BALTEX Assessment of Climate Change for the Baltic Sea Basin

- The BACC Project -

International Conference

Göteborg, Sweden

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Chapter Summaries

Preface

Leading scientists, politicians, and journalists from the Baltic Sea countries, and beyond, took part in the First International Conference on the Assessment of Climate Change for the Baltic Sea Basin on 22-23 May 2006 in Göteborg Sweden. The Conference, organised by Göteborg University, BALTEX and HELCOM, aimed at an assessment of ongoing and possible future climate variations in the Baltic Sea basin. The assessment presented is a result of a recently established BALTEX Assessment of Climate Change for the Baltic Sea Basin (BACC) Project. The BACC project is a joint venture of BALTEX and HELCOM (Baltic Marine Environment Protection Commission) as an example of a dialogue between the scientific community and environmental policy makers. It integrates available knowledge of historical, current and expected future climate change. The unique feature of BACC is the combination of evidence on climate change and related impacts on marine, freshwater and terrestrial ecosystems in the Baltic Sea basin, which encompasses the entire water catchment of the Baltic Sea. It is the first systematic scientific effort for assessing climate change in a European region. More than 80 scientists (see below and at the end of this report) from 12 countries have contributed on a voluntary basis. As such, the results have not been influenced by either political or special interests.

The present report is a summary of the assessment as presented at the BACC Conference in May 2006. The assessment is divided into 4 chapters, and this summary has been edited by the BACC chapter lead author group including (in alphabetical order):

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The detailed assessment material is currently being prepared as a book scheduled for publication in 2007.

Hans-Jörg Isemer

International BALTEX Secretariat, June 2006

Contents

Overall Summary

The BACC assessment of past, ongoing and future climate change in the Baltic Sea basin offers a review of published knowledge in four chapters, two dealing with the geophysical (atmosphere, ocean, sea ice) side and two with the ecological (terrestrial and marine) dimension.

In the past century here has been a marked increase of **temperature** of more than 0.7 ^{o}C in the region, which is larger than the global mean temperature increase of 0.5 ^{o}C. Consistent with this increase in mean and extreme temperatures, other variables show changes, such as increase of winter runoff, shorter ice seasons and reduced ice thickness on rivers and lakes in many areas. These trends are statistically significant but they have not been shown to be larger than what may be expected from natural variability. In addition, no robust link to anthropogenic warming, which on the hemispheric scale has been causally related to increased levels of greenhouse gases in the atmosphere in “detection and attribution” studies, has been established. However, the identified trends in temperature and related variables are consistent with regional climate change scenarios prepared with climate models. Therefore, it is plausible that at least part of the recent warming in the Baltic Sea basin is related to the steadily increasing atmospheric concentrations of greenhouse gases. Projections for future climate indicate a continued increase in temperature. Further effort is needed to systematically examine the inconsistency of recent trends with natural variability, regarding circulation changes as well as consistency with elevated greenhouse gas concentrations as a potential cause.

Although northern Europe has become wetter during the 20th century, the situation is less clear regarding **precipitation**. In the past, a spatially non-uniform pattern of upward and downward trends has been observed, which can hardly be related to anthropogenic climate change. For the future, increased winter precipitation may emerge later in this century over the entire area, while summers may become drier in the southern part – but this expectation is uncertain for the time being. For the water body of the Baltic Sea, a tendency towards lower **salinity** could be expected. No clear signals, whether for the past or for future scenarios, are available with regard to **wind** conditions.

In view of the large uncertainty in our knowledge about the changing climatic conditions, it is not surprising that knowledge about ecological implications of ongoing and future climate change is far from complete and also very uncertain. The observed changes in temperature in the past have been associated with consistent changes in **terrestrial ecosystems**, such as earlier spring phenological phases, northward species shifts and increased growth and vigour of vegetation. In lakes, higher summer algal biomasses have been found. These trends are expected to continue into the future; induced species shifts may be slower than the warming which causes it. In the **marine ecosystem** of the Baltic Sea the assessment is particularly difficult because of the presence of strong non-climatic stressors (eutrophication, fishing, release of pollutants) related to human activities. Changing temperatures have been related to various effects, in particular to the composition of species. A lowering of salinity is thought to have a major influence on the distribution, growth and reproduction of the Baltic Sea fauna. Freshwater species are expected to enlarge their significance, and invaders from warmer seas (such as the zebra mussel *Dreissena polymorpha* or the North American jelly comb *Mnemiopsis leidyi*) are expected to enlarge their distribution area. The expected changes in precipitation (and thus river runoff) may have additional detrimental effects on the problem of eutrophication.

