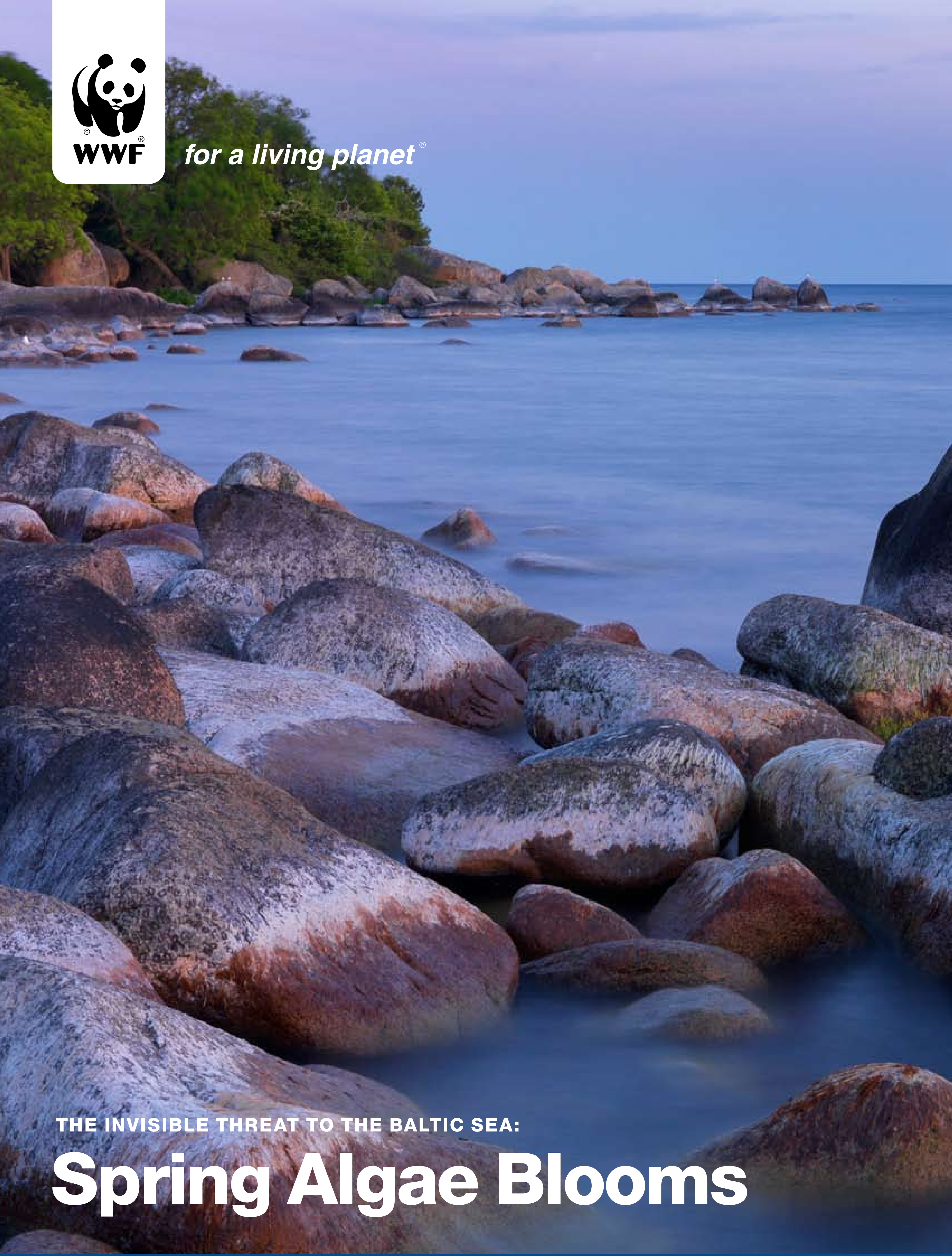

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THE INVISIBLE THREAT TO THE BALTIC SEA:

Spring Algae Blooms

WWF Baltic Ecoregion Programme 2009

Eutrophication in the Baltic Sea

Eutrophication, or nutrient pollution, has been identified as the single biggest threat to the health of the Baltic Sea. The most visible symptom of the excessive inputs of nutrients is the algal blooms that plague large areas of the Baltic Sea during warm summers. What is not as visible, but might pose an even greater threat to the Baltic Sea environment, are the spring algae blooms which take place in the Baltic Sea from March to May every year.

