waters, as obligated through the EC Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD), the Baltic Sea Action Plan by HELCOM (BSAP) and national action plans such as the Danish Action Plan for the Aquatic Environment III, have to be implemented. In the implementation process, climate change effects such as changes in precipitation and run-off patterns should be considered, respecting the time scales of climate change and political actions. Although climate change is not explicitly included in the text of the WFD, a guidance document for river basin management in a changing climate has been published (EC 2009). It states that the step-wise and cycling approach of the river basin management planning process makes it well suitable to adaptively manage climate change impacts. This approach means that plans can be revisited to scale up or down the response to climate change in accordance with monitored data. The document highlights the importance that long-term climate projections are built in to the design of measures that have a long design life and high costs. The guidance also includes suggestions for handling available knowledge and uncertainties about climate change, which are important issues that all adaptation actions have to deal with.

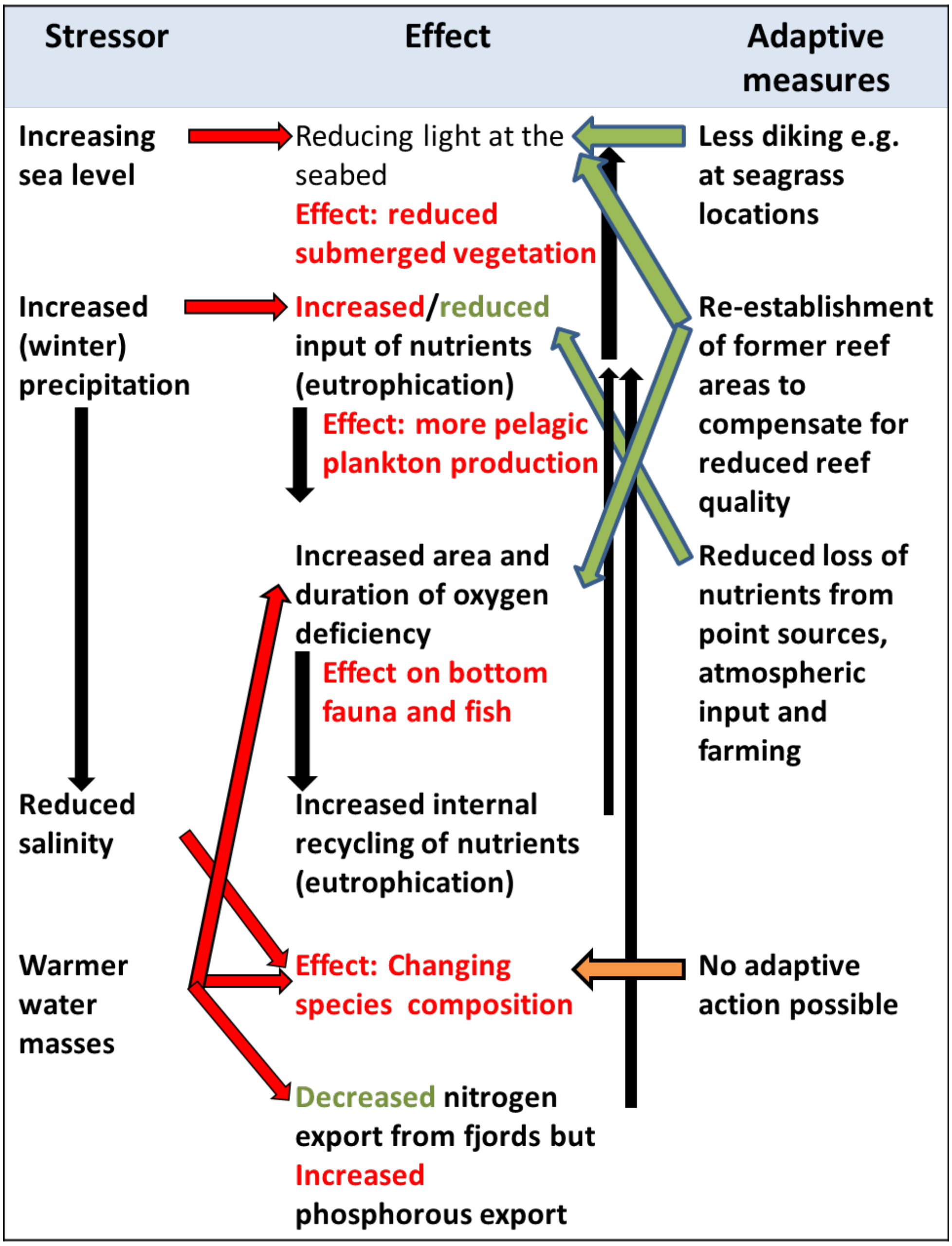

Figure 14: Projected climate change effects on the Baltic Sea ecosystem and possible adaptation to sustain the ecosystem services. Red arrows indicate negative effects on the ecosystem components induced by climate related stressors. Black arrows indicate feedback mechanisms. Green arrows indicate possible adaptation measures. With regard to changing species composition no adaptation seems possible (orange arrow).

Although different future developments are possible and many uncertainties exist, improvement of water quality will be important and for certain a "no-regret-measure" regarding climate change adaptation. Possible adaptation towards a good water quality of the Baltic Sea and its coastal waters in the future includes all kinds of nutrient reduction measures as e.g. suggested by the BSAP and WFD. These measures should be implemented both in the catchment as well as in the coastal waters and include e.g. improvement/construction of wetlands, buffer strips, filter systems in connection with drained agricultural areas, but also supporting (re-)establishment of reefs with macrophytes, mussel beds, etc. In accordance with other studies, we recommend to reduce intense cultivation in lowland areas and increase riparian buffer zones and especially for nitrogen increased retention time from both diffuse sources and point sources would be beneficial (Kronvang et al. 2005). We also suggest a strong focus on temperature effects on phosphorus including further investigations. In addition P and N loadings should be decreased simultaneously to prevent adverse effects on the ecological structure (Howarth & Marino 2006).

No adaption measures are possible to sustain ecosystem services provided by specific species that might be affected by changing temperature and reduced salinity. In case of changing distribution of commercially important fish stocks or e.g. macroalgal species used for mitigation purposes, the adaptation has to be socio-economic.

Figure 15: The result of the nature restoration project “Blue Reef” at the Danish reef Læsø Trindel in the northern Kattegat. A huge amount of Norwegian rocks was deployed on the reef area which was suffering from many years of boulder excavation for harbour protection. The quality of the reef is now restored with high biomasses and seaweed, increased biodiversity and lots of fish.
Photo: Karsten Dahl.

5 Overall evaluation of potential climate change effects on the Baltic Sea ecosystem

It is shown from the model work by e.g. Meier et al. (2012 b) and in the Danish case study that increasing temperature enlarges the area in the Baltic affected by oxygen depletion.

Increasing oxygen depletion will have a profound effect on the Baltic ecosystem. Macrobenthic communities will disappear in areas where permanent oxygen depletion will develop in the future. Changes in community structure towards species that are more tolerant to low oxygen concentrations can be expected in areas with low or frequent problems with oxygen. The ongoing spreading of the three tolerant *Marenzelleria* polychaete species replacing native species may be seen as an example of biological community adaptation to changing oxygen conditions. Increasing areas affected by low oxygen in the Baltic Proper will have a negative influence on the breeding success of the Baltic cod stock. The former important breeding areas Gotland Deep and Gdansk Deep are more or less lost today due to low oxygen concentrations in the water depth where eggs and larvae develop, and the last breeding area at Bornholm Deep is today under pressure as well, for the same reason.

The decline of cod stocks, which has partly been caused by climatic reasons, has 'cascading' effects on the lower trophic levels. Due to the disappearance of cod from the northern Baltic in the 1990s, the number of clupeids (sprat and herring) increased tremendously. This caused fierce resource competition between these plankton eating species, which induced a decline in growth of herring (Peltonen et al., pp. 35-54, this volume). Because climate change may worsen this process by increasing eutrophication and decreasing salinity in the Baltic, conditions for cod reproduction probably remain poor in a changing climate. This need to be taken into account when adapting the fisheries: the future cod stock probably does not tolerate heavy fishing in a less saline Baltic Sea – unless the status of the Baltic Sea will be markedly improved.

Previous studies by Hansen & Bendtsen (2009) and ongoing work during this project (Hansen & Bendtsen 2013) demonstrate the expected increase in oxygen deficiency in the Kattegat and the Danish straits can be counteracted by a further reduction in nutrient loads from Sweden, Denmark and German areas, given a temperature increase of 3°C over the coming 100 years.

The effect of the already observed 1.5 degree increase in the temperature may explain why the oxygen conditions have not yet improved in the Danish waters after two decades of decreasing nutrient concentrations (Hansen & Bendtsen 2009).

Increasing temperature will probably also effect the distribution of the large habitat forming algal species sugar kelp in fjords and other coastal shallow waters in the Kattegat, the Danish straits and western Baltic. The vulnerability of this species is particular interesting as there is presently a high focus on culturing sugar kelp for biofuel and feed production as well as using algal farming as a mitigating action to reduce nutrient loss from future expansion of fish farming. Such mitigating actions are now required by regulation in Denmark.

A likely climate scenario for the Baltic Sea catchment area is more precipitation in the winter and more events with heavy rainfall. Both of these climate effects will increase the risk of nutrient loss from agriculture areas, given the present crops and cultivation. If we for a moment do not consider the political actions taken to improve the water quality in the Baltic Sea region in the future, then increased nutrient loss will stimulate phytoplankton production (e.g. Meier et al. 2011c). This will result in development of oxygen depletion in new areas and promote release of nutrients otherwise buried in the seabed. Increased plankton production will also affect the development of the benthic macro vegetation consisting of e.g. eelgrass and Characean on soft bottoms and macroalgae vegetation on hard substrates. Higher phytoplankton biomasses will decrease the light reaching the seabed and the result will be a reduced depth penetration of e.g. eelgrass meadows and seaweed forests of macroalgae.

A rising sea level will result in significant loss of productivity on hard bottom areas in the southern and western part of the Baltic Sea. An increasing depth of 1 m suggested by some studies will result in a considerable loss of light available at the reef habitats. The loss will be highest in coastal areas where e.g. light reductions of 20% can be expected given the present status of eutrophication in Danish areas. In open waters the effect will be approx. half the size.

The ecological consequences of reduced light penetration to the seabed due to rising sea level and eutrophication will be reduced habitat quality for a large number of invertebrate and fish species using the reefs as breeding, nursery and feeding areas. In rocky coastal areas, adaptation in the seaweed belt is likely to take place as sea level increases.

Changes in species composition are also expected with regard to the forecasted changing salinities, especially in the central part of the Baltic and the changes will probably be accelerated by warmer waters, less ice-cover in the northern part and increasing problems with oxygen in large areas. Changes will include decreasing ratio of biomass between diatoms and dinoflagellates during spring blooms, earlier timing of plankton production and seasonal migration of zooplankton and fish in mild winters. These potential changes in plankton production, biodiversity and species distribution may further result in a mismatch between predators and preys through the marine food chain, ultimately placing additional stress on already declining fish stocks.

It is obvious that nutrient limitations are an adaptive measure to ensure important benthic fauna communities and habitats with submerged vegetation, given expected climate change with regard to warmer waters and increasing sea level rise. On the positive side, studies made as part of this project indicate that a warmer climate might reduce the nitrogen pool in shallow coastal areas primarily by increased denitrification but other processes such as shorter turn over time might also influence the burial rate of nutrients. Unfortunately the effect on phosphorus is contrary and more bioavailable phosphorous should be expected as a result of warming and hence increased risk of anoxic conditions and phosphorus release from the sediment as a consequence of this.

In reaction to the continuing problematic environmental status of the Baltic Sea, several political actions have been taken. The Baltic Sea Action Plan (BSAP, HELCOM 2007a) aims directly at improving the ecological status of the Baltic Sea whereas the EC Water Framework Directive (WFD) and the EC Marine Strategy Framework Directive (MSFD) aim at improving water quality in the European Union and thereby also in the Baltic Sea and its catchment. Efforts to reach the ambitious goals will most likely have profound effects on the Baltic Sea in the next decades. Simulation studies show that implementation of the BSAP will improve the conditions of the Baltic Sea, but in a warmer climate the effect of BSAP on the water quality may not be as large as it would in today's climate (Meier et al. 2011a, Neumann et al. 2012, Friedland et al. 2012).

References

BACC (2008): Assessment of climate change for the Baltic Sea Basin. - Series: Regional Climate Studies. Springer-Verlag, 474 pp.

Belkin, I.M. (2009): Rapid warming of Large Marine Ecosystems. - Progress in Oceanography 81, 1-4, pp. 207-213.

Bendtsen, J., Gustafson, K., Söderkvist, J., Hansen, J.L.S. (2009): Ventilation of the bottom water in the North Sea-Baltic Sea transition zone. - Journal of Marine Systems 75: 138-149.

Bendtsen J. and Hansen J.L.S. (2013): Effects of global warming on hypoxia in the Baltic Sea-North Sea transition zone. Ecological Modelling. Vol. 264: 17-26

Bleich, S., Powilleit, M., Seifert, T. & Graf, G. (2011): β-diversity as a measure of species turnover along the salinity gradient in the Baltic Sea, and its consistency with the Venice System. - Marine Ecology Progress Series 436: 101-118.

Bonsdorff, E. & Pearson, T.H. (1999): Variation in the sublittoral macrozoobenthos of the Baltic Sea along environmental gradients: A functional-group approach. - Australian Journal of Ecology 24: 312-326.

Bonsdorff, E. (2006): Zoobenthic diversity – gradients in the Baltic Sea: Continuous post-glacial succession in a stressed ecosystem. - Journal of Experimental Marine Biology and Ecology 330: 383-391.

Boström, C. (1995): Flowering and fruit-bearing Zostera marina in Åland, Northern Baltic Sea. - Mem. Soc. Fauna Flora Fenn 71: 7-9.

Calewaert, J.-B., Heip, C., McDonough, N. & Philippart, C.J.M. (Ed.) (2011): Climate change and marine ecosystem research. Synthesis of European research on the effects of climate change on marine environments. - Marine Board Special Report. European Science Foundation, Marine Board: Oostende, 151 pp.

Carstensen, J., Krause-Jensen, D., Dahl, K. & Henriksen, P. (2008): Macroalgae and phytoplankton as indicators of ecological status of Danish coastal waters. National Environmental Research Institute, University of Aarhus. 90 pp. - NERI Technical Report No. 683. http://www.dmu.dk/Pub/FR683.pdf

Carstensen, J. (2011): Klimatiske forhold. - In: Hansen, J.W. & Petersen D.L.J. (red.): Marine områder 2010: NOVANA. Tilstand og udvikling i miljø- og naturkvaliteten. - Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi, nr. 6, Aarhus Universitet, pp. 21-26.

Conley, D., Carstensen, J., Ærtebjerg, G., Christensen, P.B., Dalsgaard, T., Hansen, J.L.S. & Josefson, A. (2007): Long term changes and impact of hypoxia in Danish coastal waters. - Ecological Applications 17(5): 165-184.

Dahl, K. & Carstensen, J. (2008): Tools to assess conservation status on open water reefs in Nature-2000 areas. National Environmental Research Institute, University of Aarhus. 25 pp. - NERI Technical Report No. 663.

Dahl, K., Ærtebjerg, G., Nørrevang Jensen, J., Gissel Nielsen, T., Krause Jensen, Bondo-Christensen, P. (1995) Marine Områder - Fjorde, kyster og åbent hav. Vandmiljøplanens overvågningsprogram 1994. Danmarks Miljøundersøgelser. Faglig rapport fra DMU nr. 142.

Danielsson, Å., Papush, L. & Rahm, L. (2008): Alterations in nutrient limitations - Scenarios of a changing Baltic Sea. - Journal of Marine Systems 73: 263-283.

Dawson, R.N. & Murphy, K.L. (1972): The temperature dependency of biological denitrification. - Water Research 6: 71-83.

Diaz R.J., Rosenberg R. (2008): Spreading dead zones and consequences for marine ecosystems. Science 321: 926 – 929

EC (European Communities) (2009): Common implementation strategy for the Water Framework Directive (2000/60/EC). River basin management in a changing climate. Guidance document No. 24.

Edwards, M. & Richardson, A.J. (2004): Impact of climate change on marine pelagic phenology and trophic mismatch. - Nature 430: 881-884.

Eriksson, O. (1993): Dynamics of genets in clonal plants. - Trends in Ecology & Evolution 8: 313-316.

Friedland, R., Neumann, T. & G. Schernewski (2012): Climate change and the Baltic Sea action plan: Model simulations on the future of the western Baltic Sea. - Journal of Marine Systems 105-108: 175-186. http://dx.doi.org/10.1016/j.jmarsys.2012.08.002

Froelich, P.N. (1988): Kinetic Control of Dissolved Phosphate in Natural Rivers and Estuaries: A Primer on the Phosphate Buffer Mechanism. - Limnology and Oceanography 33: 649-668.

Glockzin, M. & Zettler, M.L. (2008): Spatial macrozoobenthic distribution patterns in relation to major environmental factors - A case study from the Pomeranian Bay (southern Baltic Sea). - Journal of Sea Research 59: 144-161.

Granéli, E., Wallström, K., Larsson, U., Granéli, W. & Elmgren, R. (1990): Nutrient Limitation of Primary Production in the Baltic Sea Area. - Ambio 19: 142-151.

Gray JS, Wu R.S. and Or Y.Y. (2002): Effects of hypoxia and organic enrichment on the coastal marine environment. Mar Ecol Prog Ser 238: 249-279

Gustafsson, E. (2012): Modelled long-term development of hypoxic area and nutrient pools in the Baltic Proper. - Journal of Marine Systems 94: 120-134.

Hannerz, F. & Destouni, G. (2006): Spatial Characterization of the Baltic Sea Drainage Basin and Its Unmonitored Catchments. - AMBIO: A Journal of the Human Environment 35(5): 214-219.

Hansen, J.L.S. & Bendtsen, J. (2009): Den globale opvarmnings indflydelse på fremtidens iltforhold i de indre danske farvande. - In: Dahl, K. & Josefson, A.B. (Eds.); Marine områder 2007. NOVANA. Tilstand og udvikling i miljø- og naturkvaliteten. Danmarks Miljøundersøgelser, Aarhus Universitet. Faglig rapport fra DMU; nr. 707. pp. 81-90.

Hansen, J.L.S. & Bendtsen, J. (2013): Parameterisation of the oxygen dynamics in the North Sea - Baltic Sea transition zone. - Marine Ecology Progress Series. Vol. 481: 25–39

HELCOM (2003): The 2002 oxygen depletion event in the Kattegat, Belt Sea and Western Baltic. – Baltic Sea Environmental Proceedings No. 90.

HELCOM (2007a): Baltic Sea Action Plan. Helsinki Commission. Available at www.helcom.fi

HELCOM (2007b): Climate Change in the Baltic Sea Area – HELCOM Thematic Assessment in 2007. Baltic Sea Environmental Proceedings No. 111.

HELCOM (2009): Eutrophication in the Baltic Sea – An integrated thematic assessment of the effects of nutrient enrichment and eutrophication in the Baltic Sea region. - Baltic Sea Environmental Proceedings No. 115A & 115B.

HELCOM (2010): Ecosystem Health of the Baltic Sea 2003-2007: HELCOM Initial Holistic Assessment. - Baltic Sea Environmental Proceedings No.122.

HELCOM (2011): Fifth Baltic Sea Pollution Load Compilation (PLC-5). - Baltic Environmental Proceedings No. 128.

HELCOM (2012): www.helcom.fi/environment2/eutrophication/en_GB/front/

Henriksen, P., Storm, L.M., Carstensen, J., Møller, E.F. (2011): Pelagisk produktion og sigtdybde. - In: Hansen, J.W. & Petersen, D.L.J. (red.) (2011): Marine områder 2010. NOVANA. Tilstand og udvikling i miljø- og naturkvaliteten. Aarhus Universitet, DCE - Nationalt Center for Miljø og Energi. 120 p. - Videnskabelig rapport fra DCE - Nationalt Center for Miljø og Energi nr. 6. http://www2.dmu.dk/Pub/SR6.pdf

IPCC 2007: Summary for Policymakers. In: Climate Change (2007): The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Howarth, R.W. & Marino, R. (2006): Nitrogen as the Limiting Nutrient for Eutrophication in Coastal Marine Ecosystems: Evolving Views over Three Decades. - Limnology and Oceanography 51: 364-376.

Isla, A., Lengfellner, K. & Sommer, U. (2008): Physiological response of the copepod Pseudocalanus sp. in the Baltic Sea at different thermal scenarios. - Global Change Biology 14: 895-906.

Jeppesen, E., Kronvang, B., Meerhoff, M., Søndergaard, M., Hansen, K.M., Andersen, H.E., Lauridsen, T.L., Liboriussen, L., Beklioglu, M., Özen, A. & Olesen, J.E. (2009): Climate Change Effects on Runoff, Catchment Phosphorus Loading and Lake Ecological State, and Potential Adaptations. - Journal of Environmental Quality 38: 1930-1941.

Jeppesen, E., Kronvang, B., Olesen, J.E., Audet, J., Søndergaard, M., Hoffmann, C.C., Andersen, H.E., Lauridsen, T.L., Liboriussen, L. & Larsen, S.E. (2011): Climate change effects on nitrogen loading from cultivated catchments in Europe: implications for nitrogen retention, ecological state of lakes and adaptation. - Hydrobiologia 663: 1-21.

Jonasson, L., Hansen, J.L.S., Wan, Z. & She, J. (2012): The impacts of physical processes on oxygen variations in the North Sea-Baltic Sea transition zone. - Ocean Science 8: 37-48. doi:10.5194/os-8-37-2012.

Josefson, A.B. (2009): Additive partitioning of estuarine benthic macroinvertebrate diversity across multiple spatial scales. - Marine Ecology Progress Series 396: 283-292.

Josefson, A.B., Norkko, J. & Norkko, A. (2012): Burial and decomposition of plant pigments in surface sediments of the Baltic Sea – role of oxygen and benthic fauna. - Marine Ecology Progress Series 455: 33-49. doi 10.3354/meps09661.

Kahru, M., Leppänen, J., Rud, O. & Savchuk, O. (2000): Cyanobacteria blooms in the Gulf of Finland triggered by saltwater inflow into the Baltic Sea. - Marine Ecology Progress Series 207: 13-18.

Kain J.M. (1979): A view of the genus Laminaria. - Oceanography and Marine Biology: an Annual Review 17: 101-161.

Klavins, M., Kokorite, I., Ansone, L., Eglite, L., Rodinov, V. & Springe, G. (2012): Spectrofluorimetric study of dissolved organic matter in River Salaca (Latvia) basin waters. - Knowledge and Management of Aquatic Ecosystems 404: 06. http://dx.doi.org/10.1051/kmae/2011086.

Kokorite, I., Klavins, M., Rodinov, V. & Springe, G. (2011): Trends of natural organic matter concentrations in river waters of Latvia. - Environmental Monitoring and Assessment 184(8): 4999-5008. doi 10.1007/s10661-011-2315-0.

Kronvang, B., Jeppesen, E., Conley, D.J., Søndergaard, M., Larsen, S.E., Ovesen, N.B. & Carstensen, J. (2005): Nutrient pressures and ecological responses to nutrient loading reductions in Danish streams, lakes and coastal waters. - Journal of Hydrology 304: 274-288.

Köster, F.W., Möllmann, C., Hinrichsen, H.-H., Wieland, K., Tomkiewicz, J., Kraus, G., Voss, R., Makarchouk, A., MacKenzie, B.R., St. John, M.A., Schnack, D., Rohlf, N., Linkowski, T. & Beyer, J.E. (2005): Baltic cod recruitment - the impact of climate variability on key processes. - ICES Journal of Marine Science 62: 1408-1425.

Lee, J.A. & Brinkhuis, B.H. (1988): Seasonal light and temperature interaction effects on development of Laminaria saccharina (Phaeophyta) gametophytes and juvenile sporophytes. - Journal of Phycology 24: 181-191.

Maximov, A.A. (2011): Large-scale invasion of Marenzelleria spp. (Polychaeta; Spionidae) in the Eastern Gulf of Finland, Baltic Sea. - Russian Journal of Biological Invasions 2(1): 11-19.

Meier, H.E.M, Andersson, H., Dieterich, C., Eilola, E., Gustafsson, B., Höglund, A., Hordoir, R. & Schimanke, S. (2011a): Transient scenario simulations for the Baltic Sea Region during the 21st century. SMHI. - Oceanografi Nr. 108.

Meier, H.E.M., Andersson, H.C., Eilola, K., Gustafsson, B.G., Kuznetsov, I., Müller-Karulis, B., Neumann, T. & Savchuk, O.P. (2011b): Hypoxia in future climates: A model ensemble study for the Baltic Sea. - Geophysical Research Letters 38: L24608, doi: 10.1029/2011GL049929.

Meier, H.E.M., Eilola, K. & Almroth, E. (2011c): Climate-related changes in marine ecosystems simulated with a 3-dimensional coupled physical-biogeochemical model of the Baltic Sea. - Climate Research 48: 31-55.

Meier, H.E.M, Hordoir, R., Andersson, H.C., Dieterich, C., Eilola, K., Gustafsson, B.G., Höglund, A. & Schimanke, S. (2012a): Modeling the combined impact of changing climate and changing nutrient loads on the Baltic Sea environment in an ensemble of transient simulations for 1961-2099. - Climate Dynamics 39: 2421-2441. doi: 10.1007/s00382-012-1339-7.

Meier, H.E.M, Müller-Karulis, B., Andersson, H.C., Dieterich, C., Eilola, K., Gustafsson, B.G., Höglund, A., Hordoir, R., Kuznetsov, I., Neumann, T., Ranjbar, Z., Savchuk, O. & Schimanke, S. (2012b): Impact of climate change on ecological quality indicators and biogeochemical fluxes in the Baltic Sea: a multi-model ensemble study. AMBIO 41: 558-573.

Montalvo, A.M., Williams, S.L., Rica, K.J., Buchmann, S.L., Cory, C., Handel, S.N., Nabhan, G.P., Primack, R. & Robichaucx, R.H. (1997): Restoration biology: a population biology perspective. - Restoration Ecology 5: 277-290.

Moy, F.; Christie, H.; Stålnacke, P.; Aksnes, D.; Alve, E.; Aure, J.; Bekkeby, T.; Fredriksen, S.; Gitmark, J.; Hackett, B.; Magnusson, J.; Pengerud, A.; Sjøtun, K.; Sørensen, K.; Tveiten, L.; Øygarden, L.; Åsen, P. A. (2008): Sluttrapport fra sukkertareprosjektet. STF-rapport TA-2467/2008.

Neumann, T. (2010): Climate-change effects on the Baltic Sea ecosystem: A model study. - Journal of Marine Systems 81: 213-224.

Neumann, T., Eilola, K., Gustafsson, B.G., Müller-Karulis, B., Kuznetsov, I., Meier, H.E.M. & Savchuk, O.P. (2012): Extremes of temperature, oxygen and blooms in the Baltic Sea in a changing climate. -AMBIO 41: 574-585.

Nielsen, K., Risgaard-Petersen, N., Sømod, B., Rysgaard, S. & Bergø, T. (2001): Nitrogen and phosphorus retention estimated independently by flux measurements and dynamic modelling in the estuary, Randers Fjord, Denmark. - Marine Ecology Progress Series 219: 25-40.

Nielsen, R., Kristiansen, Aa., Mathiesen, L. & Mathiesen, H. (1995): Distributional index of the benthic macroalgae of the Baltic Sea area. - Acta botanica fennica. Baltic Marine Biologists Publication 155 (18).

Norkko, J., Reed, D.C., Timmermann, K., Norkko, A., Bonsdorff, E., Gustafsson, B.G., Slomp, C.P., Carstensen, J. & Conley, D.J. (2012): A welcome can of worms? Hypoxia mitigation by an invasive species. - Global Change Biology 18: 422-434. doi: 10.1111/j.1365-2486.2011.02513.x.

Nowicki, B.L. (1994): The Effect of Temperature, Oxygen, Salinity, and Nutrient Enrichment on Estuarine Denitrification Rates Measured with a Modified Nitrogen Gas Flux Technique. - Estuarine, Coastal and Shelf Science 38: 137-156.

Nowicki, B., Kelly, J., Requintina, E. & Van Keuren, D. (1997): Nitrogen losses through sediment denitrification in Boston Harbor and Massachusetts Bay. - Estuaries and Coasts 20: 626-639.

Ojaveer, H., Jaanus, A., MacKenzie, B.R., Martin, G., Olenin, S., Radziejewska, T., Telesh, I., Zettler, M.L. & Zaiko, A. (2010): Status of biodiversity in the Baltic Sea. - PlosONE 5(9): e12467, doi: 10.1371/journal.pone.0012467.

Remane, A. (1934): Die Brackwasserfauna (Mit besonderer Beruecksichtigung der Ostsee). - Zool. Anz. 7: (Supplementband) 34-74.

Reusch, T.B.H., Boström, C., Stam, W.T. & Olsen, J.L. (1999): An ancient eelgrass clone in the Baltic. - Marine Ecology Progress Series 183: 301-304.

Savchuk, O.P., Wulff, F., Hille, S., Humborg, C. & Pollehne, F. (2008): The Baltic Sea a century ago - a reconstruction from model simulations, verified by observations. - Journal of Marine Systems 74: 485-494.

Schernewski, G. & Neumann, T. (2005): The trophic state of the Baltic Sea a century ago: a model simulation study. - Journal of Marine Systems 53: 109-124.

Schiedek, D. (1997): Marenzelleria cf. viridis (Polychaeta: Spionidae) – ecophysiological adaptations to a life in the coastal waters of the Baltic Sea. - Aquatic Ecology 31: 199-210.

Siegel, H., Gerth, M. & Tschersich, G. (2006): Sea surface temperature development of the Baltic Sea in the period 1990-2004. - Oceanologia, 48 (S): 119-131.

Skov, H., Dahl, K., Dromph, K., Daunys, D., Engdahl, A., Eriksson, A., Floren, K., Gullström, M., Isaeus, M & Johanna O. (2012): Modelling of the potential coverage of habitat-forming species and development of tools to evaluate the conservation status of the marine Annex I habitats. - TemaNord 2012: 532. ISBN 978-92-893-2368-0. Nordic Council of Ministers.

Springe, G., Birzaks, J., Briede, A., Druvietis, I., Grīnberga, L., Konošonoka, I., Parele, E., Rodinovs, V. & Skuja, A. (2012): Climate change indicators for large temperate river: case study of the Salaca River. - In: Kļaviņš, M. & Briede A. (Eds.): Climate change in Latvia and adaptation to it. University of Latvia Press, Riga, pp. 79-94.

Stal, L.J., Staal, M. & Villbrandt, M. (1999): Nutrient control of cyanobacterial blooms in the Baltic Sea. - Aquatic Microbial Ecology 18: 165-173.

Tomkiewicz, J., Lehmann, K.M. & St. John, M.A. (1998): Oceanographic influences on the distribution of Baltic cod, Gadus morhua, during spawning in the Bornholm Basin of the Baltic Sea. - Fisheries Oceanography 7(1): 48-62.

Villnäs, A. & Norkko, A. (2011): Benthic diversity gradients and shifting baselines: implications for assessing environmental status. - Ecological Applications 21(6): 2172-2186.

Wan, Z., Jonasson, L. & Bi, H. (2011): N/ P ratio of nutrient uptake in the Baltic Sea. - Ocean Science 7: 693-704.

Wan, Z., Bi, H., She, J., Maar, M. & Jonasson, L. (2012): Model study on horizontal variability of nutrient N/P ratio in the Baltic Sea and its impacts on primary production, nitrogen fixation and nutrient limitation. - Ocean Science Discussions 9: 385-419, doi:10.5194/osd-9-385-2012.

Wasmund, N., Nausch, G., & Matthäus, W. (1998): Phytoplankton spring blooms in the southern Baltic Sea - spatio-temporal development and long-term trends. - Journal of Plankton Research 20: 1099-1117.

Wasmund, N., Göbel, J. & v. Bodungen, B. (2008): 100-years-changes in the phytoplankton community of Kiel Bight (Baltic Sea). - Journal of Marine Systems 73: 300-322.

Zettler, M.L., Schiedek, D. & Bobertz, B. (2007): Benthic biodiversity indices versus salinity gradient in the southern Baltic Sea. - Marine Pollution Bulletin 55: 258-270.

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Appendix

Appendix 1: Temperature effect on nutrient concentrations in estuaries – less nitrogen and more phosphorous

Increased annual mean temperature seems to stimulate the removal of total nitrogen (TN) but increase total phosphorous (TP) concentrations.

Based on 22 years of environmental monitoring in Danish seas and estuaries we made an analysis of the combined effect of climate parameters and the input of nutrients from rivers on the total nitrogen concentration in the estuaries. The analysis was made for five stations in inner and outer parts of three estuaries. All 5 data sets showed decreasing TN concentration with increasing annual mean temperature. Each of the individual correlations is not statistically significant but 5 negative correlations are a significant result ($p = 0.03$). The aforementioned correlations were robust against different statistical analysis methods. The results are consistent with a previous analysis in the estuary Limfjorden in northern Denmark where negative correlations between water temperature and TN-concentration were found for seven out of seven stations and in addition there are several other studies that support the findings (Nowicki et al. 1997). We therefore hypothesize that increased temperatures will reduce the level of nitrogen in temperate estuaries.

Our results predict a reduction of TN concentrations of 1-5% $°C^{-1}$ for three of the stations. At the two stations situated in Randers Fjord, correlations predicted reductions of 20-25% $°C^{-1}$. This is an order of magnitude higher than the other stations and significantly higher than what could be expected from denitrification alone according to literature values (Nielsen et al. 2001). Randers Fjord differs a lot from the two other estuaries, it is a long narrow estuary and receives most of its nutrients from its main tributary (Gudenåen river). In Gudenåen there has been a clear increase in macrophytes over the last decades. This has likely increased the N retention in the estuary since the N retention in Randers Fjord is mainly due to sedimentation and burial of organic material from the river. Since the macrophyte biomass in the river is not included in the analysis, the effect will be assigned to other co-varying parameters such as temperature. The retention time in Randers Fjord can be as low as three days, therefore the influence of sediment processes like denitrification is limited and highly dependent on variations in retention time.

Other studies have shown that the denitrification rate is temperature sensitive in an exponential relationship which results in an increased removal of 7% to 16% $°C^{-1}$ (Dawson & Murphy 1972, Nowicki 1994). Increasing temperatures have also been shown to speed up removal of N both in experiments and in field studies (Nowicki 1994, Nowicki et al. 1997). Other studies (Nielsen et al. 2001) have shown that denitrification removes from about 6% and up to 23% of the nitrogen input to estuaries depending on concentration and retention time. If this is combined with the coefficient for temperature, we would expect an increase in N removal of 1.2% to 3.7% $°C^{-1}$. This is in accordance with the increased N removal of 1-5% $°C^{-1}$ of TN that we report. If this trend is extrapolated to a predicted temperature increase of 3-5°C it will result in a decreased N concentration of approx. 3-20% in year 2070-2100 without any change in loading.

Cyanobacteria which can contribute significantly to the N input in aquatic system do not occur in substantial amount in the estuaries we have investigated. This is mainly due to high salinity. However, in estuaries or parts of the Baltic Sea with lower salinity, an increase in temperature and phosphorus concentration might stimulate the growth of cyanobacteria and their possible nitrogen fixation may act as a source for increased nitrogen input. There is evidence that N-fixing cyanobacteria blooms are enhanced by low N:P ratios and stable water column, especially in the Baltic Proper(Granéli et al. 1990, Stal et al. 1999, Kahru et al. 2000).

The analyses of total phosphorus concentration (TP) and temperature dependence showed generally a positive correlation between P and temperature. The correlations were not as robust as for N and they were very biased by the large reduction in the late 1980s, but there was still a general positive trend.

The observed increase ranged from approx. 5 to 15% $°C^{-1}$. If this trend is extrapolated to a predicted temperature increase of just 3 °C, it will result in an increased P concentration of approx. 15-50% in year 2070-2100 and for 5°C the concentration might at worst double, without any change in loading.

We suggest two mechanisms that can lead to a positive relationship between temperature and phosphorus concentration. The literature shows that increasing temperatures can lead to decreasing adsorption of soluble phosphorus to particles (Froelich 1988). However, the most important mechanism is probably that phosphorus is released during anoxic conditions in sediment and bottom waters. As anoxia and hypoxia are enhanced by elevated temperatures, it brings about an indirect effect of temperature rise.

Impacts

In many of the Danish estuaries, phosphorous concentration is limiting algae growth in the early season. Therefore even small increases in P levels can enhance algal growth and exacerbate Secchi depth especially during algal blooms in spring. An intense spring bloom may negatively influence water quality the rest of the season. A severe algal bloom can leave a large amount of organic material on the bottom which can enhance anoxic conditions later in the year. Normally spring blooms are dominated by diatoms but they tend to become silica limited where there is a major surplus of N and P; this may lead to blooms of toxic algae like *Chatonella spp.* subsequent to a diatom bloom. In-creased P run-off from increased precipitation has also been predicted (Jeppesen et al. 2009) which makes the demand for further reduction in P loading more current.

N is still thought to be the limiting nutrient in most of the growth season and it has also been shown to be the limiting nutrient in most parts of the Baltic Sea though large areas like the Bothnian Bay might be more controlled by phosphorous (Granéli et al.1990). Therefore, the focus should still be on reductions of both nutrients.

Depending on the exact temperature effect, the expected reductions in N might more or less cancel out the increased loading that is due to increased run-off from non-point sources and change in cropping patterns. In the Danish coastal catchment areas, the N run-off is predicted to increase annual loading by 5-7% in 2070-2100 compared with our prediction of a decreased N concentration of 3-20% for the SRES A2 scenario. The final development will be dependent on the specific estuary, hydraulic retention time and its catchment area but it is most likely that the combined changes due to climate change will be less important than the anthropogenic contribution and reduction in this. Our combined expectations are summarized in Figure 16.

In addition to the temperature effects on nutrients, other processes such as nitrification and degradation of organic material will increase with increasing ammonia and organic loading and the rates are also positively affected by temperature while warm water even contains less oxygen and hence increases the risk of hypoxia (see Chapter 4).

Uncertainties

The analytical methods are subject to some uncertainty while there are many co-varying parameters and relatively few observations. This increases the risk to conclude that there is a relationship where there is not. In our case we are very confident about the nutrient concentration and temperature relationships since they seem to be thorough and are supported by several other studies but because of co-variance, the complexity of the nutrient cycling and the relatively low variance in temperature the exact quantification of the effects are less confident. The residence time in each of the estuaries also has a high impact on the effect of e.g. denitrification and hence the effect of temperature variations.

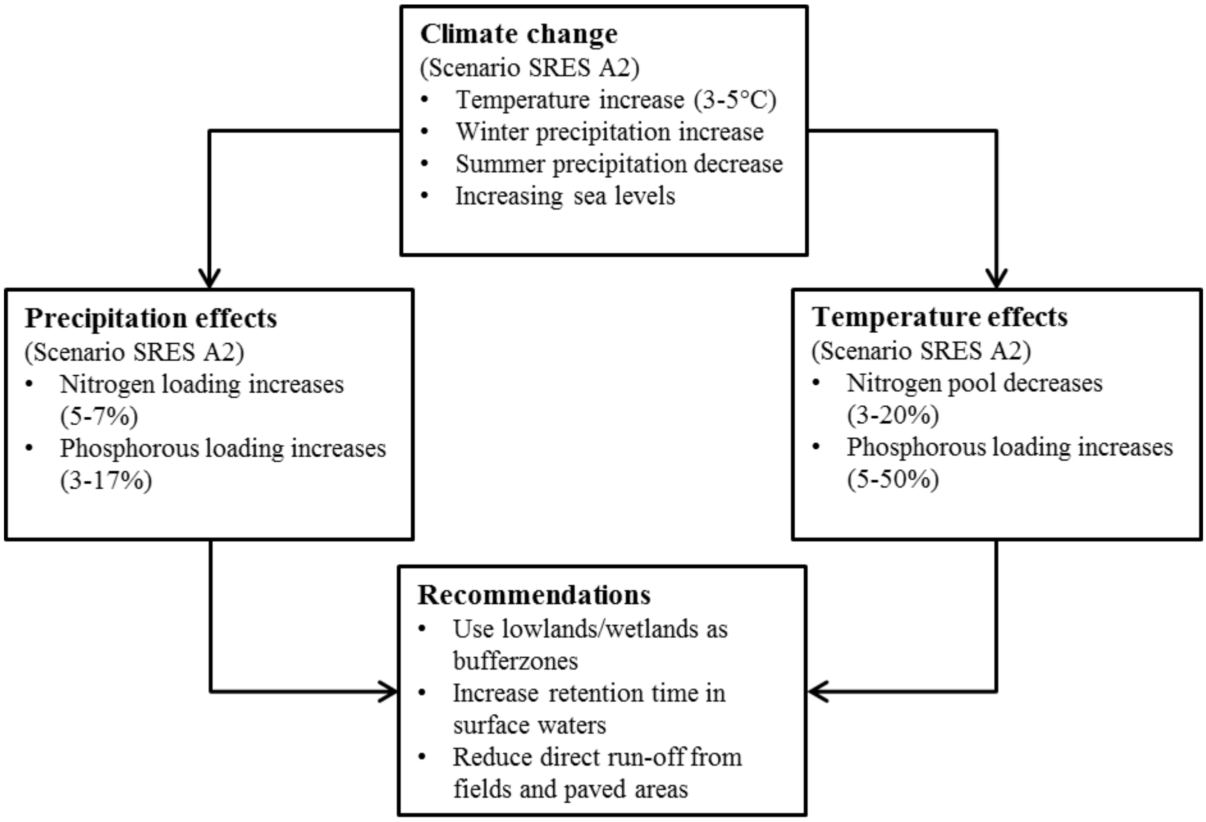

Figure 16: Schematic summary of the predicted change in nutrient loadings in Danish estuaries due to climate change and some recommendations. Some of the same effects are expected for northern and western part of the Baltic Region.

Appendix 2: Impact of a warmer climate on hypoxia in the North Sea – Baltic Sea transition zone

Oxygen conditions in the Baltic Sea have been deteriorating since the 1950s due to increased external nutrient inputs and eutrophication processes. Oxygen depletion is a reoccurring problem in the inner Danish coastal waters in the transition zone between the North Sea and the Baltic Sea (Figure 17). Every year in late summer hypoxic events occur but the extent of the affected areas varies considerably. However, almost every year the benthic fauna are damaged to some degree and in the worst cases, the fauna community becomes completely destroyed. The effect of hypoxia is evident when dead fish wash ashore. However, before the damages become so visible and spectacular, the benthic fauna has typically already been affected (Conley et al. 2007).The latest severe oxygen depletion event was in the years 2002 and 2003, when hypoxic water covered large areas of the sea bottom in the inner Danish waters for months. Oxygen depletion has become a growing problem in many coastal areas throughout the world due to eutrophication (Diaz & Rosenberg 2008) and has been considered as the greatest threat to benthic biodiversity (Gray 2002). Even though action plans have been implemented and the nutrient concentrations have been declining, there have been no significant improvements of the oxygen conditions in the inner Danish waters. However, the climate also plays a role for the oxygen dynamics in the area. In particular the wind determines the ventilation of the bottom water and the temperature determines the respiratory oxygen demand. In fact, the climate change that has been documented for the last decades may already have caused negative effects on the oxygen conditions.

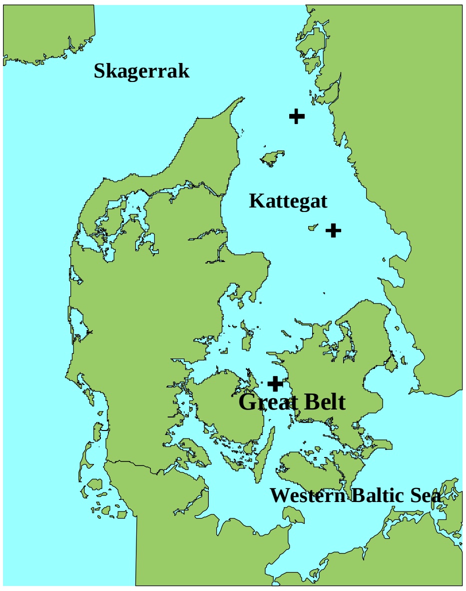

Figure 17: The inner Danish waters located in the transition zone between the North Sea/Skagerrak and the Baltic Sea. Crosses mark the position of monitoring stations used to calibrate the oxygen model OXYCON.

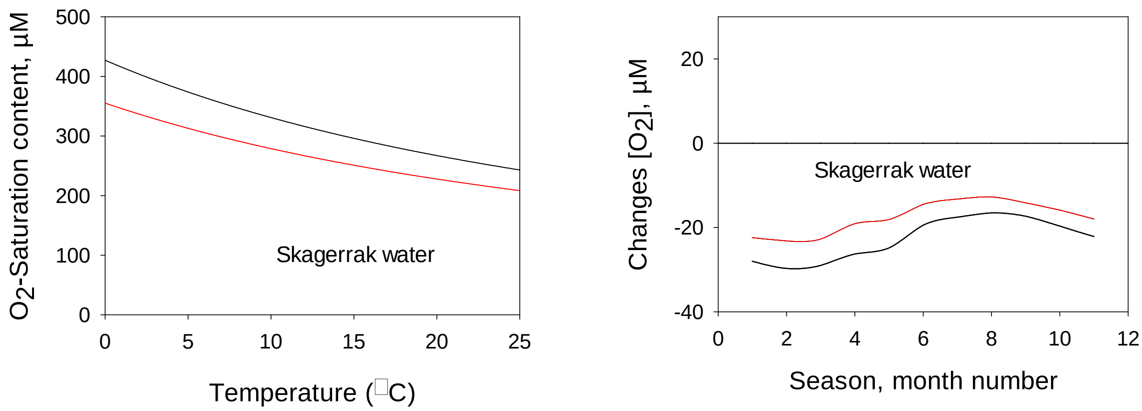

Figure 18: Left: Oxygen concentration at 100 % saturation in the two water masses that mix in the inner Danish waters: the water from the Baltic Sea (black Line) and the water from the North Sea and Skagerrak (red line) versus the water temperature. Right: The changes in the oxygen concentration during the seasons if the water column is warmed by 3°C all year round.

In contrast to life on land where oxygen is plentiful, the pool of oxygen available for respiration in aquatic environments is small due to its low solubility in water. Hypoxia describes the situation where biological respiration is limited by the amount of oxygen in the water and where the organisms begin to die depending on tolerance limits of the species. Logically, hypoxia starts to develop when oxygen consumption in a water body exceeds the input of oxygen due to production (photosynthesis) and due to ventilation of the water column by oxygen-rich surface water. The larger the initial pool of oxygen in the bottom water, the longer it takes for hypoxia to develop. In most cases hypoxia develops in periods where the bottom water is warm and stagnant due to calm weather conditions and thereby low ventilation efficiency.

The effect of global warming on hypoxia

The solubility of oxygen in water decreases with the temperature and this means that the pool of oxygen in the bottom water will be used up faster. This is particularly relevant for areas like the transition zone between the Baltic Sea and the North Sea where the water column is permanently stratified and where ventilation by mixing of the water column is limited. Advection of bottom water from the northern boundary of the area (the North Sea/Skagerrak) is the most important source of oxygen for the Kattegat area. Therefore increasing temperature will cause less oxygen in the bottom water advected into the Kattegat. The oxygen decrease due to increased temperature is also observed in riverine ecosystems flowing into the Baltic Sea (Springe et al. 2012). Increasing temperatures will also cause increasing respiratory oxygen consumption rates. Typically the respiration rate increases by a factor of 2-4 if the temperature rises by 10°C. Due to these two effects, hypoxia is tightly coupled to the temperature and almost exclusively occurs during the summer period. A model, OXYCON, has been developed to describe the influence of temperature on the oxygen dynamics in the North Sea-Baltic Sea transition zone (Hansen & Bendtsen 2013) and tested in Jonasson et al. (2012). The model considers the combined influence from biological processes and physical transports on oxygen concentration in the bottom water. Oxygen sinks due to the pelagic and benthic microbial respiration together with the benthic macrofaunal oxygen consumption are considered. Ventilation of bottom water due to mixing and advection (i.e. transport by currents) is described by applying a, so called, “ventilation age tracer” which has previously been shown to resolve the basic dynamics of bottom water ventilation in the area (Bendtsen et al. 2009).