Detection of Past and Current Climate Change

The variability in **atmospheric circulation** has a strong influence on the surface climate in northern Europe (temperature, precipitation, wind speed, etc.). From about the 1960s until the 1990s westerly airflow has intensified during wintertime. This increased frequency of maritime airmasses has contributed to higher wintertime temperatures and enhanced precipitation at regions exposed to westerly winds especially during the 1990s. In centennial timescale it can be seen that relationships between large scale atmospheric circulation and surface climate elements show strong temporal variability.

During the period 1871 – 2004 there were significant positive trends in the annual **mean temperature** for the northern and southern Baltic Sea basin, being 0.10 °C/decade on average to the north of 60° and 0.07 °C/decade to the south of 60° N. The trends are larger than for the entire globe which amount to 0.05 °C/decade (1861 – 2000). In the annual mean temperatures there was an early 20th century warming that culminated in the 1930s. This was followed by a smaller cooling that finished in the 1960s, and then another strong warming until present days. Warming is characterised by a pattern where mean daily minimum temperatures have increased more than mean daily maximum temperatures. Spring is the season showing the most linear and strongest warming whereas wintertime temperature increase is intermittent but larger than in summer and autumn. A general tendency is that the start of the climatic seasons in the spring half-year (e.g. spring, growing season, summer) start earlier, whereas the climatic seasons in the autumn half-year (e.g. autumn, frost season, winter) start later. Changes in **extreme temperatures** have broadly followed changes in mean temperatures. The number of cold nights has decreased, while the number of warm days has increased. These changes have been stronger during winter than summer.

Over the latter part of the 20th century, on average, northern Europe has become wetter. The increase in **precipitation** is not spatially uniform. Within the Baltic Sea basin the largest increases have occurred in Sweden and eastern coast of the Baltic Sea. Seasonally largest increases have occurred in winter and spring. Changes in summer are characterised with increases in the northern and decreases in the southern parts of the Baltic Sea basin. In wintertime, there is an indication that number of heavy precipitation events has increased.

Characteristics of **cloudiness and solar radiation** have remarkable inter-annual and inter-decadal variations in the Baltic Sea area. A decrease in cloudiness and increase in sunshine duration was observed in the south (Poland) while opposite trends revealed in the north (Estonia). In the 1990s, all these trends turned their sign. Long-term observations in Estonia show that an improvement in air quality (i.e. a decrease in the aerosol emissions to the atmosphere) reversed decreasing trend in atmospheric transparency and direct radiation during the 1990s. Presently the atmospheric transparency is at the same level as in the 1930s.

Centennial time series from southern Scandinavia uncover that there are no long-term trend in **storminess** indices. There has been a temporary increase in the 1980s-1990s. In the Baltic region different data sources give slightly different results with respect to trends and variations in the extreme wind climate especially concerning small-scale extreme winds. At the same time there are indications of increasing impact from extreme wind events. But this increasing impact results from a complex interaction between climate and development trends that increase the exposure to damage and/or the vulnerability of nature and society.

The interannual variability in **water inflow** (river runoff to the Baltic Sea) is considerable, but no statistically significant trend can be found in the annual time series for the period of 1921-1998.

The analysis of the long-term dynamics of the **dates of the start and ending of ice events and duration of the ice coverage** for the rivers of the Russian territory of the Baltic Sea drainage basin showed that since the middle of the 20th century to its end a stable positive tendency was observed.

As to the maximal **ice cover thickness** the negative tendency has been established for all – Polish and Russians study lakes. In the territory of Finland both decreasing and increasing trends can be found in the maximum ice thickness time series

Recent decrease of **snow cover duration and water equivalent** has been observed in southern parts of all the Fennoscandian countries, while the opposite trend prevails in the north. Changes of **snow depth** are quite similar, i.e. decrease in south-western regions and increase in the north-eastern regions

The Baltic Sea **mean salinity** decreased during the 1980s and 1990s, but similar decreases appeared also earlier in the 20th Century. No long-term trend was found during the 20th century.

