EcoChange.

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Umeå University

Linnæus University

CONTENTS

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COVER PHOTO: The coastal pike seems to have an inherent capacity for adaptation that allows it to survive in a changed environment.

EcoChange aims to increase awareness of the consequences of climate change in aquatic systems, and in the long term motivate authorities to introduce effective measures to address the effects of climate change.

THE STARTING POINT is that climate change affects the temperature, salinity and concentrations of dissolved organic carbon and nutrients in the Baltic Sea. This leads to a deterioration in food web efficiency, and thus an increased accumulation of contaminants in marine organisms.

FOOD WEB EFFICIENCY is a key concept within EcoChange, and is also an indicator of a healthy ecosystem. The food web efficiency can be altered by changes in, for example, species diversity, productivity, food web dynamics, population structure, amount of steps in the food web, evolutionary processes, and contaminants in the ecosystem.

THE BALTIC SEA consists of several basins, which have fundamental differences in hydrological conditions and food web structure. Specific studies in the different basins are important for projections of future conditions. The gradients in salinity, temperature and other variables are an important part of the EcoChange research. Umeå and Linnaeus Universities collaborate in field work, laboratory experiments and modelling.

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IN THE SPIRIT OF THANKS

I have had the privilege to the Ecochange coordinator since the start of this research environment. Through the years, a great many people have contributed in various ways to make Ecochange what it is today, and they have strived to increase our understanding of the Baltic Sea ecosystems in the era of climate change.

While writing the application at the start of Ecochange, we received incredible support from the Grants office at Umeå University. They helped to clarify the issues surrounding building a new marine research environment with the EcoChange program. The application was evaluated by an international expert group, and we received a very good evaluation. The program was first granted during a 5-year period and later, after a very good evaluation, we were granted an extension of another 5 years.

In the past ten years, several prominent researchers have since retired. They have meant a lot for Ecochange, by encouraging us and paving the way for younger researchers. They have been our role models. They have helped us with research networks and supported our efforts to carry out marine research and train young excellent researchers.

The universities apply a functioning and well-thought-out management of EcoChange, where the board consists of, among other things, high-level university representatives. The collaboration between Umeå University and Linnaeus University has also been a factor of success for the environment. Thanks to a large commitment from researchers from both universities, the collaboration has been characterized by consensus and a common goal.

Thanks to a great commitment from researchers from both universities, the collaboration has been characterized by consensus and a common goal.

To guide the focus and assess the relevance of our research, EcoChange has a reference group made up of representatives of the marine environment management. Many sub-projects within EcoChange have been developed in close collaboration with these representatives and other environmental officials. This has been a success factor for our research. The reference group has also contributed wise opinions and interesting arguments during the annual conferences organized by EcoChange.

In this type of larger research environment, where many actors are involved, the administrative and financial work is complex. Thanks to skilled administrators and a well-functioning contact network within the environment, we've managed to work together successfully. We have scientifically knowledgeable communicators connected to the environment who, through their professional work, strongly contribute to disseminating the research results to a wider audience.

I am also very proud that we within EcoChange have trained young excellent researchers to receive their doctoral degrees. It is an enthusiastic bunch that contributes innovation and energy to the research environment. They constitute a new generation of marine environmental scientists, who can lead the research forward at a time when well-founded knowledge of the marine environment is more important than ever. ●

WATER TRANSPARENCY CAN LEAD TO ERRORS IN MEASURING WATER STATUS

Immersing a standard, white disc into the water is a way to measure water transparency quickly and easily. However, this method can lead to serious sources of error caused by optical components when measuring eutrophication.

Measuring water transparency is easy and inexpensive, and the results are used to assess the status of eutrophication in the Baltic Sea. However, the method can lead to serious errors if disparities in the optical properties are not taken into account.

Eutrophication is one of the greatest challenges when trying to achieve good water quality in the Baltic Sea. To assess the status of eutrophication a variety of parameters are measured, including nutrient concentration, oxygen conditions and phytoplankton community composition. Other important parameters are chlorophyll-A concentration and water transparency. In both the EU Water and Marine Environment Directives, water transparency and chlorophyll concentrations are used for assessing eutrophication status along with the other parameters.

Easy and inexpensive

The reason that water transparency is used to assess eutrophication status is its coupling to the amount of phytoplankton in the water.

In the case of eutrophication, the amount of phytoplankton in the water increases and the water becomes turbid, which reduces the depth of view. The amount of phytoplankton can be measured indirectly by analyzing the water content of the pigment chlorophyll-a, which all phytoplankton contains.

Water transparency is measured by immersing a standardized white disc into the water until it is no longer visible to the eye. Measuring in this way is simple and inexpensive, and is used as a standard method in environmental monitoring.

Serious sources of error

However, new studies show that there may be serious sources of error in using this method to assess eutrophication, due to optical components not linked to eutrophication.

Water transparency depends in part on the amount of chlorophyll in the water, but there are also other factors that affect the optical properties of the water. This applies to the entire Baltic Sea, but especially to the Baltic Sea coastal areas.

The Baltic Sea is an inland sea, strongly affected by a large influx of river water, and has a slow turnover. In the coastal areas in particular, the optical conditions are affected by the river water and the suspended particulate matter that accompanies the river water out into the sea. The river water contains a large amount of organic material, which colors the water brown and adds particulate matter. This particulate matter can either absorb or scatter the light in the water, depending on whether it is completely dissolved in the water and whether the particles are organic or inorganic.

Especially misleading in coastal areas

There are substantial differences in optical properties between different areas of the sea, and also between different seasons. In coastal areas, the water content of dissolved organic matter and particles can even have a greater impact on water transparency than chlorophyll concentration has. This can lead to errors in reference values for water transparency with major consequences for, for example, what measures to take. For marine management authorities, it is therefore of the utmost importance to know the natural variation in water transparency in different areas and, above all, what causes it, and to adjust reference values and limit values with regard to the natural optical properties of the water.

Harvey, E. T., Walve, J., Andersson, A., Karlson, B., & Kratzer, S. (2019). ***The effect of optical properties on Secchi depth and implications for eutrophication management.*** Frontiers in Marine Science, 5, 496. The study is largely financed by the Swedish National Space Agency.

COSTLY TO OVERLOOK BACTERIAL RESPIRATION

In areas of low productivity, such as the Bothnian Sea, a reduction in nutrients does not necessarily lead to improved oxygen status. Bacteria, which are the largest oxygen consumers in the sea, will continue to consume as much oxygen despite a decrease in nutrients. And the high costs for nutrient reducing measures risk being tossed into the sea.

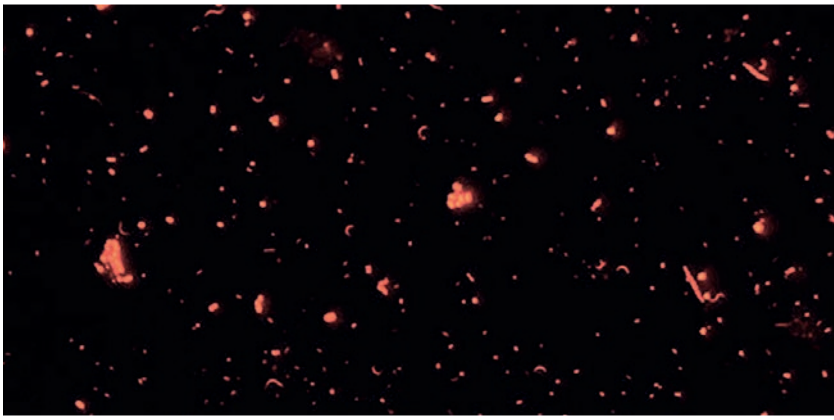
Bacteria are the largest oxygen consumers in the seas. Through their respiration, they account for over half of the ocean's oxygen consumption. Thus, they play a key role in the problem of oxygen deficiency in different sea areas around the world. Despite this, bacterial respiration has been overlooked when discussing measures against hypoxic bottoms. Instead, the nutrient status has been at the center of the discussions, and expensive measures have been put in place to reduce the amount of nutrients supplied to the seas in areas where oxygen levels are low.