Model simulations of the oxygen dynamics in the transition zone

The distribution of oxygen has been modelled for the three consecutive years 2001-2003 and the simulations correspond very well with observations from the area (Hansen & Bendtsen 2013, Jonasson et al. 2012). The years 2001-2003 differed markedly with respect to hypoxia. The oxygen conditions were relatively good in 2001, whereas 2002 experienced the worst conditions for decades due to calm weather conditions during the summer and in 2003 bad oxygen conditions were due to high temperatures (HELCOM 2003). Thereby the simulated period covers the range of seasonal hypoxia in the area. To describe the oxygen conditions in a future warmer climate, a scenario with the 2001-2003 climate conditions but with 3°C higher temperatures has been conducted (Figure 19). The temperature anomaly of 3°C is within the expected range of temperature increase by the end of this century (BACC 2008).

The results show that the oxygen concentration in the bottom water will be lowered significantly with 30-60 µM throughout the year with the most significant reductions during summer and in the southern part of the area. Hypoxia will occur in the northern area where there is presently no hypoxia. In the central Kattegat the hypoxic season will increase from a few weeks to about one month and in the Great Belt the duration will increase from about 1 month to about 3 months. The minimum oxygen concentration will also be lower and anoxia will occur in the Great Belt in some years in the future.

The total area affected by severe hypoxia (oxygen concentration < 2 mg O_2/l) under the present-day climate ranges from 3,000 km^2 to about 15,000 km^2. A climate change scenario where the temperature is 3°C higher than today but where the input of organic matter to the bottom water is at the same level as today will result in an increase in the hypoxic area by 50-100% (Figure 20, orange line). In the extreme case where the temperature is increased by 3°C and where the benthic communities respire 20% more organic material, the hypoxic area will increase by 100-400%.

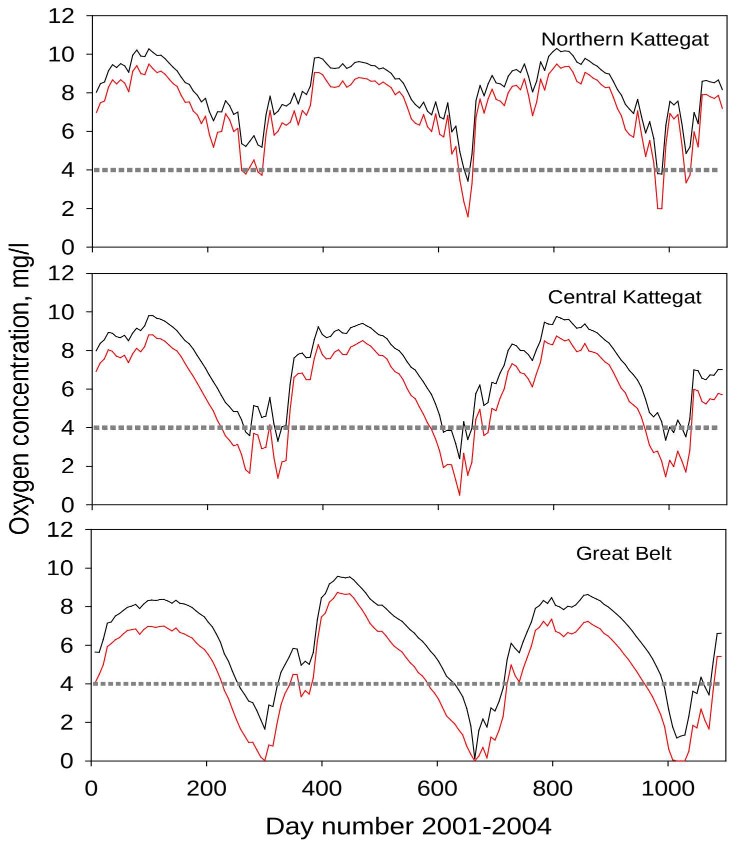

Figure 19: Black line: Temporal distribution of bottom water oxygen during 2001-2003 at three stations in the northern and central Kattegat and in the Great Belt. Red line shows the distribution of oxygen under similar meteorological conditions but with a 3°C higher air temperature and water temperature in the inflowing Skagerrak bottom water throughout the year. Dotted line indicates the conventional limit for hypoxia in the area.

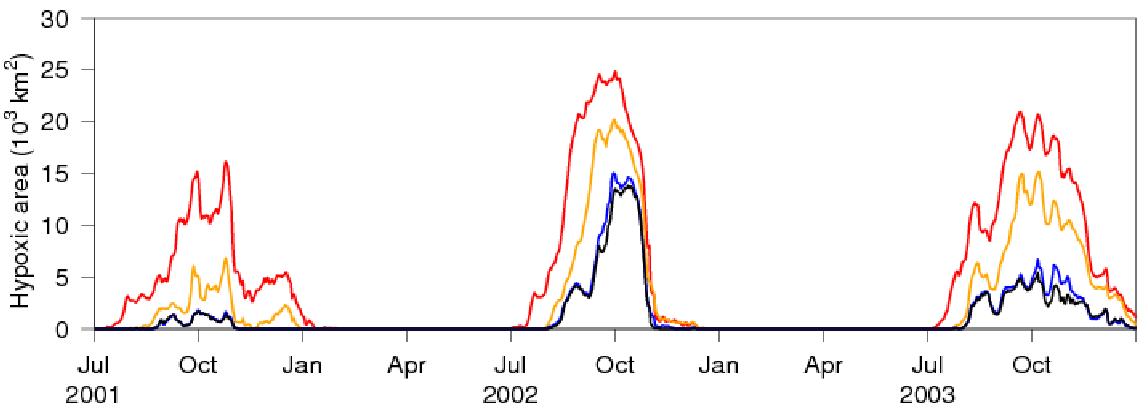

Figure 20: Total hypoxic area in the western Baltic Sea, the Belt Sea and in the Kattegat in km^2 during the season as simulated with OXYCON for different climate scenarios. All scenarios are based on the climate conditions obtained for the 2001-2003 period. Black lines show reference conditions (corresponding to the black line in Figure 18) and red lines show the hypoxic area under a 3°C warmer climate. Orange lines show a climate scenario with (+3°C) combined with a 45% reduction in the benthic respiration (the total carbon mineralization is maintained at the present-day level corresponding to the red line in figure 18) Blue lines show a climate scenario (+3°C) combined with a 30% reduction in the total primary productivity in the area.

In order to compensate for effects of increasing temperatures on the oxygen concentration, it is necessary to decrease the primary productivity. Model solutions show that a 30% reduction in the total primary export production combined with a 3°C temperature increase will result in the same oxygen conditions as observed during the present-day climate (Figure 20, blue line). In the Kattegat and the Belt Sea this means that inorganic nitrogen, which is the limiting nutrient for export production, should be decreased correspondingly. This is to some extent possible by reducing the riverine contribution from land.

The warmer the climate will be in the future, the stronger the negative effect on the oxygen conditions. Figure 21 shows the expected relationship between the number of hypoxic days in the central Kattegat and the temperature anomaly shows an almost linear relationship in the range of temperature changes between -2 and +5°C. This scenario corresponds to the most extreme scenario where the simulated oxygen concentration is not adjusted to the present-day primary productivity level.

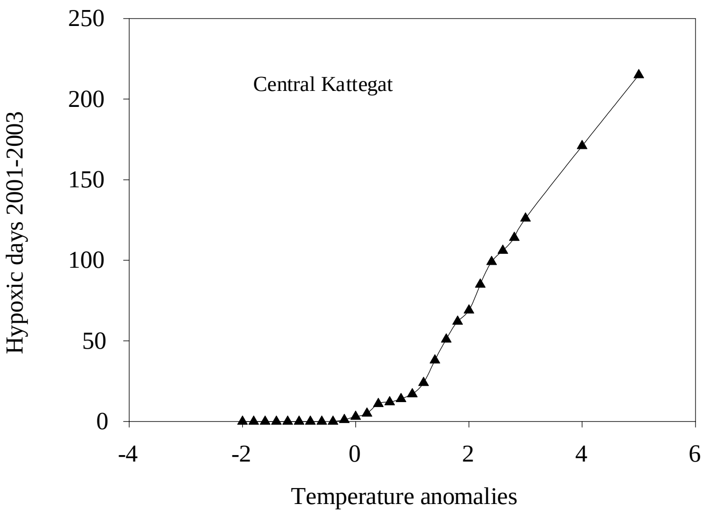

Figure 21: Number of hypoxic days in the central Kattegat versus the temperature anomalies as simulated with OXYCON.

For the Baltic Sea, different projections for climate change effects on oxygen contents exist. Projected increasing river discharge and precipitation might strengthen the stratification thereby reducing downward oxygen transport to deeper waters and worsen bottom oxygen condition in the deeper parts of the Bothnian Sea and the Baltic Proper. Other studies suggest a decreasing stability of vertical stratification e.g. in the Gotland Sea due to increased wind-induced mixing and slightly improved oxygen conditions in deep waters (Neumann 2010). Oxygen-rich inflows from the Northern Sea also play a major role for the oxygen conditions in the deeper parts of the Baltic Sea. Projected less oxygen-rich salt water inflows will have a negative effect on the oxygen content of bottom water (Meier et al. 2011a).

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Climate Change Impacts on the Baltic Sea Fish Stocks and Fisheries - Review with a focus on Central Baltic herring, sprat and cod

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Abstract

Climate change is likely to induce substantial changes in the Baltic Sea, as it is a species-poor ecosystem where virtually all species live close to their environmental tolerance range. The vitality of the fish stocks and viability of fisheries should be supported by consideration of global change in the management of environment (protection, sustainable use and restoration) and of fisheries. A shift away from sector-by-sector management towards the integrated management of land, water and living resources may be necessary to sustain the productivity of fish stocks. The climate change and other concomitant human pressures induce substantial uncertainties for the future, especially as responses of marine ecosystems to changes in temperatures and in other forcing factors may not be linear, but abrupt changes may occur, which also need to be considered in exploitation of fish resources.

1 Introduction

1.1 Scope of the fish stocks and fisheries review

This review aims to highlight the expected effects of climatic change on fish resources in the Baltic Sea, especially on Baltic herring, sprat and cod in the Baltic Proper, because these species have the highest contribution to fisheries, to other fish stocks and to the ecosystem function. However, focusing on these stocks does not mean that the importance of other fish stocks and basins of the Baltic Sea could be ignored in the climate context. The review also addresses the fisheries sector as well as the fisheries and ecosystem management.

1.2 Fish biodiversity in the Baltic Sea

The diversity of the Baltic Sea fish community is linked in particular to the geological evolution of the basin after the last ice-age, to climatic and oceanographic evolution, and to biogeography i.e. distribution of species in space through geological time (e.g. Hiddink and Coleby 2011). The Baltic Sea fish stocks are from various origins: marine, freshwater and migratory species as well as glacial relicts. Besides, specimens from marine species which cannot establish themselves are irregularly found and an increasing numbers of invasive species occur. The number of species gets smaller with decreasing salinity and towards higher latitudes. In the Kattegat, 175 species of fish and lampreys have been found while in the Bornholm Basin 108, in the northern Baltic Proper 61 and in the Bothnian Bay 48 species have been observed (HELCOM 2012).

Marine fish species dominate especially in the open sea area but freshwater species are abundant in coastal and estuarine areas where salinity is low. The share of marine fishes decreases and freshwater fish increases towards the northern and eastern parts. River spawning migratory fish, such as Atlantic salmon, trout and whitefish support important commercial and especially recreational fisheries around the Baltic Sea. However, especially many migratory fish stocks have already collapsed or disappeared due to anthropogenic environmental changes (e.g. destruction of the reproduction areas of migratory species, eutrophication) and because of excessive exploitation.

Endemic fish species have not been reported to be found in the Baltic Sea (Ojaveer et al. 2010) but e.g. Ojaveer & Kaleis (2005) stated that the Baltic fish populations of marine origin have been adapted to the environmental conditions of the Baltic Sea so that they cannot be treated as having the same biological and life history parameters as their ancestors that live in comparatively constant oceanic conditions. A typical example is the Baltic herring, a subspecies of the Atlantic herring.

1.3 Characteristics of the marine fish populations of Baltic Sea

Herring

Herring has a wide distribution and high economic importance for fisheries in seas of the northern hemisphere. In the Baltic Sea, herring forms together with sprat and cod the bulk of the fish biomass and catches. The distribution of herring covers virtually the whole Baltic Sea as they can tolerate e.g. low salinity. However, studies about genetics of herring have found zones of decreased mixing of populations between the northern and southern populations in the Baltic Sea (Jørgensen et al. 2005a) although the genetic differences are small within the Baltic Sea and even between the Baltic herring and herring from the North Sea and the Atlantic Ocean (Ryman et al. 1984, André et al. 2011). Even herring which spawn on the same locations in discrete spawning waves may represent genetically distinct spawning populations (Jørgensen et al. 2005b).

Morphological variations among sub-populations of herring as well as variation in spawning times and migration patterns also support that locally adapted populations exist (e.g. Aro 1989; Parmanne et al. 1994). Moreover, the consistent area-specific patterns in weight-at-age (e.g. ICES 2012) and the spatial differences in the concentrations of persistent pollutants in the tissues of herring (Bignert et al. 2007, Karl & Ruoff 2007, Vuorinen et al. 2012) prove the existence of local relatively stable subpopulations. As suggested in the case of Atlantic herring (McQuinn 1997, McPherson et al. 2003, Mariani et al. 2005), the Baltic herring dynamics and population structure may well be described with the theory of metapopulations. Along these lines, there apparently exists a certain degree of isolation between Baltic Sea herring spawning populations but they mix during feeding. In fisheries management it is a challenging task to ensure that even weak subpopulations survive if the species is exploited in a mixed stock fishery and climate is changing at the same time.

The growth rate of herring is low in the Baltic Sea and they only grow to a fraction of the weight attained in more saline waters. The herring growth rates tend to decrease towards areas with lower salinity and salinity has been shown to be a factor to influence herring weight (e.g. Rönkkönen et al. 2004). Salinity may influence fish growth via direct impacts to physiology (see Boeuf & Payan 2001) or through influences in ecosystem function and in ecological interactions (Rönkkönen et al. 2004). As the weight-at-age does not exactly follow the salinity gradients, it is possible that the subpopulations of herring have differences in salinity tolerance or other environmental factors partly mask the impacts of salinity.

During the recent decades there have been remarkable variations in herring growth rates (Figure 1). The smaller fish are poor material for the processing industry (Stephenson et al. 2001) and slow growth rates also contribute to the high concentrations of persistent organic pollutants via bioaccumulation (Kiljunen et al. 2007, Peltonen et al. 2007). In the Gulf of Finland the weight-at-age peaked in 1975–1980 and thereafter decreased even to one third (J. Pönni, unpublished). Several reasons have been suggested to contribute to the decreased growth rate, linking the changes with impacts of fishing, fish species interactions (predation, competition), changes in migrations patterns, eutrophication, climate change, hydrography and alien species (Beyer & Lassen 1994, Raid 1998, Flinkman 1999, Cardinale & Arrhenius 2000, Rönkkönen et al. 2004, Casini et al. 2006, Peltonen et al. 2007, Casini et al. 2010). As the fluctuations in the herring growth rates during the recent decades have occurred relatively coherently but in somewhat different magnitude in different basins of the Baltic Sea, they are likely to at least partly arise from common, climate-induced processes.

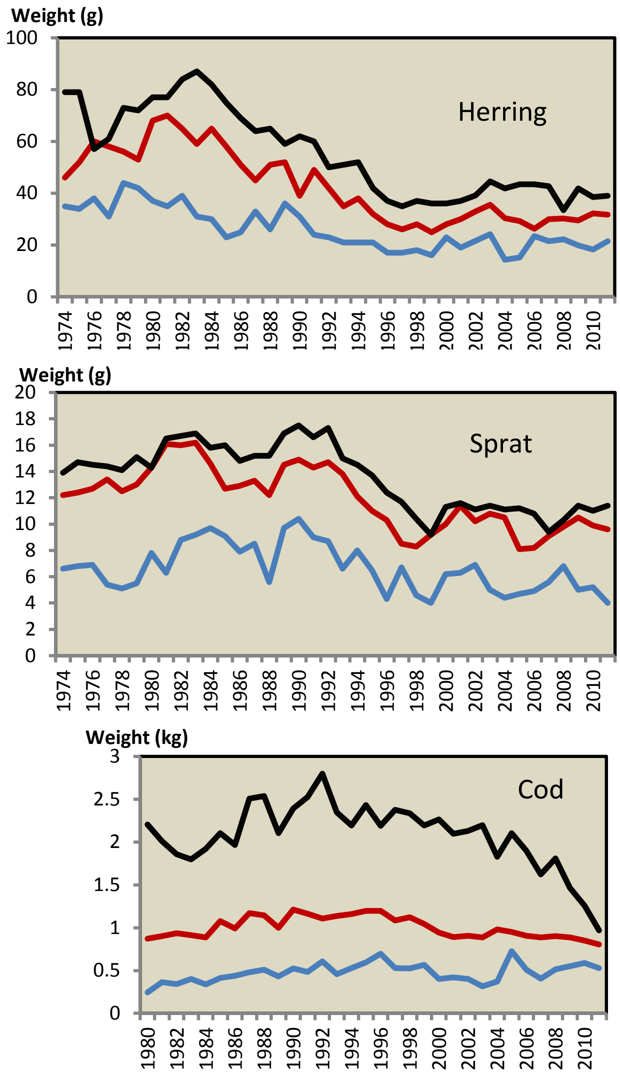

Figure 1: The average annual weight-at-age of the central Baltic herring, sprat and cod in ages 2 (blue), 4 (red) and 6 years (black) in the commercial catches (ICES 2012).

Sprat

Sprat is a small, pelagic, schooling, zooplankton feeding fish species distributed over a broad geographical range. In Europe it occurs from the Black and Mediterranean Seas in the south to the European Atlantic shelf, including the North and Baltic Seas (Parmanne et al. 1994, Peck et al. 2012). It tolerates a wide range of salinities and is abundant also in estuarine habitats (Peck et al. 2012). Sprat makes seasonal migrations depending on the environmental conditions but there is no certainty if sprat in the Baltic Sea is a uniform population or not (Parmanne et al. 1994). The growth rate of sprat decreased during the 1990’s (Figure 1).

Cod

Cod is a large predatory fish important for the ecosystem function and for fisheries. It is considered that there are two distinct cod populations in the Baltic Sea (excluding the Kattegat). The eastern stock is found east of Bornholm and up to the Gulf of Finland and Gulf of Bothnia and the western stock to the west of the Bornholm Island (Aro 2000 and references therein). However, the populations also mix and the distribution areas of each stock component tend to get wider when the abundance is increasing.

Nielsen et al. (2003) found that genetic differentiation increased gradually along a transect from the North Sea through the Danish straits to the Baltic Sea, while there were not significant differences between samples from Bornholm basin, Gdansk Basin and Gotland Basin. Genetic differences between populations can tell whether there is mixing between populations, but based on such information it is difficult to know if a collapsed fish population could be replaced with immigrants from adjacent areas, because even small genetic differences between populations can be constant and biologically meaningful in marine fish (Knutsen et al. 2011). In marine species even a minimal genetic difference inducing single amino acid replacement in a protein can be essential for adaptation to rising temperature, while adaptation is a challenge e.g. if a cold-water species has during evolution lost the genes needed for coping with rising temperature (Somero 2010).

As the cod spread out far away from the spawning grounds, a large cod stock can support substantial fisheries in the Bothnian Sea and Gulf of Finland while during times of low abundance cods are absent from these areas (e.g. Aro 2000). The cessation of reproduction in the northernmost reproduction areas due to unfavorable environmental conditions during the recent decades (Cardinale and Svedäng 2011) may influence the rate of dispersion of cod to the northern Baltic. Although the eastern Baltic cod stock has recently started to recover, after two decades of severe depletion, the stock has not re-occupied its former wide distribution range, but has so far mainly remained in a limited area in the southern Baltic Sea (Eero et al. 2012). The weight-at-age of cod has decreased dramatically during the last few years (Figure 1). It is remarkable that there have been changes in spatial distribution of key species as central Baltic herring and sprat abundance has gradually increased in the northern and decreased in the southern parts of the Main Basin (Eero et al. 2012). As fisheries compete with cod of the same prey stocks (herring and sprat), it is essential to consider the spatial overlap between species in developing ecosystem based fisheries management aiming at rebuilding predator stocks (Eero et al. 2012).

1.4 Fisheries and catches

The Baltic Sea has high fish production in respect to surface area and the fish stocks support substantial commercial and recreational fisheries (Figure 2). ICES (2012) has summarized the characteristics of the Baltic Sea fisheries:

“The main target species in commercial fishery are cod, herring and sprat. They constitute about 95% of the total catch. Other target fish species having either local economical importance or ecosystem importance are salmon, plaice, flounder, dab, brill, turbot, pike-perch, pike, perch, vendace, whitefish, burbot, eel and sea-trout.

The main fisheries for cod in the Baltic use demersal trawls, pelagic trawls and gillnets. The importance of longlines has increased in later years probably due to cheaper costs of vessels exploitation in that type of passive gear fishery and also due to maintained quality of the fish. In the cases where longlines are increasing it is in general at the expense of gillnet fishery. There was a substantial increase in gillnet fisheries in the 1990s and because of the change in stock age composition in late 1990’s and early 2000. During 2005 the use of passive gears has increased in relation to trawls, which is probably a reflection of the rising fuel prices.

The catches of the pelagic species are used for human consumption, reduction to oil and meal and to animal fodder. The allocation of the catches into these categories differs not only by country, but also over time. The usage is to a large extent driven by the market conditions.

While feeding in the sea, salmon are caught by long lines (as drift nets have been banned in the Baltic) and during the spawning run they are caught along the coast, mainly in trap nets and fixed gillnets. Where fisheries are allowed in the rivermouths, set gill nets and traps nets are used.

The coastal fishery targets a variety of species with a mixture of gears including fixed gears (e.g. gill, pound and trap nets, and weirs) and Danish seines. The main species exploited are herring, salmon, sea trout, flounder, turbot, cod and freshwater and migratory species (e.g. whitefish, perch, pikeperch, pike, smelt, vendace, eel and burbot). In addition, there are demersal trawling activities for herring, cod and flatfishes in some parts of the Baltic, although the trawling is forbidden in the coastal zone in most of the countries. Coastal fisheries are conducted along the entire Baltic coastline."

During the 20th century the catches from the Baltic Sea increased ca. 10 fold when more fish was left for the fisheries after extermination of marine mammal populations, the sea became more eutrophied due to anthropogenic nutrient release and fishing became more efficient (Elmgren 1989, Thurow 1997). However, as the estimated total landings by the ICES (International Council for the Exploration of the Sea) may not include all unreported landings, discards and recreational removals, the true removals of fish from the populations may have been at least 35% higher during 2000-2007 (Zeller et al. 2011).

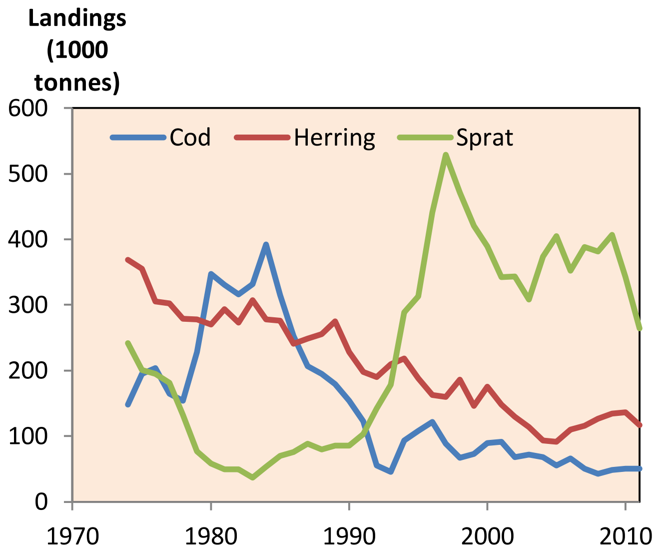

Figure 2: The landings of the central Baltic cod, herring and sprat during 1974–2011 (ICES 2012).

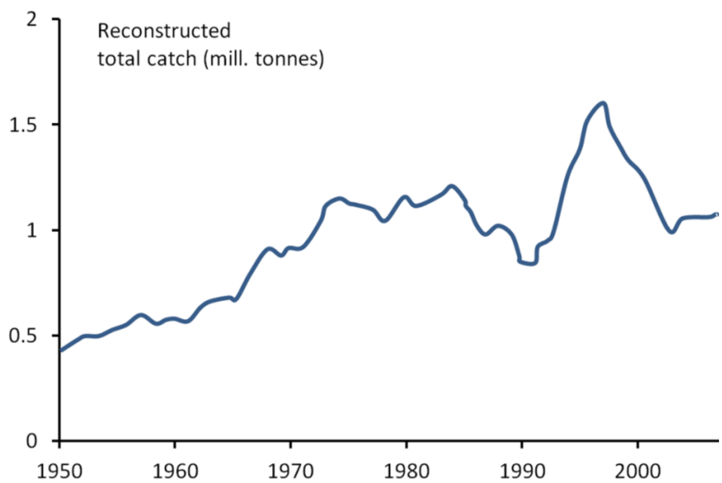

Figure 3: Reconstructed total catches (1950–2007) from the Baltic Sea in millions of tonnes (redrawn from Zeller et al. 2011).

Thus, the reconstructed removals increased from ca. 0.5 million tonnes in 1950's to ca. 1.6 million tonnes in 1997 in the Baltic Sea excluding Kattegat (Figure 3) but decreased to roughly 1.0 million tonnes in 2005–2007 as e.g. the abundance and catches of sprat decreased.

1.5 Fish stock assessment and advice to support management

Fish stock assessment is a fundamental element in fisheries management. Several monitoring programmes annually collect data on catches and fisheries in the Baltic Sea to be used in the assessment work, and also collect fishery-independent data on the stock dynamics of the most important marine fish stocks (e.g. ICES 2012). Such data sets have been collected during the past 2–4 decades, while more indirect calculation methods have been applied to derive fish biomass estimates in earlier decades (Elmgren 1989, Thurow 1997, Harvey et al. 2003, Alheit et al. 2005, Österblom et al. 2007). The assessments conducted and management advice considering the marine species can be found in ICES (2011, 2012). Salmon and trout are assessed in another expert group within the ICES.

1.6 Fisheries management

As the Baltic coastal states except Russia are members of the European Union, their fisheries are regulated by the EU which has a bilateral fisheries agreement with Russia. The EU member states have limited freedom to introduce national regulations except in inshore fisheries within the 12 nautical mile limit from the coastline.

The management of the Baltic Sea fisheries has been summarized as follows (Burns & Stöhr, 2011 and references therein).

“The EU countries agreed in 1983 on the Common Fisheries Policy (CFP). With about 2000 rules, it is one of the most comprehensive fisheries governance agreements world-wide regulating all aspects of fishing. In this governance system, the EU Council of Ministers is the highest decision-maker determining broad policy measures that are to be implemented by the member-state Fishing Ministries. The most important determination is the annual total allowable catches (TACs), which are distributed among the member states according to the “principle of relative stability”. The European Commission (more precisely, DG Maritime Affairs and Fisheries, DG MARE) prepares and proposes the regulations for the Council. The Council together with the EU Parliament are the main co-deciders of legislation and policy.

Although the regulatory power is concentrated at the EU level, the decisions are informed by several knowledge sources. The most important knowledge source for EU fisheries policy is the International Council for the Exploration of the Sea (ICES), an umbrella organization for the national research institutes, where the data collected on status and prognosis of fish stocks are organized and interpreted. Based on the data obtained and the application of the precautionary principle, ICES provides recommendations for policy measures of which the annual Total Allowable Catch (TAC) is the most important. In addition, the Commission established the Scientific, Technical and Economic Committee for Fisheries (STECF) in 1993 and renewed it in 2005. The Committee consists of scientists that provide advice on the current status of fisheries resources, their development and any consequent economic implications. The second source of information comes from stakeholders that, especially in the recent years, have gained greater opportunities to provide advice to the European Commission.”

In 2004 a new organization type, namely Regional Advisory Council (RAC), was established in EU fisheries management system by a Council Decision (2004/585/EC). The aim is to enhance to participation of fisheries and other sectors. RACs have a possibility to give recommendations and suggestions to the Commission. There are seven RACs. Five of them focus on specific geographical areas and two operate on highly mobile, long-distance fleets (EC 2012a).

Baltic Sea RAC was started in 2006. It has members from fishing sector ranging from fisheries organisations to processors and marketing. In addition, also environmental and consumer organizations have their representatives as well as recreational and sports fisheries. The Baltic Sea RAC has also a women's network. The RAC has three working groups: demersal fisheries, pelagic fisheries and a working group for salmon and trout fisheries (BSRAC 2012).

EU regulations comprise also technical regulatory measures, such as mesh sizes, minimum landing sizes, by-catch limitations and periods, and closed areas. In spite of some success, the CFP has not enabled optimal use of fish resources (http://ec.europa.eu/fisheries/reform/index_en.htm):

“Europe’s fisheries policy is in urgent need of reform. Vessels are catching more fish than can be safely reproduced, thus exhausting individual fish stocks and threatening the marine ecosystem. Today, three out of four stocks are overfished: 82% of Mediterranean stocks and 63% of Atlantic stocks. The fishing industry is experiencing smaller catches and facing an uncertain future. It is time to make fishing environmentally, economically, and socially sustainable.”

By bringing fish stocks back to sustainable levels, the new common fisheries policy (CFP) aims to provide EU citizens with a stable, secure and healthy food supply for the long term. It seeks to bring new prosperity to the fishing sector, end dependence on subsidies and create new opportunities for jobs and growth in coastal areas. At the same time, it fosters the industry’s accountability for good stewardship of the seas.

The reformed CFP will enter into force in 2013. The overall objective of the proposal is to ensure fishing and aquaculture activities that provide long-term sustainable environmental conditions and contribute to the availability of food supplies. The policy shall be aimed at exploitation of living marine biological resources that restores and maintains fish resources at levels which can produce the maximum sustainable yield, not later than 2015. The CFP shall implement the precautionary and ecosystem approaches to fisheries management.

In addition to annually set TACs, the EU has adopted multiannual management plans for specific fisheries. Nine multiannual management and recovery plans have been established for nine different fisheries (EC 2012b):

“Each multiannual plan is based on a harvest control rule that is tailor-made for the fishery in question. This is a simple mathematical formula which converts quantifiable scientific data into proposed catch and effort limits for the coming year. As a general rule, annual changes in TAC and effort should not exceed a certain percentage, except where stocks are under the most pressure. In this way, the plans also provide greater stability for the fishing industry and enable operators to plan ahead.”

In 2007 a multiannual plan for managing cod stock in the Baltic Sea was launched (Council Regulation (EC) No 1098/2007). Its aim is to reduce fishing mortality on a long period to set the set target. The multi-annual plan for cod is the only multi-annual plan in force in Baltic Sea so far, but a similar plan is being prepared for pelagic fisheries. The European Commission has also proposed a plan for the Baltic salmon.

2 Climate Pressure

Climatic variations induce changes in the environmental gradients across the Baltic Sea, e.g. in salinity, temperature, oxygen concentration and ocean acidification. Climate also influences the vertical stratification of the water column in respect to several environmental features. Due to climate change, the area covered with sea ice is expected to decrease which will influence the ecosystem in large areas (BACC 2008 and references therein). According to regional climate projections, air temperature over the Baltic Sea will increase by ca. 3°C during the 21st century, the largest changes predicted for the Gulf of Bothnia (Meier et al. 2012).

Climate is a driver inducing fluctuations in the salinity of the Baltic Sea. During the 20th century the mean salinity of the Baltic Sea was at its lowest, ca. 7.2, in 1930–1935, increased steadily from 1936 to 1954, remained at 7.9–8.2 during 1955–1979 and declined again to ca. 7.3 during 1980–1993

(Heino et al. 2008). Thus, the current low salinity period is not yet exceptional but the predicted changes for the next century are larger than any changes during the recent history of the Baltic Sea.

Both air temperature and sea surface temperature (SST) of the Baltic have already increased. Air temperatures increased by +0.08°C per decade during 1871–2004 (Heino et al. 2008). Sherman et al. (2009) found that SST had increased in 61 of the 63 Large Marine Ecosystems of the world during 1982–2006, and the most pronounced increase, 1.35°C, had occurred in the Baltic Sea. The exceptionally rapid warming of the Baltic Sea can apparently be explained by its northern location, strong influences from the surrounding continent, the small water volume and shallow mixed surface layer. Local long-term studies have confirmed that the summer SST has increased by at least 1°C during the past 50 to 60 years in the open sea of the northern (Rönkkönen et al. 2004) and southern Baltic (MacKenzie & Schiedek 2007). A more extensive review of expected climate driven changes in Baltic Sea hydrography is given in the Baltadapt Climate Info Bulletins (www.baltadapt.eu).

3 Environmental Consequences of Climate Change

3.1 Climate change is likely to influence the eutrophication

Eutrophication is apparently the foremost environmental problem in the Baltic Sea. To support the productivity of the key marine fish stocks, it is essential to improve the eutrophication status in the Baltic Sea by decreasing the anthropogenic nutrient release to the sea. The Baltic Sea Action Plan (BSAP) for ecosystem management and protection has defined management goals for the Baltic Sea (Helcom 2007).

Due to climate change, it will be necessary to increase the efforts to reduce nutrient loading even more than scheduled so far for example in the BSAP (Meier et al. 2012). Impacts of climate change on the eutrophication of the Baltic Sea have been highlighted in the Baltadapt Climate Info Bulletins (www.baltadapt.eu).

3.2 Climate change and biodiversity

As most species in the Baltic Sea live close to their tolerance limits in regard to one or more environmental factors, climate variations influence the distribution and productivity of species and the productivity of the fish stocks. During the ‘oceanization’ of the Baltic Sea in 1936–1954, various marine taxa such as certain copepods, jellyfish, barnacle, as well as cod, garfish and mackerel spread hundreds of kilometres northwards, whereas species preferring low saline waters retreated (Segerstråle 1969). During the recent desalination period (from 1980) a reverse process has taken place.

Climate change is likely to enable formerly subordinate species to increase and more alien species to become established. For example, both published and anecdotal information suggest that of the local fish species e.g. the three-spined stickleback may be increasing in the Baltic Sea as a consequence of intensive exploitation of predatory fish, eutrophication and climate change (Sieben et al. 2011, Candolin & Selin 2012). Increase of this species may induce chains of events inducing eutrophication in the coastal areas (Sieben et al. 2011) but as higher density in coastal areas promote invasion of stickleback to pelagic zone (Candolin & Selin 2012) they may increasingly compete for prey and feed on young herring, sprat and cod, and suppress production of these species.

Oceanographic variations influence the physiology of fish as well as the ecological fitness of fish via changing the ecosystem structure and function. Johannesson et al. have summarized the impacts of environmental changes on the Baltic Sea biota as follows:

“Environmental change challenges local and global survival of populations and species. In a species poor environment like the Baltic Sea this is particularly critical as major ecosystem functions may be upheld by single species. A complex interplay between demographic and genetic characteristics of species and populations determines risks of local extinction, chances of re-establishment of lost populations, and tolerance to environmental changes by evolution of new adaptations. Recent studies show that Baltic populations of dominant marine species are locally adapted, have lost genetic variation and are relatively isolated. In addition, some have evolved unusually high degrees of clonality and others are representatives of endemic (unique) evolutionary lineages. We suggest that a consequence of local adaptation, isolation and genetic endemism is an increased risk of failure in restoring extinct Baltic populations. Additionally, restricted availability of genetic variation owing to lost variation and isolation may negatively impact the potential for evolutionary rescue following environmental change.”

3.3 Climate change and ecosystem regime shifts

Ecosystems are at constant change. The changes can be gradual, but numerous studies have found and discussed step-like shifts in aquatic ecosystems. Regimes are considered as relatively stable states, during which e.g. gradual increase in temperature or nutrient loading has little effect but as a threshold is reached a large shift occurs that might be difficult to reverse (Scheffer & Carpenter 2003). It has been stated that the anthropogenic effects (nutrient and pollutant release, hunting of marine mammals, depletion of predatory fish) together with climate change have pushed the Baltic Sea ecosystem through a series of regime shifts during the 20th century (Österblom 2007, Möllmann et al. 2009). Alheit et al. (2005) emphasized that climatic forcing induced the remarkable shift in the ecosystem in late 1980's, which occurred simultaneously with a corresponding shift in the North Sea. As a consequence, phytoplankton biomass increased, growing season extended, abundance of copepods (that are essential food for key fish species) exhibited coherent changes in abundance with NAO (North Atlantic Oscillation) and increased the productivity of the sprat population (Alheit et al. 2005).

3.4 Climate changes and zooplankton production

Zooplankton is an essential link in the food chain between lower trophic levels and the fish populations in the open sea. Virtually all young fish feed on zooplankton and thus, variations in zooplankton community influence the nourishment of larval and young fish, and contribute to the year-class strength and to the productivity of the fish stocks. The pelagic food chain (in which zooplankton plays an essential role) has become more important for fish production in the open sea during the recent decades because hypoxia has e.g. decimated the energy pathways from the benthic fauna to cod in large deep water areas (Elmgren 1989, Tomczak et al. 2012).

Several studies have pointed out that climatic variations in the Baltic Sea and northern Atlantic area propagate through hydrography to productivity of zooplankton suitable for larval and older herring, sprat and cod. In particular, the decrease of the large copepod *Pseudocalanus* which live in the Baltic proper on the margin of distribution with respect to salinity is considered as a key factor controlling herring and cod stock dynamics (Hinrichsen et al. 2002, Möllmann et al. 2003, Rönkkönen et al. 2004). However, also abundant stocks of planktivorous fish can contribute to shifts in zooplankton community, which can lead to retarded growth and poor condition in planktivorous fish (Dippner et al. 2001, Möllmann et al. 2005, Casini et al. 2006, Casini et al. 2010). Another contemporary change in zooplankton has taken place as eutrophication and climate warming have contributed to the blooms of cyanobacteria which have diverted the energy pathways in the ecosystem in a way which does not support fish production (Karjalainen et al. 2007). Furthermore, climate warming may support invasion of alien species, such as the predatory warm-water-preferring *Cercopagis pengoi* waterflea which may add another level to the food chain especially in areas with low salinity, and thereby decrease fish production (Gorokhova et al. 2000, 2005).

4 Consequences of Climate Change on Fish Stocks

Climate change challenges local and global survival and productivity of marine populations and species, and endangers fisheries. In particular, multiple stresses on fish stocks e.g. climate change together with excessive exploitation can endanger survival of the unique fish populations adapted to the Baltic Sea. In the Baltic Sea, climate change is likely to have drastic consequences to the fish stocks and fisheries as changes will take place e.g. in salinity, temperature, oxygen content, acidification as well as in ecosystem function. Decreased salinity is likely to decrease marine fish reproduction, which is the most sensitive life cycle stage, while large fish can survive in lower salinities.

4.1 Climatic impacts on reproduction of fish

Cod

The climatic effects contributing to the reproduction of cod have been emphasized in several studies (Köster et al. 2005 and the references therein, McKenzie et al. 2005, 2007, Heikinheimo 2008, Eero et al. 2011). Cod is a marine species, but the eastern Baltic Sea cod in particular, is adapted to low salinity. The eggs are buoyant and can survive if the salinity is above 11 and oxygen concentration is above 2 ml/l (Wieland et al. 1994). These thresholds delimit the pelagic habitat suitable for cod reproduction which is also known as the reproductive volume (Wieland et al. 1994).

The conditions for cod reproduction depend on the frequency and magnitude of inflows of saline oxygen-rich North Sea water and precipitation and freshwater run-off from the drainage basin. The reproduction of cod is poor during periods without major inflows of saline oxygen-rich water (Nissling 2004). During these stagnant periods the decomposing sinking organic material depletes oxygen reserves in deep water. While the eastern Baltic cod historically spawned at three known locations: the Bornholm Deep, the Gdansk Deep and the Gotland Deep (Aro 1989), due to unfavourable environmental regime only the Bornholm Basin is known to serve as a spawning site in recent years (Cardinale and Svedäng 2011). Anyhow, so far cod reproduction has succeeded each year to some extent in spite of low abundance of spawning fish, unfavourable oceanographic conditions and high abundance of clupeid fish, sprat in particular which feed on the eggs and larvae of cod (e.g. Cardinale & Svedäng 2011, ICES 2012). Indeed, Heikinheimo (2008) has questioned the utility of the reproductive volume concept, because she found that variations in salinity together with the spawning stock abundance better explained the eastern Baltic cod year-class strength.

The long term projections for the salinity, temperature and oxygen concentration (Meier et al. 2012) suggest that the cod reproduction area may slightly decrease towards the 22nd century even if nutrient loading would decrease. However, there was relatively large variation among models, and e.g. the expected increase in agricultural nutrient load may increase nutrient loads to the sea and bring about unwanted changes in water quality (Meier et al. 2012).

So far excessive fishing has been a major force to delimit cod production in the Baltic Sea. In spite of the relatively poor conditions for the reproduction during the last two decades of the 20th century, lower fishing pressure on cod would have enabled a rapid increase in cod biomass (e.g. Heikinheimo 2008). However, inefficiency in fisheries management and illegal fishing enabled too large catches in respect to the productivity of the cod stock, whereby the spawning stock was on a low level during two decades since the late 1980's (Cardinale & Svedäng 2011, ICES 2012). Ultimately, in 2005–2010 the fishing mortality in the Eastern Baltic cod (dwelling in the areas to the east of Bornholm Island) decreased drastically as a consequence of new fisheries management methods, and a rapid increase in the cod spawning stock biomass is taking place even in the current 'cod hostile' environment which indicates the fundamental impact of fishing on the Baltic Sea fish stocks (Cardinale & Svedäng 2011, Eero et al. 2012) and highlights the need for adaptive fisheries management in the case of multiple stressors affecting the fish stocks.

Sprat

Sprat eggs are buoyant in salinities above 6 (Parmanne et al. 1994). Thus, they float higher than cod eggs and are not as much exposed to hypoxia. Although the spawning areas of sprat and cod overlap, sprat is able to utilize larger areas for spawning (Köster et al. 2003). From these areas sprat spread to large areas up to the Bothnian Sea and Gulf of Finland where they substantially contribute to the catches (e.g. ICES 2012). However, the sprat larvae are often exposed to temperatures below 5°C which is a temperature below which the mortality of larvae increases (Nissling 2004). The variations in reproduction success have induced large fluctuations in sprat stock density and in catches (Köster et al. 2003, Nissling 2004) although predation mortality by cod and fishing pressure also influence the spawning stock biomass (ICES 2012).

While the rising trend in water temperatures due to climate change apparently favors high sprat abundance (MacKenzie & Köster 2004, MacKenzie et al. 2007), lower salinity causes an adverse impact. Anyhow, for example the projected salinities during 2070–2100 (Graham et al. 2008, Meier et al. 2012) would imply that salinity is likely to be high enough e.g. in the Gotland deep area to enable sprat reproduction. However, it is likely that the area suitable for the reproduction of sprat will diminish from its eastern and northern parts (MacKenzie et al. 2007).

Herring

The distribution of herring encompasses virtually the whole Baltic Sea and the spawning of herring takes place in coastal areas of all major basins (Parmanne et al. 1994). Although high temperatures have been considered to support herring recruitment (MacKenzie et al. 2007 and references therein), coastal eutrophication due to excessive anthropogenic nutrient loads and increasing temperatures is likely to decrease the areas suitable for reproduction of spring spawning herring. The autumn spawning herring – which in the past was important but had greatly decreased already by early 1970's – spawns in deeper water (Parmanne et al. 1994), but also in these areas increasing eutrophication and coastal hypoxia may have decreased reproductive success.

4.2 Climate change and other key processes influencing the fish stocks in the central Baltic Sea

Both anthropogenic impacts and interactions between species are of prime importance for the Baltic Sea fish stocks. In fisheries management it is essential to understand the tight interaction between cod, herring and sprat and how these interactions are modified by climate change (Figure 4).

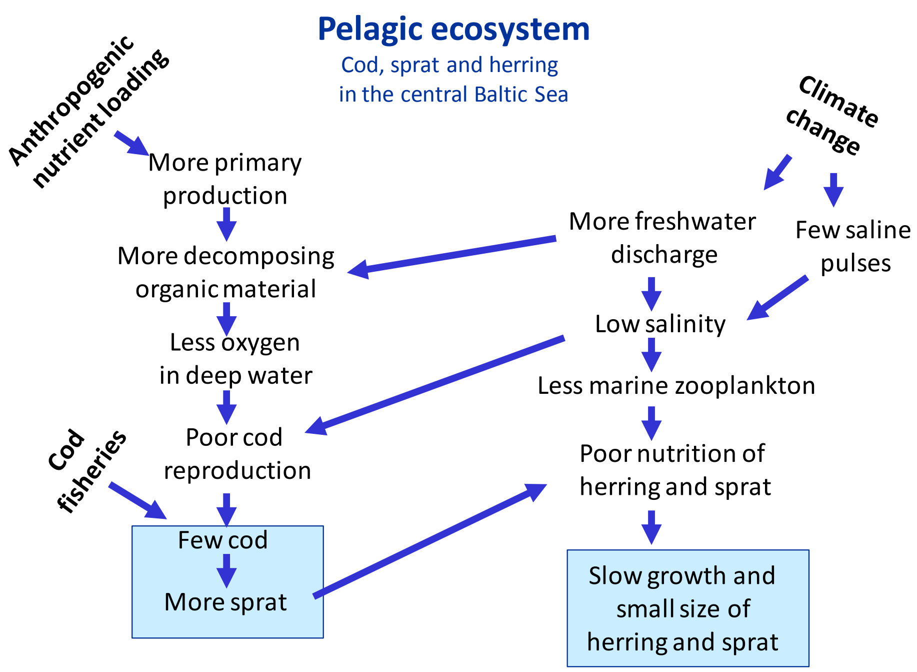

Figure 4: Key processes to influence the fish stocks in the central Baltic Sea.

Herring and sprat constitute a major part of the diet of large cod and e.g. in the early 1980's the predation by cod strongly contributed to the dynamics of sprat especially because cod was abundant and sprat stock on a low level (e.g. ICES 2012). Also the predation on young herring peaked in the early 1980's when cod abundance was on the highest level (ICES 2012). Herring and sprat are the major constituents of the diet of large cod, but sprat and herring feed on the pelagic eggs of cod and thereby delimit the stock size of cod (Köster and Schnack 1994, Köster and Möllmann 2000). Because of such interactions among species, the Baltic open sea fish community has a tendency to shift between cod-dominated and clupeid (sprat and herring)-dominated states, though fishing and climate-driven oceanographic variations can contribute to the shifts between cod-dominated and clupeid-dominated states (Rudstam et al. 1994, Nissling 2004, Österblom et al. 2007, Heikinheimo 2011).

4.3 Dynamics, management and ecosystem services of cod in a changing climate

During ca. 20 years from the late 1980's until early 21st century, fishing on cod in the Baltic Sea was excessive considering the relatively unfavourable climatic and oceanographic regimes in cod reproduction (e.g. Cardinale & Svedäng 2011, ICES 2012). Larger catches of cod would have been taken with lower fishing intensity or by catching older specimens, and the recruitment would have been higher if the spawning stock would have been larger. However, a larger cod stock would suppress the abundance of herring and sprat. Total catches of sprat, herring and cod could decrease if cod would recover. However, the predators such as cod also feed on prey species which are not utilized by fisheries (Pauly et al. 1998, 2002) and some predation mortality can even be considered beneficial for the prey species, for ecosystem function and even for the fishing industries. In the Baltic Sea more predation on herring could increase herring weight-at-age as cod selectively feed on smaller individuals from each age-groups (e.g. Beyer & Lassen 1994). Additionally, higher mortality on herring and sprat would also alleviate the competition for food and thus increase the growth rate of herring (Peltonen et al. 2007). Larger herring would e.g. support fishing industries by providing larger fish for processing (Stephenson et al. 2001).

The risks associated with excessive fishing mortality also include unwanted genetic changes in harvested populations (e.g. Kuparinen & Merilä 2008). Another disadvantage of removing the top-predators such as cod from a food web is the increased likelihood of outbursts of unwanted species (Pauly et al. 2002) whereas an abundant cod stock might control the increase of alien species and the production from such species would add to the nourishment of the cod stock.

Above all, a low exploitation rate serves as quarantine against the risk of collapse or even extinction of a heavily exploited species or population (Roberts & Hawkins 1999, Musick et al. 2000). A population which is heavily exploited already when the specimens are young consists of only few age-groups. Poor recruitment due to unfavourable environmental conditions during several successive years can decimate such populations. Decreasing the exploitation rates can be considered as a sound strategy to follow when seeking to build capacity against the adverse effects of climatic variations and climate change. In the Baltic Sea there is not any other fish species capable to fill in the ecological niche presently occupied by cod and to support equally valuable catches.

