PRACTICAL GUIDELINES ON SEA-BASED MEASURES

Picture: Mikko Voipio

John Nurminen Foundation 2021

Miina Mäki, Marjukka Porvari & Eeva Tähtikarhu

EUROPEAN UNION
European Regional Development Fund

Interreg Central Baltic

SEABASED
SEABASED MEASURES IN BALTIC SEA NUTRIENT MANAGEMENT

SEABASED Project *(Seabased Measures in Baltic Sea Nutrient Management)*

Eutrophication is one of the most large-scale problems of the Baltic Sea. While the nutrient load from land-based sources has been cut significantly during past decades, nutrients that are stored in the seabed and are being released from the sediment back to the waterbody, especially in anoxic conditions, are currently slowing down the recovery of the ecosystem. The SEABASED Project (2018-2021) examined and assessed measures that potentially improve the status of marine area by reducing this "internal load" of nutrients from the seabed. The project implemented small scale local pilots on selected measures in Finland, Åland and Sweden.

Pilot activities, projects, plans and research on sea-based approaches have been going on for some years in both Sweden and Finland, but at the same time, a lack of comprehensive cross-sectoral discussion exists, both within and between sectors and countries. Thus, one of the aims of SEABASED Project has been to strengthen cooperation and share knowledge between scientific communities as well as among authorities, political decision makers and third sector actors of the region on the feasibility, risks, and sustainability of the different sea-based approaches in different scales and sea areas, as well as on their financial sustainability.

John Nurminen Foundation of Finland was the Lead Partner of the SEABASED Project, facilitating also the cross-regional discussion. Regional authorities are key actors for local water quality improvement – therefore the partnership involved regional authorities from Sweden, Finland and Åland: County Administrative Board of Östergötland, S-W Finland ELY Centre and the Government of Åland. Local pilots were implemented by the authotities, Stockholm University and the Fishfarmers' Association of Åland. s. In addition, practical concept for marine nutrient compensations was developed in Åland for utilization of sea-based methods in the future. The sustainability of the measures has been assessed, taking into consideration ecological, social, legislative, and financial aspects. The private sector's interest in improving water quality locally and Baltic Sea wide was represented by several companies and NGOs engaged in the project activities as stakeholders.

The SEABASED Project is co-financed by the EU Interreg Central Baltic Programme.

More information: www.seabasedmeasures.eu

Contacts, John Nurminen Foundation:

Miina Mäki
Project Manager
miina.maki(a)jnfoundation.fi

Marjukka Porvari
Director, Clean Baltic Sea Projects
marjukka.porvari(a)jnfoundation.fi

Summary

The Practical Guidelines for sea-based measures is a compilation of both practical and scientific knowledge gained in the previous pilot projects as well as in the project SEABASED, including estimates on impacts and sustainability, risks, costs, and feasibility of available sea-based measures. The Guidelines are targeted at political decision makers, environmental administration on national and regional levels, private and public financiers as well as NGOs carrying out water protection measures, and, are meant to provide neutral and verified information on different sea-based measures for policy making as well as for planning concrete actions for protecting the Baltic Sea. As the aim is to provide practical information for the different end users, references and examples of pilot projects implemented in the Baltic Sea region are emphasized in Guidelines and less attention is given for studies based on modelling.

Existing monitoring data, scientific knowledge and personal consultations with researchers were utilized for the environmental risk assessment and the criteria established for site selection. The most important criteria for sites where different sea-based measures can potentially be applied, is the role of internal nutrient leakage on the eutrophication status of the targeted area. However, the suitability of the sea-based measures is always site-specific, and the results from one site cannot be directly applied to other locations or from local pilots to open sea as such. Depending on the measure, environmental impacts to be considered might also not be restricted to the marine environment. Identified knowledge gaps also exist, e. g., in understanding of sediment processes, nutrient cycles and impacts of the climate change in the Baltic Sea marine environment.

Estimations on the technical and financial feasibility and cost-efficiency of measures are based on data from existing pilots and does not include market values for products for which there is not any true demand existing yet. As cost estimates should be based on realistic information on both, costs, and nutrient reduction efficiency of the measure, it was found difficult, or in some cases even impossible, to reliably estimate the economic feasibility of part of the measures. Some methods, however, e. g. aluminium treatment in Sweden, have already been taken in use in coastal water protection, and have proven cost-efficient as supplementary measures for land-based load reductions. However, concerning large-scale (open sea) applications, no techniques are mature enough yet for utilization in Baltic Sea protection.

There is no specific legislation for sea-based measures existing, and different practices are applied in countries related to implementation of sea-based measures e. g. in permitting of the measures. Thus, the feasibility of future sea-based applications is dependent on both, national laws and permitting practices and interpretations of international regulation. Social acceptance of the measures was studied in connection to the community involvement, e. g. with stakeholder interviews, surveys and in local information events related to pilot implementation. The need for efficient water protection measures is evident, however, the potential risks related to sea-based measures raise concern among authorities, and other stakeholders like NGOs.

As a main conclusion, the focus of reducing the eutrophication of the Baltic Sea should still be kept in reducing land-based nutrient load, but in cases where the internal nutrient load exceeds the external load, and there are no other possibilities for mitigating eutrophication at certain area, use of sea-based applications might become relevant. More research and technical development are needed for applications of the geo-engineering measures, before they can be taken in wider use in marine water protection, even though some of them seem potential. Comprehensive monitoring of effects and documentation of all steps of the implementation is crucial for learning from future pilots.

Contents

Attachments

1) ***SEABASED Sustainability Survey for authorities***
2) ***SEABASED Local's voice Survey***

SEABASED Project Team visiting Cementa's facilities in Gotland (2019). Picture: John Nurminen Foundation

Fig. 1. Bottom fauna does not survive at oxygen depleted bottoms of the Baltic Sea. Picture: Jukka Nurminen

Background

Measures to reduce land-based nutrient pollution have been carried out for several decades in Finland and Sweden, and in other countries surrounding the Baltic Sea, to improve the state of the sea. As most of the cost-effective mitigation measures have already been implemented, e. g. in wastewater treatment, there is an increasing interest in sea-based approaches to complement the measures on land and to improve local water quality in the coastal sites. During past few years, it has also been brought to discussion that these new activities may be needed for reaching international targets on reducing eutrophication (Helcom BSAP, EU MSFD, EU WFD, SBSR) and reviving the Baltic Sea. Thus, the measures to tackle the internal nutrient load might be considered to complement, but not to replace, the land-based nutrient load reduction measures.

Ideas of different measures for sea-based nutrient reductions have recently been brought up to discussion, especially in Finland and Sweden, and the development of some practical applications for them have also been started by different organisations. However, these measures cannot yet be directly applied by governments, authorities or third sectors actors, as most of the ideas are novel and not applied before in marine environment. Single measures like oxygenation of the seabed (e.g., BOX, PROPPEN) or binding of phosphorus with aluminium (Rydin et al. 2017) have been tested regionally in pilot projects and some ideas of large-scale applications have also been brought up; however, there is a lack of comprehensive understanding of risks, effects, costs, feasibility, and financial sustainability of different measures. Thus, there has not yet been enough information and practical knowledge available on their applicability. Moreover, applicability of such measures is often site-specific, and to gain more comparable information, the measures would need to be piloted in different scales, regions, and sea areas. Helcom contracting parties as well as scientists are not unanimous but have adopted different approaches to these new measures.

What is internal nutrient load?

The physical, chemical, and biological characteristics and the main environmental challenges of the Baltic Sea are well described in detail e. g. in Helcom 2018 and Vahanen Environment 2018 reports, therefore describing them again is not in focus of this report but only a short, general explanation on the term “internal load” is provided.

The main cause of eutrophication of the Baltic Sea are the excessive nutrient inputs during several decades, especially from 1950’s to 1980’s, from human activities on land: wastewaters, industries, agriculture, and forestry. The symptoms of eutrophication can be seen e. g. in increased biomass of phytoplankton and filamentous algae, murky waters, and oxygen depleted sea bottoms (Fig. 1). It has also been shown that chemical conditions in anoxic sediments change the ratio of available nitrogen and phosphorus in the water, to a direction that favors the growth of cyanobacteria (‘bluegreen algae’), which have a role in sustaining eutrophication in the Baltic Sea, thus creating a self-sustaining “vicious circle” of eutrophication in the sea (Conley et al. 2009, Vahtera 2007). Nitrogen fixation, or the internal nitrogen load, by cyanobacteria has recently estimated to almost equal to the external, anthropogenic nitrogen load to the Baltic Sea (Olofsson et al. 2021). Consequently, increasing abundance of nitrogen-fixing cyanobacteria further increases the eutrophication of the sea.

According to current research, the nutrient inputs have been markedly reduced beginning from the 1990’s to present, and, thus, the internal nutrient fluxes, especially phosphorus, exceed the annual inputs from land-based sources. However, also the internal phosphorus reserves originate from land-based nutrient load, and, thus, the flux of phosphorus from the sediment is not a new source of loading but rather circulating the accumulated land-based phosphorus back to the use of algae. (Baltic Sea Centre 2018, Helcom 2018). The biogeochemical processes that store phosphorus in sediments and release it into the water are complex and dependent on the surrounding circumstances: interaction of organic matter, microbiota and zoobenthos, minerals, metals, oxygen, and the physical characteristics like water movements in the sea (Conley et al. 2009, Baltic Sea Centre 2018). Therefore, it is difficult to estimate which measures affecting these cycles would have a desired effect on enhancing the recovery of the sea and, also, which might be causing severe risks to the functions of the marine ecosystem.

As the nutrients entering the Baltic Sea are partly flushed to the North Sea through the Danish Straits and partly permanently buried in the bottom sediment, it is considered evident that by reducing external load of nutrients the total pool of available nutrients in the Baltic Sea will also be reduced in time. It has also been estimated, that by reaching the reduction targets set in the HELCOM Baltic Sea Action Plan, both the primary production (phytoplankton growth) and the nitrogen fixation by cyanobacteria will be decreased during the following 50-100 years (Saraiva et al. 2018). Therefore, further studies and piloting of new sea-based measures for enhancing the recovery of the sea can rather be considered as a potential for complementing the work for reducing nutrient load from land, but not for replacing it. (Baltic Sea Centre 2018, Helcom 2018).

Aim of the Guidelines

SEABASED Practical Guidelines summarizes the practical knowledge and experience gathered on technical feasibility and costs of the implementation of different measures piloted in SEABASED Project (Sea-based Measures in Baltic Sea Nutrient Management), feedback and views collected from stakeholders as well as simplified version of a risk assessment framework for coastal scale sea-based applications. In addition, information on some measures that have been piloted in previous projects, but not in SEABASED, and on which there is sufficiently documented information available from literature, is also included in these Guidelines.

The aim of the Guidelines is to provide compiled information from implemented pilot projects for relevant authorities conducting consultations and permitting related to these so-called sea-based measures. The Guidelines also provide practical guidance for different actors potentially planning to carry out measures to reduce the so-called internal nutrient load in Baltic Sea coastal waters.

Information on permitting processes, technical feasibility and costs of different measures has been gathered from practical pilots implemented in SEABASED Project, and, in addition, from some well-documented previous projects where selected sea-based measures have been studied.

Either open sea pilot projects in actual marine environment in the Baltic Sea (*in situ* pilots) or research on large scale sea-based measures is not yet existing, except for some studies based on modeling. Therefore, it has been impossible to estimate on reliable basis the applicability or sustainability of any of the measures for large open sea scale applications. In addition, the ecosystems and their processes are also different in coastal and open sea marine environment, and therefore the results from local coastal pilots cannot be directly applied in larger scale. Thus, these Guidelines should only be applied to small-scale coastal measures, i. e. measures which do not have potentially significant transboundary effects. *

During the guideline development work, the input, knowledge, and views from several different stakeholder groups have been collected e. g. via the following process (Fig. 2) and activities:

- International opening conference of the project (Helsinki, 18.4.2018)
- State of the play -background report (literature review on previous projects and research, 2019)
- Scientific Workshop in Finland (Risk assessment of sea-based measures, Turku, 30.-31.10.2018)
- Scientific Workshop in Sweden (Risk assessment of sea-based measures, Stockholm, 5.-6.11.2019)
- Stakeholder Workshop in Finland (Turku, 13.11.2019)
- Stakeholder Workshop in Sweden (Stockholm, 3.10.2018)
- Locals' voice -questionnaire (2019 and 2020 at information events)
- Sustainability survey for environmental authorities (in 2020, in Sweden, Finland, Åland and Estonia)
- Stakeholder interviews (stakeholder views, 2019 and 2020)
- Commenting round of the draft Guideline document (2021)
- Drafting of ecological risk assessment framework for sea-based measures in Helcom ad hoc working group MINUTS, and John Nurminen Foundation representatives' participation in the development work of BSR regional recommendation and guidelines in MINUTS group as an observer organization during 2019-2021.
- In other regional conferences on the topic, e. g. Helcom Conference on Baltic Sea internal load (Göteborg, 28.-29.11.2017), Oxygenation seminar (Stockholm, 15.5.2019), Marine restoration conference (Stockholm 11.-12.3.2020

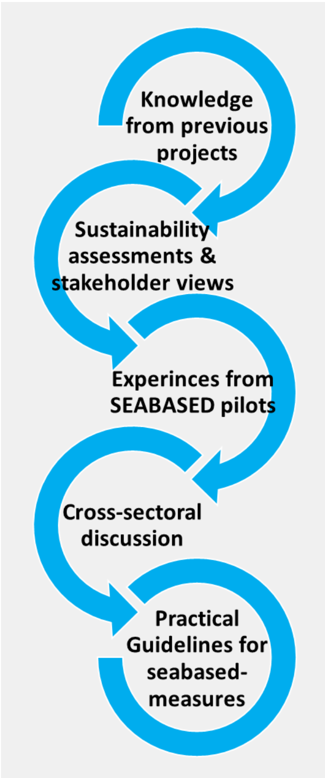


Fig. 2. Participatory process was used in Guideline development.

**Transboundary effects referring to impacts on the marine area of other states around the Baltic Sea.*

Introduction to sea-based measures

In these Guidelines, a "sea-based measure" refers to any measure that is taken in the marine environment, and targeted to decrease the amount of nutrients, especially phosphorus, available in the internal pools of coastal waterbodies – either by removing the nutrients from the sea, binding them permanently into the seabed or by some other way changing the nutrient balances to reduce the amount of nutrients available for algae growth in the marine areas suffering from consequences of excess nutrients, especially originating from the internal pools.

The different applications of measures can be either technical, chemical (so-called "geo-engineering" methods) or biological (e. g. removal of biomass, biomanipulation) by their nature. There are only few pilot projects implemented in the Baltic Sea marine environment prior to the SEABASED Project, and very little published information on them exist. However, many of the measures have been tested or utilized in lake restoration already for years or even decades, both in Finland and Sweden.

In addition to SEABASED pilots, information has been gathered from e. g. published scientific studies, project reports and outcomes of some recent national and regional workshops on the matter. Some measures implemented or studied in other marine areas outside the Baltic Sea region have been reviewed in the report by Vahanen Environment (2018): *Speeding up the ecological recovery of the Baltic Sea by engineering*, and the basic conclusion on needs for further research can be made also for those measures before any large-scale applications can be implemented in the Baltic Sea.

As the focus of the SEABASED project is in the Baltic Sea, which is many ways different from any other marine areas or oceanic environments, mainly measures applied in the Baltic Sea are included as references to these Guidelines. In addition, as the aim of these Guidelines is to provide practical information on implementation of different sea-based measures, only such previous projects that have piloted measures in practice have been included as a reference to these Guidelines, and, consequently, studies that are based on modeling data only have been delimited outside the scope of this work.

Efficiency of measures: overview on pilot projects

Experiences from lakes

Restoration measures implemented in lakes aim either at controlling the internal nutrient reserves restored in bottom sediments and reducing their availability to algae growth or at changing of the ecosystem balance e. g. with biomanipulation by fishing planktivorous, non-predatory fish and by supporting the predatory fish stocks, which have top-down controlling functions on the food web, and, thus also on the algae growth (Bernes et al. 2015, Olin et al. 2006). Depending on the circumstances and the history of external loading at individual lakes, the results of restoration measures have varied from relatively poor to quite successful cases. Consequently, the measures applied should be planned for each lake individually, based on careful consideration of all local factors affecting the status of the water environment, from morphology of the lake to human activities within the lake's drainage area.

Most utilized measures in lake restoration have been oxygenation of hypoxic basins, binding of phosphorus with chemicals (iron or aluminium compounds) or food web biomanipulation by reduction fishing of large amounts of non-predatory fish, e. g. the cyprinids that often become abundant in eutrophic lakes. In addition, by removing biomass a certain amount of nutrients is also being removed from water environment. Also dredging of nutrient-rich organic sediment is sometimes used.

Fig. 3. In SEABASED pilots, activated limestone was spread from a helicopter. Picture: Tara Jaakkola

"Geo-engineering" methods

The so-called "geo-engineering" methods aim at reducing the nutrient release from the bottom sediment by chemically or technically affecting on the nutrient cycles. Most of the methods target on enhancing the nutrient binding capacity of the sediment either by adding phosphorus-binding chemical compounds to the bottom or by improving the natural capacity of the sediment to bind nutrients by reducing anoxia (oxygenation). In addition, sediment removal also targets to take up part of the nutrients bound to the organic top-layer if the sediment.

Binding of phosphorus into the seabed

Projects and pilot activities where different chemicals or other substances are used for binding soluble phosphorus to bottom sediments usually aim at decreasing the 'internal load', the leakage of phosphorus from seabed to the water. When the availability of phosphorus in the waterbody is reduced, the algae growth is expected to decrease accordingly. Consequently, when there is less algae growth, there will also be less oxygen-consuming organic matter entering the bottom as the algae die, which is expected to create a positive feedback and in time also potentially improve the oxygen conditions in eutrophic bays with anoxic/hypoxic bottom areas. However, there are not yet many long-term monitoring results from the Baltic Sea region pilot projects existing to verify the hypothesis. Some results also indicate, that using aluminum for phosphorus binding might mobilize hazardous substances from the sediments (Wikström 2018).

In addition to the chemical binding of phosphorus, covering of the bottom with sand has been utilized in Denmark for permanent burial of nutrients in the bottom sediment. Sand-covering can also be combined to the restoring of endangered eelgrass habitats on sandy bottoms (Timmermann et al. 2015).

<u>Binding of phosphorus with activated limestone (“marl”)</u>
(for further information, see SEABASED WP T4 Report, Ekeroth 2021)

Marl in general refers to a mixture of fine-grained minerals. In the project "Permanent binding of phosphorus in the Baltic Sea bottom" (BS2020), Blomqvist and Björkman (2014) have investigated whether Gotland marl, a calcium-based byproduct from limestone mining industry, can effectively bind phosphorus in the Baltic Sea bottom sediment. In these studies, it was found that in laboratory tests marl adsorbs phosphorus efficiently from the water, and the heat treatment of the material remarkably increases the binding capacity of sorbent. The residue marl is stored in Gotland in large piles (Fig. 4).