Discarded measures?

Nutrients are central to high-productivity areas with eutrophication problems. By reducing the amount of nitrogen and phosphorus there, you can improve the oxygen status, although it may take time to achieve the desired results. But in low-productivity areas, such as the Gulf of Bothnia, this type of measure may be futile. It can take years before effects are measurable and thus years before it is clear whether the efforts were fruitful or if the costs were literally thrown into the sea.

Respiration maintains life functions

The explanation as to why nutrient reduction may be ineffectual lies in the different types of bacterial respiration, and above all their maintenance respiration. Maintenance respiration is defined as the respiration that is in progress even though growth in the bacterial community is low. This maintains vital functions in the bacteria, just as how humans must breathe to live. More than half of the bacteria's respiration is maintenance respiration.



Bacteria are everywhere in the world's oceans. Through their respiration they account for over half of the ocean's oxygen consumption.

Unchanged oxygen consumption

Maintenance respiration appears to be relatively independent of nutrient status in the field, and is not affected significantly by limiting emissions of nitrogen and phosphorus. This is because bacteria switch to a higher degree of maintenance respiration during low-nutrient conditions. Bacterial respiration per cell even seems to be able to increase as nutrient levels reach starvation levels, perhaps as a way to increase the effort to find food.

What activities do the starving bacteria use the consumed oxygen for? This is one of the many bacterial respiration questions that remains unanswered, and more research is needed. However, bacteria maintenance respiration is a factor to take into account when determining measures to be taken, especially in low-productivity areas such as the Gulf of Bothnia. Otherwise, there is a risk that the measures will not have the desired effect on oxygen status that we strive for. ●

Vikström, Kevin; Wikner, Johan 2019. ***Importance of Bacterial Maintenance Respiration in a Subarctic Estuary: a Proof of Concept from the Field***. Microbial Ecology, Springer 2019, Vol. 77, (3) : 574-586.

ECOCHANGE SUPPORTS SEA AND WATER MANAGEMENT

How does climate change affect the Baltic Sea's ecosystem, and how should this be handled in relation to other impacts? Elisabeth Sahlsten, in her role as senior analyst at the Swedish Agency for Marine and Water Management, struggles with these questions.

Elisabeth Sahlsten, senior analyst at the Swedish Agency for Marine and Water Management, is a member of the Ecochange reference group. She values the opportunity for the authorities to access research results.

Elisabeth Sahlsten is a member of the EcoChange reference group, and has participated in a number of the research program's conferences.

"It is very rewarding to learn about the latest research findings from EcoChange, and to also have the opportunity to discuss the results from a management perspective," says Elisabeth.

Microbial food web

In particular, she wishes to highlight the part of the research that deals with the microbial food web, and how it may be affected by a changing climate.

"It is very important to understand the basic processes going on there, which can then have effects in higher parts of the food web. I really appreciate that the research focuses on the microbial processes, which are the basis for the circulation of nutrition and energy within the ecosystem. For example, research within EcoChange has clearly shown how the finely tuned balance between bacteria and phytoplankton is disturbed in a changing climate, and how it then affects all levels up to fish."

Hazardous substances in the food web

Another area of research that concerns Elisabeth is hazardous substances, and how these end up in the different parts of the food web.

"The links between hazardous substances and the food web are extremely important to understand to be able to implement measures and manage our seas well. The studies done within Ecochange where you can now follow the path of various hazardous substances into the food web and further on, I see as central."

This article is based on an interview with Elisabeth Sahlsten from February 2020.

Future challenges

Elisabeth points to some areas where even more action is needed. One of these areas is multiple stressors, that is, the effect of different environmental problems simultaneously affecting marine life.

Exploitation of coastal areas is another challenge that requires strong management, and something that concerns Elisabeth. Exploitation is increasing, and shallow coastal environments that are important for the ecosystem are under threat. More research is needed that shows the importance of protecting these areas and the risk of exploitation.

Important method development

But it's not all about gaining more knowledge about how the ecosystem works. Elisabeth is careful to also emphasize the important role of research in developing new monitoring methods.

"Here, research has a very important role in developing methods that can facilitate environmental monitoring and make it even more efficient. We need methodology to be able to investigate the complicated processes in the ecosystem and how they are affected by environmental disturbances."

Continued cooperation

Marine and water management faces major challenges, and needs a great deal of support from research to monitor, protect, and manage in the right ways. This is where research programs like EcoChange come in, and Elisabeth looks forward to continued cooperation.

"Marine and water management needs the research to get a complete picture of the situation. We hope that EcoChange will continue to produce important research on our marine environment, and that we will continue to be able to share results and participate in discussions on the application of these results within marine and water management authorities.

ORGANIC POLLUTANTS CAN AFFECT MARINE BACTERIA

It is well known that organic pollutants can negatively impact humans and animals. But how do these pollutants affect bacteria, the very smallest organisms in the food web?

Bacteria play a key role in the marine ecosystems, using organic molecules as a source of nutrition and energy. Among other things, they have the ability to use dissolved organic carbon, which is one of the largest stocks of carbon in the seas. It would be conceivable that the bacteria could benefit from organic pollutants by breaking down and consuming organic molecules as food, unless the bacteria are adversely affected by the toxins. So far, knowledge about this is limited.

Previous studies have shown that both phytoplankton and cyanobacteria can be adversely affected by environmental pollutants, and cocktail effects have also been shown on these organism groups, that is, mixtures of toxins can have a greater impact than the sum of each individual substance.

Testing common bacteria

The EcoChange researchers investigated how organic pollutants affect marine bacteria. They chose to study a specific bacterium, *Rheinheimera* sp. BAL341. This bacterium is commonly found in the seas, and has previously been shown to respond to changes in the environment. The pollutant test groups were all chemicals found in the marine environment, such as PAHs, alkanes, organophosphates and PFAS. By examining both direct effects on growth and effects on the gene expression of the bacteria, the researchers expected to find both positive and negative effects.

Inhibited by toxins

However, results showed no positive effect on the growth of the bacteria. Instead, adverse effects were noted, suggesting that the chemicals had a toxic effect on the bacteria. When the bacteria were exposed to the toxins at the same concentrations as those found in the marine environment, the growth and production of the bacteria were inhibited.

The environmental toxins not only had a direct effect on the bacteria, but were also found to alter the gene expression of the bacteria. The toxins thus appeared to initiate processes in the bacteria, possibly in defense of the toxic effects of the substances.

Missing gene

We know that many microorganisms have genes to break down PAH substances, but that they still can be negatively affected by these substances. *Rheinheimera* sp BAL341 lacks the gene to break down PAHs, which may be an explanation for the negative impact the PAHs had on the bacterium.

Important information

PFAS is a group of substances that have only recently been recognized for their worldwide spread and persistence. There are many chemicals in this group, all of them very hard to break down. For example, there are no reports that PFOS and PFOA can be broken down under natural conditions. This is one explanation that the substances have spread so widely.

In the experiments with *Rheinheimera* sp BAL341, PFAS had no effect on the growth during the short time that the experiments were performed. However, a clear effect on gene expressions could be demonstrated. These results suggest that prolonged exposure, as is the case under natural conditions, could affect the growth of the bacterium. The results also show the value of using the modern technology for gene expression studies to detect environmental toxicity problems before they have effects on the ecosystem.

How do environmental toxins affect marine bacteria? The commonly occurring bacterium Rheinheimera sp. BAL341 was used to investigate this question.

Karlsson, Christofer M. G.; Cerro-Galvez, Elena; Lundin, Daniel; et al. 2019. ***Direct effects of organic pollutants on the growth and gene expression of the Baltic Sea model bacterium Rheinheimera sp. BAL341***. Microbial Biotechnology, WILEY 2019, Vol. 12, (5) : 892-906.