Optimization of cod fisheries would not just ensure maintaining steady biomass and high level in annual cod catches even if environmental variations occur but also help to resolve the problems arising from the high concentrations of persistent pollutants such as dioxins and PCBs in the Baltic Sea fish (Kiljunen et al. 2007, Peltonen et al. 2007). Currently, the Baltic Sea ecosystem is severely contaminated by organic toxic substances such as PCBs and dioxins. In fatty fish such as salmon and herring the concentrations especially in the central and northern Baltic often exceed the limits set by EU for foodstuffs (Bignert et al. 2007, Karl and Ruoff 2007, Vuorinen et al. 2012). Higher predation mortality in herring and sprat would decrease the fraction of very old individuals having the highest concentrations of toxic substances. Besides, some predation on these fish stocks could also decrease their completion of food resources (e.g. zooplankton), increase growth rate, induce higher rate of growth dilution of persistent pollutants (as fish eat less per unit of weight increase and that way acquire less such substances) and decrease concentrations of these contaminants in fish (Kiljunen et al. 2007, Peltonen et al. 2007). Apparently, predation by cod would be more efficient than fishing to enhance the growth rates of herring and sprat and to decrease the concentrations of persistent pollutants in fish (Peltonen et al. 2007).

Cod supports the most valuable fisheries in the Baltic Sea, it is a key species in the ecosystem, and it supports numerous ecosystem services. But it is also the most susceptible of the key species to the effects of climate change. As the shifts in the vital environmental constraints have not yet prevented reproduction of cod, we do not yet know how close the total failure of reproduction has been. The cod stock must not be exploited efficiently especially during the periods of poor recruitment and the management model parameters derived in good environment cannot be applied in altered environment (Köster et al. 2009, Lindegren et al. 2010, Eero et al. 2011). The management must ensure that a wide age and size spectrum in the population will enable survival of the cod stocks even though climate change together with other environmental stressors would cause exceptionally poor reproduction in one year or even in several successive years. Exceptionally small year classes of cod are more likely to occur in future, because in addition to the impacts of climate change, other anthropogenic pressures on marine life are also continuously increasing.

While cod may control the abundance of prey fish, the cod stock on the other hand supports nutrition for the increasing number of seals. Anyhow, MacKenzie et al. (2011) consider that dual management objectives (recovery of both seal and cod populations) are realistic but success in achieving these goals will also depend on how climate change affects cod recruitment.

5 Adaptation Measures

The fishing in the Baltic Sea is a diverse trade, the operational environment of which is constantly changing. Fisheries have always needed to adapt as changes have taken place in fish resources, technologies, regulation of fishing, demand of fish, costs of fishing etc. These factors together with the pace and magnitude of the climate-induced changes determine if and how well the fish stocks and fisheries will be able to adapt.

There are few major fish stocks in the Baltic Sea, but they constitute renewable natural resources which have enabled maintaining major fisheries for hundreds of years. Although, the current share of fishing is relatively small in the economies in any of the riparian countries around the Baltic Sea, it is likely that also in future there will be demand of fish, especially as the worldwide demand of food and raw material is rapidly increasing.

It is inevitable that fishing can only continue if there is a sound resource base i.e. productive fish stocks available. During the recent decades the exploitation of the Baltic Sea fish resources has been excessive leading to loss of profit and to damage to the fish stocks and to the marine environment. An improved status of fish stocks can be achieved through environmental management (protection, sustainable use and restoration) and through fisheries management.

The severe and increasing anthropogenic environmental stress on the Baltic Sea calls for a holistic view so that the impacts of an individual sector of human activity (such as marine transport, construction, excavation, release of substances, fishing etc.) are not evaluated in isolation from the other activities. Thus, the management of the living resources of the Baltic Sea should rely on the principles of the ecosystem approach i.e. of the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. It remains to be seen if the reform of the common fisheries policy or the management of marine environment relying largely on EU regulation will be influential. Österblom et al. (2010) discuss how the ecosystem approach could be made operational in the Baltic Sea concluding that emphasis on multilevel governance structures that provide space for experimenting and spread of social innovations at local and regional scales can provide key elements for stimulating an adaptive capacity for dealing with this dynamic ecosystem and the services generated.

Reliable data is needed to support assessment and management of the marine ecosystem and the fisheries. For example, as there may be substantial biases in the catch statistics, the total catch estimates should also include unreported landings, discards and recreational catches (e.g. Zeller et al. 2011) as well as unobserved fishing mortality (mortality of fish due to encounter with fishing gear, e.g. Rahikainen et al. (2004)). However, the needs for the quality of the monitoring and the modeling of the marine environment and the fish stocks depend on the level of exploitation. If fish stocks are intensively exploited, intensive monitoring and reliable modeling are needed to support management that will avoid excessive exploitation and collapses of populations. If the marine environment will be more variable due to climate change, more monitoring efforts would be needed in future. However, the costs of observing fisheries are large as there are many small fleets. The resources that will be allocated on monitoring also depend e.g. on the valuation – i.e. are other ecosystem services relying on the fish stocks and on a healthy ecosystem considered or just the commercial value of the catches?

According to the Commission proposal for a new CFP regulation, multiannual approach in management of all stocks will become a rule, not an exception. In comparison to time scales relevant in climate change dynamics the multiannual plans still have a short-term perspective and thus are not a tool for adaptation as such. The CFP regulations are usually set for 10 year periods, which is also a rather short time in comparison to climate change dynamics. However, the idea of long-term thinking could be incorporated into EU fisheries policy development. A possible method is so called 'adaptation tipping points' approach. A tipping point is a situation when changes caused by climate change reach a magnitude when the existing management strategy will not anymore meet the agreed objectives. In such a situation a policy may fail and new one is needed (Kwadijk et al. 2010). Identification and characterization of such tipping points or triggers as "warning signs" could help fisheries management to take into account possible climate change impacts.

6 Knowledge Gaps

Although much is known about the dynamics of the principal marine fish species and about the processes that have shaped the fish stocks, uncertainties are substantial in forecasting the dynamics of the ecosystem and the fish species. In particular, it is challenging to forecast the influences of simultaneous changes in several forcing factors. It is evident that each species should not anymore be examined in isolation from other species and from the environment, especially as a fish population collapse can release unforeseen ecological processes on other ecosystem levels. So far few efforts have been made to include the impacts of fish and fisheries in models on ecosystem dynamics. Anyhow, ecosystem modeling is needed to assess the human impacts on fish populations and to assess the potential value arising from a healthier ecosystem and from productive fish populations. Ecosystem services and non-monetary values which fish stocks support are poorly known although they may be much more important than the economic value of commercial catches.

There are uncertainties as regards population structures of many Baltic Sea fish stocks as they may consist of sub-populations which mix on the feeding grounds. It is unlikely that immigrants from other populations (e.g. from the North Sea) would be able to substitute the original ones and moreover, collapses of original populations and species may facilitate immigration of unwanted alien species.

It is a challenge to forecast the marine ecosystem dynamics though high quality work is being conducted around the Baltic Sea. Fish stocks are dependent on the production on lower trophic levels. But will the food webs in the Baltic Sea support energy to higher trophic levels or will the function of the food webs change so that pathways of energy will be diverged away from fish production? Will there be more harmful algal blooms, diseases and species competing about the same resources with fish?

It is widely agreed that fishing should not cause damage to fish stocks, to non-target species or to marine environment. But the adaptation of fisheries depends on many other aspects than fish resources including e.g. socio-economic issues. These may be even more challenging to predict than dynamics of fish stocks. Management has to find out how much fish could be caught and how much to leave in the sea so as not to endanger future catches and to ensure ecosystem function. And how to manage in a socially and economically reasonable way – e.g. how to find a balance between nations or fleets and between commercial, recreational and artisanal fishing? And how much to weight the expected long term productivity compared to the short term gains?

7 Summary and Conclusions

The Baltic Sea is a productive ecosystem but several aspects make the ecosystem and the species of the Baltic Sea and the fisheries particularly vulnerable for climate change. Fish stocks are impacted as the Baltic Sea is experiencing a larger rate of temperature elevation than any other large marine ecosystem. Changes are occurring in hydrography, in saline water pulses from the North Sea to the Baltic Sea, in freshwater run-off, in loads of substances to the sea and in the biogeochemical processes and pathways of substances in the sea. Concomitantly with the climate change, the Baltic Sea is facing increasing anthropogenic stress due to a multitude of other human activities (even if some positive changes have taken place, especially recovery of some species once heavily reduced due to chemical pollution).

A cornerstone for the management of renewable natural resources is that the exploitation must not deplete the resource beyond recovery. In the Baltic Sea fisheries this is a very relevant aspect considering that re-colonization from adjacent areas is unlikely if current populations from the Baltic Sea disappear. Species adapted for the local environment are unlikely to be re-established if once lost from the Baltic Sea. The Baltic Sea has restricted connections with possible donor areas of marine species which may hinder re-colonization if local populations became extinct, while established populations are not able to "escape" climate change by shifting their distribution ranges northwards. Due to isolation from other populations, the species have lost genetic variation, which may prevent their evolutionary rescue from climate change. The steep vertical and horizontal environmental gradients and seasonal variations challenge survival of species and delimit re-colonization as virtually all species live close to their environmental tolerance range in respect to one or more environmental factors. As the Baltic Sea is a species-poor ecosystem where major ecosystem functions are upheld by single or a few species, disappearance of such a species could lead to a major reorganization of the ecosystem with unforeseen and very likely unwanted consequences.

While many local populations suffer from climate change, invasions of alien species may increase, but the impacts of such species for ecosystem function and for fisheries are very difficult to forecast.

Climate change is inducing a multitude of shifts in the Baltic Sea which influence the fish stocks and fisheries. Fisheries management should promote sustainability in fisheries better than in the past, i.e. manage the fisheries considering the impacts of climate change and concomitant increasing exploitation of the Baltic Sea for various purposes. Ecosystem approach should cover human actions so that the resilience of the Baltic ecosystem towards unwanted shifts could be rebuilt. The roles of fish in the ecosystems should be better understood to e.g. find out how fisheries influence the whole ecosystem and if fisheries management could support mitigation of the anthropogenic effects on the sea, including the effects of climate change.

References

Alheit, J., Möllmann, C., Dutz, J., Kornilovs, G., Loewe, P., Mohrholz, V. and Wasmund, N. (2005): Synchronous ecological regime shifts in the central Baltic and the North Sea in the late 1980s. ICES J. Mar. Sci. (62):1205–1215.

Andre, C., Larsson, L.C., Laikre, L., Bekkevold, D., Brigham, J., Carvalho, G.R., Dahlgren, T.G., Hutchinson, W.F., Mariani, S., Mudde, K., Ruzzante, D.E., and Ryman, N. (2011): Detecting population structure in a high gene-flow species, Atlantic herring (Clupea harengus): direct, simultaneous evaluation of neutral vs putatively selected loci. Heredity 106: 270–280.

Aro, E., (1989): A review of fish migration patterns in the Baltic. — Rapp.P.-v. Réun. Cons. int. Explor. Mer. 190: 72-96.

Aro, E. (2000): The spatial and temporal distribution patterns of cod (Gadus morhua callarias L.) in the Baltic Sea and their dependency on environmental variability – implications for fishery management. Ph.D. thesis. Department of Ecology and Systematics. University of Helsinki.

Beyer, J.E. and Lassen, H. (1994): The effects of size-selective mortality on the size-at-age of Baltic herring. Dana 10: 203-234.

Bignert A, Nyberg E, Sundqvist KL, Wiberg K. (2007): Spatial variation in concentrations and patterns of the PCDD/F and dioxin-like-PCB content in herring from the northern Baltic Sea. Journal of Environmental Monitoring 9:550-556.

Boeuf, G. and Payan, P. (2001): How should salinity influence fish growth? Comparative Biochemistry and Physiology Part C 130: 411-423.

BSRAC 2012. Baltic Sea Regional Advisory Council. (website accessed September 21, 2012, URL: http://www.bsrac.org/ooizzCMS/DA/home)

Burns, T.R. and Stöhr, C. (2011): Power, knowledge, and conflict in the shaping of commons governance. The case of EU Baltic fisheries. International Journal of the Commons 5, No 2 (2011). 13 pp.

Candolin, U. and Selin, M. (2012): Density-dependent habitat selection in a growing threespine stickleback population. International Journal of Zoology, Volume 2012, Article ID 378913, 6 pp. doi:10.1155/2012/378913

Cardinale, M., and Arrhenius, F. (2000): Decreasing weight-at-age of Atlantic herring (Clupea harengus) from the Baltic Sea between 1986 and 1996: a statistical analysis. – ICES Journal of Marine Science, 57: 882–893.

Cardinale, M. and Svedäng, H. (2011): The beauty of simplicity in science: Baltic cod stock improves rapidly in a ‘cod hostile’ ecosystem state. Marine Ecology Progress Series 425: 297–301.

Casini, M., Cardinale, M. and Hjelm, J. (2006): Inter-annual variation in herring, Clupea harengus, and sprat, Sprattus sprattus, condition in the central Baltic Sea: what gives the tune? Oikos 112: 638-650.

Casini, M., Bartolino, V., Molinero, J.C. and Kornilovs, G. (2010): Linking fisheries, trophic interactions and climate: threshold dynamics drive herring Clupea harengus growth in the central Baltic Sea. Marine Ecology Progress Series 413: 241–252.

Dippner, J. W., Hänninen, J., Kuosa, H., and Vuorinen, I. (2001): The influence of climate variability on zooplankton abundance in the Northern Baltic Archipelago Sea (SW Finland). – ICES Journal of Marine Science, 58: 569–578.

EC 2012a. Regional Advisory Councils. European Commission. (web site accessed September 21, 2012, URL: http://ec.europa.eu/fisheries/partners/regional_advisory_councils/index_en.htm)

EC 2012b. Multi-annual plans. European Commission. (website accessed September 21, 2012, URL:http://ec.europa.eu/fisheries/cfp/fishing_rules/multi_annual_plans/index_en.htm)

Eero, M., MacKenzie, B.R., Köster, F.W., and Gislason, H. (2011): Multi-decadal responses of a cod (Gadus morhua) population to human-induced trophic changes, fishing, and climate. Ecological Applications, 21: 214–226.

Eero, M., Vinther, M, Haslob, H., Huwer, B., Casini, M., Storr-Paulsen, M., Koster, F.W. (2012): Spatial management of marine resources can enhance the recovery of predators and avoid local depletion of forage fish. Conservation Letters 0: 1–7.

Elmgren, R. (1989): Man's impact on the ecosystem of the Baltic Sea: Energy flows today and at the turn of the century. Ambio 18: 326-332.

Flinkman, J., Aro, E., Vuorinen, I., and Viitasalo, M. (1998): Changes in northern Baltic zooplankton and herring nutrition from 1980s to 1990s: top-down and bottom-up processes at work. Mar. Ecol. Prog. Ser. 165: 127–136.

Gorokhova, E., Aladin, N. and Dumont, H.J. (2000): Further expansion of the genus Cercopagis (Crustacea, Branchiopoda, Onychopoda) in the Baltic Sea, with notes on the taxa present and their ecology. Hydrobiologia 429: 207–218, 2000.

Gorokhova, E., Hansson, S., Höglander, H., Andersen, C.M. (2005): Stable isotopes show food web changes after invasion by the predatory cladoceran Cercopagis pengoi in a Baltic Sea bay. Oecologia 143: 251–259.

Graham et al. (2008): Projections of future anthropogenic climate change. In.: BACC Author Team: Assessment of climate change for the Baltic Sea Basin. Springer Verlag Berlin Heidelberg. P. 133-219

Harvey, C. J., Cox, S. P., Essington, T. E., Hansson, S., and Kitchell, J. F. (2003): An ecosystem model of food web and fisheries interactions in the Baltic Sea. – ICES Journal of Marine Science, 60: 939–950.

Heikinheimo, O. (2008): Average salinity as an index of environmental forcing on cod recruitment in the Baltic Sea. Boreal Environment Research 13: 457-464.

Heikinheimo, O. (2011): Interactions between cod, herring and sprat in the changing environment of the Baltic Sea: A dynamic model analysis. Ecological Modelling 222: 1731–1742.

Heino, R., Tuomenvirta, H., Vuglinsky, V.S. et al. (2008): Past and Current climate change. In.: BACC Author Team (2008) Assessment of Climate Change for the Baltic Sea Basin. Springer-Verlag, Berlin and Heidelberg, pp. 35-131.

HELCOM (2012): Checklist for Baltic Sea Fish and Lamprey Species. In: Checklist of Baltic Sea Macro-species. Baltic Sea Environment Proceedings No. 130. pp. 196-199.

HELCOM, (2007): HELCOM Baltic Sea Action Plan. HELCOM Ministerial meeting, Krakow, Poland 15th November 2007. 102 p.

Hiddink, J.G. and Coleby, C. (2011): What is the effect of climate change on marine fish biodiversity in an area of low connectivity, the Baltic Sea? Global Ecology and Biogeography, 21: 637–646.

Hinrichsen, H-H., Möllmann, C., Voss, R., Köster, F.W., Kornilovs, G. (2002): Biophysical modeling of larval Baltic cod (Gadus morhua) growth and survival. Canadian Journal of Fisheries and Aquatic Sciences, 59, 1858–1873.

ICES (2011): Report of the ICES Advisory Committee, 2011: Book8, Baltic Sea. 134 p.

ICES (2012): Report of the Baltic Fisheries Assessment Working Group (WGBFAS). ICES Advisory Committee ICES CM 2012/ACOM: 10. 853 p.

Johannesson, K., Smolarz, K., Grahn, M., and Andre, C. (2011): The Future of Baltic Sea Populations: Local Extinction or Evolutionary Rescue? AMBIO (2011) 40:179–190. DOI 10.1007/s13280-010-0129-x

Jørgensen, H.B. Hansen, M.M., Bekkevold, D., Ruzzante, D.E. and Loeschcke, V. (2005a): Marine landscapes and population genetic structure of herring (Clupea harengus L.) in the Baltic Sea. Molecular Ecology 14: 3219–3234.

Jørgensen, H. B. H., Hansen, M. M., and Loeschcke, V. (2005b): Spring-spawning herring (Clupea harengus L.) in the southwestern Baltic Sea: do they form genetically distinct spawning waves? ICES Journal of Marine Science, 62: 1065-1075.

Karjalainen, M., Engström-Öst, J., Korpinen, S., Peltonen, H., Pääkkönen, J.-P., Rönkkönen, S., Suikkanen, and Viitasalo, M. (2007): Ecosystem consequences of cyanobacteria in the northern Baltic Sea. Ambio 36(2-3): 195-202.

Karl, H. and Ruoff, U. (2007): Dioxins, dioxin-like PCBs and chloroorganic contaminants in herring, Clupea harengus, from different fishing grounds of the Baltic Sea. Chemosphere 67: 90–95

Kiljunen, M., Vanhatalo, M., Mäntyniemi, S., Peltonen, H., Kuikka, S., Kiviranta, H., Parmanne, R., Tuomisto, J.T., Vuorinen, P.J., Hallikainen, A., Verta, M., Pönni, J., Jones R.I. and Karjalainen, J. (2007): Human dietary intake of organochlorines from Baltic herring: Implications of individual fish variability and fisheries management. Ambio 36(2-3): 257–264.

Knutsen, H., Olsen, E.M., Jorde, P.E., Espeland, S. H., André, C. and Stenseth, N. C. (2011): Are low but statistically significant levels of genetic differentiation in marine fishes 'biologically meaningful'? A case study of coastal Atlantic cod. Molecular Ecology 20, 768–783.

Kuparinen, A. and Merilä, J. (2008): Detecting and managing fisheries induced evolution. TRENDS in Ecology and Evolution 22: 652-659.

Kwadijk, J.C.J., M. Haasnoot, J.P. M. Mulder, M.M.C. Hoogvliet, A.B.M. Jeuken, R.A.A. van der Krogt, N.G.C. van Oostrom, H. A. Schelfhout, E. H. van Velzen, H. van Waveren and M. J. M. de Wit (2010): Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. Wiley Interdisciplinary Reviews: Climate Change 1(5): 729-740.

Köster, F.W., and Möllmann, C. (2000): Trophodynamic control by clupeid predators on recruitment success in Baltic cod? ICES Journal of Marine Science, 57: 310–323.

Köster, F.W. and Schnack, D. (1994): The role of predation on early life stages of cod in the Baltic. Dana, 10: 179-201.

Köster, F.W., Hinrichsen, H-H., Schnack, D. et al. (2003): Recruitment of Baltic cod and sprat stocks: identification of critical life stages and incorporation of environmental variability into stock-recruitment relationships. Scientia Marina, 67 (Suppl. 1), 129–154.

Köster, F.W., Vinther, M., MacKenzie, B.R., Eero, M., and Pliksh, M. (2009): Environmental effects on recruitment and implications for biological reference points of Eastern Baltic Cod (Gadus morhua). J. Northw. Atl. Fish. Sci., 41: 205–220. doi:10.2960/J.v41.m636

Lindegren, M., Möllmann, C., Nielsen, A., Brander, K., MacKenzie, B.R., and Stenseth, N.C. (2010): Ecological forecasting under climate change: the case of Baltic cod. Proc. R. Soc. B, 277: 2121–213.

MacKenzie, B., Eero, M. and Ojaveer, H. (2011): Could seals prevent cod recovery in the Baltic Sea? PLoS ONE 6 (5) e18998. www.plosone.org

MacKenzie, B.R., Gislason, H., Möllmann, C. and Köster, F.W. (2007): Impact of 21st century climate change on the Baltic Sea fish community and fisheries. Global Change Biology 13: 1348–1367.

MacKenzie, B. and Köster, F. (2004): Fish production and climate: sprat in the Baltic Sea. Ecology, 85: 784–794.

MacKenzie, B.R. and Schiedek, D. (2007): Daily ocean monitoring since the 1860s shows record warming of northern European seas. Global Change Biology (2007) 13, 1335–1347, doi: 10.1111/j.1365-2486.2007.01360.x

MacKenzie, B.R., St.John, M.A, Schnack, D., Rohlf, N., Linkowski, T., Beyer, J.E. (2005): Baltic cod recruitment – the impact of climate variability on key processes. ICES Journal of Marine Science 62: 1408–1425.

Mariani, S., Hutchinson, W.F., Hatfield, E.M.C., Ruzzante, D. E., Simmonds, E.J., Dahlgren, T.G., Andre, C., Brigham, J., Torstensen, Else, Carvalho, G.R. (2005): North Sea herring population structure revealed by microsatellite analysis. Marine Ecology Progress Series. 303: 245–257.

McPherson, A.A. Stephenson, R.L., Taggart, C.T. (2003): Genetically different Atlantic herring Clupea harengus spawning waves. Marine Ecology Progress Series. 247: 303–309.

McQuinn, I.H. (1997): Metapopulations and the Atlantic herring. Reviews in Fish Biology and Fisheries 7: 297-329.

Meier, H. E. M., Hordoir, R., Andersson, H.C., Dieterich, C., Eilola, K., Gustafsson, B.G., Höglund, A., and Schimanke, S. (2012): Modeling the combined impact of changing climate and changing nutrient loads on the Baltic Sea environment in an ensemble of transient simulations for 1961–2099. Clim Dyn DOI 10.1007/s00382-012-1339-7

Musick, J.A, Harbin, M.M., et al. (2000): Marine, Estuarine, and Diadromous Fish Stocks at Risk of Extinction in North America (Exclusive of Pacific Salmonids). Fisheries 25(11): 6-30

Möllmann, C., Kornilovs, G., Fetter, M., and Köster, F. W. (2005): Climate, zooplankton, and pelagic fish growth in the central Baltic Sea. ICES Journal of Marine Science, 62: 1270-1280.

Möllmann, C. et al. (2009): Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: a discontinuous regime shift in the Central Baltic Sea. Global Change Biology 15: 1377–1393.

Möllmann et al. (2003): The marine copepod, Pseudocalanus elongatus, as a mediator between climate variability and fisheries in the Central Baltic Sea. Fish. Oceanogr. 12:4, 1–9.

Nielsen, E.E., Hansen, M.M., Ruzzante, D.E., Meldrup, D., and Grønkjær, P. (2003): Evidence of a hybrid-zone in Atlantic cod (Gadus morhua) in the Baltic and the Danish Belt Sea revealed by individual admixture analysis. Molecular Ecology 12: 1497–1508.

Nissling, A. (2004): Effects of temperature on egg and larval survival of cod (Gadus morhua) and sprat (Sprattus sprattus) in the Baltic Sea – implications for stock development. Hydrobiologia 514: 115–123.

Ojaveer, E., and Kalejs, M. (2005): The impact of climate change on the adaptation of marine fish in the Baltic Sea. ICES Journal of Marine Science, 62: 1492-1500.

Ojaveer, H., Jaanus, A., MacKenzie, B.R., Martin, G., Olenin, S., et al. (2010): Status of biodiversity in the Baltic Sea. PLoS ONE 5(9): e12467. doi:10.1371/journal.pone.0012467

Parmanne, R., Rechlin, O. and Sjöstrand, B (1994): Status and future of herring and sprat stocks in the Baltic Sea. Dana 10: 29–59.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. and Torres, F. (1998): Fishing down marine food webs. Science 279: 860-863.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R. and Zeller, D. (2002): Towards sustainability in world fisheries. Nature 418: 689-695.

Peck, M.A. et al. (2012): The ecophysiology of Sprattus sprattus in the Baltic and North Seas. Progress in Oceanography 103: 42–57.

Peltonen, H., Kiljunen, M., Kiviranta, H, Vuorinen, P.J., Verta, M. and Karjalainen, J. (2007): Predicting effects of exploitation rate on weight-at-age, population dynamics and bioaccumulation of PCDD/Fs and PCBs in herring (Clupea harengus L.) in the northern Baltic Sea. Environmental Science and Technology, 41: 1849-1855.

Rahikainen, M., Peltonen, H. and Pönni, J. (2004): Unaccounted mortality in northern Baltic Sea herring fishery – magnitude and effects on estimates of stock dynamics. Fisheries Research. 67: 111-127.

Raid, T. (1998): Herring in the North-Eastern Baltic Sea in the 1970-1990s: ecology stock structure and fishery. PhD Thesis. University of Helsinki and Estonian Marine Reseach Institute. 56 p.

Roberts, C.M. and Hawkins, J.P. (1999): Extinction risk in the sea. TREE 14: 241-246.

Rudstam, L.G., Aneer, G., and Hilden, M. (1994): Top-down control in the pelagic Baltic ecosystem. DANA 10: 105-130.

Ryman, .N, Lagercrantz, U., Andersson, L., Chakraborty, R. and Rosenberg, R. (1984): Lack of correspondence between genetic and morphologic variability patterns in Atlantic herring. Heredity 53: 687–704.

Rönkkönen, S., Ojaveer, E., Raid, T. and Viitasalo, M. (2003): Long-term changes in Baltic herring (Clupea harengus membras) growth in the Gulf of Finland. Canadian Journal of Fisheries and Aquatic Sciences, 61: 219–229.

Scheffer, M. and Carpenter, S.R. (2003): Catastrophic regime shifts in ecosystems: linking theory to observation. TRENDS in Ecology and Evolution 18 (1): 648-656.

Segerstråle, S.G. (1969): Biological fluctuations in the Baltic Sea. Prog Oceanogr 5:169-184.

Sherman, K., Belkin, I.M., Friedland, K.D., O´Reilly, J., Hyde, K. (2009): Accelerated warming and emergent trends in fisheries biomass yields of the World's large Marine Ecosystems. Ambio 38:215-224.

Sieben, K., Ljunggren, L., Bergström, U. and Eriksson, B.K. (2011): A meso-predator release of stickleback promotes recruitment of macroalgae in the Baltic Sea. Journal of Experimental Marine Biology and Ecology 397:79–84.

Somero, G.N. (2010): The physiology of climate change: how potentials for acclimatization and genetic adaptation will determine ‘winners’ and ‘losers’. The Journal of Experimental Biology 213: 912-920.

Stephenson, R., Peltonen, H., Kuikka, S., Pönni, J., Rahikainen, M., Aro, E. and Setälä, J. (2001): Linking biological and industrial aspects of the Finnish commercial herring fishery in the northern Baltic Sea. In: F. Funk, J. Blackburn, D. Hay, A.J. Paul, R. Stephenson, R. Toresen, and D. Witherell (eds.). Herring: Expectations for a new millennium. University of Alaska Sea Grant, AK-SG-01-04, Fairbanks, pp. 741-760.

Thurow, F. (1997): Estimation of the total fish biomass in the Baltic Sea during the 20th century. – ICES Journal of Marine Science, 54: 444–461.

Tomczak, M.A., Niiranen, S., Hjerne, O. and Blenckner, T. (2012): Ecosystem flow dynamics in the Baltic Proper — using a multi-trophic dataset as a basis for food–web modeling. Ecological Modelling 230: 123–147.

Vuorinen, P.J, Keinänen, M., Kiviranta, H., Koistinen, J., Kiljunen, M., Myllylä, T., Pönni, J., Peltonen, H., Verta, M., and Karjalainen, J. (2012): Biomagnification of organohalogens in Atlantic salmon (Salmo salar) from its main prey species in three areas of the Baltic Sea. Science of the Total Environment 421-422: 129–143.

Wieland, K., Waller, U. and Schnack, D. (1994): Development of Baltic cod eggs at different levels of temperature and oxygen content. Dana 10: 163-177.

Zeller, D., Rossing, P., Harper, S., Persson, L., Booth, S., Pauly, D. (2011): The Baltic Sea: Estimates of total fisheries removals 1950–2007. Fisheries Research 108: 356–363.

Österblom, H. et al. (2007): Human-induced trophic cascades and ecological regime shifts in the Baltic Sea. Ecosystems (2007) DOI: 10.1007/s10021-007-9069-0

Österblom et al. (2010): Making the ecosystem approach operational — Can regime shifts in ecological-and governance systems facilitate the transition? Marine Policy34: 1290–1299.

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Climate Change Impacts on Infrastructure in the Baltic Sea Region

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Abstract

Infrastructure in the Baltic Sea region will be affected by climate change in various ways. Rising temperatures, decreasing sea ice cover, sea level rise, changing precipitation and storm patterns directly impact infrastructure such as coastal protection, maritime traffic, ports and touristic infrastructure. Indirect effects of climate change such as shifts in tourism or changes in demand will have further consequences for the maritime sector. The planning horizon for new infrastructure covers in general a few decades. Climate change impacts, associated costs and adaptation measures have to be implemented in investment decisions. Concrete scientific information on localized impacts is demanded by authorities and economy to implement climate change scenarios in their planning efforts. Climate change adaptation will require planning on different time scales: from immediate actions e.g. with cooling systems in response to heat waves, to new technologies or longterm planning and construction of protection schemes in response to sea level rise. Overall, climate change is only one factor when considering future development of infrastructure in the Baltic Sea region; major players are economical, political, and societal changes.

1 Introduction

The term infrastructure refers to the basic physical/technical and organisational structures that support a society and its economy, such as roads and waterways, water supply, waste water treatment, sewers, electrical grids, and telecommunications. Regarding coastal area and the sea, human settlements, coastal protection, maritime traffic, ports, lighthouses, radio-locators and other navigation and defence related technical installations for communications, freshwater resources, canalisation, roads, railways, cycle tracks, waterways, and energy supply (wind power, power plants, transformer stations) are of special importance. The planning horizon for new infrastructure covers in general a few decades. Therefore, this sector needs to consider various environmental conditions, including climate change impacts, which will appear mostly not in the next years but are likely to have an impact in the next decades. Climate change impacts, adaptation measures and associated costs have to be implemented in investments decisions.

Infrastructure in the Baltic Sea Region will be affected by a variety of anticipated climate change impacts. High concentrations of human settlements and transport infrastructure systems are located in coastal areas and disruption or destruction of these infrastructures would have great effects not only on the coastal population and tourism but also on industrial development and trade at a larger scale (ESPON-IRPUD 2011).

For this report it was decided to concentrate on possible climate change impacts on specific infrastructural aspects in the Baltic Sea Region such as coastal protection, ports and maritime traffic.

As tourism is an important economic sector in the southern coastal areas of the Baltic Sea, special regard will be laid on infrastructure aspects of this sector as well. For a broader assessment on climate change impacts on the tourism sector, see Baltadapt assessment by Kūle et al. (pp. 91 - 132, this volume); for more information on climate change impacts on biodiversity and eutrophication see Baltadapt assessment by Dahl et al. (pp. 1-34, this volume), for impacts on the fishery sector see Peltonen et al. (pp. 35-54, this volume), and for more information on climate change impacts on the Baltic Sea basin see BACC Author team (2008 and new issue coming in 2014). Bruneniece (2012) has elaborated a Baltadapt gap-fit analysis also dealing with e.g. knowledge gaps for the infrastructure issue in the Baltic Sea Region, and Alberth et al. (2012) contains a Baltadapt vulnerability assessment of the infrastructure sector.

The objective of this review is to compile existing literature and knowledge – e.g. from past and ongoing projects – on climate change impacts on coastal infrastructure and adaptation measures in the Baltic Sea Region and to identify research needs. Following questions are sought to be answered:

1. What are the direct and indirect impacts of climate change on environmental conditions and on uses and functions, in particular concerning

   a) coastal protection,

   b) maritime traffic,

   c) ports, and

   d) tourism related infrastructure?

2. Which adaptation measures are possible?
3. What is still unknown, where do knowledge gaps exist?

2 The Baltic Sea and anticipated climate change impacts on its environmental conditions

The Baltic Sea is one of the world's largest brackish inland seas with nine countries bordering its coast. Five additional countries are included in the Baltic Sea Drainage Basin. Approximately 16 million people live within a distance of 10 km from the coast (Hannerz & Destouni 2006).

The Baltic Sea water is characterized by large variations in salinity, both horizontally and vertically. The surface salinity is very low in the Gulf of Bothnia and the Gulf of Finland, due to large river run-off, and increases gradually towards the south and the North Sea. The Kattegat is a transition area between the brackish Baltic Proper and the more oceanic Skagerrak. The Baltic Sea water is strongly stratified with a permanent halocline (layer where the salinity changes rapidly with depth). In the central part of the Baltic Proper the halocline is usually found at a depth of 60–70 m. As a consequence of the strong stratification the water becomes stagnant in the deeper parts of the Baltic Proper and depleted of oxygen. Eutrophication aggravates the situation in the bottom waters where oxygen is consumed. Inflows of more saline and oxygen rich water through the Danish Straits and the Sound improve the oxygen conditions in the bottom waters temporarily.

The Baltic Sea surface temperature shows large seasonal variations, from more than 20°C in summer to freezing conditions in winter. In spring the surface water warms up and a shallow thermo-cline (layer where the temperature changes rapidly with depth) is created. Winter turnover of the water mass breaks down the thermocline and in areas with depths less than 60 m or with weak salinity stratification, the turnover may reach down to the bottom and renew the bottom water. The Gulf of Bothnia and the Gulf of Finland are normally ice covered during the winter season. The ice cover records show large interannual variations in the maximum ice extent. Particularly high variability of ice conditions are observed in ports located in the central and eastern Baltic Sea regions.

Large inputs of nutrients from its vast catchment area enter the Baltic Sea mainly through riverine transport and atmospheric deposition. Internal fluxes of nutrients from the sediments can also be significant. Due to its large catchment area, the small volume of water and limited exchange with the North Sea, the Baltic Sea is very sensitive to excessive nutrient loads. Only the Bothnian Bay and the Swedish parts of the north-eastern Kattegat are not affected by eutrophication today (HELCOM 2009a, 2010a).

Climate change will affect future conditions in the Baltic Sea in many ways. Due to the large area of the Baltic Sea Region and different scenarios and regional models used for the projections, only general trends are summarised in this report. The considered time period is up to 2100.

Model simulations indicate a strong increase in air temperature in the Baltic Region, especially in winter and most so in the north-eastern part (Baltadapt Climate Info #1), influencing the sea ice conditions in the area (Baltadapt Climate Info #14). Cold winter extremes are expected to be unusual while hot summer extremes will become more frequent (Nikulin et al. 2011). The ocean climate simulations yield a general increase in sea surface temperature, with the largest change found in the Bothnian Bay in summer (Baltadapt Climate Info #7). In winter a substantial increase is found in the Gulf of Finland. The projected volume averaged temperature will also be higher than today (Meier et al. 2012a).

The climate simulations also show an increase in precipitation and, again, the winter will be more affected (Baltadapt Climate Info #2). The amount of extreme events will also increase according to the scenarios. Although many models indicate an increase in wind speed over the Baltic Sea Region, the uncertainty is very large (Baltadapt Climate Info #3). Consequently, projected sea surface currents, which are wind driven to a large degree, and wind waves are uncertain as well (Baltadapt Climate Info #10).

Changes in sea surface level are determined by changes in the global mean sea level, land uplift and future changes in the local wind and pressure patterns. Although the size of the global mean level change is under debate the total effect is anticipated to be larger in the southern and south-eastern part of the Baltic Sea, the Gulf of Riga and Gulf of Finland while the northern part will be less affected due to the ongoing uplift (Meier et al. 2004; Meier et al. 2006; Baltadapt Climate Info #4). Postglacial uplift is still ongoing in the northern part of the Baltic Sea whereas southern parts are sinking (Ekman 1996, Steffen & Wu 2011).

Although the modelled future averaged river discharge (Baltadapt Climate Info #11) shows an increase in most areas the largest change is found in the seasonal variations. Hence, it is anticipated that discharge will increase by a large amount in winter but decrease in summer. Scenario simulations show a future decrease in both surface and bottom salinity (e.g. Meier et al., 2012a, Neumann 2010, Neumann et al. 2012, Friedland et al. 2012; Baltadapt Climate Info #6). The decrease is mainly due to the expected increase in river run-off and a deepening of the permanent halocline.

A reduction in bottom oxygen concentrations (Baltadapt Climate Info #5) in the deeper parts of the Bothnian Sea and the Baltic Proper may be expected due to climate change (Meier et al. 2011a, Meier et al. 2012b, Neumann 2012). The decrease is explained by higher temperatures causing lower solubility in the inflowing water and an increased decomposition/oxidation rate of organic matter (Meier et al. 2011b). The total nutrient load from rivers (Baltadapt Climate Info #12) may also increase, due to an increase in river run-off, thereby enhancing the oxygen consumption. In the surface layer nutrients and phytoplankton concentrations may increase and the water transparency in the Baltic Proper may be reduced (e.g. Meier et al. 2011a, Meyer et al. 2012b, Friedland et al. 2012). If the Baltic Sea Action Plan (BSAP) is realized bottom oxygen concentrations may increase along the slopes of the Gotland Sea and in the Gulf of Finland. However, in a warmer climate the effect of the BSAP on the water quality may not be as large as it would in today´s climate (e.g. Meier et al. 2011a, Friedland et al. 2012, Baltadapt Climate Info #13).

The projected climate changes are linked to uncertainties of various degrees (Kjellström et al. 2011). Results that are based on a large set of simulations are more robust than those based on just a few scenario runs. In general, statements about future conditions in the ocean are based on a more limited set of simulations. The most robust results are those concerned with the future atmospheric temperature. Since the ocean is heated by the atmosphere the projected ocean temperatures are also relatively certain. The future regional precipitation is more uncertain and, consequently, the projected river run-off and salinity. The largest uncertainties concern changes in wind speed which means that statements on future currents and waves, and possibly also mixing, are highly uncertain as well. The simulated changes generally get stronger with time. However, the high degree of natural variability in the region implies that changes temporarily may be stronger or weaker than what would be expected from a continuous change. Such variability can amplify or weaken the signal on time scales of years to decades. The emission scenarios that form the basis of the simulations are coupled to different 'story lines', describing the future developments on Earth (e.g. IPPC 2000). These developments may be faster or slower, or take another course, than those anticipated.

3 Climate change impacts on infrastructure and adaptation options

3.1 Costal Protection

Coastal protection has been and will be an important issue for many coastal communities in the Baltic Sea Region also in the future. On the one hand, existing coastal protection is affected by climate change, on the other hand, coastal protection is part of the adaptation process e.g. in the case of sea level rise.

The coastline of the Baltic Sea has a total length of about 40,000 km, of which 70% belong to Sweden and Finland. In general, the southern coastlines as well as parts of the south coast of Sweden consist of sandy shores, which are at risk of erosion, whereas the more northern parts and the Gulf of Bothnia are characterised by rocky coasts. In Denmark, Germany, Poland, and on a local scale in the Baltic States, technical measures like beach replenishment and construction of revetments are used to avoid coastal erosion and retreat; about 25% of the eroding coastlines in the Baltic Sea Region are artificially stabilized (Hofstede 2011). The decisions for applying a strategy are specific to the coastal section. They depend on many natural and anthropogenic factors. In several cases there are legacies of previous decisions which have led to the present threats and shore protection necessity.

Sea level rise/Wind/Wind waves

Climate change and its consequences will significantly impact sandy coasts and coastal lowlands but also cliffs especially at the southern Baltic Sea coast. Due to uncertainties in global sea level rise, no detailed projections for future sea level in certain areas of the Baltic Sea Region are possible (chapter 2). However, sea level rise and its consequences such as coastal flooding, erosion and ecosystem losses will differ from region to region. The exposure and sensitivity of coastal regions to climate change impacts depend on e.g. bathymetrical, morphological, and ecological factors.

The risks of flooding and coastal erosion will probably rise due to higher storm surge water levels (Hofstede 2011). Model simulations indicate an increasing occurrence of storm surges with a return period of more than 20 years in the Western Baltic Sea (Sassnitz and Wismar at the coast of North-east Germany; Gräwe & Burchard 2011). Sea level rise has a greater potential to increase storm surge levels than increased wind speed (Gräwe & Burchard 2012). However, the influence of sea level rise on storm surges is difficult to estimate; storm surges depend on several additional factors such as bathymetry of the coast, main wind direction and velocity, and coastal morphology (Meier et al. 2006). Although information and data about future storm events (frequency and intensity) in the Baltic Sea are not very sufficient, possible storm events and their consequences have to be taken into account. Particularly low-lying coasts are vulnerable due to erosion and saline intrusion into coastal groundwater aquifers. At least the southern and south-eastern parts of the Baltic Sea, the Gulf of Riga and the Gulf of Finland have to be prepared for increasing sea level and storm surges. Large flood prone areas exist in Denmark, Germany and Poland. Different areas (morphodynamically different coastal types) are affected to different degrees due to the configuration of the coastline, availability of fine sediments and the variation in geological structure and resistance of the coastal strata to wave erosion. For a freely chosen example cross-section the coast will retreat in an order of magnitude of approximately 100 m for a sea level rise of 1 m (Fröhle et al. 2011). Based on indicators, different coastal areas have been separated in Latvia: high risk, average risk and low risk areas are separated by the degree of erosion, damage risk for properties and infrastructure at storms of different intensities, surge levels, wind direction, and duration (Lapinskis 2012).

In general, coastal flood defence and protection schemes are supposed to have a life and operating time of approximately 50–100 years; therefore, adaptation to increasing risks from climate change will be necessary. Traditionally, adaptation strategies focus on technical measures such as sea dikes, revetments or beach replenishments (Hofstede 2011). An increase of coastal protection at the southern Baltic Sea Region will be necessary, but also the development of new techniques and standards, alternatives and non-technical options. Artificial reefs could fulfil several purposes such as coastal protection (absorption of wave power), attraction for divers and potential settlement area for macrophytes and other organisms. As there still is a wide range of possible sea level changes, both for the mean value and for the extremes, flexible and sustainable measures and strategies are necessary (Hofstede 2011). Also, some countries are not able to make large investments for technical coastal protection measures (e.g. levees and seawalls) or the necessary financial efforts to maintain safety standards could become unacceptable for society (Hofstede 2011). Alternatives such as ‘giving up’ coastal protection, for example in sparsely populated areas, and coastal realignment can be considered (Weisner & Schernewski 2013). Non-used areas or scarce populations will allow ‘soft’ solutions such as set back standards in building regulations and thereby an increase of the width of the seashore protection belt. Along sandy coasts and in flood-prone coastal lowlands specific regulations for building areas like flood-proof housing, identification of coastal buffer zones (setback lines) and hazard zones in regional plans are necessary (Hofstede 2011). Protected zones between sea and hinterland strongly restrict human utilisation and development.

Most affected countries have already started to include sea level rise due to geological changes and climate change in their coastal protection strategies. For example in Germany (340 km sea dike at the Baltic coast, Hofstede 2011) coastal protection plans take into account climate change by raising dikes and planning a reserve capacity for any necessary further expansion. In Latvia, recommendations for coastal protection measures (Lapinskis 2012) differentiate areas by priority. This includes for ‘low priority’ areas coastal protection measures such as dune planting of osier and maran grasses (‘green’ method) and/or ‘soft methods’. ‘High priority’ coastal sections have the necessity for ‘hard’ coastal protection structures. Also the combination of ‘hard’ coastal protection structures and ‘green actions’ can be considered as suitable. Proposed anti-flood measures in Riga City that are identified by the Integrated Strategy for Riga City to Adapt to the Hydrological Processes Intensified by Climate Change Phenomena include rising the level of existing paved roads and embankments, construction of new embankments, reconstruction of existing canal locks and culverts, and installation of new canal locks and culverts. Table 1 gives an overview on potential climate change impacts on coastal protection and adaptation options.

Table 1: Potential climate change impacts on coastal protection and adaptation options.

Climate change impact	Adaptation options
Precipitation changes: Increase (projected for the winter season)	
Flooding: damage to infrastructure constructions e.g. river bank/coastal protection structures	Intensification of river bank/coastal protection
	Development of new concepts for increased coastal resilience: coastal realignment, non-technical options, new techniques, vegetation and stabilisation of dunes, combination of hard and soft measures
	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
	Improved information and knowledge distribution

Landslides/soil erosion: loss of territory (e.g. beaches) and infrastructure constructions e.g. river bank/coastal protection structures	Intensification of river bank/coastal protection
	Development of new concepts for increased coastal resilience: coastal realignment, non-technical options, new techniques, vegetation and stabilisation of dunes, combination of hard and soft measures
	Constructional measures to protect sandy beaches (flood barriers, dunes, dikes, groins)
	Beach replenishment
	Maintenance of sediment supply and buffer zones
	Setback zones that allow landward migration of the coastline/beach (difficult in built areas)
	Improved information and knowledge distribution
Rise of groundwater level: damage to infrastructure constructions e.g. coastal protection structures	Adaptation of building constructions
	Adaptation of coastal cities to changes in hydrological processes/regimes
Increase of wetland areas: damage to infrastructure constructions e.g. coastal protection structures	Development of new concepts for increased coastal resilience: coastal realignment, non-technical options, new techniques, vegetation and stabilisation of dunes, combination of hard and soft measures
	Relocation of buildings
	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
Precipitation changes: Decrease (projected for the summer season)	
Droughts: damage to vegetation (particularly sensitive forests on dunes for coastal protection and to control dune movement)	Choice of resistant species
Changes in wind regime: Potential increase in storms (intensity):	
Damage to coastal protection, properties, particularly high structures like coastal forests	Resistant materials and constructions, resistant species (e.g. deciduous tree species are less susceptible to storms during winter)
Variability of weather/extremes: Potential increase	
More extreme rainfall, snowfall or heat events: damage to constructions	Adaptation of infrastructure constructions (new concepts, techniques)
	Improved weather information
More frequent extreme hydrological regimes in rivers: damage to hydrological constructions at river mouths	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
	Improved weather information
Sea level rise (SLR): Flooding/coastal zone erosion	
Damage to infrastructure constructions (e.g. coastal protection structures) and loss of territory (e.g. beaches)	Including SLR in coastal protection strategies
	Intensification of coastal protection
	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
	Integration of SLR in building regulations: set-back standards, flood-proof housing
	Adaptation of coastal cities to changes in hydrological processes/regimes
	Improved information and knowledge distribution to inhabitants, owners/users of constructions in coastal zones
	Development of new concepts for increased coastal resilience: coastal realignment, non-technical options, new techniques, vegetation and stabilisation of dunes, combination of hard and soft measures
Ice covers: Decrease	
Less ice-induced stress/damage to coastal protection constructions (e.g. dykes, groins)	Less costs, new opportunities for local economy
Wind waves: Potential increase	
Erosion of different coastal types/beach enlargement due to sand accumulation processes	Intensification of coastal protection
	Development of new concepts for increased coastal resilience: coastal realignment, non-technical options, new techniques, vegetation and stabilisation of dunes, combination of hard and soft measures; artificial reefs

	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
Increase of ocean temperatures and decrease of salinity:	
Risk of improved survival rate of invasive species which damage constructions	Resistant materials in constructions
	Improved information and knowledge distribution to owners/users of constructions

3.2 Maritime traffic

According to HELCOM (2009b), the Baltic Sea is one of the seas in the world with most traffic, accounting for up to 15% of the world's cargo transportation. The number and size of ships as well as the quantities of cargo afloat on the Baltic Sea are growing rapidly. At any moment, there are about 2000 ships in the Baltic Sea (according to Automatic Identification System AIS for monitoring maritime traffic: www.marinetraffic.com/ais, HELCOM 2009b), including large oil tankers, ships carrying dangerous cargoes, and many large passenger ferries. The Baltic Sea's narrow straits and shallow waters, which are covered by ice for prolonged periods in winter, make navigation very challenging and bear a high risk for shipping accidents (HELCOM 2009b). The main environmental effects of shipping and other activities at sea include air pollution, illegal deliberate and accidental discharges of oil, hazardous substances and other ship-generated wastes, and release of alien species via ships' ballast water. Shipping also adds to the problem of eutrophication in the Baltic Sea with its nutrient inputs from sewage discharges and nitrogen oxides (NO_x) emissions (HELCOM 2009b).

