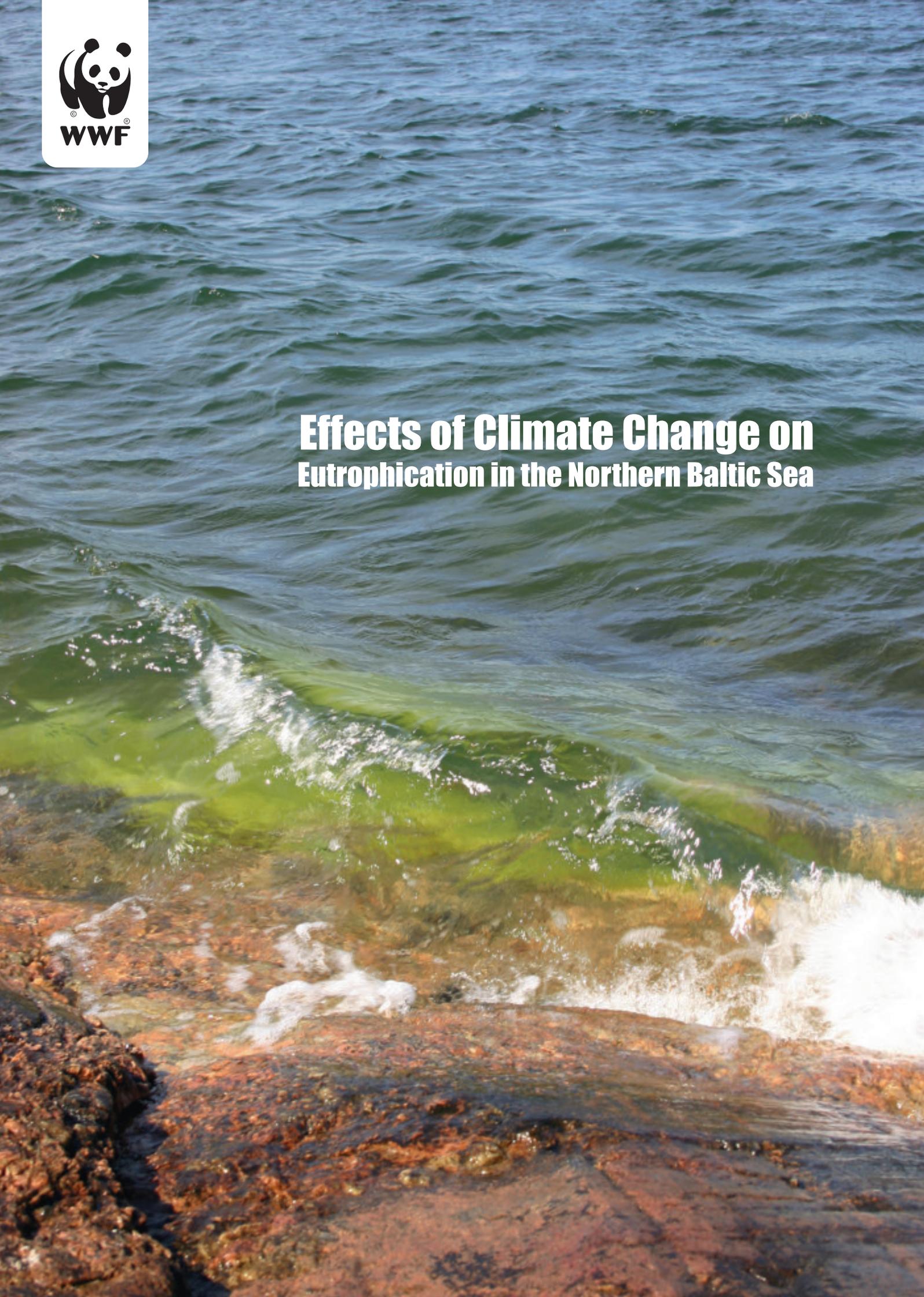




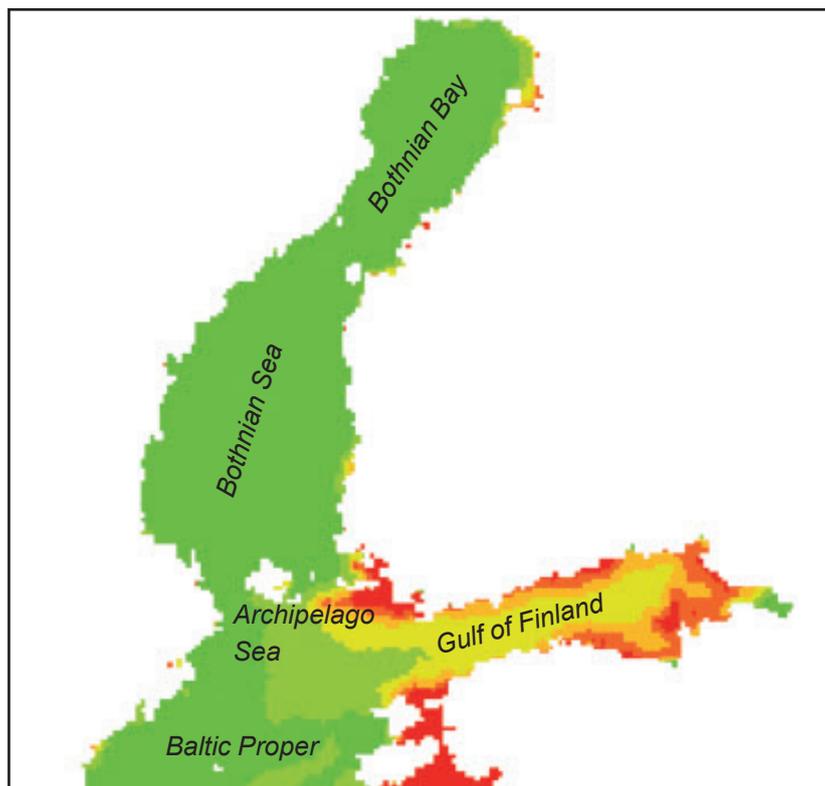
Effects of Climate Change on Eutrophication in the Northern Baltic Sea





Contents

Introduction: Symptoms of climate change	3
Aims and methods: Model calculations	4
Results: Scenarios examining the effects of climate change on eutrophication	6
Scientific conclusions by Professor Harri Kuosa	9



Map 1

Summary

This WWF report analyses the impacts of climate change on eutrophication in the northern waters of the Baltic Sea.

Two scenarios are presented. The first scenario, the Climate Change Scenario, assesses the impacts of predicted climate change under circumstances where no additional conservation measures are carried out. The second scenario, the Climate Change and the Baltic Sea Action Plan Scenario, assesses whether the Baltic Sea Action Plan (BSAP) prepared by the Helsinki Commission (HELCOM) can reach one of its main targets – “a Baltic Sea unaffected by eutrophication” – despite the impacts of climate change.

Both scenarios show that climate change will stimulate further eutrophication in the Northern Baltic Sea. The Gulf of Finland, the Archipelago Sea and the Gulf of Riga will

receive increasing nutrient loads, resulting in higher algal biomasses. If fully implemented, the BSAP will compensate for the effects of climate change by mitigating the increase in algal biomass. However, the predicted impacts of global warming evidently make the BSAP’s strategic goal on eutrophication unattainable. In spite of the conservation measures proposed in the BSAP, eutrophication will continue to be the most serious environmental problem facing the Baltic Sea. Consequently even stricter country-wise