OLD SINS CAUSE NEW PROBLEMS

Dioxins in herring do not decrease at the expected rate, despite the fact that many sources of air pollution have reduced emissions. Earlier chlorophenol use may be part of the explanation.

The dioxins are formed as pollutants in various processes. They are persistent, and hardly change when transported by air, water and bound to particles.

Dioxin concentrations in the Baltic Sea have long been so high that the sale of fish as food for both humans and animals is outlawed in the EU. In humans, dioxins are suspected to affect reproduction and the immune system, and also appear to cause cancer. They bind to organic matter and fat, and can therefore accumulate in animals with high fat content, such as herring.

This is a well-known and widely discussed environmental problem for the Baltic Sea. When the dioxin problem was discovered in the 1970s, measures were put in place, and levels in fish have dropped since then. In recent years, however, the declining rate of these toxic levels has been less pronounced, and the composition of dioxins in herring has changed. What sources are most important today? Why has the composition changed and why do toxic levels in fish not decrease faster?

Formed during combustion

Dioxin is not just one substance, but a collective name for hundreds of different substances. The various dioxins, and their related dibenzofurans and biphenyls (PCBs) have very similar basic structures, with various numbers of chlorine atoms bound to them. How the chlorine atoms are placed in the molecules determines whether they are classified as dioxin or dioxin-like substances and importantly, their toxicity. Different sources have different composition and the composition of the dioxin mixture tells you where the dioxins come from.

The dioxins are formed as pollutants in various processes, usually under high temperatures, for example in waste incineration and metal production. Chlorophenols, which were previously used to prevent fungal infections in the timber industry, also contain high levels of dioxins. The use of chlorophenols in Sweden has been prohibited for over 30 years, but the dioxins remain in the soil or in nearby sediments in a large number of places where chlorophenol was previously used.

Researchers track the sources

For many years, EcoChange researchers have focused on dioxins and closely related substances, and have developed methods for tracing the sources of the dioxins found in the marine environment. Developments in the environment have also been closely monitored, and concentrations in the physical environment have decreased as emissions to the air have decreased. But the dioxin mixtures found in the physical environment are not the same as those found in herring, and the decline seen in the physical environment is not as clear when it comes to the levels in herring in different parts of the Baltic Sea.

Unclear sources

The dioxins are persistent, which means that they hardly change when transported by air, water and bound to particles. But even though the substances are stable, the different forms of dioxins are absorbed to different degrees and metabolized differently in the fish. This means that the composition of dioxins changes when they enter the herring, making it more difficult to determine the source of the dioxins in the fish. The results from herring are therefore more difficult to interpret, but by linking the results from concentrations and composition in herring with the previously known patterns for different dioxin sources, the researchers have been able to draw some conclusions about the sources of the dioxins in the herring.

Leakage is ever important

Dioxin emissions from various forms of combustion are decreasing, but still account for a large proportion of dioxins in herring. Sweden accounts for about a third of the deposition of dioxins from air, so measures in other countries are therefore also important in reducing levels. In recent years, dioxins derived from chlorophenols of various kinds appear to constitute an increasing proportion of the dioxins in the herring. Leakage from sediments or directly from contaminated areas on land seems to be an increasingly important contribution to the dioxins in the fish.

To some extent, this may be a result of remediation measures for air emissions given priority over leakage from coastal contaminated soils and sediments. Changing levels may explain why the current trend is slowing down compared to twenty years ago. If the growth of the herring decreases, a fish of a certain length will be older, and thereby have stored more dioxins in its body. Changes in composition may have several physical and ecological explanations linked to various possible sources. Factors such as increased runoff with increased land leakage, altered food choices in marine organisms, new species, altered food webs and other ecological factors affect uptake and transport in the food chain, and may result in a changed composition in fish. ●

Due to high dioxin content in herring from the Baltic, it is not allowed to export the fish within the European Union.

Assefa, Anteneh; Tysklind, Mats; Bignert, Anders 2019;. ***Sources of polychlorinated dibenzo-p-dioxins and dibenzofurans to Baltic Sea herring.*** Chemosphere, Elsevier, Vol. 218 : 493-500.

FISH EMBRYOS DISPLAY COCKTAIL EFFECTS

In the Gulf of Bothnia there are areas that have been heavily burdened by industrial activities, and where the bottom sediment contains a variety of environmental toxins. The problems with polluted sediments are well known, but how toxic are they?

The sediments of the seabed serve as large sinks for a variety of environmental toxins.

To find out, it is not enough to measure which chemicals are in the sediment. The toxicity and effects of individual substances on the ecosystem may be relatively well-known, but it is much more difficult to assess the so-called cocktail effect, i.e. the effect of mixtures. Is one plus one always two, or can the combinations of different substances increase or decrease toxicity?

Examining toxic sediments

A group of EcoChange researchers investigated the sediments from Kramfors, Örnsköldsvik and Sundsvall. The areas are in the Bothnian Sea, and have a long history with sawmill industry, pulp industry and other industrial operations. The sediments within these marine areas are heavily burdened by various environmental toxins. To get a picture of the sediment's potential impact on the ecosystem, the researchers used newly fertilized zebra fish embryos.

Fish embryos provide answers

The aim of the study was to investigate how much information about toxicity and effects can be obtained by using the so-called FET

Zebrafish embryos are exposed to sediments containing environmental toxins, in order to assess the so-called cocktail effect.

method. FET stands for Fish Embryo Acute Toxicity Test, and has been developed as an alternative both to the commonly used AFT (Acute Fish Toxicity Test) method and to performing cell-level testing. A common FET involves using zebra fish embryos, following the OECD 203 recommendations.

The embryos are exposed to testing conditions, and are followed closely for four days. During the the test, the embryos develop hearts and basal motor functions. In addition to measuring survival, one can also measure effects on the heartbeat, morphological changes, and certain behavioral changes. The method is fast and relatively inexpensive and can provide information on effects on more complicated organisms, which cell-level testing cannot.

This type of toxicity test provides opportunities to get a more nuanced picture of the effects on the ecosystem. In addition to measuring mortality after a certain period of exposure, it is possible to measure a number of other factors, such as coagulation of the eggs, morphological development and heartbeat. Neurological damage, morphological malformations, and changes in behavior can provide important information about effects not only on individuals but also at the population level.

Highest toxic load in Kramfors area

In this study, fish embryos were kept in sediment solutions from the different areas. The sediments were also analyzed for, among other things, over 200 organic pollutants. The effects that emerged among fish embryos were then linked to various compositions of environmental toxins. These analyzes showed that the sediments from Kramfors had the highest environmental pollutant load of the three areas. The Kramfors sediments also contained much higher concentrations of PAHs, while the sediments from Örnsköldsvik contained pesticides against fungi and insects.

Different effect patterns

Some effects occurred in all areas, while others were specific to one of the areas. All embryos exposed to Kramfors sediment developed curved spines and slow, spastic movements. A decreased heart rhythm was detected in tests from all three areas, although the effect was most evident in the Kramfors sediment test. Thus, it was possible to distinguish different effect patterns for the different areas, which could be linked to the sediment composition of environmental toxins. The study was able to show effects that were the result of the different mixtures of environmental toxins, so the method seems to work well for testing cocktail effects, and to be able to assess how different mixtures of environmental toxins can affect populations and the marine environment. ●

Massei, R., Hollert, H., Krauss, M. et al. 2019. ***Toxicity and neurotoxicity profiling of contaminated sediments from Gulf of Bothnia (Sweden): a multi-endpoint assay with Zebrafish embryos***. Environ Sci Eur 31.

DEADLY VITAMIN DEFICIENCY IN THE SEA

Salmon, eider, gulls. These top predators in the marine food web, and possibly more, are deficient in vitamin B_1, or thiamin. Vitamin deficiency has serious effects on survival and reproduction. But why does the problem arise?

