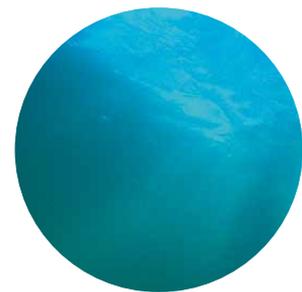


Living Coast Project

Effective measures against eutrophication

– a story about regaining
good ecological status in coastal areas

Linda Kumblad & Emil Rydin



Seven years ago, **Björnöfjärden in Värmdö Municipality** was one of the most eutrophic bays in the Stockholm archipelago. Oxygen-free “dead zones” were widespread and nutrients were leaking from a number of different sources.

After the implementation of remediation measures, Björnöfjärden is now a healthy bay with clear water and rich plant and animal life and is on the way to having a natural fish community and oxygenated bottom waters with bottom dwelling animals.

This is the Living Coast’s White Paper that describes the project’s implementation, results, costs, conclusions and recommendations. If you want to learn more, see the complete White Paper on our website (in Swedish).

www.balticsea2020.org.

Clean water in Björnöfjärden again

During 2011, the BalticSea2020 Foundation initiated the Living Coast project. The objective was to show that it is possible to restore a eutrophic bay and to find out what it costs and what other lessons can be learned from such a project. The project has been permeated by a scientific approach and has had the goal to summarise and communicate results, approaches and experiences.

The project was conducted in Björnöfjärden, a bay that can be described as a “miniature Baltic Sea” because of extensive eutrophication, limited water exchange and large areas of anoxic (oxygen depleted) bottom waters. Within the project we implemented measures that reduce the supply of the nutrients nitrogen and phosphorus from land and bottom sediments to the water, thereby regaining good water quality and an improved environment. The project mainly focused on phosphorus as more measures have been developed to reduce the phosphorus supply. In addition, it is often phosphorus that regulates eutrophication in Baltic Sea archipelagos.

On the basis of the results in Björnöfjärden, we aimed higher and calculated what emission reduction the measures could contribute if they were fully implemented, such as along the whole of the Swedish Baltic Sea coast.

The objective of the project was achieved. This publication is the Living Coast’s White Paper (1.0) which describes preparatory studies, implementation, actions, results, costs and conclusions.

We hope that our work inspires and motivates to more remediation work and that this text contributes to knowledge and experience on how the work can be done. The Water Framework Directive applies to the Baltic Sea coastal waters and the Living Coast project hopes to strengthen the water management efforts with the knowledge and experience gained during the work of restoring Björnöfjärden. On our website, www.balticsea2020.org, you can find more information about the Living Coast project, the complete white paper, the project’s scientific publications and other documentation.

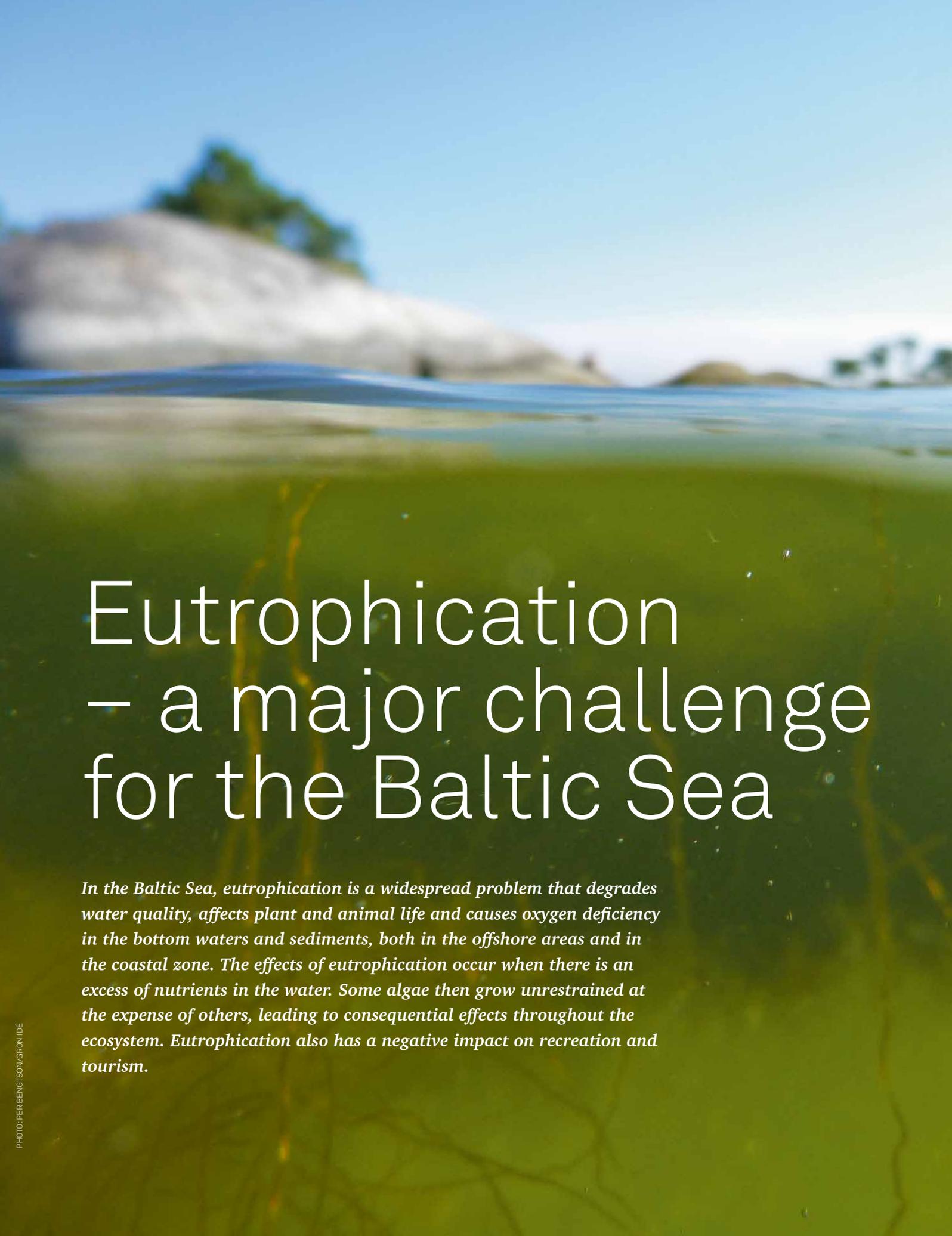
/Linda Kumblad and Emil Rydin, BalticSea2020



PHOTO: MALIN HÖLESTAD/SVD

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Eutrophication – a major challenge for the Baltic Sea

In the Baltic Sea, eutrophication is a widespread problem that degrades water quality, affects plant and animal life and causes oxygen deficiency in the bottom waters and sediments, both in the offshore areas and in the coastal zone. The effects of eutrophication occur when there is an excess of nutrients in the water. Some algae then grow unrestrained at the expense of others, leading to consequential effects throughout the ecosystem. Eutrophication also has a negative impact on recreation and tourism.

The Vicious circle

Phytoplankton and other algae rely on nutrients such as nitrogen and phosphorus. When the algae die, they sink to the bottom where they are decomposed by bacteria and bottom fauna. During decomposition, oxygen is consumed in the bottom water and the nutrients are released again. If there is plenty of oxygen in the bottom water, phosphorus can bind to the iron in the sediment, but if the oxygen runs out, the iron loses its phosphorus-binding ability. Then the phosphorus leaks back into the water and becomes available for phytoplankton and other algae. More algae growth, in turn, contributes to even more organic material to be broken down, and even more anoxic bottoms; a "vicious circle" arises.

Where do the nutrients come from?

About one third of the nitrogen and one tenth of the phosphorus that reaches the Baltic Sea is naturally supplied by rivers and streams¹. The remainder is a result of human activities in the catchment area, such as discharge from sewage with poor treatment, wastewater treatment plants and industrial operations, agriculture and forestry, and reaches the Baltic Sea mainly via rivers (Figure 1). Nutrients from the catchment area mainly come from the areas where a lot of people live and where there is most farmland. However, the release of phosphorus from the sediment (the internal load) is the predominant source of phosphorus to the Baltic Sea waters.

The nutrient supply from the Baltic Sea catchment area to the sea has decreased over the past thirty years, and is down to roughly the same levels as in the mid-20th century⁴ (Figure 2). The eutrophication status throughout the Baltic Sea has gone from "bad" (red) at the beginning of the 1980s to "unsatisfactory" (orange) or "moderate" (yellow)⁵ (Figure 3). The reason that eutrophication persists and the recovery takes a long time is the large amount of nutrients that already are present in the sea, where they are turned over year after year⁴, and the Baltic Sea's limited water exchange that means that nutrients that end up in the sea, stay for a long time.

Nutrients that reach the Baltic Sea mainly enter via rivers that bring nutrients from, for example, wastewater treatment plants, industrial operations, forestry and agriculture.

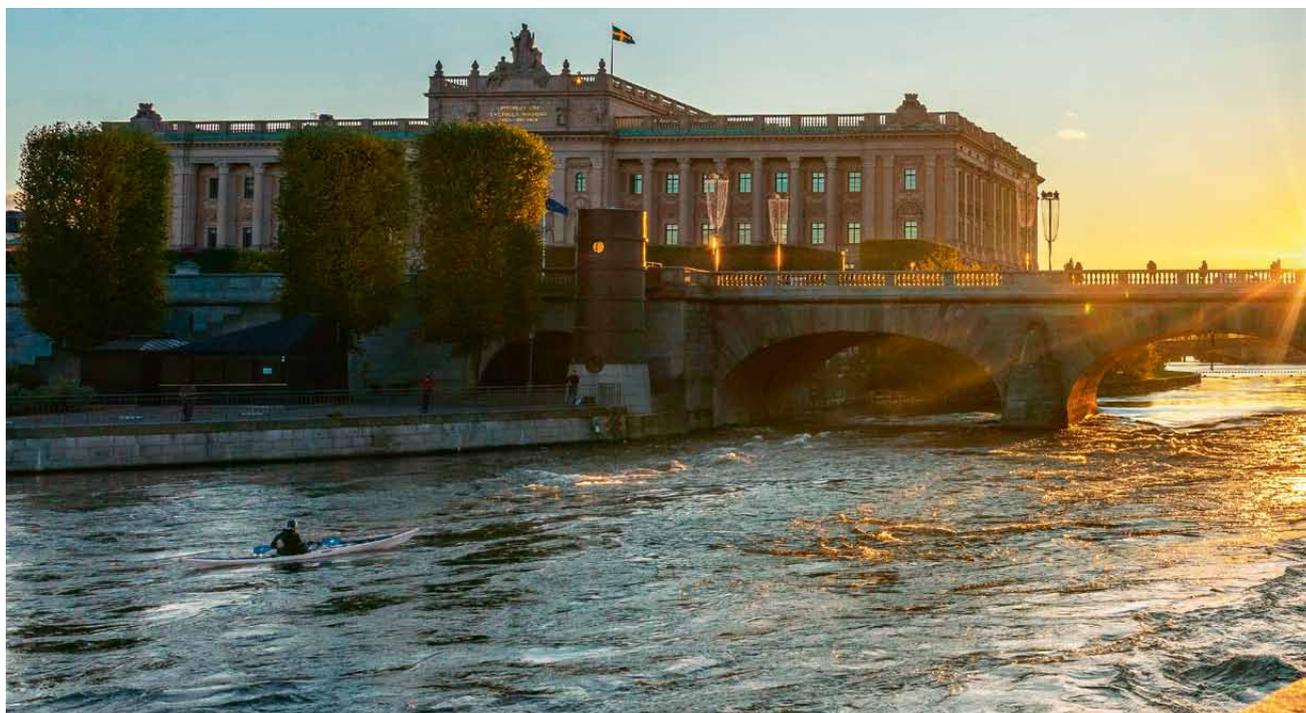


PHOTO: STEFAN HOLM/SHUTTERSTOCK

Sources of nutrients in the Baltic Sea

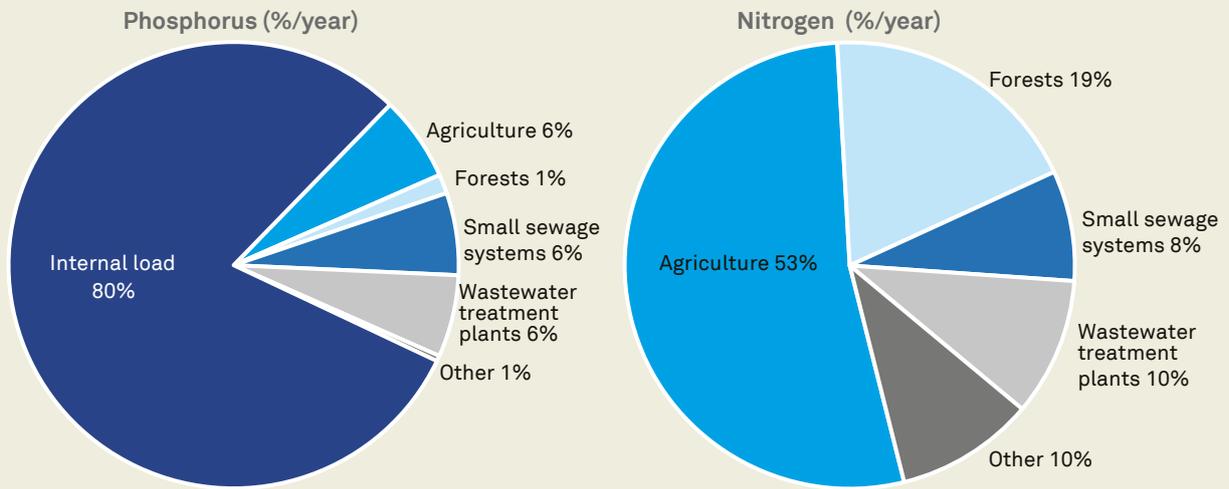


FIGURE 1. Source distribution of phosphorus and nitrogen to Baltic Sea waters. The size of the external nutrient load to the whole Baltic Sea (31 thousand tonnes of phosphorus/year and 826 thousand tonnes of nitrogen/year) is from Helcom's PLC-6 (2018)² and the source distribution of the external nutrient load from Arheimer, et al. (2012)¹. The internal phosphorus load is estimated by Savchuk (2018)³ to 100–150 thousand tonnes of phosphorus/year. The internal nitrogen turnover in the Baltic Sea is complex and is not in the diagram of nitrogen sources.

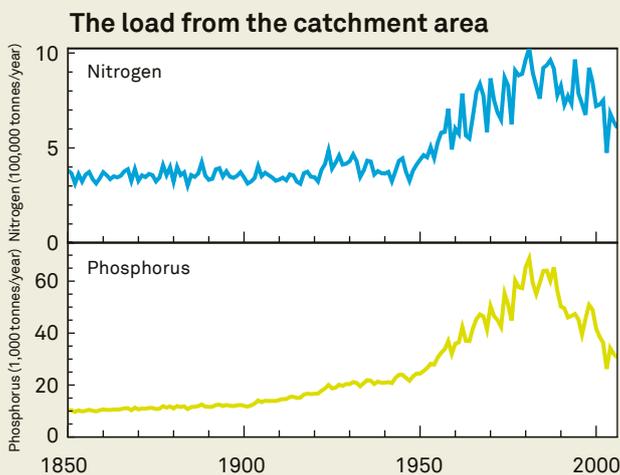


FIGURE 2. The load of nitrogen and phosphorus in the Baltic Sea from the catchment area increased significantly from the 1950 to 1980, and then decreased as a result of measures. Figure data from Gustafsson (2012)⁴.

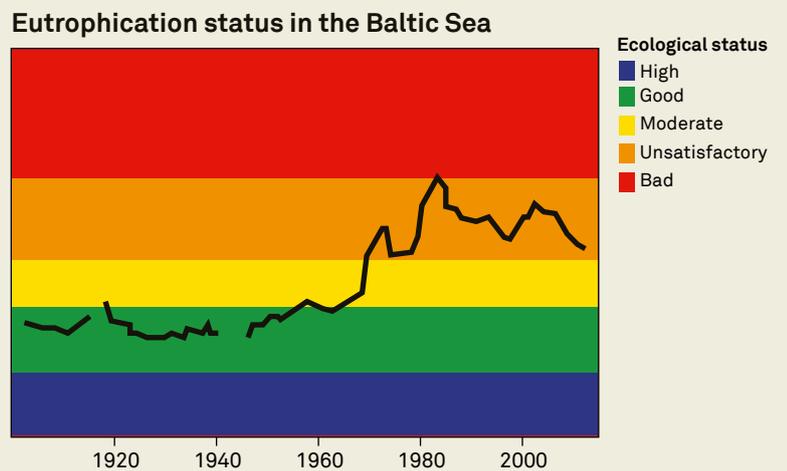


FIGURE 3. The aim of the Baltic Sea Action Plan is for the Baltic Sea to be unaffected by eutrophication. However, it takes time to achieve positive results and it was only in recent years that the ecological status has improved. The figure is from Andersen et al. (2015)⁵ and the line represents a five-year average.

BALTIC SEA CONVENTION AND BALTIC SEA ACTION PLAN

The Baltic Sea Convention (Helcom) was established in 1974 to protect and improve the Baltic Sea environment. Helcom decided on an action plan, the Baltic Sea Action Plan (BSAP), where the necessary measures were identified to restore the Baltic Sea to good ecological status by 2021. In order to reduce eutrophication, Helcom has estimated how much nitrogen and phosphorus emissions from each country in the Baltic Sea catchment area will need to be reduced annually. According to the latest agreement from 2013, Sweden needs to reduce its emissions by almost 10,000 tonnes of nitrogen and just over 500 tonnes of phosphorus per year. In Sweden, water authorities drew up 2015 ambitious action programmes for the EU Water Framework Directive, which would also meet the Swedish BSAP quota, but after a government decision in 2016⁶, the action programmes were strongly watered down. Although much has been done since 2013 and water quality is better in many places, much remediation work remains to be done, both for Sweden and other countries around the Baltic Sea.

The BSAP does not take into account the nutrients that have already reached the sea from land, the so-called internal nutrient load. The commitments in the BSAP are not legally binding, which can be a contributing factor to the slow pace of the remediation work.

EU WATER FRAMEWORK DIRECTIVE – an incentive for the Living Coast project

Under the EU Water Framework Directive (WFD), all surface waters must achieve good ecological status by 2027. An important component in order to do this is to reduce eutrophication. In the work on the WFD, environmental quality standards and action programmes are decided every six years. The first management cycle ended in 2009, the following 2015 and the next 2021. A work cycle begins with the mapping of the environmental status and assessment of the water status and impact. Based on this, action programmes, management plans and environmental quality standards are set. The action programmes are binding for authorities and municipalities, but not for individual users or landowners.

The water management work in Sweden is divided into five different water districts and is led by the water authorities in the respective districts under guidance from the Swedish Agency for Marine and Water Management (SWAM) and the Geological Survey of Sweden (SGU).

The Water Framework Directive applies to the Baltic Sea coastal waters and the Living Coast project hopes to contribute knowledge and experience gained during the work of restoring Björnöfjärden to the water management efforts.

The background of the slide is a photograph of a serene water body, likely a bay or fjord, under a clear blue sky. The sun is positioned in the upper right corner, creating a bright lens flare. The water is calm and reflects the sky and the surrounding greenery. In the foreground, there are tall, thin reeds or grasses on the left side. The far shore is lined with a dense forest of trees. The overall atmosphere is peaceful and natural.

Living Coast – a full-scale remediation project

Seven years ago, Björnöfjärden at Ingarö in Värmdö Municipality was one of the most eutrophic bays in the Stockholm archipelago. Oxygen-free “dead zones” were widespread and nutrients were leaking from a number of different sources. Now Björnöfjärden is healthy and has clear water, with a rich plant and animal life. The bay is also on the way to having a natural fish community and oxygenated bottoms with bottom-dwelling animals.

Successful results after action against eutrophication

The project's systematic remediation efforts have reduced the supply of phosphorus to Björnöfjärden's waters by around 70 per cent. Eutrophication was caused by nutrients leaching from poor sewage systems, agricultural activities, horse keeping and from earlier discharges stored in the sediment of the bay. This phosphorus is released when the sediment becomes oxygen-free. Björnöfjärden's environment also improved due the fact that the water exchange with the nutrient-rich bay outside is limited. If the water exchange were greater, the water quality in the bay outside would control the water quality that can be achieved in Björnöfjärden.

Where do the nutrients come from?

