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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.

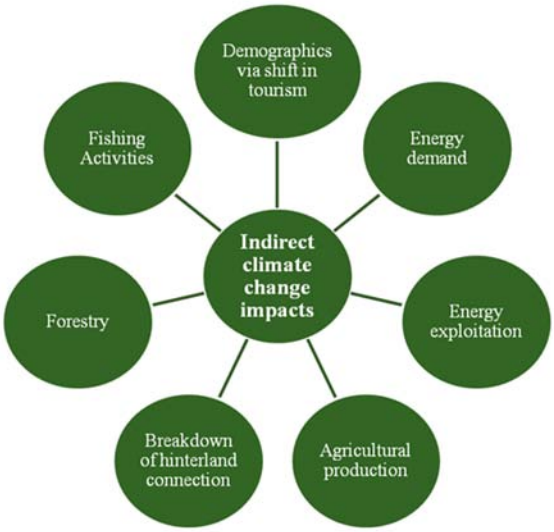

Figure 1: Indirect climate change impacts on ports.

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	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.
Reduced ice cover	
Change of stratification	
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).

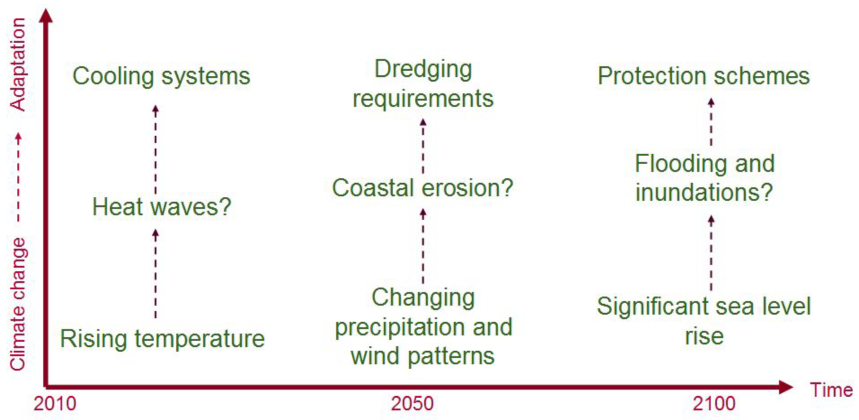

Figure 2: Planning on different time scales.

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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