Reproductive disorders in salmon were discovered over 45 years ago. It was not until the 1990's that the problem was identified: thiamin deficiency.

To find the underlying cause of this problem, Emil Fridolfsson, researcher at Linnaeus University, has focused on the base of the food web, where it all begins. In December 2019, Emil defended his doctoral thesis on thiamin in the aquatic food web.

Thiamin is one of eight B-vitamins, known as B_1. It is an essential vitamin for all animals, and has an important function in metabolism of carbohydrates and proteins. However, animals cannot produce thiamin themselves; they must get it through their food. Thiamin is also water-soluble, which means that storage is limited. Animals must therefore have a continuous supply of it throughout their lives.

An inexplicable solution

Reproductive disorders in salmon were discovered over 45 years ago, causing major problems with high fry mortality. It was not until the mid-1990s that researchers identified thiamin deficiency as the cause of these disorders.
In fish farms, the yolk-sac fry could be bathed in thiamin, which restored survival to normal

levels. However, the problem was recurring, and explanations for this vitamin deficiency remained a mystery.

For many years, research focused on the top of the food web, where the effects were most evident. Could the explanation be found in changes in the salmon's diet?

Salmon mainly feed on planktivorous fish such as herring and sprat, which differ in the amount of thiamin they contain in relation to fat and energy. Researchers considered that changes in the balance of a salmon's diet between these two species explained the resulting vitamin deficiency. However, the direct link between those changes and the symptoms of thiamin deficiency was not straightforward. Finding an explanation and a solution to this question required starting at the source, where the flow of thiamin in the food web begins.

Tiny thiamin producers

The thiamin found in the aquatic environment and organisms have been produced by small microorganisms, mainly bacteria and phytoplankton. Not all species have the ability to produce thiamin; some must absorb thiamin from the surrounding water. However, the concentrations of thiamin in seawater are very low, many times below the detection limit.

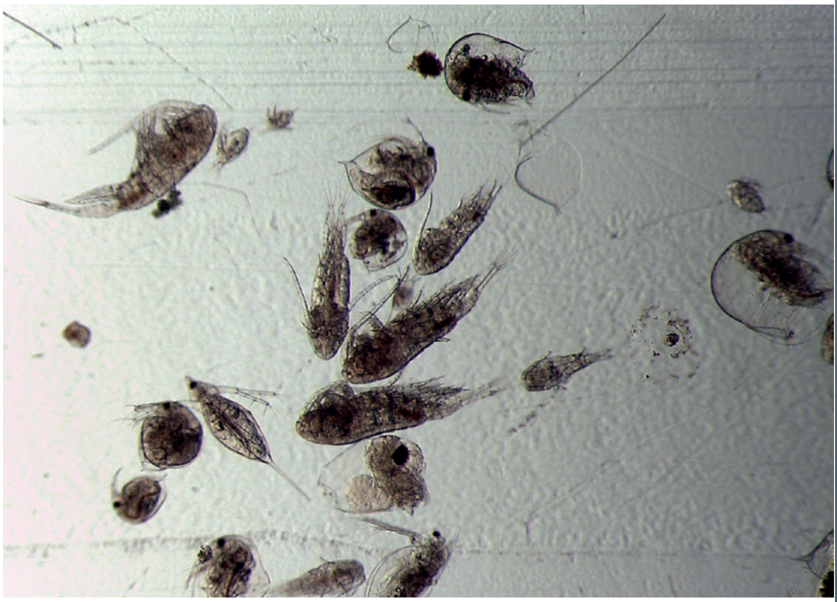
Higher organisms, such as zooplankton and fish, acquire thiamin via food. The small thiamin producers are eaten by zooplankton and small crustaceans, which in turn are eaten by higher organisms.

The key role of phytoplankton

Thiamin-producing phytoplankton plays an important role in the ecosystem. They constitute food for zooplankton, and thus incorporate the essential thiamin into the food web. Thiamin content varies widely between different species of phytoplankton, which means that the phytoplankton community composition plays a crucial role in how much thiamin will be available for animals at higher levels in the food web. The availability of thiamin may also vary between different types of phytoplankton. This fact is the key to resolving the problems with thiamin deficiency. If the composition of species changes, it can have major consequences for the animals at the top of the food web.

Inaccessible thiamin in cyanobacteria

Among the phytoplankton species studied, filamentous cyanobacteria have the highest concentrations of thiamin, but they are a low-quality food for zooplankton. The thiamin present in the filamentous cyanobacteria is thus not transferred as efficiently to zooplankton and fish.



Zooplankton acquire thiamin by eating phytoplankton. The zooplankton in turn are consumed by larger animals higher up in the food web, such as fish.

Smaller individuals - more thiamin

There is a tendency for smaller individuals to contain relatively more thiamin. This has been shown for zooplankton as well as for blue mussels. At the same time, a shift towards smaller phytoplankton appears to pose a greater risk of thiamin deficiency at the top of the food web, due to a less efficient transfer from small picoplankton to zooplankton.

The cause is still not clear

Various theories have been presented in the past about what causes thiamin deficiency, and connections have been made to, for example, how much planktivorous herring and sprat there are. These species' content of thiaminase , an enzyme that degrades thiamin, has also been discussed.

Since thiamin is produced by phytoplankton and bacteria, it is reasonable to assume that changes in these microbial communities could be the cause of the thiamin deficiency. Recent studies on thiamin deficiency in salmon indicate that thiamin deficiency occurs in large-scale changes in certain abiotic conditions. A correlation was found between thiamin deficiency in salmon and stagnation periods, with lower salinity, lower phosphate and silicon levels, and higher levels of nitrogen. These stagnation periods affect the composition of both phytoplankton and zooplankton. During these periods, there were also relatively large populations of herring and sprat. However, although it is possible to demonstrate a link to the abiotic conditions and the food web structure, it is still difficult at present to say exactly how the thiamin deficiency arises. ●

Fridolfsson, Emil 2019. ***Thiamin (vitamin B_1) in the aquatic food web.*** Doktorsavhandling, Linnaeus University Press Växjö 2019.

PIKE – SURVIVORS IN A CHANGING ENVIRONMENT?

Coastal pike have been studied in the area around Kalmar and Öland, and major genetic differences have been detected within what was previously considered a population. The pike's ability to adapt to a diverse environment may be its key to survival.

Is the pike a survivor in the Baltic Sea of the future? It seems to have an inherent ability to adapt to changes in the environment.

The pike has a key role in freshwater and brackish water throughout the Northern Hemisphere. It is large and long-lived, and as a top predator it can regulate lower levels of food web. Furthermore, the pike has great value for both commercial and sport fishing.

Coastal pike live in mixed populations during the foraging season in coastal waters. When it is time to spawn, the pike split up. About half of the pike stay in the coastal area's brackish water to spawn, while half migrate to fresh water to spawn. The pike that migrate into fresh water are driven to search for the area where they were originally hatched. The pike that migrate in freshwater therefore divide into a variety of populations.

Adapted to the environment

The low salinity in the Baltic Sea means that many species live on their limit of distribution. This applies to both freshwater and marine species. Recently, specific brackish water populations have been detected for many species, and in some cases adaptation to the brackish water environment has gone so far that separate species have been developed. Already in last year's annual report for EcoChange, researchers showed the importance of salinity for the behavioral and morphological differences detected in pike.

Genetically different

EcoChange researchers have continued to work on questions about the pike's ability to adapt to different environmental conditions, and have now also been able to show genetic differences between pike. The pike that spawn in fresh water are clearly different from those that stay in the brackish water environment to spawn. There are also clear genetic differences between pike living on the mainland coast compared to those living on the coast around Öland. Genetic differences have also been detected between pike that spawn in different waterways, even though the spawning areas are only a few kilometers apart.