In the last 150 years, the Baltic Sea has gone from a pristine, nutrient poor, clear water sea to permanent eutrophic conditions. Eutrophication, due to excessive inputs of nutrients, already affects a majority of Baltic biotopes, while the area affected by hypoxia (shortage of oxygen) has increased four-fold since the early 20th century (European Marine Lifestyles, 2007).

Based on a recent Baltic Marine Environment Protection Commission assessment (HELCOM 2009), 176 coastal and open sea long-term monitoring sites of the studied 189 sites were classified as "areas affected by eutrophication". The ecological status of a great majority of these sites were classified as "bad". The 13 'areas not affected by eutrophication' were all located in the Bothnian Sea or the Bothnian Bay.

The most commonly observed symptom of eutrophication is the summer algae blooms. These blooms are typically formed by microscopic plankton, so-called blue-green algae (actually cyanobacteria), that can show exploding growth under warm and phosphorus-rich sea water conditions.

Spring bloom

A major part of the algae biomass, however, is produced during the spring bloom of microscopic phytoplankton (Fig. 1) which takes place already from March to May. The spring bloom takes place so early that there are almost no recreational activities going on in the Baltic Sea – and therefore it is easily missed as nobody is watching it. It can be seen, by the careful observer, in the brownish colour of the water and high turbidity (cloudiness of water caused by suspended particles).

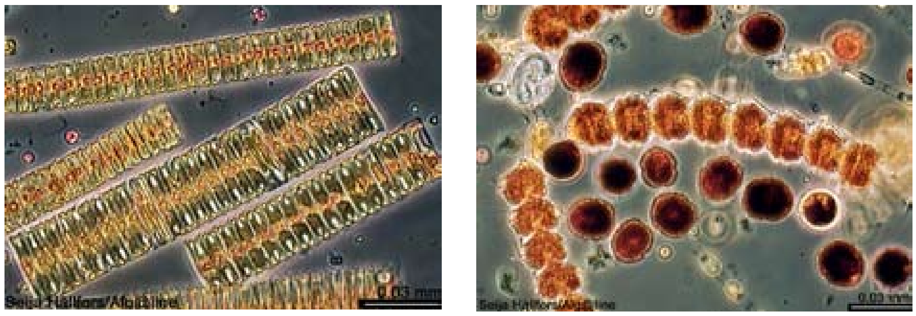

Figure 1. A major part of the algae biomass is produced during the spring bloom of microscopic phytoplankton. The spring bloom consists of large and heavy algal cells like Diatoms and Dinoflagellates.

"Only the strongest summertime blue-green algal blooms can come close to producing a similar amount of algae as the average spring bloom does every year."

Figure 2. ***Pilayella***, a littoral nuisance brown macroalgae, contributes to the primary production in the spring. The algae eventually end up on the sea bottom and further deplete the already scarce oxygen reserves.

Simultaneously with the phytoplankton production, macroscopic filamentous algae are growing closer to the shoreline and adding to the spring biomass production (Fig. 2). These macroscopic algae add to the total biomass, but are not covered by this report and their biomass is not included in the calculations.

The spring algae bloom does not produce any other visible evidence, such as the floating accumulation of the blue-green algae which characterize the summer algae blooms.

Diatoms and Dinoflagellates

The spring bloom consists of large and heavy algal cells like Diatoms and Dinoflagellates (Fig. 1) which quickly sink to the sea bottom within a few weeks. A major part of the spring bloom decomposes on the sea bottom where they consume the already scarce oxygen reserves of the Baltic Sea. This has significant implications for the Baltic Sea ecosystem, leading to the formation of dead zones which further threaten Baltic biodiversity and lead to decreased reproductive success of commercial fish stocks such as flatfish and cod.

Substantial volume

The maximum spring bloom algae biomass is substantial (Fig. 3). Only the strongest summertime blue-green algae blooms can come close to producing a similar amount of algae biomass as the average spring bloom does every year.