In the area around Björnöfjärden, there are almost 1,000 homes, a farm, some horse farms and a conference centre with a cider press, brewery and distillery operations. The nutrients (phosphorus and nitrogen) that reach the bay from the catchment area come partly naturally from forests and open land, but mainly from human activities in the form of leakage from agriculture and horse keeping, as well as emissions from homes with poor treatment of toilet waste (Figure 4). The nutrient supply was reduced by various measures described on pages 17–40.

Before the project started, the largest phosphorus source to the bay's waters was from the phosphorus emissions of earlier years stored in Björnöfjärden's bottom sediment (Figure 4). The accumulated phosphorus leaked back to the water to a much larger extent when the sediment became anoxic. This is because iron, which usually binds phosphorus in sediment, loses its ability to bind phosphorus in anoxic conditions.

The natural annual phosphorus load was estimated at 58 kg phosphorus, assuming relatively low losses from forests (1075 hectares, 0.04 kg phosphorus/hectare, 43 kg phosphorus/year) and open land/pasture (243 hectares, 0.06 kg phosphorus/hectare, 15 kg phosphorus/year).



▲ Nutrients from the catchment area reach Björnöfjärden mainly via ditches. The supply varies widely over the year. Most will come during the spring when the snowmelt brings nitrogen and phosphorus with it in both dissolved form and bound in

Phosphorus supply to Björnöfjärden

Before action: approx. 840 kg/year

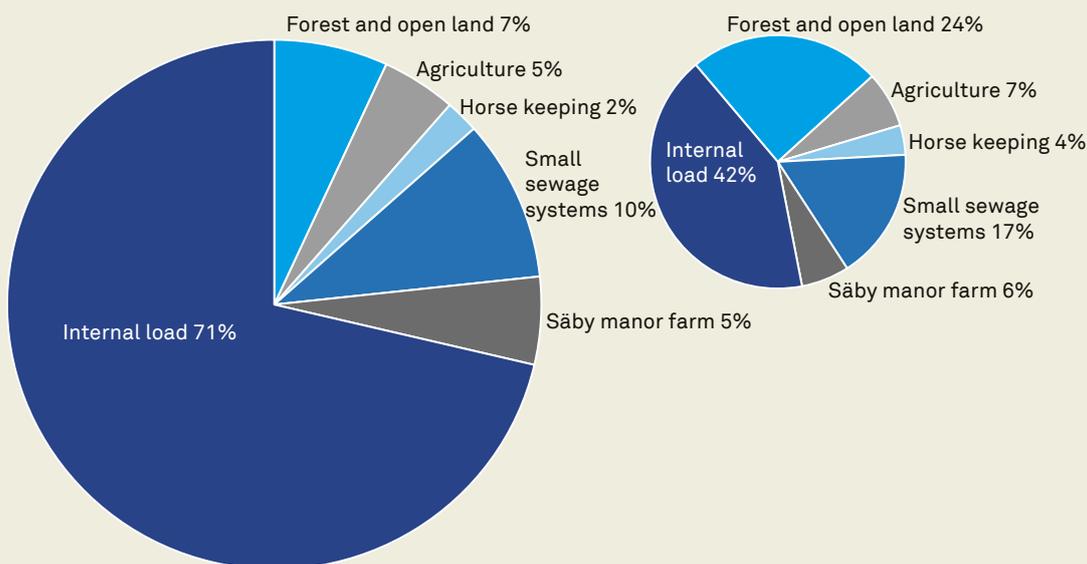
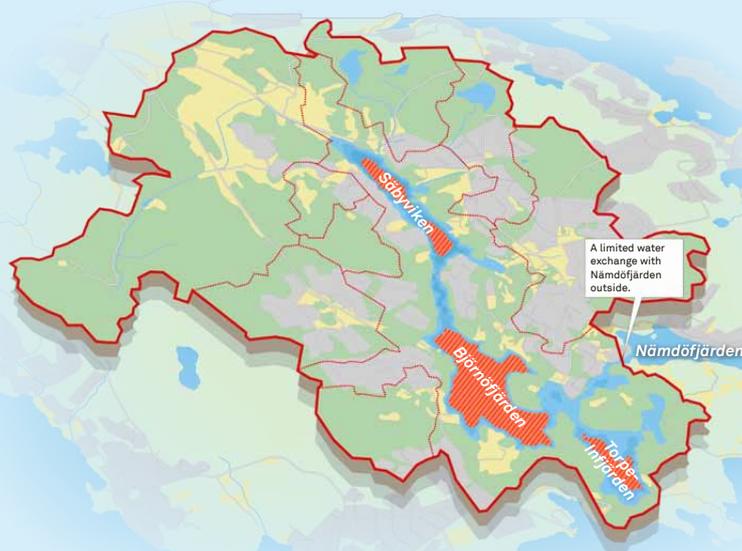


FIGURE 4. These figures show where the phosphorus that reached Björnöfjärden's water came from at the start of the project 2011 and when the measures implemented have reached full effect (% per year from the respective nutrient source).

BJÖRNÖFJÄRDEN

Björnöfjärden's surface area is 1.5 km² and the catchment area (the land area that supplies the bay with water from, for example, precipitation) is 15 km². The maximum depth of the bay is 25 metres. At a depth of about six metres, there is a strong stratification, a thermocline, between two water masses. Under the thermocline, it is oxygen-free (highlighted) for most of the year, and the area of the anoxic bottom area corresponds to about half the bay's area. The bay's water is brackish, with a salinity that varies between approximately 4.0 and 5.5 per mille. The water exchange with Nämndöfjärden outside is through a narrow shallow strait, and the average water exchange period is about three months. This is a long enough holding time for local action to provide a measurable local effect.

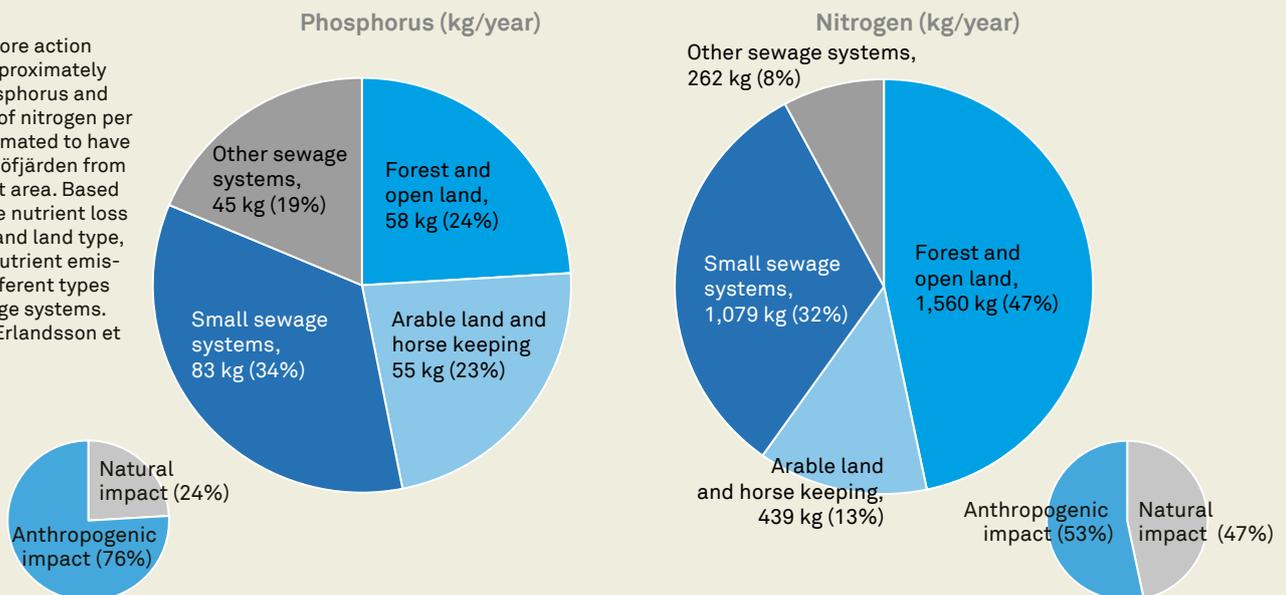


The corresponding nitrogen contribution was 1,560 kg of nitrogen/year (forests: 1,074 kg nitrogen/year, open land/pasture: 486 kg nitrogen/year)⁷. In the calculations, it is assumed that the land in the catchment area without modern human influence would consist of woodland and extensive pasture and would have no point sources.

The human phosphorus load (180 kg/year) consists mainly of sewage emissions and agricultural leakage. There are just over 850 residential buildings without municipal sewage connections, located both on moraine and on clay soil⁷. About 200 properties had illegal or defective sewage solutions at the start of the project⁹. Originally, development consisted mainly of summer cottages with small plots, but recently, more and more properties have been used for accommodation year-round¹⁰.

Source distribution of nutrients from Björnöfjärden's catchment area

FIGURE 5. Before action was taken, approximately 240 kg of phosphorus and over 3,000 kg of nitrogen per year were estimated to have reached Björnöfjärden from the catchment area. Based on the average nutrient loss per unit area and land type, and average nutrient emissions from different types of small sewage systems. Figures from Erlandsson et al. (2013)⁷.



Intensive agriculture of approximately 45 hectares of the catchment area and about thirty horses kept in the area also contribute to Björnöfjärden's eutrophication. In addition to this is the nutrient load from Säby conference facility and Smakriket Säby with its cider press, brewery and distillery operations in the north of the bay. A few years into the project, when more information from the area became available, it was found that the sewage systems of Säby conference and Smakriket Säby worked significantly worse than first estimated¹⁰, which means that the annual load to the catchment area was about 20 per cent higher than first estimated.

The load estimates are based on the source distribution analysis of eight different sources aggregated into the four largest: forests, arable land, open land (incl. pasture and gardens) and small sewage systems (incl. community facilities) (Figure 5).

Internal load dominant

Although nutrient leaching from Björnöfjärden's catchment area is significant, the largest phosphorus supply to the water came from the bay's sediment (Figure 4), which also applies to nitrogen¹¹. This is because the load to the bay exceeded the sediment's ability to store phosphorus for many decades. Phosphorus released when, for example, algae is broken down, leaks back to the water instead of being bound in the sediment. The situation is exacerbated by the sediments having been anoxic for decades, which reduces the phosphorus-binding ability. The phosphorus inclined to leak, which is estimated to be unreleased to the water over time, consists in Björnöfjärden's sediments of organically bound phosphorus and amounts to 1.5 g phosphorus/m² (12).

Anoxic areas spread in the 20th century

Sediment cores examined to reconstruct the oxygen situation in the bay indicate that at Björnöfjärden's deepest point (25 m), oxygen deficiency has occurred for at least 200 years¹³. However, the large increase in the spread of anoxic bottom waters occurred during the 20th century, especially in the 1960s to 1970s (Figure 6). It was during this time that the nutrient load from the bay's catchment area by all indications accelerated, in pace with the expansion of summer accommodations around the bay. During that period, the nutrient levels were also very high in the entire Stockholm archipelago as a result of poor wastewater treatment¹⁴. Strong algal blooms in the archipelago were common, unlike today when the algae blooms often originate in the offshore areas, where the phosphorus that drives the blooms mainly is released from the deep bottoms of the offshore areas. Imports of algal blooms from Nämndöfjärden may have been a source of nutrients for Björnöfjärden, along with increased nutrient loads from the catchment area. The strait between Björnöfjärden and Nämndöfjärden was dredged in 1968, which probably increased the influx of heavier and saltier bottom waters. If the dredging led to a less frequent exchange of bottom water since then, meaning that the exchange of oxygenated bottom water decreased, it may also have contributed to the greater expansion of anoxic bottom areas¹⁵.

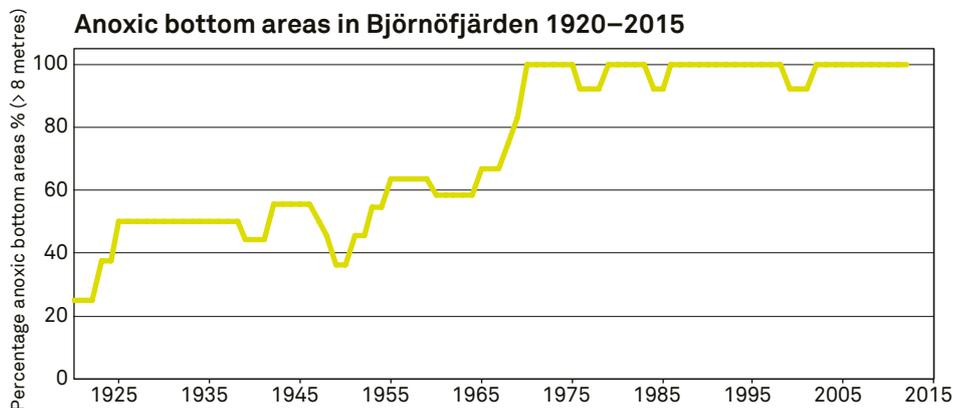


FIGURE 6. The percentage of bottom areas deeper than 8 metres in Björnöfjärden that has been anoxic at least during the summer in the past.

Preparation, evaluation and action

Before the remediation work started, the bay and the catchment area were examined for a year in order to obtain a clear picture of the baseline and thereby measure the effects of remediation. At the same time, a nearby bay, Fjällsviksviken, with similar eutrophication problems was examined but no action was taken. The use of a “comparison bay” made it possible to distinguish the effects of remediation from the results of variations in weather between different years. To reduce nutrient supply to the bay, remediation measures were implemented in the area around the bay and in the water. These measures led to a significant improvement in the environment in Björnöfjärden.

Monitoring of Björnöfjärden and Fjällsviksviken

A sampling programme in which water chemistry, plankton and sedimentation traps were studied on a continuous basis¹⁶ is supplemented once a year with studies of, for example, extension of anoxic bottoms¹⁷, fish stocks^{18,19}, benthic fauna²⁰ and underwater vegetation^{21, 22, 23}. In addition, the water level is continuously measured in the bays¹⁶, as well as the water exchange between Björnöfjärden and Nämndöfjärden outside. The sampling started in 2011 and is scheduled to last until 2022.

Water chemistry and plankton are measured between 15 and 20 times a year, both in Björnöfjärden's and Fjällsviksviken's various sub-basins and also just outside the respective bays. In order to detect the concentration differences between surface water in different parts of the bay at the time for sampling, a so-called volume-weighted and depth-integrated sampling procedure is used. Several surface water samples from the different parts of the bay are mixed together into a sample that is analysed and represents the entire surface water above the thermocline for the respective basin²⁴. In addition, at the deepest point in each sub-basin, three water samples are taken at specific depths, evenly distributed between the thermocline and the bottom, for the measurement of nutrients and hydrogen sulphide. At the deepest point of the bays, temperature, salinity and oxygen are measured at one-metre intervals from surface to bottom. Sedimentation of nutrients and materials in the bays is also measured in sedimentation traps placed above and below the thermocline.

The fish communities of the bays are monitored using multi-mesh gillnets¹⁸, trap nets and juvenile fish sampling using small underwater detonations¹⁹. The density and species composition of the benthic fauna are examined²⁰ and the composition and depth spread of the vegetation belt are inventoried in annual diving investigations^{21,22,23}. Concentrations of aluminium in bladderwrack, benthic fauna and perch are also measured annually to see if the aluminium treatment of the bottoms to stop the bay's internal load contributed to increased levels in plants and animals²⁵.

Both Björnöfjärden and Fjällsviksviken are also included in the Svealand Coastal Water Management Association (SKVVF) surveys, in which a large number of stations are studied, which form the basis for the status classification of Svealand's coastal waters according to the water management assessment program.

Björnöfjärden's contributing water courses

In order to identify nutrient sources and appropriate measures in the catchment area and to evaluate the effects of action, water samples are also taken in all major waterways²⁶. In some waterways, samples are taken only in the outlet, in others samples are taken at several points to be able to distinguish the effects from different sub-areas or activities (Figure 7). New sampling points were added when new sources were discovered or when measures were implemented. Sampling is usually done once a month, but more often during high water flows during spring and autumn. In order to calculate the transport of nutrients from different sub-catchment areas, water flow calculations from SMHI are used. This type of study is the basis for assessing the nutrient contributions of different sources and the effects of remediation measures. It often needs to run for several years as differences in precipitation between years affect when the nutrient transport takes place.

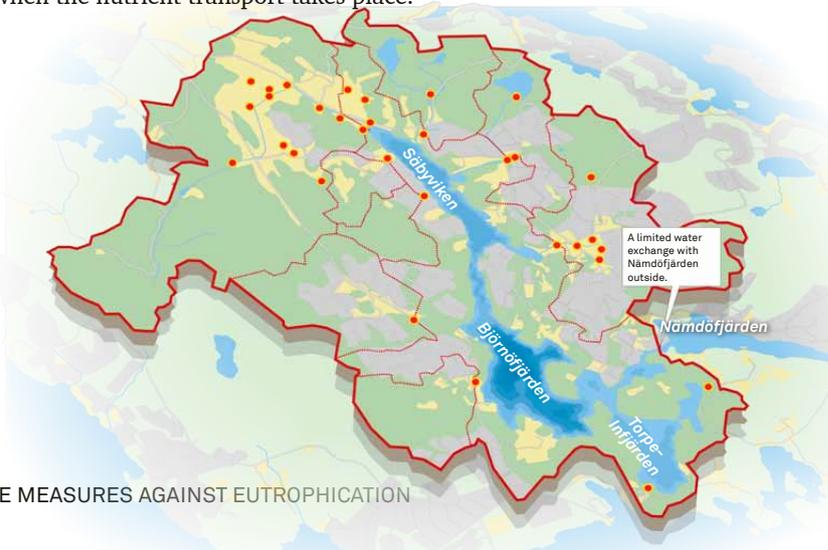


PHOTO: FREDRIK SEDERHOLM

▲ Water quality in Björnöfjärden (above) and in the catchment area (below) is examined more than 15 times a year in order to be able to monitor how the environment changes as a result of reduced nutrient supply due to remediation measures.

FIGURE 7. The Björnöfjärden catchment area (thicker red line) has been divided into ten smaller sub-catchment areas (dashed red lines). The levels of nitrogen and phosphorus in the contributing waterways of these areas are studied around 20 times a year (sampling points marked in red).



▲ The ecosystem is studied each year in both Björnöfjärden and in the comparison bay Fjällsviksviken. To be able to identify changes, it is important to both be able to compare with what it looked like before the measures started and what changes occur naturally, for example due to variations in temperature and precipitation.

READ MORE ABOUT...

the project's investigations and analyses in the Living Coast projects complete White Paper.

Measures to reduce eutrophication

In order to reduce the nutrient supply to the water and to counteract the effects of eutrophication, a number of measures were implemented, both in the Björnöfjärden catchment area and in the bay itself (Figure 8, page 16). The total supply of phosphorus from the various sources, external and internal, ranges from approximately 3 kg to 600 kg per year. All measures are important, but the greatest effect on the total phosphorus reduction was from the aluminium treatment of sediment, followed by improved private sewage systems.

The next page summarises the measures implemented in and around Björnöfjärden. More information on the prerequisites and implementation of the respective measures can be found on pages 17–40.

All measures are important

Immediately after the aluminium treatment, phosphorus levels in the bay's water decreased and after just a few months the levels were cut in half. It has positively affected the underwater environment in many ways, as described on pages 47–52.

Land measures are estimated to cut in half the nutrient transport from land to the bay in the long run. It will take a few years before the measures have been fully effective, because a large amount of nutrients are stored in the soil and ditches for a long time.

Although the aluminium treatment binds the most phosphorus and provides a rapid effect, it is very important to also minimise the nutrient supply from land; otherwise new nutrient stores are built up in the sediment that begins to leak to the water again.