Among all modes of transport, shipping is comparatively energy efficient and thereby contributes to protection of the present climate. However, the efficiency of goods and passenger transport on waterways may be severely affected by consequences of climate change in the future. Climate change might have various impacts on maritime traffic and maintenance of nautical construction materials (UNCTAD 2008).

Ice

A reduction of ice cover and a shortening of the ice season will facilitate shipping especially in the Gulf of Bothnia, the Gulf of Finland, and the Gulf of Riga. The potential danger of ice pressure would also diminish. Nordic and Eastern Baltic icebreaker fleets will have to adapt to the changing sea ice cover. Reduction of ice cover in winter might have some implications for ship order books (e.g. ice-class ships) and icebreaking services (UNCTAD 2008). Sailing distances and shipping time might be reduced. Fuel consumption and greenhouse gas emissions might decrease and result in lower freight rates. To adapt to reduction and changes in ice cover and use them in an optimal way, the new routes and ice free areas will have to be mapped. However, due to sudden heavy ice conditions smaller ships that are not prepared for ice conditions can be impacted negatively (as experienced in February 2011 when 34 smaller ships were frozen in Riga Bay).

Icing is a serious hazard to shipping and occurs when air temperature is colder than the freezing point of the sea water. 'Icing increases the weight and raises the centre of gravity of ships, lowering freeboard and reducing stability, a potentially catastrophic problem, particularly for smaller vessels such as fishing trawlers' (PIANC 2008: 26). The areas where icing occurs might shift if climate change modifies wave heights, wind direction or speeds, air temperature, sea surface temperature or the freezing point of sea water due to changes in salinity.

Wind/Wind waves/Variability of weather

An increase in extreme storm events would challenge maritime traffic and its manoeuvring; risks for accidents would increase. Stronger ships might help to avoid accidents, therefore cooperation between scientists and shipyards is needed (UNCTAD 2008). The call for a binding law for pilots to en-sure marine security is also getting louder, but this is not practicable without Russia's agreement (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety Germany 2003).

Altered sea surface currents might also have an impact but this is one variable for which the projections are very uncertain.

Sea level rise

Newly submerged reefs in the Swedish and Finnish archipelago will need to be marked new for avoidance if the sea level rises significantly (PIANC 2008).

Water temperature/salinity

The amount of organisms attacking maritime construction materials will rise with warmer temperatures. ‘Just a small amount of [bio]fouling can lead to an increase of fuel consumption of up to 40 %, and possibly as much as 50%, since the resistance to movement will be increased. A clean ship can sail faster and with less energy’ (IMO 2002:3). Hydrozoa are also capable of blocking the cooling water supply of motor boats (Scheibe 2009). To combat biofouling, biocides are widely used. However, this bears many risks and more studies about impacts of biocides on the ecological system and sediment management are needed (Federal Ministry of Transport, Building and Urban Affairs Germany 2007). The delayed prohibition of harmful organotin compounds on ships underlines the importance of those investigations (European Parliament 2003). Alternatives such as non-toxic anti-fouling coatings should be developed further.

A warmer and less saline surface layer makes the upper water layer less dense thereby de-creasing buoyancy. The effect is that ships cannot carry the same loads.

Stability and environmental sustainability of nautical construction material depends heavily on temperature, salinity, marine chemistry and hydrological conditions. The German research project KLIWAS (Impacts of climate change on waterways and navigation - Searching for options of adaptation) focuses on this topic and analyses the potential consequences of climate change for navigation on inland and coastal waterways. The project aims to formulate appropriate strategies for adaptation to the changed environmental conditions in the future. The project also assesses the consequences of climate change on hydrology, transportation costs, and other economic aspects and derives options for actions in waterway management, and industrial branches requiring the transport of bulk goods (www.kliwas.de).

Indirect climate change impacts

Changes in transport goods and amounts due to climate change (e.g. agricultural and forestry products) will have implications also for maritime traffic. A prolongation of the tourism season might in-crease the demand for cruise lines (see 3.3 ‘ports’), a sector which already has experienced a strong increase in the Baltic Sea in the last decade (for statistics see e.g. www.cruisebaltics.com). A simultaneous increase in tourism and maritime shipping might lead to conflicts of interest and an integrated spatial and maritime planning is needed.

Changing precipitation patterns will lead to altered river discharges and sedimentation patterns. A shift in dredging requirements will be the result (Federal Ministry of Transport, Building and Urban Affairs Germany 2007). Massive coastal erosion occurs after extreme storm and rain events and increases the need for dredging. On the other hand sea level rise at least at the Southern Baltic Sea coast might allow ships with more draft without excavating the waterways (Schnellhubner & Sterr 1993).

Table 2 gives an overview on potential climate change impacts on coastal protection and adaptation options.

Table 2: Potential climate change impacts on maritime traffic and adaptation options.

Climate change impact	**Adaptation options**
Increase of atmospheric temperatures:	
Changing tourism seasons and activities: increasing demand for cruise ships, changes in water sports such as sailing; simultaneous increase in tourism and maritime shipping might lead to conflicts of interest	Integrated spatial and maritime planning, adaptation of maritime offers
Higher microbial activity – risk for materials like wood	Resistant construction materials
Precipitation changes: Increase (projected for the winter season)	
Changing precipitation patterns lead to altered river discharges and sedimentation patterns.	Shift in dredging requirements
Changes in wind regime: Increase in storms (intensity) and wind waves	
Damage/increasing risks to maritime traffic and its infrastructure such as bridges	Adaptation of constructions, safety measures and facilities
	Safety distance between ships should be stretched during storms
	Capacity of rescue services should be evaluated and adapted
Variability of weather/extremes:	
Changes in icing conditions	Resistant construction materials, new techniques
Massive coastal erosion due to extreme storm and rain events	Shift in dredging requirements
Frequent freeze and thaw cycles could damage equipment and cargo	Improvements of materials and constructions
Extreme weather situations (storm, hail, extreme rainfall) lead to increasing financial risks to remedy damage and for necessary financial precautions	Changes of insurance policy
Increase of intensity or frequency of storms or number of foggy days	More harbours of refuge needed (incl. maintenance)
Increase of insurance costs	Changes of insurance policy
Sea level rise: Flooding/coastal zone erosion	
Higher water table	Submerged reefs in the Swedish and Finnish archipelago will have to be marked new
	Shift in dredging requirements; might allow ships with more draft to enter ports without excavating the waterways
	Stronger and higher bridges could be necessary
Erosion/changes in sediment transport	Shift in dredging requirements
Decreased ice covers:	
Less ice-induced stress/damage to constructions	New possibilities for maritime traffic, adaptation of e.g. coastal fishing activities
Less ice cover	Implications for ship order books (e.g. ice-class ships) and adaptation of icebreaking services
	Sailing distances and shipping time might be reduced; fuel consumption and greenhouse gas emissions might decrease and result in lower freight rates
	Mapping of new routes and ice free areas
	Adaptation of planning processes
Increase of ocean temperatures and decrease of salinity:	
Decrease of surface water layer density - decreasing buoyancy	Less loads on ships resp. more energy necessary: adaptation of ship construction
Potential increasing risk of introduction and establishment of non-indigenous species (e.g. by ballast water) which could damage constructions; faster shipping (due to new techniques and melting of sea ice which might open new shipping routes in the polar region) enhances the chance of survival for	Implementation of ballast water safety standards and measures. More research necessary, e.g. effects on indigenous species, effects of increasing temperature and decreasing salinity. Adaptation of coastal fishing activities

species transported in the ballast water. Decreasing salinity might hinder maritime species to establish in the Baltic Sea and serve as a natural barrier though.	
Potential increasing risks that more organisms attacking maritime construction materials or hulls (biofouling lead to increasing fuel consumption).	Use of biocides or other materials e.g. steel, and development of alternatives (non-toxic antifouling coatings)
Potential increasing numbers of hydrozoa being capable of blocking cooling water supply of motor boats.	

3.3 Ports and marinas

In the Baltic Sea Region, more than 200 ports exist, which differ in types and volumes of cargo traffic, fishing and other activities (logistics, industry, warehouses, passenger transport and terminals, cruise tourism, yachting). A large part of freight moves by ship and ports are situated in vulnerable locations often close to river mouths, prone to sea level rise, storm surges, and flooding both from the sea as well as from the river (Becker et al. 2011). As the transaction volume will continue to increase, Baltic Sea ports need to adapt to a changing climate to guarantee safety and effectiveness. Climate change might have various impacts on port operations and infrastructure (UNCTAD 2008).

Ports may have to develop adaptation measures in regard to port infrastructure and flood control as well as safety measures and facilities; technological changes in design and construction of ships due to climate change impacts on shipping routes could also make changes of ports necessary. In general, adaptation of existing buildings to future environmental conditions will have to be orientated towards their remaining useful life. But also new building concepts and techniques will have to be developed.

Ice

Climate change scenarios show a decrease in sea ice extent for most Baltic Sea regions. This would have a positive impact on ports. However, most ports are situated at river mouths and more freshwater discharge in the north of the Baltic Sea could result in more ice at river outlets (PIANC 2008). In ports where ice conditions are less frequent (not every winter) costs for maintaining or/and renting icebreakers remain. Increasing uncertainty in ice conditions creates additional obstacles to planning and marketing of these ports. The ports located in the western part of the Baltic Sea might even profit from a melting of arctic sea ice due to increased traffic, whereas most of the other Baltic ports subsist from regional trade and will not be affected. However, Baltic Sea shipping can also lose freight as to competition from Barents Sea that can have improved shipping conditions due to climate change.

Storage buildings for winter months are an important income source for marinas. If less sea ice occurs, sailing boat owners might let their boats hibernate. Port authorities need to inform sailing boat owners that winter storms are also a hazard to their boats (Scheibe 2010). Besides, sea ice can still occur as deviations from mean values are not predictable.

Temperature

Large spatial and/or temporal variations of temperature in the Baltic Sea region are also possible due to climate change. Frequent freeze and thaw cycles could damage infrastructure, equipment and cargo. To avoid high construction and maintenance costs, intelligent architecture for isolation and ventilation as well as heat resistant materials are required (UNCTAD 2008). If heat waves occur during summer, higher energy consumption in ports will be the logical consequence as more refrigeration is needed. Energy-efficient cooling and ventilation systems are necessary (UNCTAD 2008).

Sea level rise

Sea level rise at least at the southern Baltic Sea coast might allow ships with more draft to enter ports without excavating the waterways (Schnellhubner & Sterr 1993). However, rising sea levels may necessitate reconstruction work. Flooding and inundations might damage port infrastructure (such as piers), equipment and cargo if the sea level rises significantly. A reduction of clearance between ships and booms might affect the loading process of ships. General adaptation possibilities include relocation of infrastructure and businesses and restriction on existing port developments and limitations for new projects (PIANC 2008, UNCTAD 2008). Protection schemes (e.g. levees, seawalls, dikes, infrastructure elevation) could be installed, foundations be strengthened and docks and wharf levels be raised. Stronger and higher bridges would be essential (UNCTAD 2008, UKCIP 2011). Especially smaller and older harbours will be affected by sea level rise as their piers are only a couple of decimetres above current water level (Scheibe 2010). Relocation of marinas might be more cost effective in some cases than reconstruction. Floating breakwater pontoons and piers are another alternative.

Precipitation

An increased number of flooding events would affect ports and urban areas located at river mouths. Changing precipitation patterns will lead to altered river discharges and sedimentation patterns. A shift in dredging requirements will be the result (Federal Ministry of Transport, Building and Urban Affairs Germany 2007).

Wind/Wind waves/Extreme weather events

Future wind projections are highly uncertain. However, storm surges are a serious hazard for power supply and distribution networks in ports. Power outrages, impacts on service provisions, losses and stoppages of operations are the result. To adapt ports one might have to relocate high voltage lines (UKCIP 2011). Storm surges cause also damage to port buildings, cargo and infrastructure. Barriers or slope-retention structures could moderate the impacts of storm surges (UNCTAD 2008). ‘Looping’ of retaining walls can facilitate the drainage (Uhlendorf 2011). Wharf fenders to barrier ships at docks might need to be redeveloped to deal with higher pressures (PIANC 2008). A case study at the port of Felixstowe in Great Britain showed that wind speeds of more than 45 miles/hour were critical for high level cranes. Rubber tired gantries operate at higher height levels and are therefore also more vulnerable to wind (UKCIP 2011). Port authorities need to collaborate with manufactures to develop more robust designs.

Storm surges are also a challenge for manoeuvring and loading processes. Caldwell et al. (2002) share the opinion that lift-on/lift-off will replace roll-on/roll-off traffic in ports affected by an increasing frequency of storm surges. Paper handling, an important factor for Baltic Sea ports, is especially vulnerable to extreme wind and precipitation events. Shelter for loading processes might be useful. Larger areas for anchoring vessels will be needed if storms disrupt port services. Passenger vessels may suffer from more downtime and ports need to think about more waiting halls for passengers. Higher wind speeds decrease the regularity of ports. An increased downtime requires also more storage capacity for sensible goods (PIANC 2008).

The safety distance between ships has to be stretched during storms; hence fewer vessels can enter the port area. Who will get the priority? Large container ships? Passenger vessels? The port management needs to examine this problem and implement it in their strategies.

Also, the capacity of rescue services should be evaluated and adapted. If the intensity or fre-quency of storms or the number of foggy days increases, more harbours of refuge will be needed in the Baltic Sea. To maintain them is often a financial problem and responsible authorities have to be found. The port of refuge in Darßer Ort, a small village in north-eastern Germany, is a good example for several aspects and problems which might intensify in the course of climate change. Every year the port entrance has to be costly dredged as it is filled by sand regularly. Coastal erosion and there-fore sediment transport could further accelerate as climate change modifies the frequency and intensity of storm events. Consequently, the expenses for dredging would rise simultaneously. It is no option to give up the harbour because more storms mean also more hazards for sailors and refuges are urgently needed. Currently, Darßer Ort port shelters also a rescue boat. A floating offshore port might be an alternative and is currently debated among authorities and habitants (DGzRS 2008).

Also, energy installation plans need to consider climate change and deserve information on changes of extreme weather events (wind).

Impacts by extreme weather situations (storm, hail, drought, extreme rainfall) will lead to in-creasing financial risks to remedy damage and also for necessary financial precautions (Ministry of Economy, Labour and Tourism Mecklenburg-Vorpommern 2010).

Water temperature/Salinity

The spread of alien species in the Baltic Sea is increasing steadily (HELCOM without date) with serious consequences for local ecosystems. Ballast water is estimated as one of the most important vectors for (future) introduction of non-indigenous species (HELCOM 2010b). Rising sea temperatures support the establishment of certain new species.

Shipping will be faster in the future as a consequence of the ongoing technical progress. Additionally, melting of sea ice might open new shipping routes in the polar region and reduce the shipping time (PIANC 2008). Shipping time reduction enhances the chance of survival for the species transported in the ballast water of ships. On the other hand changing precipitation patterns especially in the north of the Baltic Sea might lead to an increase of freshwater input to the Baltic Sea. Therefore the current salt-gradient might move to the southwest and hinder maritime species to establish in the Baltic Sea and serve as a natural barrier. Which species will benefit from warmer sea temperatures and a possible decrease of salinity? Will the shipworm *Teredo navalis* continue to spread? *Teredo navalis* drills wood structures and can cause major damages to fenders, dolphins and stilts. If ports are infested with shipworms, they could use different coating materials (e.g. synthetic), impregnate structures or trim them with balanidae or replace wooden pillars with steel pillars (Paalvast & Van der Velde 2010, Tuente et al. 2002a and b). Biofouling is another factor which causes damages to port constructions. The amount of organisms attacking maritime construction materials will rise with warmer temperatures. To combat biofouling, biocides are widely used. Alternatives such as non-toxic anti-fouling coatings should be developed further (see also 3.2 Maritime traffic).

In the German project RADOST (Regional adaptation strategies for the German Baltic Sea Coast, 2009–2014), between others, long term 'climate-proof' investments in ports, ship construction and related infrastructure facilities are investigated. The subproject 'Ports and Maritime Economy' identifies medium- and long-term adaptation requirements for ports and related infrastructure facilities, as well as for ship construction, elaboration of adaptation strategies for individual sectors of port planning and management, and integration of environmental data into the innovative design and construction of ships to optimize their performance for specific routes. One specific implementation project aims at integrating marine environmental data including climate change impacts into a route-specific optimisation of ship design (www.klimzug-radost.de).

Indirect climate change impacts

Ports may be affected indirectly through changes in maritime transport services as a result of changes in demand, induced by climate change effects on trade, investment decisions, fishing activities, energy demand and exploitation, agricultural production, forestry, breakdown of hinterland connection, and demographic changes (UNCTAD 2008).

Caldwell et al. (2002) state that coal shipment declines as cleaner forms of energy are substituted. The statistics from the European Sea Port Organisation (ESPO) show a decrease of coal import in the port of Rostock, Germany, from 1,145,000 tonnes in the year 2004 to 695,000 tonnes in 2009. 'Heating oil and liquid natural gas shipments might also decline as winter heating needs lessen. In contrast, agricultural shipments are likely to rise as longer growing seasons make multiple harvests in a single year more common. Timber shipments (particularly hardwood) may also rise' (Caldwell et al. 2002:12). Especially Finnish and Swedish ports will have to react to shifts in demand if timber shipment rises. In contrast to Caldwell et al. (2002) other sources state that turnover in oil ports has significantly increased during the last years, especially in the Gulf of Finland due to the Russian oil tanker fleet. An increase of up to 30% of oil transhipment is mentioned for the Baltic Sea (Schleswig-Holsteinischer Landtag 2007).

A prolongation of the tourism season might increase the demand for cruise lines and thereby has many positive economic effects. However, as a consequence new infrastructure for cruise ships will be needed, particularly in ports of the former Eastern bloc. Larger amounts of sewage will be produced on these vessels, which have to be collected in port reception facilities.

A simultaneous increase in tourism and maritime shipping might lead to conflicts of interest and an integrated spatial planning for the coast is needed. As cruise tourists are 'higher yield tourists', spending above average (Hall 2001), higher financial benefits can be expected for coastal communities; negative effects on social, cultural and environmental aspects occur particularly for small communities. There will be more demand for coastal tours (city- and nature-based day trips including golf). Cruise tourism's impacts on marine and coastal environment and destinations might vary due to climate change; however there is a lack of research with focus on the Baltic Sea. Johnson (2002) underlines that 'whilst cruise tourism presents a potential market opportunity for destinations, mobile mass tourism challenges sustainable tourism ideals' and provide the following evidence from this sector:

1) The need to continue to take a long-term view fostering holistic integrated management planning involving international agencies, cruise line operators and host communities;

2) The need for operators to continue to invest in and promote the Best Possible Environmental Option;

3) The need for political will to safeguard destinations, given the proven adverse impacts of poorly managed cruise tourism;

4) The need for greater profit sharing between cruise line shareholders and destination communities; and

5) The need for both operators and destinations to raise their customers' environmental awareness.

Indirect effects on ports are also possible through climate induced changes which lead to alterations in landuse planning and constructions and this again to competition with ports for land adjacent to shores (Figure 1). Further indirect impacts on ports can occur as hinterland connections can break down after extreme weather events. Ports cannot operate as usual if rail and road traffic or other infrastructure is disturbed after severe flooding or storms (UNCTAD 2008).

Mitigation measures to reduce sulphur and greenhouse gas emissions also affect shipping and interact with adaptation strategies (see discussion).

Table 3 gives an overview on potential climate change impacts on coastal protection and adaptation options.

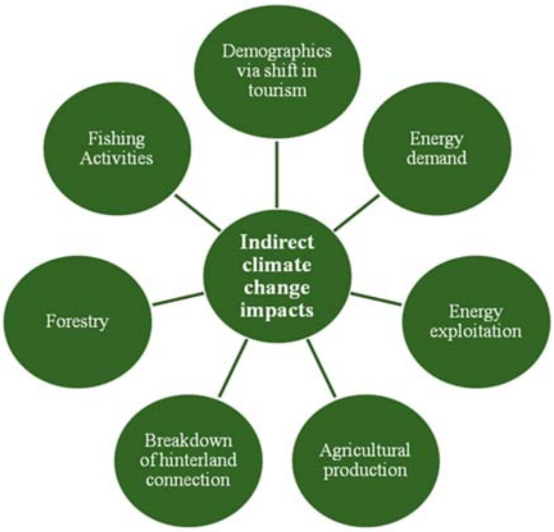

Figure 1: Indirect climate change impacts on ports.

Table 3: Potential climate change impacts on ports and adaptation options.

Climate change impact	**Adaptation options**
Increase of atmospheric temperatures:	
Less demand for heating/higher demand for cooling	Adaptation of air conditioning systems and sophisticated isolation- and shading-systems; intelligent architecture for isolation and ventilation as well as heat resistant materials required
Heat waves during summer - higher energy consumption in ports for refrigeration	Installation of energy-efficient cooling and ventilation systems (port and fishing entrepreneurs)
Increased humidity – increased growth of fungus and mould: damage to buildings	Resistant materials in constructions and improved ventilation
Prolongation of the tourism season – increasing demand for cruise lines	Integrated spatial and maritime planning needed; new concepts to be developed, reception facilities for sewage have to be increased and new port infrastructure to be built
Less snow and ice – better road conditions	Less costs for maintenance
Precipitation changes: Increase (projected for the winter season)	
Flooding: damage to - infrastructure constructions - sewerage systems - effects on freshwater availability, quality and supply - higher risk of flooding: decrease of property values, increase of insurance costs	Intensification of river bank/coastal protection
	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
	Improvement of rainwater management (e.g. rain and sewage reservoirs, sustainable urban drainage systems
Landslides/soil erosion: loss of territory and built-up structures	Intensification of coastal protection, adaptation of constructions
Rise of groundwater level: damage to buildings and infrastructure, negative impact on drinking water quality	Adaptation of building constructions (new 'climate-proof' concepts, techniques) and drinking water supply
	Relocation of infrastructure
	Restrictions and limitations for new infrastructure developments
Changing precipitation patterns lead to altered river discharges and sedimentation patterns	Shift in dredging requirements

Changes in wind regime/wind waves: Increase in storms (intensity):	
Damage to infrastructure of ports (e.g. buildings), cargo	Adaptation of infrastructure constructions (new 'climate-proof' concepts, techniques), safety measures and facilities. Technological changes in the design and construction of ships could also make changes of ports necessary. Larger areas for anchoring vessels will be needed if storms disrupt port services. Higher wind speeds decrease the regularity of ports. An increased downtime requires also more storage capacity for sensible goods; waiting halls for passengers
	Intensification of coastal protection
Damage to power supply and distribution network in ports - power outrages, impacts on service provisions, losses and stoppages of operations	Relocate high voltage lines
Challenge for manoeuvring and loading processes	Lift-on/lift-off instead of roll-on/roll-off traffic
Effects on handling of especially vulnerable cargo (e.g. paper) to extreme wind and precipitation events	More shelter for loading processes
	More storage capacities
High wind speeds critical for high level cranes	Development of more robust designs
Variability of weather/extremes:	
Increased variability of weather will increase maintenance costs in ports (idle standing of icebreakers or renting for accidentally cold season)	Adaptation of planning processes
More extreme rainfall or snowfall: damage to properties and infrastructure	Adaptation of building constructions (new 'climate-proof' concepts, techniques)
More frequent extreme hydrological regimes in rivers: damage to hydrological constructions at ports situated at river mouths	Adaptation of building constructions (new 'climate-proof' concepts, techniques)
	Intensification of riverbank/coastal protection
	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
More extreme snowfalls: disturbances, damage to electricity supply infrastructure	Change of snow removal and salt spreading plans
Massive coastal erosion occurs after extreme storm and rain events and increases the need for dredging	Shift in dredging requirements
Frequent freeze and thaw cycles could damage infrastructure, equipment and cargo.	Adaptation of building constructions (new 'climate-proof' concepts, techniques)
	Adaptation of planning processes
	Change of insurance policy
Extreme weather situations (storm, hail, drought, extreme rainfall) will lead to increasing financial risks to remedy damage and also for necessary financial precautions	Change of insurance policy
Increase of intensity or frequency of storms or number of foggy days	More harbours of refuge needed (incl. maintenance)
Sea level rise: Flooding/coastal zone erosion	
Loss of territory and loss of resp. damage to port infrastructure (e.g. roads, buildings, piers), equipment and cargo	Intensification of coastal protection; protection schemes (e.g. levees, seawalls, dikes, infrastructure elevation) could be installed, foundations be strengthened and docks and wharf levels be raised.
	Adaptation of building constructions (new 'climate-proof' concepts, techniques)
	Relocation of infrastructure
	Restrictions and limitations for new infrastructure developments
Erosion/changes in sediment transport, higher water table (might allow ships with more draft to enter ports without excavating the waterways)	Shift in dredging requirements
Reduction of clearance between ships and booms might affect the loading process of ships.	Adaptation of such processes

Especially smaller and older harbours will be affected by sea level rise as their piers are only a couple of decimetres above current water level	Relocation of infrastructure might be more cost effective in some cases than reconstruction. Floating breakwater pontoons and piers are other alternatives.
	Adaptation of building constructions (new 'climate-proof' concepts, techniques)
Decreased ice covers:	
In general positive impacts on ports. However, most ports are situated at river mouths and more freshwater discharge could result in more ice at river outlets. Increasing uncertainty in ice conditions creates obstacles to planning and marketing of ports.	Adaptation of planning processes etc. Adaptation of coastal fishing activities
Positive effects for maritime transports: less ice-induced stress/damage to constructions	Adaptation of icebreaker fleets, innovative design and construction. Adaptation of coastal fishing activities
Implication for ship order books (e.g. ice-class ships) and icebreaking services	Adaptation of planning processes
Storage buildings for winter are important income sources for marinas. If sea ice melts, sailing boat owners might let their boats hibernate.	Dissemination of information: winter storms are also a hazard to boats and sea ice can still occur as deviations from mean values are not predictable
Increase of ocean temperatures and decrease of salinity:	
Increasing risk of introduction and establishment of non-indigenous species (e.g. by ballast water) which could damage port infrastructure (e.g. shipworm); faster shipping (due to new techniques and melting of sea ice which might open new shipping routes in the polar region) enhances the chance of survival for species transported in the ballast water. Decreasing salinity might hinder maritime species to establish in the Baltic Sea and serve as a natural barrier though.	Implementation of ballast water safety standards and measures. More research on the effects on indigenous species, possible invading species, chances for the shipworm *Teredo navalis* (drills wood structures and can cause major damages to fenders, dolphins and stilts; adaptation: use of different coating materials (e.g. synthetic), impregnate structures or trim them with balanidae or replace wooden pillars with steel pillars.)
Potential increasing risk that more organisms attacking maritime construction materials (biofouling).	Use of other materials (e.g. steel), biocides, development of alternatives (non-toxic antifouling coatings)
Indirect changes:	
Changes in transport goods and amounts	Adaptation of planning processes and port infrastructure
Indirect impacts: hinterland connections can break down after extreme weather events: ports cannot operate as usual if rail and road traffic or other infrastructure is disturbed after serious flooding or storms.	Adaptation of emergency plans. Change of insurance policy. Increase of the size of deposit of oil and other strategic commodities

3.4 Coastal tourism infrastructure

This chapter focuses on tourism related infrastructure, for a broader assessment on climate change impacts on the tourism sector, see Kūle et al. (pp. 91-132, this volume). Tourism is an important economic sector at the southern coastal areas of the Baltic Sea, but also coastal areas and large archipelagos in other parts (e.g. Turku and Stockholm archipelago, Åland islands) are important for domestic tourism and recreation. Furthermore, large coastal cities such as St. Petersburg, Stockholm, Riga, Helsinki, Copenhagen, and Gdansk and their coastal metropolitan regions with satellite coastal resort towns attract many visitors.

A tourism destination is a place or area that provides the infrastructure to meet the tourists' demands. A destination is characterized by its original and its derived offer: The original offer is defined by natural and socio-economical resources and **basic infrastructure** (implying all resources and services from institutions: landscape, traffic infrastructure and public services, such as waste management, water and energy supply) whereas the derived offer includes everything which is created specifically for tourism – the **supra-infrastructure** (e.g. gastronomy, accommodation, long-haul traffic) (Kaspar 1996). Although this definition is subject to criticism (Mundt 2006), for reasons of simplicity it will be used when portraying the cross-dimensional challenges for tourism infrastructure. Some aspects concerning tourism such as marinas and cruise lines were already covered in 3.2 and 3.3.

Urban and cultural tourism will be impacted similarly by climate change as coastal urban areas in general; especially storm surges, flooding and extreme weather events will become a threat. In general, tourism in the Baltic Sea Region is concentrated in the summer and it is important to consider seasonal specific climate changes.

Finland's national adaptation strategy (Marttila et al. 2005), a study on climate change impacts in Helsinki metropolitan area (Järvinen et al. 2010), City of Stockholm's climate change adaptation strategy (Ekelund 2007), and a report on climate change adaption in Åland (Anonymous 2011) see many positive aspects of climate change in terms of potential for tourism and recreational use of the coasts. These findings are possibly applicable to many other parts of the Baltic Sea Region. Positive outcomes apply especially to summer time recreational opportunities that will improve due to longer summer and ice-free seasons and due to increasing water temperature. In addition, Finland's national adaptation strategy anticipates that in the mid- and long-term climate conditions become unfavourable for tourism in Southern Europe. The report states that predictions on where the tourism will be directed to are prone to several uncertainties, but there is a possibility that northern areas may benefit from increased tourism (Marttila et al. 2005).

Climate change will affect directly and indirectly environmental and societal frame conditions for tourism and recreation. Impacts will vary greatly with location and tourism branch and thus create problems with assessing the relationships between climate change and tourism (Simpson et al. 2008) and to design proper adaptation measures. The complex nature of the interactions that exist between tourism, climate system, environment and society is a cause to the difficulty to isolate the direct observed impacts of climate change upon tourism activity (Simpson et al. 2008). Inability to fully capture the complexity of tourism, and its non-linear and multi-dimensional problems is one of the explanations for the very limited understanding of how climate change impacts will interact with other long-term social and market trends influencing tourism demand and development, including ageing populations, increasing travel safety and health concerns, increased environmental and cultural awareness, advances in information and transportation technology and shifts towards shorter and more frequent holidays (Scott & Becken 2010).

Predicted changes for the cross-sectoral tourism business are diverse. Strategies to adapt to climate change will therefore have to be multidimensional and reach from small-scale behavioural adaptation of tourists themselves to infrastructural adaptation measures. Nevertheless the approach to forecast infrastructural adaptation for tourism infrastructure is essential. Considering the fact that tourism and its infrastructure is a major influencing factor for the coastal landscape in the southern Baltic Sea Region – besides urban development, agriculture, marine industry, and forestry (Gee et al. 2006) – adaptation measures are able to significantly change the appearance of the Baltic Sea coast.

Increasing air and water temperature and changing precipitation patterns

Warmer temperatures can prolong the tourism and outdoor recreation season. Tourism flows will likely be influenced by the increase of annual mean number of summer days. The indicator ‘days with maximum temperatures above 25°C’ points out changes in regional climate extremes with respect to summer temperatures and has from a territorial perspective relevance for the tourism sector as well as for human wellbeing (ESPON-IRPUD 2011). In Europe the volume of tourism might be twice as high in the summer as in the winter season (ESPON-IRPUD 2011). Summer tourism in the Nordic Countries is likely to benefit from improved conditions. Increased temperatures are expected to make this region more attractive to international tourists during summer.

With a projected rise of air temperature there will be an increased risk of summery heat waves and tropical nights (>20°C) and for droughts. In terms of adaptation, cooling and safeguarding water supplies might become more important for some regions. This will concern buildings and public traffic systems (vehicles and roads), and could include air conditioning systems and sophisticated isolation- and shading-systems. Shading and secured water supply is also crucial for all kinds of activities outside, and road and path networks for cyclists, hikers and horse riders will have to be adjusted to the effects of droughts and heat as well. The predicted shift from summer to winter precipitation will have consequences for the water supply in summer. Especially water-intense activities such as golf depend on an adequate amount of water. Outdoor activities could also be limited by an increased danger of forest fires and resulting fire bans for certain recreational areas.

Medical institutions and health services need to adapt their treatment range to heat-related issues; besides from heat and extreme weather events, this could be (among others): intensified UV-radiation, increased exposition of allergen- and air-pollutants and hygiene problems of food and water supply (Eis et al. 2010). The demand for an intensified medical infrastructure (not only in tourism destinations) will be strengthened by the predicted ageing of Western societies as a consequence of demographic change.

Together with an increase of air temperatures, also the water will warm up. That will foster the increase of the length of swimming and water sport season.

The quality of water supply and swimming sites are important aspects that are interlinked with warmer temperature. Due to algae, germs or amoeba in swimming waters, health risks are within reach (Semenza & Menne 2009, Heggie 2010) and swimming, sailing, kayaking, canoeing, diving or fishing can be negatively affected. Availability and quality of marine and freshwater resources are also important for marine and coastal tourism (Orams 1998, Garrod & Wilson 2003). For climate change impacts on water quality and organisms, see e.g. Dahl et al. (pp. 1-34, this volume). Intensified monitoring systems, upgraded waste-water-management and -facilities and visible certification and information (e.g. Blue Flag) can be useful and necessary tools. Alternatives to beach-bathing may prove to be inevitable – swimming pools or other activities – and recreational offers may need to be implemented.

Extreme weather events

Although the development of extreme weather events under global climate change is highly uncertain, an increased occurrence of weather extremes could affect the tourism industry through infrastructure damage, additional emergency preparedness requirements, higher operating expenses (e.g. insurance, awareness campaigns, backup power and water systems, and evacuations), and business interruption (UNEP-CAST 2008). Adapting to a possible rise of extreme weather events will make it necessary to build resilient infrastructure that can withstand hazardous conditions. Since coastal tourism in the Baltic Sea Region is typically a summer time activity, increase of winter storms will not affect tourists directly, but may cause damage to coastal infrastructure and thus indirectly affect tourism.

Traffic infrastructure and activity facilities outside will be affected by heavy rainfall, storms, droughts etc. Extreme weather events can cause a loss of tourist attractions such as beaches, natural and cultural heritage sites/objects, changes of travel plans and increasing insurance costs. Besides from robust construction, shelters with emergency communication equipment could become a key element in ‘climate proof’ activity-based-infrastructure. The need for capacity of rescue service might increase. Of course, not only supra-infrastructure will be affected by climate impacts; basic infrastructure, which tourists also depend on, has to lower its vulnerability on climate impacts as well: power supply, health care, food and water supply need to adjust to climate change likewise.

Sea level rise

One of the most obvious impacts on shoreline infrastructure and the beach itself as part of the ‘natural infrastructure’ is the rise of sea level in the southern parts of the Baltic Sea Region. Beach erosion due to sea level rise is a crucially negative impact to coastal tourism (e.g. Bigano et al. 2008, Phillips & Jones 2006, Buzinde et al. 2010) as tourists do not prefer artificial coastlines or groynes (Hamilton

2007, Meyer-Arendt 2001). The impact of sea level rise intensifies in combination with other climate-influenced changes such as alterations of streaming patterns, wave and wind motions, and number and intensity of extreme weather events. Beaches as one of the most important natural resources for tourism on Baltic coasts might need intensified coastal protection against rising sea levels and altered erosion processes (see also 3.1). Constructional measures – such as flood barriers, dunes, dikes, and groins –, originally built to protect land and people's lives, often also help protecting sandy beaches. However, the construction of more or higher coastal protective measures could locally provoke a significant decrease of the perceived attractiveness of coastal areas. One alternative is (regular) beach replenishment, which implicates high costs though. In addition to beaches, also piers, mobile beach infrastructure, hotels and gastronomy on the shoreline may be threatened by an increased physical energy and pressure from the sea towards the coast. Adaptive measures seek to increase coastal resilience, a concept with ecological, morphological and socio-economic components. Measures to promote coastal resilience include the protection, vegetation and stabilisation of dunes, the maintenance of sediment supply and the provision of buffer zones, rolling easements or setbacks that allow the landward migration of the coastline (Defeo et al. 2009).

Touristic supra-infrastructure situated close to the shoreline and beaches will face climate-induced challenges, too. A rising Baltic Sea threatens buildings such as hotels, restaurants, etc. and holds the potential to force them to relocate further from the shoreline. The shrinkage of existing beaches may force municipalities to allocate new waterfront space for bathing in areas that at present have other functions, such as beach gastronomy in the first row to the water. However, there are also many coastal areas where beaches will be enlarged due to accumulation process as a part of morphodynamic process (Lapinskis 2012). The provision of setback zones, allowing the beach to migrate inland as the sea rises holds minimal ecological consequences for beaches, but is an expensive tool in urban areas (Defeo et al. 2009). Besides from an increased pressure from the sea, beaches are challenged from land based changes as well. Future stressors could be a further intensified recreational beach use due to possibly rising tourist numbers. Amongst the infrastructural consequences of such a development will be the need for intensified beach cleaning management and according facilities such as disposal areas and collection vehicles. Intensified cleaning of beaches from litter (and beach wrack) however technically often involves the removal of sand, a highly valuable touristic resource. However, climate change will probably have only little impact on macroalgae and thereby the amount of beach wrack, at least at the German Baltic coast (Mossbauer et al. 2013).

Adapting to these future challenges for touristic infrastructure in coastal areas will be controversial as the settling of the shorelines is the result of centuries of coastal development. It might include constructional adjustments, building bans in flooding areas and new regulations for constructing buildings or the use and application of mobile infrastructure.

Socio-economic impacts

Further to impacts that can be traced back to new meteorological realities or their direct physical consequences (e.g. a storm flood with high erosion capacity), other impacts on infrastructure in coastal areas will be caused by alterations in the socio-economic background of tourists, tourism stakeholders and tourism destinations. A rise of temperature with less precipitation in summer will likely mean a shift of the tourist season into spring and autumn, especially for southern European destinations. Next to an overall extension of the tourism season, it could also enhance summer holiday conditions in the Baltic Sea area. Fluctuating tourism demand affects tourism flows and thus has an impact also on other sectors like construction, agriculture, and crafts (Council of Ministers of Latvia 2009).

An increased attractiveness of the Baltic Sea for cruise ships will have consequences such as an increasing touristic use of ports (see 3.3) and a rush on adjacent coastal communities.

Marine traffic will not be the only traffic undergoing severe challenges. With an increased attractiveness for bathing tourists and a possible increase of tourist numbers in summer months, railways, streets and airports could reach their maximum capacity in the peak season and regions might require new and expanded coastal traffic systems. Basic and supra-infrastructure for supply, accommodation, entertainment and gastronomy need to be established and adjusted to increased tourism numbers. There are unutilized tourism infrastructure capacities in important coastal resort towns of the former all-Soviet Union where renewal is needed. Adaptation strategies could be included already in the near future and make these areas easier to adapt than other regions.

Regardless of how extensive future changes may be – in contrast to the fairly new challenges which are caused by direct and indirect physical climate impacts – infrastructure adaptation to socio-economic challenges can be built to some point upon experiences from the past. Expanding tourism numbers, resulting pressure on tourism infrastructure and resources and changing tourism pattern are no new phenomena – experiences and insights made by other destinations can help the Baltic Sea Region to cope with it. Every destination has a limited capacity though. Possible adaptation measures may include zoning regulations, building codes, preventive planning and growth strategies (Wall & Mathieson 2006).

Table 4 gives an overview on potential climate change impacts on coastal protection and adaptation options.

Table 4: Potential climate change impacts on coastal tourism infrastructure and adaptation options.

Climate change impact	Adaptation options
Increase of atmospheric temperatures:	
Longer tourism season, increasing attractiveness for e.g. bathing tourists and cruise ships with consequences such as increasing tourist numbers, increasing touristic use of ports and beaches and rush on adjacent coastal communities in summer months; railways, streets and airports could reach their maximum capacity in the peak season	New opportunities for local economy
	Integration in spatial planning/regional plans (e.g. ICZM)
	Adaptation of tourism infrastructure (expansion of accommodation, entertainment and gastronomy)
	Adaptation (expansion) of coastal traffic infrastructure and systems (including parking places), road and path networks for cyclists and hikers
	Intensified beach cleaning management and according facilities such as disposal areas and collection vehicles
	Air conditioning systems and sophisticated isolation- and shading-systems
	Safeguarding water supply
	Expansion of port infrastructure, larger ships as well as transport from port to hinterland
	Simultaneous increase in tourism and maritime traffic might lead to conflicts of interest
Changes in tourism activities	New opportunities for local economy; adaptation of offers regarding water sports such as sailing (marinas)
Risk of summer heat waves and tropical nights, intensified UV-radiation, increased exposition of allergen- and air-pollutants and hygiene problems of food and water supply	Adaptation/intensification of medical infrastructure
	Air conditioning systems and sophisticated isolation and shading systems
	Adaptation (safeguarding) water supply, establishment of stations with free drinking water
	Improved information and knowledge distribution, using regional media as early warning systems
	Path networks for cyclists and hikers will have to be adjusted to the effects of droughts and heat
Increased humidity – increased growth of fungus and mould: damage to buildings	Resistant materials and improved ventilation
	Improved information and knowledge distribution
Precipitation changes: Increase (projected for the winter season)	
Flooding: damage to tourism infrastructure constructions	Intensification of coastal protection
	Development of new concepts for increased coastal resilience: coastal realignment, non-technical options, new techniques, vegetation and stabilisation of dunes, combination of hard and soft measures

	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
	Improved information and knowledge distribution
	Building ban for areas threatened by regular flooding events; camping areas in flood prone areas which can be rapidly evacuated
Landslides/soil erosion: loss of territory (e.g. beaches) and infrastructure constructions (e.g. buildings)	Intensification of coastal protection
	Development of new concepts for increased coastal resilience: coastal realignment, non-technical options, new techniques, vegetation and stabilisation of dunes, combination of hard and soft measures
	Constructional measures to protect sandy beaches (flood barriers, dunes, dikes, groins)
	Beach replenishment
	Maintenance of sediment supply and buffer zones
	Setbacks that allow landward migration of the coastline
	Improved information and knowledge distribution
Rise of groundwater level: damage to infrastructure constructions e.g. buildings	Adaptation of building constructions
	Adaptation of coastal cities to changes in hydrological processes/regimes
Increase of wetland areas: damage to infrastructure constructions e.g. buildings; increase of mosquitoes	Development of new concepts for increased coastal resilience: coastal realignment, non-technical options, new techniques, vegetation and stabilisation of dunes, combination of hard and soft measures
	Relocation of buildings
	Integration in spatial planning/regional plans (e.g. ICZM): identification of buffer zones, flood plains and hazard zones
	New tourism activities
Precipitation changes: Decrease (projected for the summer season)	
Shift from summer to winter precipitation: consequences for water supply in summer. Especially water-intense activities such as golf depend on adequate amounts of water	Changes of water supply and watering practices
Droughts: damage to vegetation, increasing risk of forest fires	Changes of watering practices; improved information and knowledge distribution
Changes in wind regime: Increase in storms (intensity):	
Damage to coastal tourism infrastructure (since coastal tourism in the Baltic Sea Region is typically a summer time activity, increase of winter storms will not affect tourists directly, but may cause damage to coastal infrastructure and thus indirectly affect tourism)	Adaptation of infrastructure construction (new concepts, techniques)
	Adaptation of building constructions
	More shelters with emergency communication equipment
	Capacities of rescue services should be evaluated and adapted
Damage to electricity supply	
Variability of weather/extremes:	
Safety risks (e.g. higher operating expenses, and business interruption)	Adaptation/intensification of medical infrastructure
	Emergency preparedness (e.g. insurance, awareness campaigns, backup power and water systems, and evacuations, more shelters with emergency communication equipment)
	Improvement of information
	Infrastructure constructions that can withstand hazardous conditions (new concepts, techniques)
	Evaluation and adaptation of rescue service capacities
More extreme rainfall or snowfall: damage to properties and tourism infrastructure	Adaptation of building materials and constructions
Traffic infrastructure and activity facilities outside affected by heavy rainfall, storms, droughts etc.	Adaptation of coastal traffic infrastructure; change of insurance policy
Loss of tourist attractions such as beaches, natural and cultural heritage sites/objects	Protection

Sea level rise: Flooding/coastal zone erosion	
Damage to coastal protection structures, housing, cultural monuments (cemeteries), port infrastructure piers, mobile beach infrastructure, hotels and gastronomy on the shoreline	Intensified coastal protection, adaptation of infrastructure constructions (new concepts, techniques) etc. (see Table 1)
Loss of territory (e.g. beaches) and built structures (e.g. roads, buildings, cultural monuments, port infrastructure)	Intensified coastal protection etc. (see Table 1) Shrinkage of beaches may force municipalities to allocate new waterfront space for bathing in areas that at present have other functions, such as beach gastronomy in the first row to the water.
	Constructional measures to protect sandy beaches (flood barriers, dunes, dikes, groins) - more or higher coastal protective measures provoke decrease of perceived attractiveness of coastal areas though
	Beach replenishment
	Maintenance of sediment supply and buffer zones
	Setbacks that allow landward migration of the coastline
	Improved information and knowledge distribution
	Besides from an increased pressure from the sea, beaches are challenged from land based changes as well (e.g. intensified recreational beach use due to rising tourist numbers) – integrative planning
Increase of water surface and wetland areas	New tourism activities
Decreased ice covers:	
	Change of tourism activities (decrease of ice-fishing)
Wind waves:	
Moderate changes in wave conditions	Change of tourism activities: new opportunities for sports using wind and waves (wind-surfing, kiting, etc.), positive for local economy, but requirements for new infrastructure (sport tourists); potential restrictions to swimming and boating.
Increase of water temperatures:	
	Change of tourism activities. New opportunities for local economy. New opportunities for bathing tourism and water sports, less need for swimming pools with heated water
Possible increase of algal blooms	Change of tourism activities (e.g. increasing need for pools)

4 Knowledge/Research Gaps

4.1 Climate change impacts on environmental conditions

Although a number of model simulations have been carried out, still high uncertainties with regard to model results remain. Local information of climate change (e.g. temperature, precipitation), detailed timeframes and magnitudes are often lacking. For example for precipitation, wind, and evaporation, large uncertainties exist and thereby projections of e.g. future river discharge are highly uncertain.

Due to the knowledge gaps in climate change e.g. regarding temporal and spatial scales, knowledge on climate change impacts on environmental conditions is also often missing or highly uncertain. Different scenarios and different models deliver different results, which makes adaptation planning difficult. It is a complex issue, many interrelations exist with environmental stress such as from anthropogenic nutrient emissions. Some examples of identified research needs/topics are listed in Table 5, a broad overview was also given by the Marine Board (2011). However, detailed (case) studies always need good background data (improvement of climate and ecosystem modelling).