nutrient reduction allocations than those suggested in the BSAP are indispensable for the catchment area of the Northern Baltic Sea and particularly the Gulf of Finland. The scenarios presented in the report were built using a 3D-ecosystem model, which calculates water flows, nutrient concentrations and algal biomass.



Introduction

Symptoms of climate change

More rain, less sea ice

The most widely predicted consequences of climate change in the Baltic Sea catchment area are rises in average temperatures and increases in rainfall. These changes are expected to be most pronounced during the winter months.

Increasing rainfall will change the hydrological balance of the Baltic Sea. Coastal waters will receive increased fresh water inputs, lowering their salinity, and this trend may have an effect on the whole Baltic Sea basin. At the same time, inputs of dissolved materials including eutrophying nutrients from the catchment area will also tend to increase.

The average extent of the sea ice will decrease. During an average winter, sea ice has normally covered the northern half of the Baltic for several months. During the winter 2007–2008, however, the whole of the Baltic Sea remained practically free of ice.

Ice cover acts as a lid over the sea, preventing wind from mixing the water. Ice cover has an important effect on the dispersal of river water, salinity stratification, and also probably on oxygen conditions near the sea bottom.

Increasing nutrient loads

The lack of ground frost, together with heavy winter rains, will increase nutrient flows from the catchment area into the Baltic Sea, with rivers carrying increasing amounts of the key nutrients phosphorus and nitrogen.