The blue-green algae of the summer blooms continue to float when their active growth is over. A floating and decomposing bloom is a clear nuisance for recreation, but from the point of view of the bottom oxygen conditions, the effect is not as serious as with the spring algae bloom. Of course, the summer algae blooms also pose a serious threat to the ecosystem health of the Baltic Sea.

The intensity of the spring bloom is mainly governed by the nutrient load entering the sea from the Baltic Sea catchment drainage area as well as from atmospheric deposition.

Every year large amounts of nutrients, mainly nitrogen and phosphorus, are released into the Baltic Sea from three main sources: agriculture, waste water and the combustion of fossil fuels. Agricultural practices are responsible for 40% of the phosphorus and 60% of the nitrogen emissions (HELCOM 2009).

> "Of the total anthropogenic nutrient input, agricultural point sources and agricultural land runoff, represent more than half of the nitrogen entering the sea."

Spatial distribution – where can the algae be found?

The distribution of the spring algae bloom is characterised by high concentrations in the eastern parts of the Baltic Sea, which are shallow and receive a high nutrient load from the drainage area. The Gulf of Finland is particularly affected, suffering twice the biomass, per unit area, compared to the Baltic Proper.

Areas of high biomass can also be found in the Archipelago Sea, Gulf of Riga and off the river mouths in the south-eastern Baltic Proper. In contrast, the spring bloom can hardly be detected in the Bothnian Bay (Fig. 3).

Nitrogen load main factor

The nitrogen load is the main factor responsible for the powerful spring blooms. The major part of the nitrogen load comes to the Baltic Sea via rivers.

The three top polluters are, according to HELCOM 2006 statistics, Poland, Sweden and Russia (Fig 4).

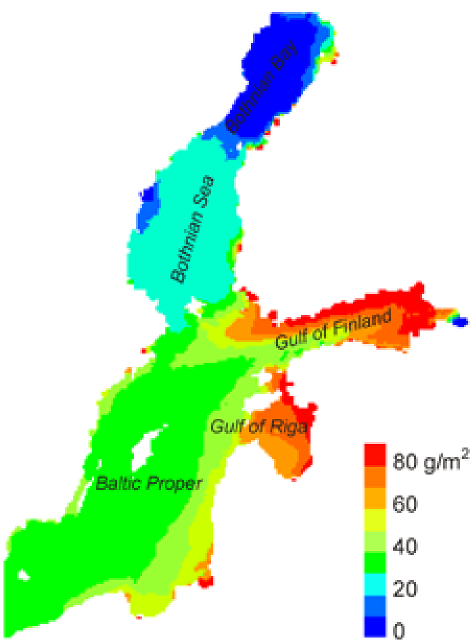

Figure 3. The average simulated biomass maximum of spring bloom calculated by a EIA-SYKE 3D ecosystem model in the Baltic Sea presented as vertically integrated fresh weight of algae.

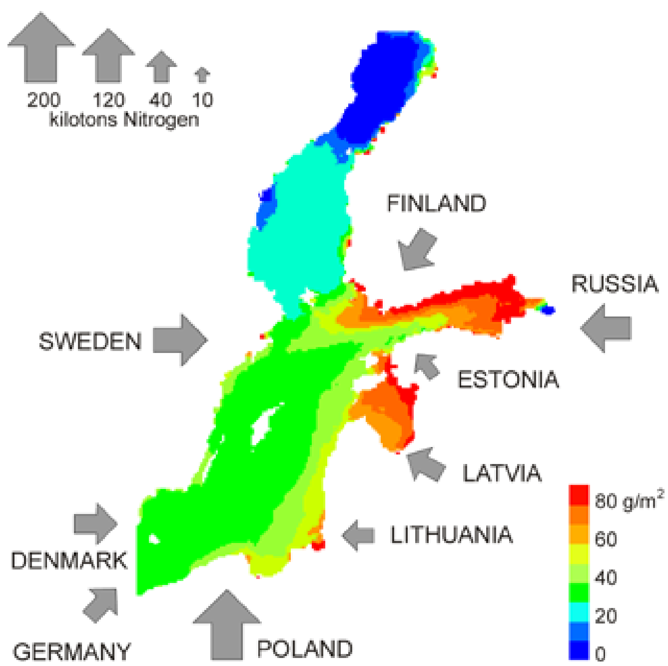

Figure 4. The nitrogen load to the Baltic Sea representing the year 2006. The loading graphs include atmospheric deposition of nitrogen. The three top polluters are, according to 2006 statistics, Poland, Sweden and Russia. The simulated biomass maximum is the same as in figure 3.