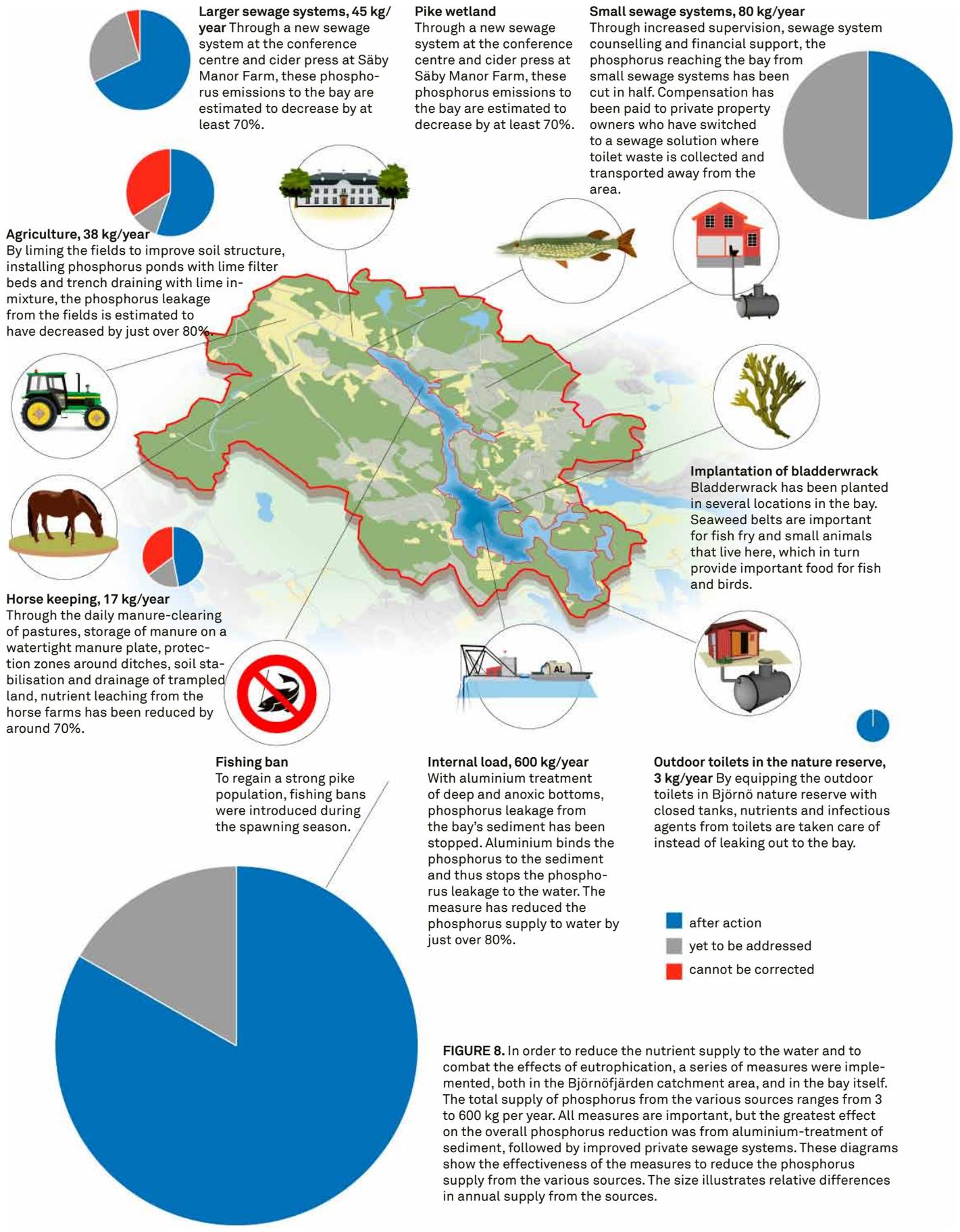


FIGURE 8. In order to reduce the nutrient supply to the water and to combat the effects of eutrophication, a series of measures were implemented, both in the Björnöfjärden catchment area, and in the bay itself. The total supply of phosphorus from the various sources ranges from 3 to 600 kg per year. All measures are important, but the greatest effect on the overall phosphorus reduction was from aluminium-treatment of sediment, followed by improved private sewage systems. These diagrams show the effectiveness of the measures to reduce the phosphorus supply from the various sources. The size illustrates relative differences in annual supply from the sources.

Measures to reduce nutrient losses from agriculture

Agriculture is today the single largest source of nutrients from land to the Baltic Sea and accounts for about half of the total nutrient supply². Since the 1950s, the agriculture in Sweden has undergone rapid development to intensify the production on ever larger farms, which are often specialised in plant or animal production^{27, 28}. This development, combined with extensive treading, has contributed to nutrient losses from operations that reach the Baltic Sea to varying degrees, where sensitive environments become eutrophic and are damaged²⁸.

Measures have reduced the supply – but more needs to be done

Measures in areas such as wastewater treatment, industry, forestry and agriculture have reduced the nutrient supply to the Baltic Sea, which today is judged to have returned to the levels of the 1960s (for phosphorus)⁴. In agriculture, the measures have, for example, resulted in improved manure handling, fertilisation restrictions and counselling to farmers, as well as opportunities for financial support for certain environmental protection measures. Nevertheless, more efforts are needed, at the same time that a resource-efficient food production is maintained.

Today, large quantities of nutrients are imported into the Baltic region in the form of commercial fertilisers for plant production and feed for livestock³⁰. The manure produced in the region is poorly used; only half of the nutrients in the manure is converted to harvested crops³¹. The rest remains in the ground or is lost to air or water, and contributes to eutrophication. The nutrient flow is largely one-way. For efficient nutrient utilisation without nutrient leaching to the environment, the cycle of nutrients needs to be closed. It is also important to take good care of the fields through careful crop selection, cultivation techniques, working of the soil and manure yields, as well as to ensure that the soil has a good structure and good drainage conditions so that crops can use the nutrients in the soil effectively.

Choice of measures

In order to increase nutrient utilisation and minimise the impact of agriculture on the Baltic Sea, both short- and long-term measures are needed, both at the farm level and at the Baltic Sea catchment level.

- Examples of large-scale/structural measures are to introduce economic incentives to reduce imports of commercial fertiliser and animal feed and thereby stimulate increased recycling of livestock manure to plant production in order to close the nutrient cycle to a greater extent.
- Examples of measures at the farm level are having safe manure handling, avoiding overdosing with fertilizer, using stored phosphorus in the soil, keeping the soil overgrown during the autumn, liming the fields to improve soil structure, installing lime filter ditches, protection zones along waterways, phosphorus ponds and lime filter beds.

It is crucial for a high action effect that the right measures are implemented in the right order, at the right place and at the right time³². Often 90 per cent of the nutrient losses in a catchment area are from 10 per cent of the area, during 1 per cent of the time. Consequently, site-specific knowledge is important.

There are a number of different measures that can be implemented to minimise nutrient leaching from agricultural activities. Within the Living Coast project, several different agricultural measures were implemented: structure liming, phosphorus ponds with lime filter beds, two-step ditches and lime-filter ditches, see pages 20–22.

READ MORE ABOUT...

How to reduce nutrient load in the Baltic Sea in the complete Living Coast White Paper and in reports from SLU^{33,34} and the Swedish Board of Agriculture³². An action catalogue is available in the water authorities' Water Information System of Sweden (www.viss.lansstyrelsen.se). The Goodla project has gathered readily accessible knowledge about environmental measures in agriculture on film. The project is run by SLU and LRF and is financed by Formas (<https://www.slu.se/institutioner/mark-miljo/samverkan/goodla/>).



▲ For farm-level actions to be successful, local involvement and good knowledge of the site are required. The agricultural measures at Björnöfjärden were implemented in cooperation with the farmer of Säby Farm.



▲ To obtain high efficiency of actions, it is crucial that the right measures are implemented in the right order, at the right place and at the right time.

Prerequisites for agricultural measures

Responsibility

It is the farmers' responsibility to ensure that the necessary environmental measures are implemented. The county administrative board has responsibility for the activities for which a permit is required, but the supervision is often delegated to the municipalities. The requirement for agricultural companies to reduce nutrient leaching to bodies of water that do not achieve good ecological status is possible regardless of whether environmental aid from, for example, the Rural Development Programme is obtained or not. However, such call for action have not yet been made in Sweden.

For agricultural companies with activities subject to permits (with animal husbandry), environmental improvement measures in accordance with the Environmental Code can be binding for individual farmers. The instruments available for this are supervision and self-inspection. For other agricultural companies (and horse keeping), the action potential is in cooperation, consultations, recommendations, agreements and compensation, where opportunities for environmental aid and compensation in the rural development programme or other funding have a crucial role in actions taking place.

Financing

Support for the financing of agricultural and horse keeping activities is mainly carried out through the Rural Development Programme (administered by the Swedish Board of Agriculture) and LOVA grants (local water management projects administered by the county administrative board). Both require co-financing.

Counselling

Counselling plays a key role in the remediation work in agriculture. The counselling project Greppa Näringen [Getting hold of nutrients], which is a collaboration between the Board of Agriculture, the Federation of Swedish Farmers (LRF) and the county administrative boards (2001-2020), has led to an annual reduction in nutrient leaching by 790 tonnes of nitrogen and 15-30 tonnes phosphorus, while at the same time helping to make every single farm more resource-efficient, according to the project itself.

LIVING COAST on measures in the agricultural landscape

The pace of action in agriculture is too low to achieve the objectives of, for example, the Water Framework Directive, Sweden's national environmental targets or the Baltic Sea action Plan (BSAP).

The municipal supervision of agricultural activity is inadequate. The fact that action is not being required to a greater extent may be due to there not being enough overview and knowledge to identify the main nutrients sources.

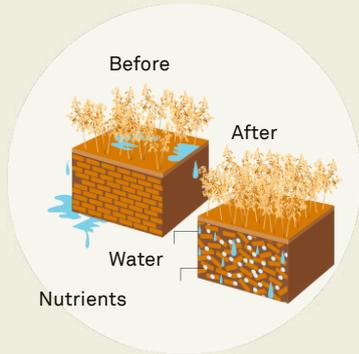
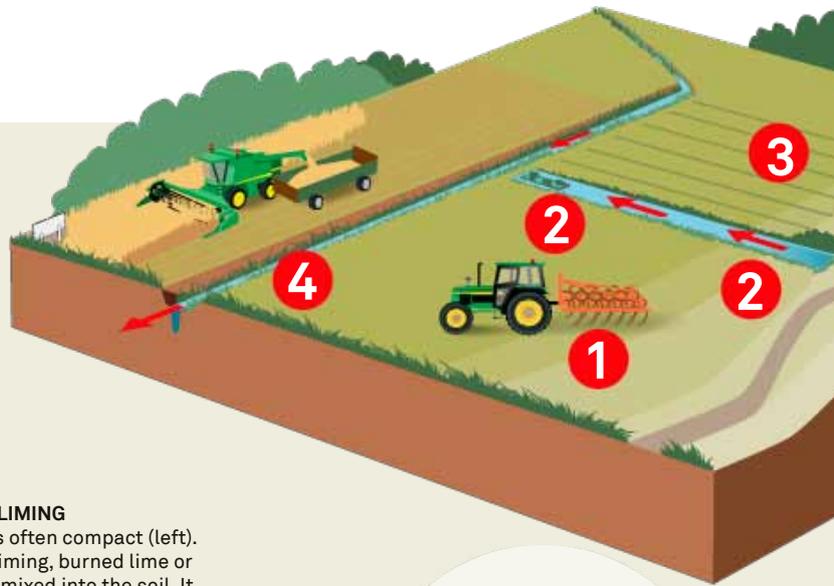
The individual farmer, with unique knowledge of his or her land, can often by small means reduce nutrient losses to waterways. Clear incentives are needed **that reward farmers who minimise the nutrient loss** from their activities.

Agricultural measures (and other measures) need to be **carried out on the basis of a catchment area perspective.** The county administrative boards have an important role as initiators, coordinators, catalysts and driving forces, and the work should be coordinated by a catchment officer or action coordinator.

The costs for a necessary pace of action need to be identified and distributed between agricultural companies and the public sector, and a long-term plan for investment needs to be developed. Short-term, unpredictable investments are at risk of being ineffective, which is why better evaluation of action effects is necessary.

There is room to reduce the impact of agriculture on the Baltic Sea without the need to reduce production. Structure liming can even increase crop yield.

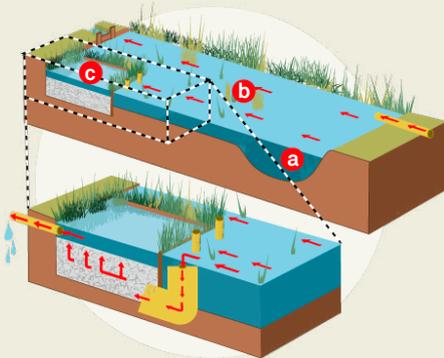
Agricultural measures within Living Coast



1 STRUCTURE LIMING
Clayish soil is often compact (left). In structure liming, burned lime or quenched lime is mixed into the soil. It makes the soil more porous (right), so that the crop's roots more easily access water and nutrients. The crops grow better and phosphorus leaching can be reduced by up to 50 per cent.



3 LIME FILTER DITCH
In trench draining, excess water is diverted from the field into buried pipes. When the pipes are dug down, lime is mixed into the soil. The lime is active for about 30 years and binds the phosphorus that is dissolved in the water into the soil around the pipes. Trench draining is necessary for the crop to grow well. If it grows poorly, nutrients leach out of the field instead of being taken up in the crops.



2 PHOSPHORUS POND WITH LIME FILTER BED
A phosphorus pond with lime filter beds can reduce nutrient transport by up to 60 per cent for phosphorus and 25 per cent for nitrogen. Water from the fields' drainage system is collected in the deep part of the pond (a) where large phosphorus-rich particles sink to the bottom. Smaller particles are trapped among aquatic plants in the shallow part (b). Phosphorus in dissolved form is trapped in the lime filter beds (c). Phosphorus that is trapped in the pond can be dug up and re-used on the field.

1. STRUCTURE LIMING

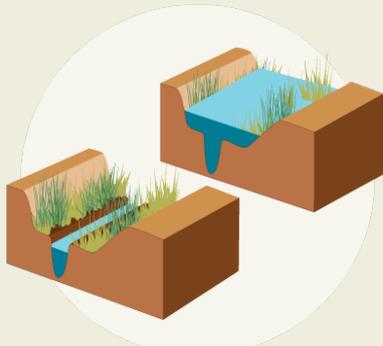
Structure liming is a well-known agricultural measure that makes the soil structure of clay soil more fine-grained and porous, so that water and nutrients are kept in the soil and the roots can grow deeper. The measure contributes both to a reduction in nutrient transport and to a better growth of the crop, and does not require specific maintenance.

Structure liming is suitable in well-drained fields in the southern and central part of Sweden where soils with a high clay content are common³⁵.

Structure liming in figures

- Structure liming can cut in half phosphorus losses from arable land that has a clay content over 20 to 30 per cent^{36,37}.
- In Sweden, the action potential is the largest in Östergötland, Uppsala, Västmanland and Södermanland counties. So far, only just over 4 per cent of the country's suitable arable land has been structure limed³⁸.
- Today, there is uncertainty about the long-term effect of structure liming. The duration affects the treatment cost which varies between SEK 900 and 2,700 per kilogram of phosphorus, depending on whether the effect lasts for 30 or 10 years, respectively. It is uncertain why the effect of the structure liming of some clay soils appears to fade within a decade, as seen in the structure liming at Bornsjön.

FIGURE 9. If the proper agricultural methods are used, the harvest will be good, while leaching of nutrients and organic material is minimised. In cooperation with Säby Farm, located at Björnöfjärden, four agricultural measures were implemented to reduce the impact of the farm: structure liming, phosphorus ponds with lime filter beds, lime filter ditches and two-stage ditches.



4 TWO-STAGE DITCHES
Two-stage ditches can reduce nutrient transport and promote biodiversity. At high water levels, water spreads out on grass plateaus where nutrients are absorbed and particles are trapped. The risk for erosion decreases and aquatic animals thrive in the middle trench.

READ MORE ABOUT...

Structure liming in "Soil-structure improvement measures – Structure liming of clay soil" (SLU), at Goodla (SLU/LRF) and the websites of the Greppa Näringen project and Project Born.

There is also more information in the full Living Coast White Paper and the report "Structure liming on a large scale – what is required and what does it cost"³⁸.



▲ At Säby Farm at Björnöfjärden, structure liming and phosphorus ponds with lime-filter beds, among other measures, have reduced the nutrient load from agriculture to the bay by just over 80 per cent. In the middle of the picture, the narrow phosphorus pond is visible with the lime filter bed on the right. To the left of the pond is a pile of structure lime to be incorporated into the clay field.

Conditions for structure liming

There are recommendations from, among others, the Board of Agriculture and the Greppa Näringen project on where and how to implement the structure liming. But it is up to the individual farmer to take the initiative and implement the measure. Funding support can be sought primarily from the county administrative boards' LOVA grants, but also from the Board of Agriculture's Rural Development Programme.

The structure liming in Sweden has mainly been carried out in the scope of major remediation projects. In order to increase the pace of action and to improve the structure liming of individual farmers, the following are needed:

- More targeted financing support for structure liming. The measure is often too expensive without support financing.
- Driving forces that coordinate and administer the measure for larger areas, as farmers find it difficult and financing support is sometimes uncertain.
- A quicker response to decisions on financing support so that the applicant can have time for the structure liming during the short period of the year in which circumstances are suitable.

2. PHOSPHORUS POND WITH LIME FILTER BED

Nutrient transports from arable land and land around livestock farms may be reduced if run-off water is led through a phosphorus pond with lime filter beds. The installations should be located close to the source of the pollutant, preferably high up in the catchment area next to agricultural land with high phosphorus losses. For the phosphorus pond to be effective, it must be large enough to even out the flow so that most of the water flow is led through the lime filter. At optimal placement, the installations are cost-effective measures, but they require relatively extensive supervision and maintenance to maintain good functioning.

Phosphorus ponds with lime filter beds in figures

- For the most arable land inclined to leaching in the Baltic Sea coastal areas, phosphorus ponds with lime filter beds are estimated to be a suitable measure for about 15 per cent of the area, and lime filter beds alone are suitable for another 55 per cent³⁹.
- The average treatment effectiveness seen over 20 years for the installations is up to 60 per cent for phosphorus and 25 per cent for nitrogen³⁹.
- Optimally placed installations can be cost effective, SEK 500-1,300/kg phosphorus assuming a life span of 20 years³⁹.

Conditions for phosphorus ponds and lime filter beds

It is up to individual farmers to establish phosphorus ponds and lime filter beds. Financing support can be applied for from the Rural Development Programme through the Swedish Board of Agriculture. To increase the rate of action so that more phosphorus ponds with lime filter beds are built, environmental aid compensation needs to be increased by around 20 per cent. This is to cover the loss of income for arable land that is decommissioned and the cost of establishment which is often higher than what the level of aid is calculated for. The payment procedures for environmental aid also need to be streamlined and simplified³⁹.

It is difficult to get an installation with optimal function, in part because the function is affected by many factors:

- **Water flow:** Nutrient retention is only effective at low water flow rates.
- **Size:** The larger the pond, the lower the water flow and the greater capture of nutrients.
- **Age:** when vegetation in the shallow part of the pond is established, the purification efficiency increases.
- **Extreme events:** Downpours, pond embankment collapses, faeces from flocks of birds and more, can significantly impair the pond's function.
- **Establishment/adjustment:** during excavation, surfaces are exposed to erosion, which for a period increases turbidity and export of nutrients to waterways.

3. LIME FILTER DITCHES

Good drainage of fields is necessary both for the crop to grow well, and for minimising fertilizer leaching from the field. If the crop grows badly, nutrients leach out of the field instead of being taken up by the crop. In trench draining, excess water is diverted from the field into buried pipes that flow into ditches surrounding the fields. With lime filter ditching, lime is mixed into the soil that surrounds the trench drainage pipes. The lime effectively binds phosphorus that is dissolved in the water, and the measure is assumed to work for about 30 years. Within the Living Coast project, lime filter ditches were built, but are not yet evaluated, as there is not yet enough data.

4. TWO-STAGE DITCHES

Fields are dependent on ditches for good drainage, but ditches speed up the transport of nutrients from the fields to the sea. Two-stage ditches can be built to reduce nutrient transport while increasing the biodiversity of the agricultural landscape. The two-stage ditches have a middle trench, which is surrounded by higher, plant-covered terraces. In normal flows, the water goes into the middle trench and at higher flows, the water rises onto the terrace where nutrients are absorbed, nitrogen escapes to the air and nutrient-rich soil particles are trapped among the vegetation. The risk of erosion from the edges of the ditch is small. Both the middle trench and the terrace are good environments for plants and hiding places and feeding areas for animals. Within the Living Coast project, two-stage ditches were built, but will not be evaluated. This is because the two-stage ditch was built relatively late in the project and it takes a few years before the ditch acquires the intended function.

READ MORE ABOUT...

Phosphorus ponds with lime filter beds in the complete Living Coast White Paper and the report "Action potential in agriculture and the possibility of reduction with lime filter beds and phosphorus ponds"³⁹.



▲ A phosphorus pond will not be effective at purifying the water until after a few years when vegetation that prevents erosion from the pond itself has established.