Estimates of increases in nutrient loads in published studies vary between 5% and 25%, depending on the study area and the climate scenarios used.

What is eutrophication?

Eutrophication is a process where bodies of water, such as lakes, estuaries, slow-moving streams, or whole seas like the Baltic receive excess nutrients that stimulate excessive plant growth. Eutrophication is caused by two main nutrients – nitrogen (N) and phosphorus (P).

Eutrophication boosts the productivity rates of aquatic primary producers. Its effects are reflected in reduced water clarity due to the proliferation of microscopic phytoplankton, and the increased growth of visible filamentous algae and aquatic plants. In the worst cases, eutrophication may result in the increased occurrence of massive blooms of algae including blue-green algae (cyanobacteria), oxygen depletion on the sea bottom, and dramatic changes in fish stocks.

Eutrophication is the most serious environmental threat facing the Baltic Sea, due to its far-reaching ecological and economic consequences. It reduces the biodiversity of the Baltic Sea dramatically, and also lowers its recreational value.

Aims and methods

Model calculations

Objectives of the study

Two scenarios were defined to examine the impacts of climate change on eutrophication in the Northern Baltic Sea:

- **Climate Change Scenario:** This scenario examines how global climate change will affect eutrophication in the Northern Baltic Sea if no additional conservation measures are carried out.
- **Climate Change and the Baltic Sea Action Plan Scenario:** This scenario incorporates the measures to tackle eutrophication included in the Baltic Sea Action Plan (BSAP) prepared by the Helsinki Commission (HELCOM), aiming to investigate whether the fully implemented BSAP can reach one of its main targets – “a Baltic Sea unaffected by eutrophication” – despite the impacts of climate change.

The two scenarios were compared with data on the present state of the Baltic Sea.

Data on hydrographical changes

To our knowledge, no scientific studies have been published concerning hydrographical changes caused by climate change in the Baltic Sea that would affect eutrophication. In the present study we have applied a historical approach and selected data from certain years in the late 1990s to represent either average climatic conditions over the whole 20th century, or conditions in exceptionally warm years.

The exceptionally warm years 1997 and 1999 were selected to represent post climate change weather and hydrographic conditions. The years 1996 and 1998 were selected as representing typical conditions over the last century.

Model scenarios were calculated using recorded weather information, ice maps and measured water temperatures for these years.

Data on nutrient loads

For the purposes of this study, a figure for nutrient load increases of 15% was chosen for riverine loads of both phosphorus and nitrogen load throughout the Baltic Sea drainage area, as an average of the figures ranging from 5% to 25% published in related research findings.

The nutrient loads used in the calculations are presented in Figure 1.