Spring Algae Blooms

The Baltic Sea receives this nitrogen load also as atmospheric deposition, which is easily transported long distances. The atmospheric load from the countries surrounding the Baltic Sea accounts for 16 % of the total nitrogen load. The top three countries responsible for atmospheric loading are Germany, Poland and Denmark (Fig 5).

The internal nutrient load, i.e. the accelerated release of phosphorus from the bottom sediment, which is a major factor controlling the blue-green algal blooms, plays only a minor role in the formation of the spring bloom.

"The spring bloom is a major factor controlling sedimentation of organic matter, oxygen consumption and thus distribution of the dead zones and internal nutrient load in the Baltic Sea."

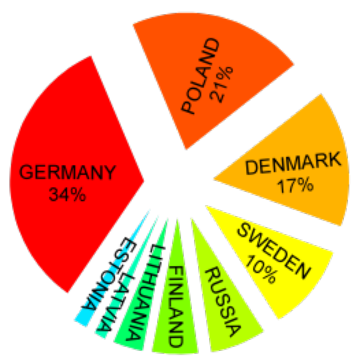

Fig. 5 Atmospheric nitrogen deposition from the surrounding countries is 120 000 tons/ year, which is 16% of the total nitrogen load to the Baltic Sea. These figures do not include the loads from ship traffic (HELCOM 2009).

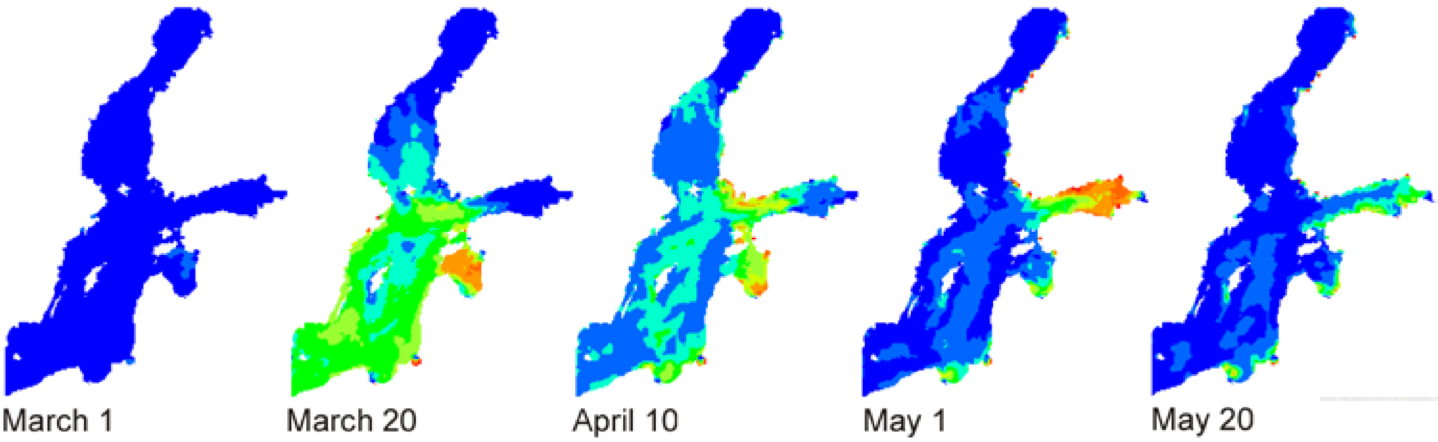

Figure 6. A modelled time series of the seasonal succession of an average spring bloom. The biomass scale is the same as in Figures 1 and 2.