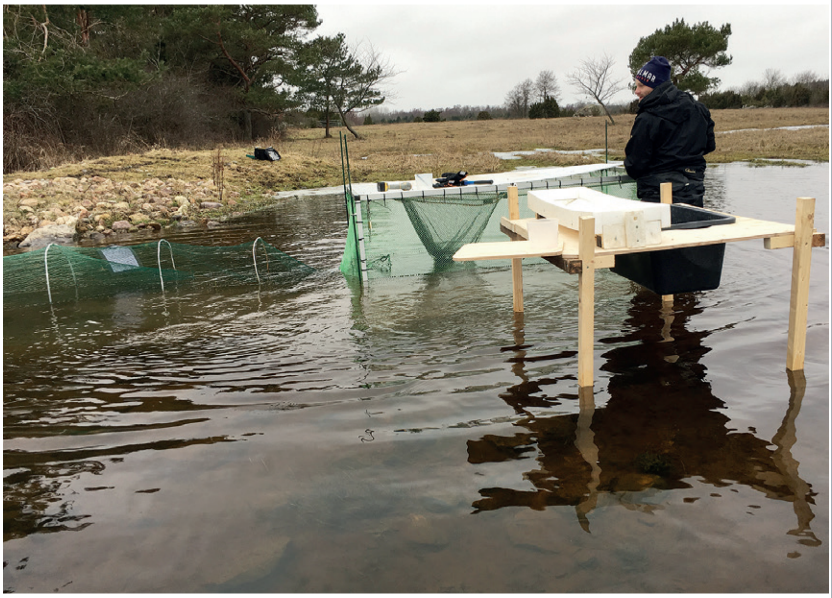
Separated by barriers

These differences require barriers that prevent populations from mixing while spawning. With regard to pike, these barriers do not consist of physical obstacles. The pike can migrate in any fresh water, and they live together for much of the year. Instead, the barrier seems to be a combination of large distances between the populations, adaptations to different environmental conditions and homing behavior, meaning that pike have a strong drive to return to the area where they once hatched when it is time to spawn.

Temperature adapted pike families

Last year's EcoChange report described the pike's adaptation to various salinity levels. The researchers have now gone further, and have also examined the pike populations' adaptation to different temperature conditions. Two areas have been studied, one on the mainland north of Kalmar and the other on Öland. At first glance, the water temperatures in the wetlands appear to be relatively similar during the year. However, there is a big difference between the two areas: In one area, the running water that connects the wetland to the sea dries out early, which means that pike that spawn in this area are forced to spawn early in the season and then have time to swim back to the sea. Therefore, these pike will spawn at significantly lower temperatures, and hatchlings and fry will be exposed to low temperatures. The question is: how are different populations adapted to the different temperature conditions they are exposed to during spawning, and what inherent ability do they have to cope with a changing environment?

Exposing the eggs and fry from the different populations to different temperatures proved that the pike were adapted to the environment not only at the population level, but even at the family level. The pike that were forced to spawn at lower temperatures adapted to these conditions so that their eggs hatched and the fry survived and grew better at lower temperatures compared to pike that spawned at higher temperatures.



Pike spawning in fresh water is compared to pike that remain in the coastal area for spawning. The results show that there are a wide variety of genetically diverse populations of pike within a geographically small area.

Important knowledge for action

Pike populations in coastal areas have decreased, and a number of measures have been put in place to restore populations of this keystone predator fish. Wetlands suitable for pike reproduction have been created, and in some cases pike breeding has also been set in the hope that it will strengthen the populations. But in order for the measures to have the desired effect, it is necessary to know what controls the structure of the fish populations in these areas. In many cases, previous decisions on measures have been made based on the assumption that the coastal pike belong to one and the same population. The detailed studies conducted provide a completely different picture, with a variety of genetically diverse populations of coastal pike.

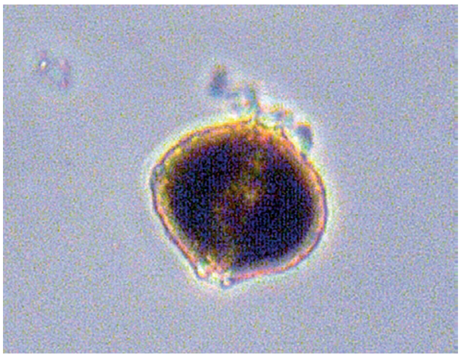
Future survivors?

Climate change already affects the sea and coastal areas, and we know that ecosystems will be subject to major changes. Generally, sea temperature increases, but on a local scale, for example, pike populations may be forced to spawn at lower, not higher, temperatures. This can be caused by greater variations in weather conditions and increasing frequency of dry periods. It seems that the coastal pike has an inherent ability to adapt. This allows it to survive even in a changed environment. However, it is crucial that the management of these pike populations takes this into account, so that the genetic variation that exists among the coastal pike is maintained. ●

Nordahl, Oscar; Koch-Schmidt, Per; Sunde, Johanna; et al. 2019. ***Genetic differentiation between and within ecotypes of pike (Esox lucius) in the Baltic Sea. Aquatic conservation.***

Sunde, Johanna; Larsson, Per; Forsman, Anders. 2019. ***Adaptations of early development to local spawning temperature in anadromous populations of pike (Esox lucius).*** BMC Evolutionary Biology, BMC 2019, Vol. 19.

TOXIC ALGAE EQUIPPED FOR THE FUTURE



The dinoflagellate *Alexandrium ostenfeldii* unfortunately seems well-equipped for the changing environmental conditions of the future.

Unfortunately, the toxic dinoflagellate *Alexandrium ostenfeldii* seems able to withstand changes in both temperature and salinity without affecting how its dormant cysts germinate. There is significant genetic variation within this dinoflagellate, and it is well-equipped to meet climate change.

Resting stages in the form of cysts is an effective method for plankton to ensure its survival through periods of poor environmental conditions. The stocks of dormant cysts function as reserves, often with a higher genetic variation than the part of the population that is in the growth phase. As a result, these cysts can be an important factor for survival in a changing environment.

Many phytoplankton species have these resting stages. Cysts can survive in bottom sediment in lakes and seas for years, sometimes even for decades. In dinoflagellates, this type of cyst is common, and effective for survival.

Germination over time

The process of when cysts emerge from the dormant stage to germinate, can be triggered by favorable environmental conditions. This can mean that a large proportion of the cysts germinate in synchronization for a limited period of time. In other cases, germination is spread out over longer periods of time, which indicates that they can withstand a great variation in environmental conditions.

Can increase in future conditions

The dinoflagellate *Alexandrium ostenfeldii* causes toxic algal blooms in the shallow, coastal Baltic Sea waters. Like many other dinoflagellates, it produces resting stages as part of its life cycle. Previous studies have shown that the supply of dormant cysts in coastal sediments reveals a large genetic variation.

The increase in temperature of 3 to 5 degrees that has been forecast for the Baltic Sea is likely to be even greater in the shallow, stratified waters where *A. ostenfeldii* is most common. Elevated summer temperatures could increase *A. ostenfeldii* blooms, which could cause problems due to its ability to produce toxins. It is therefore important to have a thorough understanding of the mechanisms behind the growth of the species, in order to predict the species' impact on the sea of the future.

The researchers therefore wanted to investigate whether changes in salinity and temperature affect the extent to which the resting cells awaken and begin to divide. They studied whether special strains of the dinoflagellate are selected by the changed environmental conditions when the resting stages come to life, or if this selection occurs later in the growth phase.