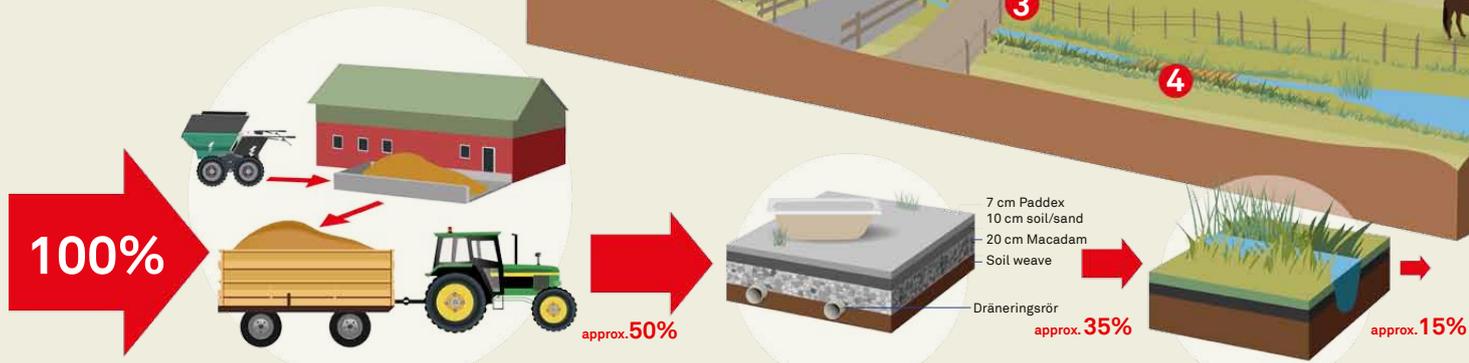
▲ When a lime filter ditch is installed, the lime is mixed into the backfilled soil. The lime binds phosphorus that is dissolved in the water.

Horse keeping also contributes to eutrophication

In Sweden, horse keeping is an extensive small-scale business often conducted by private individuals as a leisure pastime⁴⁰. It is common for horse manure to be handled carelessly and that pastures are used so intensively that the vegetation cover is worn down, which leads to nutrient leaching and eutrophication.



Living Coast's measures at horse farms



100%

Nutrient loss from a horse farm can be reduced by about 90 per cent through four measures:

1 DAILY MANURE CLEARING
The phosphorus loss from a horse farm can be cut in half if the pastures are cleared from manure daily, the manure is stored on a watertight manure plate and returned to arable land where the nutrients are recirculated.

approx. 50%

2 PROTECTING THE SOIL
Avoid having more than two horses per hectare of pasture in order not to wear down the vegetation cover. With fewer horses in the pasture, stabilization and good drainage where the ground is easily trampled, for example at gates and feeding locations, nutrient losses are further reduced.



approx. 35%

3 PROTECTION ZONES
About half of the remaining phosphorus can be bound by plants in protection zones along ditches and waterways. The horses should be kept away from ditches with the help of fencing.

approx. 15%

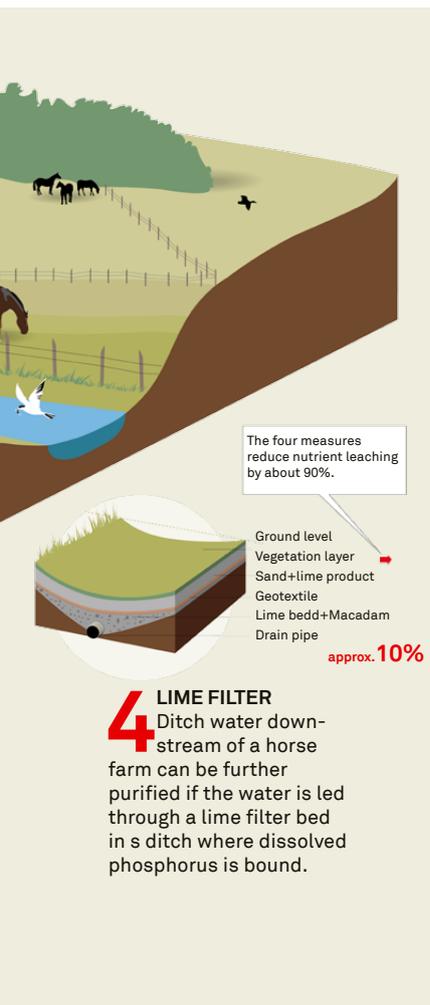
Daily manure clearing and avoiding a bare soil-surface most important

An adult horse excretes as much nutrients as it receives through its feed⁴¹. The phosphorus leaves the horse mainly via its faeces, if it is not over-fed, then some also ends up in the urine⁴². This often leads to high nutrient levels in soil where horses are kept^{43, 44, 45, 46}. Some of the manure that is not removed from pastures is tied up in the soil, but the soil's vegetation cover needs to be complete in order to hold the nutrients from the horses. If the soil is saturated with nutrients or the vegetation cover is worn down, the risk is very high for nutrient losses to waterways, lakes and the Baltic Sea. Measures are therefore most important where many horses are kept on a small area, especially if the horses are kept close to ditches and waterways.

Horse keeping in figures

- In Sweden, there are just over 100,000 properties where horses are kept⁴⁷, most of which (75 per cent) only have one to five horses⁴⁸. About 75 per cent of the horses are in or near larger towns⁴⁹.
- The most horses are in Skåne, Västra Götaland and Stockholm counties⁴⁷.
- At more than 2-3 horses per hectare, the soil is worn down and leaks nutrients⁵⁰.
- Nutrient loss would decrease 20-30 per cent if the compound feed was excluded for recreational horses⁵¹.

FIGURE 10. There are many measures that can be done on horse farms to reduce nutrient losses. Horse breeders can do several themselves through changed routines and small efforts on the farm, while other measures require work by contractors for various types of installation work and construction.



▲ If more than two to three horses are kept per hectare of pasture, the soil is at risk of being worn so hard that the vegetation cover breaks down and the soil's ability to bind nutrients deteriorates significantly.

Conditions for measures on horse farms

Responsibility

Horse keepers are responsible for ensuring their activities do not damage the environment or interfere with the surroundings. Small-scale horse activities are not covered by the Board of Agriculture's rules on animal husbandry in agriculture, but are by general rules of consideration in the Swedish Environmental Code⁵². In addition, there are regulations and general guidelines issued by the Swedish Board of Agriculture and the Swedish Environmental Protection Agency to be followed. The municipality may also decide on local regulations for manure handling⁵³. In practice, the regulation of the small-scale horse farm is unspecific and the supervision of the horse farms is sparse or non-existent. This contributes to that the pace of action is low.

Financing

So far, there has been no special support financing earmarked for measures that reduce nutrient losses from horse keeping. Within the new LOVA ordinance (Swedish Ordinance on local water management projects)⁵⁴, the possibility of support financing for measures on horse farms should be considered.

Supervision & Counselling

It is the municipalities that are responsible for supervising to ensure that horse keeping is carried out in accordance with the Environmental Code, regulations and general guidelines. There is no advisory programme like "Greppa Näringen" aimed at horse breeders. It would be desirable to have an initiative from equestrian organisations.





Horses in summer grazing contribute very little, if at all, to the nutrient load on the surrounding waters. They also help keep the landscape open. If the horses also are fed concentrates, however, it entails a net supply of nutrients that risk contributing to eutrophication, especially if the horses are kept close together and the ground is worn too hard.

LIVING COAST on measures at horse farms

The environmental impact of horse keeping is underestimated, the municipal supervision is deficient and the rate of action is too low. The number of horses in Sweden is growing and it has become obvious that horse activities contribute to eutrophication. The problem is extensive, and what is crucial to the environmental impact of horse keeping is the number of horses in relation to the area they are kept on. Most important is to collect and manage manure right and to ensure that the ground is not worn too hard. Nutrient losses from horse keeping can be fixed relatively easily, but small-scale horse farms fall between the cracks, both in terms of regulation and supervision, which is why the pace of action is behind. In addition, horses are often kept by private individuals or associations with limited finances and environmental knowledge. They often lease stables, which further complicates the implementation of measures.

TO REDUCE THE ENVIRONMENTAL IMPACT OF HORSE KEEPING, THE FOLLOWING IS NEEDED:

- *Information to horse owners:* Horse breeders often do not know that horses contribute to eutrophication. Horse owners are a large and diverse target group, which can be difficult to reach. Readily available information and concrete advice on measures are needed, preferably within the framework of an advisory programme.
- *Adapting legislation to small-scale horse keeping:* Existing regulations are not adapted to the prevailing reality, where many operators have a few horses, often on a small area. In the Environmental Code, there is support for requiring action, but this rarely happens. New regulations are needed, which clarifies that:
 - 1) It is important to collect and manage manure in a safe way
 - 2) The environment is damaged when many horses are kept on a small area
 - 3) Horses should not be kept next to ditches and waterways.
- *Supervision of horse farms:* Municipalities need to exercise supervision in areas with horse farms to ensure that the environment is not harmed, and to inform about measures required to reduce the impact.
- *Increased support financing:* It can be costly for an individual horse owner with a few horses to implement measures. In order to quickly improve the situation, it may be cost-effective to investigate opportunities for grants for demolition and remediation of old manure storage areas and construction of new watertight manure slabs. These are the most expensive, but at the same time the most important measures.

READ MORE ABOUT...

measures at horse farms in the complete Living Coast White Paper and in the report "Nutrient leaching from horse keeping in Sweden – National overview and proposed measures"⁵¹.

A scenic view of a Swedish coastal town. In the foreground, a yellow house with a red roof sits on a rocky shore next to a wooden dock. The background features a dense forest of green trees covering a hillside, with several other houses visible. A large blue lake or sea is on the right side of the image. The sky is clear and blue.

Toilet waste must be removed from the coast

In Sweden, more than one million people live in properties that are not connected to a municipal wastewater treatment plant⁵⁵, and many summer cottages add to this. Instead of municipal sewage treatment, they have small private sewage systems or dry toilets. The small sewage systems are estimated to account for roughly the same amount of emissions to lakes and the sea as the municipal wastewater treatment plants^{55,56}.

Land-based treatment is not enough on the coast

Common technical solutions for the treatment of toilet waste in small sewage systems are septic tanks and infiltration bed, phosphorus trap with an infiltration bed, mini-treatment plants or closed tanks. Dry toilets with private handling of toilet waste on the plot is also common, but are rarely included in compilations⁵⁷. A report from 2017 shows that more than 80 per cent of Sweden's small sewage systems have septic tanks, infiltration plants or filtration beds, or unknown technical solutions⁵⁵. In other words, most have a treatment technology that relies on soil purification.

What technical solution a sewage system has and how the sewage is managed affects emissions⁵⁸. In coastal and archipelago areas, where the layers of soil are thin, the possibility of soils to bind phosphorus is limited. It is uncertain how well the binding works over time, and several studies indicate that the binding is less than previously assumed^{59,60,61}. With these technical treatment solutions the nutrients accumulate locally, with a high risk of nutrient losses to the Baltic Sea, sooner or later (Figure 11). Therefore, in order to protect coastal waters and groundwater in areas where the ability of the soil to bind phosphorus (soil retention) is limited or unknown, sewage solutions where the toilet waste is collected and transported away for treatment in wastewater treatment plants are needed. Alternatively, sewage could be recycled in for example a hygienification plant (Figure 11).

Bathing, dishwashing and laundry water (grey water) no longer contributes to the eutrophication problems. Nowadays, phosphorus is forbidden in dishwashing and laundry detergents, so a very small percentage of the nutrients from a property are found in the grey water. Around 90 per cent of all nutrients leaving a household are in the household's toilet waste⁶².

Small sewage systems in figures

- More than 35 per cent of Sweden's small sewage systems have inadequate treatment, and about half of these are illegal⁶³.
- Small sewage systems make up 10 per cent of all domestic sewage systems, but are estimated to account for as much phosphorus emissions as the 90 per cent connected to municipal wastewater treatment plants⁶⁴.
- On average, only about 1-2 per cent of all small sewage systems are improved annually⁶³.
- About 80 per cent of the properties around Björnöfjärden that had poor treatment of their sewage and had inspections and demands set by the municipality implemented measures within one year⁹. Only 40 per cent, voluntarily implemented measures after information campaigns, sewage system counselling, administrative help and subsidies. The rate of "other" voluntary resolution in the municipality is 3-4 per cent per year.

Conditions for fixing defective small sewage systems

In accordance with the Swedish Environmental Code, small sewage systems are classified as an environmentally hazardous activity that is subject to permit or registration⁵³. Toilet waste handled in a WC becomes "water based" and is classified according to sewage legislation, while toilet waste collected in a dry toilet is classified as household waste. Although the origin is the same, it falls under different regulations, and is handled differently in supervision and permit assessments.

Responsibility

It is the property owner's responsibility to ensure that the sewage system meets the requirements of the Environmental Code. The property owner needs to know the system's capacity, technology and function, as well as the environment's conditions for receiving and purifying emissions. This is difficult and requires specialist knowledge. The responsibility of municipalities is to examine and grant permits, supervise and monitor and ensure that all small sewage systems have the necessary permits, and that the sewage systems work as they should⁶⁵. Municipalities often provide property owners with an exemption for private treatment of toilet waste from dry toilets on their own property (plot). The owner is responsible for ensuring that latrine composting is done correctly⁶⁶.

Living Coasts measures for small sewage systems

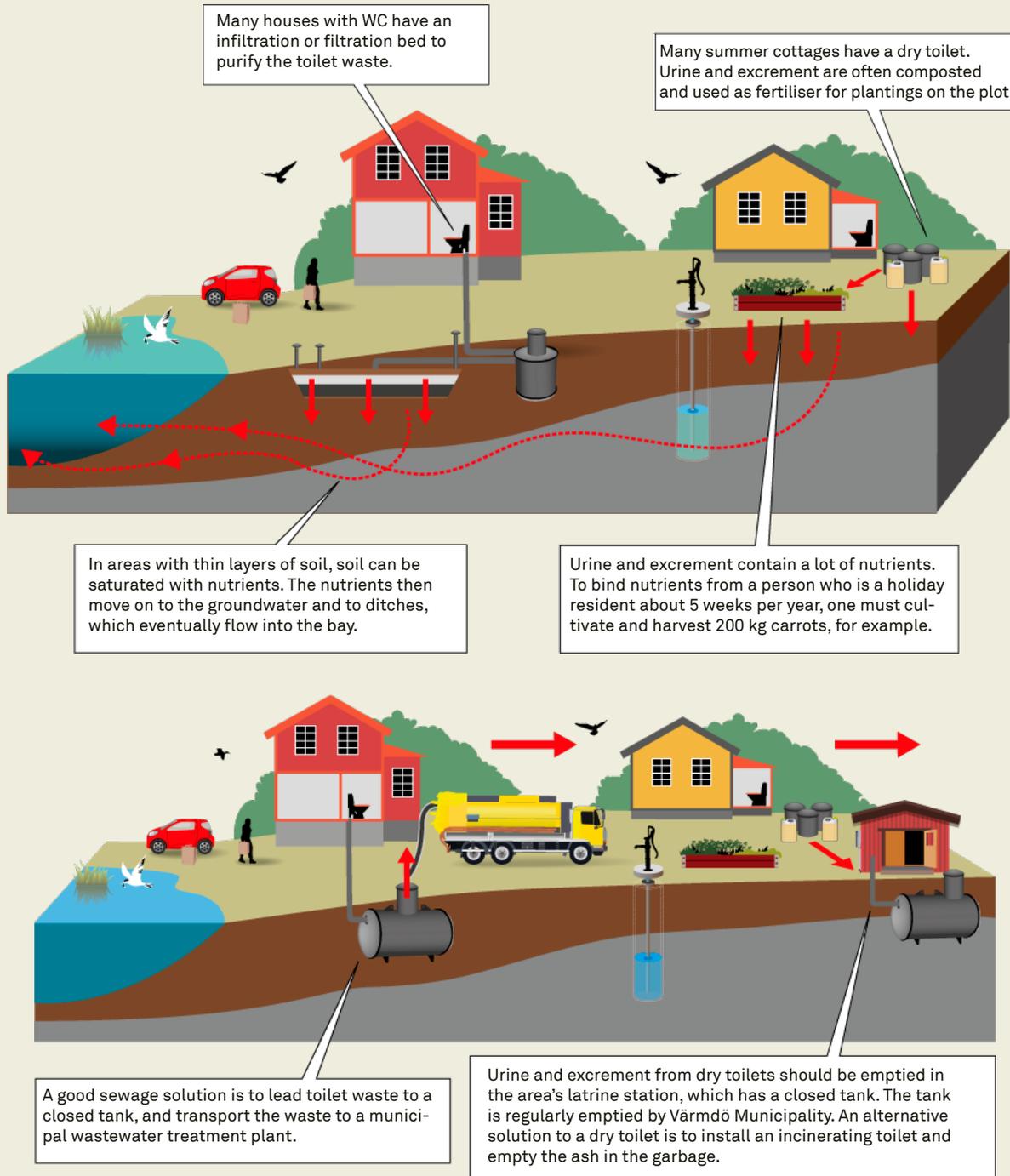


FIGURE 11. The top figure illustrates sewage solutions that rely on soil purifying wastewater from nutrients, bacteria and viruses. These types of purification techniques are not suitable in areas with thin soil layers near lakes and seas. Examples of unsuitable solutions are infiltration plants, filtration beds, mini-treatment plants (require a lot of supervision and care) and handling one's own human toilet waste on the plot. The best sewage solutions for properties in areas close to lakes and seas are those where the toilet waste is sorted out and transported away from the area, as the lower figure illustrates. Examples of good solutions are closed tanks, incineration toilets and human waste retrieval or emptying of urine and excrement at a central collection station.

Financing

There is no support financing that property owners who want to fix their sewage systems can apply for. However, the cost is not always the deciding factor. Few of the property owners who did not fix their sewage system within the Living Coast project said that higher subsidies than the 10-20 per cent of the total cost they were offered, would have motivated them to implement measures⁶⁷.

Supervision & Counselling

Municipalities must conduct supervision to ensure that all small sewage systems have permits and that they work as they should⁶⁵. Some municipalities offer sewage system counselling to their municipality residents, which is very good as this counselling seems to be a factor that encourages action. Almost all property owners who received visits with counselling and support with permit applications within the Living Coast project, fixed their sewage systems. The counselling also contributed to quicker processing and seems to have reduced the number of appeals.

LIVING COAST on fixing small sewage systems

- The municipal supervision is in many places inadequate, and the willingness of the property owners to voluntarily improve their sewage system to reduce their environmental impact is weak. **The rate of inspections needs to be increased, especially in the North and South Baltic Sea water districts where the largest emissions occur. The coastal zone and areas near lakes and waterways need to be prioritised, and the focus should be on toilet waste (grey water contains almost no nutrients at all).**
- There are major regional differences in property density, soil retention and proximity to eutrophication-sensitive bodies of water, which play a major role in the impact of small sewage systems on the environment. **If there is uncertainty about the risk of emissions, the precautionary principle should be applied, and efforts implemented that seek to ensure that toilet waste is collected and transported away from the area.**
- **Stronger incentives are needed to get a good sewage treatment.** Today municipalities need to be able to point to emissions from small sewage systems in order to be able to require measures. This can be done with measurements or calculations if input data is available, but is difficult in practice.
 - In practice, it leads to high levels of demands for new small sewage systems while older systems are often allowed to continue to emit poorly treated wastewater into the environment. This is both unfair and bad for the environment.
 - It needs to be easier to reassess old permits.
- **The own disposal of toilet waste on the property** (the plot) is a forgotten health risk and can be a **source of eutrophication**. It is not a local recycling solution, as is considered by many municipalities. These nutrient sources are rarely included in load calculations, which means that the environmental impact of sewage/toilet waste is underestimated.
- Few property owners voluntarily choose a recycling sewage solution, among other things because they are more expensive. In addition, many municipalities lack the infrastructure and systems needed for handling for recycling, although the recycling of nutrients should be pursued^{65,68}.
- Access to sewage system counselling is a factor that increases action. However, despite free sewage system counselling, help with the permit application, and a financial subsidy, there were still many property owners who did not fix their sewage system within the Living Coast project.

READ MORE ABOUT...

fixing small sewage systems in the complete Living Coast White Paper and in the report "Fixing small sewage systems. Experience from the project "Help your bay – Improve your sewage system"⁹, or on the websites of VA-guiden (the sewage system guide) and the Swedish Agency for Marine and Water Management.