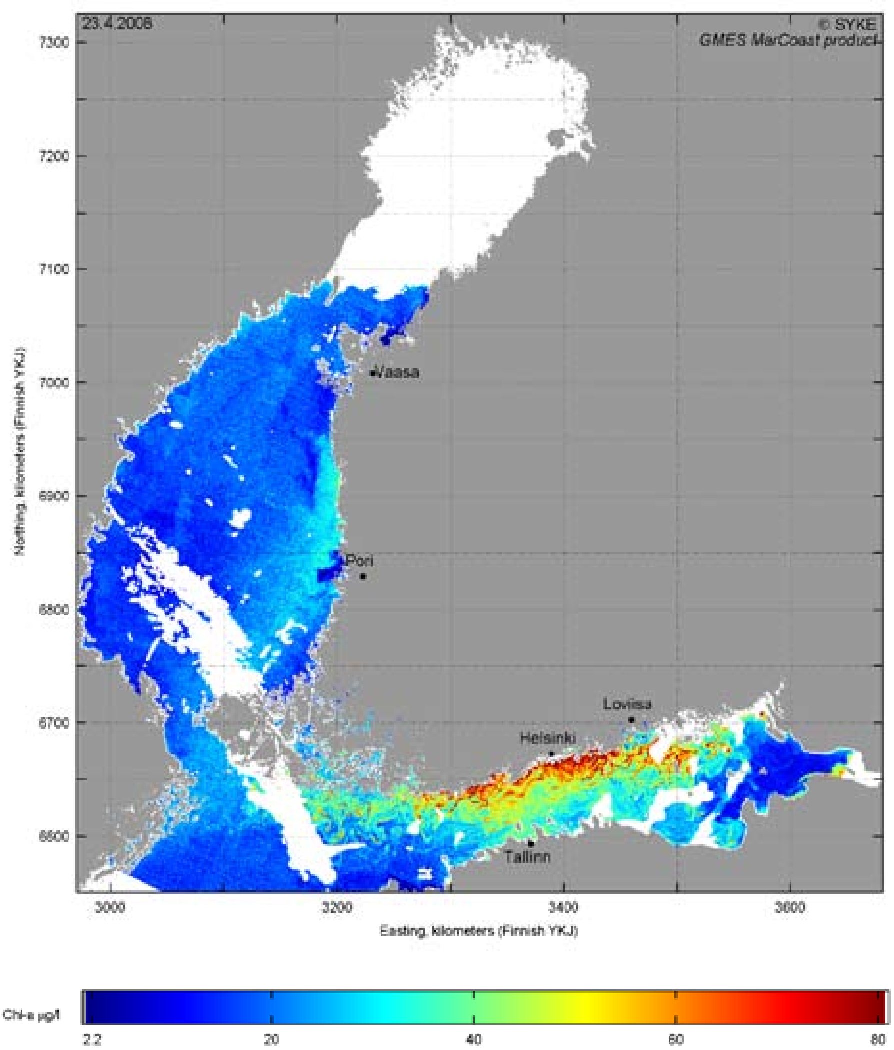

Figure 7. Satellite image of the northern parts of the Baltic Sea 23.4.2008 showing very intensive late spring bloom in the Gulf of Finland. Image by Finnish Environment Institute / Jenni Attila.

Spring bloom – part of a vicious cycle

The spring bloom is a major factor controlling sedimentation of organic matter, oxygen consumption and thus distribution of dead zones (areas of the sea floor nearly, or completely, devoid of oxygen).

Normally, phosphorus slowly binds to the sediments on the sea bottom and is thereby removed from the water. When there is no oxygen left at the sediment-water interface, these compounds are transformed and the phosphorus is released back into the water in a process called internal loading.

Phosphorous is the main controlling factor for the summer blue green algal blooms and the vicious cycle is closed as these blooms have the power to fixate gaseous nitrogen into nutrients that will feed next years spring blooms.

The progression of the spring bloom

The spring bloom starts in the southern parts of the Baltic Sea in early March. It follows the edge of the melting sea ice in April to the Gulf of Finland (Fig. 6). In April-May the bloom is still visible in the coastal areas of the Gulf of Finland (Fig. 7).

Spring Algae Blooms

Current situation

In 2009 the northern Baltic Proper witnessed the strongest spring bloom of the past 15 years, with production peaking this year at the end of April (Baltic Sea Portal 2009).

No rising trend can be detected in the intensity of the spring bloom from 1992 to 2008 in the Gulf of Finland, the Northern Baltic Proper or the Arkona Basin (HELCOM 2008). Instead, the biomass production has been constantly high over the years with natural yearly fluctuations reflecting the scale of the nutrient reserves and the climatic conditions.