Unaffected germination

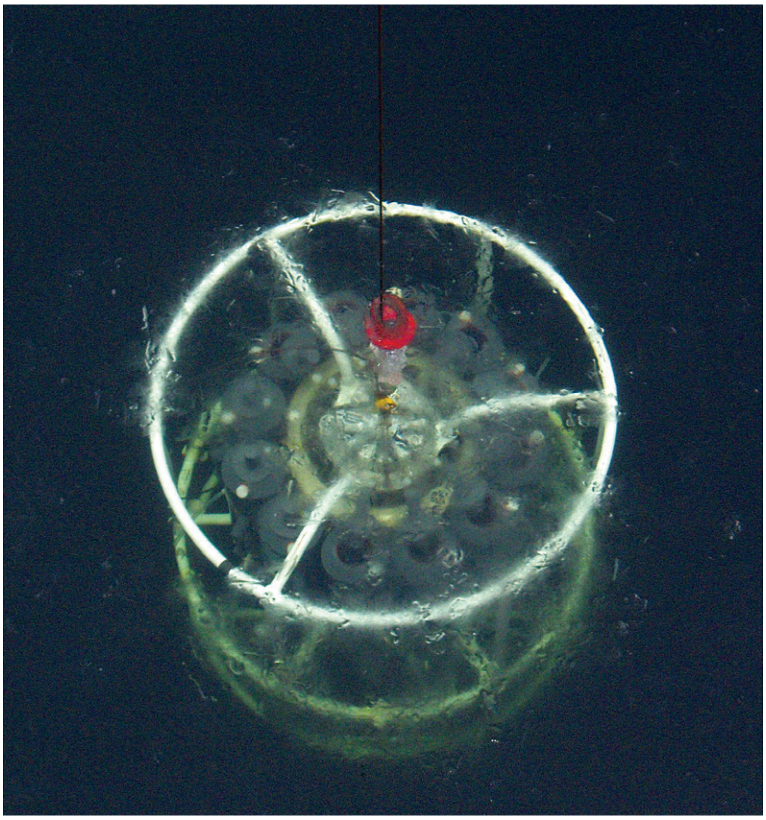
Surprisingly, results showed that the germination rate was largely unaffected by the changes in salinity and temperature. Thus, it does not appear that certain strains of the species are selected at the germination of salinity and temperature changes. In later growth phases, however, salinity and temperature can have a major impact on this species.

Well-equipped for the future

A. ostenfeldii does not appear to have a distinct resting stage during the year. The dormant cells can come to life at any time during the year, even though it mainly occurs during spring and summer. The resting cells appear to have a wide genetic variation, and thus the species is inherently tolerant to varying environmental conditions. Unfortunately, it seems to be well-equipped to cope with changing environmental conditions, due to its high tolerance to different conditions, its adaptability and the standing genetic variation of the population. ●

Jerney, Jacqueline; Suikkanen, Sanna; Lindehoff, Elin; Anke Kremp 2019. ***Future temperature and salinity do not exert selection pressure on cyst germination of a toxic phytoplankton species.*** Ecology and Evolution, WILEY 2019, Vol. 9, (8) : 4443-4451.

IMPORTANT VARIATION IS EASILY MISSED



From day to day, the microbial community in the Baltic Sea's surface water varies. Frequent data collection over several years has allowed researchers to show a variation that may be crucial information, but which is easily missed during less frequent sampling.

Frequent sampling reveals a variation that is otherwise easily missed. In the picture a so-called rosette sampler with twelve separate water sampling bottles.

Bacteria play a very important role in the marine ecosystem, not least in the Baltic Sea. They regulate the flow of nutrients and energy in the food web, and half of the carbon that is fixed by the phytoplankton photosynthesis is used by bacteria for their growth, respiration and metabolism.

Reciprocal effects

Bacteria are influenced by phytoplankton, and phytoplankton blooms lead to clear increases in bacterial growth. But the opposite also applies - the bacteria affect the supply of nutrients, and thus influence phytoplankton growth. It shows the complexity of the system, and that ecological interactions can have a major impact on the microbial food web, with repercussions on higher trophic levels like zooplankton and fish.

Intensive measurements

Despite the vital role of marine bacteria, knowledge of how bacterial communities vary over time is limited. To investigate this variation, EcoChange researchers journeyed out to the LMO sampling station, Linnaeus Microbial Observatory. The sampling station is located 11 kilometers off the coast of northeastern Öland, and for four years water samples were taken from it twice a week. The average sampling frequency in, for example, environmental monitoring is once a month, or even less frequent.

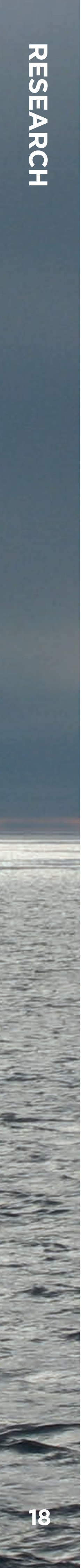
Frequent sampling shows variation

With a high-resolution time-series, the researchers were able to show that the monthly measurements give a sufficiently good picture of certain abiotic factors, such as temperature. But it seems that changes in the microbial communities are happening on a much finer scale, over periods of days up to weeks. The monthly measurements thus miss major changes that may be important to know for example, assessments of the microbial community's productivity and ecological function.

Safer predictions

High frequency sampling of bacteria and phytoplankton enables analyses of how processes change over time. Understanding the variation in the ecosystem, how the different parts are affected by each other and how they are affected by changing environmental conditions can make models of the ecosystem better and the forecasts of the future of the Baltic Sea more accurate. ●

Bunse, Carina; Israelsson, Stina; Baltar, Federico; et al. 2019. ***High Frequency Multi-Year Variability in Baltic Sea Microbial Plankton Stocks and Activities***. Frontiers in Microbiology, FRONTIERS MEDIA SA 2019, Vol. 9



INCREASING DIVERSITY IN SHALLOW COASTAL AREAS

Species diversity may not generally be expected to increase as a result of climate change, but this appears to be the case in some northern shallow coastal areas of the Baltic Sea. In a thorough study of the basal production in the food web shows a shift in the balance between phytoplankton, mixotrophs and bacteria. A balance that changes as a consequence of climate change.

The very smallest organisms in the sea have a fundamental role in the marine ecosystem. In a drop of water, we find large quantities of virus, bacteria, cyanobacteria, phytoplankton and mixotrophs. Some of them can fix carbon dioxide and sunlight and convert it into organic matter. Others can break down dead organic matter, and make the nutrition and energy available to the ecosystem again.

Primary producing phytoplankton

Phytoplankton are autotrophs, which means that they can produce organic matter from carbon dioxide in the atmosphere and sunlight, i.e. photosynthesis. This process, also known as primary production, is the dominant way of incorporating new carbon and new energy into the ecosystem. Marine phytoplankton contribute half of the world's primary production.

Plants and animals together

Mixotrophs are both animals and plants at the same time - they can both photosynthesize and eat other organisms. Under special conditions, they seem to be able to out-compete both autotrophs and heterotrophs, as they can utilize light when available and take up organic compounds present in the water. The competition between autotrophs, heterotrophs and mixotrophs provides a balance between the different types of organisms. This balance can easily be disrupted when conditions change.

Since mixotrophs can combine photosynthesis with, for example, eating bacteria, they can gain a competitive advantage when nutrition and light conditions are poorer.

Bacteria consume estuarine carbon

Bacteria are heterotrophic, which means that they are incapable of performing photosynthesis. Instead, they must rely on primary producers to gain access to organic carbon compounds. The bacteria can utilize readily available organic carbon compounds released to the water by phytoplankton. Water that has flowed into the sea from land contains large amounts of dissolved organic matter, especially when the water originates from wetlands. These carbon compounds are not as readily available to the bacteria as compounds that have leaked from phytoplankton, but because these types of carbon compounds are in such abundance, they make the bacteria less dependent on the phytoplankton.

Seasonal variation

The growth of microorganisms varies during the year and among water ecosystems. In the spring, the water is cold, and the conditions favor large species of phytoplankton, such as diatoms.

Spring bloom in the Bothnian Sea.

When the nutrient supply in the water is depleted and the water warms, smaller plankton will benefit. These may be autotrophic, mixotrophic or heterotrophic. Their small size gives these tiny plankton a competitive advantage - they have a larger area in relation to their volume than the larger phytoplankton.