Excess phosphorus is bound in the sediment

Even if all nutrient emissions from the Baltic Sea catchment area are stopped immediately, it would probably still take many decades before the eutrophication ceases, and the same applies to many coastal areas. This is because the phosphorus emissions of earlier years, which have been stored in bottom sediments for a long time, leak back into the water and contribute to eutrophication.



◀ Due to lack of oxygen in the water, white veils of sulphur bacteria were formed at a depth of about 6 metres. Björnöfjärden 2011.

What is internal load?

During eutrophication, more phosphorus has been transported to a bay, than the bottom sediments can permanently bind (Figure 12). The phosphorus originates from various sources on land and is tied up in organic material, especially plankton, in the water column. Phosphorus is released again when the organic material is mineralized instead of being retained by, for example, iron, aluminium or calcium. The binding to the different substances varies in strength and some phosphorus leaks back into the water. This leakage is usually called internal load.

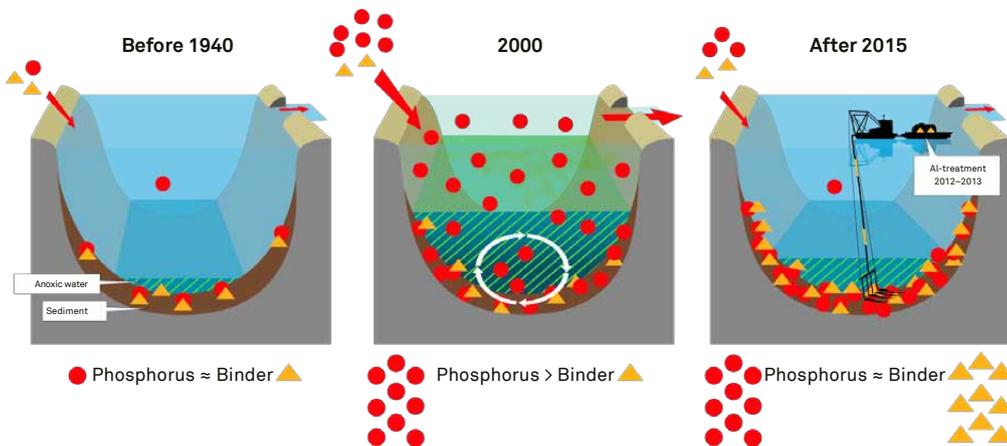
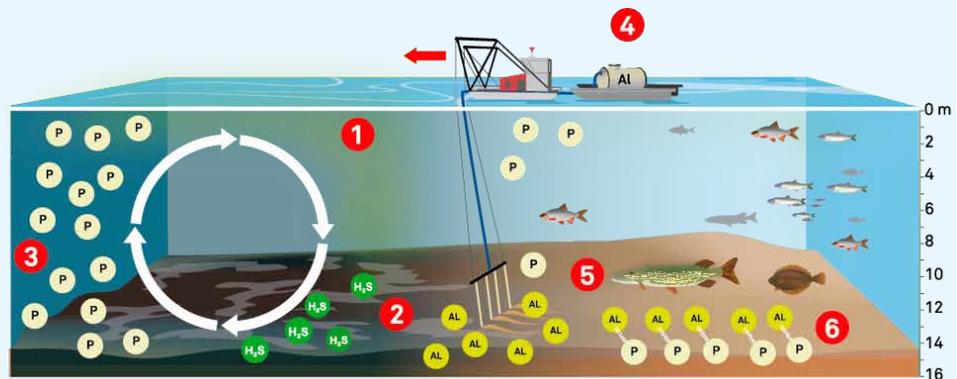


FIGURE 12. At the beginning of the 20th century, there was a balance between the supply of phosphorus and phosphorus-binding substances to Björnöfjärden. This meant that the internal load was very small. In the second half of the 20th century, more phosphorus was introduced than phosphorus-binding substances, for example due to emissions from agriculture or properties with poor treatment of their sewage. It led to strong internal load and that Björnöfjärden became eutrophic. During the summers of 2012 and 2013, aluminium treatment was implemented in the bay where aluminium was added to the sediment that could bind the abundance of phosphorus. Measures to reduce the supply of nutrients from land again led to a balance between the supply of phosphorus and phosphorus-binding substances again, whereby eutrophication slowed down.

If the sediment becomes anoxic, iron loses its phosphorus-binding capacity and the internal load is amplified. Internal load is often a predominant source of eutrophication. More phosphorus in the water contributes to increased eutrophication and more organic material to be broken down, more oxygen is consumed, an even greater lack of oxygen and an even greater internal load. This is usually called the vicious circle (see fact box below).

Internal load of phosphorus can be stopped with aluminium treatment. This adds aluminium that binds the dissolved phosphorus in the sediment. Often the same precipitating chemical is also used in both drinking water purification as well as wastewater treatment plants (polyaluminium chloride). The phosphorus bound to the added aluminium can be considered permanently bound in the sediment and could in principle be dredged up and reused in the future.

HOW ALUMINIUM TREATMENT WORKS



BEFORE TREATMENT: "THE VICIOUS CYCLE"

- 1. Nutrients cause algal blooms.** When there is a lot of nutrients in the water, the growth of phytoplankton and filamentous algae increases greatly, and there will be algal blooms.
- 2. Decomposition of algae causes oxygen deficiency.** When the algae die, they sink down to the bottom where they are decomposed by bacteria and small animals. Oxygen is used in the water during the decomposition. If the oxygen runs out, hydrogen sulphide is produced, which is toxic.
- 3. Oxygen deficiency releases phosphorus (P).** In a healthy sediment, phosphorus binds to iron, aluminium or calcium. In anoxic bottoms, iron loses its phosphorus-binding ability and a large part of the phosphorus is released to the water and contributes to eutrophication, which in turn leads to even more algal blooms and even more anoxic bottoms. A vicious circle develops.

POST-TREATMENT: "HEALTHY ECOSYSTEM"

- 4. Phosphorus leakage (P) stops** when an aluminium solution (AL) is gently mixed down into the surface of the sediment. Aluminium permanently binds dissolved phosphorus in the sediment and is dosed according to a calculation of the amount of phosphorus likely to leach contained in the sediment.
- 5. Eutrophication ceases.** When the phosphorus leaching from the sediment is stopped, the growth of algae, and thus the amount of organic material that reaches the bottoms, decreases. It leads to less nutrients being released and less oxygen being used.
- 6. The vicious circle is broken.** Aluminium treatment has bound phosphorus permanently in the sediment and the phosphorus levels in the bottom water have decreased by more than 95 per cent. The effect will remain as long as the supply of new phosphorus from land is limited.

Internal load and aluminium treatment in figures

- In Björnöfjärden, the internal load was just over 70 per cent of all phosphorus supplies to the water. This is similar to the ratio in the Baltic proper, where the external phosphorus supply is estimated to be between 15,000 and 20,000 tonnes annually, while the internal load is estimated at about 100,000 tonnes per year².
- To bind 1 kg of phosphorus in the sediment, 10 kg of aluminium is required. The cost of binding one kilogram of phosphorus varies between SEK 400-2,000/kg. The lower cost applies to larger bays.
- Aluminium treatment inactivated phosphorus in Björnöfjärden with an average of 1.3 mg phosphorus per square metre and day. After 3.5 years, this corresponds to about 1.5 g phosphorus per square metre and 1.3 tonnes total in Björnöfjärden¹².
- Aluminium treatment in Björnöfjärden has cut in half the phosphorus level in the water as a whole and reduced the phosphorus level in the bottom water by more than 80 per cent¹¹.

Aluminium treatment in Björnöfjärden

The predominant source of phosphorus to Björnöfjärdens water was the internal phosphorus load from bay's anoxic sediments that are deeper than six metres, about 50 per cent of the bottom area (0.7 km²). The internal load was stopped with an aluminium treatment of sediments during the summers 2012 and 2013. This method is a well-known lake remediation measure which was used for the first time in a marine environment in Björnöfjärden.

The aluminium treatment provided a rapid and clear reduction of available phosphorus in the water¹¹ (Figure 13). The proportion of aluminium-bound phosphorus in the sediment, which can no longer be released to the water, increased significantly¹¹ (Figure 14). This in turn has led to a halving of the phosphorus levels in the water compared with before the aluminium treatment and compared to the comparison bay.

Risks of aluminium treatment

Aluminium can be harmful to aquatic organisms if it occurs in a dissolved form at high concentrations. The solubility of aluminium is controlled by the pH value of the water. At the pH level generally prevailing in the Baltic Sea bottom sediment (around pH 7), the solubility is very low, which means that the risk of precipitation changing to dissolution is very small.

The treatment method used in Björnöfjärden is well proven in lakes⁶⁹ where it has provided both reduced phosphorus in the water and more favourable habitats for plant and animal life, without apparent negative side effects.

During and immediately after the aluminium treatment in Björnöfjärden, the aluminium content increased in the water and in plants and animals. One year later, the levels in the water were equal to, or lower than before treatment, and after another year the levels had also gone down in plants and animals. Traces of the treatment could accordingly be seen in the form of elevated aluminium levels in the ecosystem, but the increase was not lasting.

Björnöfjärden's bottoms that are deeper than 6 metres were aluminium treated in the summers of 2012 and 2013 with the help of a special craft. ▶

From a rig mounted in the boat's fore ran hoses that were gently pushed down into the sediment surface. Phosphorus leaching is stopped by adding the aluminium solution to the sediment via the hoses. ▶

Just a few days after the aluminium treatment, the water of Björnöfjärden became clearer. ▶▶

METHODS OF STOPPING INTERNAL LOAD

There are three fundamentally different methods to reduce leaching of dissolved phosphorus from deeper bottom areas in lakes and coastal areas with poor oxygen conditions:

- Oxygenation that increases the natural phosphate-binding in the surface sediment by dissolved iron oxidising and being able to bind phosphorus.
- The addition of phosphorus-binding substances to increase phosphorus binding under anoxic conditions.
- Dredging to remove sediment layers containing phosphorus likely to leach out.

READ MORE ABOUT...

Aluminium treatment and internal load in the complete Living Coast White Paper and in the article "Re-mediation of a Eutrophic Bay in the Baltic Sea"¹¹.

Aluminum bound phosphorus in sediment

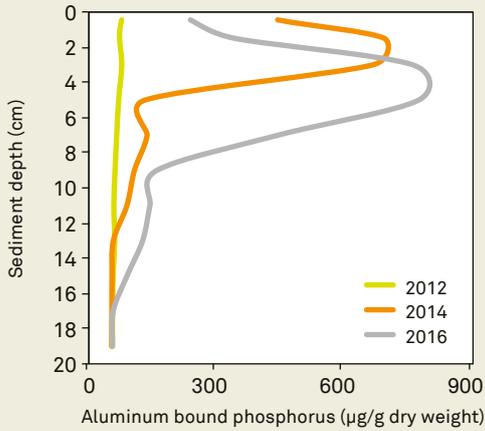


FIGURE 13. Aluminium-bound phosphorus in the top 2 dm of the sediment. Before the aluminium treatment (2012), the concentration was about the same size at all depths. Two and four years after treatment, a lot of phosphorus is bound to aluminium in sediment at approximately 2-4 cm deep (2014) and 4-6 cm deep (2016). New sediment that reaches the surface each year contributes to the concentration peak being moved downwards.

Phosphorus content in Björnöfjärden and a comparison bay

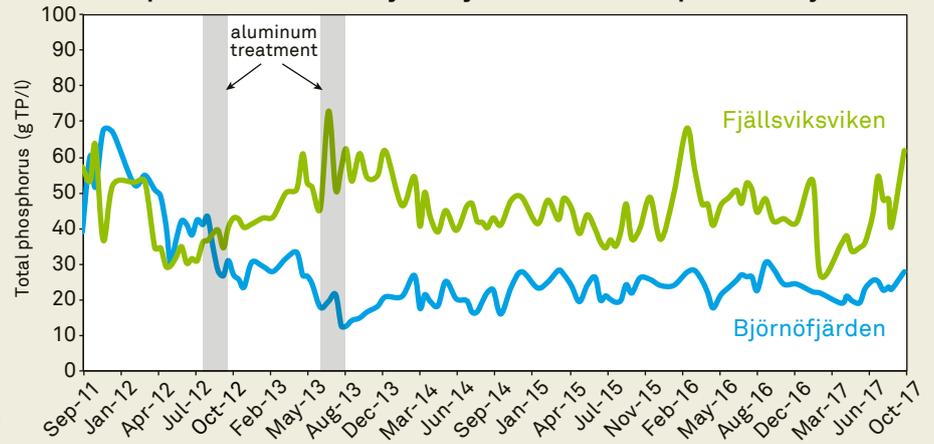


FIGURE 14. The average concentration of phosphorus in Björnöfjärden is about half compared with Fjällsviksviken (comparison bay) and compared with the period before the aluminium treatment.



LIVING COAST on resolving the internal load of phosphorus

- Aluminium treatment of deep, anoxic archipelago bottoms is an effective way to reduce the internal phosphorus load to the water. The cost of phosphorus-binding is lower than for many measures on land.
- There is currently no indication that aluminium treatment would be dangerous to organisms in marine bays. For safety reasons, the effects of the Björnöfjärden treatment will be followed up until 2022 to verify that no unexpected side-effects occur.
- An increased phosphorus binding in a restored bay's bottoms is also important from a larger perspective by reducing phosphorus exports to the outlying archipelago.
- Future remediation work should include measures both against the external and internal nutrient load. The percentage of external and internal phosphorus sources to the water should be reflected in the action conditions. If so, the phosphorus supply that is taking place today will be reduced proportionally to earlier phosphorus supply, which would have a positive effect on the eutrophication situation.
- Aluminium treatment of bottom sediments is a means of reinforcing the phosphorus-binding capacity of the sediment in the anoxic bottoms, thus deactivating and compensating for the pulse of eutrophic phosphorus that previously deficient treatment contributed to. The reduced production of oxygen-consuming materials (especially phytoplankton) resulting from aluminium treatment should lead to bottoms that were oxygenated until the middle of the 20th century to regain an oxygenated surface sediment and a naturally higher phosphorus-binding ability¹².
- Today it is unclear whose responsibility it is to identify and correct internal phosphorus load. Perhaps the estimation of a previous load on a body of water may be the basis for whose responsibility it is to implement and finance the measure? Perhaps it can be regarded as a "retroactive" purification of untreated wastewater?
- Today, knowledge of how and where phosphorus likely to leach out is accumulated is small. With more knowledge of how the phosphorus likely to leach out is distributed over coastal and seabeds, the method's possibilities on a larger scale can be evaluated. Given that the bottoms most likely to leach out are placed so that aluminium treatment is possible, it would cost about SEK 13 billion to fix 10 per cent of the Baltic Sea's anoxic bottom area (7,000 km²)⁷⁰.



Measures to strengthen predatory fish stocks

Predatory fish such as perch and pike are important in the fight against eutrophication. They are at the top of the food web and can affect the structure of the rest of the ecosystem, but since the middle of the 1990s, predatory fish have declined along the Baltic Sea coast. The Living Coast project has implemented several measures to strengthen the stock of predatory fish in Björnöfjärden.

Predatory fish important to the whole ecosystem

Predatory fish have a very important function in the sea, both on the coast and further out to sea. They are at the top of the food web and may affect the structure of the rest of the ecosystem (Figure 15). On the coast, pike is the most important predatory fish. Pike eat smaller fish, such as roach. If there are plenty of pike in a bay, it reduces the number of roach. Roach in turn eat zooplankton, and if there are few roach, there is a lot of zooplankton left. Zooplankton eats phytoplankton and when there is a lot of zooplankton, they graze a large portion of the water's phytoplankton. In this way, pike helps to reduce phytoplankton blooms (algal blooms) that quickly grow when the water is eutrophic and there is a lot of nutrients in the water. Further out to sea, cod is the most important predatory fish. In the same way as the pike, cod controls the growth of phytoplankton in the offshore areas.

Since the middle of the 1990s, pike and perch have declined along the Baltic Sea coast. This is probably due to a combination of large-scale changes in the Baltic Sea ecosystem as a result of, for example, overfishing and exploitation of nursery habitats, as well as diking of freshwater environments that are important spawning grounds.

Wetland to strengthen pike stocks

To strengthen the pike stock in the archipelago, pike wetlands can be created (Figure 16). Near the sea, an embankment is built that catches rain and melt water from the catchment area. Pike migrate up into the wetland via a fish migration path where there is enough water in the spring to allow an adult fish to swim up and spawn and then down to the sea again when the spawning is over. In early summer, the water flow decreases so that fish can no longer reach the wetland. The pike fry are then protected against predatory fish for a few months. At midsummer, the pike fry are ready to swim out into the bay. Then the water in the wetland is released through a regulating ring. The regulating ring is closed during the autumn for rain and melt water to again be collected in the wetland for the next spring's pike spawning.

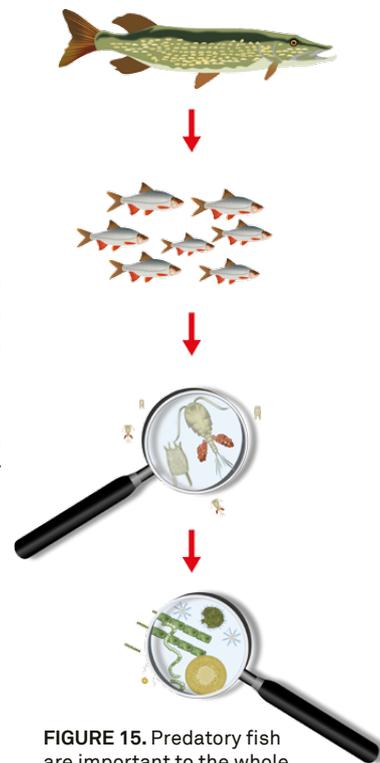


FIGURE 15. Predatory fish are important to the whole ecosystem. They are at the top of the food web and may affect the structure of the rest of the food web.

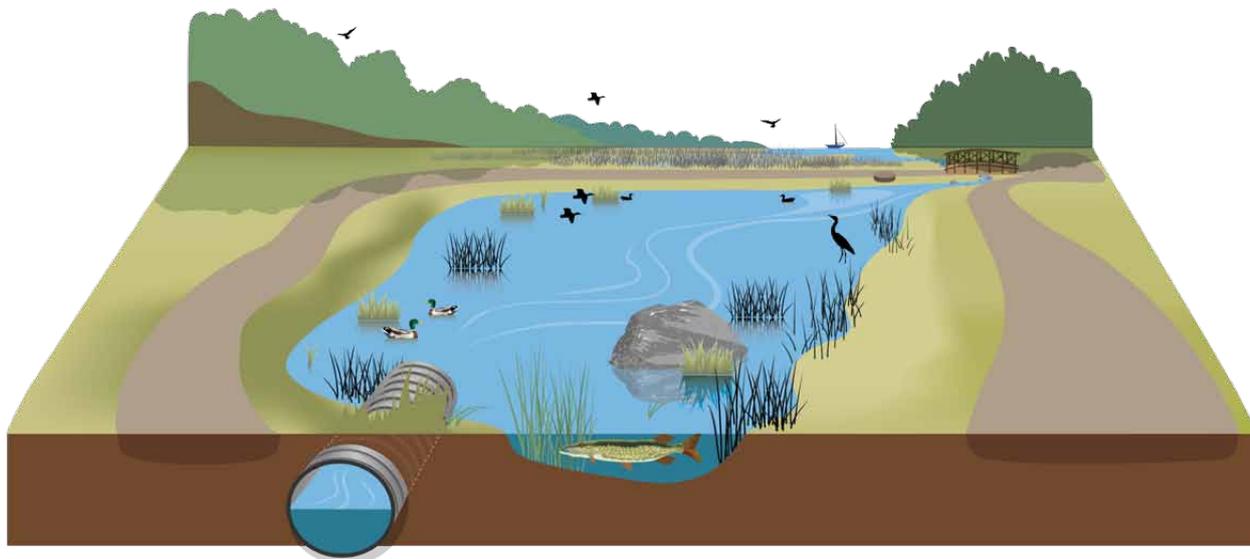


FIGURE 16. Pike is a species that like to find wetlands to spawn. To strengthen the pike stock, pike wetlands can be made where the pike can spawn and the pike fry can grow up in a protected environment.

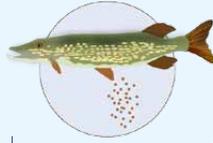
PIKE SPAWNING IN FRESH WATER



1

Spawning in fresh water

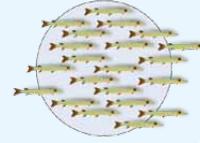
Early in the spring, pike seek out the areas where waterways flow out and flood grass meadows. Here, the water become warm faster than in the sea. Pike can migrate up between rocks against the current.