Large areas without oxygen

When the dead and decomposing algae sink to the sea bottom, they start to consume oxygen. The oxygen is taken from the water layer just above the bottom.

Below is a calculation of how thick a layer of well-oxygenated water (10 mg/l) is theoretically consumed to zero oxygen concentration by the theoretical biomass maximum of an average spring bloom. The corresponding water layer thickness varies from 0.4 to 2.5 m and the sub basin specific zero oxygen layers are presented in the table below.

The Gulf of Finland and Gulf of Riga*	2.5 m
The Baltic Proper	1.6 m
The Bothnian Sea	0.9 m
The Bothnian Bay	0.4 m

*The algae biomass – oxygen consumption ratio is based on large experimental data. 1 kg of algae biomass contains on average 110 g of organic carbon. When decomposing on the sea bottom, it consumes on average 350 g of oxygen.

Because oxygen is already scarce and there are already large areas without any oxygen in the water layer above the bottom, the present spring algae bloom effectively prevents the recovery of the bottom ecosystems.

Algae bloom – average simulated biomass maximum

The maximum algae biomass in an average spring bloom as g/m^2

- in the Gulf of Finland and Gulf of Riga* 50-80 g/m^2
- in the Baltic Proper 30–50 g/m^2
- in the Bothnian Sea about 20 g/m^2
- in the Bothnian Bay 5–10 g/m^2

The maximum algae biomass in an average spring bloom as truckloads** per square kilometre

- in the Gulf of Finland and Gulf of Riga on average 7 truckloads of algae
- in the Baltic Proper on average 4 truckloads of algae
- in the Bothnian Sea on average 2 truckloads of algae
- in the Bothnian Bay less than 1 truckload of algae.

The spring bloom maximum for the whole subbasin corresponds to

- the Baltic Proper 1 000 000 truckloads of algae
- the Gulf of Finland 200 000 truckloads of algae
- the Gulf of Riga 100 000 truckloads of algae
- the Bothnian Sea 100 000 truckloads of algae
- the Bothnian Bay 20 000 trukloads of algae

* The maximum algae biomass in the Gulf of Finland and Gulf of Riga is equivalent to having one large onion floating in the sea every one metre.

** 1 truckload = max 12 m truck carrying c.a. 10 m^3 or 10 ton).

1 million truckloads of algae from the Baltic Proper would constitute one line of trucks of 12 000 km long, twice the distance from Barents Sea to Mediterranean Sea.

The high biomass production is reflecting the scale of the nutrient reserves and the climatic conditions.

What can be done?

The mechanisms of the "vicious cycle" of spring and summer algal blooms clearly show the need to reduce both phosphorus and nitrogen emissions to the Baltic Sea. The main sources of anthropogenic nitrogen and phosphorus inputs are agriculture, municipal waste water and (for nitrogen) the combustion of fossil fuels. Agricultural practices are responsible for 40% of the phosphorus and 60% of the nitrogen emissions. While several quick and cost-efficient measures can be taken to reduce nutrient concentrations of waste water, including a ban on phosphates in detergents and improved waste water facilities, we cannot expect to solve the eutrophication problem without a radical change in agricultural policy.

A key component in solving the problem of eutrophication lies on the land and in the promotion of more sustainable farming and land management practices. Successive reforms of the EU Common Agricultural Policy (CAP) have started the process of putting agriculture on a more sustainable footing but much remains to be done. Subsidies that are still used to promote production should instead be used to support environmentally sustainable rural development. Dramatically decreasing eutrophicatoin of the Baltic Sea, and a wide range of other environmental problems associated with European agriculture, demands further, progressive reform of the CAP.

In agriculture an increasing problem is the vast amount of manure being produced but not recycled as valued fertilizer.

Minimizing nitrogen emissions

The spring algae bloom is primarily limited by the nitrogen concentration in the Baltic Sea. The best way to reduce the spring bloom is therefore to reduce the massive external nitrogen loading of the Baltic Sea. More work is needed in all sectors with nitrogen emissions, both point and diffuse sources.