In the SEABASED project, pilot examples with marl application to phosphorus-rich bottom sediments were implemented in coastal bays in Sweden (Kyrkviken, Djuröfladen, Farstaviken) and Finland (Kolkka) (Ekeroth 2021). The pilot started with a short development phase to define exact amounts of heat-treated marl for the application, after which the material was heat-treated in a special kiln and spread from helicopter on the surface of pilot bays (Fig. 3). Monitoring was in place before and after the implementation to be able to define the effect and the phosphorus binding capacity of the piloted substance in marine environment.

Technically, it was found feasible to spread the marl over the targeted area from helicopter. The samples taken after the spreading show that a short positive effect was detected in the P concentration of the top-layer of sediment and near-bottom water, however, the effect lasted only for few hours and no long-term reduction of phosphorus was observed, on the contrary to the expectations based on the laboratory tests. In further experiments it was found out that, although the material had some binding capacity, it was not enough to cause measurable effect in the bay-scale experiment, and, further, the heat-treatment of the used material had not been optimal for achieving the desired binding capacity. Thus, further development needs were identified especially in optimizing the heat-treatment process of the sorbent.

Fig. 4. Processing of limestone in Gotland. Picture: Jenni Blomqvist / JNF

In addition to the phosphorus binding capacity of marl, other potential effects in pilot areas have been thoroughly monitored, and no clouding of the material in water or other harmful environmental effects have been detected. Monitoring will be continued to be able to follow long-term effects of the treatment in the marine environment. In addition to the environmental impacts in the marine environment, it needs to be noted that the heat-treatment process of limestone is relatively energy consuming, and calcination during the heating also releases CO^2 to the atmosphere (equal to approximately 15% weight loss during the process, e. g. from 1 ton marl 850 kg of sorbent and 150 kg of CO^2 is produced. Eva Björkman, pers. comm. 2021).

One of the main targets of the pilot was also to gather comparable and reliable information on the technical feasibility and costs of the implementation of the method. Basically, the implementation of the measure was found feasible and not expensive (see chapter 6), if the binding capacity would respond to what was achieved in laboratory scale, however, the efficiency could not yet be verified in SEABASED pilots. Scaling up of the heat-treatment process still needs further development, and, in addition, based on the SEABASED experiences, it is recommended to test the material in Baltic Sea circumstances in smaller scale in parallel when implementation of further pilots in the scale of coastal bays. With optimizing and further research of the treatment process, utilization of limestone sorbent still seems a potential future measure for binding phosphorus in coastal eutrophied sea bays (Ekeroth 2021).

<u>Aluminium treatment, pilot project in Björnöfjärden, Sweden</u>
(Rydin et al. 2017, Project Living Coast, BS2020)

The techniques for aluminum treatment are basically simple and have been used already for some decades on lakes. Treatment of the selected area can be done from boat by injecting the dissolved aluminum directly on the top of the sediment (used in Sweden, described e. g. in Rydin et al. 2017) or by simply spreading the substance on the surface of the waterbody (used at lakes in Finland). Spreading of aluminum on water surface may cause fish deaths as a side effect when the substance is mixed with water on its way to the bottom and, thus, may accumulate to the gills of fish. However, in some cases the fish deaths might also be a desired effect, targeting to decrease the population of unwanted species like roach or common bream (see for example: case Lake Littoistenjärvi, Sarvala 2018). It should also be noted, that in a pH outside from the "normal" range of approx. 6 to 8,5, aluminium may become more soluble and pose risk to biota (Rydin 2014, Rydin et. al 2017).

In a project carried out by BalticSea2020 Foundation in 2011–2016, a full-scale aluminum treatment with dissolved polyaluminum chloride was carried out in severely eutrophied Björnöfjärden bay in Sweden (area 1.5 km2, maximum/mean depth 25/6 m) (Rydin et al. 2017). The treatment was carried out in two stages, with a special equipment that was planned to spread the chemical evenly over the bottom sediment. After the treatment, a follow-up monitoring was carried out in Björnöfjärden and in a relatively similar reference area nearby (Fjällsviksviken, area 0.7 km2, maximum/mean depth 15/4 m) and the conditions of these two bays were then compared.

As a result of the treatment, much lower phosphorus concentrations were measured in the treated area than in the reference bay, and the overall supply of phosphorus was reduced over 90%. Good results were also obtained in water clarity and improved ecological status in several different aspects. The concentration of aluminum in fauna living in the bay was also monitored, and no harmful effects were found, however a short-term rise in the concentration of aluminum was observed in certain fish and bottom fauna right after the treatment. By the time of publishing the monitoring results, however, the sediment of the bay remained anoxic/hypoxic, and it remains to be seen whether the ecosystem in the bay is capable of restoring itself to the situation before severe nutrient loading and eutrophication had started. It has also been shown in studies that in high pH (over 9) the aluminium-phosphorus binding process is not working optimally, and therefore, the method is not optimal for shallow eutrophied sea bays where pH might rise relatively high during intensive algae blooms.

In addition to Björnöfjärder pilot, the aluminium treatment has recently been used for improving the ecological state of some severely euthrophicated inner archipelago bays in Stockholm (Brunnsviken, Djurgårdsbrunnsviken) and more measures are being planned for 2021 and 2022 (http://miljobarometern.stockholm.se/vatten/).

Testing of iron for phosphorus binding in shallow eutrophic bay
(Project Living Coast, Baltic Sea 2020 Foundation)

Iron is one of the natural binders of phosphorus in marine sediments and iron or aluminium chemicals are also commonly used for precipitating phosphorus in wastewater treatment. Another project of BalticSea2020 Foundation has investigated iron as one potential substance for binding phosphorus and tackling eutrophication in shallow eutrophied bays. The project seeked to identify alternatives to aluminum, tested in Björnöfjärden, as aluminum was found not always optimal in shallow eutrophic areas. In natural conditions in the Baltic Sea sediment, phosphorus is bound to iron under oxic conditions. However, when the circumstances become anoxic, phosphorus is released back to the water. Therefore, it can be assumed that adding of iron into the seabed would result in efficient P binding only in such bays where prevailing conditions aren't anoxic or the waterbody is being constantly mixed.

According to the project's website, the efficiency of iron has been studied in laboratory, and the results show that iron compounds bind phosphorus as efficiently as aluminum, and, thus, iron could be used for reducing phosphorus release from the sediment. The project has also planned to test phosphorus binding of two different iron compounds in one pilot bay (Gran Bay) with chamber-like enclosures. Results from the tests have not yet been published. (BS2020)

"Clay bombing"

Binding of phosphorus with clay is an idea brought up e. g. by Mikko Kiirikki (pers. comm. Luode Consulting), according to which the glacial or post-glacial clays from dredging sites could potentially be utilized for binding phosphorus in eutrophic coastal basins. The hypothesis of this "clay bombing" is that as clay naturally contains aluminium and iron compounds (Fe(III)oxides), adding clay on sediment surfaces would promote phosphorus binding to these compounds. Thus, the binding capacity of the sediment would be increased and phosphorous leakage from the sediment would be reduced (Mikko Kiirikki, Jouni Lehtoranta and Petri Ekholm, 2021, pers. comm.). The method is also described in Vahanen (2018). However, as no pilot studies exist yet, there are no results currently available on the applicability of the measure. Nor can the cost be estimated. Potential risks related to the method might be e. g. hazardous compounds bound in the dredged material or compounds released from the sediment in the target area in case of resuspension.

Pilot projects on oxygenation

Oxygenation has been a commonly used method for rehabilitating eutrophied lakes already for decades in Sweden and Finland, and it has also recently been tested in the marine environment in a couple of pilot projects (e. g. PROPPEN, BOX). The target of oxygenating the near-bottom waters or the sediment surface is to improve the phosphorus binding capacity of the sediment. In well oxygenated sediment phosphorus is bound to, e. g., iron compounds as in anoxic conditions phosphorus is released from these compounds back to the water body. By reducing the flux of phosphorus from the sediment to the water, there is less phosphorus available also for algae growth and reductions in algae biomass can be expected (Conley et al. 2009, Lehtoranta et al. 2012). However, there are still knowledge gaps existing in understanding the role of anoxia in biogeochemical cycles of nutrients in the Baltic Sea, and, thus, there is no consensus among the scientists that oxygen concentration is the only factor controlling the internal nutrient load (Conley et al. 2009, McCrackin 2018).

Oxygenation of water can refer to several techniques: pumping of air, water, or pure oxygen to the deeper water layers. To dissolve oxygen in water chemically is quite complicated and oxygen might be only partly dissolved to water when pumping of air. Thus, pumping of air does not necessarily increase the oxygen content enough near or in the sediment. In recent pilots in the Baltic Sea, pumping of oxygen-rich water from the near-surface layer has been used for transferring oxygen to the bottom. This, however, caused increased oxygen consumption in sediment due to the higher temperature of surface water used. Thus, to avoid rise of temperature, and, also to reduce energy demand for pumping, it has been proposed that pumping of mid-layer water to the bottom could be used instead.

Even though the method is commonly used in lakes, the results vary a lot depending on, e. g., the local conditions, load history and duration of oxygenation. In most lakes also the anoxic conditions on the bottom tend to return if pumping of oxygenated water ends. (Conley et al. 2009, McCrackin 2018, Horppila 2018: presentation in seminar on lake restoration methods). Some examples from coastal marine areas in the U.S. are also mentioned in the Vahanen Report, and the experiences form these projects imply that hypoxia easily tends to return on oxygenated areas also in the marine environment if the pumping of water or air rich in oxygen is stopped (Vahanen Environment 2018).

<u>Experiences from pilot projects PROPPEN and BOX (2009–2012)</u>
(Swedish Agency for Marine and Water Management, 2012. Reference Group Evaluation.)

Both projects PROPPEN and BOX were carried out within a programme launched by the Swedish EPA in 2009. The main goal of these projects was to test in coastal bays if pumping of oxygen-rich water to hypoxic or anoxic bottoms could oxygenate the sediment surface and increase the phosphorus binding capacity of the sediment, eventually preventing the long-term leakage of phosphorus from the sediment to waterbody.

Projects had altogether three pilot sites, two in Sweden and one in Finnish coast. However, due to technical challenges, e. g. insufficient pumping capacity at the Finnish site (Sandöfjärden), only the tests at the two sites in Sweden were successful (Byfjorden on the western coast and Lännerstasundet in the Stockholm archipelago). The implementation and results of the projects were evaluated afterwards by a scientific referee group.

Both projects showed that pumping of well oxygenated water in coastal scale is technically possible. Increases in the oxygen concentration in the near-bottom water and decreases in phosphorus were also observed at both sites (Byfjorden and Lännerstasundet) during the pumping. The conclusions from PROPPEN suggest that these results were achieved partly because pumping of water increased the flow of oxygen-rich water from nearby basins to pilot area which resulted in increase in oxygen also in the near-bottom water of the pilot basin. PROPPEN also concludes that the method could be applicable in small, coastal scale under certain conditions but further tests and information on ecological and physical effects is needed on the applicability on larger scales (Rantajärvi et al. 2012). However, the conclusion of the BOX project, on the contrary, was that the potential risks are smaller than ecological benefits of the measure, even in larger scales (Stigebrandt et al. 2015).

According to the referee group evaluation of PROPPEN and BOX (Swedish Agency for Marine and Water Management, 2012), a proper ecological risk assessment for oxygen pumping was not included in neither of the projects even though it was included in the original project requirements set by Swedish EPA. As the pumping periods in both projects were relatively short, the long-term effects of the measure remain unclear. It was also observed in both projects, that pumping of warm surface water to the bottom caused increase of water temperature in near the bottom, which resulted in an unwanted consequence, increased oxygen consumption in the sediment. The evaluation also concludes that the time of the pumping was too short for seeing e. g. the effect of the method on the long-term release of harmful substances (e. g. heavy metals, hazardous organic compounds) from the sediments.

In further discussion, it has been suggested that water should be pumped to the deep bottoms from the middle layers of water body instead of surface waters. The effects of largescale oxygenation of the Baltic Proper have been evaluated in the BOX-WIN Project, however, the results are based on modeling scenarios only (Stigebrandt 2018). Vahanen (2018) evaluates the biological risks and advantages of large-scale oxygenation against GES (Good Ecological Status, EU WFD), however it is clearly stated in the scientific referee evaluation of BOX and PROPPEN projects that the ecological risks were not studied nor evaluated sufficiently even in the small-scale pilots, and, thus, these evaluations should be considered mostly hypothetical.

Seabed restoration by removing the top-layer of sediment

Like many other restoration measures, removing organic sediments has been used in restoration of eutrophied lakes in both Finland and Sweden. Removing of the organic-rich sediment layers decrease the oxygen consumption of the sediment, and, thus, reduce the formation of anoxia in the bottom. Under oxic conditions, phosphorus would also be bound efficiently by iron compounds in the sediment. In addition, the removed organic sediment contains nutrients that could potentially be utilized e. g. as fertilizers. However, it has been suggested by recent studies (Laakso 2017) that not all sediments are suitable for agricultural use as such due to their ability to bind phosphorus in soil and thus reduce the availability of nutrients for cultivated plants. It should also be noted that the marine sediments might contain hazardous substances that prevent the utilization of sediments in agriculture without process for removing these compounds (Renella 2021).

Fig. 5. Janne Suomela from ELY Centre taking sediment samples at planned SEABASED pilot sites. Anoxic sediment from the bottom on the right. Pictures: Irma Puttonen / ELY

Within few years this measure has also been proposed for the Baltic Sea, and, in Sweden, also a new, patented technique for removing only a thin sediment surface layer without causing resuspension of the sediment on the bottom have been developed by KTH and Teknikmarknad AB. The technique has also been tested in coastal lake Barnarpasjön (NEFCO 2015 & Teknikmarknad 2015) and even at a 120m deep basin in Oxelösund in 2014–15 (NEFCO 2015, Bengt Simonsson, Teknikmarknad, pers. comm.). Some other pilot projects are currently ongoing in Sweden (e. g. LifeSURE, LIFE IP Rich Waters, Ramboll 2017), and other companies providing the same kind of methodology have also emerged (NUVA/ WAENS).

However, as scientific studies on the effects of such dredging projects do not yet exists, further studies, monitoring results and assessment of ecological effects of the measure are needed. The method was also planned to be piloted in Finland in project SEABASED (Fig. 5 and 6), but the offers received for the implementation exceeded the project budget. Therefore, a laboratory scale incubation test was carried out instead to find out the potential capacity of the measure in improving the status of heavily eutrophied marine coastal bays (SEABASED, WP T5 report).

Fig. 6. The scope of SEABASED sediment removal pilot was to determine sustainable solutions for different steps of sediment uptake process and test the measure in practise in the marine environment.

Picture: Irma Puttonen / ELY

<u>Results and conclusions from SEABASED sediment incubation test</u>
(for further information, see SEABASED WP T5 report)

Incubation tests for sediment tubes taken from constantly anoxic pilot bay, Hålax vik, were carried out in 2020. Part of the tubes were left intact, whereas from the others different layers (5-25 cm) of top-sediment were removed and the oxygen demand of the sediment, as well as nutrient and carbon concentrations in different sediment layers were measured. (For details, see reference reports). The thickness of the organic-rich layer of the sediment in the test samples was 25–30 cm.

Although the incubation time was rather short, particularly high oxygen demand was observed, and the test units were almost entirely exhausted of oxygen during the incubation. The tests were carried out in room temperature, and, thus, oxygen demand would probably be lower in situ due to lower temperature in the near-bottom water. During the tests, the oxygen demand varied widely between the test units. The determined oxygen consumption (BOD_7) decreased slightly towards deeper layers in the sediments, and the highest values of oxygen demand were observed in the test units with the original sediment surface (i.e., no sediment was removed). Thus, these additional tests suggest that sediment removal can moderate sediment oxygen demand.

The results from the sediment incubation test suggest that sediment surface layer removal might slightly lower oxygen demand temporarily. However, the decrease would not be enough to maintain high oxygen concentration in the near bottom water. Furthermore, each year a new layer of decaying organic matter will sink to the seafloor, increasing the oxygen demand again to the precedent level. Therefore, sediment surface layer removal should be repeated annually to achieve lower oxygen demand at the sediment surface and in the near-bottom water on permanent basis. In addition, the decrease in oxygen demand might still be insufficient to enhance iron oxide formation and consequent binding of phosphorus in the sediment surface.

The measured concentration of phosphorus (DIP, dissolved inorganic P) in the water was highest in the incubation test tubes where no sediment was removed, and lowest in the tubes where 25 cm of sediment was removed. However, the variation in DIP concentration between different incubations and sediment removals was not constant. The direction of phosphate flux between the water and sediment depends on the concentration difference between sediment pore water and the near-bottom water just above the sediment surface, and P can also be released from the deeper sediment layers if the surface layer is removed. Considering that, reducing phosphate concentrations in the water by sediment surface layer removal is uncertain.

Considering the experiences and results gained in SEABASED, sediment removal appeared to be a costly measure in marine environment (chapter 6), with several challenges still to be solved. According to the SEABASED test results, only the removal of the whole organic-rich layer - 25 cm thick in Hålax vik –- could lower oxygen demand and phosphate concentrate in the near-bottom water. Therefore, the measure should be repeated annually or almost all the organic-rich sediment with high phosphorus content should be removed to achieve anticipated effects. Notwithstanding, the outcome would be uncertain.

Experiences from other pilot projects

Project on thin layer sediment dredging in 2015 at Lake Barnarpasjön (Jönköping, Sweden) was financed by the Baltic Sea Action Plan Trust Fund (Nefco 2015) in August 2015. According to Nefco and Teknikmarknad, who carried out the project, the project resulted in doubled oxygen levels and reduced eutrophication of the lake. However, no scientific report is available on the results and accurate long-term monitoring data on the pilot site have not been published. In the project report (Teknikmarknad 2015), the achieved reductions of P and oxygen demand has been calculated with very general level assumptions e. g. based on estimates of P release in Baltic Sea hypoxic bottoms by A. Stigebrandt and not based on measured data (at least not available in public). In Oxelösund pilot, only the technical capacity of pumping sediment from a deep basin was tested, and, in general, was found technically possible (NEFCO 2015).

In southern Finland, lake Gallträsk was dredged 2008–2011 to reduce nutrient concentrations in the water and mitigate the consequences of eutrophication. Conventional dredging method and equipment were used to carry out the project. The volume of the dredged soft, fine-grained, and organic-rich sediment was 26 000 m^3. The sediments were dewatered in geotubes. The seepage water was treated to precipitate nitrogen, phosphorus, and toxic metals. After the treatment, the water met the quality specifications for drinking water. After dewatering the sediments were used as landfills in different targets. (https://www.kauniainen.fi/files/5056/Galltraskin_ruoppaus_yhteenveto.pdf; in Finnish)

LifeSURE Project in Malmfjärden, Kalmar (2017–2021), targets to improve the environmental quality of a pilot bay by removing 40 000 m^3 of sediments. A low-flow dredging equipment will be constructed, tested in small scale and then piloted in the Malmfjärden bay. The project also aims at demonstrating an ecologically sustainable process for retrieving and recycling sediments into a resource. The project is led by Kalmar municipality, and the total budget of the project is approximately 3.5 million euros (LifeSURE Project).

Fig. 7. Irrigation of lay with brackish water in SEABASED pilot in Åland. The water was pumped from the bottom of a bay nearby.