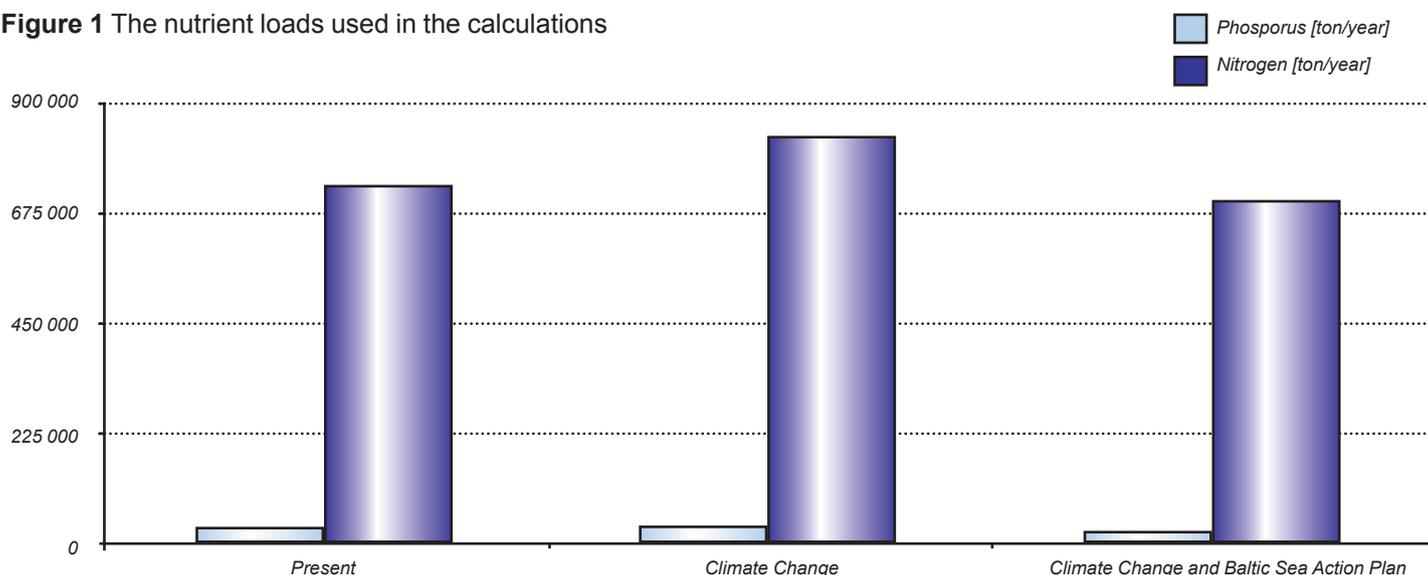
Reliability

The area used in this study covers the whole of the Baltic Sea except for the Danish Straits. The model applies grid squares of 5 km x 5 km, meaning that small-scale local effects cannot be reproduced.

The model has so far only been thoroughly tested for the Gulf of Finland and the North-eastern Baltic Proper. The area where the model's results are most reliable is indicated by the map on page 2 (Map 1). In the southern waters of the Baltic Proper the model's results are only indicative.

Five years is a long enough period for the Gulf of Finland to demonstrate how changes in nutrient loads and hydrographic conditions affect the amounts of algae, because the water residence time is around 3 years. Contrastingly in the Baltic Proper, where the water residence time is estimated to be up to 30 years, a five-year-long simulation does not necessarily illustrate algal biomass changes in their full extent. The reliability of the five-year-long simulation model used in the study therefore decreases towards the southern part of the Baltic Proper.

Figure 1 The nutrient loads used in the calculations



The Baltic Sea Action Plan

The Helsinki Commission (HELCOM) works to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental co-operation between Denmark, Estonia, the European Community, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden.

The HELCOM Baltic Sea Action Plan (BSAP) is a programme designed to restore the good ecological status of the Baltic marine environment by 2021. The BSAP was agreed in 2007.

To combat eutrophication, the BSAP aims to considerably reduce nutrient loads. The plan especially targets phosphorus loads, which should be reduced in the Baltic Proper by 65% and the Gulf of Finland by 30%. No nutrient reductions schemes have been defined for the Gulf of Bothnia.

For more information on the BSAP see: www.helcom.fi

Behind the scenarios: The 3D-ecosystem model

The simulated scenarios presented in this WWF report were built using the EIA-SYKE 3D-ecosystem model that calculates water flows, nutrient concentrations and algal biomass in boxes called calculation (grid) cells distributed around the Baltic Sea (Kiirikki et al. 2001, 2006).

Each calculation cell covers a sea area of 5 km x 5 km, and depending on depth there can be as many as 17 cells of greatly varying depths between the surface and the sea bottom. This 3D-ecosystem model thus contains hundreds of thousands of active calculation cells simulating the various parts of the Baltic Sea.

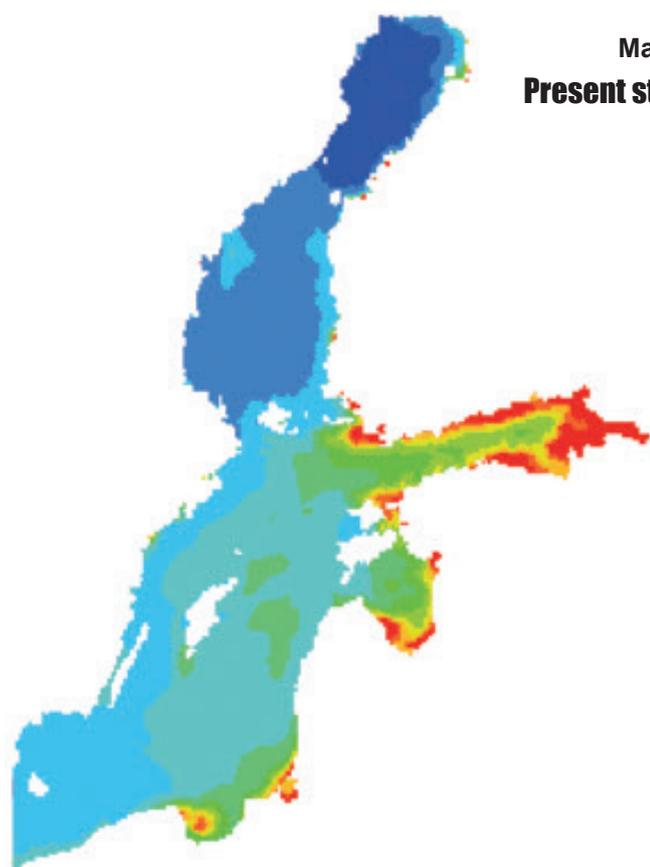
During every time step the model calculates water flows between all pairs of adjacent cells, and also produces figures for the transportation of nutrients, the consumption of nutrients by algae, and the subsequent algal growth.