2

100,000s of roe

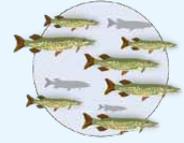
The pike spawning lasts for a few days. In that time, 100,000s of roe are laid and fertilised by the males' milk. The roe stick to the blades of grass and hatch after a few weeks.



3

Fry grow bigger

The pike fry grow quickly in the wetland where there is plenty of food and protection. The fry eat zooplankton, bottom-dwelling animals and small fish. At midsummer, they are ready to swim out to the sea.



4

Moving out to the bay

Pike fry continue their life in the bay. The fry that have grown up in wetlands are often larger than those in the sea, and therefore cope better. When the pike become sexually mature, they often return to spawn where they hatched.

Fishing ban

Another way to protect and strengthen the predatory fish stock in coastal areas is to restrict or prohibit fishing, which has been shown to have a positive effect on, for example, pike⁷⁴. The introduction of new fishing regulations is easier when stakeholders are informed and agree that a fishing ban is needed. The motives must be scientifically based and long-term management must be taken into account. It is the Swedish Agency for Marine and Water Management that makes a decision on the matter.

Remediation of vegetated bottoms

On shallow bottoms, bottom-living vascular plants and algae create an important habitat for animal life in and by the sea. Fish seek out these environments in search of food, to find suitable spawning and nursery grounds, and to seek refuge. Both plant- and fish-eating birds are also drawn here. The bottom vegetation also takes up nutrients from land runoff and stabilises the sediments, contributing to clearer water.



▲ Pike fry that grew up in a pike wetland are often larger than those that grew up in the bay outside.



▲ Areas with bladderwrack are important spawning and nursery environments for fish, among other things. In Björnöfjärden, attempts were made to replant bladderwrack. The seaweed survives, but it has difficulties to reproduce.

PHOTO: SVERIGES VATTENKÖLÖGER

Shallow habitats are, however, sensitive and easily affected by exploitation and eutrophication. Where possible, building docks, dredging, anchoring and intensive boat traffic should be avoided, as it has been shown to adversely affect vegetation that is important to fish recruitment⁷². To speed up the recovery of vegetation in shallow environments, remediation attempts have been made with bladderwrack and pondweeds. The methods tested may have potential, but need to be developed further to be reliable more widely.

Shore meadow remediation

Shore meadows are an important biotope that has become unusual since grazing by cattle has largely ceased in such areas. Reduced grazing pressure means that competitive vegetation, such as reed, often out competes other vegetation. This leads to overgrowth and loss of important functions, such as spawning grounds for coastal pike, and breeding and resting areas for birds.

To recreate wet meadows, the reeds need to be sharply cut back and transported away from the area. Areas with thick reeds may need to be cut for another one or two years. In order to maintain the wet meadow, grazing, preferably with cattle, may need to be established.

Recreating environments often difficult and expensive

In addition to its important role and function in the ecosystem, predatory fish are of great value for both sports and commercial fishing. Reduced predatory fish stocks along the Baltic Sea coast have led to various measures to strengthen predatory fish recruitment in different parts of the country, for example new spawning and nursery areas have been brought into use and migration barriers to natural spawning grounds have been removed. These measures have been successful in many cases. However, it often takes time (many years) and patience for a recreated/landscaped environment to have the desired function. It can also be very expensive if you are unlucky in the establishment, or if it involves large areas.

READ MORE ABOUT...

Measures to strengthen predatory fish stocks in the complete Living Coast White Paper and on predatory fish on the website of the Swedish Anglers Association: (www.sportfiskarna.se/rovfisk).



▲ To try to recreate a wet meadow next to Björnöfjärden, the reeds were cut down by an amphibious reed cutter.

Since reed areas are important areas for birds, cutting the reeds during the nesting season should be avoided. It can also be good to save some reeds to benefit the bird life.



▲ In the strait to Björnöfjärden, the project investigated how much spawning fish migrates into the bay during the spring.

Potential actions and effects

Before actions were taken, the average annual total nutrient supply to Björnöfjärden from the entire catchment area was estimated to be about 240 kg of phosphorus and just over 3000 kg of nitrogen^{7,8}. About 70 per cent of the phosphorus and 45 per cent of the nitrogen were due to anthropogenic impact such as agriculture, horse keeping and sewage. The remainder is the background load from the forest and open land.

Project Manager Emil Rydén next to a pile of lime material for a lime bed.



The impact of agriculture on Björnöfjärden is estimated to decrease by around 85 per cent as a result of the steps taken in the Living Coast project.



▲ Horse farms' contribution to nutrient loss is best minimised by manure clearing of pastures and taking care of manure in a good way and making sure that the horses are not kept so dense to avoid that the vegetation cover is worn down in the pasture.

Potential actions and effects

This section presents the action potential and the action effect of the respective sources and measures. The results are compiled in Table 1 on page 45. The calculations are based mainly on standard values because there are not yet sufficient time series from the project's own measurements in the catchment area to calculate the action effects; mainly due to inter-year variations in precipitation.

Agriculture

The total annual nutrient loss from arable land in the area (50 hectares) was estimated to be 38 kg of phosphorus and 252 kg of nitrogen, assuming the annual area specific loss per hectare before measures was 0.75 kg phosphorus and 5 kg nitrogen⁷.

The action potential, without reducing production, was estimated to be 25 kg of phosphorus per year if the measures had been fully implemented in the area, which, however, was not suitable or economically feasible. To reduce the nutrient supply as much as possible:

- Most (42 hectares) of the arable area was structure limed, which improves the retention of phosphorus in the soil and reduces the load by **8-14 kg of phosphorus per year**.
- Phosphorus ponds and lime filter beds that catch water from 70 per cent of the arable area were built. The installations trap about **8 kg of phosphorus per year**, which leaves the field in spite of structure liming. Some nitrogen is also trapped.

The cost of structure liming, including land mapping, was SEK 5,000 per hectare. It is expensive to establish a phosphorus pond with lime filter beds, especially if the establishment does not become optimal. The cost of the Living Coast's phosphorus ponds with lime filter beds was SEK 360,000 (0.29 hectares) and SEK 725,000 (0.25 hectares). It can be much more cost effective with large installations and better conditions³⁹.

Horse keeping

The phosphorus losses from horse keeping in the area (25 horses divided into three stables) were estimated to be about 17 kg of phosphorus per year (1.5 kg phosphorus/hectare and year; 11 hectares)⁷. That corresponds to one third of the horses expected turnover in total.

The action potential is difficult to assess, but estimated to be about 11 kg of phosphorus per year, which means that the average area-specific loss after measures should not exceed average leaching from arable land (0.5 kg phosphorus/hectare year). If the number of horses per unit area is kept so low that the pastures are not trampled, ditches are protected and the manure clearing of pastures is stored on a watertight manure slab and recycled, most of it should be able to be rectified. On the other hand, a large amount of nutrients have already been stored in the soil around the stables and will leak for a long time to come.

The action effect is also difficult to assess. Assuming that the measures implemented have the estimated effect, the nutrient loss should be reduced to about 8 kg of phosphorus per year. However, previous years' accumulated soil nutrients will continue to contribute to elevated levels in ditch water leaving the area, which means that it will take time for the measures to have full effect. To date, the action effect is estimated to be half of the impact that is expected to be achieved with the actions taken by the project; meaning about **4 kg of phosphorus per year**.

The cost of all measures on the horse farms around the bay was about SEK 1,250,000, and is expected to reduce the phosphorus supply to Björnöfjärden by about 8 kg annually once the measures have had full effect.

Small sewage systems

At the start of the project, the total annual nutrient losses from small sewage systems was estimated to be about 80 kg of phosphorus and 1000 kg of nitrogen⁷. The emissions were mainly caused by the 200 properties (of just over 850) that had illegal or poor sewage solutions.

The action potential to install a closed tank on properties with soil-based purification of toilet waste is estimated to be 100 per cent.

However, it takes a long time for the measures to have full effect, as there is a lot of nutrients already stored in the soil near sewage systems with poor purification.

During the project, half of the 200 properties either switched to a closed tank, or they empty their toilet waste from their dry toilet at the latrine station that the project built. By extension, this will reduce the load to the bay by about 40 kg of phosphorus and 500 kg of nitrogen per year. A few years after implementation, the effect is assumed to be on average half of the fixed gross supply to the soil, i.e. about **20 kg of phosphorus per year**. Over time, the stored phosphorus remains in the ground, which has not been permanently bound, is assumed to have leached out and the effect is then 40 kg of phosphorus per year.

The average cost of installing a closed tank was SEK 75,000 per property. The cost of the 100 properties that switched from soil-based purification to the closed tank (or equivalent) thus becomes SEK 7,500,000. Since the measure is estimated to reduce the supply to the bay by about 40 kg of phosphorus per year when it has full impact, the purification cost will be nearly SEK 10,000 per kilogram of phosphorus seen over 20 years (excluding sludge removal costs).

The Nature Reserve's outdoor toilets

Two dry toilets at the Björnö Nature Reserve supplied Björnöfjärden with about **3 kg of phosphorus and 15 kg nitrogen per year**⁹. Since both action potential and action effect are estimated to be 100 per cent, the inflow is estimated to have decreased by about 3 kg of phosphorus and 15 kg of nitrogen per year as a result of the outdoor toilet being equipped with a closed tank. Unlike fixed small sewage systems, the effect of the installation of the tank is not delayed, since the waste before measure was composted right next to the shores of the bay.

The cost of installing the closed tank on two dry toilets was about SEK 100,000. Over 20 years, the purification cost will be around approximately SEK 1,600 per kg of phosphorus, at the degree of utilisation that prevails today.

Säby Manor Farm

The conference facility at Säby Manor Farm is estimated to produce about 40 kg of phosphorus and 250 kg of nitrogen per year. A 15-year old infiltration facility with limited purification function was disconnected in 2015 and replaced by a system with phosphorus precipitation, a septic tank and a dense filtration bed.

The action potential is estimated to be 95 per cent (38 kg) for phosphorus and 50 per cent (125 kg) for nitrogen for the new plant⁷¹. The action effect is assumed to be the same as the action potential when full effect is reached. Since the installation of the new system, there has been a lot of fine-tuning problems, which is why the action effect so far is only estimated at half the action potential, i.e. **19 kg of phosphorus per year**.



▲ Sewage solutions relying on the soil to purify wastewater from nutrients are not suitable in areas with thin soils near lakes, streams and seas.



▲ Composting urine and excrement in composting bins is a common solution for outdoor toilets in nature reserves. When done near the water, it is very likely that nutrients will leach out and contribute to eutrophication.

◀ Säby Manor Farm is located right by Björnöfjärden. In order to minimise the impact of operations, a new sewage system was installed.



◀ Process water from the operations at Smakriket Säby contains a large amount of organic materials and varies widely in volume over the year. This makes it difficult to use a standard solution for treating the water.

Smakriket Säby

Smakriket Säby with cider press, brewery and distillery operations is estimated to annually produce a total of 5 kg phosphorus and 12 kg nitrogen⁷.

The action potential is difficult to assess. With closed systems, 100 per cent of the nutrients can be removed, but in practice it is difficult to achieve such a system because large volumes of water must be treated. Different solutions to take care of, and preferably reuse, waste products from the cider press and brewing operations have been tested, but no long-term sustainable solution has yet been set. At present, the action effect is assumed to be half of the emissions, i.e. **2.5 kg of phosphorus per year**.

Sediment

Björnöfjärdens deep bottoms (> 6 metres) are anoxic sediment accumulation areas and occupy 0.73 km² (about 50 per cent of the bottom area). Material and new sediment layers are formed on accumulation bottoms. When the organic material is broken down, nutrients are mobilized and stored in the sediment for a shorter or longer period or are released directly to the water. The storage of phosphorus likely to leach out in Björnöfjärdens accumulation bottoms is 2.2 tonnes (approx. 3 g phosphorus/m²)¹². Overall, the average leaching rate from the accumulation bottoms is estimated to be approximately 500 kg of phosphorus per year; an estimate based on the amount of phosphorus bound to aluminium as a result of aluminium treatment¹². Bottom areas at between four and six metres depth are estimated, on average, to contribute about 100 kg of phosphorus per year to the water, because the material is also periodically deposited on these bottoms. The total action potential of Björnöfjärdens sediments is thus estimated to be about 600 kg of phosphorus per year.

Immediately after the aluminium treatment, phosphorus losses essentially ceased from the deeper bottoms. After 3.5 years, 1,300 kg of phosphorus had been bound to added aluminium¹². An additional 300 kg of phosphorus is assumed to be bound in 2018 and 2019. Then most of the estimated pool of sediment phosphorus likely to leach out (2.2 tonnes) is assumed to be bound to aluminium. The shallower bottom areas (4-6 metres) could also have been aluminium treated, but unlike the anoxic deep bottoms, the shallower bottoms are oxygenated and inhabited by plants and animals. For reasons of precaution, the project refrained from treating these bottoms; the treatment of the anoxic accumulation bottoms was estimated to provide sufficient efficacy.

The cost of stopping the internal load in Björnöfjärden with aluminium treatment was approximately SEK 9 million, including development costs. The added aluminium (50 g Al/m²) is estimated to be able to bind upwards of 4 tonnes of mobile phosphorus in the sediment, which gives a cost of SEK 2,250 per kg of inactivated phosphorus. The measure broke an annual internal load of 0.5 tonnes of phosphorus.

Total remediation potential and action effect

The overall effect of all the measures to date in the catchment area is estimated to be a reduced phosphorus load of approximately 70 kilograms of phosphorus per year (44 per cent), and will increase to 114 kg per year (70 per cent) when each measure reaches full effect (Table 1). The phosphorus supply to Björnöfjärden from the catchment area will thus be cut in half, from about 241 to 114 kg of phosphorus per year.

There is still a further approximately 50 kg of phosphorus per year to be reduced before the entire action potential is reached, which essentially involves fixing the remaining 100 small sewage systems which account for about 40 kg of phosphorus. The remaining action potential is judged to be very costly to reach, or involve the cessation of activities (horse keeping, agriculture, conference activities).

TABLE 1. Action potential and action effect for phosphorus supply (kg P/year) from the catchment area (mainly based on standard calculations) and from sediment (mainly based on project measurements) to Björnöfjärden's water. Numbers in parentheses indicate the action effect when the measures have been fully effective.

ACTION POTENTIAL AND ACTION EFFECT FOR PHOSPHORUS SUPPLY					
Area	Load (kg P/year)	Action potential (kg P/year)	Remaining (kg P/year)	Action potential (kg P/year)	Action potential (%)
Phosphorus from the catchment area					
Background (forest, open land)	58	-	58	-	-
Arable land	38	25	13	22	88
Horse keeping	17	11	6	4 (8)	38 (72)
Small sewage systems*	80	80	0	20 (40)	25 (50)
Dry toilets in the nature reserve	3	3	0	3	100
Säby Manor Farm	40	38	2	19 (38)	50 (95)
Smakriket Säby	5	5	0	2.5	50
Total	241	162	79	71 (114)	44 (70)
Phosphorus supply from sediment					
Sediment (4-6m)	100	100	0	0	0
Sediment (>6m)	500	500	0	500	100
Total	600	600	0	500	83
Total phosphorus supply to the water					
Total	841	762	78	571 (614)	75 (80)

* Refers to properties with soil-based treatment of toilet waste, including own disposal, excluding grey water.

Decrease in net export of phosphorus from Björnöfjärden

There is a continuous water exchange between Björnöfjärden and Nämdöfjärden outside. In Nämdöfjärden, as well as in the entire Baltic proper, the nutrient levels are elevated. Thus, the water exchange will not only mean that nutrients will be exported from Björnöfjärden, but Nämdöfjärden's water is also a source of nutrients for Björnöfjärden. Nutrient bound in, for example, plankton and particles in Nämdöfjärden's water can sink out from the water to the sediment when it reaches Björnöfjärden and thus bring nutrients to Björnöfjärden.

Before the measures were implemented in and around Björnöfjärden, the annual phosphorus exports were estimated at about 800 kg from Björnöfjärden to Nämdöfjärden, while imports were about 200 kg. Net exports of phosphorus out of Björnöfjärden at the start of the project were about 600 kg per year.

After the measures, phosphorus levels in Björnöfjärden's water have decreased and are usually lower than in Nämdöfjärden. Total annual exports have been cut in half and are now averaging 400 kg of phosphorus, while imports remain the same. Net exports of phosphorus out of Björnöfjärden, after the measures, are thus 200 kg of phosphorus per year, which means a load reduction of about 400 kg of phosphorus per year on the archipelago outside.

Since phosphorus levels in Björnöfjärden have fallen to levels corresponding to those in Nämdöfjärden, the limit on the water quality that can be achieved in Björnöfjärden has been achieved. The big challenge now is to further reduce the supply from the Björnöfjärdens catchment area. Unless it succeeds, the phosphorus levels in the water will slowly increase again and new supplies of sediment phosphorus likely to leach out in are built up the bay's sediments again.



◀ Björnöfjärden was previously a phosphorous source for the archipelago beyond, but now serves as a filter for nutrients that come from the area around the bay. Thanks to the measures, less phosphorus ends up in the water and what does is largely bound in sediment.

Björnöfjärden has regained good water quality



The reduced nutrient supply to Björnöfjärden has led to the bay regaining good water quality in just a few years, and the bay's plant and animal life are recovering¹¹.

Improved water quality after measures

Phosphorus levels in Björnöfjärden's water has been cut in half from about 40 to 20 μg of phosphorus per litre due to the aluminium treatment in summer 2012 and 2013¹¹ (Figure 17). This reduction means that the bay has gone from poor to good status in terms of phosphorus, while concentrations in the comparison bay remain high¹¹.

Figure 18 shows the difference in the mean concentration of phosphorus and chlorophyll, and Secchi depth between Björnöfjärden and the project's comparison bay before, during and after the aluminium treatment. Before the project started, the concentrations of phosphorus and chlorophyll were higher in Björnöfjärden than in the comparison bay, while the Secchi depth was roughly the same. Chlorophyll is a measure of the amount of phytoplankton in the water and is controlled among other things by access to nutrients (nitrogen and phosphorus). In turn, the amount of phytoplankton affects the Secchi depth. When there is a lot of phytoplankton (chlorophyll) in the water, the Secchi depth and thus the light emitted into the water degrade. Immediately after the aluminium treatment, both phosphorus and chlorophyll levels in Björnöfjärden's water decreased, and were lower than in the comparison bay. At the same time, the Secchi depth improved.

Aluminium treatment stopped the internal load of phosphorus from Björnöfjärden's deeper bottoms. Nitrogen (ammonium), on the other hand, continued to be released, but the concentration began to fade after a few years (Figure 19), possibly as an effect of reduced deposition of phytoplankton¹¹. The declining phosphorus supply resulted in reduced algal blooms and increased Secchi depth. In the comparison bay, no clear reduction of nutrients in the bottom water was measured during the same period (Figure 20).

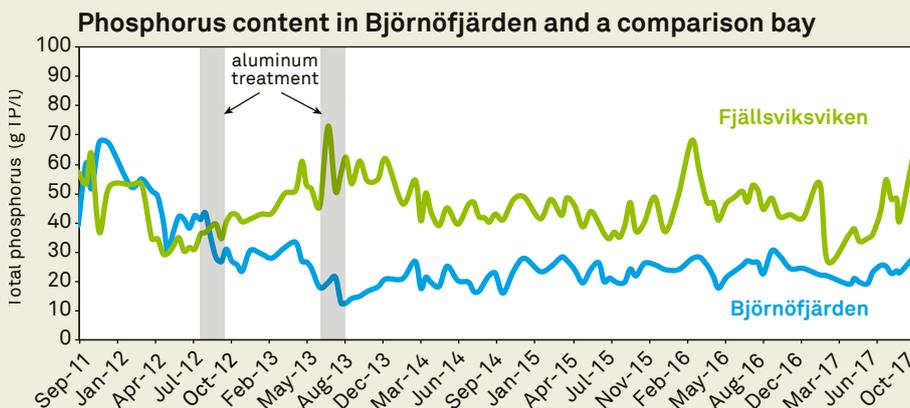


FIGURE 17. The average concentration of phosphorus in Björnöfjärden is about half compared with Fjällsviksviken (comparison bay) and compared with the period before the aluminium treatment.