Picture: Annica Brink / Government of Åland

Nutrients from sea to field with irrigation
(for further information, see SEABASED WP T2 Report)

In SEABASED Project, two fields in Åland were irrigated for two seasons, 2019 and 2020, with brackish, nutrient-rich near-bottom water from the strongly eutrophicated bays Kaldersfjärden and Ämnäsviken (Fig. 7). In addition, two fields were irrigated for one season (2020) with water taken from Djupsjö coastal lake in Sweden. In both, Sweden and Åland, surface water from enclosed bays and coastal lakes is generally used for irrigation during dry summers. The pilot's main goal was to evaluate this sea-based method for reducing nutrients in the marine environment and restore the coastal areas into better conditions while presenting a win-win solution for the farmers and the Baltic Sea.

The pilots investigated how large the capacity was for removing nutrients from the bays, whether the crops could tolerate brackish water, and if the soil and groundwater could be negatively affected by the salt. In addition, it was compared in Sweden whether it was beneficial for crops to use bottom water instead of surface water for irrigation during dry seasons. An extensive monitoring program was included in the pilot to be able to determine the answers to these questions. Similar activities have also been carried out in Sweden outside SEABASED pilots, with no detected accumulation of salt (chloride) in the soil, as chloride has been observed to eventually be washed out by rain and surface runoff.

The results (SEABASED WP T2 report) show that ley production increased by 40–170% in the pilot areas compared to the control areas while maintaining high crop quality (Fig. 8). For the time frame of SEABASED pilot, no adverse effects on the soil composition were observed. However, an increase in chloride concentration was detected. Nevertheless, soil fertility was not affected. An increase in chloride concentration was also found in the groundwater, emphasizing the importance of knowing the run-off pattern in the irrigated area and use brackish water irrigation in moderation intermittently over the years. The estimated amount of salt when using brackish water on pilot fields was approx. 1kg / m^2. During two-year pilot activity, 29,5 kg of nitrogen and 2,6 kg of phosphorus was removed from the two pilot bays in Åland. Based on a rough model by ÅLR (Government of Åland), this removal corresponds to 6% (Kaldersfjärden) and 1% (Ämnäsviken) of what would need to be removed from the bays to achieve good ecological status (EU WFD). In Djupsjö pilot (Sweden), the uptake of P was compared when using surface or near-bottom water for irrigation. The measured uptake, with addition of altogether 160l water / m^2 (4 x 40mm) on the fields, was 7g or 48 – 64 g, and, respectively, addition of P to fields with irrigation was estimated to be 0,48kg P / 10 ha or 3,8 – 5,8 kg P /10ha.

Fig. 8. Ley of the reference field with no irrigation (left) and ley irrigated with brackish water (right), in SEABASED pilot in Åland. Picture: Annica Brink / Government of Åland

As a conclusion, based on pilots in SEABASED as well as previous studies in Sweden, nutrient-rich brackish water could be utilized for irrigation of ley but with caution for salinization of soil and groundwater. Therefore, irrigation on fields with brackish water is not recommended on annual basis, but rather during dry summers when irrigation would be needed in any case, to boost for crop production while simultaneously removing nutrients from the Baltic Sea and entering them into a circular system. Existing phosphorus concentration in the soil should also be considered before irrigating with nutrient-rich waters if other fertilizers are used simultaneously, to avoid nutrient runoff and accumulation of excess P in soil. However, with usage of nutrient-rich near-bottom water for irrigation instead of surface water, the use of other fertilizers could potentially be reduced. Nevertheless, monitoring is recommended to be able to detect possible unwanted, adverse effects.

In SEABASED, the suitability of the measure was evaluated only for production of ley, and, thus, for other crops than ley, further studies are needed before adopting the measure.

Pictures: John Nurminen Foundation & Jukka Nurminen (mussels)

Removing nutrients with biomass

The reduction of nutrients from marine environment with biomass of e. g. fish, mussels, common reed or algae (seaweed) have been examined and reviewed in recent years e. g. in projects within the Submariner network (https://www.submariner-network.eu/), and also by Kostamo et. al (2020). In measures related to biomass removal, verification of the amount of nutrients bound to the biomass is in most cases relatively easy. However, the actual ecological effects in the environment are difficult to show, due to complex interactions and food web structures between species, and processes related to nutrient cycles in different marine ecosystems. In many cases for example in lake restoration, the removal of certain fish species has been aiming more at food web biomanipulation than actual reduction of nutrients.

Management fishing

Fishing is the most traditional way of removing nutrients from the marine environment with fish biomass. Management fishing of low valued fish species, like the cyprinids, has long traditions in lake restoration. The results have been varying, depending on e. g. the local conditions of individual lakes. Overview on the results from Finnish lakes also show that the measure should be well planned to gain sustainable effects (Sammalkorpi 2018). The cyprinid fish, for example, contain approximately 0,08% (wet weight) of phosphorus (Setälä et al. 2012), so the phosphorus removal is relatively easy to estimate and verify. In the Baltic Sea, the coastal populations of cyprinid species and there-spined stickleback have increased due to the eutrophication (Olsson et al. 2019), and the abundance of these fish have also been shown to increase the nutrient release from the bottom (cyprinids) and the growth of filamentous algae (Klemens Eriksson et al. 2020, Kostamo et al. 2020).

Local Fish Project

In Finland, the management fishing of cyprinids has been piloted first in a governmental project in 2010–2011, and then 2015-2019 in the Local Fish Project (Mäki, 2020) and Project NutriTrade by John Nurminen Foundation, with the aim of commercializing the use of cyprinids for human food. The results seem promising: the annual catches in Local Fish Project grew from 35,000 kg in 2015 to 200,000 kg in 2019 and the first consumer product made of common bream was launched with Finnish Kesko in 2017. During the project, altogether approx. 700 000 kg of cyprinids were caught, and 5 t phosphorus was removed from the Baltic Sea with the catches. Sustainability of the fishing was ensured in the project with specific preconditions, according to which e. g. all bycatches like predatory and migratory fish were released alive back to the sea (Mäki, 2020).

In 2018, a Finnish governmental financing programme for enhancing nutrient recycling and improving the state of the Archipelago Sea searched projects for advancing ecologically and economically sustainable management fishing in Finland, and just recently also in Sweden governmental financing has become available for similar attempts.

<u>Stickleback harvesting</u>

According to recent studies, the abundant stickleback population has negative effects to the populations of predatory fish, due to the heavy predation of the eggs and juvenile fish by the stickleback (Bergström et al. 2015) and causing cascade effects in Baltic coastal food web and increasing the growth of annual, filamentous algae (Klemens Eriksson et al. 2020).

In SEABASED, harvesting of stickleback was piloted in Sweden and Åland (Fig. 9), with the aim to uptake nutrients with the fish biomass, and, in addition, to develop techniques to efficiently harvest the abundant population of these small fish. Different techniques were tested in Åland and Sweden, and the utilization possibilities for the catch were also examined. It was shown that there are a lot of stickleback present in coastal waters of Åland, however, catching them with regular fishing gear was found to be difficult. Thus, a special seine was developed, and technical guidance on how to catch stickleback the best is published on SEABASED project website by Åland Fishfarmers' Association.

The fishing continued in Åland in spring 2021, and studies on utilizing the catches will also be carried out in future projects. The nutrient content in stickleback has been estimated to be 2,2% N and 0,7% P in Archipelgao Sea (Luke). Thus, harvesting the abundant population of stickleback might provide an opportunity to remove nutrients from the Baltic Sea ecosystem, and, at the same time, find potential new raw material for fish feed or high value products (e. g. omega 3) refined from these fish.

Fig. 9. Catching of stickleback in SEABASED pilot in Åland. Pictures: Rosita Broström, Åland's Fishfarmers' Association

Mussel farming

In addition to fishing, blue mussel (*Mytilus trossulus*) cultivation for removing nutrients has been piloted in the Baltic Sea in several projects in Sweden and Finland (e. g. Baltic Blue Growth, NutriTrade). A lot of potential has been put on mussel farming as a water protection measure. However, despite of several attempts, no commercial use for Baltic Sea blue mussel has yet been found and the measure has been estimated to be quite expensive in relation to other nutrient reduction methods (Project NutriTrade 2018). The challenges with Baltic blue mussel are partly related to the fact that as a marine species, these mussels grow very slowly in the brackish waters of the Baltic Sea and remain a lot smaller that in oceanic waters. Thus, the commercial sustainability is hard to reach. In addition, techniques for treating the mussels e. g. for producing animal feed are not mature enough for commercial production (e. g. Minnhagen 2017, Baltic Eye).

The ecological effects of the mussel cultivation and harvesting has been reviewed from previous studies by Kostamo et al. (2020). Mussels filtrate the water while feeding, and, thus, they might have positive effects on water clarity. However, it has been estimated, that about 25% of nutrients consumed by the mussels during their growth can be taken up in the harvest. In addition, mussel cultivation might also have negative effects on marine environment as local eutrophication can be detected underneath the mussel farms, due to nutrients excreted by the mussels.

Harvesting of seaweeds and common reed

Several national and international projects on cutting of common reed (*Phragmites australis*) for removing nutrients and developing utilization possibilities have been implemented in recent years. Most of the projects have taken place on lakes, but also some Baltic Sea coastal pilots exist. During the summer, the fresh reed contains less than 1% phosphorus (dry weight) (Project SAAVI). The potential for removing nutrients with reed harvesting is summarized in Kostamo et al. (2020) and Ajosenpää (2014), with mean values of reduction potential being 60-120 kg of nitrogen and 5-11 kg of phosphorus per ha, respectively. However, reed is relatively easy to collect and several potential utilization possibilities (biogas, construction, utilization on fields) have been identified. Attention needs to be given to biodiversity issues if reed is planned to be cut down in large areas, as common reed provides important habitats for fish, birds, and insects, however, the rapidly growing reed also outcompetes other plants in coastal habitats (Kostamo et al. 2020). There are several ongoing projects in Sweden, Finland and Åland on reed harvesting, aiming at restoration of coastal habitats, removal of nutrients, and examining the utilization possibilities for reed biomass: e. g. 'Rannikkoruokohanke' (John Nurminen Foundation), 'Så I vassen' (Leader Åland) and 'Skydd under ytan' (Stockholm Skärgårdsstiftelse).

Harvesting of macroalgae and seaweed cultivation has been studied e. g. by company Origin by Ocean in Finland, and the GRASS Project. A recent report by Kotta et al. (2020) estimates the cultivation potential of macroalgae in the coastal areas of the Baltic Sea. These studies, however, are early estimates and commercial applications are not yet existing in the Baltic Sea. In addition, the sustainability of harvesting seaweed from natural habitats formed by perennial macroalgae should be carefully examined as these important habitats are already threatened already by euthrophication and harvesting them would undoubtedly cause severe negative effects in the coastal ecosystem.

Collection of seaweed from beaches have also been suggested as one way of circulating nutrients from the Baltic Sea. Some local projects have been implemented and utilization of seaweed for e. g. biogas production have been tested. In Project BIOFISK—bioeconomy in organic feed innovation for beach municipalities, utilization of seaweed in a chain for animal feed production is being studied. The project targets to extract nutrients from the sea with seaweed and to provide a new means of producing animal feed in the future (BIOFISK).

Sustainability of the sea-based measures

Environmental aspects

SUMMARY

- **The suitability of the sea-based measures is always site-specific.**
- **Environmental risk assessment is needed for any sea-based project.**
- **Results from one site cannot be directly applied to other locations.**
- **Concerning large-scale (open sea) applications, results from local pilots can't be generalized to open sea ecosystem as such.**
- **Impacts to be considered might not be restricted to the marine environment (e. g. utilization of biomass, biodiversity).**

Background

There is only little experience and research existing on the ecosystem effects of different sea-based measures in the marine environment, and, in addition, knowledge gaps exist also in understanding the functions of nutrient cycles in sediment and marine biogeochemical processes, especially for the deep bottoms of the Baltic Sea. Therefore, precautionary principle should be applied when considering the use of the sea-based measures for decreasing the eutrophication in the sea, and ecological risks should be carefully assessed before applying measures on which no long-term research is existing.

Potential environmental risks, and negative or unknown effects of the measures, can be mitigated by careful site selection, which excludes any pristine bottom areas with e. g. fish spawning grounds or other ecologically valuable habitats. Pilots could be implemented for example in coastal anoxic bottom areas that have been historically under high anthropogenic nutrient load, with little possibilities of significant flora or fauna to survive without restoration measures. It can also be recommended, that the sites and measures would be selected by experts and authorities, based for example on earlier water quality monitoring and bottom sediment data, which would also form the basis for comparing the effects before and after the measure(s) have been taken. Long-term monitoring of pilot sites, as well as documenting of all steps of implementation, is also crucial for gathering further knowledge on the environmental effects of the novel measures and for planning of future pilots.

In the SEABASED Project, the views on the ecological risk assessment for the utilization of coastal scale sea-based measures was discussed in project's scientific workshops with researchers representing different fields of marine sciences, e. g. ecology, fish and marine food webs, biogeochemical processes, nutrient cycles, and physics. Altogether 20 scientists participated in the workshops organized in Finland and Sweden, and the development of the risk assessment framework presented here is based on the outcome from these workshops. Even though there were different views among the participants on the application of sea-based measures in general, the evaluation of the potential ecological effects or risks related to different measures is primarily based on scientific views and functions in the marine environment. No individual views or statements are presented.

In addition, preconditions for suitable pilot sites and criteria for site selection were established in the beginning of the project, prior to the implementation of the SEABASED pilots.

Criteria for site selection

In general, sea-based measures should be targeted only at areas identified as potential/significant sources of internal nutrient loading, e. g. areas with severely hypoxic/anoxic dead bottoms. Recent studies have taken place both in Sweden and Finland (Fig. 10), which could be utilized when estimating the potential sources of internal load. In addition, the following preconditions and factors should be considered when choosing locations for small scale coastal sea-based measures:

<u>Preconditions for pilot sites suitable for sea-based measures</u>

- Enclosed/ semi-enclosed conditions to control and limit the environmental effects
- Existing (preferably long term) monitoring data before implementation
- Monitoring possible also after implementation for a sufficiently long time
- In areas contaminated with hazardous substances, specific attention should be paid beforehand to the risk of releasing contaminants when applying the measure.
- At oxic, shallow areas with high pools of mobile nutrients, thorough evaluation of negative and positive impacts on local ecosystem (bottom fauna, cascading effects etc.) is needed before the implementation of measures.
- Reduced external loading from land-based sources

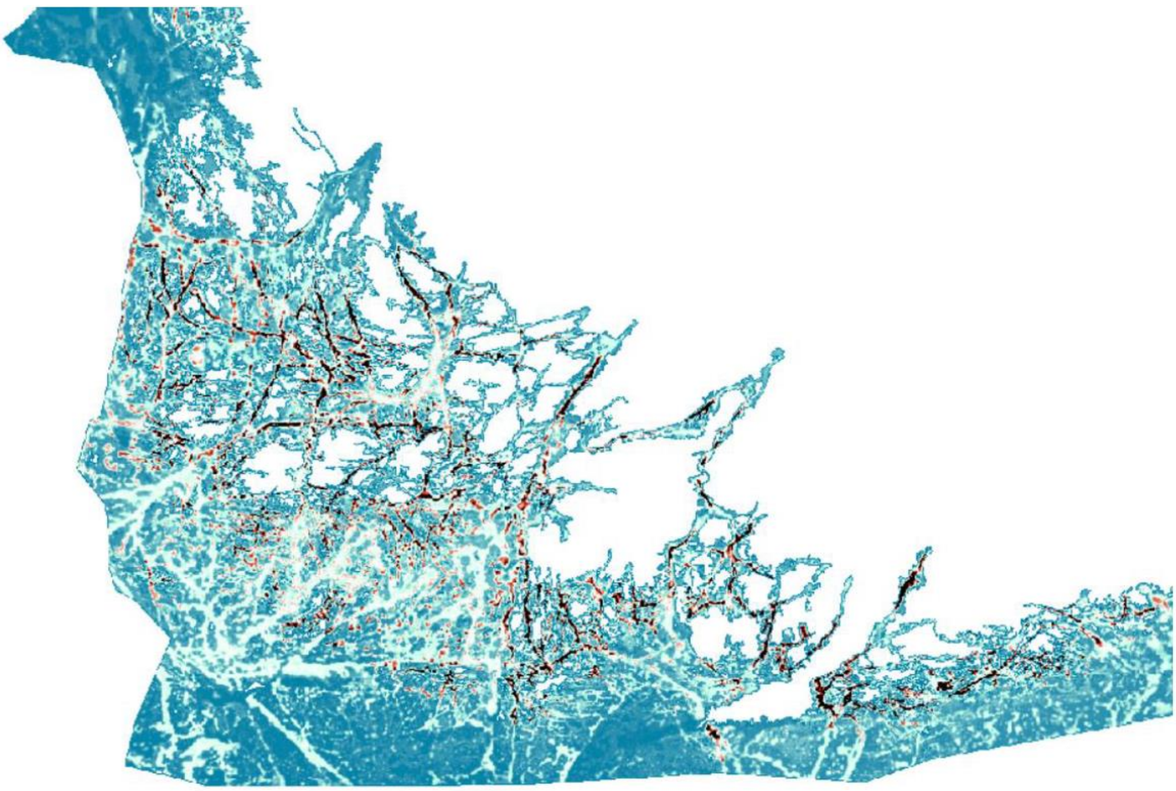


Fig. 10. The predicted extent of anoxic seabed areas above 25 m in the Archipelago Sea has been recently studied e. g. in Virtanen et al. 2019 (Source: Virtanen et al. 2019)

Choosing of measures

The suitability of sea-based measures is always site-specific, and, thus, special attention should be paid on the selection of both the site and the measure (Fig. 10). Local circumstances at the selected site should be studied beforehand.

In general:

- Methods should be used that minimize:
  - increase of turbidity caused by the measure
  - release of nutrients/hazardous substances from the sediments
  - negative impacts to local ecosystem (ecosystem indicators)
  - mixing of the stratification in water column (salinity, temperature)

- When removing biomass, the whole chain should be well planned, to avoid release of nutrients back to the marine ecosystem, concerning e. g. the following:
  - Handling of the residues of dredging
  - Usage of catches of removal fishing
  - Usage of harvested algae/reed/blue mussels etc.

Ecological impact assessment and indicators

By evaluating the added values and impacts on different ecological indicators, biggest risks and risk thresholds, “no-go’s”, as well as potential benefits can be identified for the planned measure. These are also the key issues to consider when evaluating the applicability of possible future pilots. In addition, ecological impact assessment might be required when permitting the planned measure.

Ecological impact assessment should aim at

a. Identifying potential ecological effects, benefits and risks related to the planned measure and

b. Understanding e.g.
- direction (positive/negative, indicators)
- magnitude
- extent
- duration (in time)

of the identified effects.

Different ecological indicators can be used for evaluating the effects of sea-based measures. Part of the indicators are measure-specific, and, thus, might not be relevant in case of all measures. Therefore, the impact assessment should be planned thoroughly to ensure the selection of the most relevant indicators for different measures.

Indicators

There are some general, essential indicators that will likely be affected by application of sea-based measures, and, thus, should be included in most cases when assessing and monitoring of the potential effects of planned measures at selected site(s). However, in individual cases not all of the general indicators are relevant either, but more measure-specific indicators should be utilized instead.