There are indications of a more rapid eustatic sea level rise in the 20th century compared to the 19th century.

A climate warming can be detected from the time series of the maximum **annual extent of sea ice and the length of the ice season** in the Baltic Sea. On the basis of the ice extent, the shift towards a warmer climate took place in the latter half of the 19th century. This gradual shift has been identified as the ending of the Little Ice Age in the Baltic Sea region.

Appearing in various regions of the south Baltic coastal damages generally result from a combination of strong storms, their increased number, accelerated sea-level rise and decreasing trend of the presence of ice cover in the winter, that is at times where the most intensive storms occur.

Projections of Future Climate Change

Increasing greenhouse gas concentrations are expected to lead to a substantial warming of the global climate during this century. Cubasch et al. (2001, in: Houghton, J.T. et al. (eds) Climate Change, Cambridge University Press) estimated the annual globally averaged warming from 1990 to 2100 to be in the range of 1.4 to 5.8°C. This range in temperature change takes into account differences between climate models and a range of anthropogenic emissions scenarios, but it excludes other uncertainties (for example, in the carbon cycle) and should not be interpreted as giving the absolute lowest and highest possible changes in the global mean temperature during the period considered.

Projected future warming in the Baltic Sea basin generally exceeds the global mean warming in **GCM (global climate model)** simulations. Looking at the annual mean from an ensemble of 20 GCM simulations, regional warming over the Baltic Sea basin would be some 50% higher than global mean warming. In the northern areas of the basin, the largest warming is generally simulated in winter; further south the seasonal cycle of warming is less clear. However, the relative uncertainty in the regional warming is larger than that in the global mean warming. Taking the northern areas of the basin as an example, the warming from late 20th century to late 21st century could range from as low as 1°C in summer (lowest scenario for summer) to as high as 10°C in winter (highest scenario for winter). The simulated warming would generally be accompanied by an increase in precipitation in the Baltic Sea basin, except for in the southernmost areas in summer. The uncertainty for precipitation change is, however, larger than that for temperature change, and the coarse resolution of GCMs does not resolve small-scale variations of precipitation change that are induced by the regional topography and land cover.

A more geographically detailed assessment of future anthropogenic climate change in the Baltic Sea basin requires the use of statistical or dynamical downscaling methods. Yet, as only a limited number of GCM simulations have been downscaled by **RCMs (regional climate models)** or statistical downscaling methods, the range of results derived from those downscaling experiments does not fully reflect the range of uncertainties in the GCM projections. Accepting this, the range of results from available downscaling studies is presented below as it gives an indication of plausible future changes. All values refer to changes projected for the late 21st century, represented here as differences in climate between the years 1961-1990 and 2071-2100. .

Consistent with GCM studies, all available downscaling studies also indicate increases in temperature during all seasons for every subregion of the Baltic Sea basin. Combined results show a projected warming of the mean annual temperature by some 3 to 5 ºC for the total basin. Seasonally, the largest part of this warming would occur in the northern areas of the Baltic Sea basin during winter months and in the southern areas of the Baltic Sea basin during summer months. Corresponding changes in temperatures would be 4 to 6 ºC in winter and 3 to 5 ºC in summer, as estimated from a matrix of regional climate model experiments. As noted above, these ranges most probably underestimate the real uncertainty. The diurnal temperature range - the difference between daily maximum and minimum temperature - would also decrease, most strongly in autumn and winter months. Such levels of warming would lead to a lengthening of the growing season, defined here as the continuous period when daily mean temperature exceeds 5 ºC. An example from one RCM indicates that the growing season length could increase by as much as 20 to 50 days for northern areas and 30 to 90 days for southern areas by the late 21st century. The range depends on which of the different emissions scenarios that is used.