Table 5: Research needs/topics identified for climate change impacts on environmental conditions important for infrastructure at the Baltic Sea area (partly extracted from Bruneniece 2012)

Climate change impact	**Research needs (topics)**
General	Poor representation of the Baltic Sea (Region) in climate models
	Inadequate sampling of uncertainties in the chain of climate change to impact scenarios
	Lack of good data for model evaluation purposes
	Fragmentation of existing information on climate change impacts and measures to be taken to adapt to it – need for systemic and interdisciplinary researches
	Missing capacity in area of the climate change modelling and major doubts on the applicability on possibilities to use approaches
	Lack of research and information on climate change impacts on ecosystems, on ecosystems goods and services
	Missing knowledge on the systemic character of climate change system and impacts, and therefore - how to adapt to climate change
	Develop climate change scenarios that integrate environmental, land-use, geographical and socio-economic aspects
	Develop tools for multi-disciplinary research (for combining various types of inform.)
	Impacts on habitats and organisms
	Impacts on turbidity
Flood risks	Altitude information is imprecise e.g. in Helsinki coastal area, leading to mistakes in flood prognoses
	Synthesis studies, e.g. flood risk maps
	Research on flood dynamics
	Combined use of different information sources (hydrology models, hydraulic models, flood maps, etc.)
	Flood/drought event case studies
	Economic assessment of flood risks and flood risk mitigation
	Risk-index system needed
	Mathematical modelling of sand outwash dynamics
Sea level rise	Coastal zone erosion and flooding and which areas and constructions would be affected (e.g., detailed maps)
Extreme weather events	Development and changes/erosion of different coastal types
Precipitation	Improved understanding of changes in river run-off, nutrients loads, and eutrophication as well on a Baltic Sea wide scale as on a local scale
Salinity Reduced ice cover Change of stratification	Many knowledge gaps; improved understanding of changes and their effects on the ecosystem necessary. Distinction between a variety of effects such as eutrophication and climate change.
Water quality	Impact of climate change induced land-based changes

4.2 Climate change impacts on infrastructure

Resulting from uncertainties in climate change knowledge and its impact on environmental conditions, also many uncertainties exist for infrastructure aspects. Some general research needs identified are (see also Table 6):

- economical (cost-benefit) and management aspects of possible climate change adaptation measures
- participatory action research and policy transfer (Baltic Sea Region-wide, EU-wide and trans-national) with focus on climate change adaptation options used in coastal infrastructure
- linking mitigation and adaptation measures, particularly in buildings, structures and transport used in economical activities on the coast

- improvement of indicators used, data availability and monitoring in relation to climate change impacts and adaptation measures in coastal areas
- review of coastal monitoring data
- integrated development of off-shore and coastal areas. Preparation of scenarios, adaptation strategies and intervention plans towards mitigation of impacts of climate change on coastal area (ESPON-IRPUD 2011)
- holistic approaches to identify impacts of climate and global change (including demographic changes).
- climate change impact assessments on coastal and island areas, including tourism and water quality (algae blooming) (ESPON-IRPUD 2011)
- support to research and practice thus encouraging innovative activities and learning of individuals and organizations. Support to model, pilot and demonstration actions where public, private and scientific organisations are jointly participating (ESPON-IRPUD 2011)

Coastal protection

Knowledge on regional/local changes and their time horizon are especially necessary when planning adaptation measures for coastal protection. On the one hand, many details are already known as coastal protection is also an issue today, on the other hand, much knowledge is lacking on a local scale. Also, impacts of changes in temperatures and precipitation on materials and construction have to be investigated.

There are very few numerical studies on the hydrodynamic parameters of a coastal underwater slope and specific bottom profile properties. To improve understanding of coastal evolution, parameters of longshore wave currents and surf zone dynamic peculiarities must be analysed. The available data regarding sediment types, sources and budget are sparse and fragmented. This gap in research is associated with insignificant knowledge to date about longshore sediment drift parameters, which are essential for choosing adequate coastal protection measures.

Monitoring of coastal geological processes, particularly in the sections most vulnerable are necessary. For instance, a stationary network which covered all key areas of the coastal stretch of Latvia was formed during early 1990s. Monitoring of coastal processes was based on repeated measurements of cross sections of the upper (subaerial) part of the coastal slope. Since 2010, due to lack of funding, measurements were terminated in most areas. Furthermore, there are no data on cultural monuments (including buildings and cemeteries) directly affected by erosion. The use of erosion-affected buildings is often unknown in many Baltic Sea Region countries, particularly post-Soviet, and it is also unclear how many people are living permanently on the coast and for how many people endangered buildings are the only residence. That complicates studies on vulnerability. Buildings can be used permanently or seasonally as second homes or for tourist activities and accommodations.

Modelling of coastal evolution will be further required. For instance, there have been no large-scale coastal evolution modelling attempts in Latvia except cases when limited available data were used in some simplified calculations. Process-based morphodynamic modelling could be a valuable tool for coastal scientists and managers. It is necessary to have the possibility to investigate the effects of climate change in association with possible adaptation measures.

Analysis of effectiveness, environmental impacts and longevity of different possible coastal protection measures will be necessary. To adopt the most appropriate decision regarding manage-ment of the coastal sections with erosion and/or flooding risk, knowledge is required respecting all possible consequences. Coastal protection and especially hard engineering measures are in most cases connected with many short and long-term impacts to the coastal processes in adjacent areas, quality of environment, landscape, recreation, protected nature areas etc.

Table 6: Research needs and challenges identified for climate change impacts on infrastructure at the Baltic Sea area (partly extracted from Bruneniece 2012).

Climate change impact	Research needs
General	Fragmented existing information on climate change impacts and adaptation measures – need for systemic and interdisciplinary researches (connecting e.g. social and natural sciences); social science, economics, spatial planning, and organization studies to proceed from studying impacts towards adaptation research
	Analysis of international trends in economy (e.g. agriculture markets, energy prices) especially also for neighbouring areas
	Review and policy transfer options proposal/Analysis of climate change adaptation activities in other countries
	Research on linkages between coastal uses and economic activities (energy, infrastructure, tourism, transport, housing): collect available domestic and international data and conduct a comprehensive research, which would form the general basis for further policy developments in respective sectors.
	Develop methodology to assess the costs of inaction as opposed to cost of preventive/adaptive measures.
	Climate change catalyses new and innovative measures to be taken to avoid damage from extreme weather events: develop overview of best practices and policy recommendations. Need to include climate change adaptations in mainstream policy instruments that are facilitating innovative practices in the EU and national policies.
	Climate change influences local and regional authorities (especially those located on coastal areas) and catalyses their involvement in adaptation issues. Research to develop guidelines and good practices for the involvement of local and regional authorities in adaptation issues. There is a need for national and Baltic Sea regional level recommendations. Need to cooperate with VASAB. Multi-national trans-disciplinary research is needed between spatial planning, architecture and construction and climate change experts.
	Need for data on climate change impacts (gains and losses, including land and property). Further research on analyzing coastal changes and forecasting climate fluctuation impacts' on the coastal dynamic and ecosystems of the Baltic Sea (e.g. in Latvian territorial waters; maps 'Coastal processes. Forecast and risk'). Interdisciplinary research how coastal processes influence socio-economic factors.
	Research to understand linkages between coastal hazards and coastal risks, and implications to policy design
	Research to minimise various aspects and dimensions of uncertainties in climate change – particularly the need of research on time scales for each impact type and possible measures (see example- UKCIP 2011:4)
	Improvement of coastal monitoring and its methods. Mainstreaming climate change adaptation data needs into general socio-economic and environmental data needs at international, national and regional levels
Flood risks - damage to housing, implications for spatial planning	In some countries, mapping of buildings at the coast is not accurate or up to date, or statistical data are missing on e.g. use of buildings, number of people living permanently at the coast. This complicates studies on vulnerability and recommendation preparation of possible policy options.
	Research how land-use planning can tackle both climate change mitigation and adaptation
	Economic assessment of flood risks and flood risk mitigation
	Risk-index system is needed
Extreme weather events	Impacts on sea transport and port operations - oil pollution, coastal erosion and high raised coastal installations (wind turbines etc.)
Extreme weather events/increase of precipitation	Socio-economic studies on river basins affected by increased river run-off/flooding including economic losses and adequate policy measures proposed at local level (e.g. Nemunas River, Dane River and Minija River)
Changing climate and extreme weather events	Develop methodology for assessment of economic damage/losses of climate change-related extreme weather events (storms, floods).

Maritime traffic and ports

Many research gaps exist for climate change impacts on maritime traffic and ports. Next to in depth studies for local/regional climate changes (temperature, solar radiation, precipitation, wind, sea level), several analyses would be necessary, e.g. (Ministry of Economy, Labour and Tourism Mecklenburg-Vorpommern 2010):

- Analysis of requirements of building/construction owners/users due to changed climatic conditions
- Analyses of behavioural changes of building users and possibilities of achieving such
- Analyses of possible adaptation of planning criteria for buildings/constructions and for determination of their energy demand as well as the design of buildings
- Analysis of requirements of design, dimensioning and operational/system management
- Analyses of future demand of buildings for design, dimensioning and energy demand of air conditioning systems
- Analyses of possibilities for the use of green energy
- Maximal power of heating systems should be adapted to changing temperatures

Tourism related infrastructure

Regional/local vulnerability analyses for coastal tourism areas that clearly depict the potential economical impacts of existing infrastructure vulnerabilities might help to sensitize local politicians and entrepreneurs as well as responsible authorities for the absence of strategic adaptation but also for adaptation potentials of their destination. Availability of data for those analyses is likely to differ within the Baltic Sea Region. Further research on regional impact will be necessary with regard to climate, economical and social sciences. Knowledge on potential shifts of tourism flows within Europe is scarce and potential demand changes highly speculative. Further research on potential shifts of the attraction of tourism destinations will be needed.

Future studies on climate change impacts on tourism are suggested (Dubois & Ceron 2006) to perform in various forms:

- Comparative research: exploring why some destinations are more sensitive to climate change than others (e.g. diversity of supply and demand factors), what are the different methodologies used to assess the potential impact of climate change? Linking tourism destinations with similar climate change impacts, facilitating learning and policy transfer.
- Studies of the impacts of extreme events on tourism and capacity to cope with it, studies on vulnerability of particular tourism sites (resorts).
- Trans-disciplinary research activities linking social, economic and climate change (natural sciences) researchers from different Baltic Sea Region countries.
- Activity-oriented and participatory action research, dealing with the impacts on activities, e.g. bathing activities by concentrating on the climate linked resources of tourism.

Until now there are no specific Baltic Sea Region-wide studies on climate change impacts and its adaptation for tourism with focus on marine and coastal tourism. Identified knowledge gaps and topics for further investigation in the field of climate change adaptation for the tourism sector and relevant to Baltic Sea coastal area (based on Turton et al. 2010, modified):

- Creating better, more regionally specific climate projections. Tourists are generally mobile within a regional destination, and broad effects mapping may not take account of local variations and tourist behaviour, e.g. coastal cooling breezes vs. inshore heating.
- How will tourism behaviour change by changing climate elements and their variability?

- Technologies to help mitigate and adapt to climate change – adequate technologies for different types of coast (dynamics and morphology) and the degree of tourism development (urbanization, share of built-up areas).
- Environmental (climate change mitigation), cultural, social and economical impacts of switching outdoor activities to indoor places (indoor mountain skiing, water sports, field sports, running, etc).
- Improvement of tourism professional education, improvement of information distributed to tourists and tourism agencies, cooperation with editors of tourism guides, advertisement information etc.

In many countries of the Baltic Sea Region, the topic of coastal tourism and climate change has been studied little, which is probably reflecting the relatively low importance of coastal tourism business and anticipated low risk of negative climate change impacts.

Some open questions related to climate change impacts are: Will higher temperatures lead to a prolonged season for water sports and economic benefit? Or will too calm periods for sailing occur regularly during summer due to stable weather conditions and heat waves and weaken the attractiveness of the Baltic Sea for sailors? Will new water sports (for instance wind surfing) be introduced or other changes occur to existing opportunities (ice-fishing)? How safe will pleasure boats have to be in the future? Will canoe tours still be justifiable or is the changing climate threatening leisure activities?

5 Discussion and conclusion

This report summarizes anticipated climate change impacts and adaptation options regarding certain issues of coastal infrastructure in the Baltic Sea Region. However, climate change impacts always have to be seen in the context of other developments. Societal, economical, ecological, and political influences will play a major role for future developments. These influencing factors will affect among others markets, trade, cargo, economic growth, and energy policy. Political decisions, economical developments, and technical innovations may cause major changes within short time scales as past experiences (e.g. rapid increase of alternative energies such as offshore wind farms) have shown.

Apart from climate change impacts in the Baltic Sea Region, maritime shipping will, for example, become globally affected by climate change and other future developments. Ports worldwide are furthermore connected via various waterways. Hence, drastic changes in other port-regions will also have to be taken into account when considering the Baltic Sea Region.

Regarding climate change in the Baltic Sea Region, several contradictory developments are possible, it remains uncertain what will be dominating or whether effects will level each other out. One example is sea level rise which could lead to deeper waterways without dredging at the southern Baltic Sea and ships with more draft could enter ports. However, on the other side extreme storm events due to climate change could lead to coastal erosion which could require an increasing need for dredging (Schnellhubner & Sterr 1993). Another example is that higher temperatures lead to a prolonged season for water sports. However, calm periods during summer due to stable weather conditions and regular heat waves could make the Baltic Sea less attractive for sailors. Climate change scenarios show for most Baltic Sea regions a decrease in sea ice extent. This would have a positive impact on ports. But more freshwater discharge in the north of the Baltic Sea could result in more ice at river outlets (PIANC 2008) and most ports are situated at river mouths.

Summarizing overall effects – and disregarding specific difficulties on a detailed level – sea level rise and a possible increase in wind/waves and extreme weather situations will be of major importance and present high risks to infrastructure in the Baltic Sea Region (Table 7). However, model results regarding especially these issues are associated with many uncertainties. Anticipated increases of air and water temperature and an accompanying decrease in sea ice cover offer many chances to infrastructure in the Baltic Sea Region though. It is often argued that risks should be classed in different categories and a concept of consequences should be defined.

Table 7: Relative importance of anticipated climate change to selected infrastructure sectors.

	atm. temp.	water temp.	preci-pitation	wind	waves	extreme weather	SLR	ice	sali-nity	preci-pitation
	↑	↑	↑	↑	↑	↑	↑	↓	↓	↓
Coastal protection	yellow	yellow	orange	red	red	red	red	green	yellow	yellow
Maritime traffic	yellow	yellow	yellow	red	red	red	green	green	yellow	yellow
Ports and marinas	yellow	yellow	orange	red	red	red	red	green	yellow	orange
Touristic infrastructure	yellow	yellow	orange	red	red	red	red	green	yellow	orange

Red: high climate change impacts/risks anticipated; orange: medium climate change impacts/risks anticipated; yellow: indifferent; green: positive impacts anticipated

Consequences of climate change will affect the coasts of the Baltic Sea Region differently – depending on exposure/sensitivity and the adaptive capacity of specific coastal sites. Adaptive capacity of coasts depends on a broad set of 'soft' and 'hard' factors such as:

- coastal protection measures and its funding,
- spatial planning instruments and their implementation,
- willingness to establish multifunctional use of coastal zones,
- environmental awareness, etc., risk communication and other relevant information distribution,
- other flexible and innovative approaches through the creation of new knowledge and the transfer of best policy options available.

Climate change is very likely to have a significant impact on coastal infrastructure in the Baltic Sea Region – both positive and negative impacts are possible and anticipated. However, most literature – especially on climate change adaptation – deals with negative impacts, probably because people seek to be prepared for risks and adaptation measures cost. It is for example necessary to increase coastal protection measures to protect infrastructure from rising sea levels. In respect to the precautionary principle, it is unlikely that coastal protection would be reduced if storm intensity would be projected to decrease as there will always be the risk of single hazard events.

Although most of the addressed infrastructure lasts for several decades, the planning horizon for investment decisions is in general shorter (Becker et al. 2011, Becker et al. 2012). As a consequence authorities and economy have to deal with the problem of different time frames. Investigating in climate change adaptation needs 'long-term decisions which are incompatible with the investment timeframes of businesses' (UKCIP 2011: 2). The port of Felixstowe in England decided to use different time scales and scenarios for its assessment (UKCIP 2011: 4):

- The current climate e.g. for decisions relating to contracts/office management.
- The 2030s climate e.g. for decision relating to new equipment technologies.
- The 2060s climate e.g. for decisions relating to new developments.

This approach could be practical to adapt by authorities in the Baltic Sea. Reacting to more regular occurring heat waves with cooling systems that can easily and rapidly be installed is an example of planning in shorter time scales. However, coastal protection measures in reaction to sea level rise need a long political and administrative planning horizon (Figure 2).

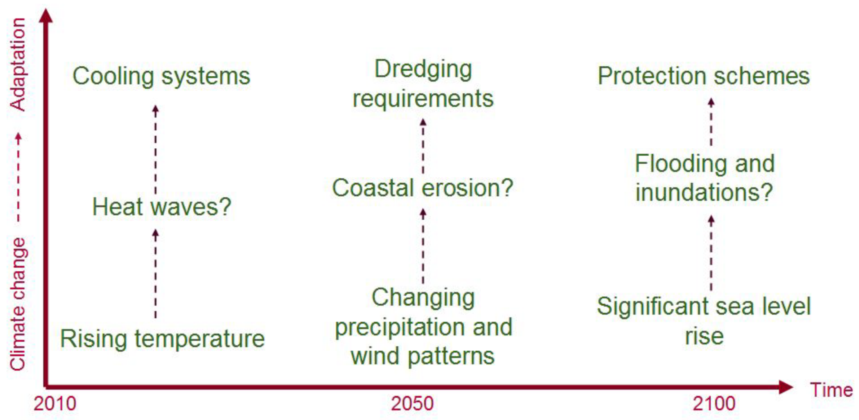

Figure 2: Planning on different time scales.

Also, some changes will occur al-ready in the next decades whereas others will come more slowly. But to implement climate change scenarios and adaptation possibilities in their planning efforts, port authorities need scientific information on localized impacts which is still quite limited (Becker et al. 2011) and time frames for anticipated changes. Hence, high resolution models for coastal zones in the Baltic Sea are demanded. Coastal geological process monitoring needs to be improved nationally and there has to be an exchange of information on coastal evolution modelling and on planning and utilization of coastal protection measures in the Baltic Sea area, particularly among coasts of similar types.

This review shows that adaptation can take place at various levels. Hard measures such as raising docks or building dikes can be implemented, but focus should also be on adaptation strategies regarding management options and supporting flexibility. The concept of 'no-regret measures' should always be considered. There is a knowledge gap between concrete technical adaptation measures and very vague or general principles of adaptation (Eisenack et al. 2012). These authors also mention that there is not much knowledge on factors that might impede or strengthen implementation as well as how to select and implement adaptation. Adaptation to climate change in coastal areas is not so much a technical challenge, but rather a political, economic and social function. Spatial planning approaches (legal regulation, communicative and participatory planning approaches as well as Integrated Coastal Zone Management) play a prominent role in climate adaptation policies – most countries in the Baltic Sea Region implement adaptation and retreat measures in the coastal zone using spatial planning regulations. Spatial planning approaches are appropriate both in solving conflicts in coastal zones and integrating different land and coastal uses. Climate change can have impacts on the factors 'safety', 'reputation' or on 'costs' (UKCIP 2011) and often different sections in the authority are responsible.

One challenge to implement adaptation measures in ports might be the limited space to ex-pand. Urban sites close to the sea are attractive zones for settlements or tourism and have to compete with the shipbuilding industry and other marine uses (Innenministerium des Landes Schleswig-Holstein 2006). Countries that do not have built-up areas close to the sea coast have to maintain such policies in spite of developers' interests and property market shorter demands (Council of Ministers of Latvia 2011).

Adaptation costs may seem to be high at the moment, but 'ensuring adequate financing for adaptation in maritime transport is likely to also achieve some collateral benefits (e.g. transport efficiency and trade facilitation), which could help partly offset the adaptation costs' (UNCTAD 2008: 15).

Adaptation as a topic is becoming more popular among port authorities but specific regional information and concrete scenarios are missing. The first international survey of port administrators by Becker et al. (2011) showed that only 34% felt sufficiently informed. This emphasizes the need of collaboration between scientists and stakeholders. Stakeholder involvement and public awareness rising will be an important issue.

Other problems beyond climate change might appear more urgent to port authorities. For example, the Fehmarn belt fixed link between Germany and Denmark was debated hotly during a workshop for port directors although the main topic of the meeting should have been climate change adaptation. Consequently there is limited pressure to invest in adaptation, but ‘to remain efficient and resilient, seaports must anticipate the impacts of climate change and proactively prepare for sea level rise, increased flooding, and more frequent extreme storm events’ (Becker et al. 2011: 1).

Regarding climate change adaptation, the German Federal Government (2008) sees the necessity

- to improve the knowledge base in order to identify and communicate opportunities and risks and demonstrate opportunities for action,
- to create transparency and participation by broad communication and dialogue processes and to support various stakeholders by providing, for example, decision support and aids,
- to promote awareness and information through public work,
- to develop strategies to deal with uncertainty.

Table 8: Mitigation measures related to infrastructure in the Baltic Sea Region.

Mitigation measures for ports	**Reference**	**Linkage to climate change impacts or adaption strategies**
Electrification of trucks and cranes; installation of on-shore power supply	Becker et al. 2011	Are high voltage lines storm- and flood-proof?
Co-investing in land equipment and vehicles such as feeders, barges and rail solutions	UNCTAD 2008, Reise 2009	Modal split as an adaptation option? Offshore anchored container terminals with feeder services?
Reconfiguring terminals to improve barge access, enhance on-dock rail capabilities, accelerate loading	UNCTAD 2008	Lift-on/Lift-off might replace roll-on/roll-off in loading processes?
Taxation, differentiated port fees and emission trading programmes	UNCTAD 2008	Incentives for ports which have already implemented adaptation measures?
Mitigation measures for maritime traffic	**Reference**	**Linkage to climate change impacts or adaption strategies**
Use of extra sails (wind power)	Federal Ministry of Transport, Building and Urban Affairs Germany 2007	Changing wind patterns have to be considered
Technologies to increase energy efficiency; use of alternative fuels (natural gas, less controversial biofuels (e.g. waste-based), solar panels, hydrogen-propelled ships, fuel cell power for auxiliary engines)	UNCTAD 2008	Ships using liquid natural gas (LNG) need special permits to enter ports; hence international binding regulations and admissions are required. Increased solar irradiation might be positive for ships using solar panels.
Speed reduction and re-routing	UNCTAD 2008	New routes have to be mapped.

Infrastructure in the Baltic Sea Region will be affected by a variety of climate change impacts. Climate change impacts and associated costs have to be implemented in investments decisions. However, details are not sufficiently known. Explicit scientific information on localized impacts is demanded by authorities and economy to implement climate change scenarios in their planning efforts. Insurance is an important topic, not only for adaptation to climate change in ports but for all coastal aspects, but to discuss insurance options and incentives goes beyond the scope of this review.

Mitigation strategies to combat global warming are in general more progressive and advanced in the maritime sector whereas adaptation studies in the Baltic Sea Region are often fragmented and an overarching framework is missing. Some of the mitigation measures might interact with adaptation strategies or have to be reconsidered in regard to climate change impacts (Table 8). Climate change could also allow new opportunities for alternative energy sources such as e.g. solar and wind energy.

For further information, recent projects which deal with climate change impacts on infrastructure and adaptation options in the Baltic Sea Region are pointed out (Table 9).

Table 9: Projects which explicitly focus (in subtopics) on climate change impacts and adaptation possibilities for infrastructure of the Baltic Sea Region (apart from Baltadapt).

Project		Funding	Period
BaltCICA	Climate Change: Impacts, Costs and Adaptation in the Baltic Sea Region (www.baltcica.org)	Baltic Sea Region Programme	2009-2012
ESPON-CLIMATE	Climate Change and Territorial Effects on Regions and Local Economies in Europe (www.espon.eu)	ESPON 2013 Programme	2009-2011
KLIWAS	Impacts of climate change on waterways and navigation - Searching for options of adaptation (www.kliwas.de)	Federal Ministry of Transport, Building and Urban Development Germany	2009-2013
RADOST	Regional adaptation strategies for the German Baltic Sea Coast (www.klimzug-radost.de)	Federal Ministry of Education and Research Germany	2009-2014

References

Alberth, J., M. Hjerpe & I. Schauser (2012): Conceptualisation of Vulnerability and Review of Assessments around the Baltic Sea Region. Baltadapt Report # 7. Danish Meteorological Institute, Copenhagen. www.baltadapt.eu.

Anonymous (2011): PM om anpassningsåtgärder p.g.a. klimatförändringen. Mariehamn, Ålands Landskapsregering/Miljöbyrån. 23 pages. www.regeringen.ax/.composer/upload//socialomiljo/oversvamning_klimat_PM.pdf.

BACC Author team (2008): Assessment of Climate Change for the Baltic Sea Basin. Springer, Berlin.

Baltadapt Climate Info Bulletins: Climate Change in the Baltic Sea Region. www.baltadapt.eu

Becker, A., M. Fischer, B. Schwegler & S. Inoue (2011): Considering Climate Change: A survey of global seaport administrators. CIFE Working Paper 128. Stanford University.

Becker, A., S. Inoue, M. Fischer & B. Schwegler (2012): Climate change impacts on international seaports: knowledge, perceptions, and planning efforts among port administrators. Climatic Change 110: 5-29.

Bigano, A., F. Bosello, R. Roson & R.S.J. Tol (2008): Economy-wide impacts of climate change: A joint analysis for sea level rise and tourism. Mitigation and Adaptation Strategies for Global Change 13: 765-791.

Briede, A. (2006): Latvijas klimata mainības tendences./Tendencies of climate change in Latvia. LU 64. zinātniskā konference (Ģeogrāfija. Ģeoloģija. Vides zinātne),), Latvijas Universitāte, Rīga, pp 19-21. (in Latvian)

Bruneniece, I. (2012): Gap-fit Analysis on Adaptation to Climate Change Research and Policy Design. Synthesis Report. Baltadapt Report # 1. Danish Meteorological Institute, Copenhagen. www.baltadapt.eu.

Buzinde, C.N., D. Manuel-Navarrete, E.E. Yoo & D. Morais (2010): Tourists' perceptions in a climate of change: Eroding destinations. Annals of Tourism Research: 37: 333-354.

Caldwell, H., K.A. Quinn, J. Meunier, J. Suhrbier & L. Grenzeback (2002): Impacts of global climate change on freight. Proceedings, Federal Research Partnership Workshop “The potential impacts of climate change on transportation.” U.S. Department of Transportation Center for Climate Change and Environmental Forecasting.

Council of Ministers of Latvia (2009): Latvijas Tūrisma attīstības pamatnostādnes 2009.-2015.gadam Globālās tendences un perspektīvas pasaules tūrismā, Pielikums Nr. 2 [Latvia Tourism Development Policy Guidelines 2009-2015, Global trends and challenges in the World tourism, Annex 2] Prepared for the Council of Ministers of Latvia, 2009. www.mk.gov.lv/doc/2005/EMpamn_060509_turpamn.315.doc.

Council of Ministers of Latvia (2011): Piekrastes telpiskās attīstības pamatnostādnes 2011.-2017.gadam. [Guidelines for the Spatial Development of the Coastal Area 2011-2017]. Adopted by the Council of Ministers 20.04.2011. http://polsis.mk.gov.lv/view.do?id=3634.

Dahl, K., A. Josefson, C. Göke, J.P.A. Christensen, J. Hansen, S. Markager, M.B. Rasmussen, K. Dromph, T. Tian, Z. Wan, I. Krämer, M. Viitasalo, K. Kostamo, K. Borenäs, J. Bendtsen, G. Springe & E. Bonsdorff (2012): Climate Change Impacts on Marine Biodiversity and Habitats in the Baltic Sea – and Possible Human Adaptations. Baltadapt Report # 3. www.baltadapt.eu

Davies, R. (1984): What is a wave dominated coast? Marine Geology 60, 313–329.

Defeo, O., A. McLachlan, D.S. Schoeman, T.A. Schlacher, J. Dugan, A. Jones, M. Lastra & F. Scapin (2009): Threats to sandy beach ecosystems: A review. Estuarine, Coastal and Shelf Science 81: 1-12.

DGzRS – Deutsche Gesellschaft zur Rettung Schiffsbrüchiger (2008): DGzRS Station Darßer Ort. (www.dgzrs-darsserort.de).

Dubois, G. & J.-P. Ceron (2006): Tourism and Climate Change: Proposals for a Research Agenda. Journal of Sustainable Tourism 14: 399-415.

Eberhards, G. (2003): Latvijas jūras krasti. Latvijas Universitāte, Riga. (in Latvian).

Eberhards, G., I. Grine, J. Lapinskis, I. Purgalis, B. Saltupe, & A. Torklere (2009): Changes in Latvia`s seacoast (1935–2007). Baltica 22 (1): 11–22.

Eberhards, G., J. Lapinskis, & B. Saltupe (2006): Hurricane Erwin 2005 coastal erosion in Latvia. Baltica 19 (1): 10–20.

Eberhards, G. & J. Lapinskis (2008): Baltijas jūras Latvijas krasta procesi: Atlants/ Processes on the Latvian Coast of the Baltic Sea. Atlas. Latvijas Universitāte, Rīga.

Eis, D., D. Helm, D. Laußmann & K. Stark (2010): Klimawandel und Gesundheit. Ein Sachstandbericht. Berlin: Robert-Koch-Institut.

Eisenack, K., R. Stecker, D. Reckien & E. Hoffmann (2012): Adaptation to climate change in the transport sector: a review of actions and actors. Mitigation and Adaptation Strategies for Global Change 17: 451-469.

Ekelund, N. (2007): Anpassning till ett förändrat klimat. Miljöförvaltningen Stockholm stad. www.stockholm.se/Global/Stads%C3%B6vergripande%20%C3%A4mnen/Klimat%20%26%20Milj%C3%B6/Klimat/Rapporter/Klimatanpassning.pdf

Ekman, M. (1996): A consistent map of the postglacial uplift of Fennoscandia. Terra Nova 8: 158-165.

ESPON-IRPUD (2011): ESPON Climate: Climate Change and Territorial Effects on Regions and Local Economies, Final Report - Scientific Report. Luxembourg: ESPON & IRPUD, TU Dortmund University.

European Parliament (2003): Regulation (EC) No 782/2003 of the European Parliament and the Council of 14th April 2003 on the prohibition of organotin compounds on ships. Official Journal of the European Union.

Fairbridge, R.W. (2004): Classification of Coasts. Journal of Coastal Research 20 (1): 155–165.

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety Germany (BMU - Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit) (2003): Schutz für Nord- und Ostsee wird verbessert. www.bmu.de/meeresumweltschutz/doc/4273.php, May 27th 2011.

Federal Ministry of Transport, Building and Urban Affairs Germany (Bundesministerium für Verkehr, Bau und Stadtentwicklung - BMVBS) (2007): Navigation and waterways in Germany – meeting the challenges of Climate Change. A Review. BMVBS, Bonn, 58p.

Finkl, C.W. (2004): Coastal classification: Systematic approaches to consider in the development of a comprehensive system. Journal of Coastal Research 20 (1): 166–213.

Friedland, R., Neumann, T. & G. Schernewski (2012): Climate change and the Baltic Sea Action Plan: Model simulations on the future of the western Baltic Sea. Journal of Marine Systems http://dx.doi.org/10.1016/j.jmarsys.2012.08.002.

Fröhle, P., C. Schlamkow, N. Dreier & K. Sommermeier (2011): Climate Change and coastal protection: adaptation strategies for the German Baltic Sea coast. In: Schernewski, G., J. Hofstede & T. Neumann (Eds.): Global Change and Baltic Coastal Zones (Series: Coastal Research Library, Vol. 1), pp 103-116.

Garrod, B. & J.C. Wilson (2003): Marine Ecotourism: Issues and Experiences. Clevedon: Channel View Publications.

Gee, K., A. Kannen & K. Licht-Eggert (2006): Raumordnerische Bestandsaufnahme für die deutschen Küsten und Meeresbereiche. Forschungs- und Technologiezentrum Westküste der Universität Kiel (Hrsg.). Berichte Nr. 38 (http://iczm.ecology.unikiel.de/servlet/is/524/060821_BBR_Bestandsaufnahme.pdf?command=downloadContent&filename=060821_BBR_Bestandsaufnahme.pdf, 9th July 2012)

Gräwe, U. & H. Burchard (2011): Regionalisation of climate scenarios for the Western Baltic Sea. In: Schernewski, G., J. Hofstede & T. Neumann (Eds.): Global Change and Baltic Coastal Zones (Series: Coastal Research Library, Vol. 1), pp 3-22.

Gräwe, U. & H. Burchard (2012): Storm surges in the Western Baltic Sea: the present and a possible future. Climate Dynamics 39: 165-183.

Gudelis, V. (1967): Morfogenetycheskye tipi beregov Balt`iskogo morya. Baltica 3:123-145 (in Russian).

Hall, C.M. (2001): Trends in ocean and coastal tourism: the end of the last frontier? Ocean & Coastal Management, 44, 601-618.

Hamilton, J.M. (2007): Coastal landscape and the hedonic price of accommodation. Ecological Economics 62: 594-602.

Hannerz, F. & G. Destouni (2006): Spatial characterization of the Baltic Sea drainage basin and its unmonitored catchments. AMBIO 35: 214-219.

Heggie, T.W. (2010): Swimming with death: Naegleria fowleri infections in recreational waters. Travel Medicine and Infectious Disease 8: 201-206.

HELCOM (2009a): Eutrophication in the Baltic Sea. An integrated thematic assessment of the effects of nutrient enrichment in the Baltic Sea region. Baltic Sea Environment Proceedings No. 115A and B. Helsinki Commission, Helsinki, Finland.

HELCOM (2009b): www.helcom.fi/stc/files/shipping/Overview%20of%20ships%20traffic_updateApril2009.pdf

HELCOM (2010a): Ecosystem health of the Baltic Sea 2003–2007: HELCOM Initial Holistic Assessment. Baltic Sea Environment Proceedings No. 122.

HELCOM (2010b): Maritime Activities in the Baltic Sea – An integrated thematic assessment on maritime activities and response to pollution at sea in the Baltic Sea Region. Baltic Sea Environment Proceedings No. 123.

HELCOM (without date): www.helcom.fi/environment2/biodiv/alien/en_GB/alienspecies (June 2012).

Hofstede, J. (2011): Climate Change and the need for Integrated Coastal Risk Management in the Baltic Sea. In: Schernewski, G., J. Hofstede & T. Neumann (Eds.): Global Change and Baltic Coastal Zones (Series: Coastal Research Library, Vol. 1), pp 93-102.

Hooke, J. M. (1979): An analysis of the processes of river bank erosion. Journal of Hydrology 1–2: 39–62.

Hooke, J. M. (1980): Magnitude and Distribution of Rates of River Bank Erosion. Earth Surface Processes 5 (2): 143–157.

Hudson, H. R. (1982): A field technique to directly measure river bank erosion. Journal of Earth Sciences 19 (2): 381–383.

IMO - International Maritime Organization (2002): Anti-fouling systems. (www.imo.org/OurWork/Environment/Anti-foulingSystems/Documents/FOULING2003.pdf, 27th May 2011).

Innenministerium des Landes Schleswig-Holstein (2006): Raumordnungsbericht Küste und Meer 2005. Landesplanung in Schleswig-Holstein, Kiel, 76p.

IPPC (Intergovernmental Panel on Climate Change) (2000): IPPC Special Report Emission Scenarios – Summary for Policymakers (www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf, 19th September 2012)

Järvinen, S., S. Kankaanpää, J. Lounasheimo & P. Aarnio (2010): Ilmastonmuutoksen vaikutukset pääkaupunkiseudulla. Osa C. HSY Seututieto, Helsinki.

Johnson, D. (2002): Environmentally sustainable cruise tourism: a reality check. Marine Policy 26: 261-270.

Kaspar, C. (1996): Die Tourismuslehre im Grundriss. 5th revised edition. Paul Haupt Verlag: Bern, Stuttgart.

Kjellström, E., G. Nikulin, U. Hansson, G. Strandberg & A. Ullerstig (2011): 21st century changes in the European climate: uncertainties derived from an ensemble of regional climate model simulations. Tellus A 63: 24-40.

Kule, L. et al. (in prep.): Climate Change Impacts on Tourism in the Baltic Sea Region. Baltadapt Report # 6.

Lapinskis, J. (2006): Jūras krasta pārejas zonas dinamika Kurzemes rietumos (1992–2005). LU 64. zinātniskā konference. (Ģeogrāfija. Ģeoloģija. Vides zinātne), Latvijas Universitāte, Rīga, pp 181-182 (in Latvian).

Lapinskis, J. (2009): Jūras krasta rajonēšana Latvijā pēc litomorfodinamiskām pazīmēm. Rīgas Tehniskās Universitātes zinātniskie raksti, Materiālzinātne un lietišķā ķīmija 19 (1): 168–174 (in Latvian).

Lapinskis, J. (2012): Climate change impacts on coastal erosion, sediment transport and coastal protection in Latvia. Appendix 1 in: Krämer, I., Borenäs, K., Daschkeit, A., Filies, Ch., Haller, I., Janßen, H., Karstens, S., Kule, L., Lapinskis, J. & Varjopuro, R.: Climate Change Impacts on Infrastructure in the Baltic Sea Region. Baltadapt Report # 5. Danish Meteorological Institute, Copenhagen. www.baltadapt.eu.

Marine Board Special Report (2011): Climate change and marine ecosystem research - Synthesis of European Research on the effects of climate change on marine environments. (www.medmpaforum2012.org/sites/default/files/synthesise_european_research_effect_climate_change_marine_env.pdf)

Marttila, V., H. Granholm, J. Laanikari, T. Yrjölä, A. Aalto, P. Heikinheimo, J. Honkatukia, H. Järvinen, J. Liski, R. Merivirta & M. Paunio (2005): Finland's National Strategy for Adaptation to Climate Change. Publications 1a/2005. Ministry of Agriculture and Forestry, Helsinki.

Meier, H.E.M., B. Broman & E. Kjellström (2004): Simulated sea level in past and future climates of the Baltic Sea. Climate Research 27: 59-75.

Meier, H.E.M., B. Broman, H. Kallio & E. Kjellström (2006) Projections of future surface winds, sea levels, and wind waves in the late 21st century and their application for impact studies of flood prone areas in the Baltic Sea Region. Geological Survey of Finland, Special Paper 41, 23-43.

Meier, H.E.M, Andersson, H,. Dieterich, C., Eilola, E., Gustafsson, B., Höglund, A., Hordoir, R. & S. Schimanke (2011a): Transient scenario simulations for the Baltic Sea Region during the 21st century. SMHI. Oceanografi Nr. 108.

Meier, H.E.M, H. C. Andersson, K. Eilola, B. G. Gustafsson, I. Kuznetsov, B. Müller-Karulis, T. Neumann & O.P. Savchuk (2011b): Hypoxia in future climates: A model ensemble study for the Baltic Sea. Geophysical Research Letters: 38, L24608.

Meier, H.E.M, R. Hordoir, H.C. Andersson, C. Dieterich, K. Eilola, B.G. Gustafsson, A. Höglund & S. Schimanke (2012a): Modeling the combined impact of changing climate and changing nutrient loads on the Baltic Sea environment in an ensemble of transient simulations for 1961–2099. Climate Dynamics 39: 2421-2441.

Meier, H.E.M, Müller-Karulis, B., Andersson, H.C., Dieterich, C., Eilola, K., Gustafsson, B.G., Höglund, A., Hordoir, R., Kuznetsov, I., Neumann, T., Ranjbar, Z., Savchuk, O. & S. Schimanke (2012b): Impact of climate change on ecological quality indicators and biogeochemical fluxes in the Baltic Sea: a multi-model ensemble study. AMBIO 41: 558-573.

Meyer-Arendt, K.J. (2001): Recreational development and shoreline modification along the north coast of Yucatán, Mexico. Tourism Geographies 3: 87-104.

Ministry of Economy, Labour and Tourism Mecklenburg-Vorpommern (Ministerium für Wirtschaft, Arbeit und Tourismus Mecklenburg Vorpommern) (Hrsg.) (2010): Folgen des Klimawandels in Mecklenburg-Vorpommern. Studie.

Mossbauer, M., S. Dahlke, R. Friedland & G. Schernewski (2013): Consequences of Climate Change and environmental policy for macroalgae accumulations on beaches along the German Baltic coastline. In: Schmidt-Thomé, P. (Ed): Climate Change Adaptation: Implementing Strategies in the Baltic Sea Region.

Mundt, J. (2006): Tourismus. 3rd, revised edition. Oldenbourg: Munich, Vienna.

Neumann, T. (2010): Climate-change effects on the Baltic Sea ecosystem: A model study. Journal of Marine Systems 81: 213-224.

Neumann, T., K. Eilola, B.G. Gustafsson, B. Müller-Karulis, I. Kuznetsov, H.E.M. Meier & O.P. Savchuk (2012): Extremes of temperature, oxygen and blooms in the Baltic Sea in a changing climate. AMBIO 41: 574-585.

Nikulin, G., Kjellström, E., Hansson, U., Jones, C., Strandberg, G. & A. Ullerstig (2011): Evaluation and future projections of temperature, precipitation and wind extremes over Europe in an ensemble of regional climate simulations. Tellus 63A: 41–55.

Orams, M. (1998): Marine Tourism: Development, Impacts and Management. London: Routledge.

Paalvast, P. & G. van der Velde (2011): Distribution, settlement, and growth of first-year individuals of the shipworm Teredo navalis L. (Bivalvia: Teredinidae) in the Port of Rotterdam area, the Netherlands. International Biodeterioration & Biodegradation 65: 379–388.

Peltonen, H., R. Varjopuro & M. Viitasalo (2012): Climate Change Impacts on Fish Stocks and Fisheries in the Baltic Sea Region Review with a Focus on Central Baltic Herring, Sprat and Cod. Baltadapt Report # 4. www.baltadapt.eu.

Phillips, M.R. & A.L. Jones (2006): Erosion and tourism infrastructure in the coastal zone: Problems, consequences and management. Tourism Management 27: 517–524.

PIANC (2008): Climate Change and Navigation - Waterborne transport, ports and waterways: A review of climate change drivers, impacts, responses and mitigation. EnviCom - Task Group 3. (www.pianc.org/downloads/envicom/envicom-free-tg3.pdf, April 23rd 2011).

Reise, K. (2009): Coastal Adaptations. In: The international review of landscape architecture and urban design. Water – Resource and Threat 69: 82–87.

Scheibe, R. (2009): Aspekte der zukünftigen Entwicklung der touristischen Angebotspalette des Oder-Haff-Gebietes unter dem Eindruck natürlicher und gesellschaftlicher Veränderungen. In: Schernewski, G., H. Janßen & S. Schumacher (eds.): Coastal Change in the southern Baltic Sea region. Coastline Reports 12: 61–72.

Scheibe, R. (eds.) (2010): Entwicklungstrends im Wassertourismus im südlichen Ostseegebiet. IKZM-Oder Berichte 62, 36p.

Schleswig-Holsteinischer Landtag (2007): Tankschiffverkehr in der Ostsee. Kleine Anfrage des Abgeordneten Dr. Heiner Garg (FDP) und Antwort der Landesregierung – Minister für Wissenschaft, Wirtschaft und Verkehr. (www.landtag.ltsh.de/infothek/wahl16/drucks/1300/drucksache-16-1334.pdf, May 23rd 2011).

Schnellhubner, H.J. & H. Sterr (eds.) (1993): Klimaänderung und Küste. Einblick ins Treibhaus. Springer, Berlin, Heidelberg, New York, 400p.

Scott, D. & S. Becken (2010): Adapting to climate change and climate policy: progress, problems and potentials. Journal of Sustainable Tourism 18: 283–295.

Semenza, J.C. & B. Menne (2009): Climate change and infectious diseases in Europe. The Lancet Infectious Diseases 9: 365-375.

Simpson, M.C., S. Gössling, D. Scott, C.M. Hall & E. Gladin (2008): Climate Change. Adaptation and Mitigation in the Tourism Sector: Frameworks, Tools and Practices. UNEP, University of Oxford, UNWTO, WMO Paris, France.

Steffen, H. & P. Wu (2011): Glacial isostatic adjustments in Fennoscandia – A review of data and modeling. Journal of Geodynamics 52: 169–204.

Swift, D.J.P. & J.A. Thorne (1991): Sedimentation on continental margins: a general model for shelf sedimentation. Sedimentology 14: 3–31.

The German Federal Government (Die Bundesregierung Deutschland) (2008): Deutsche Anpassungsstrategie an den Klimawandel. www.bmu.de/files/pdfs/allgemein/application/pdf/das_gesamt_bf.pdf.

Tuente, U., J. Witt, & U. Filbrand (2002a): Die Bohrmuschel in Bremerhaven – Nachweis, Schäden, Prävention. Häfen & Wasserstraßen. Hansa 5: 2–4.

Tuente, U., D. Piepenburg & M. Spindler (2002b): Occurrence and settlement of the common shipworm Teredo navalis (Bivalvia: Teredinidae) in Bremerhaven harbours, northern Germany. Helgoland Marine Research 56: 87–94.

Turton, S., T. Dickson, W. Hadwen, B. Jorgensen, T. Pham, D. Simmons, P. Tremblay & R. Wilson (2010): Developing an approach for tourism climate change assessment: evidence from four contrasting Australian case studies. Journal of Sustainable Tourism 18: 429–447.

Ulsts, V. (1998): Baltijas jūras Latvijas krasta zona. Valsts Ģeoloģijas Dienests, Rīga (in Latvian).

Uhlendorf, H.-J. (2011): Niedersachsen Ports GmbH & Co. KG. Personal communication, 31st March 2011.

UKCIP – UK Climate Impacts Programme (2011): UKCIP Adaptation Wizard case study: Port of Felixstowe. (www.ukcip.org.uk/wordpress/wp-content/Wizard/Felixstowe_Case_study.pdf, 27th April 2011).

UNCTAD – United Nations Conference on Trade and Development (2008): Maritime transport and the climate change challenge. United Nations Conference on Trade and Development. (www.unctad.org/en/docs/cimem1d2_en.pdf).

UNEP-CAST (2008): Disaster risk management for coastal tourism destinations responding to Climate Change: A practical guide for decision makers. United Nations Environment Programme, Paris.

Wall & Mathieson (2006): Tourism. Change, impacts and opportunities. Harlow, UK: Pearson.

Weisner, E. & Schernewski, G. (2013): Adaptation to climate change: A combined coastal protection and re-alignment measure in a southern Baltic tourism region. In: Conley, D.C., Masselink, G., Russell, P.E. and

O'Hare, T.J. (eds.), Proceedings 12th International Coastal Symposium (Plymouth, England), Journal of Coastal Research, Special Issue 65: 1963-1968.

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Climate Change Impacts on Coastal Tourism in the Baltic Sea Region

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Abstract

Climate change impacts will have both positive and negative consequences for the tourism industry in the Baltic Sea region (BSR). Here we identify, based on existing knowledge and new knowledge obtained as part of the Baltadapt project, various aspects of climate change that may impact tourism industry in the BSR. Research findings on climate change impacts on tourist comfort and behaviour, tourism flows, destinations and activities are reviewed for the BSR. Coastal and cold-climate-dependent tourism are highly vulnerable to climate change-related risks. A future warmer climate can also bring new weather-related opportunities to the BSR. The regions' tourism industry has longstanding traditions and innovative enterprises; although tourism adaptive capacities with relation to climate change vary in different parts of the BSR. Most vulnerable will be low income regions, less populated coastal areas and those that depend on wildlife tourism. A review is also given of possible adaptation measures relevant for coastal and cold-climate tourism destinations. Finally, research and knowledge gaps are identified and discussed with the aim to support research, cooperation between science and industry in relation to climate change adaptation and tourism in the BSR.

1 Introduction

1.1 Scope of the coastal tourism review

This review has been prepared with the objective to compile and analyse existing knowledge on climate change impacts and adaptation relevant for coastal tourism and recreation in the Baltic Sea Region (BSR) (Figure 1). Coastal tourism and recreation are complex sectors that are vital contributors to the quality of life, employment and the economical wellbeing of the region. This review aims at demonstrating the diversity of challenges and opportunities that the coastal tourism in the BSR is facing as a consequence of climate change. The review focuses on tourist comfort and behaviour and changes to tourist flows, coastal tourism destinations and activities in the region (for coastal tourism infrastructure see Krämer et al. (pp. 55-90, this volume)). Only brief insight is given to climate change impacts with relevance to tourism supporting sectors, such as: public health, food, transport, insurance services, construction and indoor climate.

1.2 Relevance of climate change impacts and adaptation to tourism

Climate change is perhaps the most pressing environmental issue in the world today, although the tourism sector is a late comer to the discussion of challenges and opportunities due to climate impacts. While the Intergovernmental Panel on Climate Change (IPCC 2007) only mentions tourism in passing (in relation to transport, coastal systems and regional overviews), today studies and publications on climate change impact and adaptation relevant for tourism is growing rapidly in numbers.