General indicators for impact assessment:

- Secchi depth
- a-chlorophyll
- Oxygen content (water volume, in the sediment and in the water column)
- Nutrient concentrations (especially P, but also N)
- Changes in sediment phosphorus (P) concentration
- Sediment phosphorus (P) fractination (bound or loosely adsorped, bound to Fe, Al or organic matter)
- Bottom vegetation and fauna (depth of submerged vegetation, vegetation cover, species composition)

In addition, special attention should be paid on hazardous substances. It is substantial to know what is in the sediment before implementing any measures, e.g.

- sediment analysis and/or mapping of the previous uses of the planned area
- PAHs, TBT, dioxins etc. in contaminated sediment or in biota, e. g. in fish

Depending on the chosen measure, specific indicators should be applied according to the method of impact of the planned measure. These indicators should be selected with assistance of specialist of relevant field of expertise (marine ecology, sediment geology etc.).

<u>Potential risks related to sea-based measures</u>

There are severe ecological risks and impacts that should be considered and included in the impact assessment when planning the application of sea-based measures that affect the processes in marine ecosystem (Fig. 10). However, part of the most likely risks are also measure specific, which should be taken into account when planning the assessment.

The risks with severe consequences should be considered in the impact assessment, depending on the planned measure. Examples of such risks are presented below:

- Disturbing of the ecosystem functioning (cascade effects, interactions in the ecosystem that we do not yet understand)
- Risk of biodiversity loss, e.g.
    - Impacts on specific habitats (e. g. spawning or nursery habitats for fish)
    - Impacts on species and species composition in the ecosystem
- Impacts on nutrient concentrations in productive water layer
- Risk of releasing of nutrients/ hazardous substances from the sediments
- The measure-specific aspects, e.g.
    - Phosphorus (P) fractionation and nutrients in the sediment (mobile P)
    - Changes of pH in shallow areas (aluminum treatment, marl)
    - Disturbance of the bottom (dredging, spreading of aluminum to the bottom)
    - Increasing the oxygen consumption in the bottom (e.g. oxygenation/dredging, if not planned right)
    - Other consequences (e. g. long-term impacts that are not yet known)
- Effects of changes in the environment over longer period of time (however these are difficult to assess in detail, e. g. impacts caused by land uplift, climate change etc.)

Monitoring and management of risks

For enabling the management of potential risks, a thorough plan for monitoring of the targeted area is usually needed, in addition to the evaluation of environmental impacts (Fig. 11). This is usually required also by the authorities when permitting the planned measure. The management plan should include a description on e.g.

- How the status of the target area will be identified and followed prior, during, and post to the activity (e.g. indicators relevant to include in the monitoring plan)
- Spatio-temporal coverage of the monitoring plan (e.g. plan for identifying possible long-term effects or effects on neighboring water areas)
- Evaluation of impacts on Natura 2000 and other marine protected areas
- How the potentially identified risks or negative effects will be minimized during and after the implementation of the planned measure.

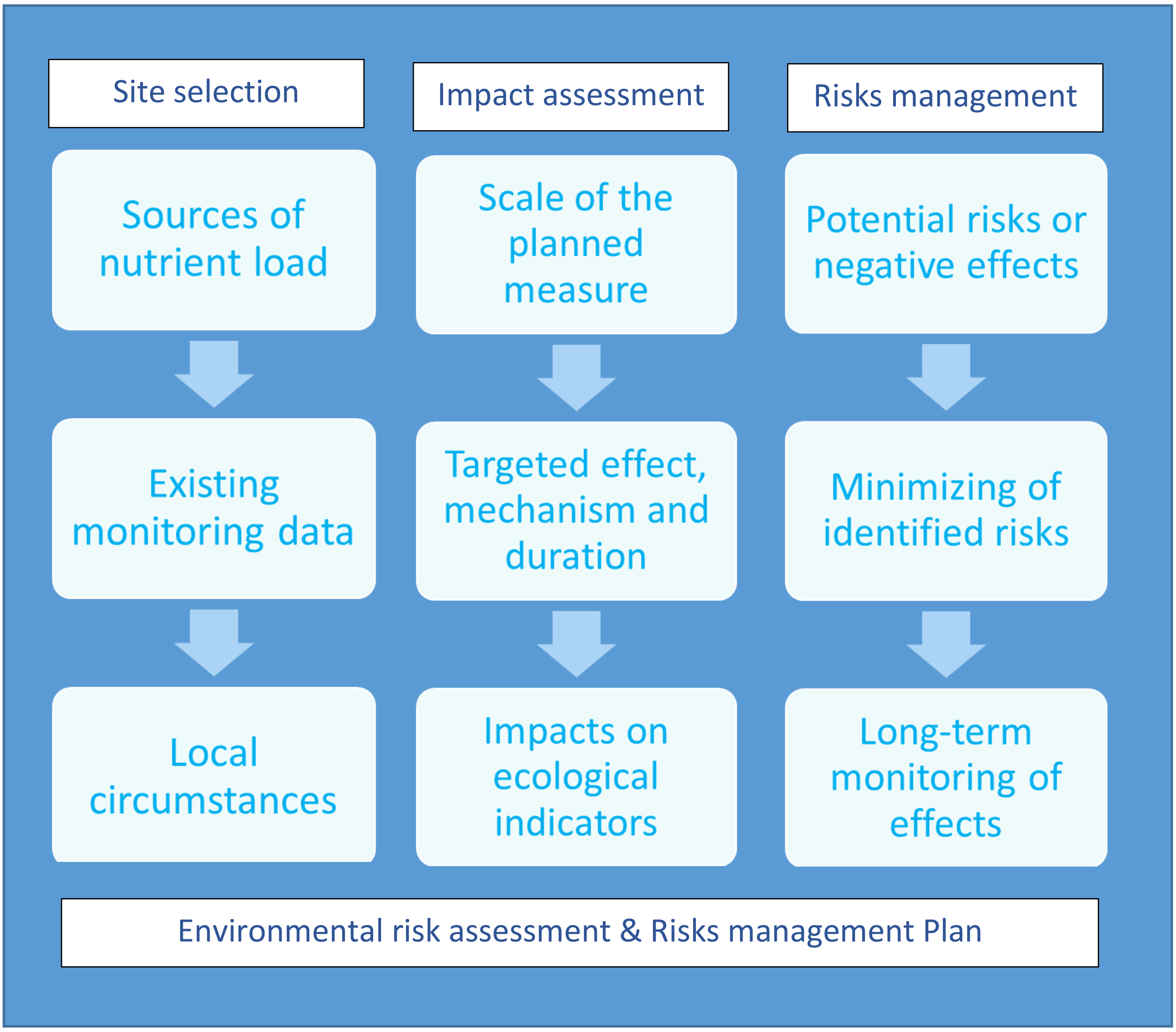


Fig. 11. A thorough environmental risk assessment should include information on the local circumstances at the planned site, mechanism, potential impacts and scale of the planned measure and a monitoring plan for managing the identified impacts and risks.

Social sustainability of the sea-based measures

SUMMARY

- **General acceptability for small-scale coastal measures is rather high, however, only as supportive measures to land-based load reductions.**
- **Open communication and sharing of information on planned measures and results increases acceptability and benefits also future projects.**
- **More information is needed on the risks and effects of the measures to increase the acceptability of especially applications for larger scale than coastal bays.**

Background

In Sweden and Finland, and, also Baltic Sea wide in Helcom (Baltic Marine Environment Protection Commission – Helsinki Commission), a discussion on to which extent the sea-based measures could be utilized in national and regional marine water protection is ongoing, including the question on whether some, or which, of these measures should also be included in the water management plans for coastal waters. Simultaneously, the public discussion has sometimes been overruled by strong opinions posed by very few individuals, representing e. g. private companies or the science community, who are either pressing for rapid deployment of the new measures, even in large open sea scale, or, on the contrary, stating that not even the research of the sea-based measures should be supported, based e. g. on the fear that the land-based measures would be replaced by the sea-based activities. Thus, based on the outcome from the different public forums, general views among e. g. the researchers or environmental authorities towards the sea-based measures have been rather difficult to recognize.

When considering the use of sea-based measures in local marine water protection, the multiple values related to the use of coastal waters as well as views of several stakeholders must also be taken into account. Even though protection measures in general aim at improving the water quality of the targeted area, and thus are likely to also improve the possibilities for recreational or economic use of the coastal waters, some measures have temporary effects that might hinder the utilization possibilities or are likely to rise concern among the local inhabitants or entrepreneurs. These concerns should be listened to, and enough information should be shared on the planned measures to the local communities for allaying the possible fears and anxieties among the people. For successful implementation of local water protection, possible contradictions between targets and views of responsible authorities and local people and community would be beneficial to solve beforehand, although conflicting interests e. g. between different livelihoods or local individuals are usually always present to some extent.

In the SEABASED Project, the views, general acceptability, and the social sustainability of the utilization of coastal scale sea-based measures was mapped and assessed among several different stakeholder groups. The views of environmental and permitting authorities and other stakeholders, e. g. environmental NGOs, were collected by interviews and surveys. A total of 54 local, regional, and national environmental authorities answered the online SEABASED Social Sustainability Survey (Attachment 1) in 2020. In addition, 30 stakeholders, including representatives from NGOs and research institutes, were interviewed personally. For local communities, information events were organized at SEABASED pilot sites, and the participants were offered a possibility to answer a survey for mapping the views of local people. A total of 40 local inhabitants and landowners answered the Local's voice surveys in the information events (Attachment 2). In addition, the private sector companies were engaged in the discussion in stakeholder forums where the potential and risks related to the novel measures, as well as the incentives and obstacles for their use were discussed.

Views and acceptability of sea-based measures among environmental authorities

The SEABASED sustainability Survey was targeted especially to authorities who are responsible for national, regional, or local level marine water protection and/or permitting of measures targeted on coastal regions. The survey was carried out in Webropol, and a link to the survey was sent 240 recipients in Finland, Åland, Sweden, and Estonia. The majority, approx. half of all 54 respondents represented regional authorities (e. g. ELY centers, County Administration), 25% municipalities or other local authorities and 25% national ministries (see attachment 1 for the full survey results).

In general, hardly any disagreement exists on the fact that the large internal nutrient reserves in the Baltic Sea are currently hindering the recovery of the sea, even though the external nutrient load have been cut remarkably in past decades (HELCOM 2018). Based on the survey, the authorities find the concrete improvements on marine environment the biggest potential benefits for using sea-based measures on a coastal scale, whereas the biggest risks were seen in the efficiency and the costs of implementing the measures. In addition, the lack of knowledge and information on long-term effects raised concern, but also the lack of financing and political will were found hindering the use of sea-based measures. This might relate to the emerging need for efficient measures to combat the eutrophication of the sea and the pressures in meeting the targets set in marine water protection plans, both on national and regional levels. The high scores for economic aspects in the survey might also reflect the lack of resources for efficient water protection in general and, thus, are not related only to the use of sea-based measures.

The majority of public authorities and researchers also seem to agree on the need of further research and development of the new measures before taken in wider use and, thus, are mostly supportive towards small-scale pilots or research projects rather than large-scale applications of novel measures or techniques. The biggest differences between countries were found in the views about the entity that should be implementing the sea-based measures, which might reflect the national differences in the resources available for public entities to implement water protection measures in general.

Despite over 80 % of environment authorities who answered the survey supported including sea-based measures to the new marine water management plans, the general view still was that these measures should be seen as supplementary to land-based measures. However, the importance of sea-based measures in the marine water management plans may increase in the future, when there is more information available about the effects, prerequisites, risks, and technical feasibility of the applications.

Stakeholder views on sustainability of sea-based measures

Based on 30 stakeholder interviews, the general view among the stakeholders was that the focus should keep on reducing external nutrient load. Therefore, sea-based measures were considered the most acceptable only when implemented at the same time with land-based measures, as supportive measures. Also, the lack of funding was raised, and it was not seen sustainable to reallocate the funds for implementing the sea-based measures from the funds intended to be used for land-based measures.

Attitudes were found to be the most positive towards measures, which have also other benefits in addition to nutrient removal, such as habitat restoration or nutrient recycling. Biomass removal is desirable over the other sea-based measures, especially if the biomass is utilized and nutrient recycling is possible. Most reservations were found regarding such measures which have physical contact with benthal deposits, due to possible risks related to e. g. hazardous substances. However, also measures on seabed were accepted if targeted at areas, where there is no risk to cause harm on the local ecosystems. Piloting of new measures was found to be more acceptable if the projects include research and long-lasting monitoring of environmental effects. The importance of knowledge on marine ecology in project planning, as well as thorough environmental assessment, especially of impacts and risks, was emphasized by several interviewees. Based on the stakeholder views, a wide cooperation between authorities, research institutes, NGOs and local communities would increase the feasibility and acceptability of projects and the development of new, economically viable measures.

The following organizations were represented in the stakeholder interviews:
Baltic Sea Action Group (BSAG, FI), Baltic Sea Challenge (FI), Coalition Clean Baltic (CCB), County Administrative Board of Stockholm, County Administrative Board of Östergötland, ELY Center of SW Finland, ELY center of Uusimaa, Estonian Fund for Nature, Finnish Association for Nature Conservation (SLL), Finnish Environment Institute (SYKE), Government of Åland, Helcom, Ministry of the Environment and Energy (SWE), Ministry of the Environment of Finland, Natural Resources Institute Finland (Luke), Natur och Miljö (FI), Nordic Environment Finance Corporation (NEFCO), Protection Fund for the Archipelago Sea (FI), Race for The Baltic (SWE), Swedish Environmental Research Institute (IVL), WWF Sweden, Åbo Akademi, Östersjöfonden (ÅL)

In addition, representatives of several private companies participated in the stakeholder forums in Sweden and Finland where feedback was collected.

Engaging of local communities

In SEABASED, local pilots of different sea-based measures were implemented at several localities in Sweden and Finland. The pilots raised high interest among local communities and inhabitants (Fig.12). Information about the pilots was shared in local media, information letters and at information events organized for local people. The views from participants of the events were collected via Local's voice Survey (Attachment 2).

From the local people's perspective, communication and informing about the measures were found to be the most important means to reach social sustainability. People are more open to new measures if they understand what will be done and why. Therefore, when planning of local water protection projects, it is important to openly inform local community about the expected results, but also about the related uncertainties and risks, so that the expectations are realistic. From the perspective of social sustainability, it's also equally important to offer local people a possibility to ask and discuss about the planned project and the measures chosen. The active engagement of local community, for example by organizing information events, can increase the acceptability among local communities. At its best, successful communication of a local project could also increase people's general interest towards water protection.

Conclusions: the acceptability of the sea-based measures in future use

Based on the SEABASED surveys and interviews, most of the environmental authorities and other stakeholders support the general idea to utilize sea-based measures in marine water protection more widely to be able to reach the ambitious water protection targets in the future, but only if further studies of the new measures indicate that the measures are effective, and risks are manageable. Consequently, it seems evident that further research on the environmental effects and risks related to the different sea-based measures is needed before these measures can be accepted in wider use.

Furthermore, the most acceptable use of these measures could be rather as a part of a catchment area or restoration project than as a separate measure. Nor does it seem probable that sea-based measures could be considered cost-efficient or safe enough to be applied in the open sea scale in near future.

One remarkable reason for the reserved attitudes among the authorities and other stakeholders was found to be the assumably high costs of many of the sea-based applications. Many experts and stakeholders casted doubts on the cost-efficiency of small-scale sea-based measures as their impacts might vanish due to the dynamics of the sea environment and, thus, could not be reliably verified. For that reason, attitudes in general are more positive towards such approaches, which have at least some potential to develop economically viable, such as removal of different biomasses, e. g. fish, reed or seaweeds, and their further utilization. Also, the risks of biomass-based measures are seen relatively lower compared to more technical and novel "geo-engineering" methods, like sediment removal or binding of phosphorus with chemical compounds.

One of the general assumptions raised in the interviews was the increasing relevance of cutting internal load in the future if the effects of the climate change will increase the amount of land-based nutrient load to the Baltic Sea. Therefore, the interest towards also novel water protection measures, especially the "geo-engineering" measures, is likely to increase accordingly in the future. Thus, more resources would be needed for further studying these methods to be able to increase the knowledge-base and verify the efficiency, potential risks, and the sustainability of these measures.

From the social sustainability perspective, open sharing of the experiences and results of future applications of novel measures is of high importance, both during and after the implementation of the pilot projects. In addition, that open communication would increase trust towards the projects, it would also benefit from further studies and other projects on similar topics. Furthermore, reliable monitoring and documentation of results and planning of the future utilization of gathered knowledge would maximize the benefits of the efforts and advance not only the development but also the acceptability of future projects.

Fig. 12. Spreading of limestone sorbent raised interest at SEABASED Kolkka pilot site, Finland (2020). Local authorities and inhabitants were informed beforehand about the pilot activities.

Pictures: Eeva Tähtikarhu & Tara Jaakkola

Economic aspects and cost-efficiency of measures

SUMMARY

- **Cost estimates should be based on realistic information on both costs and nutrient reduction efficiency of the measure.**
- **Some measures based on biomass removal seem to be cost-effective**
    - **with estimated costs of less than 200 € / kg P removed**
    - **when compared to the measures for reducing land-based load from diffuse sources (e.g. agriculture)**
    - **even when no assumption on market value for the biomass has been included in the calculation**
- **The "geo-engineering" measures seem to be clearly less cost-effective than the present land-based measures**
    - **For some measures, piloting even in coastal scale has turned out to be challenging due to high implementation costs.**
    - **Some measures could be used locally for small coastal areas, where the role of internal load on eutrophication is proven and water quality cannot be improved with other means.**

Background

Cost-efficiency is an important perspective when considering the feasibility and applicability of any water protection measures. Moreover, one of the reasons behind the increasing interest towards sea-based measures in recent years has been that the cost of nutrient-abatement measures on land has increased after the most of "low-hanging fruits" from municipal and industrial point-sources around the Baltic Sea have already been implemented. Decreasing diffuse pollution has proven to be slow and in many cases much more expensive than the abatement measures implemented for point sources. It has also been proposed by some scientists that the cost-effectiveness of nutrient load abatement with sea-based measures might already be better than with land-based measures.

However, for large part of the sea-based measures, it is basically impossible to establish any cost-efficiency estimates if there is either no verified information on the actual effect of the measures on nutrient reductions (or e. g. decreased loading from the seabed) or on abatement costs. In many cases impacts on load have been calculated based on theoretical assumptions or modeling, without knowledge on actual, monitored effects in the Baltic Sea ecosystem. This emphasises the future need to study thoroughly, with proper monitoring arrangements and long enough time series the impacts of sea-based measures in the marine ecosystem.

Cost estimates from pilots implemented in SEABASED or other previous projects are summarized in Table 1. The comparison table is based on the actual, realized costs or cost estimated based on received offers for pilot implementation. Potential commercial values for presented measures are not included in the cost estimates, to make the costs more comparable. Results from modelling studies are not included. In addition, the sea-based measures included in the comparison table are currently not seen as alternative but rather as complementary for load reduction from land-based sources, and, thus, land-based measures are not included in the comparison of costs.