Nutrients enter the modelled sea area from almost 100 separate loading points or areas – mainly rivers and industrial or municipal wastewater outlets. Calculations also account for nutrient deposition from the atmosphere together with rainfall, as well as simulate the nutrient fluxes released from bottom sediments (i.e. internal loading).

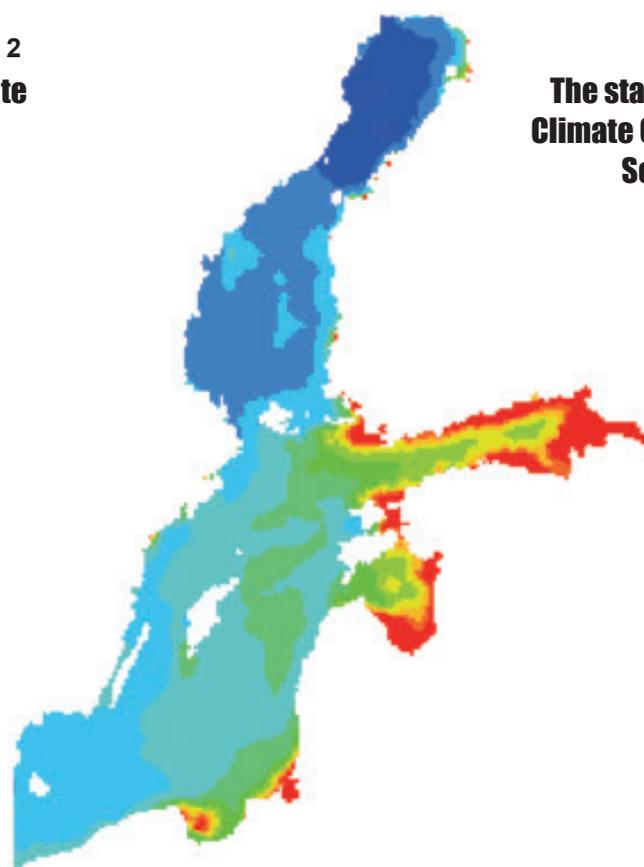
The model simulations were run for a five-year hypothetical period, using the records for “typical conditions” and “post climate change conditions”.

Simulated average algal biomasses were recorded for the last two growing seasons (April–September) and presented in the most commonly used indication for algal biomass: chlorophyll-a concentrations in microgrammes per litre (µg/l).

Algal biomass in the present state and after the scenarios:

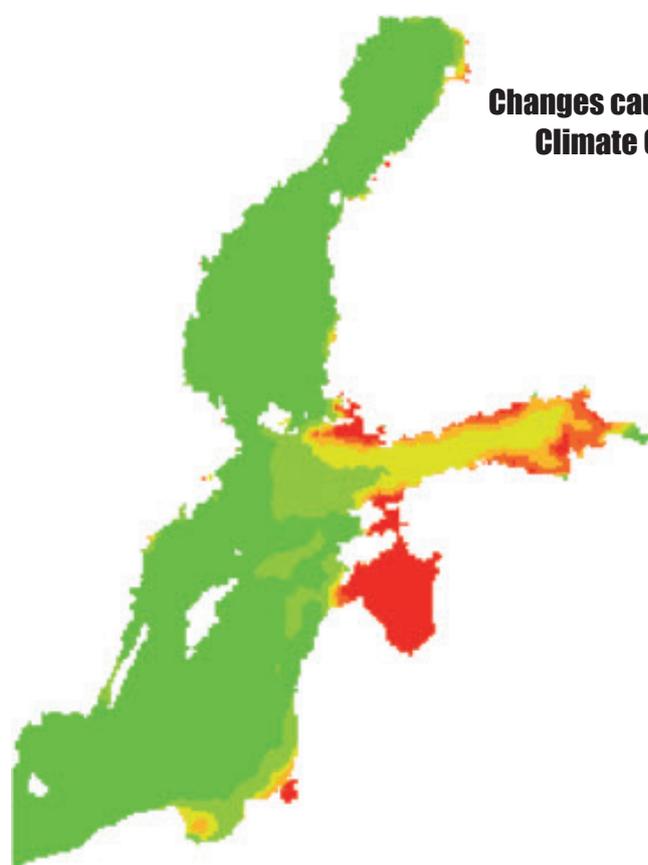


Map 2
Present state



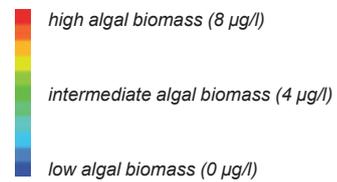
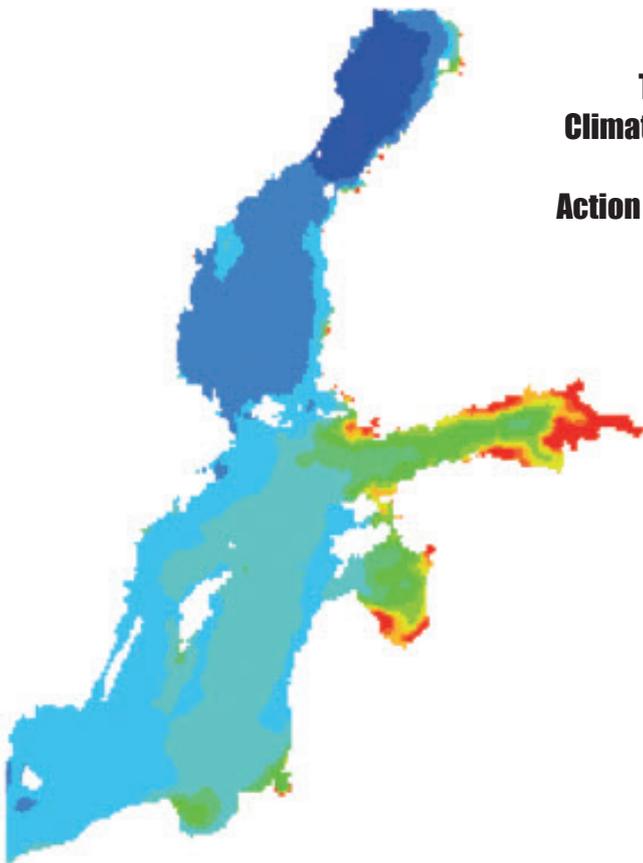
Map 4
The state after
Climate Change
Scenario

Algal biomass changes in the scenarios:



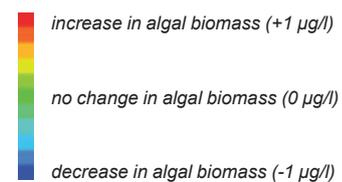
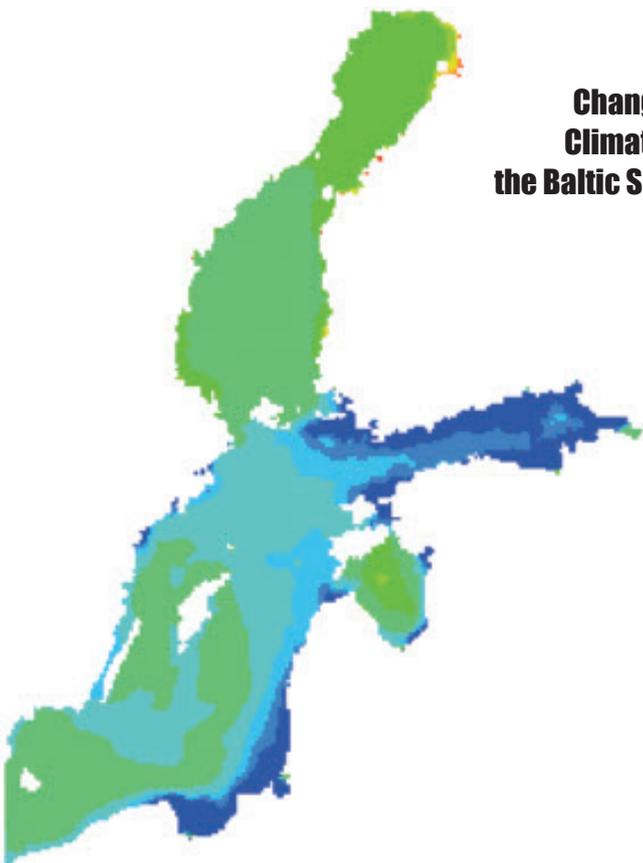
Map 3
Changes caused by
Climate Change