Traditionally the seasonal contrast drives demand for summer vacations; and the climate and weather contrast between the source and destination countries of tourists creates major tourism flows at global, European, BSR and national scale (Viner 2006). Tourism has traditionally been considered to be a highly climate-sensitive economic sector (UNWTO and UNEP 2008); some tourism, e.g. beach and skiing, destinations are particularly climate-dependent; since climate is their principal resource (UNWTO 2009). Climate and weather are important factors that influence destination image and tourism resources, long-term tourism demand, the timing of travel, the length and quality of tourism seasons, tourist experience and satisfaction and tourism industry operations and profitability (Becken & Hay 2007, Bigano et al. 2008, Gössling & Hall 2006, Scott and Lemieux 2009, OECD and UNEP 2011, Gössling et al. 2012, Nicholls 2006). Tourist decision-making depends on the weather and climate conditions at the destination (see figure 1) and also at the point of origin. Characteristics of domestic and international travellers and their motivations for travel are diverse and changing with time. Thus tourists' adaptation capabilities to changing weather conditions differ depending from their information and experience. However, evidence shows that the decision to return to a destination is largely unaffected by past experiences of poor weather (Scott & Lemieux 2010).

At the same time tourists can be found in all types of climates and natural landscapes worldwide as tourism operators have adapted to provide tourism services in every climatic zone on the planet (Scott & Lemieux 2010). Each major global tourism market segments has specific needs, opportunities and constraints regarding climate and weather and thus adaptation measures should cover the most vulnerable aspects of tourism industry with reference to sustainability, cost-benefit and social justice principles.

1.3 Socio-economic trends of tourism

When dealing with climate change adaptation in relation to tourism, it is crucial to consider the complexity of tourism industry development trends. Tourism industry is constantly changing and not only affected by the climate system such as its seasonality, inter-annual variability, extreme events and long-term changes, but also to macro-scale sectoral influencing factors such as economic growth or recession, transport access and cost, political stability or security, demographic, and technological, cultural and political change, currency exchange rates, border agreements (Scott and Lemieux 2010). Tourism is a phenomenon characterised also by a high level of dynamism, at least on the extremes. Forms of tourism have continued to multiply, e.g. increase in nature tourism, wellness and health tourism (Butler 2009). The temporal aspects of tourism is changing, e.g. gradual decline in relative importance of the summer holiday and the length of holidays, the increase of second and multiple holidays per year (Butler 2009). Fixed in space and in the usage of existing technical utilities the tourism destinations are transformed at slower speed to respond to tourism demand changes in the form of reinvestment, renovations and building new attractions (Butler 2009). Location of tourism depends on the technology and costs of transportation; particularly long-distance travel depends on energy prices and implications of climate change mitigation policies. The BSR tourism market does not dependent on long-haul travel as it is dominated by domestic tourists and tourists from neighbouring countries and overnight stays (Tables 1 and 2). Europeans are interested in "proximity" tourism, i.e. tourism to destinations/areas close to the usual place of residence (weekend trips); there are growing interest to travel independently, interest in low-cost offers, flexible travel schedules and tourism activities, desire for authentic experience of places and contact with nature and interest in adventure (EC and Eurostat 2008). Demographic change will change the characteristics of tourists; aging tourists will probably prefer convenience, safety, luxury and city trips and short breaks outside the peak seasons (ECORYS 2012a). Tourists will seek tailor-made products or will switch easily from one niche groups or specialized tourism product to another; loyalty towards one or a few destinations and repeat visits will decrease. Greater number and diversity of different destinations can have a better position in the tourism market. At the same time only more successful winter destinations will stay. An increasing number of first–time visitors will depend more on information resources and travel product advertisements. Individualisation will limit to distinguish homogeneous target groups of tourists. ‘Connectivity’ trend refers to the growing demand for meaningful relations and experiences, e.g. demand for ecologically responsible consumerism where concerns about climate change, environmental pollution and sustainable resource management are integrated (ECORYS 2009). The future tourists that will be better educated will have more focus on their health, food, fitness, and wellness. In the future, anxiety society characteristics will dominate the tourism industry. This means that there will be consumers with two courses of action: fear leads to risk-minimisation and safety concerns; and at the same time complacency leads to risk-taking and the increase of participation in adventure or hazard tourism (Yeoman et al. 2009).

The fragmentation and geographically dispersed value chain of tourism industry contributes to the complex nature of the interactions between tourism, climate system, environment and society (Simpson et al. 2008). More than 90% of all enterprises in the tourism sector employ less than 10 persons that are mainly located in the tourist destination itself and this trend will continue. Due to changes in information technology the tourism industry is undergoing organisational changes and becoming a dynamic, interactive and demand-centred economical activity, where consumers can directly ‘assemble’ a ‘customised’ offer, while tour operators are loosing their dominance and these tour operators which remain are becoming global and larger-size enterprises (ECORYS 2009 and 2012a). Coastline tourism and yachting will grow (ECORYS 2012a). Coastal tourism destinations are affected by complexity of changes - primary drivers are tourism itself, the expansion of the built environment, industrial development and trade, fisheries and aquaculture; and secondary drivers for the changes in coastal zone are as listed climate change, provision and supply of energy and agriculture (Vermaat et al. 2005). Maritime and coastal tourism is considered to be a catalyst for economic development of coastal areas. Previously these areas were depended extremely on fisheries and industries related to that, but this is now in decline (EC 2010).

Table 1: Economic dimension of tourism and tourist arrivals in 2011 (Bastis 2013)

Countries	Tourism direct contribution to GDP		Tourism total contribution to GDP	Tourism direct contribution to employment		Tourism total contribution to employment	Tourist arrivals	International tourist arrivals
	%	billion EUR	%	%	number	%	million	%
Russia	1.4	18.5	5.9	1.3	954,000	5.5	-	23.7 million
Sweden	1.8	7.1	5.5	1.7	110,000	5.6	24.0	21
Poland	1.9	6.9	4.8	1.9	306,000	4.7	21.5	20
Lithuania	1.6	0.5	4.2	1.6	22,500	4.0	1.6	60
Latvia	2.9	0.6	7.7	2.8	27,000	7.3	1.6	67
Germany	1.6	41.9	4.6	1.8	709,000	4.9	141.7	20
Finland	2.1	4.1	6.2	2.2	58,000	6.5	10.7	24
Estonia	3.3	0.5	12.7	3.4	18,000	12.4	2.7	67
Denmark	1.8	4.4	6.0	7.0	217,000	11.3	6.2	35

1.4 Tourism system in the BSR

In 2011 the BSR’s tourism industry contributed to 267 billion EUR the total GDP and employed around 7.8 million people in the region (Bastis 2013). In 2011 the BSR had 72 million tourist arrivals (increase by 33% since 2002), 190 million overnight stays (increase by 20% since 2002) and 20,000 tourism establishments (increase by 5% since 2002) with 2.5 million beds (increase by 8% since 2002) (Eurostat data cited in Bastis 2013) (Table 1).

Tourism economic contribution among the BSR countries differs (Table 1). Most of the tourists in the BSR are domestic or from neighbouring countries (Table 2). In the BSR there are no mass tourism sites comparable to the Mediterranean area, but the concentrations of tourists in some areas is very high, e.g. on the German coast. Large disparities in volumes and intensity of tourism development exist in the BSR. In the Baltic States, international tourists and overnight stays in hotels dominate; in other countries domestic tourists and overnight stays in campsites and other than hotel accommodations dominate, except Finland where hotel overnight stays dominate (Table 2). Tourism is an important economic sector for the southern coastal areas of the Baltic Sea, but also for urban regions located on the coast, islands and archipelagos. The increase in tourism over recent years, both within the Baltic Sea region and from elsewhere, demonstrates the attraction of resorts and their economic potential for the region.

Table 2: Tourist accommodation (Eurostat 2012) and total overnight stays (Bastis 2013)

Countries	Number of bed places, 2010 (1.000)	Change in the number of bed places, 2007–10 (%)	Share of hotels in the total number of bed places, 2010 (%)	Coastal region with the highest number of bed places, 2010	Total overnight stays, million, 2011	Total overnight stays by non-residents, total % and larger segments by country of origin in %, 2011	
EU-27	28 077.5	2.6	43.8	Venezia	-	-	-
Denmark	393.4	4.0	20.7	Sydjylland	28.2	34	25% Germany 18% Norway 16% Sweden 7% Netherlands
Germany	636.4	10.8	32.4	Ostholstein	339.0	19	17% Netherlands 7% Switzerland 7% USA 7% UK
Estonia	39.8	11.7	63.6	Pohja-Eesti	5.4	70	45% Finland 13% Russia 6% Germany
Latvia	27.3	32.0	80.5	Rīga	3.3	67	19% Russia 10% Germany 8% Finland 8% Lithuania 8% Norway
Lithuania	10.9	– 5.6	50.7	Klaipėdos apskritis	3.3	58	16% Russia 14% Poland 12% Germany
Poland	194.2	– 4.2	21.1	Koszaliński	57.2	18	38% Germany 7% UK
Finland	130.4	– 1.0	57.1	Uusimaa	20.0	21	23% Russia 10% Sweden 10% Germany
Sweden	591.9	6.3	30.2	Vastra Gotalands	48.7	24	27% Norway 16% Germany 8% Denmark
Russia	-	-	-	-	189.7	6	-

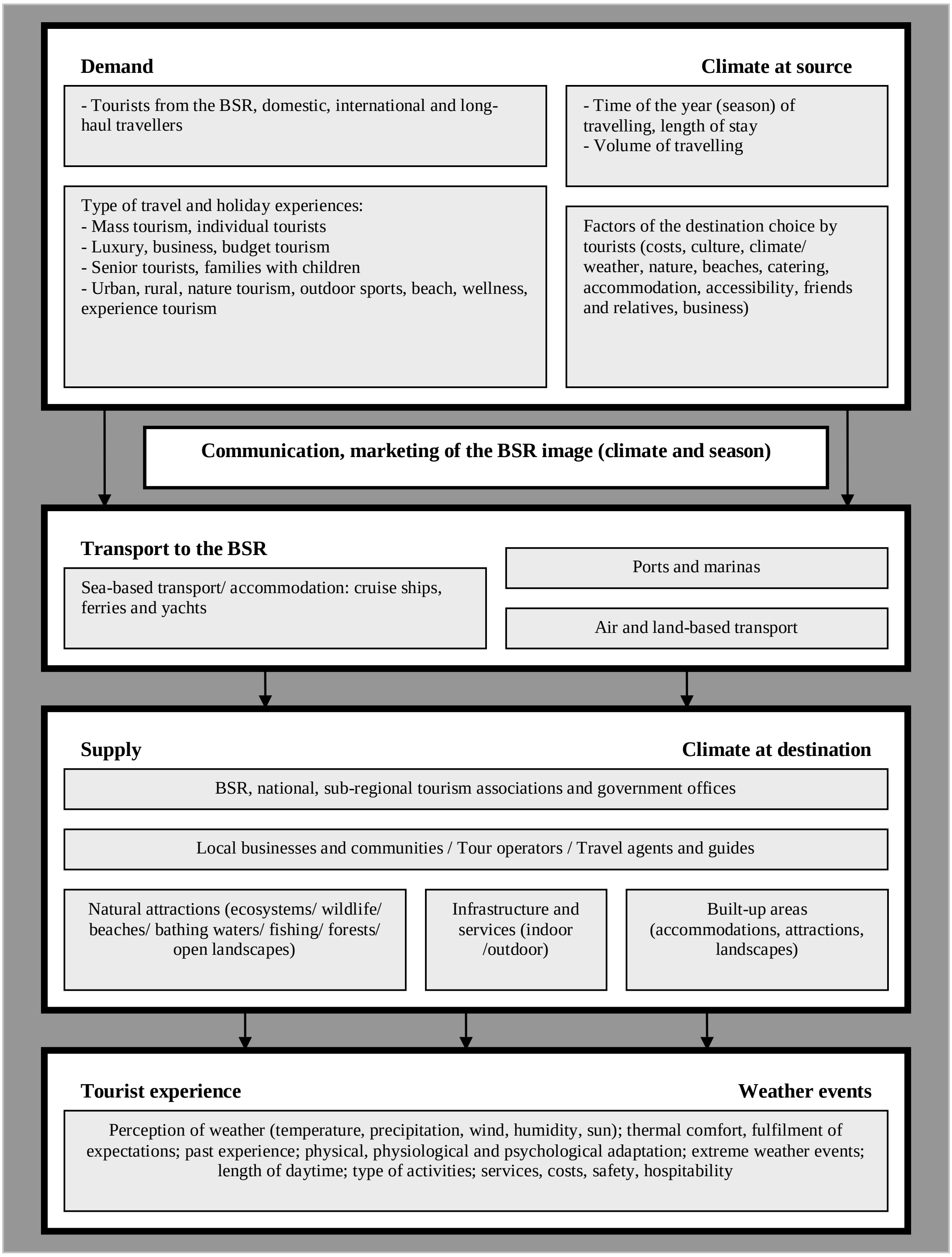

Figure 1: Structure of tourism sector in the BSR.

2 Environmental Consequences of Climate Change

Climate and weather as a motivator for travel and a component of the destination image have an impact on tourist demand which will affect destination choice, attraction to particular tourism activities and the timing and the duration of travel. Thus climate and weather can be both an asset for the destinations as well as a disruptor of tourism activities (Day et al. 2013). The impacts of climate change on tourism can be classified as either physical (e.g. the loss of biodiversity, damage to tourism infrastructure), economic (e.g. reduced tourism expenditure, reduced employment opportunities, increased costs for businesses and society, increased costs for insurance), or social (e.g. health impacts, change of lifestyle, place identity and destination brand) (Buultjens et al. 2007).

2.1 Average air temperature rise

According to climate model projections, temperatures in the Baltic Sea area are expected to increase with a mean of 2.6°C by year 2100, and this increase is generally larger than the increase in global mean temperature. It is expected that North European summers will become 'better' and appear 'more reliable' (Mather et al. 2005). However expected temperature rise will not change the BSR's core markets, the major change will be on high tourism season extension, the potential to increase the attractiveness of marine destinations and enhancing the BSR as all-year-round short break destination. Irrespective of improvements, the seasonality in the BSR will remain one of the main challenges for the tourism business. The physical ''signals'' of changes in temperature due to climate change are weak in value compared to variation in temperature due to daily, seasonal, and regional variations. This creates physiological barriers for climate change adaptation measures (Schott et al. 2010). Perception and experience of climate and weather do not depend only on temperature, but on 'thermal comfort' that is defined in combination with radiation, wind, humidity, precipitation and the appearance of the sky and quality of light of a location (de Freitas 1990). The BSR's temperate climate will be more favourable for the family and senior citizen tourism, particularly during periods when other parts of Europe will have higher and intolerable temperatures. The tourist industry is mainly interested in daytime temperature and its changes, rather than in daily mean as nights are normally spent indoors (Førland et al. 2013). Warming can not only impact the 'thermal comfort' of tourists, but also their behaviour (Gössling et al. 2008) and the decisions concerning destinations or activities. Rise of temperature might increase the number of people switching from cars and public transport to bicycle and the visitation in national parks and taking part in nature tourism activities (OECD and UNEP 2011). However, the same process can change natural ecosystems and thus nature tourism resources. With milder winters the likelihood of road accidents might be reduced. With a possible increase of tourist numbers in summer months, railways, streets and airports could reach their maximum capacity in the peak season and coastal regions might require new and expanded traffic systems, as well as basic and supra-infrastructure for accommodation, catering, retail and tourism attractions need to be adjusted to increased tourism numbers.

2.2 Average water temperature rise and the shrinkage of sea ice

Different climate simulations predict a 2 - 2.5°C increase of the water temperature for the coming 90 years. The warming in the BSR will occur strongest in the northern regions in winter and in the southern regions during the summer months (Störmer 2011). The Baltic Sea surface temperature has large seasonal, interannual and regional variations. Water and air temperature rise combined with less rain in summer have positive impacts on beach tourism, due to a longer bathing and water sports season in the BSR. However, increased water temperatures in summer might also negatively impact tourism with the occurrence of and distribution of various water species like cyanobacterial blooms, jelly fish (Wenk & Janßen 2011), aliened species, and pathogens like vibrio-related diseases (e.g. Cholera) (Störmer 2011).

The maximum sea ice extent in the Baltic Sea has been decreasing since about 1800 and the extent of the maximal cover is projected to shrink further; water and air temperature rise will lead to a shorter period and lesser coverage of sea and coastal surface water ice, although predictions are made with uncertainty (EEA 2012a, Störmer 2011). The resulting changes in the freezing conditions of water bodies and the formation of snow cover are connected to several climatic factors that are hard to predict (Heikkinen et al. 2011). There will still be a large inter-annual variability spanning between almost ice free winters and severe ice winters. Ice-free conditions will be beneficial for water sports, cruise lines and water transport. Ice-fishing and other types of recreation and sports on ice, e.g. ice-yachting, can expect negative impacts from temperature rise (Järvinen et al. 2010, Ekelund 2007).

Milder winters are also likely to cause significant negative consequences in the operation of ice roads (Hudecz 2012).

2.3 Change in precipitation patterns

On an annual mean basis the precipitation in all of the Baltic Sea run-off regions is projected to increase and there is a strong correlation with the increase in temperature. The projected increases are largest and most consistent during winter. In summer the scenarios generally show more precipitation in the north. In the south, with large uncertainty precipitation is projected to change only little, or even decrease. The volume and the type (rain, snow or fog) of precipitation are crucial for tourism attraction and tourist experiences and for the image and marketing of a tourism destination. Snow reliability in Scandinavia will remain higher than in many parts of the Alps, the region could "increase its market share in alpine and Nordic ski sports" (Ehmer & Heymann 2008). Large volumes of snow due to light reflection capability can create idyllic winter destination even in dark sky conditions, while 'cloudy, windy and rainy winters would not have the same draw' (Yeoman & McMahon-Beattie 2006). As a result of intensive precipitation landslides and flooding can affect not only tourism accommodation, but also cultural and natural heritage. More intense precipitation events, increased humidity, higher microbial activity, increased growth of fungus and mould can be cause of increased decay processes (e.g. in wood), decreased durability of materials, damaged or flooded buildings and structures (Penney 2012). Negative impacts expected for road maintenance in winter and thus road deterioration, particularly with gravel surfaces (Hudecz 2012). More precipitation, high humidity and fog events can cause lower visibility that will have negative impacts for sightseeing (Førland et al. 2013, Yeoman and McMahon-Beattie 2006), as well as for safe travel, particularly aviation. With less rain in summer, destinations get more attractive, since the risk of rainy holidays will be reduced. An increase in the duration of sunlight slightly increases a shift from car/public transport to cycling/walking (Inturri & Ignaccolo 2010).

2.4 Increase of extreme weather events and weather variability

It is likely, that extreme weather events such as floods, droughts, heavy rains (snowfall) and storms will increase in a future climate. Extreme seasons (exceptionally hot, dry summers or mild winters) or short-duration weather hazards (windstorms, heavy precipitation leading to flooding or snowfall, fog or extreme heats or cold) are crucial for tourism and recreation, particularly to outdoor activities. Population health is sensitive to isolated extreme events (e.g. heavy rainfall and flooding, high and low temperatures, strong winds) through direct impact of through damage to the public health infrastructure, although inferring causal relationships from a single weather event is usually not possible due to lack of sufficient reliable data at relevant spatial and temporal resolution (Kovats and Bouma 2002). Increased occurrence of weather extremes could directly affect tourists, host communities and the tourism industry through basic infrastructure damage, additional emergency preparedness requirements, higher operating expenses (e.g. change of travel plans, increase of insurance costs, awareness campaigns, backup power and water systems, food supply and health care systems and evacuations), tourism business interruption (UNWTO and UNEP 2008) and to tourists to either shifting to other destinations or simply staying at home. It is also a reason for lowering visitor satisfaction (Pang et al. 2013).

There is reported shortcoming is the lack of applicable local wind and wave projections that is important for tourism development (Førland et al. 2013). Wind is used as an essential resource for surfing and kiting. Strong winds will negatively impact fishing, water skiing, motor boating, cruise and ferries. It may for instance impact the timetables of inter-island ferries (Yeoman & McMahon-Beattie 2006). In the BSR, climate change simulations reveal a large spread in changes in wind speed. Projected changes in wind extremes are quite uncertain, with a slight tendency to an increase in the south and a decrease in the north of the BSR. Estonian empirical research shows that storminess in winter has increased (Kont et al. 2011). The climate simulations indicate that the changes in storm surge height in the scenarios can be consistently explained by an increase in mean sea level and variation in wind speed (Gräwe & Burchard 2012). The largest changes are expected in the extreme values in wind speed and in the increase of wave height and frequency. As a consequence, shallow areas can expect more severe erosion events, although additional studies are needed to understand the local effects of changes in wave conditions in the Baltic Sea now and in the future.

Coastline areas tend to be most vulnerable to storm surges, given that the majority of the tourists reside close to the coast and temporal variations in tourism can cause peak moments which make tourists extra vulnerable to flooding (Kellens et al. 2012). Rising sea levels, combined with storm surges and other extreme weather events have negative impact, particularly on safety aspects on walking, cycling and motoring activities, and cause weather-related traffic disruption and delays, damage to rail-bed support structures and to roadside infrastructure by high winds, flooding and erosion of roadways, as well as landslides and mudslides that damage roadways and tracks (Jaroszweski et al. 2010, Hudecz 2012, Inturri & Ignaccolo 2010). The most severe impacts might occur during peak hours and on already congested routes; adverse weather can also lead to less walking and cycling trips, and this can encourage a shift to motorised transport, although for short trips, particularly in urban areas, the impacts of extreme weather are expected to be rather low (Eichhorst et al. 2010). At the same time it is expected that the number of tourists that consume hazard events and their consequences (e.g. storm chasers and observers, canoeing in flooded rivers) is rising. Trees damaged by the storms and/or costal erosion and left undisturbed by human activities (often in national parks and other nature protection areas) create attractive landscape in coastal nature protection areas preferred by nature tourists. Extreme weather events and infrastructure failure can damage tourism destination image through negative press and feedback from visitors on their return (Yeoman & McMahon-Beattie 2006). Coastal tourism in the BSR are highly affected by seasonality, with summer having a high season, and thus the majority of tourists will not be affected directly by the increase of winter storms, but they may cause damage to coastal infrastructure and thus indirectly affect tourism. Also a smaller number of tourists in coastal resort towns or budget tourists using off-season price advantages might be affected by coastal storm and flood events in winter or spring.

With a projected rise of air temperature there will be an increased risk of long, frequent, and intense heat waves (>35°C daytime) and the occurrence of tropical nights (>20°C), and consequent risks of droughts in the BSR. The increase of the number of days with maximum temperatures above 25°C is another indicator used to measure regional climate extremes and has from territorial perspective relevance for the tourism sector as well as for human wellbeing (ESPON-IRPUD 2011). Heat waves have twofold role for coastal tourism, on the one hand destinations have to be well prepared for such weather events as they will have negative effects on human mortality (Beniston 2007); and on the other hand, warm weather will bring more tourist to the sea coast from nearby urban areas, as well as from more distant places. In periods of droughts and heat weaves the most vulnerable tourists seem to have been campers and caravanners. During extreme heat local people, especially those living in large cities, tended to abandon their cities whenever possible and retreat to the coasts and rural areas joining the normal tourist influx and increasing congestion on roads and beaches (Perry 2006). Foreign tourists do not receive advice or warning on extreme weather events before their departures, assistance is expected from tour operators and guides with little medical knowledge (Perry 2006). Droughts can create dangerous wildfire conditions (see below). Droughts can also have a negative impact on recreational fishing and the length of river-rafting season (Scott & Lemieux 2010), while heavy rains and even floods can have a positive impact on rafting.

2.5 Change of the length and characteristics of seasons

Regional climate influence the characteristics of seasons. In the BSR global warming will result in longer summer tourism season versus shrinking winter tourism season. Seasonal tourism demand is comprised by the interplay of natural and institutional seasonality (Scott & Lemieux 2010, Koenig-Lewis & Bischoff 2005, Butler 2001). Tourism business is particularly dependent on the variability of weather conditions in the most popular public and school holidays. Fluctuating tourism demand affects tourism flows and thus has an impact also on other sectors like construction, agriculture, and crafts (CM 2009). The variability of weather conditions affects also tourism infrastructure. Increased and more freeze-thaw cycles in cold winter climates, accompanied with higher temperatures can cause premature deterioration of road network, pavement and concrete, increased corrosion, accelerated deterioration of building facades, premature weathering, fractures and spalling (Penney 2012, Hudecz 2012). Uncertainties related to tourist climate preference and destination loyalty require attention if projections of the geographic and seasonal redistribution of visitor flows are being prepared (Simpson et al. 2008). Climate change is likely to alter tourism demand seasonal pattern and patterns of seasonal attractions (Hall & Higham 2005). Any changes in the length of the operating season will have considerable implications for the short- and long-term viability of tourism and recreation enterprises, and will allow quicker returns on investment with more intensive utilisation of facilities over a longer period (Perry 2006). Seasonality co-determines the suitability of locations for a wide range of tourist activities, and has an important influence on the profitability of tourism enterprises and their operating costs, such as heating-cooling, snowmaking, irrigation, food and water supply, and insurance costs (Simpson et al. 2008). Tourism stakeholders consider a shift of seasonality and the changes of seasons' characteristics and length such as belated and shorter winters or earlier summers as of high significance (Tervo-Kankare 2011). The combination of the length of the daytime, temperatures, precipitation and other climate parameters create seasons that have been traditionally important for public and school holidays and thus for tourism and recreation activities. According to climate model projections, the length and characteristics of seasons is expected to change. In Europe the volume of tourism in the future might be twice as high in the summer as in the winter season (ESPON-IRPUD 2011); increased air and sea temperatures and less precipitation in the summer are likely to encourage a longer season of outdoor activities, particularly will be beneficial for the northern part of the BSR. Although improvements of the relative conditions in the shoulder seasons will not change conditions for beach tourism at a large scale in Europe (Moreno & Amelung 2009).

2.6 Sea level rise

Coastal areas have been identified as the most vulnerable when it comes to climate change (Nicholls & Kebede 2012, Moreno & Becken 2009, IPCC 2007, Kont et al. 2008, Kont et al. 2003). Sea level due to global warming is not rising uniformly at all locations. The Baltic, besides Mediterranean and Black Sea coasts are most vulnerable to sea-level rise due to their low tidal range (Vermaat et al. 2005). Coastal impacts also depend on the vertical movement of the land, which can either add (the south of the Baltic Sea) to or subtract from climate-induced sea-level change (the north of the Baltic Sea) (EEA 2012a). The consequences of rising sea levels will differ along the coastline, with lowland areas and densely populated regions being more affected. Other climate-influenced changes such as alterations of streaming patterns, wave and wind motions and extreme weather events can intensify the impact of sea level rise. The total rise will be much larger in the southern and south-eastern parts of the Baltic Sea (up to 60 cm) while the northern part will be less affected due to on-going land rise. Particularly low-laying and sandy seashores and coastal lagoons (Störmer 2011) will be affected. Large natural variability and lack of good quality long observational records makes detecting long-term changes in trends in extreme coastal sea levels difficult (EEA 2012a). The Baltic Sea on shorter time-scales is affected by the local meteorological conditions which may give rise to storm surges and floodings. The rise of sea-level will cause loss of land territory, e.g. beaches, nature and culture heritage and coastal constructions. In some cases the increase of water surface and water table can be used with the purpose of landscaping and nature restoration, e.g. creating green infrastructure. Tourism infrastructure, e.g. hotels, restaurants, access roads etc. and resources e.g. archaeological sites, cultural heritage sites, historic landscapes and coastal habitats, might be threatened or damaged by the rise of sea water level (Vermaat et al. 2005). The infrastructure of coastal protection can confine the attractiveness of coastal views. Infrastructure of ports and marinas, waterfront developments and coastal greenways are sensitive to sea-level rise that in combination with erosion can cause shrinking of beaches and the relocation of tourist attractions inland. At the same time some coastal areas might experience an enlargement of beaches due to accumulation processes as a part of morpho-dynamic process (Lapinskis 2012). Rising sea levels can also cause salt-water intrusion into low-lying aquifers and endanger coastal ecosystems, wetlands and drinking water supply. Higher flood levels increase the risks to life and property, including sea dikes and other infrastructure, with possible follow-up effects on tourism, recreation and transportation functions. Damage associated with sea-level rise would frequently result from extreme events, such as storm surges, the frequency of which would increase as the mean sea-level rises (EEA 2012a).

2.7 Coastal and beach erosion

Several studies report that extreme erosion events caused by increased storminess in the eastern Baltic Sea and the decline in the occurrence of sea ice are observed more frequently (Ryabchuk et al. 2012, Žilinskas 2008, Kont et al. 2008, Lapinskis 2012). BSR-wide projections for coastal erosion are not available (EEA 2012a). There is an uncertainty whether climate change is the cause for increasing cliff erosion in the southern BSR (Wenk and Janßen 2011). The local effects of erosion in different parts of the Baltic Sea should be studied in detail as several factors are affecting coastal erosion (Swedish Government 2007):

- sea level relative to land elevation;
- wave conditions – height, frequency, direction, extreme conditions;
- wind and current conditions – direction, intensity;
- geology/soil types on land and seabed;
- topography and morphology – heights of dunes and areas behind the beach as well as the form of the shoreline; and
- bathymetry – seabed depth and gradient.

Coastal and beach erosion can be intensified by cleaning beaches from litter (and beach wrack) as well as dredging of marinas, that can cause the removal of sand, a highly valuable touristic resource. Some types of tourism and recreational infrastructure (such as restaurants, entertaining centers, yacht-clubs etc.) can cause an acceleration of erosion processes (Ryabchuk et al. 2012). The most extreme erosion events are observed when three hydro-meteorological factors act together: long-lasting westerly or south-westerly storms, high water levels, and the absence of stable sea ice. The coastal erosion processes have become more intensive as the frequency of these combinations has increased (Ryabchuk et al. 2012, Dailidiené et al. 2012). Most beaches have been eroded due to storms (Tonisson et al. 2008); in only a few places accumulation processes have been observed as thus recovery of beaches occurred (Kont et al. 2008). Beach and dune erosion, coastal damages and protection systems may lead to less attractive shoreline, negative impact on coastal destination image and tourism industry as tourists do not prefer artificial coastlines or groynes (Hamilton 2007, Jennings 2004, Buzinde et al. 2010, Kont et al. 2003). Coastal erosion might affect roads, railways, water supply and sewage systems, tourist facilities, valuable land, valuable natural environments and recreational areas. Several studies stresses that the Curonian Spit National Park is particularly vulnerable to extreme storm events that might cause spit breaching as it has "weak points" where storm waves can break through the sand body (Ryabchuk et al. 2012, Armaitienė et al 2007). Numerous studies classify the segments of the Baltic Sea coastline in accordance to vulnerability to erosion (Uscinowicz et al. 2004, Fenger et al. 2008), but a BSR-wide effort is missing to coordinate these studies.

2.8 Risk of salt water intrusion into ground water

Sea level rise and floods may cause this problem in coastal regions and on islands, leading to the intrusion of salt water into the fresh water supply system. Potentially most exposed here are the southern sandy shores and less so the rocky shores of the Baltic Sea. Salt water intrusion into ground water will require investments in new fresh water supply system and maybe leading to limited capacity to accommodate tourists.

2.9 Increased risks of forest fires

Longer fire seasons and the occurrence of dry and hot summers are expected to result in increased forest fire activity and wildfires have already impacted tourism destinations, particularly the eastern part of the BSR, Russia (Hall et al. 2011, Hall 2011). Wildfires have negative impacts on attractiveness and tourist perception, health effects of air pollution, and can cause the loss of recreation opportunities (access to certain areas, ban on open fires, damaged infrastructure, cancellation of nature walking, hunting, berry and mushrooms picking) and the loss of attractions (cultural heritage, landscape and wildlife) (Hall et al. 2011, Brown et al. 2008). Metropolitan, tourist and second-homes areas are more often affected by wildfires, and that can also negatively affect the air quality. Forest fires might threaten or actually destroy camp sites, making campers and caravanners most vulnerable to high risk of wildfire (Perry 2006).

2.10 Less fresh water input in summer and increased nutrient loads to the sea

Changes in precipitation may lead to less fresh water influx during summer. Fresh water is needed for direct consumption in a variety of tourist infrastructure and services, including food production, bathrooms, for laundry and cleaning, swimming pools, spas, irrigated gardens or golf courses. Increased precipitation in winter in turn leads to more river discharge and there will be a risk of more nutrients leaching to the sea, leading at a later stage to more algae blooming during summer time and influence the quality of the see bathing water (Wenk & Janßen 2011, Mossbauer et al. 2012, Swedish Government 2007).

2.11 Rise for prices of water and energy

Tourism can make strong seasonal pressure on water use on coastal regions (EEA 2012b). Less fresh water in summer in combination with potential growth of demand could increase the price level of fresh water. In very dry summers it may even lead to water shortage and a limitation of water-intense touristic activities (i.e. golfing, indoor swimming or snow-making). There are large differences between countries of the BSR in current average availability of freshwater resources per capita. Latvia, Finland, Sweden and Estonia have the highest rate of freshwater availability. Lithuania and particularly Poland and Germany have comparably low availability of freshwater resources per capita, and thus can expect even more freshwater availability related problems in the future. However even in the countries with average high availability of water resources, warmer summers can create geographically and temporally problematic aspects with quality and quantity of water resources (Swedish Government 2007).

The need for cooling in hot summers in buildings and public transport can raise energy consumption and price. The BSR has experience with heating, while the need for cooling requires new knowledge; it can affect the costs of existing and new buildings. Higher energy prices can have a negatively influence on costs of long-haul travel and thus can decrease the number of long distance international tourists.

2.12 Changes in marine and coastal flora and fauna

Climate is one of the key conditions for the regional biodiversity. With a change of climate new species will appear, others will disappear or move to other locations. Thus nature-based tourism especially in peripheral regions will be affected by species loss and ecosystem changes (Hall & Higham 2005; Gössling et al. 2008). Coastal tourism can be negatively affected by the eutrophication of the Baltic Sea that may worsen due to climate change (Marttila et al. 2005, Störmer 2011). While new and exotic interpreted species may attract tourists, e.g. in parks, gardens, agro-tourist farms, the viniculture at the Baltic Coast (Schernewski 2011), the propagation of other species may lead to direct health risks (blue-green algae, ticks, mosquitoes) or to problems for coastal infrastructure (naval shipworm) and resources (increase of jellyfish). Recreational sea and coastal fishing might have negative impacts due to changes in species of fish; higher value game fish will be replaced by fish that are not perceived to be of the same value (Swedish Government 2007). Tourism might be affected by the loss of local fish species that are considered as the iconic emblems and used in tourism destination image building and branding such as wild salmon (Yeoman & McMahon-Beattie 2006).

Climate change can reformulate natural landscapes if species or biotopes are changed, and this can have a visual effect on vegetation and landscape that is important issue for scenery-based tourism industry (Yeoman & McMahon-Beattie 2006). Event-based tourism and recreational activities, e.g. in spring and autumn, depend on phenological phases of plants (blossoming or fall foliage seasons); and changes due to climate impacts might have negative implications for tourists and the tourism industry with reference to the timing of trips and their promotion (Scott & Lemieux 2010); studies with relevance to Europe or the BSR are missing. Coastal forests, particularly dry pine forests and high bogs, are well known as recreational resource with opportunities for walking, wild berry (Pouta et al. 2006) and mushroom picking. Bird-watching as an activity of nature tourism is widely developed in coastal areas, including saltwater meadows, wetlands and lagoons of the BSR. Negative climate change impacts might be expected for bird-watching due to the loss of the breeding grounds for birds (coastal meadows, flooded meadows and reed beds) (Kont et al. 2003), although more studies are needed. Change of biotopes and the distribution of species can have an impact on hunting that is a part of rural life style and tourists' activity, particularly in scarcely populated areas; however more studies are needed for assessment. A report by the Swedish Government (2007) suggests that opportunities for hunting should improve with climate change, due to greater production of forage. However, the elk may decline in southern Sweden, thus hunting opportunities will be reduced here. Warmer temperatures, insect (mosquitoes and ticks) disturbances (Epstein 2002) and drought in summer are documented negative impacts on reindeer herding (Keskitalo 2010, Swedish Government 2007) and thus can have an impact on wildlife and nature tourism in the northern parts of the BSR. Despite some reductions, relatively snow-rich winters in the BSR' northern part can offer various tourism activities combined with reindeer husbandry and thus in a European perspective, will become increasingly unique in line with the changes in climate (Swedish Government 2007).

With warmer and drier summers it is projected that tick-borne encephalitis will be driven into higher altitudes and latitudes (Semenza & Menne 2009, Epstein 2002). Tick-borne encephalitis has fluctuated considerably from year to year in many countries of the BSR, the increase in incidence are explained by a number of factors, including climate change, and increased travel and outdoor pursuits, placing people in increased contact with infected ticks (Petri et al. 2010). The distribution of tick, accelerate the spread of Lyme disease; still, higher temperatures are on balance with preferences for public health in northern Europe, "where sicknesses surrounding cold weather greatly outweigh any inconvenience of incidental heat peaks in the summer and tick bites" (Vries 2010).

3 Consequences of Climate Change on Coastal Tourism

There is a limited understanding of how climate change impacts will interact with other long-term social and market trends influencing tourism demand and development (Scott & Becken 2010). Changing preferences and demands for tourism and recreation due to climate change can be studied at the macro level (which demands insights into climatic influences on patterns of mobility) and at the micro level (analysis of specific venues and settings taking into account geographical and climatic diversity) (Higham & Hall 2005). Despite of problems with assessing the relationships between climate change and tourism (Simpson et al. 2008) the only direction towards diminishing uncertainty is to contribute to new issue-relevant research and to review and discuss the existing research findings in order to design proper adaptation measures.

3.1 Climatic impacts on tourist comfort and behaviour

Weather stability is an important factor for tourism industry (Agarin et al. 2010); and there has been a longstanding interest to capture, assess or measure the climatic suitability of a potential or existing tourist destination (Becken 2010). Climate is a resource exploited by tourism; from tourism industry to individual tourist there is an interest in criteria for ideal, suitable, acceptable or unacceptable weather conditions that the selection of such criteria is admitted as one of the major problems. De Freitas (2005) summarizes that ideal atmospheric conditions for humans are those producing 'slightly warm' conditions in the presence of scattered cloud (0.3 cover) and with wind speeds of less than 6 m s^{-1}. Northern European tourists can have different preferences for ideal beach tourism weather (Morgan et al. 2000). Climate preferences may also change in time (e.g. through acclimatization to a warmer climate) (Moreno & Amelung 2009). For any human body physical, physiological and psychological factors will determinate the acceptable climatic range, while aesthetical, cultural, social and economical factors will play a role when choosing a tourism destination, product, activity or venue. Due to rise of adventure and alternative tourism, often weather parameters that may cause risks to the human body have high appeal and can thus be considered an asset (de Freitas 2003). Although due to technological, societal and environmental changes, suitability of different climates to different forms of tourism is becoming increasingly dynamic and thus will have implications on the future development of the tourism industry (Higham & Hall 2005). The relationship between weather and recreation is highly dependent on the kind of activity that is assessed, with beach recreation or walking requiring different weather conditions; this feature has been ignored in many previous assessments, which may have led to over- and under-estimations of the impact of climate change for specific tourism segments (Moreno & Amelung 2009). Indoor climate plays an important role versus time spent outdoors, e.g. people are spending around 10% of time outdoors in summer and about 4% in winter, according to an epidemiological survey conducted in the United States and Canada (Höppe 2002 in Shiue & Matzarakis 2011). Traditionally tour operators influenced greatly the choice of destinations. Today due to changes in information and communication technologies tourists can adjust their travel to particular destinations and participation in activities according to their individual preferences. Differences in preferences need to be taken into account when portraying climate for potential customers as tourists tend to be more vulnerable to climate than locals, although various segments of tourists have different characteristics with relevance to climate comfort, e.g. age, fitness, cultural background and previous experiences (de Freitas 2003).

Uncertainty on how precisely climate influences tourism will increase. Standard meteorological or climate station data are often not representative for the recreational area, a particular microclimate or location, e.g. valleys, hills, coast or a beach (de Freitas 2005). Incidence of unacceptable weather, extreme weather events and changing visitor perceptions and preferences will change the status of destinations once commonly associated with images of ideal climate (Higham & Hall 2005). Climate change is happening both on global and local scales (Matzarakis 2010) and tourists are acting upon actual weather conditions perceived as short-term events rather than climate. Averages of climate parameters have no physiological or psychological meaning, since tourists respond to the integrated effects of the atmospheric environment (de Freitas 2005). The thermal conditions experienced will vary depending on the relative influence of wind, humidity, solar radiation and level of a person's activity (de Freitas 2005). Although weather extremes are hard to predict, nevertheless they are highly relevant for tourism activity, perhaps even more important than the changes in mean conditions projected by climate models (Moreno and Amelung 2009). At the same time climate variables can play various roles when tourists choose their destinations: some climate variables are entirely physical (e.g. rain), some are physiological (e.g. air temperature), some are psychological (e.g. clear blue skies) and some are combinations of all three (de Freitas 2003) (see Table 3).

Since most physical and aesthetic factors are subjective, more often the thermal factor (Lin & Matzarakis 2011) is used for assessing changes in tourist flows. When tourists experience thermal conditions that are close to their thermal comfort zones, then tourism destinations are more visited in relation to outdoor thermal condition opposite to conditions that cause thermal stress (Lin & Matzarakis 2011). Most studies are constrained by data availability thus use a single climate factor such as air temperature, relative humidity, or number of sunshine hours, heat waves or sea surface temperatures as a proxy for climate although combined effect remains unexamined (Eugenio-Martin & Campos-Soria 2010, Hamilton & Tol 2007). Several studies use tourism climate index (TCI) (Mieczkowski 1985) or beach climate index (Morgan et al. 2000) with main difference between them in the rating and weighting schemes. Critics note that neither the temperature, nor simplified indexes based on standard monthly and simple climatological elements provide a full account of individual preferences with regard to the choice of destination (Agarin et al. 2010). There is a need for regional tourism climate indexes that must not only relate to generally subjective and context-specific tourist weather perceptions and acceptances, but also might include customised tourism climate indexes attuned to regional visitors, including area-specific weather preferences, dislikes and acceptances, connecting to the commonly extensive range of visitor motives and activities (Førland et al. 2013).

Table 3: Climate and the potential impact on tourism (after de Freitas 2003, de Freitas 2005, Becken 2010, Becken & Hay 2007).

Facet of climate	Significance	Impact
Aesthetic		
Sunshine/cloudiness	Quality of experience, sports, tourism and leisure activities	Enjoyment, attractiveness of site
Visibility	Quality of experience, sports, tourism and leisure activities	Enjoyment, attractiveness of site
Day length	Quality of experience, convenience	Hours of daylight available, enjoyment, attractiveness of site
Snow/ice	Quality of experience, sports, tourism and leisure activities	Enjoyment, attractiveness of site, place image, personal injury, damage to property, hindered mobility
Wind and waves	Quality of experience, sports activities	Enjoyment, attractiveness of site, place image, personal injury, damage to property, hindered mobility
Physical		
Wind	Annoyance, charm, water sports and tourism activities	Blown belongings, sand and dust, waves, hindered mobility
Rain	Annoyance, charm	Wetting, reduced visibility and enjoyment, hindered mobility, slippery terrain
Snow	Annoyance, charm, winter sports and leisure activities	Participation in sports and leisure activities, hindered mobility
Ice	Danger ,charm, winter sports and leisure activities	Personal injury, damage to property, hindered mobility
Severe weather	Annoyance, danger	Personal injury, damage to property, hindered mobility
Air quality	Annoyance, danger	Health, physical wellbeing, allergies
Ultraviolet radiation	Danger, attraction	Health, suntan, sunburn
Day length	Convenience	Hours of daylight available for outdoor activities
Thermal		
Integrated effects of air temperature, wind, solar radiation, humidity, long wave radiation, metabolic rate	Thermal comfort, therapeutic, restorative, tourism, sports, and leisure activities	Environmental stress, heat stress, physiological strain, hypothermia, hyperthermia, potential for recuperation

Contexts other than snow-based vacationing and sun and beach-oriented holidaymaking are rarely studied (Aaheim 2012). Research from Northern Scandinavia shows that most tourists considered weather conditions in summer as fairly good and satisfactory or acceptable and that weather aspects have relatively small behavioural impacts in comparison with overall traveller motives and intentions in addition to aspects such as comfort or wellbeing (Denstadli et al. 2011). An empirical study on German tourist preferences indicates that bad weather can influence particularly the choice regarding shorter trips in local surroundings then long-distance trips as the choice of the destination is not determined by the weather image alone (Lohmann & Kaim 1999). It is combined with other beliefs about natural environment, natural attractions, scenery and beliefs about the built environment, culture and host communities (Nadeau et al. 2008, Dwyer & Kim 2003). Tourist perception, decision-making and behaviour depend on the climate and weather at the destination as well as at the trip origin, but also on the weather forecast and conditions anticipated by traveller (Perry 1972).

3.2 Climatic impacts on tourist flows

Studies on tourist flows and their geographical and temporal redistribution and their potential shifts in visitation patterns are built on studies which seek to identify ideal climate or 'comfortable' conditions for tourists, e.g. expressed as climate indices (Becken 2013) (see above). The question of tourist weather perceptions and sensitivities are thus having been actualized since climatic assets among tourism regions are likely to be redistributed with changing climates (Denstadli et al. 2011) by changing existing tourist flows. Amelung & Moreno (2012) argue that in Western countries due to high initial values for the number of bed nights and revenues, the positive results are likely to be an overestimation; as climate change no longer induces a growth in overall tourism volumes, but leads to a redistribution of visitation. The issue of possible climate change impacts on tourist flows also has raised interest for governmental and financial organizations. Finland's national adaptation strategy states that predictions on where the tourism will be directed are prone to several uncertainties, but there is a possibility that northern areas may benefit from increased tourism (Marttila et al. 2005).

Current models predicting future climate conditions for tourism (see Figure 2) and consequent generation of tourist flows are based on two quadratic relationships:

1) cool destinations become more attractive as they get warmer, and warm destinations become less attractive;

2) cool countries generate less international tourists as they get warmer, and warm countries generate more (Bigano et al. 2008).

The argument that colder countries will benefit and can expand their tourism sector is generally accepted due to its positive message in spite of critical remarks. Present predominant tourist flows from north to south (from northwest Europe to the Mediterranean in summer) and their timing might be changed; tourists in the future might prefer colder countries and places - higher latitudes (Simpson et al. 2008, Schott et al. 2010, Coombes et al. 2009) and altitudes (Bigano et al. 2008). Current models suggest that warmer regions will experience a decrease in tourism ranging from -8% to -20%, whereas regions of higher latitude will expect an increase ranging from 1.3% to 8% (Berrittela et al. 2006). Favourable conditions are suggested not only for the BSR but also for the North Sea and the northern Atlantic coast of Spain and the Canary Islands (Heymann & Ehmer 2009). Particularly senior tourists and nature tourists might prefer northern Europe (Carthy et al. 2001) and it is predicted that the proportion of overnight stays taken by foreign tourists will increase (Ehmer and Heymann 2008). The OECD and UNEP report (2011) criticise a postulate that climate change will lead to larger tourist flows to the Baltic and the Northern countries as a result of heat stress in the Mediterranean region. The report stresses that tourist flows is not affected only by temperature but many other factors, e.g. culture and nature resources and tourism services. It is highly uncertain that tourists currently preferring the Mediterranean region will move to other more northern destinations, e.g. the BSR (OECD and UNEP 2011).

The models suggest that total number of tourists is also reduced due to climate change, because international tourism that is dominated by the Germans and the British would prefer short-haul destinations in neighbouring countries. Tourists will stay closer to home and thus importance of domestic destinations will increase (Bigano et al. 2008, Becken & Hay 2007). Domestic tourists have a greater consistency regarding destination preferences and a greater loyalty, at the same time regions with poorer climate show higher flexibility in terms of destination choice; and there is less variability in the probability of travelling domestically than abroad (Eugenio-Martin & Campos-Soria 2010). For Germans and Scandinavians their own countries are still their favourite holiday destinations. It is possible that these tourists will stay in their home country in larger numbers than they do now (Heymann & Ehmer 2009). No changes in the number of tourists are predicted for city tourism and for treatment at health resorts in the BSR due to climate change impacts (Heymann & Ehmer 2009). Currently longer-haul tourists (mainly from the USA) play a minor role for the BSR tourism industry. It is suggested that Northern American tourists will travel more to Northern Europe (Mather et al. 2005). At the same time an expected increase in travel prices will affect longer-haul holiday destinations more than closer ones (Heymann & Ehmer 2009).