"Geo-engineering" measures

As there are still very few real-life pilots existing in the Baltic Sea for the novel "geo-engineering" measures, cost-efficiency calculations have often been based on assumptions or estimates rather than actual data, with few exceptions. For aluminium treatment, the estimation of cost-efficiency can be calculated based on an existing pilot project (Rydin et al. 2017), whereas e. g. for measures based on sediment removal and oxygenation, reliable calculation of cost-efficiency is currently impossible due to lack of information on actual costs or impacts of the measure on marine ecosystem in real *in situ* conditions.

Oxygenation

There have been some pilot projects (BOX, Proppen, OXY-experiment) during the last decade to test oxygenation in the Finnish and Swedish coasts. The results, however, have been mixed (Chapter 2) and, thus, it remains unclear whether the phosphorus binding capacity of the bottom sediment could be increased, and sustained improvements achieved with oxygenation (pumping of water). Estimates for larger-scale oxygenation have also been made in e. g. in BOX-WIN project (Stigebrandt et al. 2012 & 2015). However, BOX-WIN, as well as some existing other studies on the topic, are based only on modelling and do not include measured effects or actual costs. Thus, those studies fall out of the scope of this document, as specified in Chapter 1, and are therefore not referred further in this context.

Based on the few existing pilot studies (Rantajärvi et al. 2012, Lehtoranta et al. 2012), it seems to be clear that the success of the measure depends to a large degree on site-specific issues such as bottom topography, water currents and the choice of technology, which further complicates ex-ante assessment of impacts and cost-efficiency. Although oxygenation has been used for decades in lake restoration, the results from freshwater environments cannot be used for estimating effects in the sea ecosystem, due to the differences between natural circumstances and processes in these ecosystems.

In general, oxygenation of the sea bottom seems to be relatively expensive to implement even in pilot scale. Waves, wind conditions and depth make technical arrangements rather complicated, costly and vulnerable to damage, which was proven e. g. in the Tammio open sea area pilot (OXY-experiment), by the break-up of the pumping equipment. Pumping of water is also energy-consuming, and, thus, the costs and sustainability of the measure are also to large extent dependent on the energy solutions used for the pumps.

Sediment removal

As for oxygenation, establishing cost-efficiency for sediment removal as a protection measure is currently impossible due to lack of information on actual impacts of the measure in the marine ecosystem. A specific technology developed in Sweden by Teknikmarknad Ab has been proposed for the Baltic Sea restoration, with which only a thin, a few centimetres thick layer of surface sediment is taken up from the bottom and pumped on land. The hypothesis is that the measure would both remove nutrients from the seabed, and, also by removing organic material from the bottom, decrease oxygen consumption in the deep water (Simonsson, in Helcom 2014). The dredging methods used e. g. in lakes in Finland cannot be considered as a similar measure to the top-layer dredging tested in Sweden by Teknikmarknad Ab, due to remarkable differences in technology, and, thus, these techniques have not been included in this review.

Sediment removal with the above-mentioned technology has been tested in the lake Barnarpasjö in Sweden (Teknikmarknad 2015) and only once in the Baltic Sea area in Oxelösund, Sweden (NEFCO 2015). However, as no monitoring results of the pilot have been published, cost-efficiency of the measure cannot be established. Some cost-efficiency estimations have been made (e. g. in Vahanen 2018) that include a hypothetical market value for the nutrients and organic material in the removed sediment which, in theory, are benefits which could reduce costs of sediment removal. However, as long as there is no existing market for such products, the real values cannot be included in the calculations. Different business models for nutrient recycling from marine sediments have recently been reviewed by Tell & Ökvist (2019). In addition, there is an ongoing project in Kalmar, Sweden (LifeSURE), where nutrient extraction from marine sediments is being studied.

It should be noted that until now it has been challenging to find economically viable usages even for most land-based nutrient-containing biomasses (including e. g. manure) as transport and processing costs tend to be high in comparison with the economic value of nutrients and organic material contained in the biomass. Therefore, such products have generally not been able to compete with the mineral fertilizer products in the market.

The concentration of nutrients in sea sediment is lower than e. g. in manure and many other land-based biomasses. In addition, marine sediments may contain contaminants, which could reduce the interest in their usage in farming. It is technically possible to remove the harmful substances, but this means increasing costs. In case for usage of sediment in biogas production, in addition to transport costs, in Finland also a gate fee for the biogas plant needs to be paid. Thus, at present the disposal and utilisation of marine sediments increase costs of sediment removal instead of reducing them.

It was also planned to include a sediment removal pilot within the project SEABASED, but the price of the received offers considerably exceeded the project budget. The proposed cost for taking up sediments, including also dewatering and disposal of the sediment, from a 2 ha basin (inside the 10 ha pilot area) varied from 482 000 € – 1.774 M €. The calculation of cost €/kg phosphorus (P) removed from the Baltic Sea is presented in the table 1, based on the offers received for the SEABASED pilot. Accordingly, the estimation on the amount of P that could have been removed with the pilot is derived from the results of the sediment incubation study in SEABASED (WP T5 report), in which the sediment taken from the selected pilot site was used.

The experiences from the SEABASED pilot highlight the fact that removing a thin layer of bottom sediment without causing turbulence is technically challenging and thus expensive. So is also further processing of the watery sediment without releasing the removed nutrients back to the sea. Moreover, finding a place for depositing or utilising the removed sediment is a further challenge, which increases costs. Thus, sediment removal in coastal sea bays seems to be an expensive measure, especially when implemented with adequate low-flow technology and not the traditional dredging methods used e. g. in lake restoration in Finland.

Permanent binding of phosphorus to the seabed

The project SEABASED did two pilot experiments of binding phosphorus to the bottom sediment with heat-treated, activated limestone (Gotland marl), but could not establish its effectiveness under *in situ* conditions in the Baltic Sea. Based on the previous experiments in laboratory, the P binding capacity of heat-treated limestone has been proven to be remarkably high (Table 1), but further studies and testing are needed to verify the effect also in the actual Baltic Sea ecosystem conditions.

The total cost for the two full-scale pilots in SEABASED Project was approx. 45 000€. This includes the production of the sorbent in a pilot-size kiln, approx. 0,5€ / kg, (including gasoline and oxygen needed for the heat-treatment process); transportations from Gotland to the pilot sites in Sweden (Kyrkviken bay near Linköping) and Finland (Kolkanlahti bay in Naantali), approx. 0,05€/ 1 ton of sorbent; and spreading the sorbent at the pilot sites from a helicopter, approx. 1000€/ton. The raw material was donated to the project without cost by Nordkalk. Based on the laboratory studies prior to the *in situ* experiments, a dose of 100g sorbent/m^2 (1 ton / ha) was used in the pilots, which equals the cost of approx. 1500€ / ha of treated area (spreading 1000€/ton + production 500€/ton).

The limestone material used, Gotland marl, is a residue of limestone industries in Gotland, and there are considerable amounts of this side-stream material available. Thus, this circular economy-based method could be cost-efficient and have large-scale potential in Baltic Sea restoration efforts, even if the raw material wasn't available for free as in the SEABASED pilots. However, similar phosphorus binding efficiency that was observed in the laboratory could not yet be verified in the SEABASED project. Further development and pilot studies are needed to assess the effectiveness of the method.

Therefore, currently the only chemical available for binding phosphorus in the Baltic Sea conditions and tested with long-term monitoring arrangements is dissolved polyaluminium chloride, which has been piloted in Björnöfjärden (Rydin et al. 2017). According to Kumblad and Rydin (2017), to bind 1 kg of phosphorus in the sediment, 10 kg of aluminium is required. Depending on the cost of the chemical, the cost of binding one kilogram of phosphorus varies between SEK 400-2,000/kg, equalling roughly 40-200 €/kg P, where the lower cost estimate applies to larger bays (Rydin 2014, Kumblad & Rydin 2017) (Table 1.).

Measures based on biomass removal

A crucial aspect for the cost-efficiency of measures based on removing biomass is whether there is commercially viable usage for the removed material. This is also an important issue for the long-term sustainability when implementing biomass removal: if the measure is done only from an environmental and ecosystem perspective without market-based usage for the biomass, it tends to be short-lived and last only until the project or other external public financing ends. Moreover, when measures are planned strictly from the restoration perspective without the involvement of commercial actors, development of commercially viable usages can rarely be established, and the biomasses often end up in compost or other low-value usages.

Management fishing

Cost-efficiency of management fishing varies greatly depending on the utilization of the fish and the fish species targeted. Fish can be used for producing human food, animal feed, various refined high-value products such as enzymes and food supplements, and energy (biodiesel, biogas). In the Baltic Sea region, mainly fishing of cyprinids (roach, common bream, and ide) as well as stickleback has been considered. Baltic herring is also sometimes mentioned in this context. However, as the herring fishery is based on annual quotas, from the ecosystem perspective it cannot be considered as additional nutrient removal.

When based on external support scheme in Finland in the Local Fish cyprinid fishing project implemented by the John Nurminen Foundation (Mäki, 2020), cost per reduced kg of phosphorus was approximately 66 €, based on a phosphorus removal payment of 0,531 € P/kg fish and 0,7-0,8% P content of cyprinid fish (Setälä 2012) (see Table 1). Only the phosphorus removal payments for fishermen are included in the calculation as costs. The calculation does not include any investment costs of fishing equipment by the fishermen, or any commercial benefits and surpluses accrued for the fishermen, producers making fish products and consumers. Currently, management fishing of cyprinid fish started within the Local Fish project in Finland continues without external phosphorus removal payment as a normal commercial activity, and thus produces more benefits and economic value than costs. It needs to be also noted that in the Baltic States, cyprinids are commonly used as human food on a commercial basis.

In the project SEABASED, management fishing of stickleback was tested and potential future usages for the fish were mapped, e. g. for fish feed or extracting fish oil for high-value products. However, these usages still need further studies and development. In the Archipelago Sea, the P content in stickleback has been estimated to be approx. 0,71% (LUKE). However, as it proved difficult to catch any significant amounts of stickleback in SEABASED, it is impossible to establish cost-efficiency of the measure.

Reed harvesting

As with management fishing, cost-efficiency of harvesting the common reed (*Phragmites australis*) depends on the end usage and commercial utilisation of material. There are various end usages for reed in making plant seedbeds, fodder, litter, green manure, construction materials, energy etc. In Finland and Sweden, all usages are still in a development phase and there are no functioning commercial production chains yet, whereas in the Baltic States reed is commonly used as construction material.

According to the VELHO project implemented in Finland in 2010-2014, the cost of removing reed from water is on average 700-1100 €/ha. Based on these results, it was estimated that the average reed yield per hectare equals 5 tons of dry matter which contains 60-120 kg of nitrogen and 5-11 kg of phosphorus. Thus, the price of removed nitrogen was 7-23 €/kg and phosphorus 80-270 €/kg, when no economic surplus of commercial usage is included. (Ajosenpää, 2014) (see Table 1). It needs to be noted in Finland that reed is currently harvested for biodiversity reasons to restore overgrown coastal and lake ecosystems. When utilising already harvested reed material, the cost of removing nutrients is lower as the only costs to be covered are the costs from collecting and transporting the material.

Mussel farming

Currently, there are no commercial production chains for farmed Baltic Sea benthic mussels (the blue mussel, *Mytilus trossulus*). It has been proposed to utilise mussels in animal feed production, but the production chains are not yet commercially viable. However, a lot of pilots for mussel farming have been implemented with a purpose of developing such commercial usages, and, therefore, estimates for the potential and cost of removing nutrients from the marine environment with mussel biomass exist.

Prior to the *in situ* pilot projects in the Baltic Sea, Gren et al. (2009), estimated that cost-effectiveness of nutrient removal by mussel farming is 21-57 €/kg N and 312-800 €/kg P for the Baltic Proper. However, in a later review by the Stockholm University (2018), it was stated that the cost estimate might be valid for marine farms but is too optimistic for the Baltic proper conditions. The experience from the Baltic Sea farms shows that instead of the yield level used by Gren et al., 50-70 tons ww/ha per year and a mussel harvest N content of 0.85-1.2 %, the production potential in the Baltic Sea is only 10-30 tons ww/ha per year. This means that each farming unit generates less harvest than estimated in the study, and since the cost of the maintenance remains the same, the production cost per ton of mussels is likely higher. Therefore, the estimation of nutrient removal potential of mussel farms should be based on data on the actual nutrient removal capacity of mussel occurring in the region in question, not on reported estimates from other parts of the Baltic Sea (Kostamo et al. 2020).

Minnhagen (2017) summarizes the difficulties faced in the projects in Sweden, that have led to smaller yields than expected: low growth rate in the Baltic Sea, severe ice winters, storms, unexpected technical problems, fouling by epiphytes or eider predation. Moreover, the Stockholm University review states that it is more accurate to use a lower N content or even 0.7 % (this study) rather than 1-1.2 % when estimating costs, which gives 58 % less nitrogen for the money invested in the measure. In the project NutriTrade (John Nurminen Foundation, 2018), the cost of phosphorus removed with mussel farming was 1670 - 6250 €/kg P (Table 1). The price was based on a bid procedure in Sweden and Åland Islands, in which the participating mussel farmers were compensated for the mussels produced and taken up for the project (www.nutritradebaltic.eu).

Other biomasses

Harvesting seaweed (macroalgae) or phytoplankton has been proposed for removing nutrients from the Baltic Sea. Potential usages for algae could be e. g. food, chemical compounds for food and medical industry, or energy production. However, so far there are no commercially viable usages for algae. Studies on different usages for macroalgae are reviewed in detail in the SEABASED report on aquatic compensations by Kostamo et al. (2020). The cost-efficiency of nutrient removal by macroalgae harvesting has been assessed in the project PhosCad (Olsson et al. 2013), in which the cost of collecting, drying and incinerating algae resulted in cost-efficiency of approximately 1900 €/kg P.

Table 1. Comparison on the efficiency and costs of selected sea-based measures.

“Geoengineering” measures				
Measure	**Efficiency**	**Cost €/kg P**	**Risks**	**Other remarks**
Binding P with aluminium [1)]	Binds P permanently in sediment Capacity: 10-30kg Al for 1kg P	40- 200 €/kg	Risks to biota in pH <6 and 8,5> Fish kills if Al is spread on water surface.	Technically feasible
Binding P with activated limestone (heat-treated “marl”)	In lab. tests, binds P permanently. Capacity estimate in lab.: 16.8 g P / 1 kg sorbent. Capacity not defined in situ in the Baltic Sea.	Production cost for sorbent: 0,5 €/kg €/kg P: n.a.	No identified risks to marine environment. CO^2 -release from the heating process approx. 15% (1 ton marl -> 150kg CO^2, via calcination)	Technically feasible. Production of sorbent needs further development. Heat treatment is energy consuming.
Binding P with iron compounds	In lab. tests efficient in oxic conditions	n.a.	Possible ecological risks to biota. P can be released again under anoxia.	No pilot scale trials in Baltic Sea.
“Clay bombing” Binding P with iron/aluminium compounds in glacial clays	Theory: clay contains P binding iron (Fe(III)oxides) and aluminium. Capacity not defined in lab. or in the Baltic Sea.	n.a.	Resuspension of sediment. Release of hazardous compounds.	No research yet
Oxygenation (pumping of O-rich water) - enhancing the natural binding of P to sediment [2)]	Short term positive results: increase in O and decrease in P on sediment surface. No proven long-term effects.	n.a.	Release of hazardous compounds from sediment. Mixing of water layers.	Technically feasible in small coastal scale. Effects probably stop when pumping ends. Energy consuming. Further research on risks is needed.
Sediment top-layer removal [3)]	Estimation from lab. experiment: removal of 150 kg P /ha with 10cm top-layer of the sediment. No proven effect on oxygen consumption. Capacity not defined in situ in the Baltic Sea.	482 000 € – 1 774 000 € for 2 ha pilot area -> cost from 1606 €/kg P up to 5913 €/kg P	Resuspension of sediment. Release of hazardous compounds to water. Nutrient leakage back to sea from residue water. (water content of organic sediment is high)	Technically feasible in lakes but not for larger marine coastal bays. New technical solutions needed. Deposition / usage of the sediment is a challenge. Removal should be repeated several times.

Measures based on biomass removal				
Measure	**Efficiency**	**Cost €/kg P**	**Risks**	**Other remarks**
Management fishing of cyprinids[4)]	Abundant in coastal waters, large catches. P content in fish 0,7-0,8% -> with 1 ton catch 8kg P removed	66€/kg P (commercial value not included)	Impacts on fish stocks	Population estimates on cyprinid stocks are rather uncertain. Commercially viable usages exist.
Stickleback harvesting [5)]	Can't be defined	Can't be defined		Population estimates on stickleback stocks are rather uncertain. Benefits predatory fish stocks via biomanipulation effect. No commercially viable usages yet.
Mussel harvesting[6)]	P content in mussels 0,15-0,3 % of dry weight.	800–6250 €/kg P	Local eutrophication underneath the farms.	No commercially viable usages yet.
Harvesting of common reed [7)]	Removal potential up to 10kg P/ha. Estimated amount of reed 100 000 ha in Swedish and 30 – 40 000 ha in Finnish coast.	80–270 €/kg P (commercial value not included)	Loss of biodiversity in coastal habitats (e. g. fish, birds, insects).	Should be targeted carefully to avoid the loss of biodiversity, however, can also improve biodiversity in overgrown coastal habitats.

1) Based on Björnöfjärden experiment (Rydin et al. 2017)
2) Based on Lehtoranta et al. 2012 and the reference Group Evaluation of the BOX and PROPPEN Projects, Swedish Agency for Marine and Water Management, 2012.
3) Cost estimates based on offers received for implementation of SEABASED Sediment removal pilot: removal of 10cm sediment from 2 ha area with methods avoiding turbidity, dewatering and deposition of sediment, purification of residue water before leading it back to the sea. Efficiency estimate based on sediment incubation test in laboratory, described in more retail in SEABASED WP T5 Report.
4) Cost estimate based on the Local Fish Project (Mäki, 2020) by the John Nurminen Foundation. P content in fish based on Setälä et al. 2012.
5) Stickleback harvesting was piloted in SEABASED Project. Guidance for fishing published on SEABASED website.
6) Based on information summarized in Kostamo et al. 2020, Minnhagen 2017. Cost estimate from NutriTrade Project by John Nurminen Foundation.
7) Based on Ajosenpää 2014 (VELHO Project) and information summarized in Kostamo et al. 2020.

Conclusions on cost-efficiency of sea-based measures

For most of the geo-engineering measures, the lack of information on either the nutrient removal capacity or actual costs, or both, prevent making solid conclusions on their cost-efficiency. This emphasises the future need for studies and pilots with proper research set-ups and long-term monitoring preferably for several years, to be able to reliably follow and estimate the effects in the marine environment. Many of the previously implemented projects have not had sufficient monitoring and documentation of impacts, which reduces their value for water protection policy conclusions. One of the few geo-engineering measures with well-documented information on impacts is the aluminium treatment project at Björnöfjärden (Rydin et al. 2017), with a cost estimation of 40-200 €/kg P. Based on the results from the pilot, the measure has already been taken into use for improving the status of some heavily eutrophied coastal bays in Stockholm (http://miljobarometern.stockholm.se/vatten/).