Map 6
The state after
Climate Change and
the Baltic Sea
Action Plan Scenario



*Average growing season
(April-September) algal biomass
given in chlorophyll-a units*

Map 5
Changes caused by
Climate Change and
the Baltic Sea Action Plan



*Changes in algal biomass,
presented in chlorophyll-a
units, caused by Climate
Change and the Baltic
Sea Action Plan.*

Results

Scenarios examining the effects of climate change on eutrophication

The present state of the Baltic Sea

The present distribution of algal biomass in the Baltic Sea is characterised by high biomass in the eastern parts of the Baltic, which are shallow and receive the highest loads from the catchment area. In these waters eutrophication often results in dramatic blue–green algal blooms during warm summers.

The Gulf of Finland is particularly suffering from biomass concentrations 2–3 times higher than in the Baltic Proper. High biomass concentrations can also be found in the Archipelago Sea, in the Gulf of Riga, and near river estuaries around the South–western Baltic.

The Bothnian Bay and the Bothnian Sea are the parts of the Baltic Sea least affected by eutrophication (Map 2).

Climate Change Scenario

The effects of climate change will be most pronounced in the same waters of the eastern Baltic where algal biomass concentrations are already high (Maps 3 and 4).

The Gulf of Finland, the Archipelago Sea and the Gulf of Riga will receive rapidly increasing riverine nutrient loads, resulting in even higher algal biomass. The effects of this increased loading will be particularly visible in the coastal waters of Finland, Russia, Latvia and Lithuania. Simulations show that changes will also occur in the open waters of the Gulf of Finland and the northernmost parts of the Baltic Proper.

The Gulf of Bothnia will remain almost unaffected except for increased quantities of algae in the mouths of Finnish rivers.

Swedish coastal waters show practically no changes, mainly because of geomorphological factors, since they are deeper and more open than Finnish coastal waters. In more open coastal waters river water is more rapidly mixed into larger water masses and local impacts consequently remain much lower.

Climate Change and the Baltic Sea Action Plan Scenario

If successfully implemented, the nutrient reductions defined in the Baltic Sea Action Plan (BSAP) will compensate for the eutrophication impacts of the currently foreseen extent of climate change (Map 5).

However, the expected impacts of climate change mean that one of the BSAP's main targets – “a Baltic Sea unaffected by eutrophication” – is predestined to be unattainable. The BSAP can succeed in mitigating the increases in algal biomass caused by climate change, but it will not reach its overall target for eutrophication: a state where nutrient concentrations and oxygen levels in the Baltic Sea are back at natural levels, the water is clear again, and plants and animals have their natural distributions and occurrences (Map 6).

These findings indicate that algal biomass concentrations will remain high in the eastern coastal waters of the Baltic Sea, meaning that efforts to restore the good ecological status of the Baltic Sea will most probably fail with the currently defined nutrient reduction allocations. In order to succeed, the Baltic Sea Action Plan needs to include clearer and more effective policies that will also address run-off from farmland, which is today the most important source of nutrient pollution in the Baltic Sea.

Scientific conclusions

by Professor Harri Kuosa

What we can learn from the model

Changes in the physical environment significantly affect the ecology of the Baltic Sea. Documented examples include population changes in migratory birds (Jonzén et al. 2006), seal populations (Meier et al. 2004) and pelagial zooplankton (Vuorinen et al. 1998, Dippner et al. 2000). Blue-green algal blooms clearly benefit from higher water temperatures (Kanoshina et al. 2003). The effects of climate change on Baltic marine ecosystems have been expertly summarised by Dippner et al. (2008).

The indirect effects of climate change through changes in the catchment area are more difficult to assess. This study links the impacts of climate change in the catchment area to trends in eutrophication in the Baltic Sea, and is the first attempt to evaluate the effects of predicted changes in nutrient status in detail. The results show that such impacts are considerable, and must be taken into account when planning the protection of the Baltic Sea, although we must always be prepared to review these findings in the light of any new information.