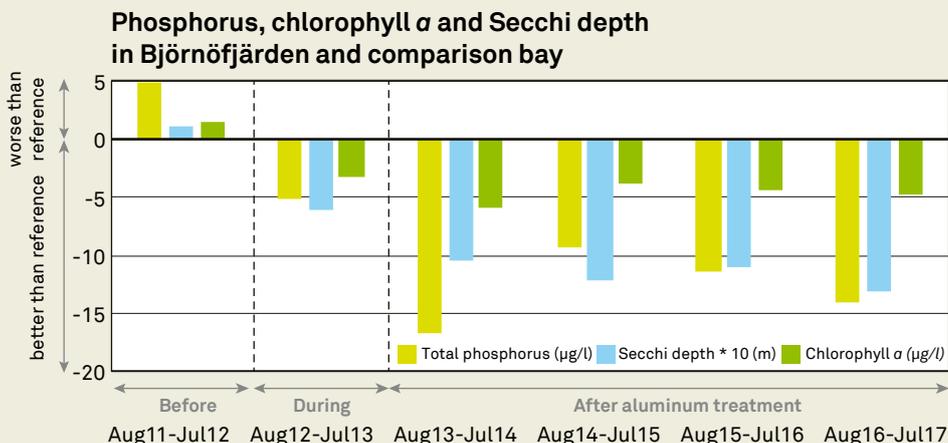


FIGURE 18. The water quality of the Björnöfjärden has been improved due to the aluminium treatment carried out during the summers of 2012 and 2013. The concentration of phosphorus and chlorophyll has decreased and the Secchi depth has increased in Björnöfjärden compared to Fjällsviksviken (comparison bay). The figure shows average annual values of the difference between the concentration of phosphorus ($\mu\text{g tP/l}$), chlorophyll a ($\mu\text{g/l}$) and Secchi depth (dm) in Björnöfjärden compared to Fjällsviksviken at each sampling: before, during and after the aluminium treatment.

The Secchi depth in Björnöfjärden has increased by about one metre as a result of the halved phosphorus concentration in the water. ▶



PHOTO: JOAKIM ODELBORG

Plant and animal life recovers

The improved water quality has had significant effects on the environment in the bay. The greater Secchi depth has resulted in that the bottom vegetation now can spread out and live just over a metre deeper (Figure 21, page 50). Reduced quantities of phytoplankton that fall to the bottom and decompose have improved the oxygen situation in the bottom water. This has allowed fish and bottom-dwelling animals to recolonise median depths. On the really deep bottoms, the situation is still strained with low, or very low oxygen levels, but the levels of hydrogen sulphide have decreased (Figure 22, page 50). It is a clear sign that there is less organic material that sinks down and decomposes on the deep bottoms.

Phosphorus and nitrogen content in the bottom water

FIGURE 19. The concentration of dissolved phosphorus (phosphate) in Björnöfjärden's bottom water decreased sharply due to aluminium treatment in the summers of 2012 and 2013. The corresponding reduction did not occur for dissolved nitrogen (ammonium).

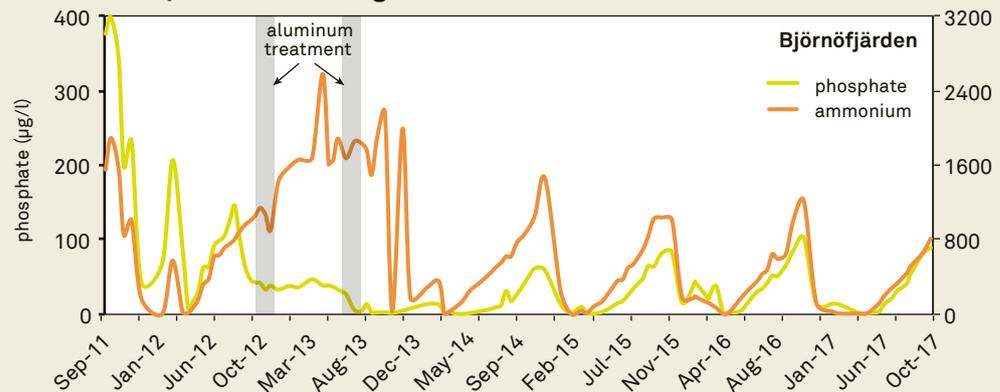
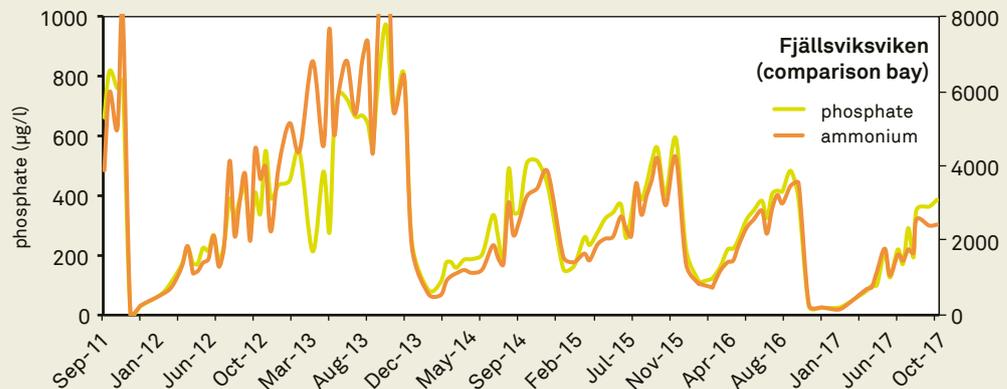


FIGURE 20. In Fjällsviksviken (comparison bay), no clear reduction in the concentration of dissolved phosphorus (phosphate) or nitrogen (ammonium) was recorded during the same period. Note that the scales differ from Figure 19.





Lake ball (*Aegagropila linnaei*)

Maximum depth of attached algae 2012–2017

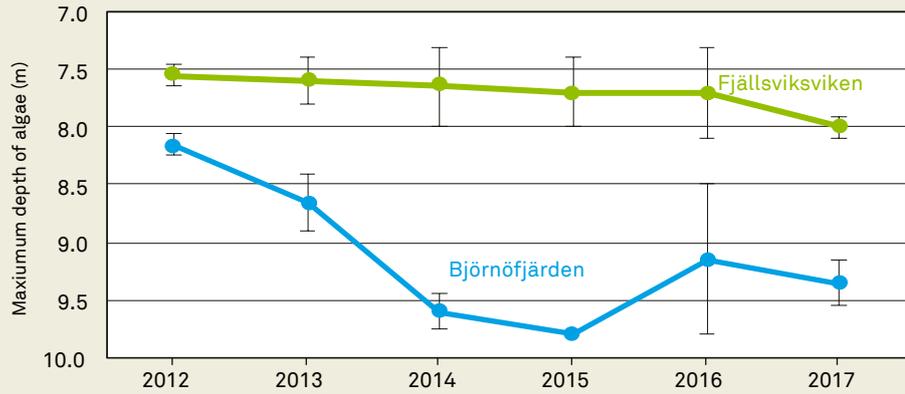
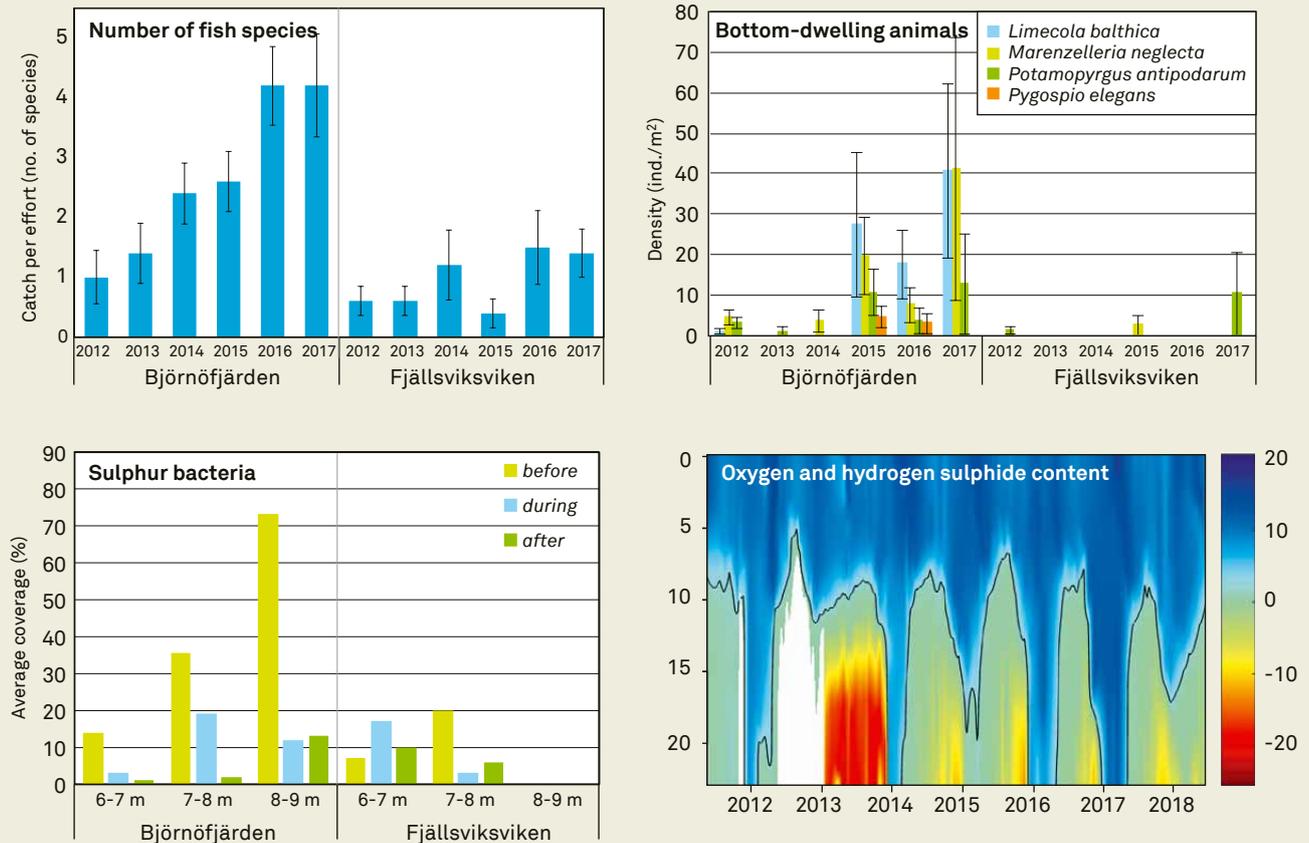


FIGURE 21. The maximum depth of lake ball (*Aegagropila linnaei*) has increased in Björnöfjärden as water quality has improved. This change is not nearly as clear in the Fjällsviksviken (comparison bay).

FIGURE 22. Due to the improved water quality in Björnöfjärden, the environment has recovered in several ways. These changes are not seen in the Fjällsviksviken (comparison bay). The number of fish species living at a depth of 8-10 metres has increased (upper left), the bottom dwellers that have free swimming larval stages have returned to the bottoms of 5-10 metres depths (upper right), the propagation of sulphur bacteria (*Beggiatoa* sp.) has decreased (lower left) and hydrogen sulphide content at deeper bottoms has decreased (lower right, negative oxygen values represent hydrogen sulphide content; white indicates that oxygen is missing with hydrogen sulphide not analysed).

Improvements in Björnöfjärden compared to the comparison bay





▲ Björnöfjärden (encircled) is one of only three bays that achieve good status for total phosphorous of the 175 locations that are investigated yearly along the coastline of Svealand.

Good ecological status in Björnöfjärden

During 2013 – 2017 (after the aluminium treatment), Björnöfjärden’s water quality has most often had ”good ecological status” according to the Svealands Coastal Water Management Association investigation programme⁷⁵. Twice a summer, samples are taken at 175 places located along the entire Svealand’s coast and range from the inner to the outer archipelago. When comparing water quality in recent years, it is clear that there are few areas that have as good water quality as Björnöfjärden (Table 2). For example, only two additional sampling sites (out of a total of 175) achieve good status for total phosphorus. On a couple of occasions during the period 2012 – 2017, according to the Svealand Coastal Water Management Association’s classification, it looks as if the conditions in Björnöfjärden have deteriorated. These occasions are due to periods of inflow of nutrient rich water from the outlying bays¹⁶.

TABLE 2. Summary of the Svealand Water Management Association status classification of water quality at 175 sampling points (of which Björnöfjärden is one) 2011-2017⁷⁵.

STATUS CLASSIFICATION WATER QUALITY			
Variable	Status of Björnöfjärden 2012	Status of Björnöfjärden (average 2012-2017)	Number of 175 sites with good status (average 2012-2017)
Total nitrogen	moderate	moderate	9
Total phosphorus	moderate	good	3*
Chlorophyll <i>a</i>	good/ moderate	good	14*
Secchi depth	moderate	good	5*

* Björnöfjärden is one of these.

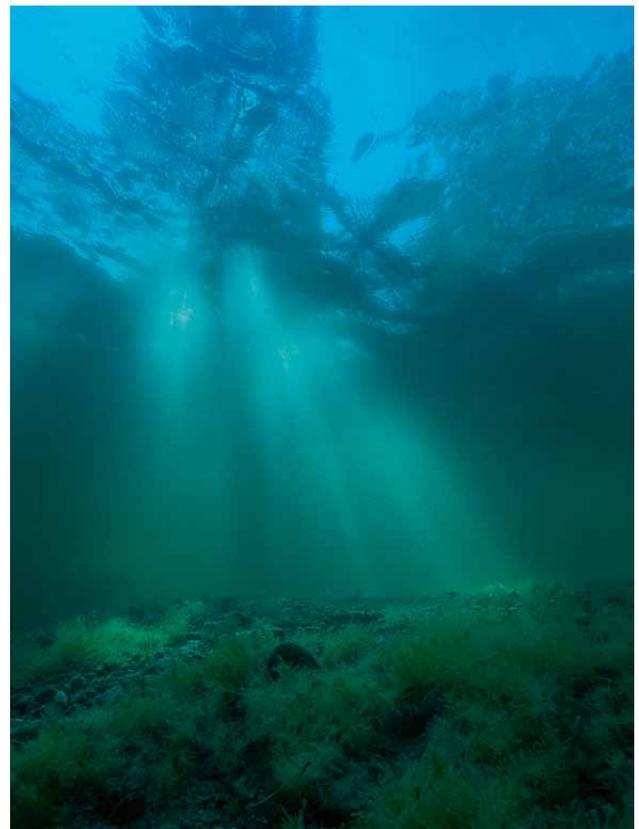


PHOTO: JOAKIM ODELBERG

▲ Water in Björnöfjärden. The photographs were taken before and after the aluminium treatment, at roughly the same depth (2-3 meters) but at different times of the year. The picture on the left is from April 2012 and the right from August 2013.

MORE LIFE IN BJÖRNÖFJÄRDEN

BEFORE....

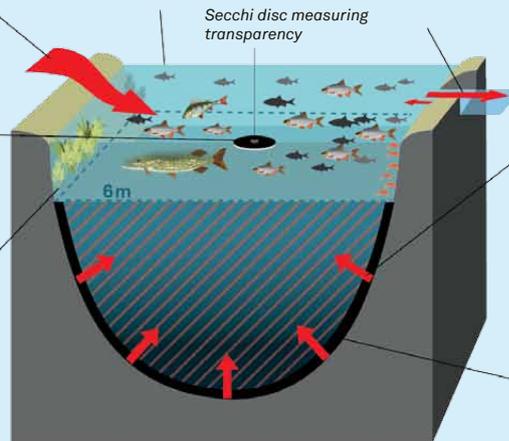
Nutrients make the bay eutrophic
A lot of nutrients from land reach the bay via ditches and waterways. The nutrients come, for example, from poor sewage systems, arable land and horse farms.

A lot of roach
The most common fish is roach. There are only fish down to six meters deep, where the water is oxic.

Nutrients are exported
There is a net export of nutrients from Björnöfjärden to the archipelago outside. The nutrients come both from land and from the sediment.

Turbid water
A lot of nutrients in the water contributes to a lot of phytoplankton that make the water turbid. Poor light conditions prevent vegetation from living on deeper bottoms.

Filamentous algae dominate
In the eutrophic bay, filamentous algae thrive covering rocks and outcompeting other bottom vegetation. Bladderwrack and vascular plants are scarce.



Phosphorus from the sediment makes the bay eutrophic
Anoxic sediment binds phosphorus poorly. The phosphorus is released to the water and contributes to eutrophication. It leads to even stronger growth of algae that need to be broken down, and thus greater spread of anoxic bottoms. A vicious circle develops.

The bottom is dead
From six metres deep, it is completely oxygen-free. Here, neither fish nor small animals can survive. Only microorganisms can live here.

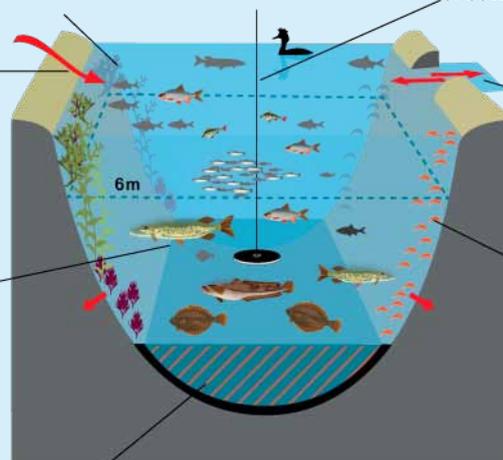
AFTER....

Vegetation spreads
Clearer water means that the bottom vegetation can live deeper. Bladderwrack and vascular plants have become more common. In these environments, small animals and fish fry thrive.

Reduced nutrient supply
Measures on land have reduced the nutrient supply. In order for the improved environment to persist, the nutrient supply must not increase again.

More pike
There are more fish in the bay. The pike wetland helps to strengthen the bay's pike stock.

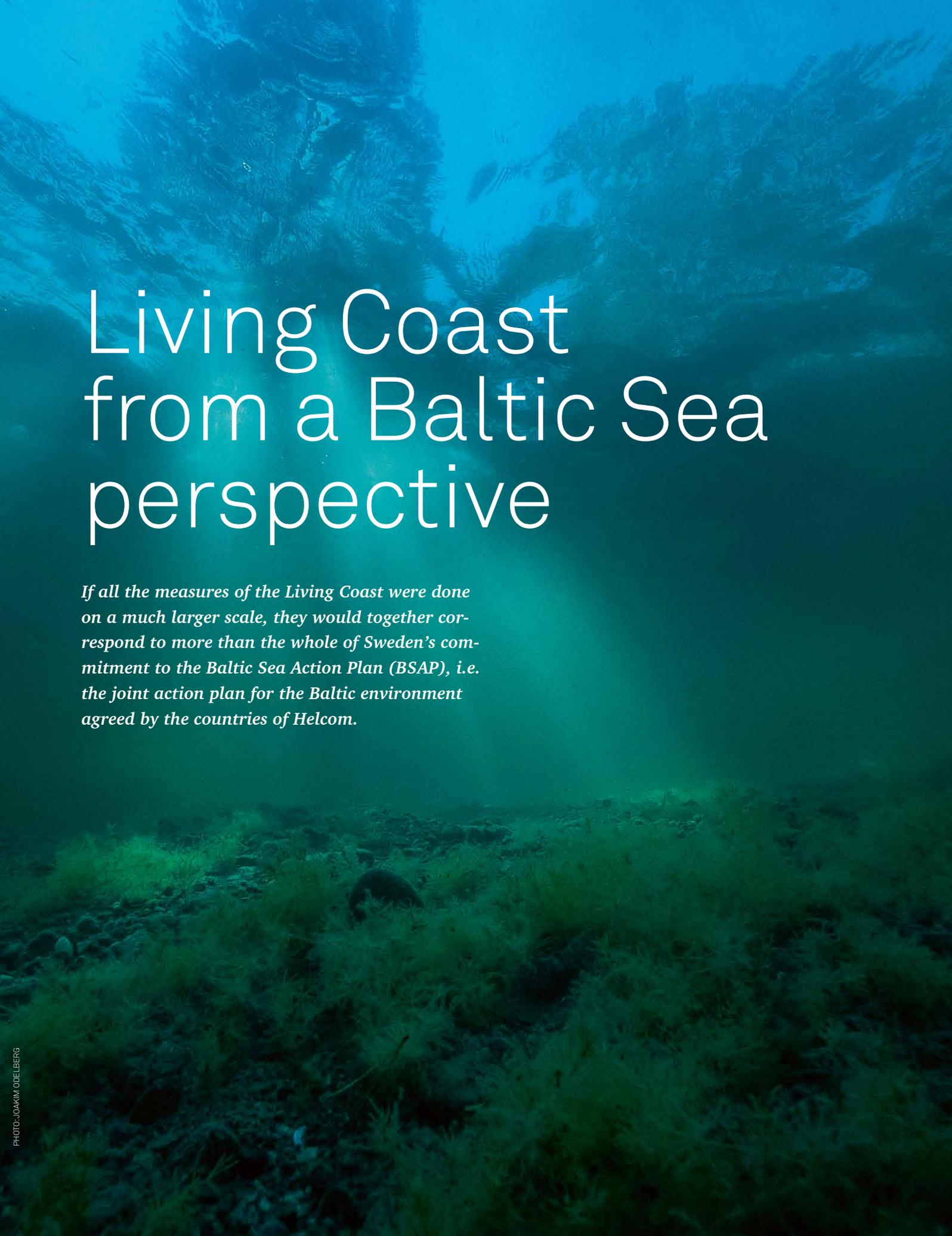
Internal load stopped
After the aluminium treatment, the phosphorus stays in the sediment and the growth of algae has decreased. When a small amount of organic material needs to be decomposed, there is more oxygen left in the bottom water. However, in the deepest areas there is still oxygen deficiency. It will take many years before it gets better here.