Out of the measures based on biomass removal, management fishing of cyprinids and harvesting of common reed seem to be the most cost-efficient, with costs ranging from 60-70 €/kg P and 16-19 €/kg

N for fish and 80-270 €/kg P and 7-23 €/kg N for reed, respectively. However, these numbers do not include any commercial value for the utilisation of biomass, which gives a distorted picture especially for the cyprinid fish catches in Finland, as there is already a rather well-established consumer market for cyprinid products.

Comparison with land-based measures

Looking at the costs of sea-based measures, aluminium treatment, as well as fishing and reed harvesting, seem to be as cost-efficient or even cheaper than the currently used land-based measures, when solely comparing the price of removed phosphorus. It has been estimated that the average price of nutrient reductions for the largest source of land-based nutrient load in Finland, diffuse pollution from agriculture, is over 200 €/kg P and 15 €/kg N (Hyytiäinen & Ollikainen, 2012) However, it needs to be noted that in the marine environment, the impact mechanism of land-based nutrient reductions differs from that of the sea-based measures, and direct comparison of cost-efficiency without looking at the ecology and functions in the marine environment may be misleading. Also, the total potential for nutrient reductions by fishing cyprinids or harvesting reed likely remains lower than what can be achieved with efficient reduction of nutrient discharges on land.

In general, the cost of implementing sea-based measures seems still to be too high for any large-scale applications, and for some, even for coastal scale applications. Also the level of potential risks in the open sea scale applications is considered high. Therefore, it can be concluded that currently sea-based measures such as aluminium treatment are mostly applicable locally in comparatively small and enclosed coastal bays, where the nutrient load from external sources has been significantly reduced and legacy phosphorus accumulated in the sediment is the main driving factor of eutrophication. In these areas, sustainable results may be achieved with feasible and realistic amounts of financing, but only if paired with efficient and sustained reduction of nutrient load from land-based sources (Fig 13).

There is still very little documented and published information available on cost-efficiency of the proposed sea-based measures. It is also problematic, that in some existing calculations, economic benefits have been included which actually do not exists in reality due to lack of end-usages and markets for biomasses. It is recommended that when assessing sea-based measures, only existing costs and benefits, and actual verified effects are included in the cost-efficiency calculations. Moreover, cost-efficiency estimates with their underlaying assumptions should be presented clearly and transparently so that governmental, municipal, and private sector decision makers can compare and understand true costs and effects of different measures.

Fig. 13. Cost-efficient nutrient reductions could potentially be achieved with combining sea-based measures and measures on land. Pictures from reed harvesting and gypsum application on fields (JNF). Pictures: Ilkka Vuorinen

Legal and administrative feasibility

Background

There is still relatively little experience of permitting and implementing sea-based measures in the Baltic Sea Region. Therefore, one of the purposes of these Guidelines is to provide information for both permitting authorities and operators and to support environmentally sustainable planning and decision-making with regard to future projects. Permitting procedures also differ between countries, for example, in Sweden larger sea-based projects can be permitted by local authorities than in Finland. Thus, no circumstantial instructions are given in this document but rather a general level understanding on the processes and steps to start with when planning a project.

Although many international conventions and EU directives apply also to sea-based measures, in practice the permitting decision is mostly impacted by the Water Framework Directive and its Weser Judgement. This makes the avoidance of any, even short-term, negative side effects of the measure on water quality an important aspect in planning and permitting also projects related to sea-based measures.

International legislative framework

A specific legal framework for sea-based measures does not exist. Measures are governed by general international, EU-wide, and national obligations and principles related to marine environmental protection. Different laws apply to different types of sea-based measures and different jurisdictional zones of the sea, described and discussed in detail in Vahanen Report (2018). Thus, a more practical view on the legislative restrictions and demands when planning implementation of different measures is applied in the SEABASED Guidelines.

<u>International Conventions</u>

The UN Convention on the Law of the Sea (UNCLOS) emphasizes coastal states' sovereign rights to utilize and manage of natural resources, but also an obligation to protect the marine environment and to ensure that activities being carried out under their jurisdiction or control do not cause damage by pollution to other states and their environment or do not spread pollution beyond their borders. All states in the Baltic Sea region are parties to the UNCLOS convention and it applies to all Exclusive economic zones (EEZ).

The London Convention and Protocol restrict dumping of wastes and other matters that can create a hazard to marine life. They establish that dumping always requires a permit. The Protocol is even stricter and establishes that only dumping of certain wastes (listed in the Protocol Annex I) can be allowed. Finland, Sweden, Denmark, Estonia, and Germany are parties to both instruments. Russia and Poland are parties to the Convention only. The London Convention and Protocol apply to all maritime zones in the Baltic Sea.

The Helsinki Convention (HELCOM) emphasizes the precautionary principle in every activity in the Baltic Sea if the effects and risks regarding the measure are uncertain. It needs to be considered especially when implementing new kind of measures with unknown effects. All coastal states of the Baltic Sea are parties to the Helsinki Convention, and it applies to all maritime zones in the Baltic Sea.

The Espoo Convention emphasizes early action to avert danger by notifying and consulting neighbouring state on a major project and sets a requirement to carry out an Environmental Impact Assessment procedure when the project might have transboundary environmental impacts. All coastal states of the Baltic Sea, except Russia, are parties to the Espoo Convention, and it applies to all maritime zones in the Baltic Sea.

EU Directives

The Marine Strategy Framework Directive and **Water Framework Directive** are the most important EU directives regarding sea-based measures and their permitting. The general aim of the directives is to reach good ecological and chemical water status in all internal waters. However, it is notable that the Directives can only be enforced for activities which require environmental permits, meaning mainly point source pollution and leaving outside the regulation sectors such as diffuse pollution from agriculture.

The Weser Judgement is an important precedent of the Water Framework Directive and governs the permitting of all kinds of activities which can lead to the deterioration of water quality status. According to the Weser Judgement, member states are required to refuse authorization for an individual project where it may cause a deterioration of the water status, even on a temporary basis.

The Environmental Impact Assessment Directive requires to carry out an EIA in any project that is likely to have significant effects on the environment. **The Marine Spatial Planning Directive** needs to be considered when planning measures which can conflict with some other uses of the sea.

The Habitats Directive and Birds Directive need to be considered when planning measures in or nearby protected areas. Measures in or nearby Natura 2000 areas should only be permitted if it is certain that no damage to the nature values will occur, unless there is a considerable societal or economic benefit, which should be taken into account.

The Waste Framework Directive needs to be considered when planning a measure which might produce some kind of "waste" like dredged material. All waste shall be managed according to the polluter pays -principle and without endangering human health or harming the environment.

Permitting of sea-based measures

Most sea-based measures require an environmental permit or at least a permission granted by authorities. Authorities granting permits base their decision on the above-mentioned international conventions, EU directives and national laws and requirements when defining, whether and with what conditions a sea-based measure can be implemented in a coastal sea area. The type of measure and its potential effect to the environment determine whether the measure is considered 'pollution of the marine environment', 'dumping', or 'marine geoengineering', and which convention, directive or national law applies to the measure.

When granting an environmental permit, the permitting authority must ensure that a project does not jeopardize public health or safety, cause considerable deterioration in the environment and its functions, or risk the local livelihoods and economics. Sea-based measures have been used in the Baltic Sea for a relatively short time, and there is little experience of their permitting in the region. In contrast to permitting of the traditional commercial activities, the main difference in permitting sea-based measures is that their main purpose is to improve the state of the sea environment, and, thus, the permitting authority might need to take a view that considers both environmental benefits and risks of a measure.

From the legal perspective, the risk of short-term water quality impacts makes the Water Framework Directive and especially its Weser Judgement a key issue for national permitting of any measures affecting the state of inland or coastal water bodies, thus also including the permitting of near-shore sea-based measures. As according to the Weser Judgement, even short-term deterioration of water quality to a lower quality class contradicts the Water Framework Directive, the permitting authority must carefully consider and rule out measures with such impacts, even though the measure would aim at possible long-term environmental benefits.

Permitting of the sea-based water protection measures is complicated also due to the lack of scientific information and practical knowledge on the impacts and consequences of any of these measures in the Baltic Sea ecosystem. Experiences of the SEABASED project reflect the fact that national regulation or permit processes in Finland and Sweden have not been designed for projects aiming at (usually long-term) improvements of the environment but entailing a risk of (at least) short-term environmental degradation. In practice, this means that the operators planning sea-based projects, should carefully plan the implementation of a measure in such a way that also the short-term environmental side impacts, for example deteriorating of submerged habitats, releasing of harmful substances, or increasing of turbidity or the amounts of mobile nutrients in the water should be minimized.

Permitting processes for projects

As there are no specific processes or legislation designed for projects designed to improve the state of the environment, the general permitting procedures apply also for the sea-based environmental projects. However, in some cases, less strict permitting requirements might stand for small scale testing, which might be reasonable to consider when designing the project.

The permitting procedure starts when the operator applies for a permit from the permitting authority. The permits to be applied are always measure and site specific, and, thus, permits must be applied separately for each location and for each individual projects. In general, the application must include a detailed description of the planned activity, assessment of its environmental and other impacts, e. g. for local livelihoods or landowners, and measures to mitigate these impacts. Moreover, long-term monitoring of environmental impacts is usually required and must be described in the permit application. Environmental consultants and external expertise are often used for writing permit applications.

The permitting procedure usually includes a public hearing (with some national differences in the details of the process), during which authorities can give their statements, parties concerned can give objections and other parties, like nearby residents, can give their opinions. After the hearing process, the applicant will be requested for rejoinders for statements and objections. The granted permit will be legally valid only after an appeal period, during which different entities still have the right to appeal against the permit decision. The permit takes effect after the appeal period and reading of possible complaints. In some cases, the process of complaints, with multiple steps in court, might last even for years.

The permitting decision includes an assessment of uncertain environmental benefits and risks for which there is not much scientific information, neither practical experience, and providing of the information needed for the assessment is on the responsibility of the permit applicant, and, thus, environmental monitoring and research might be required prior to the planned project. On the other hand, the operator is also responsible for planning the project in a sustainable way, and thus faces the same issues with limited amount of information on risks and consequences. Special companies can be hired for carrying out the environmental assessments for permits, but the costs for investigations required for the permit application will remain for the applicant, even if the permit is eventually not granted. Therefore, it is good to acknowledge the need of financial resources already for the planning and permitting phases of a project.

Permitting procedure in Finland

The type of the potential environmental risk determines whether the sea-based measure is permitted under the Environmental Protection Act (project that may cause emission or pollution) or the Water Act (water management projects that may cause structural changes in a water body).

In general, all permits under the Water Act and for the large projects the permits under Environmental Protection Act are granted by the Regional State Administrative Agency. For smaller projects under the Environmental Protection Act, permits are granted by the municipal environmental authorities. If it is unclear which kind of permit is needed, or from which authority it should be applied, it is recommended to contact the Centres for Economic Development, Transport, and the Environment (ELY centres) or municipal environmental authorities already in the early stages of project planning. The ELY centres are the national monitoring bodies for the permits, but they also give guidance and statements for applicants on the need of different permits.

Permitting procedure in Sweden

In Sweden, sea-based measures are regulated mainly through the Environmental Code and the related Ordinances. The Environmental Code includes different forms of precautionary and preventive measures, and rather strict requirements on localization. The Act on the Swedish EEZ (Exclusive Economic Zone) and the Swedish Continental Shelf Act are also central for sea-based measures taking place beyond the Swedish territorial sea. Compared with Finland, the Swedish legislation contains more specific rules on the environmental quality standards implementing the EU WFD and the Weser case.

The permitting authority depends on the nature, scale, and scope of the operation, and it is either Environmental Courts, the County Administrative Board (CAB) or local authority. The applicant is obliged to consult the CAB or the local Environmental and Public Health Committee (EPHC) before submitting a permit application. An environmental impact statement (EIS) must be submitted together with the permit application.

Guidance for project planning

When planning small-scale sea-based measures in the coastal regions of the Baltic Sea, there are several matters relevant to consider according to the characteristics of the planned experiment, with a special focus on the assessment and management of ecological risks, although project planning is dependent on the details of each individual project. A thoroughly composed project plan will be useful also when applying environmental permits or financing for the planned measures (Fig. 14).

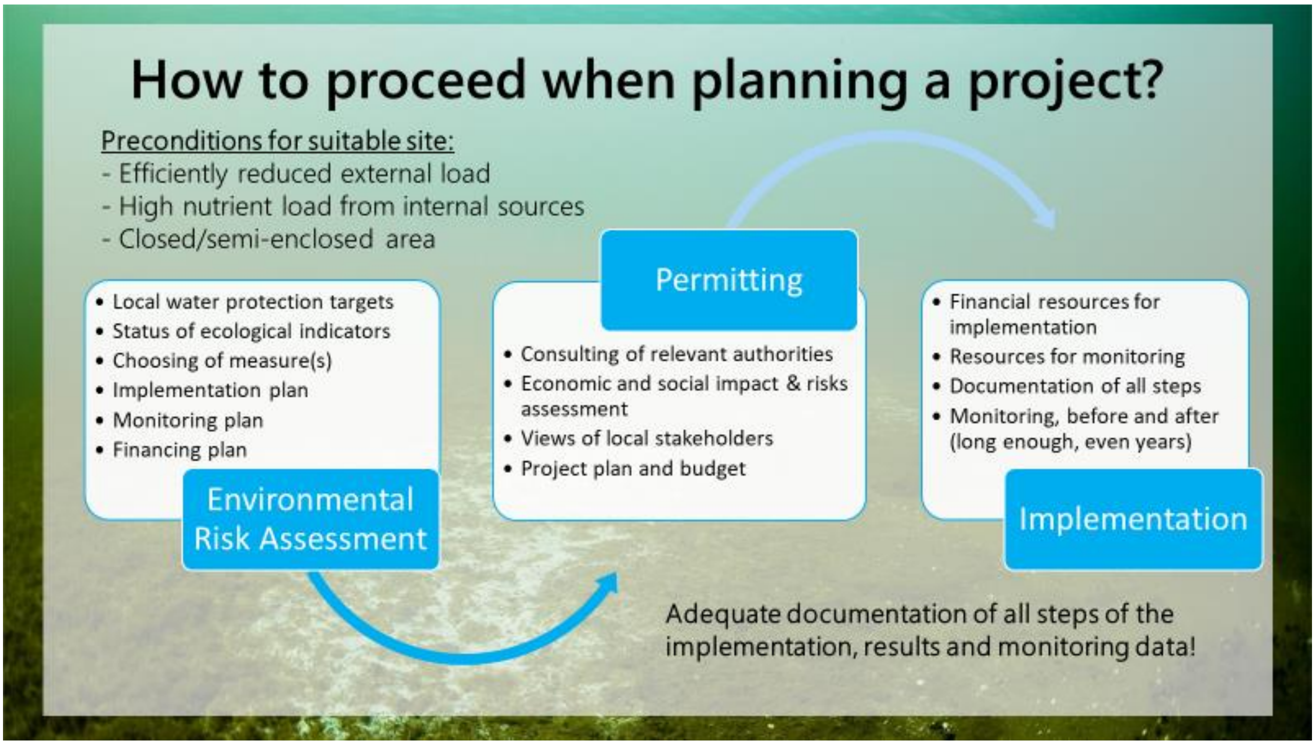


Fig. 14. A thorough planning helps forward also when considering a project that includes sea-based measures.

Checklist for project plan

In a project plan, the description of at least the following should be included:

- Description of the selected site, including nutrient load (e. g. external load, sediment)
- Targeted effect(s) of the planned measure(s)
- Technique and affecting mechanism of the measure(s)
- Scale of the measure(s)
- Estimated duration of the targeted effect(s)
- Ecological impact assessment (also positive impacts)
- Monitoring plan before and after implementation (e. g. bottom fauna & flora, sediment and water quality indicators, hazardous substances)
- Social aspects: acceptability of the measure, plan for informing of local communities, positive values and impacts on ecosystem services, e. g. recreation, fishing etc.
- Permits needed for the implementation
- Timetable for the project
- Project budget, financing and economic feasibility of the measure

Instructions for applying a permit

1) Learn the details of the permitting process and contact the relevant local or regional environmental authority for consultation on environmental permits needed for your project.
2) Permit application must be submitted well in advance. The permitting procedure might take several months or even years.
3) The permit application must include descriptions of the planned site, measurer and technology that will be used and information on both, the direct and indirect impacts of the activity. External expertise and financial resources may be needed for this.
4) During the public hearing and the appeal period, the authorities, other entities and private persons, e. g. local landowners, have the right to comment the application or appeal the granted permit.
5) Operations must not be commenced before the appeal period is over and the environmental permit is valid.
6) Fees are payable for the processing of applications regardless of positive or negative decision.

How to strengthen the social sustainability when planning a project on sea-based measures?

- make a thorough risk and environmental impact assessment beforehand
- combine sea-based measures with measures reducing nutrient loads from land areas
- utilize resources which do not reduce the resources targeted to land-based measures
- prefer multi-beneficial measures, which have also other benefits in addition to nutrient removal (e.g. habitat restoration, improving fishing opportunities, nutrient recycling)
- allocate expensive measures to such sea areas where the ecological relevance for the restoration is high
- engage relevant stakeholders (e.g. environment authorities, research institutes, NGOs, local communities) to the project
- communicate with local communities in a sufficiently early stage of the project
- act only in such areas where the environmental conditions are well-known and where it is possible to monitor the results
- include the sufficient long-term monitoring and the evaluation of the result in the project
- share the experiences and result openly during and after the project
- plan how the results of the project can be utilized in the future

EUROPEAN UNION
European Regional Development Fund
Interreg Central Baltic
SEABASED
SEABASED MEASURES IN BALTIC SEA NUTRIENT MANAGEMENT

References

Publications

Ajosenpää, T. 2014. Suunnittelulla ja ruo´on hyötykäytöllä tehokkuutta rantojen hoitoon : Tuloksia ja kokemuksia VELHO-hankkeesta. Varsinais-Suomen ELY-keskus, 2014. http://www.doria.fi/handle/10024/97313

Baltic Eye (Stockholm University): Mussel farming in the Baltic Sea. https://balticeye.org/en/eutrophication/policy-brief-musslefarming-in-the-baltic-sea/

Baltic Sea Centre (Stockholm University) 2018, Policy Brief on Internal Load: https://balticeye.org/en/eutrophication/policy-brief-internal-load/

Bergstrom, U., Olsson, J., Casini, M., Eriksson, B. K., Fredriksson, R., Wennhage, H., & Appelberg, M. (2015). Stickleback increase in the Baltic Sea: A thorny issue for coastal predatory fish. *Estuarine coastal and shelf science*, *163*(part B), 134-142. https://doi.org/10.1016/j.ecss.2015.06.017

Bernes, Carpenter, Gårdmark, Larsson, Persson, Skov, Speed & van Donk, 2015. Effects of biomanipulation on water quality in eutrophic lakes. Environmental Evidence journal. www.environmentalevidencejournal.org/content/4/1/7
Conley, D. et al. 2009. Hypoxia-Related Processes in the Baltic Sea. Environ. Sci. Technol. 2009, 43, 3412-3420. https://pubs.acs.org/doi/pdf/10.1021/es802762a

Conley, D. et al. 2009. Tackling Hypoxia in the Baltic Sea: Is Engineering a Solution? Environ. Sci. Technol. 2009, 43, 3407–3411. https://pubs.acs.org/doi/pdf/10.1021/es8027633

Gren, I.-M., Lindahl, O. & Lindqvist, M. 2009. Values of mussel farming for combating eutrophication: An application to the Baltic Sea. Ecological Engineering 35: 935–945.