In agriculture an increasing problem is the vast amount of manure that is produced but not returned to the soil. This problem is compounded by the prohibitively high costs of manure transport as well as the fact that manure is often considered to be a waste problem. The development and marketing of manure separation schemes need strong support so that valuable nitrogen and phosphorus fractions can be used instead of using mineral (artificial) fertilizers. Spatial separation of crop and meat production further impairs the efficient use of manure, and the return to farming with 'mixed practise' should be supported. Nutrient balance calculations should be introduced to aide in the effective use of manure and fertilizers as this has environmental as well as economic benefits.

Several on-field measures to reduce nutrient run-off are available in the agri-environmental subsidies system. Still the most efficient measures remain voluntary and are not always put to use where they are most needed.

Large wetlands with rich vegetation should be restored and, if needed, constructed throughout agricultural regions to enable reduction of nitrogen in agricultural runoff through denitrification. Wetlands also have an important role when it comes to organic soils as these soils also have high climatic gas emissions.

Enhanced nitrogen efficiency technology in waste water treatment plants across the Baltic Sea catchment is still poorly utilized. An EC directive and a HELCOM Recommendation requires 70% removal of nitrogen, yet over 90% reduction is achievable in existing treatment plants. Adopting such best available technology in nitrogen removal in all Baltic Sea cities is an urgently needed improvement in the near future.

Additional measures needed

Nitrogen oxide emissions from Baltic Sea shipping are increasing with increasing traffic and are currently of the same magnitude as the combined land-based air emission sources from Finland and Sweden (HELCOM 2008). The Baltic Sea countries should work within the HELCOM MARITIME Correspondence Group to apply for a 'special area' status (so called 'NECA-area') for the Baltic Sea to regulate nitrogen emissions.

Climate change forecasts promise increased precipitation to the Baltic Sea region, especially for the winter period. More rain outside the growing season will cause increased leaching of nutrients via rivers to the Baltic Sea. Thus, measures to combat climate change are also necessary and will promote the heath of the Baltic Sea.

Additional measures which could help to reduce the total nitrogen load into the sea include: increased use of public transportation, more strict requirements to follow the best available emission reduction technology in shipping and all other industries, and improvements in the sewer systems to better manage urban storm water.

MODEL SIMULATIONS

The nutrient load used in this work is based on the latest official information (HELCOM 2009) representing the years 2001-2006. Also the atmospheric deposition of nitrogen is added to the country-wise load figures (Bartnicki & Valiyaveetil 2008).

The spring bloom simulations were carried out by using recorded nutrient load, weather, sea temperature and ice data for a 5-years-period.

Vertically integrated maximum algal biomass [g/m^2 fresh weight] was recorded for each of the simulated five spring periods. The presented spring bloom biomass map is an average presentation of these five springs.

The timing of the spring bloom in the various sub-basins of the Baltic Sea is demonstrated by a recorded time series covering the spring months of March-May.

The time series represents typical ice conditions during the last decades. Only the Gulf of Finland and most of the Gulf of Bothnia have been covered by ice in March.

The model results are most reliable for the Gulf of Finland and the adjacent waters of the northern Baltic Proper. Their reliability decreases towards the southernmost parts of the Baltic Proper.

EIA-SYKE 3-D ECOSYSTEM MODEL

The three dimensional ecosystem (physical-biological) model for the Baltic Sea calculates water flow, nutrient concentrations and algal biomass in boxes called calculation cells.

- One cell covers a sea area of 5 km * 5 km.
- The cell size determines the smallest details the model can reproduce.
- The depth of a single cell varies so that close to the surface they are 2 m high.
- There is a maximum of 17 cells on the top of each others in the deep sea areas.
- There are altogether hundreds of thousands of active calculation cells in the model.
- In every time step, the model calculates the water flow between all adjacent cells, transport of nutrients, consumption of nutrients by algae and the subsequent algal growth.
- Nutrients come to the modelled sea from almost 100 separate loading points or areas describing rivers, cities, factories as well as nutrient deposition coming from the atmosphere together with rainfall.
- There is also a special part in the model, which is responsible for simulating the internal nutrient load released from bottom sediments.

Large wetlands with rich vegetation should be restored and, if needed, constructed throughout agricultural regions to enable reduction of nitrogen in agricultural runoff through denitrification.

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WWF Baltic Ecoregion Programme is part of WWF, set up to save the Baltic marine environment and restore vitality and beauty to the surrounding region.

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