Projected changes in precipitation from downscaling studies also depend both on differences in greenhouse gas emissions scenarios and differences between climate models. Moreover, precipitation results are more sensitive than temperature results to the statistical uncertainty in determining climatological means from a limited number of simulated years, particularly at regional scales. Seasonally, winters are projected to become wetter in most of the Baltic Sea basin and summers to become drier in southern areas for many scenarios. Northern areas could generally expect winter precipitation increases of some 25 to 75% while the projected summer changes lie between -5 and 35%. Southern areas could expect increases ranging from some 20 to 70% during winter while summer changes would be negative, showing decreases of as much as 45%. Taken together these changes lead to a projected increase in annual precipitation for the entire basin. These results are in broad terms consistent with GCM studies of precipitation change, although the projected summer decrease in the southern areas of the basin tends to be larger and extend further north in the available RCM studies than in most reported GCMs. This difference reflects the fact that the few GCM simulations that have been downscaled by RCMs also show this pattern of precipitation change.

Projected changes in wind differ widely between various climate models. Differences in the circulation patterns of the driving GCMs are particularly important for the modelled outcome of this variable. From the RCM results presented here, only those driven by the ECHAM4/OPYC3 GCM show statistically significant changes for projected future climate scenarios. For mean daily wind speed over land areas, this would amount to a mean increase of some 8% on an annual basis and a maximum mean seasonal increase of up to 12% during winter. The corresponding mean seasonal increase over the Baltic Sea in winter, when decrease in ice cover enhances near-surface winds, would be up to 18%. For RCMs driven by the HadAM3H GCM, the changes are small and not statistically significant. Modelled changes in extreme wind generally follow the same pattern as for the mean wind; however, the spatial resolution of both GCMs and RCMs is far too coarse to accurately represent the fine scales of extreme wind. As the downscaled projections differ widely, there is no robust signal seen in the RCM results. Looking at projected changes in large-scale atmospheric circulation from numerous GCMs, they indicate that an increase in windiness for the Baltic Sea basin would be somewhat more likely than a decrease. However, the magnitude of such a change is still highly uncertain and it may take a long time before greenhouse gas-induced changes in windiness, if ever, emerge from background natural variability. It can be noted, moreover, that ECHAM4/OPYC3 is one of the GCMs that gives higher values of change in large-scale wind.

Hydrological studies show that increases in mean annual river flow from the northernmost catchments would occur together with decreases in the southernmost catchments. Seasonally, summer river flows would tend to decrease, while winter flows would tend to increase, by as much as 50%. The southernmost catchments would be affected by the combination of both decreased summer precipitation and increased evapotranspiration. Oceanographic studies show that mean annual sea surface temperatures could increase by some 2 to 4ºC by the end of the 21st century. Ice extent in the sea would then decrease by some 50 to 80%. The average salinity of the Baltic Sea is projected to decrease between 8 and 50%. However, it should be noted that these oceanographic findings are based upon only four regional scenario simulations using two emissions scenarios and two global models.

Climate-related Change in Terrestrial and Freshwater Ecosystems

The changing climate and other associated environmental and anthropogenic changes may be expected to affect the structure and functioning of ecosystems, and threaten the services they provide to society. We assess the potential impacts of the changing environment on terrestrial and freshwater ecosystems of the Baltic Sea basin, aiming to evaluate the hypotheses:

(1) that climate change and other associated environmental change over recent decades has affected the ecosystems and their services; and

(2) that ongoing climate change will cause [further] changes in the ecosystems and their services over the remainder of the 21st century.

In order to highlight the most compelling and societally-relevant aspects of ecosystem change, the analysis focuses on:

(i) processes and indicators of particular diagnostic value for the attribution of ecosystem changes to identifiable forcing factors; for example, changes in phenology, species distributions and the seasonality of physical, chemical and biological phases in lakes;

(ii) ecosystems and functions of sectorial relevance; for example, productivity and carbon storage in forests; and

(iii) uncertainty associated with ecological complexity and limitations to process understanding; for example, regarding stress responses to changing climatic extremes.

Significant changes in climate, including increasing temperatures and changing precipitation patterns, have occurred over the Baltic Sea basin in recent decades (see above). Other associated changes include the continuously rising atmospheric CO_2 concentrations, and increases in deposition loads of atmospheric pollutants, including nitrogen compounds and other acidifying pollutants. A variety of ecosystem impacts of these changes have been identified (hypothesis 1), including the following:

- An advancement of spring phenological phases such as budburst and leaf expansion is apparent for many plant species, likely reflecting increasing mean temperatures. Many species also show delayed autumn phases, but trends are less consistent. Phenological trends are stronger in northern Europe than for Europe as a whole, possibly reflecting stronger climate warming.
- Species distributional shifts tracking isothermal migration are apparent for both plant and animal species. Possibly related changes include weaker migratory behavior, for example in some bird species. Tree line advance has been observed in the Fennoscandian mountain range.
- Increased growth and vigor of vegetation at high northern latitudes generally is apparent from satellite observations and can be attributed to increased growing season warmth and an extended growing season. Other observations, such as tree ring data, support the existence of a positive growth trend. The magnitude of the trend within the Baltic Sea basin is representative for high latitude areas in Eurasia, and strong compared with similar latitudes in North America.