Helcom 2014: https://portal.helcom.fi/meetings/PRESSURE%201-2014-184/MeetingDocuments/6-2%20Internal%20load%20of%20plant%20nutrients%20in%20the%20Baltic%20Sea.pdf

HELCOM 2018. Thematic assessment of eutrophication 2011-2016. Baltic Sea Environment Proceedings No. 156. http://www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/

Hyytiäinen, K. & Ollikainen, M., 2012. Taloudellinen näkökulma Itämeren suojeluun. Ympäristöministeriön raportteja 22/2012.

Kaczala, F. 2018. Sediment Uptake and Remediation on Ecological Basis. https://www.lansstyrelsen.se/download/18.6ae610001636c9c68e5357ca/1529495451887/9.%20LIFE%20SURE_sediment%20uptake_%20Kalmar%20kommun,%20restaureringskonferens%20Kalmar%202018.pdf (LifeSURE Project)

Klemens Eriksson, B., Yanos, C., Bourlat, S., Donadi, S., Fontaine, M. C., Hansen, J. P., Jakubavičiūtė, E., Kiragosyan, K., Maan, M. E., Merilä, J., Austin, Å. N., Olsson, J., Reiss, K., Sundblad, G., Bergström, U. & Eklöf, J.S. 2020. The rise of the three-spined stickleback – eco-evolutionary consequences of a mesopredator release. Preprint. bioRxiv 2020.05.08.083873; doi: https://doi.org/10.1101/2020.05.08.083873

Kotta, J., Jänes, H., Paalme, T., Peterson, A., Kotta, I., Aps, R., Szava-Kovats, R., Kaasik, A. &Fetissov M. 2020. Assessing the PanBaltic potential of macroalgae cultivation and of harvesting wild stocks. Estonian Marine Institute, University of Tartu. https://www.submariner-network.eu/images/grass/outputs/GRASS_OA21_pan-Baltic_map_depicting_potential_of_macroalgal_cultivation_and_harvesting.pdf

Kumblad, L. & Rydin, E. 2018. Effective measures against eutrophication – a story about regaining good ecological status in coastal areas. Living Coast Project, BalticSea2020 Foundation. https://balticsea2020.org/images/Bilagor/White_paper-Bjornofjarden-201908.pdf

Laakso, J. 2017. Phosphorus in the sediment of agricultural constructed wetlands. Department of Food and Environmental Sciences Faculty of Agriculture and Forestry University of Helsinki, Finland, 20/2017

Lehtoranta, J., Lännergren, C., Bendtsen, J., Pitkänen, H., Myrberg, K., H., Kuosa. 2012. Effects of oxygenation on the status of the pilot sites. In Rantajärvi, E. (ed.), Pitkänen, H., J. Bendtsen, J. Hansen, J. Lehtoranta, C. Lännergren, M. Ollikainen, M. Priha, M. Reinikainen, E. Saarijärvi, and M. Zandersen. 2012. Controlling benthic release of phosphorus in different Baltic Sea scales: Final Report on the result of the PROPPEN Project (802-0301-08). Finnish Environment Institute.

M. Olin, M. Rask, J. Ruuhijärvi, J. Keskitalo, J. Horppila, P. Tallberg, T. Taponen, A. Lehtovaara & I. Sammalkorpi, 2006. Effects of biomanipulation on fish and plankton communities in ten eutrophic lakes of southern Finland. Hydrobiologia (2006) 553:67-88.

Mäki, M. 2020. Pilot Fish Final Report. John Nurminen Foundation 2020. https://johnnurmisensaatio.fi/wp-content/uploads/2019/05/local-fish-project_final-report_jnf_en-.pdf

McCrackin, M. (Stockholm University Baltic Sea Center) 2018, Faq on internal load at: https://balticeye.org/en/eutrophication/faq-internal-load/

Minnhagen, S. 2017. Farming of blue mussels in the Baltic Sea. A review of pilot studies 2007–2016. https://www.submariner-network.eu/images/BalticBlueGrowth_Deliverables/Farmingof-blue-mussels-Mytilus-edulis-trossulus-in-the-Baltic-Sea-a-review-of-pilot-studies-from-2007-2016.pdf

Minnhagen, S.: Mussel farming in the Baltic Sea. Presentation at SUBMARINER Conference 2017 https://www.submariner-network.eu/files/3_wsD_SMinnhagen.pdf

Nefco 2015. Annual Review. https://www.ft.dk/samling/20151/almdel/efk/bilag/300/1638991.pdf

Olofsson, M., Klawonn, I. & Karlson, B. Nitrogen fixation estimates for the Baltic Sea indicate high rates for the previously overlooked Bothnian Sea. *Ambio* **50,** 203–214 (2021). https://doi.org/10.1007/s13280-020-01331-x

Olsson, B., Ek, M., Norén, F., Thörn, P., Tekie, H., Lindblad, M., Hennlock, M., Stigson, P., Röttorp, J. & Fortkamp, U. 2013. Full-scale site solution of phosphorous retrieval from biowaste PhosCad. IVL Report B2151 2013. IVL Swedish Environmental Research Institute Ltd.
https://www.ivl.se/download/18.34244ba71728fcb3f3f857/1591704975244/B2151.pdf

Rantajärvi, E. (ed.), Pitkänen, H., J. Bendtsen, J.Hansen, J. Lehtoranta, C. Lännergren, M. Ollikainen, M. Priha, M. Reinikainen, E. Saarijärvi, and M. Zandersen. 2012. Controlling benthic release of phosphorus in different Baltic Sea scales: Final Report on the result of the PROPPEN Project (802-0301-08). Finnish Environment Institute.
https://helda.helsinki.fi/handle/10138/167975

Renella, G. Recycling and Reuse of Sediments in Agriculture: Where Is the Problem? Sustainability 2021, 13, 1648. https://doi.org/ 10.3390/su13041648

Rydin, E., Kumblad, L., Wulff, F & Larsson, P. 2017: Remediation of a Eutrophic Bay in the Baltic Sea. Environ. Sci. Technol. 2017, 51, 4559−4566
https://www.researchgate.net/publication/315704519_Remediation_of_a_Eutrophic_Bay_in_the_Baltic_Sea

Setälä, J., Airaksinen, S., Lilja J. & Raitaniemi, J. 2012: Pilottihanke vajaasti hyödynnetyn kalan käytön edistämiseksi. Loppuraportti. RKTL:n työraportteja 10/2012.
https://jukuri.luke.fi/bitstream/handle/10024/530470/rktltr2012_10.pdf?sequence=1&isAllowed=y

Stigebrandt, A. 2018. On the response of the Baltic Proper to changes of the total phoshorus supply. Ambio 47:31-44. https://link.springer.com/article/10.1007/s13280-017-0933-7

Stigebrandt, A., B. Liljebladh, L. De Brabandere, M. Forth, Å. Granmo, P.O.J. Hall, J. Hammar, D. Hansson, M. Kononets, M. Magnusson, F. Norén, L. Rahm, A. Treusch, and L. Viktorsson. 2015a. An experiment with forced oxygenation of the deep-water of the anoxic By Fjord, western Sweden. Ambio 44: 42–54. (BOX Project)

Stigebrandt, A., Kalén, O., 2012. Improving oxygen conditions in the deeper parts of Bornholm Sea by pumped injection of winter water, *Ambio*, 41, no. 8, Dec 2012, doi: 10.1007/s13280-012-0356-4 (BOX-WIN Technical Report no. 3)

Stigebrandt, A., Rosenberg, R., Råman-Vinnå, L., Ödalen, M., 2015: Consequences of artificial deepwater ventilation in the Bornholm Basin for oxygen conditions, cod reproduction and benthic biomass – a model study. Ocean Sci. 11, 93-110, doi:10.5194/os-11-1-2015.

Swedish Agency for Marine and Water Management, 2012. Reference Group Evaluation of the BOX and PROPPEN Projects aimed at oxygenation of bottom water and sediments in the Baltic to improve phosphorus retention, https://www.havochvatten.se/download/18.b62dc9d13823fbe78c80003223/1348912824427/evaluation-box-and-proppen-projects-english.pdf

Timmermann, K. (Ed.), Gadgård Boye, A., Bruhn, A., Erichsen, A., Flindt, M., Fossing, H., Gerts, F., Jørgensen, H., Petersen J. & Steen Schwærte, S., 2015. Marine Virkemidler, Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi. Beskrivelse af virkemidlernes effekter og status for vidensgrundlag.

Vahanen Environment 2018, Speeding up the ecological recovery of the Baltic Sea by engineering. EUTROPH6, assignment by the Finnish Ministry of Environment. https://vahanen.com/app/uploads/2018/05/Speeding_up_the_ecological_recovery_of_the_Baltic_Sea-1.pdf

Vahtera, E. 2007: Internal ecosystem feedbacks enhance nitrogen fixing cyanobacteria blooms and complicate management in the Baltic Sea. Ambio 2007, 36, 186–194.

Ökvist, E. 2019. Saving the Baltic Sea – A Question of Business? An Exploratory Case Study from a Business Model Perspective. Master of Science Thesis, TRITA-ITM-EX 2019:312. KTH Industrial Engineering and Management Industrial Management.

Seminar presentations & media articles

Horppila, J. 2018. Presentation at the seminar on effectiveness of lake restoration measures 2018 (in Finnish): https://www.ymparisto.fi/fi-FI/Vesistokunnostusverkosto/Tapahtumat/Jarvikunnostusten_vaikuttavuus_seminaari(48909))

Rydin, E. & Kumblad, L. 2017. Presentation at Helcom Meeting: https://portal.helcom.fi/meetings/HELCOM-EUSBSR%20WS%201-2017-498/MeetingDocuments/Remediation%20of%20Bj%C3%B6rn%C3%B6fj%C3%A4rden%20in%20the%20Stockholm%20archipelago.pdf

Sammalkorpi, I. 2018, Presentation of at the seminar on effectiveness of lake restoration measures (in Finnish): https://www.ymparisto.fi/fi-FI/Vesistokunnostusverkosto/Tapahtumat/Jarvikunnostusten_vaikuttavuus_seminaari(48909))

Simonsson, B. (Teknikmarknad) 2016. Sedimentborttagning – Är det en realistisk åtgärd för Hjälmaren? Hjälmarseminariet 2016. https://norrmalarstrand.com/onewebmedia/Hj%c3%a4lmarseminariet%2020160114%20Bengt%20Simonsson.pdf

Svanbäck, A., Gustafsson, B., and McCrackin, M. 2018*:* Summary of the workshop outcome by Baltic Sea Center Scientists, Stockholm University: https://www.su.se/ostersjocentrum/english/about-us/news/we-don-t-know-enough-to-fix-the-baltic-sea-with-geo-engineering-1.374498

Wikström, J. 2018: https://mailchi.mp/26ea9a8c074c/vallentuna-arenan-2397485

Projects

Baltic Blue Growth: https://www.submariner-network.eu/projects/balticbluegrowth

Baltic Sea 2020. Project on phosphorus binding in shallow eutrophic bays—which substances work? http://www.balticsea2020.org/english/alla-projekt/overgodning/eutrophication-ongoing-projects/422-phosphorus-binding-in-shallow-eutrophic-bays-which-substances-work

BIOFISK: https://www.submariner-network.eu/projects/balticbluebioalliance/alliance-cases/biofisk

GRASS Project: https://www.submariner-network.eu/grass

Jönköping municipality, Restauration of Barnapasjön: https://www.jonkoping.se/byggabomiljo/naturvardochskotselavgronomraden/vattenochvatmarker/overgodningivatten/barnarpasjonovergodning/restaureringavbarnarpasjon.4.74fef9ab15548f0b80023c1.html

LifeIP RichWaters: http://extra.lansstyrelsen.se/lifeiprichwaters/en/our-projects/Pages/Eutrophication-%e2%80%93-internal-loading.aspx

LifeSURE Project: http://lifesure.kalmar.se/

Living Coast (Baltic Sea 2020), Björnöfjärden: http://www.balticsea2020.org/english/alla-projekt/overgodning/eutrophication-completed-projects/226-aluminium-treatment-in-bjoernoefjaerden

Local Fish Project, John Nurminen Foundation: https://www.johnnurmisensaatio.fi/puhdas-itameri/lahikalahanke/

Ministry of Environment in Finland, Projects on utilizing reed in: https://www.ymparisto.fi/fi-FI/Ruoko/Hankkeet

NEFCO 2015. Barnarpasjön pilot experiment. https://www.nefco.int/news/restoration-of-lakes-benefits-the-baltic-sea/

NEFCO, 2015. Nutirent retrieval from seabeds. https://www.nefco.int/case-studies/nutrient-retrieval-from-seabeds/

NutriTrade Project, 2018. Pilot Mussel Final report https://nutritradebaltic.eu/wp-content/uploads/2018/12/pilot-mussel-final-report.pdf , NutriTrade: https://nutritradebaltic.eu/

OXY-experiment, Pöyry (Afry). https://www.epressi.com/tiedotteet.html?customer=283

Ramboll 2017, Permit application document for dredging of three lakes (Tillståndsansökan för muddring i tre sjöar): https://www.soderkoping.se//globalassets/documents/02-bostad-o-miljo/09-vatten-o-avlopp/samradsunderlag/samradsunderlag-hallerstadsjon--bilagor.pdf

Rannikkoruokohanke, John Nurminen Foundation: https://johnnurmisensaatio.fi/en/projects/coastal-reed-project/

SAAVI Project: https://www.ymparisto.fi/saavi

SEABASED: www.seabasedmeasures.eu

Skydd under ytan, Stockholm Skärgårdsstiftelse: https://skargardsstiftelsen.se/om-skargardsstiftelsen/projekt/skydd-under-ytan/

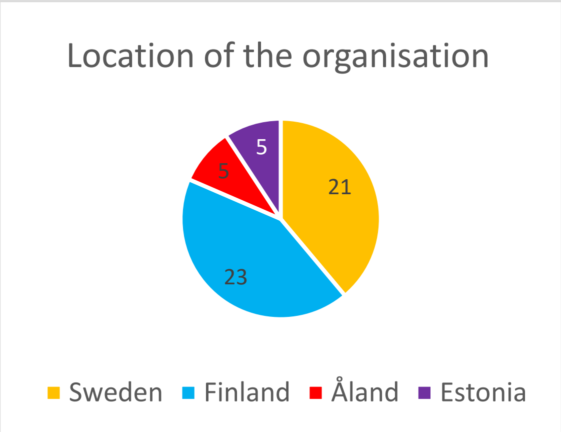
Så I vassen, Leader Åland: https://leader.ax/sa-in-i-vassen/

TechMarket 2014, Pilot tests in Oxelösund, Jönköping: https://www.nyteknik.se/energi/malet-dammsugare-skakar-liv-i-ostersjon-6397564

Attachment 1:

SEABASED Sustainability Survey for authorities

The SEABASED sustainability Survey was targeted especially to authorities who are responsible for national, regional or local level marine water protection and/or permitting of measures targeted on coastal regions. The survey was carried out in Webpropol, and link to the survey was sent to 240 recipients in Finland, Åland, Sweden and Estonia, and 54 answers were received (22,5%). The majority, half of all respondents represent regional authorities (e. g. ELY centers, County Administration), 25% municipalities or other local authorities and 25% national ministries. Distribution of respondents is presented in Figure 1.



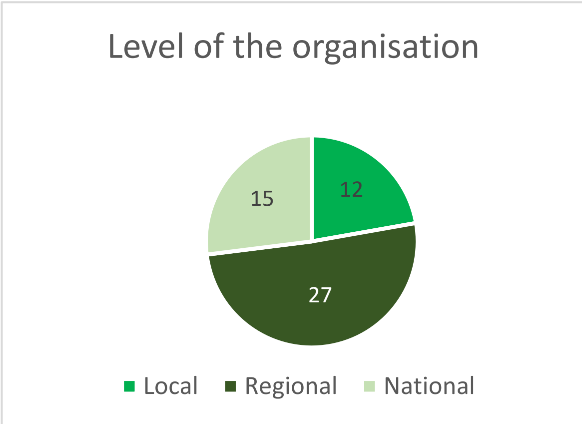


Fig. 1. Background information on organisations represented by the respondent of the SEABASED Sustainability Survey for environmental authorities in 2020 (N=54).

The Survey was sent in national languages of each participating country, except for Estonia, where the Survey was carried out in English with limited number of questions (6 of 12). The questions included in the Survey were the following: (**This question not included in Survey for Estonia*).

1) What would you see as biggest benefits of utilizing small-scale sea-based measures?
2) What, in your opinion, are the biggest risks related to the small-scale sea-based measures?
3) When there is enough information on the effects, risks and feasibility of sea-based measures, should these measures be extended to larger scale?
4) Which are the main reasons that hinder the use of sea-based measures?
5) Should the internal load and sea-based measures be included in water management plans?
6) If you answered *yes* to the previous (5), how and on which conditions could these measures be included in water management plans? *
7) If you answered *no* to the previous (5), how in your opinion could the utilization of the sea-based measures be advanced?* (only 3 respondents)
8) What kind of preconditions would be needed for utilizing sea-based measures? *
9) How could your organisation contribute to the use of sea-based measures in the future? *
10) What kind of information is currently missing from the decision-making and planning, especially related to the sea-based measures? *
11) In your opinion, which would be the best entity for implementing the sea-based measures?
12) Who should be financing the implementation of sea-based measures?*

For some of the questions, the respondents were asked to select 1-5 most important/relevant options given, whereas simply yes/no or written answers were asked for part of the questions. There was also a possibility to give optional justifications and opinions for each question in open answering fields. Summaries of the arguments given in open fields for each question are presented in this attachment document together with the Survey results.