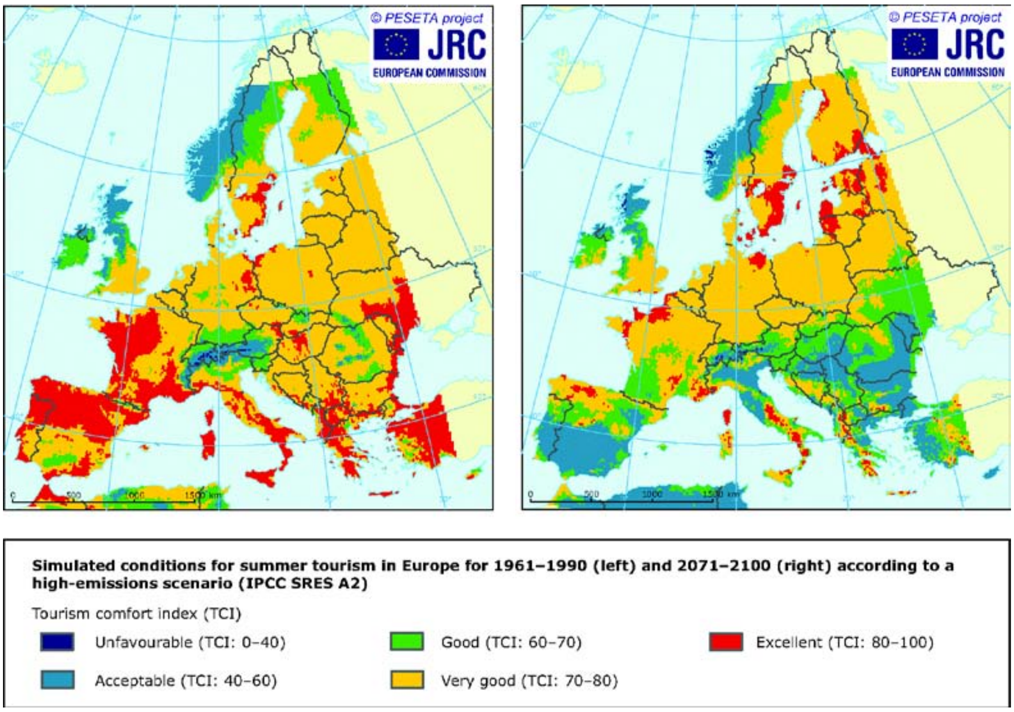

Figure 2: Modelled conditions for summer tourism in Europe for 1961 – 1990 and 2071 – 2100 (EEA 2010, Ciscar 2009, Amelung and Moreno 2009).

Several studies note the weaknesses of current models in predicting travel flows. Current models are not covering all global tourism flows, and mainly focusing on particular nationalities, e.g. German or British tourists; climate is mainly perceived as 'pull' factor for tourist motivation; 'push' factors that make tourism source areas unpleasant (hot, wet and cold weather) and the possibility of substitution between destinations are neglected. Mainly direct climate impacts on tourism destinations are considered. Uncertainties (Gössling & Hall 2005 and 2006, Goh 2012, Ciscar 2009, OECD and UNEP 2011) of current models are due to very few empirical studies, validity of databases, not adequate time-space resolution in climate data, largely unknown role of weather extremes and other weather parameters influencing thermal and perceived comfort, unclear role of information in decision-making and non-climatic parameters (cultural resources, costs of transport, personal disposable income (economic budget) and availability of leisure time (time budget) in the future, the existence of fuzzy-variables, e.g. terrorism, war, epidemics, natural disasters). Models perceive climate change as event with effects occurring suddenly in a given reference year, while in reality, climate change is phenomenon, which evolves over time, and thus there is time to adapt behaviour of tourists and tourism industry (Berrittella et al. 2006).

3.3 Climatic impacts on tourism destinations

Competitive relationships between destinations and therefore the profitability of tourism enterprises will be affected by the changes in the length and quality of climate-dependent tourism seasons (Simpson et al. 2008). Indoor or weather independent facilities will not be able to compensate fully for a low attractiveness of the outdoor weather. Flexibility to respond to climate variability and change varies between the subsectors of the tourist industry. Tourist resorts and regions that are the most vulnerable to climate change are a function of (i) the likely magnitude and extent of the climate impact, (ii) the importance of tourism to the local economy and (iii) the capacity to adapt (Agnew & Viner 2001). Suppliers of tourism services and local managers have the least flexibility; and tourists, particularly short-haul, weekend and day tourists, have the greatest flexibility (Agnew and Palutikof 2001). Tourism destinations depend on tourist operators and businesses at the venues. Tourist operators are less affected by climate change impacts as they are often with greater geographical mobility and flexible to change destinations, venues or activities depending on the tourism demands and risks at the destination. Venue-based businesses are place and activity fixed; they tend to have climate change impacts at high priority, regardless of the area of operation (Brouder & Lundmark 2011). Venue-based businesses have over time invested more money in operations and has long-term payback period; they are more aware on place-based future prognosis. Urban tourism can be considered as less climate-sensitive, as it can rely on indoor activities, developed urban infrastructure and skilled-personnel; cities due to diversified activities are often less dependent on tourism-related businesses. Resilience to climate change impacts in urban areas are greatly depends on green infrastructure, flood protection and spatial planning (EEA 2012b), although cities are major gateways for international tourists and thus play a role for tourism development at regional scale.

3.4 Climatic impacts on tourism activities

Outdoor and nature-based tourism

Climate change may affect outdoor recreation through overall comfort and enjoyment of recreation activities; the quality of the recreation experience, altering the ecological systems of an area and longer summer seasons and shorter winter seasons that will change the availability of certain recreation opportunities (Richardson & Loomis 2005, Moen & Fredman 2007). These changes will produce both winners and losers of recreation activities, where skiing is being widely acknowledged as a potential loser (Moen & Fredman 2007). Interactions of positive and negative aspects for nature-based tourism in summer and winter seasons make it difficult to assess the accumulative impact from climate change (Forsius et al. 2013). Substantial benefits to beach recreation, fishing and boating as well as reservoir, beach, golf, and stream recreation are expected, which offset losses to downhill and cross-country skiing, camping, wildlife viewing, as well as to smaller decline of benefits in forest-based recreation (Richardson & Loomis 2005). Changes of forests due to natural hazards and global warming affect also its recreational value (Blennow et al. 2010), e.g. coastal pine forests are traditionally popular for walking, mushroom or berry picking and cross-country skiing. Overgrowth of forests due to climate change will reduce access for recreationists to favoured areas for activities, and also make some areas lesser suited for traditional outdoor activities (Fyhri et al. 2009). The future of forest-based tourism attractions and destinations, e.g. national parks, do not only depend on climate impacts but also on tourists' perceptions of landscape change (Hall et al. 2011).

For cool weather destinations such as the northern part of the BSR, days with rain are a potential downside of climate change for tourism and recreation. Rain can be an obstacle to landscape sightseeing, nature-based attractions and various types of outdoor recreation, both due to individuals' perceived discomfort of getting wet and feelings of reduced safety (e.g. hiking and trekking in slippery terrain) (Førland et al. 2013). Most of the climate impact studies focus on the tourism industry, however behaviour of tourists and recreationists differs in relation to adaptation to climate change - tourists would change the location, timing and activities of their holidays while recreationists would adapt only timing and activities (Smith 1990). Heat stress and poor urban air quality in summer may push urban residents out from cities to rural and coastal tourism destinations, and outdoor recreation is likely to increase (Carthy et al. 2001). Statistics regarding levels of participation in outdoor recreation in Europe tend to be collected at the national level and thus create a barrier to prepare comparative studies (Nicholls 2006). Climate impacts on coastal tourism infrastructure might have implications for outdoor and nature-based tourism that not only depend on open access to countryside and sea coastline, but also highly values both nature and facilities (Fredman et al. 2012). Nature-based tourism operators in Finland are currently not aware of climate impacts and adaptation options (Saarinen & Tervo 2006). Increasing temperatures mean that destinations outside large urban areas will become more attractive, there will be greater demand for small-scale, rural, and nature-related tourism, e.g. Baltic States (Agarin et al. 2010). It is expected that with a future warmer climate destinations in northern Scandinavia might be more attractive for tourism, particularly recreational sea fishing, hiking, and outdoor recreation (Denstadli et al. 2011). Destinations that rely heavily upon climate as a touristic resource will be challenged to contend with changing perceptions of ideal times to visit (Higham & Hall 2005).

Weather and climate can determine the planning, implementation, financial success, visitor experience and quality of special events such as fairs, concerts, theatre, other art or sport related events that take place in outdoor venues (Scott & Lemieux 2010). Festivals or outdoor activities related to particular phonological phenomena such as flower blooming or autumn forest changes or harvesting, are more vulnerable to climate changes (Scott et al. 2005, Scott & Lemieux 2010). Also for golf industry the weather is a principal determinant of the length and quality of the season, the irrigation needs and pest management, which represent major operating costs (Scott & Lemieux 2010). Longer golf seasons in the northern countries could alter international and regional competition among major golf destinations (Scott & Jones 2007). The golfing areas might have negative impact from water shortages in summer and at the same time weather extreme events such as increased erosion; flooding and other surge damage can damage golf courses (Yeoman & McMahon-Beattie 2006).

Nautical tourism and water-based coastal tourism activities

Nautical tourism destinations (ports and marinas) in higher latitudes are often seen as a potential winning segment of climate change. A study on Northern Europe stresses that no negative effects of climate change are expected for seaside holidays on Germany's North Sea and Baltic coasts - on the contrary - there could be positive effects resulting from the longer summer season, as better conditions for seaside holidays (higher temperatures, less precipitation in summer) will compensate the risks of climate change (extreme weather events (e.g. storm surges) or coastal erosion) (Ehmer & Heymann 2008, Heymann & Ehmer 2009). Authors argue that Baltic States could attract more seaside tourists and that the Polish and Russian coasts could also benefit to some extent.

The Baltic Sea’s potential profitability of nautical tourism in a future climate is, however, expected to be second to that of the Mediterranean and Atlantic Seas (ECORYS 2012a). The density of tourism capacity is generally greater in the southern coastal regions, and climate conditions are an important explanation for this pattern. The Baltic Sea is becoming increasingly competitive in some niches such as aquatic sports and marinas, by promoting coherent strategies aimed at improving public services, infrastructures and adapting to the emerging climate conditions (ECORYS 2012a). Warming of both the atmosphere and the ocean will increase the length and quality of water sport season in the BSR (ECORYS 2012a). There are negative impacts related to water quality, sea-level rise, the erosion of beaches and threats to coastal infrastructure. Swimming, sailing, kayaking, canoeing, diving or fishing can be negatively affected by declining water quality, and there can be health risks in addition (Heggie 2010, Semenza & Menne 2009). Yachting, motor-boating, short distance coastal boating, canoeing, kayaking, sailing, rafting, surfing, kiting, and diving have specific requirements to wind and have low tolerance to precipitation, fog or storms, conditions which may change in a future climate. Yachting is expected to grow in the future with approximately 2–3% and this will also affect the development of marinas. Ice-yachting activities might be affected negative by climate change. More studies are needed to analyse climate change impacts on water-based recreational and sport activities the BSR.

Diving is considered to be highly affected by climate change (Marshall et al. 2011). When making a decision on a destination, divers expect water of high transparency; high ecological and species diversity; and variety of underwater landscapes (e.g. shipwreck). Global warming might favour diving activities in the Baltic Sea that at the present are at lower scale in comparison with other European destinations, although with a tendency to grow (ECORYS 2012a). At the same time climate change is expected to decrease water transparency in the Baltic Sea as a result of eutrophication that affects particularly the coastal waters (von Storch et al. 2008). This can have negative impacts on diving. Surfing was originally a largely warm-water activity, but with improved technology of wet suits, the activity is now pursued in temperate areas (Davenport & Davenport 2006). It is expected that with higher temperatures and longer swimming season, the Baltic Sea beaches might attract more surfing, kiting activists and related wind-dependent beach-based sport activities. Increased storminess might facilitate this trend.

Studies on climate change impact on the Baltic Sea's recreational fishing (including both angling and river fishing) are scarce. Traditional local fish species might be suffering from climate change, and invasion of alien species may increase (Peltonen et al. 2012). Higher temperatures, reduction in sea ice cover, ice depth and ice coverage and increased storminess can reduce ice-fishing activities, but increase involvement in recreational fishing in ice-free waters.

The Baltic Sea is one of the fastest growing cruise markets in the world; it is the second largest area for cruise tourism in Europe, after the Mediterranean. The Baltic Sea with 95.3 million maritime passengers had 24.1% of all passengers in the EU in 2010 (Eurostat 2012). Over the past 10 years, the demand for cruising worldwide roughly doubled (ECORYS 2012b) however cruising remains a small segment in the overall global tourism industry and a fraction of all international tourists (Clancy 2008). A warmer climate and a decrease in sea ice extent might have a positive impact on the cruise and ferry industries. The warmer winter temperature will extend the cruise season, first of all in the Mediterranean (ECORYS 2012b). Increased inter-annual variability in sea-ice extent might be a barrier for extending the cruise tourism season in the BSR. Depth of the waters in ports of call set limits to the size of ships and thus sea-level rise might provide a positive impacts if ports are adapted to new conditions (Krämer et al., pp. 55-90, this volume). Cruise tourism has developed as a relatively luxurious form of travel, however, with the building of more and larger ships; cruising is becoming affordable to more consumers, including families with children and senior tourists. The ship has become a destination in itself with amenities and attractions located on the ship, passengers need not venture ashore unless desired, and often time is limited to brief excursions (Hritz & Cecil 2008). Cruise tourism in the Baltic focus mainly on attractive cities with cultural heritage (offshore excursions), with little attention to the region's beaches or natural landscapes (ECORYS 2012b).

The price of fuel and climate change mitigation policies might have large impact on cruise industry (Adams 2010). Besides implementing more fuel efficient technologies, another strategy to save fuel is limiting the distances between ports during a voyage. Regions where destination ports are located close to each other, e.g. the southern and central part of the Baltic could experience a future growth in cruising while peripheries might have fewer cruises (ECORYS 2012b).

Destinations of the BSR largely rely on the potential of natural beaches. In the German Baltic coast the beach is the main reason for 70% of all tourists that have overnight stays (33 million) in 2009 (Haller et al. 2011). Prospective favourable weather conditions in summer might further increase the number of beach tourists. Research had identified that at present coastal communities concerns are on losses of sand caused by erosion and storm surges, and accumulations of beach wrack (Haller et al. 2011). Weather and climate are dominant imperative to travel motivation (Morgan et al. 2000, Denstadli et al. 2011, Gomez-Martin 2005). Beach tourist destinations thoroughly depend on favourable weather and climate conditions, e.g. sunshine, no precipitation, no wind, pleasant temperatures, clear waters and low health risks (Scott et al. 2008a, Moscardo et al. 2001, de Freitas 1990). Beach tourism is a major factor for tourists travelling from Northern Europe to the Mediterranean. It is argued that temperature is the most influential component of climate change for beach tourism while modifications due to changes of precipitation and sea level rise will not have such impact (Coombes et al. 2009). Research proves that reductions in beach width appear to have little influence on visitor numbers and thus geologically soft and low-lying coastlines which are vulnerable to sea level rise may experience similar levels of growth in tourism to rocky coastlines (Coombes et al. 2009). Recent developments with man-made beaches, which are created in urban waterfronts, prove this. With climate change the distribution of visitors along the coastline and across the year might be transformed, the polarisation of the utilisation of coastal resources might increase; and the length of the peak tourist season at the beach tourism destinations might be extended. Improvements of the relative conditions in the shoulder seasons will not change conditions for beach tourism at large scale in Europe (Moreno & Amelung 2009). It is expected that excellent weather conditions for beach recreation and tourism in the summer may also be found in the southern part of the Baltic and Atlantic sea regions, while still the Mediterranean Sea will be dominating in European beach tourism as the adverse climate condition will limit beach tourism season to be extended beyond summer in other European regions (ECORYS 2012a). Beach tourism that has highly seasonal character is closely related to mass tourism development and thus with the provision of accommodations.

Beach tourism involves sun bathing, swimming, surfing, kiting, beach volleyball and football, running, walking, cycling, street gymnastics and other sports and activities in children playgrounds. Any increase in beach tourism will mean that new tourism infrastructure, such as upgraded transportation networks, the expanded provision of accommodation, catering and safety, is required to provide capacity for an increase of visitors in the region (Coombes et al. 2009). Several BSR coastal resorts use natural resources, e.g. mud and mineral water. Studies on possible climate change impact on natural resources relevant for spa development are missing. Countries around the Baltic Sea have a long history of coastal tourism, wellness and spa tourism that started in the first half of the 19th century while the origins of a seaside resort comes from the 1700s (Bacon 1997, Worthington 2003, Onofri & Nunes 2013). Currently coastal resorts in the post-socialist countries of the BSR are not fully utilising their capacity; also studies of climate change impacts are missing in general in these countries.

Snow- and ice-based tourism activities

Snow-based tourism activities (downhill or Alpine, cross-country or Nordic skiing, snowboarding, snowmobiling, outdoor skating, dog-sledging, ice-fishing) and related businesses are being identified by numerous studies as tourism activities that are affected by climate change already or will be in near future (Landauer et al. 2012, Becken 2013, Fredman et al. 2012). Winter sports depend directly on climatic resources: without snow or low temperatures for the artificial production of snow, the development of winter tourism will not be possible (Gomez-Martin 2005). Snow- and ice-based outdoor activities are facing the prospect of higher temperatures, less natural snowfall, more thaw periods and shorter, more variable winter tourism seasons in the future (UNWTO and UNEP 2008). There are studies from Sweden (Moen & Fredman 2007, Brouder & Lundmark 2011, Baynes & Koivisto 2012) and Finland (Tervo 2008, Saarinen & Tervo 2006, Landauer et al. 2009, Landauer et al. 2012) that predict crucial negative impact on the economic viability of ski resorts and tourist operators acting in ski tourism. For the BSR countries skiing, skating, ice fishing and snowmobiling are favourite outdoor recreation activities and important for the regional identity, the quality of life and well-being of its inhabitants. Climate change can have an impact on tourism destination marketing and branding activities if the place image (the set of expectations and perceptions) relies on snow and ice (Landauer et al. 2012). Snow is not only a medium for winter sports but also a base for an important economic sector because of the links to tourism, winter cabins, producers of equipment, and local businesses (O’Brien 2009).

In southern Finland and Sweden, opportunities for snow-related activities are expected to decline; whereas the northern parts of Finland and Sweden could have a competitive advantage compared to winter tourism destinations in central Europe (Saarinen & Tervo 2006, Neuvonen et al. 2005, Swedish Government 2007). In Finland there is a projection that due to climate change cross-country skiing will reduce (Pouta et al. 2009; Neuvonen et al. 2005). In Baltic States regional differences observed, e.g. a considerable drop in snow-cover duration will take place on islands and in the coastal region of west Estonia (Jaagus 1997), while upland areas can still attract winter sport tourism. Winter thawing events lead to wetter snow which creates problems to skiing, snowmobiling and travel by sled (sled tours) (Keskitalo 2010). Climate change impacts will make skiers more flexible in time and space (Dawson & Scott 2010). Snow conditions are a key variable for skiers' decisions on destination choice; however other factors are also important such as skiing terrain, vertical drop and climatic conditions (temperature, precipitation and wind) are also important (Moen & Fredman 2007). The potential impact of climate change on winter tourism can be examined by the length of ski, snow-making and snowmobiling season, and the probability of being operational during the economically critical Christmas–New Year's holiday period (Tervo-Kankare et al. 2013). For the Baltic Sea climate requirements for cross-country skiing and ice-fishing, e.g. period and the depth of ice and ice-coverage of shallow coastal waters, coastal rivers and lagoons, might be as important as snowmobiling. High wind occurrence was found the most common reason for ski field closure in Finland, while snowmobiling and cross-country skiing was disturbed most by frosty conditions (Tervo 2008). The winter season can have twice as little tourism as in the summer (ESPON-IRPUD 2011) and thus the changes in the winter tourism flows can have less impact on the total annual number of tourists and the flows between countries and regions. In Finland skiing is the main purpose for about 10% of tourist trips made to participate in outdoor and nature activities, and cross-country skiing is not only a popular way to spend active holidays, but also an everyday sport and leisure activity in close proximity to residences (Landauer et al. 2009). With regards to climate change, the following research questions have been studied: the extent to which individuals change their participation habits by substituting skiing for another activity (activity substitution), participating less or more during a shortened ski season (temporal substitution), or travelling to other ski areas with better snow conditions (spatial substitution) (Dawson et al. 2011).

Climate change impacts in ski areas will likely vary greatly; low-lying ski areas are most sensitive and this will lead to a concentration of ski tourism on higher altitudes (EEA 2012a). Not the entire ski sector is at risk to climate change but rather certain individual ski areas that collectively make up a particular ski marketplace; the competition is likely to decline as individual operators of skiing become unable to afford the cost of adapting to future climatic conditions and this may actually advantage the ski areas that are able to remain operational (Dawson et al. 2011). Poorly adapted to climate change other ski resorts likely to close; skiers will travel to other remaining resorts (Dawson et al. 2011, Reynolds 2010, Scott & McBoyle 2007). Compared to alpine skiing, cross-country skiing is more vulnerable to climate change; it is predicted that air temperatures of winter days will rise; the snow depth will decrease as well as the number of days with snow cover, and thus will have direct negative influences on cross-country skiing, especially in southern Finland, where the majority of the Finnish population live (Landauer et al. 2009). Snow supplemented by snowmaking can increase snow cover and extend the season (Reynolds 2010). Artificial snow-making will increase costs and energy use and can have negative environmental impacts (increased water demand, pollution, etc), and there will be fewer days with suitable snow-making conditions (Boden 2007, Brouder & Lundmark 2011, Koponen & Pesonen 2012, Scott et al. 2008b). Finnish cross-country skiers expect the society to provide support for skiing activities and are not in general willing to pay for opportunities to ski (Landauer et al. 2009, Neuvonen et al. 2005, Landauer et al. 2012). Coastal tourism businesses in the northern Sweden have different perceptions on climate change than those in the inland – at the coast more variation than previously known is observed, and entrepreneurs are far more willing to accept one poor-snow winter as evidence of climate change and thus aware to begin to adapt new conditions (Brouder & Lundmark 2011). In Finland ski tourism destinations are smaller-scale and with less-diversified tourism product and thus their capability might be lower to adapt new conditions (Landauer et al. 2012). The shortening of the winter season is perceived as a threat to well-being of employees in tourism (Heikkinen et al. 2011). Winter safaris in Finland have a major role attracting foreign visitors; due to their need for large amounts of snow, making artificial snow is not considered as realistic adaptation mechanism (Kaján & Saarinen 2013, Tervo 2008). Instead diversification and alternative products are suggested as an option. This option will make former winter safaris destinations less competitive, due to the fact that branching out into summer tourism and focusing on summer activities (i.e. rafting, mountain-biking or hiking) means that former niche of snow-dependent tourism (unique and attractive at European scale) is lost and a new position in the market of summer tourism should gain in competition with many other places in Europe having similar products (Kaján & Saarinen 2013). Studies are missing on development of downhill and cross-country skiing tracks, outdoor skating rings, bobsleigh, luge, and skeleton tracks with opportunities to use artificial snow and ice making in the BSR, for instance exploring upland areas or urban artificial terrain and artificial lighting.

4 Adaptation Measures

Coastal tourism in the BSR is a spatially diverse, segmented, constantly changing and sensitive to climate-related risks, thus is requiring the need for complex adaptation measures (Filies & Schumacher 2013). The tourism industry has long experience in coping with climate variability and the ability to adjust to timing, places and activities. The sector is continuously adapting to be able to respond to changing demographic and economic conditions as well as to new demands and technologies (Perry 2006). Climate change requires to incorporate adaptation aspects into mainstream tourism planning, policies, information distribution and activity performance. Adaptation strategies need to cover three sides to adaptation:

- minimizing sensitivity or exposure to risk,
- developing a capacity to cope after damages have been experienced and
- acquiring the means to exploit new opportunities that arise (McCarthy et al. 2001).

Close cooperation of governments and relevant communities are needed to re-use existing tourism infrastructure and resources in affected places according to changed climate conditions. Governmental aid is needed particularly for tourism destinations, resorts and venues due to immobility of tourism-related fixed capital and infrastructure. While tourists and lesser degree, tour operators may respond immediately to unfavourable weather events; venue-based tourism business are less flexible to react to changing climate conditions, variability and extremes (Hall & Higham 2005, Perry 2006). Tourists are considered to have large adaptive capacity; however, their actual adaptive capacity and acceptable limits to change remains largely unexplored (Gössling et al. 2012, Scott et al. 2008a, Scott et al. 2012). Adaptive capacity for tourism destinations, enterprises and venues can be enhanced by creating the information and conditions (regulatory, institutional and managerial) that are required to support adaptation through public awareness, education, training, research, monitoring, and pilot and demonstration projects (Stern 2006). The BSR coastal tourism adaptive capacity is characterised by large spatial and industrial polarisation. Germany's coastal regions have medium overall capacity to adapt to climate change, the Baltic States have low capacity and Poland coastal regions are judged to have the lowest adaptive capacity in the EU. On the other hand Finland, Sweden and Denmark were assessed as having highest and high overall adaptive capacity to adapt to climate change in comparison with other regions in the EU (ESPON-IRPUD 2011). Countries that are wealthier and which have longer experiences in tourism industry might have larger adaptive capacities. Coastal cities and resort towns have larger capacity to cope with climate variability and possible changes then peripheries, e.g. countryside, former fishermen villages and nature areas. Micro and small and medium tourism enterprises may not have adequate human, social, technical and financial resources to cope with climate challenges, while it is expected that large companies, like tour operators, hotel chains, and cruise and airline companies have larger adaptive capacity.

Various types of barriers have been identified that prevent climate change adaptation in the tourism sector (Schott et al. 2010). The wide spread denial of climate change by the tourism industry is explained by 'a lack of resources to implement long-term responses, uncertainty surrounding the manifestations of climate change, and the ineffectiveness of short-term responses to climate change' (Higham & Hall 2005, Hall & Higham 2005). Fragmentation of the sector, the dependence on other sectors and the dominance of micro and small and medium enterprises are crucial barriers for voluntary adaptation actions to be taken by the sector itself. Adaptation to climate change depends on various factors such as political, legal, economic, technological, social and cultural context, planning and management context, equity and awareness, information, education and skills level (Grothmann 2010, Becken & Hay 2007). Adaptation should be placed in a wider sustainable development context, recognising that it is an ongoing process and occurs at different levels in particular, at the local level; the tourism sector should build on current adaptive experiences to cope with future climate variability and climate hazards and should also consider impacts and adaptations in other sectors (Simpson et al. 2008).

As vulnerability to climate change is likely to be unequally distributed across different groups in society, nationally and internationally, regional vulnerability analysis (Brouder & Lundmark 2011, Moreno & Becken 2009, Fussel 2007) and policies are needed to provide resources (including capital, knowledge, technology and consent) that are not held by the adapting agents themselves (Berkhout 2005). Nature-based tourism activities and dependent communities are seen as being particularly sensitive to forecasted climate change impacts (Kaján & Saarinen 2013). Glavovic (2008) suggests principles and operational imperatives for building sustainable, hazard-resilient communities that can help to guide efforts in adapting the tourism sector to climate change impacts:

- put people first;
- develop responsive and participatory processes;
- prioritise empowerment;
- prioritise ecological sustainability; and
- adopt a proactive and strategic but precautionary approach by developing a long-term, visionary approach that is implemented in a risk averse manner.

The European Commission suggests to classify adaptation options into three broad categories (EC 2009) that can be used for coastal tourism industry:

- a grey infrastructure approach: focusing on engineering techniques and infrastructures, aimed at providing physical protection against climate impacts such as floods and sea level rise, and preventing the adverse effects of climate variability, through heat-resilient road pavements, air conditioning, etc.;
- a green infrastructure approach: based on strengthening the resilience of ecosystems, using trees and green spaces to enhance cooling capacity and lessen flood impacts, and
- a soft approach: based on the application of policies, procedures, information, communication, education, economic incentives and other price signals.

Examples of adaptation measures that are utilised by tourism stakeholders are shown in Table 4.

Transnational, national and sub-regional policies have a particular role for tourism and climate change adaptation as a framework for top-down measures as well as supporting bottom-up initiatives with knowledge, organizational and financial instruments.

Table 4: A portfolio of climate change adaptations utilised by coastal tourism stakeholders (modified Scott et al. 2008a, UNWTO and UNEP 2008, Simpson et al. 2008, Wong et al. 2012, Becken & Hay 2007)

Type of Adaptation	Tourism Operators/ Businesses	Tourism Industry Associations	Governments and Communities	Financial Sector (investors/ insurance)
Technical	- Involvement in beach cleaning, coastal protection and the community infrastructure - Weather-based infrastructure design - Weather-proof (rain, wind, heat) buildings and transport - Green infrastructure - Utilising extreme weather (storms) - Free access to drinking water and shading -Real-time webcams of weather conditions	- Enable access to early warning equipment to tourism operators - Develop websites with practical information on adaptation measures - Green infrastructure	- Coastal protection - Ports, roads, and other transport infrastructure - Weather forecasting and early warning systems - Open public access to drinking water, bathing waters, shading - Green infrastructure - Water management - Drinking water supply - Increase sewer capacity/ enhance maintenance	- Building design or material (fire resistant) standards for insurance - Financing the developmental infrastructure projects - Insurance from various natural disasters
Managerial	- Contingency plans - Water conservation plans - Change of opening times / sales dates - Product and market diversification - Redirect clients - Weather sensitive marketing and branding - Selling the problem (e.g. storms) - Voluntary actions to preserve the environmental quality and nature resources - Staff adaptation and flexibility related to service quality and management - Communicate, and keep staff, customers and the media appraised	- Short-term seasonal forecasts and weather condition reports for marketing - Cooperate with media to improve destination image - Training on climate change adaptation - Encourage environmental management and preservation of natures resources - Cooperation amongst local stakeholders to reopen the destination and cross-selling among local businesses in case of weather hazards - Water conservation initiatives	- Impact management plans - Coastal zone management - Spatial planning - Natural disaster management planning - Business subsidies (insurance or energy) - Coordination of policy transfer / innovations in tourism - Coordinate improved destination branding - Ensuring the implementation of laws and policies - Replacement of vulnerable groups - Monitoring and inspections (food quality) - Marketing hazard recovery	- Provide information to customers (on weather variability) - Adjust insurance premiums or do not renew insurance policies - Restrict lending to high risk business operations - Banning approvals for high-risk jobs
Policy	- Natural hazards interruption guarantees by insurance and weather derivatives - Comply with regulation (e.g. building code) - Support innovations	-Coordinated political lobbying for climate change adaptation mainstreaming - Seek funding to implement adaptation projects - Support science and innovations	- Mainstream adaptation as an integral part of national and tourism planning - Boosting weather-proof tourism by providing economic incentives	- Consider climate change in credit risk and project finance assessments - Support investments to diversification of tourism activities and venues

	- Develop and have working emergency plan for severe weather events - Empower employees to make informed and realistic decisions	- Lobbying for weather-proof tourism	- Coastal management plans and set back policy, green infrastructure -Weather-proof building / urban design standards and location - Support education, training, science and strategic planning, innovations in tourism	- Finance developmental models in tourism sector
Research	- Site location - Green infrastructure - Water-proof design - Analysing tourism demand	- Assess awareness of businesses and tourists and knowledge gaps - Assess policies	- Climate change impacts / adaptation - Informing on changes in ecosystems - Monitoring programs	- Extreme event risk exposure (storms, floods, heat waves)
Education	- Water conservation education for employees / guests - Training of staff on emergency procedures and information campaigns in case of extreme weather	- Water conservation campaigns - Campaign on mitigation and adaptation to climate change	- Water conservation campaigns - Campaigns on risks of the UV radiation and extreme heat - Campaign on mitigation and adaptation to climate change	- Educate and inform potential and existing customers
Behavioural	- Tourists and tourism employees adjusting clothing and changing activities engaged in, timing, and places of visit	- Change of sector behaviour towards resource management and climate information and knowledge	-Politicians and civil servants changing attitude and decisions toward tourism and climate change adaptation	- Good practice in-house

The knowledge gaps on weather and climate can be reduced by better collaboration of tourism authorities with the small and medium-sized enterprises, and strategic planning would be useful to reduce the tourism industry's dependence on weather-sensitive (seasonal) activities (Rauken & Kelman 2012). Better knowledge gained through strategic planning exercises can provide higher confidence, flexibility and minimize uncertainty for the tourism entrepreneurs when dealing with climate change and other global challenges and thus give a better position of the BSR as tourism destination in general. Coordinated marketing at the BSR or national, sub-regional, and cross-border level, as well as pooling resources and publicity through tourism authorities, could be advantageous.

Aspects suggested for climate change adaptation strategies are important also for tourism sector (Easterling et al. 2004), e.g. awareness of climate vulnerability (vulnerability assessment and management), awareness of adaptation options (the need to integrate climate risk into innovation processes), uncertainty and motivation (supported by tailored information, incentives to adapt), provision of adaptation spill-over and removing (capital, knowledge, technology, consent, market or infrastructural) constraints on adaptation. Particular attention should be paid to both the innovative and the vulnerable ones in tourism, e.g. places, segments and stakeholders and for that improvements of adaptive capacity play an important role (Easterling et al. 2004). It has to be checked whether tourism infrastructure, networks and services are robust with respect to current weather conditions, and for this, additional investment is needed. Linkages with other policy domains may yield opportunities for climate related measures in tourism sector, e.g. linking tourism development to spatial planning. By strategically prioritising and implementing low cost adaptation measures first, large investments my be saved in the future in case climate effects in the tourism sector turn out to be severe (after Mark et al. 2012). The tourism industry's private sector relies on public investments and maintenance of public services and thus following public policy objectives related to climate change adaptation are relevant for it: to increase robustness of infrastructures; to inform the potentially vulnerable; to assist in the provision of early-warning and disaster relief; to facilitate, incentivize, guiding and enable adaptation and adaptive capacity; to regulate adaptation 'spillovers' and risk-shifting; increasing flexibility and adaptability of vulnerable managed systems; reversing trends that increase future vulnerability by spatial planning and regulating long-term and infrastructural assets and to improve awareness and preparedness, to regulate distributional consequences of adaptation, to provide information, knowledge and learning (Klein & Tol 1997, Easterling et al. 2004, Berkhout 2005). Maladaptation should be avoided (table 5), e.g. measures that potentially increase emissions of greenhouse gases (energy-intensive cooling), have high opportunity costs to alternatives, disproportionately burdens the most vulnerable, reduce incentive to adapt and avoid path dependency of infrastructural developments that are difficult to change in the future (Barnett & O'Neill 2010). Considering the fact that tourism and its infrastructure is a major influencing factor for the coastal landscape in the southern BSR there is a risk that adaptation measures are able to significantly change the appearance of the Baltic Sea coast (Gee et al. 2006).

Table 5: Integrating adaptation with mitigation (after Becken 2005, Milne 2004, Mills 2003).

Adaptation measure	Mitigation effects	Impact on environmental management	Economic aspect
Weather-proof tourist activities	Depends on the type of activities	Depends on the type of activities	High-yield alternative and income for local economy
Tourist education	Neutral	Increases awareness	Risk of deterring tourists
Green infrastructure	Reduces net carbon emissions through carbon sinks	Benefits water and flood management, biodiversity, reduces of fire vulnerability, health claims and deaths	Could be included in a carbon trading scheme
Water conservation	Reduces costs	Positive	Saves costs
Diversifying markets	Positive if new markets are more eco-efficient	Depends on the environmental impact	Positive if new markets are high yield
Insulated building envelopes; energy efficient construction	Reduced heat loss/gain, energy use and carbon emissions	Depends from technology used, reduced vulnerability to wind/ rainstorm damage; greater occupant comfort	Positive
Increasing air conditioning	Negative: increases carbon emissions	Depends from technology used	Expensive
Beach nourishment	Negative: energy use for mining and transportation	Disturbs ecosystems	Expensive
Reducing erosion with seawalls	Neutral	Disturbs natural currents, causes erosion elsewhere	Expensive, requires ongoing maintenance
Local renewable energy	Positive if reduced carbon emissions	Depends from energy source/technology used	Reduced business interruption

Potential evaluation criteria for adaptation options are suggested for the tourism sector (UNWTO and UNEP 2008): cost; effectiveness; ease of implementation; acceptability to local stakeholders; acceptability to financing agencies, ministries and/or donors; endorsement by experts; timeframe; institutional capacity; size of beneficiaries group; potential environmental or social impacts; and capacity to sustain over time. More detailed indicators relevant for coastal tourism industry are suggested within the preparation of the German Strategy on Adaptation to Climate (Schönthaler et al. 2010). Indicators relevant for climate change mitigation and adaptation can also be included in eco-labelling certification schemes, e.g. Blue Flag certification, QualityCoast certification and in existing natural resources monitoring and management systems.

Currently not all countries in the BSR have national legislation or strategies for tourism sector; and not all have national or regional climate change adaptation strategies. The predicted impacts of climate changes for tourism business are diverse. Strategies to adapt to climate change will therefore have to be multidimensional and should cover from small-scale behavioural adaptation of tourists themselves to infrastructural adaptation measures. Development of long-term, local adaptation strategies for tourism destinations and climate impact management plans with reference to local vulnerability and risk assessments is suggested for the tourism industry. It is important that climate change adaptation relevant for tourism is mainstreamed in other policy areas. Climate change adaptation strategies for public health, food, transport, spatial planning, coastal and marine areas, biodiversity, forestry, construction and cultural heritage sector, if such are or will be adopted can have relevance for tourism and recreation. National strategies of Germany and Finland cover tourism sector (Swart et al. 2009), as well as the report from the Swedish Commission on Climate and Vulnerability has detailed analysis of tourism sector aspects (Swedish Government 2007). Each country focus on national particularities- Finland and Sweden address reindeer husbandry, Denmark focus on coastal management; Germanys national policy highlights longer summer seasons with positive effects for tourism (Swart et al. 2009). Positive aspects of climate change in terms of its potential for tourism and recreational use of the coasts are also noted by Finland's national adaptation strategy (Marttila et al. 2005), a study on the climate change impacts in the Helsinki metropolitan area (Järvinen et al. 2010), City of Stockholm's climate change adaptation strategy (Ekelund 2007) and a report on climate change adaptation in Åland (Anonymous 2011). The same findings are applicable to the rest of the Baltic Sea. Positive outcomes apply especially to summer time recreational opportunities that will improve due to a longer summer and ice-free season and due to increasing water temperature. In addition, Finland's national adaptation strategy anticipates that in the mid- and long-term climate conditions become unfavourable for tourism in Southern Europe. The report states that predictions on where the tourism will be directed are prone to several uncertainties, but there is a possibility that northern areas may benefit from increased tourism (Marttila et al. 2005). Swedish national report states that tourism is one of the vulnerable sectors dominated by small enterprises and thus should be offered proactive information campaigns, education and courses.

Coastal tourism adaptation options with relevance to the BSR have been prepared based on research publications (Jopp et al. 2013, Mossbauer et al. 2012, Wong et al. 2012, Chen & Graham 2010, Müller & Weber 2008, Becken & Hay 2007, Mather et al. 2005, Burton & Lim 2001). Tourists can easily adapt their behaviour in response to climate variability and poor weather conditions, extreme weather events, resort or venue closures or inability to participate in selected tourism activities, while tourism destinations and venue-based enterprises will experience more adaptation challenges due to difficulties and expenses involved in structural and management-based adaptations (Gössling et al. 2012).

It is important to re-position the BSR destinations in order to capitalise the benefits of climate change by investigating climate change impacts on competing destinations and by utilising new opportunities for domestic and the BSR tourism markets due to prolonged tourism season and the development of new activities, new products and new target markets. Destination images, marketing and branding should be improved by incorporating benefits from climate change; off-seasons and the prolongation of summer season need to be emphasised. Strategies should encourage innovation and diversification of tourism products (particularly in tourism destinations dependent from snow and ice- based activities) and consider public investments and tourism business subsidies. Year-round tourism activities and attractions should be supported. Measures are needed to adapt institutional (calendar) seasonality (events, holidays, opening times) to the shift of climate-dependent natural seasonality and changes in phenology of plants that are important for event tourism. Flexible regulation to outdoor activities and climate-proof tourism infrastructure and services should be promoted (table 6); and measures are needed to respond to increasing demands and attractiveness of outdoor activities, beach and bathing tourism, water sports and cruise ships. Indoor attractions (e.g. with ventilation) need to be introduced to replace natural attractions if the appeal of the latter diminishes.

The tourism industry perceives climate change as a less urgent challenge and potentially even as beneficial for its business (Martinez et al. 2011); and tourism operators have a low awareness of climate change and there is little evidence of long-term strategic planning taking truly account of climate change (Simpson et al. 2008). Training programmes for tourism industry on climate change adaptation, as well as public education and practical information campaigns on climate change risks and adaptation measures are needed for host communities and tourists. Strengthen information network and research capacity of tourism destinations, e.g. protected area, staff with regards to climate change adaptation. Although increased temperatures might lead to more favourable tourism conditions in the BSR stakeholders need to take into consideration potential negative effects of a warmer Baltic Sea by including health risk analysis and early warning mechanisms. Unreliable coastal sea-ice conditions will increase safety risks and concerns and thus measures are needed to inform and protect tourists involved in ice fishing and walking along the coast. Access problems due to unreliable ice conditions inability to use temporary ice roads can be solve by using ferries or building safer crossings, bridges over water bodies and wetlands. There might be an increased need for outdoor lightening to compensate the loss of natural light reflection by snow. As for long-term adaptation tourism routes should be built on dry land; new routes should be planned for year-round use and to be exploitable in conditions of limited snow cover.

Table 6: Sectors in which climate change should already be taken into account during phases of planning, investments, design and construction of new infrastructure (Hallegatte 2009).

Sector	Time scale (years of operation) of new infrastructure if built today	Exposure to climate change
Water infrastructures (e.g. dams, reservoirs)	30–200	+++
Land-use planning (e.g. in flood plain or coastal areas)	>100	+++
Coastline and flood defences (e.g. dikes, sea walls)	>50	+++
Building and housing (e.g. insulation, windows)	30–150	++
Transportation infrastructure (e.g. port, bridges)	30–200	+
Urbanism (e.g. urban density, parks)	>100	+
Energy production (e.g. nuclear plant cooling system)	20–70	+

As the occurrence of extreme climate events will be exacerbated by climate change, there is a need to create a link between tourism and disaster risk reduction and management (Becken & Hughey 2013). In order to be prepared for heat waves, storms and floods and other extreme weather events improvements in early warning system, medical infrastructure and health services are needed to be sure that the specific needs of tourists will be considered. Measures should be planned and implemented against, e.g. the increase of mosquitoes and new threats to public health. Additional information and maps for tourists with safety provision during heat waves and storm and flood events (free access to shades/ wind screens/ shelters with emergency communication equipment, drinking water, changes of opening hours, and closed venues) can improve their capability to cope with extreme weather conditions. Emergency preparedness and increase of rescue service capacities (e.g. constructing of rescue centres, more harbours of refuge needed) are important and may be obtained through cooperation between tourism industry and host communities.

Wildfire proof settlements, including camping sites, second homes and caravan parking areas should be promoted. Relocation of vulnerable inhabitants and tourists if their health or accommodations are affected by direct impact of wildfire or smoke is needed. Restricted access to forest and nature areas under wildfire risk; clean-up of littering in forests and meadows, reed and grass-cutting, natural grass management by herbivorous animals (e.g. cows, wild horses) are measures to be promoted. Maintenance of open green spaces and the promotion of green infrastructure and urban forestry in order to reduce urban heat and flood risks can also be utilised as tourism attractions, e.g. the path networks for cyclists and hikers and parking places can be adjusted to green areas. Recreational fishing community, outdoor recreants and nature tourists should be informed on changes in local species and biotopes and the risk of introduction and establishment of non-indigenous species. Beach users should be informed about beach wrack.

Greater public investment in infrastructure for new tourism developments (e.g. land preparation, coastal defences or supporting infrastructure investment) to meet climate change impacts can be considered. Jointly with tourism industry specific ‘values’ at risk to climate change and sea level rise should be identified. Intensification of coastal protection; protection schemes (e.g. levees, seawalls, dikes, infrastructure elevation) could be installed, foundations be strengthened to adapt to sea-level rise. Stronger and higher bridges and piers need to be constructed. Also for tourism purposes temporary constructions, water-friendly buildings, floating breakwater pontoons and piers can be used. Technical measures to protect sandy beaches (beach replenishment, flood barriers, dunes, dikes, groins) might be considered jointly with tourism industry. Increase of nature protection (coastal forests and seaside landscapes), ex situ conservation, and restrictions and limitations for new infrastructure developments are options to be considered for coasts that are sensitive to erosion. The potential impact on land-degradation should be taken into account when making decisions on investments and expansions of recreation areas and beaches. The importance of beaches and recreational areas around the coastline is highlighted by the Swedish municipality of Ystad who estimates that the benefits of protecting and conserving the coastline are three times greater than the costs.

Safety problems with second-home areas and tourism infrastructure in flooded areas should be solved through spatial planning and integrated flood management, e.g. flood proof settlements should be promoted. Use of temporary constructions, water-friendly buildings for tourism purposes can be considered. Adaptation of water policies is needed in cooperation with tourism industry, e.g. safeguarding water supply, water conservation campaigns organized jointly by governments, communities and tourism industry, improvement of rainwater management to solve overloaded sewage problem (e.g. rain and sewage reservoirs, sustainable urban drainage systems) and provision of green infrastructure and changes in watering practices (lawn, green roofs, parks, gardens).

Changes of insurance policy and use of innovative financial instruments, e.g. weather derivatives (Tang & Jang 2012, Pollard et al. 2008) can be promoted. It is necessary that climate-related information is taken into account when decisions on site selection and investments for development of new resorts, venues and accommodations are taken; observation show that climate information is utilised more extensively in engineering, construction planning, property design and maintenance (insurance, heating–cooling) (Scott & Lemieux 2010).

5 Knowledge Gaps

Adaptation to climate change in the tourism sector has only been studied in recent years. Knowledge on adaptation approaches is thus cumulating fast. A number of academic papers have highlighted the limitations of existing knowledge and themes that are emerging otherwise studies are few (Kaján & Saarinen 2013, Becken 2013, Pang et al. 2013, Scott et al. 2012, Scott & Becken 2010, Burns & Bibbings 2009, Scott et al. 2005, Smith 1990). In 2001 the Commission on Climate, Tourism and Recreation of the International Society of Biometeorology listed research needs of government and industry (Higham & Hall 2005) e.g. climate as a resource and a limiting factor for tourism, the implications of climate variability and extreme weather events; methods for assessing relationships between climate and tourism; needs of the tourist and travel industries for climate and weather information; development of a Tourism Climate Index; advisory services for proper climatic adaptation of travellers; and contribution of tourism to climate change. Future studies on climate change impacts on tourism are suggested (Dubois and Ceron 2006, Swedish Government 2007) that are also applicable to the BSR:

- Comparative research: linking tourism destinations with similar climate change impacts, exploring why some destinations are more sensitive to climate change than others (e.g. diversity of supply and demand factors, or the presence of built/cultural attractions), investigating what are the different methodologies used to assess the potential impact of climate change; and facilitating learning and policy transfer among the BSR tourism destinations,
- Studies of the impacts of extreme events and weather variability on tourism and capacity to cope with it, studies on vulnerability of particular tourism sites (resorts) and venues,
- Trans-disciplinary research that could facilitate networking and linking social, economic and climate change (natural sciences) researchers from different BSR countries,
- Activity-oriented and participatory action research, dealing with the impacts on activities and linking scientists and tourism entrepreneurs (including large tourism operator firms, cruise, ferry and other transport managers, and micro, small and medium size tourism entrepreneurs at destinations).