- Physiological stress related to the combined effects of atmospheric pollutants and extreme weather events such as spring frosts and drought are a possible explanation for late 20th century dieback in boreal and temperate forests.
- Degradation of discontinuous permafrost in the subarctic north may be causing a shift towards a greater representation of wet habitats in tundra. Possible consequences include an increased release of methane through (anaerobic) decomposition, which would accentuate greenhouse forcing.
- Climate-related changes in lakes including higher water temperatures, advancement of ice break-up, lower water levels and increased influxes of dissolved organic matter from land have consequences for lake ecosystems, including dominance shifts in phytoplankton communities, higher summer algal biomass, and shifts in trophic state.

Climate scenarios described in the previous section consistently point to increased temperatures throughout the Baltic Sea basin by the end of the 21st century, compared with today. Precipitation scenarios are more variable but generally point to increased precipitation in winter, with southern areas experiencing decreased rainfall in summer. Combined with the effect of higher temperatures on evapotranspiration, this suggests that ecosystems of the temperate zone may face increasingly unfavorable growing season water budgets in the future. Potential impacts of these and other associated environmental changes (hypothesis 2) include the following:

- Extrapolation of recent phytophenological trends suggests that extension of the vegetation period by 2-6 weeks, depending on the climate scenario, is likely over much of the Baltic Sea basin.
- Further changes in the distributions of some species may be expected, but for many species, lags associated with population and community processes, dispersal limitations etc. are likely. Wholesale biome shifts, such as the northward displacement of the temperate-boreal forest boundary, will be slow compared to the rate of isotherm migration. Natural and semi-natural vegetation of the future may be of a transient character, e.g. aging conifer stands with an increased representation of broadleaved trees in the younger age classes. Changes may be especially marked in subarctic and alpine areas, with forest invading areas that are currently tundra. Increased local

richness is likely as species associated with the forest extend their ranges northward and upslope.

- Modelling studies generally point to increasing ecosystem production and carbon storage capacity throughout the Baltic region in the next 50-100 years, in conjunction with a longer growing season, increased atmospheric CO_2 concentrations and the stimulation of mineralization processes in warmer soils. However, increased autumn and winter temperatures may be detrimental to hardening processes in trees, increasing susceptibility to spring frost damage. Growing season drought stress may reduce or inhibit production enhancement in temperate parts of the region.
- The potential impacts of climatic change on the incidence of pest and pathogen outbreaks affecting vegetation are still largely open. It seems reasonable to assume that harmful insects and fungi from central and southern Europe may expand into the Baltic area in the warming climate.
- Warmer water temperatures combined with longer stratified and ice-free periods in lakes may be expected to accelerate eutrophication, increasing phytoplankton production and shifting the phytoplankton community structure towards species with higher temperature optima, including cyanobacteria. Shallow lakes and lake littoral zones may be particularly sensitive to climate warming. Increasing influxes of humic substances in runoff from boreal catchments would steepen light attenuation, with negative impacts on periphyton and benthic communities in lakes. Cold-water fish species may be extirpated from much of their present range while cool- and warm-water species expand northwards.

Uncertainties associated with the assessment of future ecosystem changes are substantial and include uncertainties due to understanding of the biological phenomena being modelled or projected including system-internal feedbacks and complexity, as well as variation among climate and greenhouse gas emissions scenarios on which the assessments are based. The most important source of uncertainty with regard to many impacts are the future development in non-climatic, anthropogenic drivers of ecosystem dynamics including deposition of atmospheric pollutants, land use changes, changes in forest management and agricultural practices, changes in human populations, markets and international trade, and technological development.