Impacts derived from the catchment area are concentrated in coastal waters. Such effects are considerable in the Gulf of Finland, the Gulf of Riga and the northern Baltic Proper, but less clear in the Gulf of Bothnia. It should be remembered, however, that the present model cannot fully assess dynamic situations around river mouths, as its grid is rather coarse.

Clear symptoms of eutrophication, such as blue-green algal blooms (of species other than *Nodularia*) may be found in the Gulf of Bothnia in restricted areas affected by river water. Such impacts are more pronounced on the

Finnish side of the Gulf, since Swedish coastal waters are deeper, which promotes more effective mixing of water, and agricultural activity is more widespread in the Finnish catchment area.

In the open waters of the Gulf of Finland, the Gulf of Riga and the northern Baltic Proper, the predicted changes will be reflected in increasing phytoplankton production. The most intensive period of production, the spring bloom, will intensify, creating more organic matter that will settle to the bottom. Blue-green algal blooms in the summer also benefit from additional nutrients, and the warmer summers will also increase the probability of intense blue-green algal blooms.

Seasonal changes are highly dependent on the response of nitrogen and phosphorus inputs to climate change, as spring blooms are more limited by the availability of nitrogen, and blue-green algal blooms depend more on phosphorus. The values used in this study (15% increases in the inputs of both nutrients) are rough estimates, which must be reconsidered as we receive more information on the dynamics of the catchment area.

Beyond the present model

Eutrophication can affect coastal waters in many ways. Certain fish species such as roach benefit from changes including the additional input of organic matter to the sea bottom and reduced salinity. The increasing production of filamentous algae leads to unpleasant masses of dying vegetation on the sea bottom and along shorelines. The microscopic algal species that benefit from eutrophication are generally poor quality food for zooplankton, and the

combined effect of decreasing salinity and eutrophication tends to reduce the amounts of food available for fish like the Baltic herring.

Other production related changes in addition to increased phytoplankton growth result from increasing nutrient inputs. Nearer the coastline, producers also include macrophytes in soft bottoms, and macroalgae in hard bottoms. Some species that benefit from additional nutrients such as trichal macroalgae will thrive, but bladder wrack and other species that require clear water will suffer.

The presence of more decomposing organic material will increase benthic oxygen consumption locally and in the whole of the Gulf of Finland. Oxygen deficiency is a problem for animals, and also increases blue-green algal biomass through the phenomenon of internal loading, which involves the release of nutrients from sediments on the sea floor.

Increased nutrient inputs are only one of the expected impacts of climate change. Others include the increasing turbidity of coastal water due to increasing river runoff and frost-free soil. This was clearly observed during the winter 2008 around the Finnish coast. Rivers will also bring more humic substances into the Baltic Sea, with consequences that are still relatively unknown, and subject to current research.

It is vital to combat increased nutrient leaching from soils, which directly affects coastal waters of the Baltic Sea. The need to maintain good nutrient status of fields and forests may also lead to increasing use of fertilisers. Efforts to find ways to reduce leaching or otherwise keep nutrients in the catchment area are of great importance and under active research at the moment.

This study evaluates the effects of climate change only for a limited area, and its results are most reliable for the more northerly waters of the Baltic Sea. As the predicted increase in rainfall is expected to affect the whole catchment area, the impacts are likely to be similar in other areas, however.

These findings all constitute a rather pessimistic view of the future of Baltic Sea. However, the results combining climate change and the impacts of the Baltic Sea Action Plan are more promising. The improvements expected due to the action plan should not be cancelled out by the impacts of climate change even in problematic areas like the Gulf of Finland.

In conclusion, the study's results prove that even more intense efforts would be required to reduce the nutrient loads entering the Baltic Sea enough to achieve the goal of healthy Baltic Sea ecosystem.



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Warm winters are good news for harmful algal blooms – but bad news for the Baltic Sea overall. New scenarios created by WWF show that global climate change will exacerbate eutrophication in the northern Baltic Sea, worsening the conditions for marine life – and also for people. The impacts of climate change will also complicate international efforts to save the Baltic Sea.

WWF for the Baltic Sea

WWF is one of the world's largest and most experienced conservation organisations, with almost five million supporters and a global network active in over 100 countries. WWF's mission is to stop the degradation of the planet's natural environment and to build a future where people can live in harmony with nature.

WWF is working actively to save the Baltic Sea, one of the world's most threatened marine ecosystems. Vital issues include eutrophication, shipping, fisheries, and marine and coastal protected areas.

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