Most of the tourism climate change impact studies are performed for destinations (Hall and Higham 2005). The geographic concentration of research on tourism and climate change with focus on Western countries has been criticised (Scott 2011, Scott & Becken 2010). BSR-wide studies on climate change impacts and adaptation for tourism with focus on marine and coastal tourism is missing. Little attention has been given to the islands, peninsulas (narrow spits) and low-lying coastal meadows, wetlands, lagoons and dune landscapes of the Baltic Sea. Common understanding and studies on coastal ecosystems and species relevant for recreation and tourism in the region (e.g. fish, game, wild berries, and mushrooms) as well as climate change impacts studies for them are missing. Diversification of geographical and disciplinary perspectives, including intensified place-based research conducted by researchers that are appropriately equipped to understand these place-specific factors are needed to understand local responses and options how to adapt local tourism activities to the impacts of climate change (Schott et al. 2010). High uncertainties exist in forecasting flows and defining a character of future tourism as this depends not only from several environmental and social-economic factors but also influenced by tourists and tourism industry preferences, values and market trends. Climate impacts and adaptation for tourism cannot be analysed in isolation from trends in information, transportation, construction and indoor climate technologies, the quality of life, change of life style, and public health issues.

Another limitation is related to climate and tourism data availability, accessibility and compatibility (ECORYS 2012a, Scott & Becken 2010, Turton et al. 2010, Scott & Lemieux 2009, Swedish Government 2007). Standard meteorological data typically fails to capture the microclimatic characteristics of specific tourism destinations (e.g. coastal resorts) and recreational settings (e.g. littoral zones) (Higham & Hall 2005). More studies on tourist literature and the media’s role regarding the change of perception and information distribution about climate, weather, its variables and extremes both at tourism destinations and the points of departures of tourists are needed (Scott et. al. 2008b). New impact assessment studies of tourist comfort are necessary to reflect environmental quality and the diversity in activities to complement the traditional formula of “sun, sea, and sand” (Moreno & Amelung 2009, Denstadli et al. 2011). Studies on tourism behaviour change due to changed perceptions of climatic appeal and image of certain tourism destinations and activities can give better explanation of the change of associated tourism flows (Hall & Higham 2005, Bigano et al. 2006). Within the framework of preparing the German Strategy on Adaptation to Climate Change, indicators for actions targeted on the tourism industry have been proposed (Schönthaler et al. 2010) . These indices may also be used at a BSR-level.

With relevance to the BSR research needs and topics relevant for climate change impacts and adaptation for tourism have been identified (Kaján & Saarinen 2013, Heikkinen et al. 2011, Turton et al. 2010, ESPON-IRPUD 2011, Førland et al. 2013, ECORYS 2012a, Schott et al. 2010, Swedish Government 2007, Dubois & Ceron 2006). There is a need for better representation of the BSR in climate models and studies of climate variations and scenarios at the local level with relevance to tourist industry and tourists in different social segments. Better statistics on coastal tourism (activities and venues) and recreation (including second homes), improved indicators used and data availability in relation to climate and tourism can improve knowledge on climate change impacts and adaptation to tourism. As for the BSR seasonality will still continue to be a determinative factor affecting direction and motives of tourism related travel and tourism-dependent business activities, further research on seasonality changes, shifts of tourism flows and on vulnerability of various tourism activities to a changed climate are crucial for the tourism industry.

Systematic and interdisciplinary review process of climate change impacts and adaptation to tourism in the BSR should be supported by the networking of researchers representing all countries of the region; linkages between social and natural sciences and between tourism industry, spatial planning, architecture and construction, public health and climate change experts should be strengthen. Climate research communities could receive expert support on specific development issues of tourism destinations at the Baltic Sea region by closer cooperation with the Committee on Spatial Planning and Development leading intergovernmental co-operation of 11 Baltic Sea Region countries known as the Vision and Strategies around the Baltic Sea or VASAB. This spatial planning network of the BSR has experience dealing with region-wide spatial issues including coastal areas since 1992 and recently has actively participating in marine planning. Comparative institutional analyses of climate change adaptation processes and multi-level governance aspects in relation to tourism sector could support improved national and sectoral policies. Comparative studies on host communities' (small and medium-sized enterprises and venue-based tourism businesses), large tourism industry actors (tour operators, cruise, air-travel, etc.), and luxury tourism versus budget and mass tourism adaptive capacity to respond to changing tourism demand and opportunities are helpful for proposing adaptive measures.

Transnational research on climate change and adaptation aspects integration into strategic and environmental impact assessment with relevance to tourism site selection and development has to be promoted. Tourism destinations, as well as regions from where the tourists come from should be analysed in climate change impact assessments. Knowledge gaps still exist in the sphere of climate impacts on public health, food, and visitors' comfort and behaviour with relevance to the BSR. Analyses of behavioural changes due to climate change impacts and adaptation should embrace tourists, tourism entrepreneurs and host communities. Transnational research on innovations and professional education and learning in tourism sector with reference to climate change adaptation should be supported in the BSR taking account that the region is known globally as one of the forerunner of tourism innovations. Opportunities for "weather-proof" tourism product development and the diversification of tourism activities at the destination are suggested to be explored. Studies on ecological (climate change mitigation), cultural, social and economical impacts of switching outdoor activities to indoor places and switching for natural to artificially maintained settings are needed to ensure sustainable tourism development in changing climate conditions. Research on how to link mitigation and adaptation measures and to find synergies, particularly in transport, tourism infrastructure, accommodation and catering, and other tourism related activities in coastal areas are crucial in the context of global climate policy.

To utilise new opportunities, possible limitations and benefits for tourism in the BSR due to *rising average temperature* studies on changing climate conditions, better regulation for bathing, water sports and marinas are needed. Comparative studies on climate change impacts on ice and snow-dependent tourism venues and adaptation measures with relevance to the BSR should be conducted. Studies of the *extreme weather events* and climate variability impacts on human health and tourist behaviour with relevance to the BSR are required. Trans-disciplinary studies on green infrastructure design, planning and utilisation as tourism asset should be performed. Furthermore trans-disciplinary research on *marine and coastal flora and fauna changes* and their impacts for tourism and recreation in the BSR should be undertaken. Information needs to be improved on depositional dynamic of floating algae accumulations along the Baltic coastlines; and socioeconomic analysis has to be performed whether biomass accumulations on beaches affect coastal attractiveness and local tourism revenue (Mossbauer et al. 2012). To cope with *impacts due to the sea level rise and erosion*, the improvement of coastal monitoring and methods is needed that is relevant for tourism industry. Transnational research might be supported to work out a common typology of the BSR coasts with relevance to coastal erosion and beach tourism and possible adaptation measures. Finding out tourists', host communities and tourism entrepreneurs' attitudes and perception of the sea level rise, coastal erosion and potential protection measures might be useful for proposing future adaptation strategies.

6 Summary and Conclusions

Climate change impacts will have both positive and negative consequences on tourism industry in the BSR. Coastal and cold-climate-dependent tourism are exposed to many climate change-related risks, while warmer climate can also bring new weather-related opportunities to the region. Variables of climate change and their impacts are identified based on existing reports as well as on new analyses carried out as part of the Baltadapt project. This report reviews existing research on climate change impacts with relevance to tourism destinations and activities, tourist behaviour and flows in the Baltic Sea Region. Possible adaptation measures are reconsidered with relevance to coastal and cold-climate tourism destinations. Finally, the research and knowledge gaps in relation to climate change adaptation and tourism are listed and discussed with the aim to support research and cooperation between science and industry.

Coastal tourism industry is an important contributor to regional and national economies and employments; it is the largest single maritime economic activity in Europe (ECORYS 2012a). Coastal destinations are the most popular destinations in Europe and the rest of the world (EC 2000). Coastal areas are important for the leisure and recreation to the local communities, and they are a part of regional identity, place image and branding. The BSR has a tourism industry with longstanding traditions and innovative enterprises; although tourism adaptive capacities with relation to climate change vary depending if the settings are in urban, densely of scarcely populated coastal areas or in wealthier or lower income regions. Nevertheless all coastal tourism destinations around the Baltic Sea are linked through climate change impacts relevant for the region. To create, share and distribute existing knowledge on climate impacts and to find the best and available adaptation options, joint activities are needed for the BSR tourism industry and governments. Fragmentation, polarisation and low capacity to research, innovation activities and long-term strategic planning of the tourism industry request joined support and intervention from the national and local governments, as well as coordinating action by trans-national regional organisations.

The most valuable resources for coastal tourism in the BSR are beaches and the water itself, and consequently the quality of these resources is of great significance for the decisions by tourists to spend their holidays in this area. Snow and ice in cool weather destinations, e.g. the northern part of the BSR, are equally important tourism resources. While climate change will bring many new opportunities due to the rise of average air and water temperature it also will make significant negative impacts on the quality of water and beaches and the shrinking of winter tourism season. Sea level rise and increased wind-speed, increased precipitation in winter and decreased in summer will affect natural and built-up environments and structures that are today located in a thin belt along the coast. Through increased precipitation the run-off of nutrients from cultivated land could increase the already existing problem of eutrophication which may affect, e.g. beach tourism.

There are certain barriers to climate change adaptation strategies for tourism sector (Turton et al. 2010) that makes it difficult for the stakeholders to act appropriately to the already arising impacts of climate change to the BSR:

- The scale and uncertainty surrounding climate change projections,
- Communication within and between regional, national and local actors,
- Concerns regarding the capacity of venue-based small and medium enterprises to adapt, relative to governments and larger/global tourism operators,
- Institutional, legal, community and resource limitations that inhibit, or are at least perceived to inhibit, the timely implementation of adaptation strategies.

To overcome uncertainties on climate change and its possible impacts, new knowledge and information distribution are needed not only for responsible governments at various levels, but also for tourism industry and tourists. Concerning climate change adaptation in tourism sector several key issues are identified and require the following (after Prideaux 2009, Turton et al. 2010):

- Confidence that climate is changing and this fact is recognized at wider society and acted upon,
- Common understanding that increased variability in climate is part of the climate change process,
- Overcoming communication problem among climate change experts, tourism industry and decision-makers,
- Comprehension that there are a number of drivers that underpin change and in the tourism context which are poorly understood,
- Recognition that climate change and adaptation is a moving target,
- To overcome uncertainty, the effective monitoring and evaluation of impacts and adaptation measures are needed that are relevant for tourism industry,
- Motivation from the tourism industry and destinations to avoid climate change risks or take up opportunities through adaptation actions,
- Resources from the government and private stakeholders,
- Innovation is a key strategy for tourism industry and destinations and that includes demonstration of new technologies and good practices,
- The tourism industry need to be self-organized on an industrial scale to ensure its voice is heard and concerns are accorded legitimacy; thus transitional support from the government at various levels is needed.

References

Aaheim, A., Amundsen, H., Dokken, T. and Wei, T. (2012): Impacts and adaptation to climate change in European economies. Global Environmental Change 22: 959–968.

Adams, A.W. (2010): Planning for cruise ship resilience: An approach to managing cruise ship impacts in Haines, Alaska. Coastal Management 38(6): 654–66.

Agarin, T., Jetzkowitz, J. and Matzarakis, A. (2010): Climate change and tourism in the Eastern Baltic Sea Region. In: C. Schott (ed.). Tourism and the implications of climate change: Issues and actions. Bingley: Emerald, pp. 261–281.

Agnew, M.D. and Palutikof, J.P. (2001):Impacts of climate on the demand for tourism. In: A. Matzarakis, and C.R. de Freitas (eds.) Proceedings of the First International Workshop on Climate, Tourism and Recreation: International Society of Biometeorology, Commission on Climate Tourism and Recreation, Porto Carras, Halkidiki, Greece, December 2001, pp. 1–10.

Agnew, M.D. and Viner, D. (2001): Potential impacts of climate change on international tourism. Tourism and Hospitality Research 3(1): 37–60.

Amelung, B. and Moreno, A. (2012): Costing the impact of climate change on tourism in Europe: results of the PESETA Project. Climatic Change 112: 83–100.

Anonymous (2011): PM om anpassningsåtgärder p.g.a. klimatförändringen. Mariehamn: Ålands Landskapsregering/Miljöbyrån. (website accessed July 9, 2012, URL: http://www.regeringen.ax/.composer/upload//socialomiljo/oversvamning_klimat_PM.pdf)

Armaitiene, A., Boldyrev, V.L., Povilanskas, R. and Taminskas, J. (2007): Integrated shoreline management and tourism development on the cross-border World Heritage Site: A case study from the Curonian spit (Lithuania/Russia). Journal of Coastal Conservation 11: 13–22.

Bacon, W. (1997): The rise of the German and the demise of the English spa industry: A critical analysis of business success and failure. Leisure Studies 16: 173–187.

Barnett, J. & O'Neill, S. (2010): Maladaptation. Global Environmental Change 20: 211–213.

Bastis (2013): (website accessed June 21, 2013, URL:http://www.bastis-tourism.info)

Baynes, S. and Koivisto, J. (2012): Ski tourism: Gävleborg, Sweden. Baltic Climate. (website accessed June 21, 2013, URL:http://balticclimate.org/uploads/files/SWOT-Sweden-Ski%20tourism.pdf)

Becken, S. & Hughey, K.F.D. (2013): Linking tourism into emergency management structures to enhance disaster risk reduction. Tourism Management 36: 77–85.

Becken, S. (2005): Harmonising climate change adaptation and mitigation: The case of tourist resorts in Fiji. Global Environmental Change 15(4): 381–393.

Becken, S. (2010): The importance of climate and weather for tourism: Literature review. Land, Environment & People.

Becken, S. (2013): A review of tourism and climate change as an evolving knowledge domain. Tourism Management Perspectives 6: 53–62.

Becken, S. and Hay, J. (2007): Tourism and climate change – Risks and opportunities. Clevedon: Channel View Publications.

Beniston, M., Stephenson, D.B., Christensen, O.B., Ferro, C.A.T., Frei, C., Goyette, S., Halsnaes, K., Holt, T., Jylhä, K., Koffi, B., Palutikof, J., Schöll, R., Semmler, T. and Woth, K. (2007): Future extreme events in European climate: An exploration of regional climate model projections. Climatic Change 81: 71–95

Berkhout, F. (2005): Rationales for adaptation in EU climate change policies. Climate Policy 5(3): 377–391.

Berrittella, M., Bigano, A., Roson, R. and Tol, R.S.J. (2006): A general equilibrium analysis of climate change impacts on tourism. Tourism Management 27(5): 913–924.

Bigano, A., Bosello, F., Roson, R. and Tol, R.S.J. (2008): Economy-wide impacts of climate change: A joint analysis for sea level rise and tourism. Mitigation and Adaptation Strategies for Global Change 13(8): 765–791.

Bigano, A., Hamilton, J.M. and Tol, R.S.J. (2007): The impact of climate change on domestic and international tourism: A simulation study. Integrated Assessment Journal 7(1): 25–49.

Bigano, A., Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2006): Predicting tourism flows under climate change: An editorial comment on Gössling and Hall. Climatic Change 79: 175–180.

Blennow, K., Andersson, M., Sallnas, O. and Olofsson, E. (2010): Climate change and the probability of wind damage in two Swedish forests. Forest Ecology and Management 259(4): 818–830.

Boden, B. (2007): Naturbaserad turism och klimatforandring. ETOUR Rapport 2007:17. Ostersund: ETOUR Mid Sweden University.

Brouder, P. and Lundmark, L. (2011): Climate change in Northern Sweden: Intra-regional perceptions of vulnerability among winter-oriented tourism businesses. Journal of Sustainable Tourism 19(8): 919–933.

Brown, R.N.K., Rosenberger, R.S., Kline, J.D., Hall, T.E. and Needham, M.D. (2008): Visitor preferences for managing wilderness recreation after wildfire. Journal of Forestry 106(1): 9–16.

Burns, P. and Bibbings, L. (2009): The end of tourism? Climate change and societal challenges: Twenty-First Century Society. Journal of the Academy of Social Sciences (4:1): 31–51.

Burton, I. & Lim, B. (2001): An adaptation policy framework: Capacity building for stage II Adaptation: A UNDP-GEF Project. New York: United Nations Development Program/Global Environment Facility.

Butler, R. (2001): Seasonality in tourism: Issues and implications. In: T. Baum, and S. Lundtorp (eds.). Seasonality in Tourism. London: Pergamon, pp. 5–22.

Butler, R. (2009): Tourism in the future: Cycles, waves or wheels? Futures 41: 346–352.

Buultjens, J., White, N. and Willacy, S. (2007): Climate change and Australian tourism: A scoping study. Sustainable Tourism Cooperative Research Centre. (website accessed June 21, 2013, URL:www.crctourism.com.au)

Buzinde, C.N., Manuel-Navarrete, D., Yoo, E.E. and Morais D. (2010): Tourists' perceptions in a climate of change: Eroding destinations. Annals of Tourism Research 37(2): 333–354.

Chen, N. & Graham, P. (2010): Climate change as a survival strategy: Soft infrastructure for urban resilience and adaptive capacity in Australia's coastal zones In: K. Otto-Zimmermann (ed.). Resilient cities: Cities and adaptation to climate change. Proceedings of the Global Forum 2010, Local Sustainability 1, pp. 379–388.

Ciscar, J.C. (ed.) (2009): Climate change impacts in Europe. Final report of the PESETA research project. JRC Scientific and Technical Reports. European Commission – Joint Research Centre Institute for Prospective Technological Studies, Institute for Environment and Sustainability. (website accessed June 21, 2013, URL:http://ftp.jrc.es/EURdoc/JRC55391.pdf)

Clancy, M. (2008): Cruisin' to exclusion: Commodity chains, the cruise Industry, and development in the Caribbean. Globalizations 5(3): 405–418.

CM (Council of Ministers) (2009): Latvijas Tūrisma attīstības pamatnostādnēm 2009.–2015.gadam Globālās tendences un perspektīvas pasaules tūrismā, Pielikums Nr.2.

Coombes, E.G., Jones, A.P. and Sutherland, W.J. (2009): The implications of climate change on coastal visitor numbers: A regional analysis. Journal of Coastal Research 25(4): 981–990.

Dailidiené, I., Davuliené, L., Kelpsaité, L. and Razinkovas, A. (2012): Analysis of the climate change in Lithuanian coastal areas of the Baltic Sea. Journal of Coastal Research 28(3): 557–569.

Davenport, J. and Davenport, J.L. (2006): The impact of tourism and personal leisure transport on coastal environments: A review. Estuarine, Coastal and Shelf Science 67: 280–292.

Dawson, J. and Scott, D. (2010): Examining climate change vulnerability for the US Northeast ski tourism sector using a systems based approach. Journal of Tourism Hospitality and Planning Development 7(3): 219–235.

Dawson, J., Havitz, M. and Scott, D. (2011): Behavioral adaptation of Alpine skiers to climate change: Examining activity involvement and place loyalty. Journal of Travel & Tourism Marketing 28(4): 388–404.

Day, J., Chin, N., Sydnor, S. and Cherkauer, K. (2013): Weather, climate, and tourism performance: A quantitative analysis. Tourism Management Perspectives 5: 51–56.

De Freitas, C. (1990): Recreation climate assessment. International Journal of Climatology 10: 89–103.

De Freitas, C.R. (2003): Tourism climatology: evaluating environmental information for decision making and business planning in the recreation and tourism sector. International Journal of Biometeorology 48: 45–54.

De Freitas, C.R. (2005): The effects of climate change on tourist flows and recreation patterns. In: C.M. Hall, and J. Higham (eds.). Tourism, recreation, and climate change. Clevedon: Channel View Publications, pp. 29–43.

Denstadli, J.M., Steen Jacobsen, J.Kr. and Lohmann, M. (2011): Tourist perceptions of summer weather in Scandinavia. Annals of Tourism Research 38(3): 920–940.

Dubois, G. and Ceron, J.-P. (2006): Tourism and climate change: Proposals for a research agenda. Journal of Sustainable Tourism 14(4): 399–415.

Dwyer, L. and Kim, C.W. (2003): Destination competitiveness: a model and indicators. Current Issues in Tourism 6(5): 369–413.

Easterling, W.E., Hurd, B.H. and Smith, J.B. (2004): Coping with global climate change: the role of adaptation in the United States. Arlington, VA: Pew Center for Global Climate Change.

EC (2009): Commission Staff Working Document accompanying the adapting to climate change: towards a European framework for action. Impact assessment. Brussels: European Commission.

EC (2010): Europe, the world's No 1 tourist destination – a new political framework for tourism in Europe, COM(2010) 352 final. Brussels: European Commission.

EC and Eurostat (2008): Panorama on tourism. Luxembourg: Office for Official Publications of the European Communities.

ECORYS (2009): Study on the competitiveness of the EU tourism industry: Within the Framework Contract of Sectoral Competitiveness Studies of Rotterdam/Brussels: ECORYS/ European Commission Directorate-General Enterprise & Industry.

ECORYS (2012a): Blue growth scenarios and drivers for sustainable growth from the oceans, seas and coasts: Third interim report. Rotterdam/Brussels: ECORYS/European Commission, DG MARE.

ECORYS (2012b): Blue growth scenarios and drivers for sustainable growth from the oceans, seas and coasts: maritime sub-function profile report cruise tourism (4.3). Rotterdam/Brussels: ECORYS/European Commission, DG MARE.

EEA (2010): The European Environment: State and outlook 2010: Adapting to climate change. Copenhagen: European Environment Agency.

EEA (2012a): Climate change, impacts and vulnerability in Europe 2012: An indicator-based report. Luxembourg: Office for Official Publications of the European Union.

EEA (2012b): Urban adaptation to climate change in Europe: Challenges and opportunities for cities together with supportive national and European policies. Luxembourg: Office for Official Publications of the European Union.

Ehmer, P. and Heymann, E. (2008): Climate change and tourism: Where will the journey lead? Frankfurt am Main: Deutsche Bank Research. (website accessed October 15, 2012, URL:www.dbresearch.com)

Eichhorst, U., Bongardt, D. and Miramontes, M. (2010): Climate-proof urban transport planning: opportunities and challenges in developing cities. In: K. Otto-Zimmermann (ed.). Resilient cities: Cities and adaptation to climate change. Proceedings of the Global Forum 2010, pp. 91–105.

Ekelund, N. (2007): Anpassning till ett förändrat klimat. Miljöförvaltningen Stockholm stad. (website accessed July 10, 2013, URL:http://www.stockholm.se/Global/Stads%C3%B6vergripande%20%C3%A4mnen/Klimat%20%26%20Milj%C3%B6/Klimat/Rapporter/Klimatanpassning.pdf)

Epstein, P.R. (2002): Detecting the infectious disease consequences of climate change and extreme weather events. In: P. Martens, and A.J. McMichael (eds.). Environmental change, climate and health: Issues and research methods. Cambridge: Cambridge University Press, pp. 172–196.

ESPON-IRPUD (2011): ESPON Climate – Climate change and territorial effects on regions and economies, applied research 2013/1/4, final report, scientific Report. TU Dortmund University. (website accessed October 12, 2012, URL:http://www.espon.eu/export/sites/default/Documents/Projects/AppliedResearch/CLIMATE/ESPON_Climate_Final_Report-Part_C-ScientificReport.pdf)

Eugenio-Martin, J.L. and Campos-Soria, J.A. (2010): Climate in the region of origin and destination choice in outbound tourism demand. Tourism Management 31: 744–753.

Eurostat 2012. Eurostat regional yearbook (2012): Luxembourg: Publications Office of the European Union.

Fenger, J., Buch, E., Jakobsen, P.R. and Vestergaard, P. (2008): Danish attitudes and reactions to the threat of sea-level rise. Journal of Coastal Research 24(2): 394–402.

Filies, C. and Schumacher, S. (2013): Climate change impacts on Baltic coastal tourism and the complexity of sectoral adaptation. In: Schmidt-Thome, P. and Klein, J. (eds.) Climate change adaptation in practice: From strategy development to implementation. London: Wiley-Blackwell, pp. 225–238.

Førland, E. J., Jacobsen, J. Kr., S., Denstadli, J. M., Lohmann, M., Hanssen-Bauer, I., Hygen, H. O. and Tømmervik, H. (2013): Cool weather tourism under global warming: Comparing Arctic summer tourists' weather preferences with regional climate statistics and projections. Tourism Management 36: 567–579.

Forsius, M., Anttila, S., Arvola, L., Bergström, I., Hakola, H., Heikkinen, H.I., Helenius, J., Hyvärinen, M., Jylhä, K., Karjalainen, J., Keskinen, T., Laine, K., Nikinmaa, E., Peltonen-Sainio, P., Rankinen, K., Reinikainen, M., Setälä, H. and Vuorenmaa, J. (2013): Impacts and adaptation options of climate change on ecosystem services in Finland: a model based study. Current Opinion in Environmental Sustainability 5: 1–15.

Fredman, P., Wall-Reinius, S. and Grundén, A. (2012): The nature of nature in nature-based tourism. Scandinavian Journal of Hospitality and Tourism 12(4): 289–309.

Fussel, H.M. (2007): Vulnerability: A generally applicable conceptual framework for climate change research. Global Environmental Change 17: 155–167.

Fyhri, A., Jacobsen, J.K.S. and Tommervik, H. (2009): Tourists' landscape perceptions and preferences in a Scandinavian coastal region. Landscape and Urban Planning 91(4): 202–211.

Gee, K., Kannen, A. & Licht-Eggert, K. (2006): Raumordnerische Bestandsaufnahme für die deutschen Küsten und Meeresbereiche. Forschungs- und Technologiezentrum Westküste der Universität Kiel (Hrsg.). Berichte Nr. 38. (website accessed July 9, 2012, URL:http://iczm.ecology.unikiel.de)

Glavovic, B.C. (2008): Sustainable coastal communities in the age of coastal storms: Reconceptualising coastal planning as 'new' naval architecture. J Coast Conservation 12: 125–134.

Goh, C. (2012):Exploring impact of climate on tourism demand. Annals of Tourism Research 39(4): 1859–1883.

Gomez-Martin, M.B. (2005): Weather, climate and tourism – a geographical perspective. Annals of Tourism Research 32(3): 571–591.

Gössling, S. and Hall, C.M. (2006): Uncertainties in predicting tourist flows under scenarios of climate change. Climatic Change 79: 163–173.

Gössling, S. and Hall, M. (eds.) (2005): Tourism and global environmental change: Environmental, economic, social and political interrelationships. London, Routledge.

Gössling, S., Hall, M., Lane, B. and Weaver, D. (2008): Report: The Helsingborg Statement on Sustainable Tourism. Journal of Sustainable Tourism 16(1): 122–124.

Gössling, S., Scott, D., Hall, C.M., Ceron, J.P. and Dubois, G. (2012): Consumer behaviour and demand response of tourists to climate change. Annals of Tourism Research 39(1): 36–58.

Gräwe, U. and Burchard, H. (2012): Storm surges in the Western Baltic Sea: The present and a possible future. Climate Dynamics 39(1/2): 165–183.

Grothmann, T. (2010): Governance recommendations for adaptation in European urban regions: Results from five case studies and a European expert survey. In: K. Otto-Zimmermann (ed.). Resilient cities: Cities and adaptation to climate change. Proceedings of the Global Forum 2010, Local Sustainability 1, pp. 167–175.

Hall, C.M. (2011): Seeing the forest for the trees: Tourism and the international year of forests. Journal of Heritage Tourism 6(4): 271–283.

Hall, C.M. and Higham, J. (2005): Introduction: tourism, recreation and climate change. In: C.M. Hall, and J. Higham (eds.). Tourism recreation and climate change: International perspective. Clevedon: Channel View Publications, pp. 3–28.

Hall, C.M., Scott, D. and Gössling, S. (2011): Forests, climate change and tourism. Journal of Heritage Tourism 6(4): 353–363.

Hallegatte, S. (2009): Strategies to adapt to an uncertain climate change. Global Environmental Change 19: 240–247.

Haller, I., Stybel, N., Schumacher, S. and Mossbauer, M. (2011): Will beaches be enough? Future changes for coastal tourism at the German Baltic Sea. Journal of Coastal Research, Special Issue 61, pp. 70–80.

Hamilton, J.M. (2007): Coastal landscape and the hedonic price of accommodation. Ecological Economics 62(3/4): 594–602.

Hamilton, J.M. and Tol, R.S.J. (2007): The impact of climate change on tourism in Germany, the UK and Ireland: A simulation study. Regional Environmental Change 7(3): 161–172.

Heggie, T.W. (2010): Swimming with death: Naegleria fowleri infections in recreational waters. Travel Medicine and Infectious Disease 8(4): 201–206.

Heikkinen, H.I., Kauppila, P., Lépy, É., Ponnikas, J. and Rautio, A. (2011): Tourism. In: I. Bergström, T. Mattsson, E. Niemelä, J. Vuorenmaa, and M. Forsius (eds.). Ecosystem services and livelihoods: vulnerability and adaptation to a changing climate: VACCIA synthesis report. The Finnish Environment 26/2011. Helsinki: Finnish Environment Institute, pp. 55–58.

Heymann, E. and Ehmer, P. (2009): Tourism 2030: Climate change is re-charting the map of world tourism. In: R. Conrady, and M. Buck (eds.). Trends and issues in global tourism 2009. Berlin, Heidelberg: Springer-Verlag, pp. 39–55.

Higham, J. and Hall, C.M. (2005): Making tourism sustainable: The real challenge of climate change? In: C.M. Hall, and J. Higham (eds.). Tourism recreation and climate change: International perspective. Clevedon: Channel View Publications, pp. 301–307.

Hritz, N. and Cecil, A.K. (2008): Investigating the sustainabiiity of cruise tourism: A case study of Key West. Journal of Sustainable Tourism 16(2): 168–181.

Hudecz, A. (2012): Climate change adaptation: A report on climate change adaptation measures for low volume roads in the Northern periphery. Luleå: Swedish Transport Administration/ ROADEX "Implementing Accessibility" Project.

Inturri, G. and Ignaccolo, M. (2010): The role of transport in mitigation and adaptation to Climate change impacts in urban areas. In: K. Otto-Zimmermann (ed.). Resilient cities: cities and adaptation to climate. Change Proceedings of the Global Forum 2010, pp. 465–478.

IPCC (2007): Climate change: The physical science basis summary for policymakers contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: UNEP.

Jaagus, J. (1997): The impact of climate change on the snow cover pattern in Estonia. Climatic Change 36: 65–77.

Jaroszweski, D., Chapman, L. and Petts J. (2010): Assessing the potential impact of climate change on transportation: The need for an interdisciplinary approach. Journal of Transport Geography 18: 331–335.

Järvinen, S., Kankaanpää, S., Lounasheimo, J. and Aarnio, P. (2010): Ilmastonmuutoksen vaikutukset pääkaupunkiseudulla. Osa C. HSY Seututieto, Helsinki.

Jennings, S. (2004): Coastal tourism and shoreline management. Annals of Tourism Research 31(4): 899–922.

Jopp, R., DeLacy, T. Mair, J. and Fluker, M. (2013): Using a regional tourism adaptation framework to determine climate change adaptation options for Victoria's Surf Coast, Asia Pacific. Journal of Tourism Research 18(1/2): 144–164.

Kaján, E. and Saarinen, J. (2013): Tourism, climate change and adaptation: A review. Current Issues in Tourism 16(2): 167–195.

Kellens, W., Neutens, T., Deckers, P., Reyns, J. and De Maeyer, P. (2012): Coastal flood risks and seasonal tourism: analysing the effects of tourism dynamics on casualty calculations. Nat Hazards 60: 1211–1229.

Keskitalo, E.C.H. (2010): Climate change, vulnerability and adaptive capacity in a multi-use forest municipality in Northern Sweden. In: G.K. Hovelsrud, & B. Smit, (eds.). Community Adaptation and Vulnerability in Arctic Regions. Dordrecht: Springer, pp. 285–311.

Klein, R. & Tol, R. (1997): Technological issues adaptation technologies. Technical Paper of UNFCCC.

Koenig-Lewis, N. and Bischoff, E.E. (2005): Seasonality research: The state of the art. International Journal of Tourism Research 7: 201–219.

Koetse, M.J. and Rietveld, P. (2012): Adaptation to climate change in the transport sector.Transport Reviews 32(3): 267-286.

Kont, A., Jaagus, J. and Aunap, R. (2003): Climate change scenarios and the effect of sea-level rise for Estonia. Global and Planetary Change 36: 1–15.

Kont, A., Jaagus, J. Orviku, K., Palginõmm, V., Ratas, U., Rivis, R., Suursaar, Ü. and Tõnisson, H. (2011): Natural development and human activities on Saaremaa island (Estonia) in the context of climate change and integrated coastal zone management. In: G. Schernewski, J. Hofstede, and T. Neumann (eds.). Global change and Baltic Coastal zones. Heidelberg: Springer, pp. 117–134.

Kont, A., Jaagus, J., Aunap, R. Ratas, U. and Rivis, R. (2008): Implications of sea-level rise for Estonia. Journal of Coastal Research 24(2): 423–431.

Kovats, R.S. and Bouma, M. (2002): Retrospective studies: analogue approaches to describing climate variability and health. In: Martens, P. and A. J. McMichael (eds.). Environmental change, climate and health: Issues and research methods. Cambridge: Cambridge University Press, pp.144–171.

Krämer, I., Borenäs, K., Daschkeit, A., Filies, Ch., Haller, I., Janßen, H., Karstens, S., Kule, L., Lapinskis, J. and Varjopuro, R. (2012): Climate Change Impacts on Infrastructure in the Baltic Sea Region. Baltadapt Report # 5. Copenhagen: Danish Meteorological Institute.

Landauer, M., Pröbstl, U. and Haider W. (2012): Managing cross-country skiing destinations under the conditions of climate change - Scenarios for destinations in Austria and Finland. Tourism Management 33: 741–751.

Landauer, M., Sievänen, T. and Neuvonen, M. (2009): Adaptation of Finnish cross-country skiers to climate change. Fennia 187(2): 99–113.

Lapinskis, J. (2012): Climate change impacts on coastal erosion, sediment transport and costal protection in Latvia. In: Krämer, I.; Borenäs, K., Daschkeit, A., Filies, Ch., Haller, I., Janßen, H., Karstens, S., Kule, L., Lapinskis, J. and Varjopuro, R. Climate Change Impacts on Infrastructure in the Baltic Sea Region. Baltadapt Report # 5. Copenhagen: Danish Meteorological Institute, pp 44-65.

Lin, T.-P. and Matzarakis, A. (2011): Tourism climate information based on human thermal perception in Taiwan and Eastern China. Tourism Management 32: 492–500.

Lohmann, M. and Kaim, E. (1999): Weather and holiday destination preferences: Image, attitude and experience. The Tourist Review - Zeitschrift für Fremdenverkehr 2: 54–64.

Marshall, N.A., Marshall, P.A., Abdulla, A., Rouphael, T. and Ali, A. (2011): Preparing for climate change: recognising its early impacts through the perceptions of dive tourists and dive operators in the Egyptian Red Sea. Current Issues in Tourism 14(6): 507–518.

Martinez, G., Bizikova, L., Blobel, D. and Swart, R. (2011): Emerging climate change coastal adaptation strategies and case studies around the world. In: G. Schernewski, J. Hofstede, and T. Neumann (eds.). Global change and Baltic coastal zones. Heidelberg: Springer, pp. 249–273.

Marttila, V., Granholm, H., Laanikari, J., Yrjölä, T., Aalto, A., Heikinheimo, P., Honkatukia, J., Järvinen, H., Liski, J., Merivirta, R. and Paunio, M. (2005): Finland's national strategy for adaptation to climate change. Helsinki: Ministry of Agriculture and Forestry.

Mather, S., Viner, D. and Todd, G. (2005): Climate and policy changes: Their implications for international tourism flows. In: C.M. Hall, and J.E.S. Higham (eds.). Tourism, recreation, and climate change. London: Channel View Press, pp.63–85.

Matzarakis, A. (2010): Climate Change and Adaptation at Regional and Local Scale. In: C. Schott (ed.). Tourism and the implications of climate change: Issues and actions. Bingley: Emerald, pp. 237–259.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (eds.) (2001): Climate change 2001: Impacts, adaptation and vulnerability. Cambridge: Cambridge University Press.

Mieczkowski, Z. (1985): The tourism climate index: A method for evaluating world climates for tourism. The Canadian Geographer 29(3): 220–233.

Mills, E. (2003): Climate change, insurance and the buildings sectors: Technological synergisms between adaptation and mitigation. Building Research & Information 31 (3/4): 257–277.

Milne, J. (2004): Climate change, insurance and the building sector: Synergisms, conflicts and adaptive capacity. Building Research & Information 32(1): 48–54.

Moen, J. and Fredman, P. (2007): Effects of climate change on alpine skiing in Sweden. Journal of Sustainable Tourism 15(4): 418–437.

Moreno, A. and Amelung, B. (2009): Climate change and tourist comfort on Europe's beaches in summer: A reassessment. Coastal Management 37(6): 550–568.

Moreno, A. and Becken, S. (2009): A climate change vulnerability assessment methodology for coastal tourism. Journal of Sustainable Tourism 17(4): 473–488.

Morgan, R., Gatell, E., Junyent, R., Micallef, A., Ozhan, E. and Williams, A.T. (2000): An improved user-based beach climate index. Journal of Coastal Conservation 6:41–50.

Moscardo, G., Pearce, P., Green, D. and O'Leary, J.T. (2001): Understanding coastal and marine tourism demand from three European markets: Implications for the future of ecotourism. Journal of Sustainable Tourism 9(3): 212–227.

Mossbauer, M., Haller, I., Dahlke, S. and Schernewski, G. (2012): Management of stranded eelgrass and macroalgae along the German Baltic coastline. Ocean & Coastal Management 57: 1–9.

Müller, H. and Weber, F. (2008): Climate change and tourism – Scenario analysis for the Bernese Oberland in 2030. Tourism Review 63(3): 57–71.

Nadeau, J., Heslop, L., O'Reilly, N. and Luk, P. (2008): Destination in a country image context. Annals of Tourism Research 35(1): 84–106.

Neuvonen, M., Pouta, E. and Sievänen, T. (2005): Adaptation to climate change for outdoor recreation in Finland. In: Sievänen, T., Tervo, K., Neuvonen, M., Pouta, E., Saarinen, J. and Peltonen, A. Nature-based tourism, outdoor recreation and adaptation to climate change. FINADAPT Working paper 11. Finnish Environment Institute Mimeographs 341: 21–32.

Nicholls, R.J. and Kebede, A.S. (2012): Indirect impacts of coastal climate change and sea-level rise: the UK example. Climate Policy 12(sup01): S28-S52.

Nicholls, S. (2006): Climate change, tourism and outdoor recreation in Europe. Managing Leisure 11(3): 151–163.

OECD and UNEP (2011): Climate change and tourism policy in OECD Countries. Paris: OECD Publishing.

Onofri, L. and Nunes, P.A.L.D. (2013): Beach 'lovers' and 'greens': A worldwide empirical analysis of coastal tourism. Ecological Economics 88: 49–56.

Pang, S.F.H., McKercher, B. and Prideau, B. (2013): Climate change and tourism: An overview. Asia Pacific Journal of Tourism Research 18(1/2): 4–20.

Peltonen, H., Varjopuro, R. and Viitasalo, M. (2012): Climate change impacts on the Baltic Sea fish stocks and fisheries: Review with a focus on Central Baltic herring, sprat and cod. Baltadapt Report # 4. Copenhagen: Danish Meteorological Institute.

Penney, J. (2012): Adapting to climate change: Challenges for Niagara. (website accessed June 21, 2013, URL:http://www.niagararegion.ca/government/planning/pdf/climatechangerport.pdf)

Perry, A. (2006): Will predicted climate change compromise the sustainability of Mediterranean tourism? Journal of Sustainable Tourism 14(4): 367–375.

Perry, A.H. (1972): Weather, climate and tourism. Weather 27: 199–203.

Petri, E., Gniel, D. and Zent, O. (2010): Tick-borne encephalitis (TBE) trends in epidemiology and current and future management. Travel Medicine and Infectious Disease 8: 233–245.

Pollard, J.S., Oldfeld, J., Randalls, S. & Thornes, J.E. (2008): Firm finances, weather derivatives and geography. Geoforum 39: 616–624.

Pouta, E., Neuvonen, M. and Sievänen, T. (2009): Participation in cross-country skiing in Finland under climate change: application of multiple hierarchy stratification perspective. Journal of Leisure Research 41(1): 91–108.

Pouta, E., Sievänen, T. and Neuvonen, M. (2006): Recreational wild berry picking in Finland – Reflection of a rural lifestyle. Society & Natural Resources: An International Journal 19(4): 285–304.

Prideaux, B. (2009): Resort destinations: Evolution, management and development. Oxford, Burlington, MA: Elsevier.

Rauken, T. and Kelman, I. (2012): The indirect influence of weather and climate change on tourism businesses in northern Norway. Scandinavian Journal of Hospitality and Tourism 12(3): 197–214.

Reynolds, D.M. (2010): Vulnerability assessment of skiing-dependent businesses to the effects of climate change in Banff and Jasper national parks, Canada. Calgary, Alberta: University of Calgary.

Richardson, R.B. and Loomis, J.B. (2005): Climate change and recreation benefits in an Alpine national park. Joumal of Leisure Research 31(3): 301–320.

Ryabchuk, D., Spiridonov, M., Zhamoida, V., Nesterova, E. and Sergeev, A. (2012): Long term and short term coastal line changes of the Eastern Gulf of Finland: Problems of coastal erosion. Journal of Coastal Conservation 16(3): 233–242.

Saarinen, J. and Tervo, K. (2006): Perceptions and adaptation strategies of the tourism industry to climate change: The case of Finnish nature-based tourism entrepreneurs. International Journal of Innovation and Sustainable Development 1(3): 214–228.

Schönthaler, K., Andrian-Werburg, S. Von, Wulfert, K., Luthardt, V., Kreinsen, B., Schultz-Sternberg, R. and Hommel, R. (2010): Establishment of an indicator concept for the German Strategy on Adaptation to Climate Change. Dessau-Roßlau: German Federal Environment Agency. (website accessed May 5, 2013, URL:http://www.uba.de/uba-info-medien-e/4031.html)

Schott, C., Reisinger, A. and Milfont, T.L. (2010): Tourism and climate change: Interrelationships and implications. In: C. Schott (ed.). Tourism and the implications of climate change: Issues and actions. Bingley: Emerald, pp.1–24.

Scott, D. (2011): Why sustainable tourism must address climate change. Journal of Sustainable Tourism 19(1): 17–34.

Scott, D. and Becken, S. (2010): Adapting to climate change and climate policy: Progress, problems and potentials. Journal of Sustainable Tourism 18(3): 283–295.

Scott, D. and McBoyle, G. (2007): Climate change adaptation in the ski industry. Mitigation Adaptation Strategies for Global Change 12: 1411–1431.

Scott, D. and Jones, B. (2007): A regional comparison of the implications of climate change for the golf industry in Canada. The Canadian Geographer 51(2): 219–232.

Scott, D. and Lemieux, C. (2009): Weather and climate Information for tourism. Madrid: WMO, Geneva and UNWTO.

Scott, D. and Lemieux, C. (2010): Weather and climate Information for tourism. Procedia Environmental Sciences 1: 146–183.

Scott, D., de Freitas, C. and Matzarakis, A. (2008a): Adaptation in the tourism and recreation sector. In: K.L. Ebi, and I. Burton (eds.). Biometeorology for adaptation to climate variability and change. Dordrecht: Kluwer Academic Publishing, pp. 171–194.

Scott, D., Gössling, S. and de Freitas, C.R. (2008b): Preferred climates for tourism: Case studies from Canada, New Zealand and Sweden. Climate Research 38(1): 61–73.

Scott, D., Hall, C.M. and Gössling, S. (2012): Tourism and climate change: Impacts, adaptation & mitigation. London: Routledge.

Scott, D., Wall, G. and McBoyle, G. (2005): The evolution of the climate change issue in the tourism sector. In: C.M. Hall, and J.E.S. Higham (eds.). Tourism, recreation, and climate change. London: Channel View Press, pp.44–60.

Semenza, J. C. and Menne, B. (2009): Climate change and infectious diseases in Europe. Lancet Infect Dis 9: 365–75.

Shiue, I. and Matzarakis, A. (2011): Estimation of the tourism climate in the Hunter Region, Australia, in the early twenty-first century. Int J Biometeorol 55: 565–574.

Simpson, M.C., Gössling, S., Scott, D., Hall, C.M. and Gladin, E. (2008): Climate change adaptation and mitigation in the tourism sector: Frameworks, tools and practices. Paris: UNEP, University of Oxford, UNWTO, WMO.

Smith, K. (1990): Tourism and climate change. Land use Policy 7(2): 176–180.

Stern, N. (2006): The economics of climate change: The Stern review. Cambridge: Cambridge University Press (PESETA Study), pp. 1–345.

Störmer, O. (2011): Climate change impacts on coastal waters of the Baltic Sea. In: G. Schernewski, J. Hofstede, and T. Neumann (eds.). Global change and Baltic Coastal zones. Heidelberg: Springer, pp. 51–69.

Swart, R., Biesbroek, R., Binnerup, S., Carter, T.R., Cowan, C., Henrichs, T., Loquen, S., Mela, H., Morecroft, M., Reese, M. and Rey, D. (2009): Europe adapts to climate change: comparing national adaptation strategies, PEER Report No 1. Helsinki: Partnership for European Environmental Research.

Swedish Government (2007): Sweden facing climate change – Threats and opportunities: Final report from the Swedish Commission on Climate and Vulnerability. Stockholm: Swedish Government Official Reports SOU 2007:60.

Tang, C.-H. and Jang, S.C. (2012): Hedging weather risk in nature-based tourism business: An example of ski resorts. Journal of Hospitality & Tourism Research 36(2): 143–163.

Tervo, K. (2008): The operational and regional vulnerability of winter tourism to climate variability and change: The case of the Finnish nature-based tourism entrepreneurs. Scandinavian Journal of Hospitality Research 8(4): 317–332.

Tervo-Kankare, K. (2011): The consideration of climate change at the tourism destination level in Finland: Coordinated collaboration or talk about weather? Tourism Planning & Development 8(4): 399–414.

Tervo-Kankare, K., Hall, C.M. and Saarinen, J. (2013): Christmas tourists' perceptions to climate change in Rovaniemi, Finland. Tourism Geographies 15(2): 292-317.

Tonisson, H.; Orviku, K., Jaagus, J., Suursaar, U., Kont, A. and Rivis, R. (2008): Coastal damages on Saaremaa Island, Estonia, caused by the extreme storm and flooding on January 9, 2005. Journal of Coastal Research 24(3): 602–614.

Turton, S., Dickson, T., Hadwen, W., Jorgensen, B., Pham, T., Simmons, D., Tremblay, P. and Wilson, R. (2010): Developing an approach for tourism climate change assessment: Evidence from four contrasting Australian case studies. Journal of Sustainable Tourism 18(3): 429–447.

UNWTO (2009): From Davos to Copenhagen and beyond: Advancing tourism's response to climate change. UNWTO Background Paper.

UNWTO and UNEP (2008): Climate change and tourism: responding to global challenges, (prepared by D. Scott, B. Amelung, S. Becken, J.P. Ceron, G. Dubois, S. Gössling, P. Peeters, and M.C.Simpson). Madrid: UNWTO.

Uscinowicz, S., Zachowicz, J., Graniczny, M. and Dobracki R. (2004): Geological structure of the southern Baltic coast and related hazards. Polish Geological Institute Special Papers 15

Vermaat, J.E., Bouwer, L., Turner, K. and Salomons, W. (eds.) (2005): Managing European coasts: Past, present, and future. Berlin Heidelberg: Springer-Verlag.

Viner, D. (2006): Tourism and its interactions with climate change. Journal of Sustainable Tourism 14: 317–322.

Vries, A. de (2010): European territories confronted with climate change: Awaiting the events or timely preparation? Futures 42: 825–832.

Wenk, R. and Janßen, H. (2011): A spatial development strategy for climate change – The Western Pomerania example. In: G. Schernewski, J.Hofstede, and T. Neumann (eds.). Global change and Baltic Coastal zones. Dordrecht, Heidelberg, London, New York: Springer, pp. 155–176.

Wong, E., Lacy, P.Y.T. de and Jiang, M. (2012): Climate change adaptation in tourism in the South Pacific – Potential contribution of public–private partnerships. Tourism Management Perspectives 4:136–144.

Worthington, B. (2003): Change in an Estonian resort: Contrasting development contexts. Annals of Tourism Research 30(2): 369–385.

Yeoman, I. and McMahon-Beattie, U. (2006): Understanding the impact of climate change on Scottish tourism. Journal of Vacation Marketing 12(4): 371–379.

Yeoman, I., Greenwood, C. and McMahon-Beattie, U. (2009): The future of Scotland's international tourism markets. Futures 41: 387–395.

Žilinskas, G. (2008): Distinguishing priority sectors for the Lithuanian Baltic Sea coastal management. Baltica 21(1/2): 85–94.

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