Climate-related Change in Marine Ecosystems

The Baltic Sea is not a steady state system and, since its formation, it never has been. External drivers acting on different time scales force major changes in the marine ecosystem structure and function. Postglacial isostatic and eustatic processes have shaped the Baltic Sea's coastline, topography, basic chemistry and sedimentary environment on millennium scales. Climate variability acts on centennial and decadal scales and at least over the last 150 years overlaps with human's activities in the drainage basin and the coastal zone, leading to considerable changes in the biogeochemistry of this semi-enclosed sea. Thus, the emerging impacts of anthropogenic climate change can not be separated at this time form natural variability and from other anthropogenic influences.

Studies of past and recent ecosystem changes have demonstrated the sensitivity of the marine ecosystem to **temperature** variations. For instance, Northern Baltic annual peaks of the most abundant cladoceran species were found to co-vary with surface water temperature. The higher temperatures during the 1990s were associated with a shift in dominance within the open sea copepod community from *Pseudocalanus* sp. to *Acartia* spp. Increased production and survival rates of sprat and herring populations during the last 5-10 years co varied with high temperatures and high NAO indices. In the earlier warming period in Fennoscandia during 1870 to 1940, many range shifts in birds were observed, both of the northern and southern borders, and of spring as well as autumn migration. Furthermore, extreme winter temperatures have long been documented to influence water bird mortality in the Baltic Sea, and winter conditions in the Baltic Basin are known to determine the range of land- as well as water birds. Spring migration generally occurs earlier in recent years, although there is a high variation between and within species.

Also past changing **salinities** have been associated with marked changes of the ecosystem. An increase in salinity during the first half of the century resulted in a spread of several marine species (e.g. mesozooplankton, barnacles, jellyfish, larvaceans) towards the north and the east in the Baltic Sea. Correspondingly, the decrease in salinity after the late 1970s in the northern Baltic was reflected in biomass decline of the large neritic copepod species and increase of the freshwater cladoceran species. In the deep basins of the open Baltic, the decrease in salinity resulted in reduced standing stocks of *Pseudocalanus elongatus*, an important player in the pelagic food web. In contrast, temperature-sensitive species (e.g. Acartia spp.) increased their population sizes. A retreat towards south has been found in benthic fauna, e.g. *Scoloplos armiger*. The decrease in herring and sprat growth has been related to a salinity-mediated change in the copepod community. A top predator in the pelagic food chain is the cod, a key species in the Baltic proper, which usually regulates the sprat and herring stocks, has seen a decrease. This decrease and the climatically induced enhanced sprat reproductive success, induced a switch from cod-domination to sprat-domination.

Eutrophication is a phenomenon of recent past; still it has been documented to change the biota. Several monitoring programmes have been targeted to follow it, since 1970s, mainly because it poses direct threat to health (toxic algal blooms) and biota (anoxic bottoms develop hydrogen sulphide). Changes of phytoplankton biomass and species composition reflect eutrophication, but simultaneously also climatic changes. A further twist emerges from the fact that eutrophication itself may be promoted directly by climatic factors, such as runoff and rainfall. There is some evidence that increased primary production has lead to an increase of biomass at higher trophic levels (e.g. zooplankton and fish). Especially clear this trend has been in benthos. Above halocline macrofauna biomass in the 1990s was about five-fold compared with “pristine” conditions (1920s to 1930s). The deep basins of the Baltic are frequently exposed to hypoxia and anoxia which results in periodic extinction and recolonization of bottom fauna.

Anthropogenic climate change **scenarios** for the Baltic Sea basin describe an increase in temperature especially during wintertime and an increase in rainfall in the northern part of the runoff area. The consequence of increasing precipitation is twofold. Increasing precipitation results in a decrease in salinity and in an increase of nutrients leakage and associated eutrophication.

Projected **increased temperatures**, especially during winter months, will lead to changes in growth and reproduction parameters for fauna and flora, many of which are of boreal origin, i.e., adapted to low temperatures. The following changes are considered possible

- Increased temperatures stimulate pelagic bacteria growth more than primary production, thus the ratio between bacteria biomass to phytoplankton is expected to increase with temperature in eutrophic waters.