Water is clear
Halved phosphorus content in the water gives a halved amount of phytoplankton and thus clearer water. The sunlight reaches further down and contributes to an increased spread of bottom vegetation.

Reduced nutrient transport
The measures have reduced the supply of nutrients from land and sediment. The export of phosphorus from Björnöfjärden to the archipelago outside has been halved.

Bottoms are recolonised
Better oxygen conditions at the intermediate-depth bottoms allow fish and bottom-dwelling animals to live here again.

An underwater photograph showing a rocky seabed covered in green algae. A small fish is visible in the upper right. The water is clear and blue-green.

Living Coast from a Baltic Sea perspective

If all the measures of the Living Coast were done on a much larger scale, they would together correspond to more than the whole of Sweden's commitment to the Baltic Sea Action Plan (BSAP), i.e. the joint action plan for the Baltic environment agreed by the countries of Helcom.



◀ To ensure that the Baltic Sea will continue to be a healthy sea we can all use, action on land and in water is required, as well as cooperation across all borders and patience.

750 tonnes less phosphorus per year to Baltic Sea water

The primary objective of the Living Coast project was to show that good ecological status can be recovered in an enclosed bay. Another goal was to calculate potential, effects and costs on the basis of Living Coast's results if the measures around Björnöfjärden were to be applied on a large scale. In addition to results from Björnöfjärden, calculations are based on analyses and investigations. They are described briefly on pages 56–57, and in more detail in the complete Living Coast White Paper.

Measures on land

If the land-based measures carried out around Björnöfjärden were to be implemented on a large scale, for example in the North and South Baltic Sea water districts or along the coast of the Baltic proper, phosphorus leakage to the Baltic Sea would decrease by around 200 tonnes of phosphorus per year. The total cost of land measures is estimated at over SEK 30 billion, where measures on horse farms account for more than half.

Even if the land measures were to be implemented to this extent, they would still only represent around 1 per cent of the total phosphorus load from the catchment area to the Baltic Sea, which amounts to about 32,000 tonnes of phosphorus per year, of which about half is to the Baltic proper. Furthermore, the phosphorus load from the catchment area consists partly of hard-bound phosphorus, which probably contributes to a relatively small extent to eutrophication. In the choice of measures, therefore, measures to reduce dissolved phosphorus (phosphate) should be prioritised, as they provide a greater effect.

Sea-based measures

If anoxic accumulation bottoms in the Swedish coastal zone of the Baltic proper, which are assumed to release phosphorus, would be addressed with aluminium treatment in the same way as in Björnöfjärden, an annual phosphorus turnover of about 550 tonnes is estimated to be stopped. The cost of the measure is estimated to be around SEK 3 billion.

Despite the fact that the treatment cost of resolving the internal load is much lower than the cost of land measures, it is not enough to fix the phosphorus that leaches from the bottoms. Nutrient supply from land must also decrease, otherwise new nutrients will soon accumulate in the sediment again, which again begins to leach out and regulate eutrophication.

How much action is required?

An important question is how much phosphorus reduction, both from land and sediment, that is needed in order to stop the spread of anoxic bottom areas and start reducing so that sediments can begin to store phosphorus bound to iron again.

It is a complex issue that cannot be answered here, but the possible reduction in load in different areas and activities can also be made against, for example, Sweden's reduction quota in BSAP. In such a perspective, the coastal zone is a filter for, among other things, nutrients and organic matter between land and sea.

Choice of action method

When selecting the method of action, the cost of treatment often plays a significant role, but an important experience after implementing measures on a broad scale within the Living Coast is that there are many more factors that determine whether or not a measure is ultimately effective. It is not possible to strictly rank which action is better than another. In each action situation, a catchment area perspective is needed to get an overview of both the load situation and the action potential. Based on this, action plans need to be adapted to the specific location and in the choice that measures factors such as feasibility, the need for supervision and maintenance, the operating costs, the treatment effect in relation to action potential, proportion of eutrophication-driving phosphorus that the measure reduces, etc. need to be taken into account.

The table below summarises what Living Coast's measures could mean for the Baltic proper if they were implemented on a large scale and what it would cost. The table also compares the measures with regard to different aspects/experiences for each measure.

READ MORE ABOUT...

experiences and reflections from the work on measures to combat eutrophication in the complete Living Coast White Paper.

TABLE 3. Summary of the action potential, action effect and cost of action for various sources of phosphorus and measures carried out within the Living Coast if measures were to be implemented on a large scale. The table also compares the actions based on other aspects. When comparing, a three-degree colour scale (green, yellow, red) is used to try to summarise how well an action is from different aspects.

Source:	Clay soils	Horse keeping	Small sewage systems	Internal load (sediment)
Where:	N. and S. Baltic Sea Water Districts	N. and S. Baltic Sea Water Districts	Coastal areas of S. and N. Baltic Sea Water Districts	Baltic proper coastal zone
What:	Structure liming of all arable land with clay content over 20 %.	Daily manure clearing in pastures and safe manure disposal.	Change to sewage systems where toilet waste is collected and transported away.	Aluminium treatment of accumulation bottoms.
Action potential (ton P/year)	351	83	23	549
Action effect (ton P/year)	105	75	21	549
	30 %	90 %	90 %	100 %
Action cost (SEK m)	≈ 4200	≈ 23 300	≈ 4700	≈ 3100
Treatment cost at the coast (SEK/kg P)	≈ 2000	≈ 15 500	≈ 100 000	≈ 800
Acceptance of action				
Knowledge gaps	10-30 years?			red?
Implementation*				
Care and operation	never	daily	once in a while	never
Eutrophication-driving phosphorus**	40-80 %	100 %	100 %	100 %
Response time for action in water/recipient				
Summary positive aspects	Effective and well-known action. Can increase the yield.	Easy way to make the most of nutrients and avoid nutrient losses.	Effective and established measure. Also has a positive effect on drinking water.	The only established internal load measure. Well known for freshwater and promising for coastal areas.
Summary of negative aspects	Only works on soils with high clay content. Unclear how long the effect lasts (10-30 years).	Labour intensive. Little measurement data and lack of consensus on eutrophication effect. Expensive to install a new manure slab.	Little measurement data and lack of consensus on eutrophication effects. Expensive for private persons.	First effort in brackish water. Important to evaluate the long-term effect in Björnöfjärden. Aluminium is energy-intensive to produce.

* The possibility of bringing the measure into being (need for permits, the importance of finding suitable contractor, requirements on specialist knowledge, etc.)

** The bioavailability of the phosphorus that each action reduces, i.e., percentage of dissolved phosphorus (phosphorus of total phosphorus).

How we calculated nutrient losses and action potential

Clay fields

Structural liming of fields in the North and South Baltic Sea water districts can reduce phosphorus load on the Baltic Sea by 105 tonnes of phosphorus per year (30 per cent, see Figure 22). The cost is estimated to be just over SEK 4 billion (SEK 5900/hectare) and from a coastal zone perspective, the treatment cost is about SEK 2,000/kg of phosphorus.

STRUCTURE LIMING
Reduction: 105 tonnes P/year
Cost: approx. 4 billion SEK

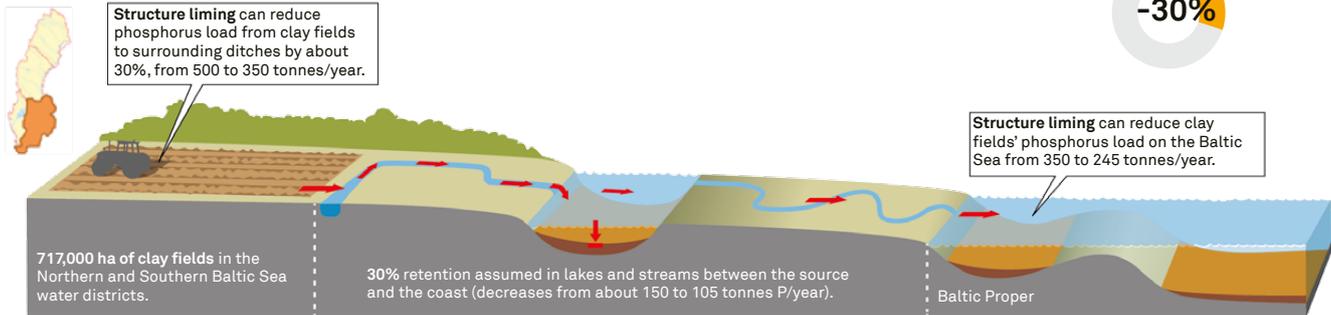


FIGURE 22. Field area with a higher clay content than 20 per cent has been estimated from SGU's arable land map (DSMS) and Statistics Sweden's statistical data on fields' utilisation³⁸. Assuming an average leakage of 0.7 kg phosphorus per hectare and year³⁹, the phosphorus loss is about 500 tonnes per year. At an average retention rate of 30 per cent from the field to the sea, about 350 tonnes of phosphorus per year reaches the Baltic Sea proper's coastal zone. If clay fields are structure limed, phosphorus losses are expected to decrease on average by 30 per cent, and the effect remains for 20 years, reducing exports to the coast by about 105 tonnes of phosphorus per year.

Horse keeping

If all pastures in the North and South Baltic Sea water districts were cleared of manure daily and the manure is taken care of, so that the nutrients in the manure does not reach the surrounding ditches, the phosphorus load can decrease by around 75 tonnes per year (Figure 23). The total cost is estimated at about SEK 23 billion, assuming that it costs approximately SEK 2,000 per kilogram of phosphorus that is taken care of on the horse farm, and that the measures are effective during a 20 year period. From a coastal zone perspective, the cost is approximately SEK 15,000 per kilogram of phosphorus. The proportion of phosphorus in the manure that is presumed to be permanently bound in the soil in the pasture will have a major impact on how much horse keeping contributes to the eutrophication of the Baltic Sea. The size of the costs will depend on the need to set up new manure slabs, which is costly.

MEASURES HORSE KEEPING
Reduction: 75 tonnes P/year
Cost: approx. 23 billion SEK

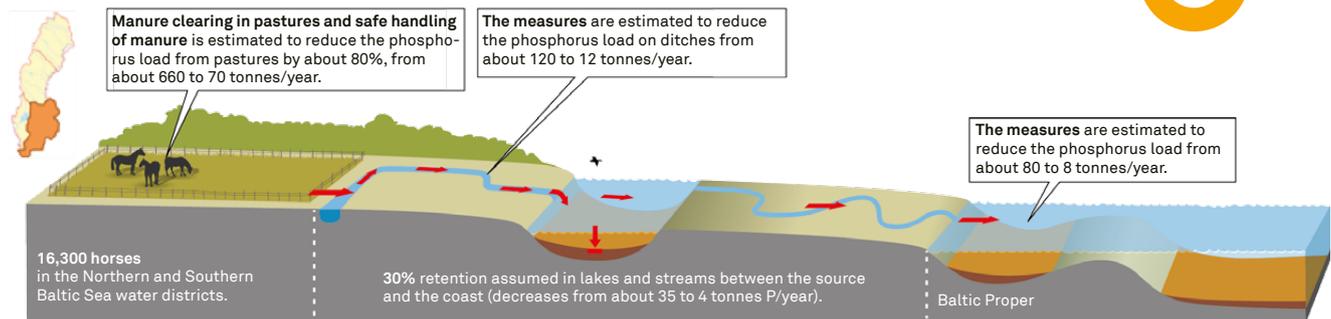


FIGURE 23. As an average horse produce approximately eight kilograms of phosphorus per year^{47,52}, horses in the North and South Baltic Sea water districts⁴⁷ produce more than 1,320 tonnes of phosphorus per year in the form of manure. If horses are in pastures for half of the day⁷⁶, half of the nutrients are produced outdoors, and about 660 tonnes of phosphorus per year are added to the soil if the pastures are not cleared from manure. Of the phosphorus that is added to the soil, 80-90 per cent is assumed to be bound permanently in the soil; a larger share of pastures in rural areas where the density of horses is assumed to be lower and the ground cover is assumed to hold better and leak less. The rest, about 120 tons of phosphorus per year, is assumed to reach ditches. At an average retention of 30 per cent from pastures to the shore, about 83 tons of phosphorus per year reaches the coast. If 90 per cent of the phosphorus that loads the pastures (660 tonnes/year) is taken care of, about 67 tonnes/year remain, of which about 12 tonnes are assumed to reach ditches, and 8 tonnes finally reach the coast.

Small sewage systems

SWITCHING TO A CLOSED TANK
Reduction: 21 tonnes P/year
Cost: approx. 5 billion SEK

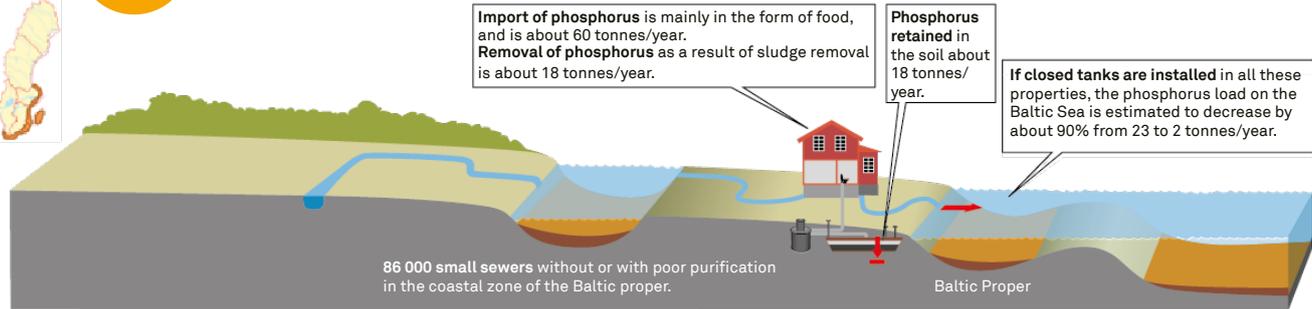


FIGURE 24. There are almost 86,000 properties with small sewage solutions along the coast of the North and South Baltic Water Districts' coastal zone⁵⁸. Based on data on the number of homes per property, distribution between year-round housing and holiday housing, time at home, average treatment for different types of technical solutions and sewage fractions that are removed via sludge and latrine emptying, these properties annually import 60 tonnes of phosphorus in the form of food, of which 18 tonnes are exported from the coastal zone mainly through desludging⁵⁸. An additional 18 tonnes of phosphorus is estimated to be permanently bound in the soil and the remaining 23 tonnes of phosphorus per year are estimated to load coastal waters. If the nutrients from these properties instead are removed from the coastal zone to 90 per cent, for example through the installation of closed tanks, the leakage is reduced from 21 tonnes of phosphorus per year to 2 tonnes of phosphorus per year.

ALUMINIUM TREATMENT
Reduction: 550 tonnes P/year
Cost: approx. 3 billion SEK

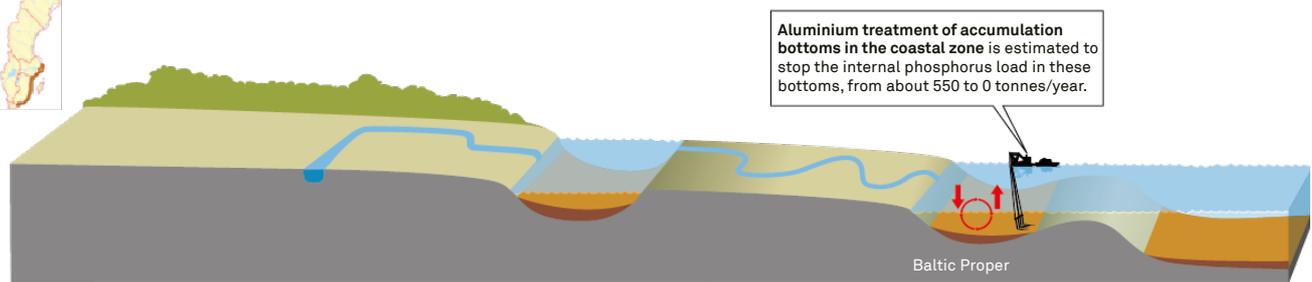


FIGURE 25. The area of the bottom areas to release phosphorus in the North and South Baltic Sea water districts' archipelagos was assumed to be the area where fine-particle nutrient-rich material accumulates (accumulation bottoms), which was estimated to be about 1,540 km²⁷⁷. Assuming that these bottoms contain on average 2.5 tonnes of mobile phosphorus per km², the sediment in these bottoms is calculated to contain about 3,840 tonnes of phosphorus likely to leach out, which on average is turned over every seven years⁷⁸. It provides a leakage of dissolved phosphorus of 550 tonnes of phosphorus per year. If this entire area were to be treated with an aluminium dose equivalent to that of Björnöfjärden (50 tonnes Al/km²), the phosphorus turnover would cease completely.

Conclusions and recommendations

After seven years of work with eutrophication measures, measurements and evaluation, the Living Coast project can conclude that:

IT IS POSSIBLE TO REGAIN GOOD ECOLOGICAL STATUS IN ENCLOSED BAYS!

- The internal phosphorus supply from the sediment must be addressed in order to get a quick improvement, while the nutrient supply from the catchment area must be minimised in order for the effect to persist.
- However, in order to have a clear local effect of actions taken, the water exchange must be limited, otherwise the effect diminishes quickly when the water is mixed with nutrient-rich water from surrounding bays.
- Eutrophication is driven by dissolved phosphorus and nitrogen that is added to the water, regardless of where the nutrients come from. Most phosphorous forms in soil and sediment are stable and contribute to a small extent to eutrophication. Measures to minimise the supply of dissolved phosphorus and nitrogen should be prioritised.



REMEDICATION WORK IS DIFFICULT

- For effective remediation work, clear goals, adequate competence, financing and patience are needed.
- To appoint a "catchment officer" to be assigned decision-making mandates and financial resources provides strength in the implementation of actions.
- The catchment area's perspective is important, but site-specific knowledge is also needed to identify the major nutrient sources and cost-effective measures.
- Strive for work based on smaller catchment areas instead of by county or municipality. Gather land users, landowners, municipalities, ditch companies, water councils and action coordinators to get a common overview, for example to walk along watercourses in the catchment. Continuous sampling and evaluation is also needed to make the work effective.

TO INCREASE THE PACE OF ACTION, THE FOLLOWING IS NEEDED:

- Clear incentives to reduce nutrient losses
- Increased inspection rate and the opportunity to receive counselling
- Possibility to receive support financing for initial investments
- Clear goals and positive examples

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This book presents the results of the **Living Coast project** in Björnöfjärden, Stockholm archipelago. The bay that can be described as a “miniature Baltic Sea” because of extensive eutrophication, limited water exchange and large areas of anoxic (oxygen depleted) bottom waters. After seven years of work and remediation actions, the bay’s water quality has become much better and plant and wildlife are recovering. The project was initiated by BalticSea2020.

The BalticSea2020 Foundation was founded in 2005 and finances projects that are action-oriented, innovative and contribute to a healthier Baltic Sea. The foundation also works to disseminate knowledge and information about the Baltic Sea to decision-makers, authorities, schools and individuals.

The aim is to improve the environment in the Baltic Sea by the year 2020, thereby improving the quality of life for the approximately 90 million people living around the Baltic Sea.



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