A lake-like sea

The shallow coastal areas in the northernmost parts of the Baltic are more like humus-rich lakes than sea areas. Unlike marine areas further south, these areas are phosphorus limited, just like many lakes. The water that flows into the sea from land is brown, due to the large wetland areas in the catchment. The brown color is detrimental to the phytoplankton, as it worsens the light climate. The bacteria, on the other hand, benefit from the large amount of organic material that comes with the water.

Increasing species diversity

A group of EcoChange researchers has done a thorough study of which parameters influence the balance between different microorganisms in a shallow coastal area in the northernmost part of the Baltic Sea. The study shows a succession that differs to some extent from what has been reported in previous studies. The results indicate, for example, that species diversity may increase in these shallow coastal areas, which in turn leads to a more efficient use of limited resources, and thus a higher total production.

Mixotrophs may benefit

The study shows that mixotrophs also seem to benefit from the poorer light conditions, the high levels of dissolved organic matter and the specific nutrient conditions. The mixotrophic flagellate that dominated was *Chrysochromulina* spp. The mixotrophs were found to play an important role in the food web in the area, and their importance increased as bacterial production increased.

Results show that succession during the year in these areas differs from farther south in the Baltic Seas. The amount of dissolved organic matter in the water is high in the spring. The bacteria predominate at the beginning of the season, while autotrophic phytoplankton predominated later in the summer. Primary production proved to be highest during the hot summer months, when flow from the rivers is low. These results show major differences between shallow, northern coastal areas and the Baltic Sea. ●

Paczkowska, Joanna; Rowe, Owen F.; Figueroa, Daniela; et al. 2019. ***Drivers of phytoplankton production and community structure in nutrient-poor estuaries receiving terrestrial organic inflow.*** Marine Environmental Research, Elsevier 2019, Vol. 151.

ECOCHANGE – FOR OUR SAKE, AND FOR THE SEA

After ten years of intensive work, the level of knowledge about the sea and climate has significantly increased, but many questions remain unanswered. Powerful and continuous research is needed on these issues, says Agneta Andersson, scientific coordinator for the EcoChange research program.

Strong and continuous research is needed on the marine environment and the effects of climate change, both for our sake, and for the sake of the sea, says Agneta Andersson, scientific coordinator for the EcoChange research program.

Why do we need EcoChange in the future? The question is put to Professor Agneta Andersson, scientific coordinator of this research program.

"For the sake of the sea, and for our sake. The marine environment is exposed to so many environmental threats, ongoing and changing. Climate change poses a real threat to the balance of the ecosystem, and disruptions have effects throughout the food web, all the way up to humans. That is why powerful and continuous research is needed."

A solid foundation

Agneta has been the scientific coordinator for the EcoChange research program ever since its inception ten years ago. She looks back on a period of developing marine research on the Baltic Sea.

"The EcoChange research program has given us the opportunity to develop our research ideas on issues related to the effects of climate change on the marine ecosystem. The appropriations for EcoChange have given us a solid foundation to stand on when we seek funding from elsewhere. This has enriched the research environment, and has also made us develop contact networks both nationally and internationally."

Rings on the water

Agneta particularly wants to emphasize the training of researchers within EcoChange. More than thirty people so far have completed PhDs in the program. These individuals have gone on to research or work within environmental management, and thus have brought the acquired knowledge to the community.

"It is a great pleasure for those of us in the EcoChange leadership to see how these people gain important positions in society. These are the rings on the water!" says Agneta, who herself has been a supervisor for a large number of doctoral students.

Strategic research areas

It all began just over ten years ago, when the government announced large sums of money to set up strategic research areas. The marine environment was identified as an area of interest, and the leadership of Umeå University invited Agneta to participate in the work of writing an application. Together with then director of the Umeå Marine Sciences Center Professor Ulf Båmstedt, she began to define the focus on sea and climate change that would become the future EcoChange.

Strong cooperation

What, then, was the recipe for success for EcoChange? Despite huge competition, why was that first grant awarded? Agneta describes a very intensive application period that involved many people dedicating many hours. The result was a well-cohesive application with a clear target wording. An important factor was also the ideas of collaboration with other universities.

"At the planning stage, we already saw the benefits of finding partners that could complement our research both scientifically and geographically. Linnaeus University, with its strong marine operations at the Kalmar Laboratory, met with these criteria, and proved to be very positive participants."

From biochemistry to fish

Since its inception, EcoChange has focused on investigating the effects of climate change on the Baltic Sea ecosystem. About sixty researchers are currently working in a variety of fields, from the smallest molecules up to fish. From the start, environmental toxins in the ecosystem were an important part of the research. Over time, interactions between the different levels of the food web have become increasingly in focus. Chemistry is linked to biology, bacteria and plankton with fish and this small sea is put in a global perspective.

"For example, we study qualitative changes in the ecosystem, how climate change can affect biological processes. The composition of fatty acids in zooplankton that is important for plankton-eating fish and thiamin deficiency that periodically occurs in the ecosystem are some of the areas we work with. Small changes that can have major consequences. We need to understand what's going on and find ways to deal with these problems."

EcoChange addresses questions about the major environmental problems, such as eutrophication and environmental toxins. This photo shows a bloom of potentially toxic cyanobacteria.

Adapting to new conditions

Increasing water temperatures, decreasing salinity and brownification of the water are effects of climate change that researchers knew even before the research program started. The changes are moving fast, and the question is whether the ecosystem will be able to adapt to the new conditions.

"The answer is both yes and no. There are parts of the ecosystem and ecosystem functions that will not be able to adapt, and where we already know that we are facing some serious consequences. At the same time, our research shows that there is an adaptability among certain organisms that may mitigate the consequences."

Maximized societal benefits

By putting the results of the Baltic Sea research in a global perspective, more general conclusions can be drawn about the mechanisms that regulate the food web. This is vital for how the results can be used in practice.

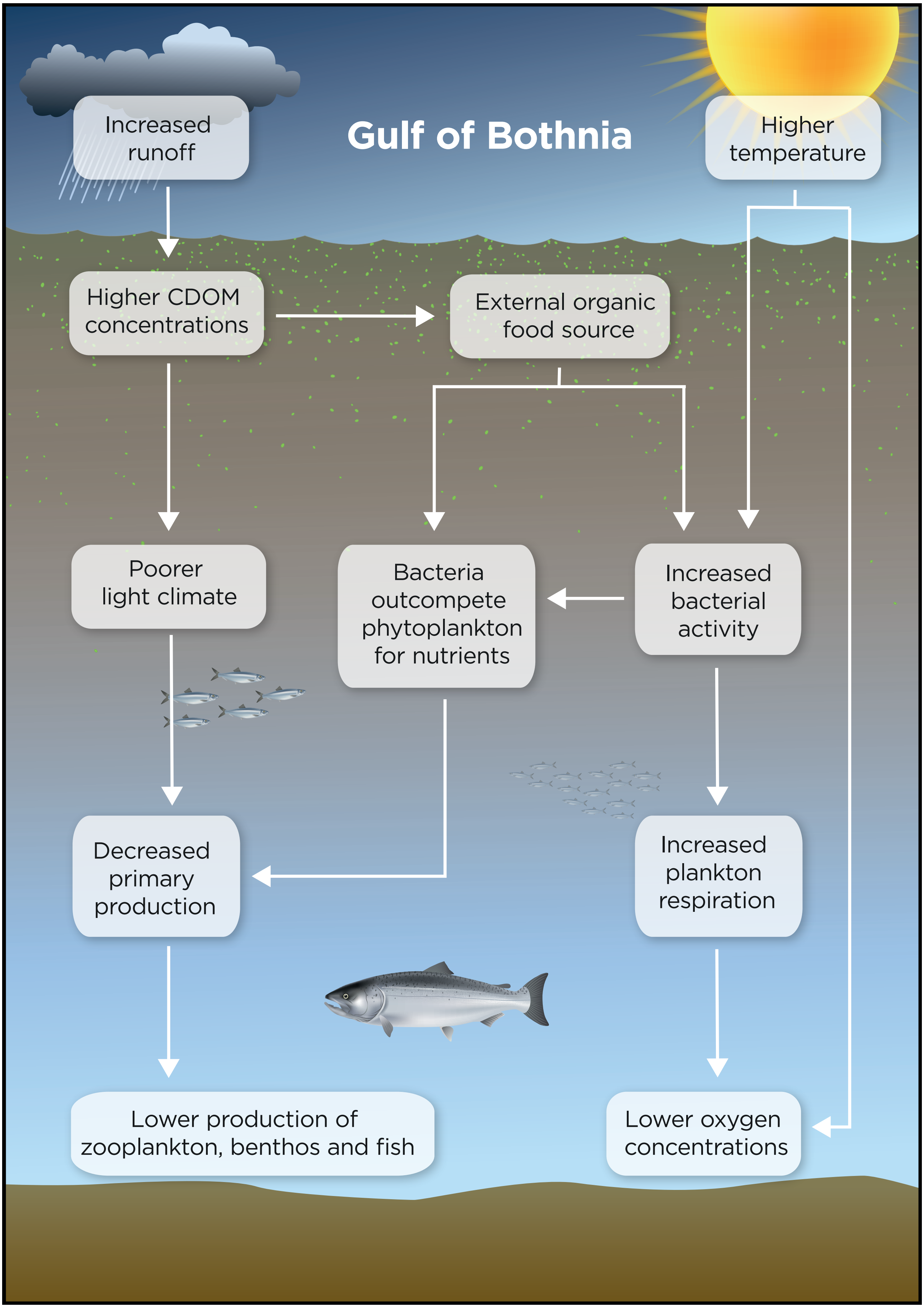
"The challenge is to determine what opportunities exist for facing the major environmental problems in the Baltic Sea, and what are the best, most cost-effective measures to take. We develop important decision-making bases, improved monitoring methods and, as advisors, assist with issues related to classification of the marine environment. Our close association with marine management is crucial for our research activities to maximize the benefits for society."