- Diatom spring blooms are subject to species change when winters become milder. Furthermore, it has been suggested that the diatom bloom itself may disappear after milder winters and be replaced by dinoflagellates.
- Increasing summer-time temperatures may enhance cyanobacterial blooms.
- Elevated winter temperatures may prevent convection in late winter and early spring with the result that nutrients are not mixed into the upper euphotic zone. In the Baltic Proper with a salinity of 7 psu, the maximum density of water occurs at ~2.5°C. If the winter temperature is below 2.5°C, seasonal surface warming in early spring will result in an unstable water column with convective overturning. If the water temperature is higher than 2.5°C, warming will result in the development of thermocline and no redistribution of nutrients due to convection will occur. This process might also result in a shift in species composition of phytoplankton in spring.

Modelling studies describe the extinction of southern subpopulations of the Baltic ringed seal as a probable effect of expected diminishing **ice** cover suitable for breeding. The grey seal, however, has been shown to have the capability to breed extensively on land even in the Baltic.

The expected decrease of **salinity** of the Baltic Sea will modify the ecology of the Baltic Sea in several ways. The most important changes are probably seen in the distribution (both horizontal and vertical), though growth and reproduction are also likely to be affected. The lower limit of approximate salinity tolerance is 2 psu for *Praunus flexuosus*, *Neomysis vulgaris,* and *Gammarus locusta*, 3 psu for *Corophium volutator* , for *Palaemon adspersus* and *Idotea baltica* 5.5 psu, for *Pontoporeia femorata* and *Harmothoe sarsi* it is 6 psu, for *Pygospio elegans and Laomedea lovéni* 7 psu, and for *Terebellides strömii* and *Fabricia sabella* 7.5 psu. Thus along the complete range of Baltic Sea surface salinity we can expect decreases of species number due to changes in species distribution areas. A decrease of marine fauna is expected to emerge first in the northern Baltic Sea surface area, because of the expected intensified rainfall in the northern part of the watershed. In the western Baltic the common starfish (*Asterias rubens*) and common shore crab (*Carcinus maenas*) are among the species expected to decrease if salinity decreases lower than 25-15 psu.

We are likely to meet a reversed situation as compared to changes in the 1950s when salinity was rising. Some of this expected trend has already been documented as species like cod, which need a certain level of salinity during a certain life stage, display low reproductive success in the Baltic Sea area. Cod eggs need a minimum salinity of 11.5 psu for buoyancy, which they usually find in the halocline regions of the deep Baltic basins. Due to low salinity but also low oxygen concentrations in the deep water, cod eggs are frequently exposed to lethal oxygen conditions in the layer where they are neutrally buoyant.

Finally, decreasing salinity enables all freshwater species to enlarge their distribution in the Baltic Sea. Because of its ecological and evolutionary history, the Baltic Sea predominantly receives species originating from both in the adjacent inland waters and oceanic coasts but also in remote seas. Most of the recent invaders in the Baltic Sea originate from warmer climate. In conditions of increasing water temperature, not only spontaneously spreading European invaders but also more exotics from warmer regions of the world can be expected to establish in the Baltic. Two target species, known to cause severe changes in invaded ecosystems, most likely will spread with climatic warming. The zebra mussel *Dreissena polymorpha* may penetrate to the Gulf of Bothnia into the areas presently avoid of large biofiltrators. The North American jelly comb *Mnemiopsis leidyi,* which recently invaded the Black and Caspian Seas, may invade the Baltic Sea and cause outbreaks changing its pelagic system.

In addition, the combination of decreasing salinity and increasing temperature will clearly reduce the general fitness of native benthic species and their adaptability to cope with other stressors, e.g. low oxygen or chemical pollution.

Accelerated **eutrophication** is an expected consequence of the anthropogenic climate change in the Baltic Sea due to freshwater runoff determining most of the nutrient load to the Baltic Sea especially in the near coastal areas.

Eutrophication is expected to enhance the production and biodiversity in the ecosystem up to a certain point, after which a collapse will appear due to several mechanisms such as chemical (anoxia), and biotic interactions (competition, predation, exploitation). After this a new ecological balance will develop, which is characterized by low biodiversity and high variability due to episodic outbursts of dominant species. Some effects of eutrophication are clear and predictable, such as general increase of primary production, but other effects, such as species-specific intra- and interactions are extremely hard to predict because of the nonlinearity and complexity of the marine ecosystem.

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