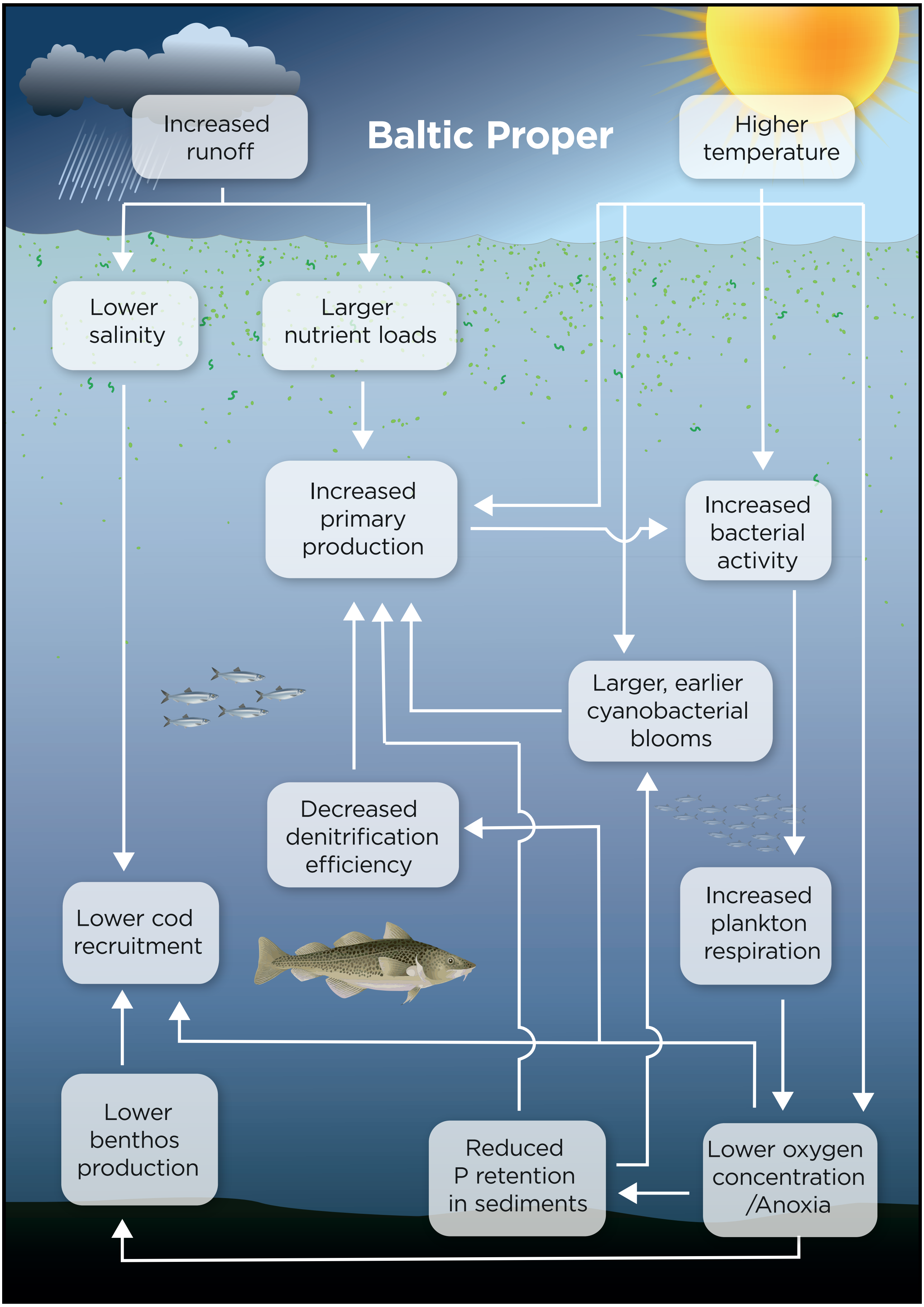
Long-term key to success

EcoChange has been active for ten years, and Agneta highlights this long term as an important factor.

"We have had the desire to be able to work more long-term than is usual in the research world. In this way, we have had the opportunity to further develop research areas, and to complete the various projects that have begun. It has definitely been one of the keys to success." ●

This article is based on an interview with Agneta Andersson from March 2020.


Gulf of Bothnia
Increased runoff
Higher temperature
Higher CDOM concentrations
External organic food source
Poorer light climate
Bacteria outcompete phytoplankton for nutrients
Increased bacterial activity
Decreased primary production
Increased plankton respiration
Lower production of zooplankton, benthos and fish
Lower oxygen concentrations


Baltic Proper
Increased runoff
Higher temperature
Lower salinity
Larger nutrient loads
Increased primary production
Increased bacterial activity
Larger, earlier cyanobacterial blooms
Decreased denitrification efficiency
Increased plankton respiration
Lower cod recruitment
Lower benthos production
Reduced P retention in sediments
Lower oxygen concentration /Anoxia

EcoChange.

EcoChange increases knowledge about the consequences of climate change in marine systems. The starting point is that climate change affects the temperature, salinity and concentration of dissolved organic carbon (DOC) and nutrients in the Baltic Sea. This leads to a deterioration in food web efficiency, and thus an increased accumulation of environmental toxins in marine organisms. Food web efficiency is a key concept within the research program, and high efficiency is a good indicator of a healthy ecosystem.

EcoChange is a part of the government's strategic research initiative on marine environmental research., and is based on a close collaboration between Umeå University and the Linnaeus University, as well as Sweden's Agricultural University and the Swedish Museum of Natural History. Umeå University hosts the program. About sixty researchers are currently working on projects linked to EcoChange. Collaboration takes place with other researchers and research groups around the world.

This report describes the activities within the research program during the year 2019. More information about EcoChange can be found at www.umu.se/en/ecochange/

UMEÅ UNIVERSITY

Linnæus University