SEABASED Sustainability Survey

The acceptability and possibilities of the use of sea-based measures

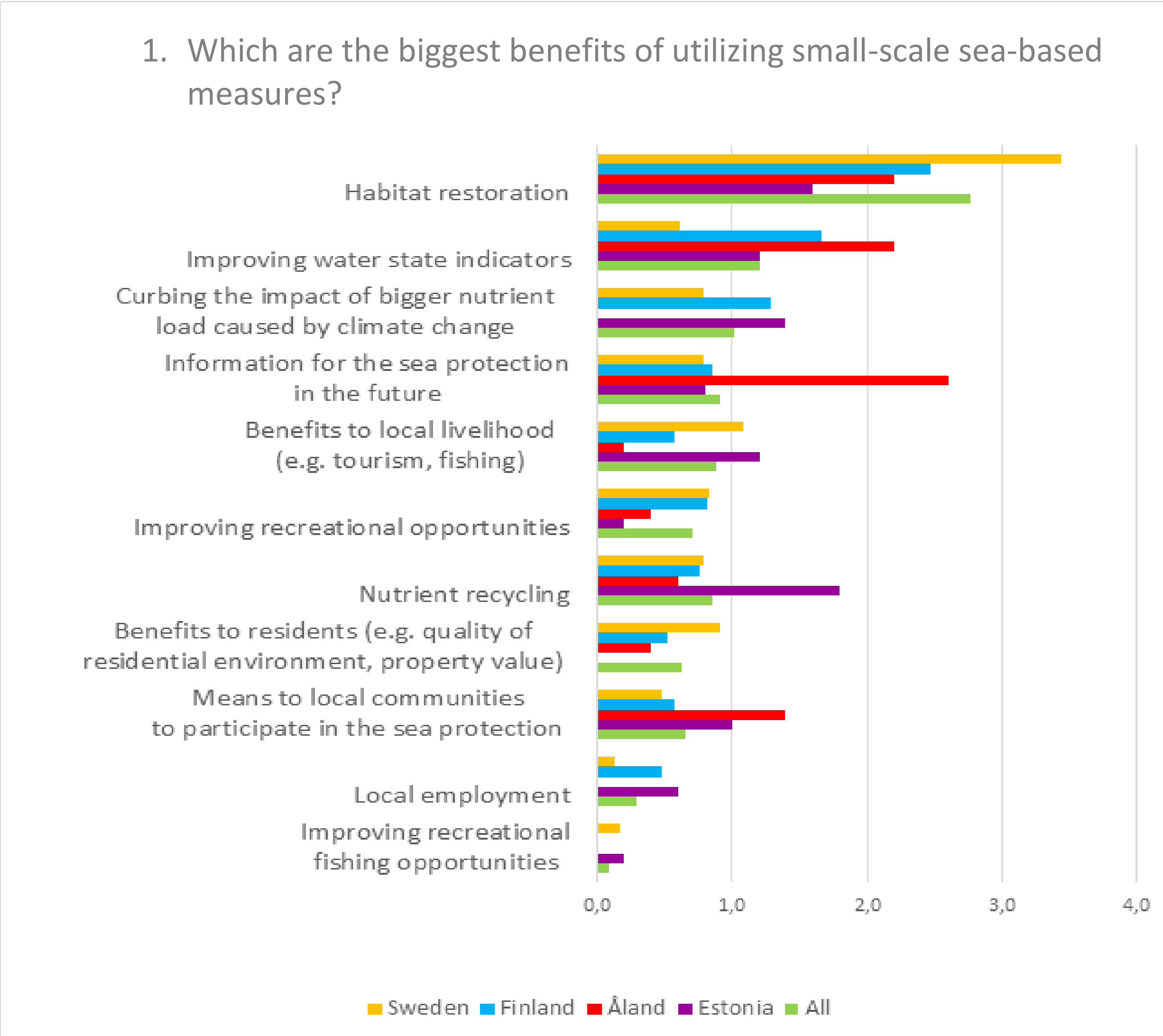


Fig. 2. The most relevant benefits related to coastal-scale sea-based measures, in the SEABASED Sustainability Survey for environmental authorities in 2020 (N=54).

<u>Summary of the arguments for most relevant benefits of coastal-scale sea-based measures:</u>

- When the state of the marine ecosystem improves, the ecosystem services that marine environments provide to humans will improve, too.
- Protection measures should always be planned primarily from the ecosystem perspective, not from business perspective.
- Without nutrient recycling, it is difficult to develop sustainable sea-based measures: pilots may remain expensive “artificial respiration” without long-lasting effects.
- Sediments and near-bottom water might contain environmental toxins and are therefore not suitable for nutrient recycling at least in farming without careful consideration and treatment.
- To have support to projects from local communities, local people should consider the project’s benefits important.

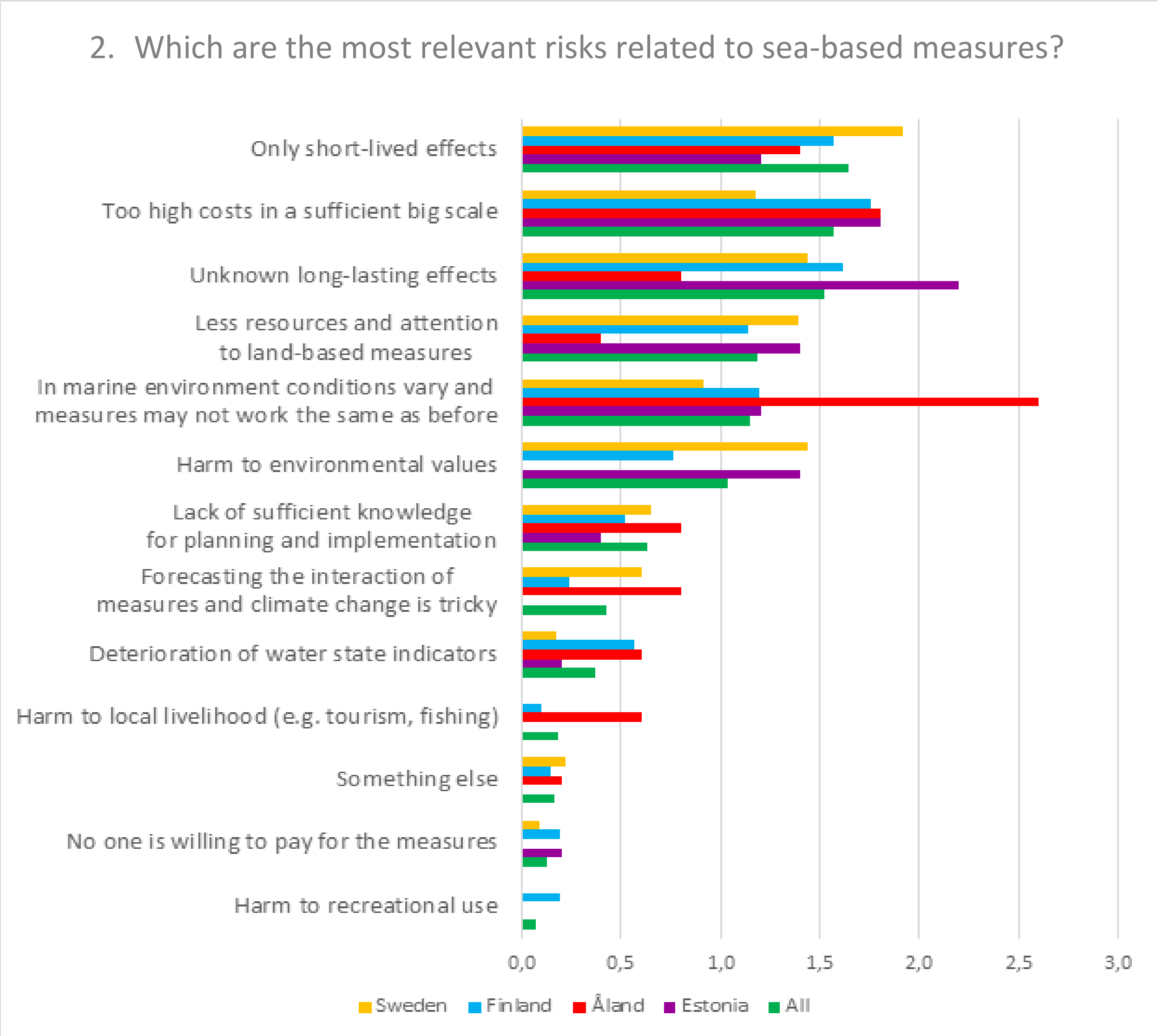


Fig. 3. The most relevant risks related to coastal-scale sea-based measures, in the SEABASED Sustainability Survey for environmental authorities in 2020 (N=54).

<u>Summary of the arguments for the most relevant risks related to the sea-based measures:</u>

- Small scale measures might get too big importance compared with their actual impacts on marine ecosystem.
- Sediments may contain environmental toxins, which could be transferred to the food cycle if used as fertilizer in fields.
- The measures might steal attention from other necessary large-scale improvements like sustainable fishing.
- If measures are not profitable business, they remain as short-time pilots without long-lasting effects.

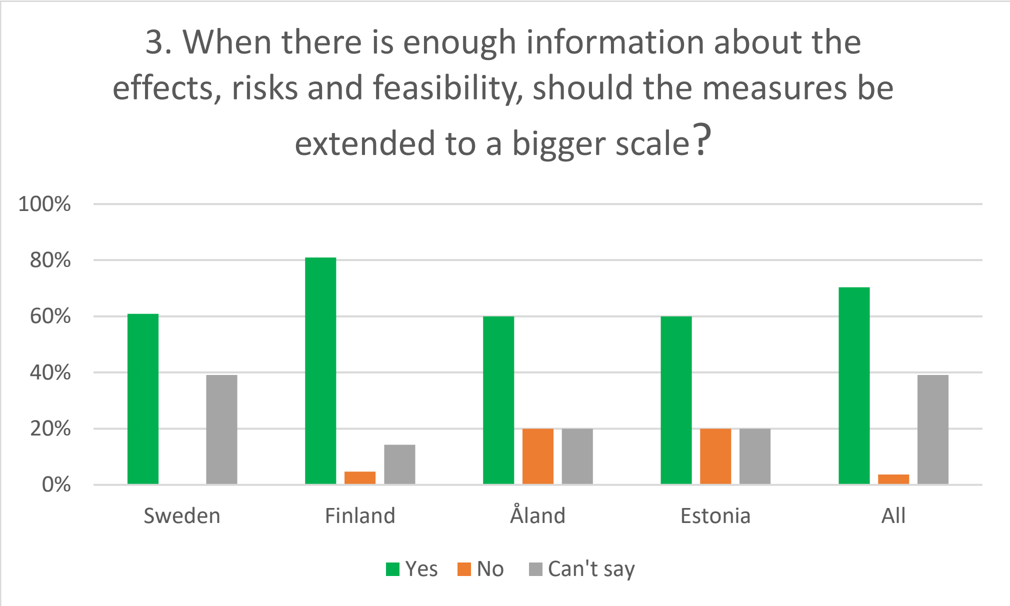


Fig. 4. The majority of the respondents were supportive towards the possibility to extend the sea-based measures to a larger scale when there is enough information available on the effects, risks and feasibility of the measures. (SEABASED Sustainability Survey for environmental authorities in 2020, N=54).

Summary of the arguments for extending the scale of the sea-based measures:

- **UNCERTAINTY ABOUT THE EFFECTS:** Local measures cannot be extrapolated into larger areas as conditions and ecosystem functioning is different there. Large-scale measures may have many negative effects as models cannot estimate the impacts and responses of larger marine ecosystems. It is hard to say anything about the measures on a larger scale right now, when we do not have a clear idea how the measures work even on a smaller scale. The results from the previous pilots indicate that the measures would not have a desirable effect on a larger scale.
- **NEED TO CUT THE INTERNAL LOAD**: We need to consider also using sea-based measures, because we cannot achieve the good ecological status of the sea fast enough by cutting only the external load. Improving the ecological status of the sea needs large and well-coordinated measures. With small-scale measures, we can improve the status of the sea only temporarily, but with larger measures we could achieve more long-lasting effects.
- **TOGETHER WITH LAND-BASED MEASURES:** Measures to cut both internal and external load are needed. Neither of them can replace the other. Sea-based measures should be implemented always together with measures which cut external load.
- **CAREFUL EVALUATION:** Before extension of the sea-based measures, we need more long-term follow-up studies. The possible extension of the measures should be done very carefully and in cooperation with HELCOM. Extension of the sea-based measures should be evaluated by scientists and environmental authorities together. The baseline for any local scale measure should be the ecosystem-based approach, which in its essence considers a larger scale.
- **COST-EFFICIENCY:** If we can find measures, which will turn out to be working and cost-effective and which benefits are bigger than risks, it is profitable to use them on a larger scale.
- **ALLOCATION:** Sea-based measures should be directed to the most important focus areas, with high risk of internal nutrient load and poor ecological status.

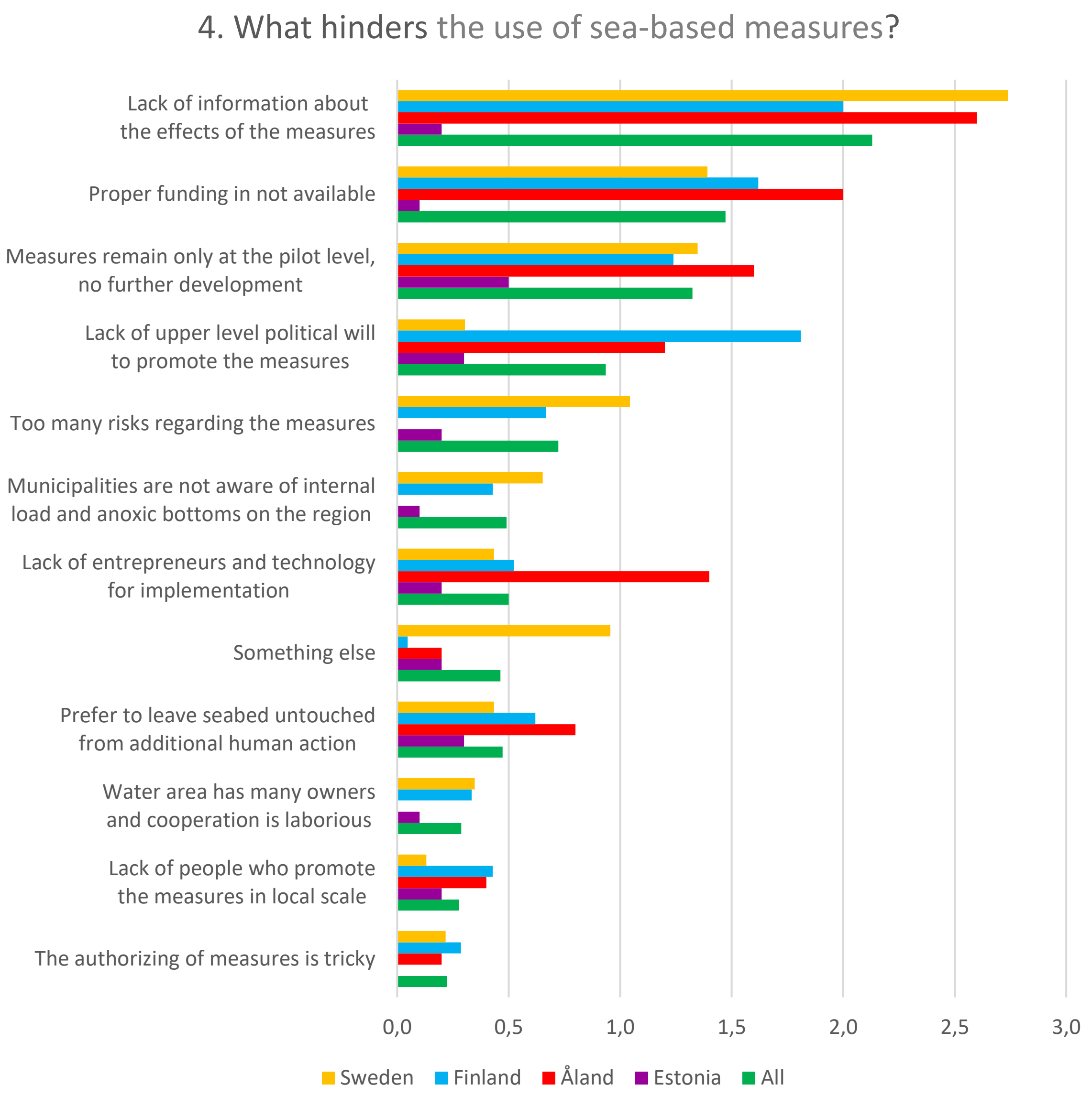


Fig. 5. The most important reasons hindering the use on sea-based measures, according to the SEABASED Sustainability Survey for environmental authorities in 2020 (N=54).

Summary of the arguments on matters hindering the use of sea-based measures:

- Large-scale and effective measures need a lot of money and big operators standing behind. Small local operators like small or middle-size municipalities do not have enough resources and competence to implement such measures. The win-win concept to implement the measures is lacking.
- Projects of this kind need a big self-financing share, which can be too difficult to collect locally.
- The focus should still be kept in the external load. At present the potential for the reduction of nutrient inputs on land has not been fully utilized.
- The whole lake restoration practice has shown the complexity of the topic and lakes are even much smaller than the Baltic Sea.
- Permitting procedures and their long complaint periods slow down the implementation. Long-term projects do not fit in the timeframe of the municipal councils and the annual budget in the municipalities.
- It is hard to find someone to coordinate the projects, because areas are owned by many municipalities and private owners.
- On a larger scale, the cost-efficiency of the measures might remain low.

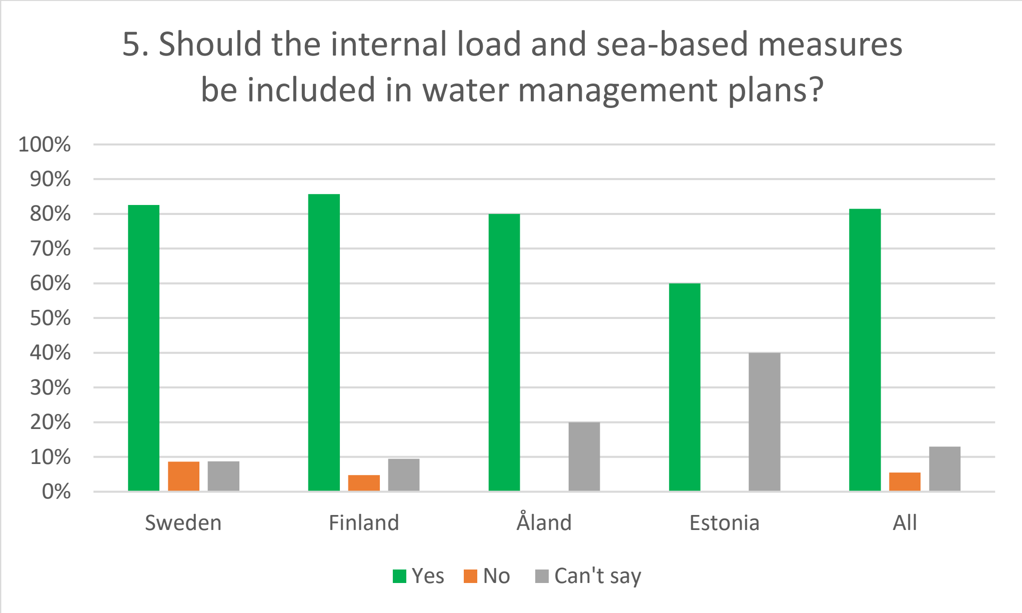


Fig. 6. The majority of the respondents was of the opinion, that the coastal-scale measures targeted for reducing the internal nutrient load should be included in water management plans. (SEABASED Sustainability Survey for environmental authorities in 2020, N=54).

Summary of the arguments on including the sea-based measures in water management plans:

YES

- We need to do something to control the internal load, even though we might not have financial possibilities to implement the most radical large-scale measures.
- Cutting the external load alone is not enough in every area.
- It is good to direct the resources also to sea-based measures.
- Cutting the internal load has an important role in the Baltic Sea protection.
- The internal load constitutes a big part of the whole nutrient load to the Baltic Sea, so it is obvious that it should be included in the water management plans. Otherwise, the measures in the plans would cover only a small part of the whole load.
- Sea-based measures could be included in the plans as pilots and small-scale projects.
- Sea-based measures could be feasible in closed sea bays.

NO / can't say (The number of "NO" responses was 3)

- We need more information and experiences before we can decide.
- We do not have clear evidence that sea-based measures would have desirable effects.
- Only usable as "the last hope" for enclosed bays, if cutting of external load is not enough

Summary of answers for QUESTION 6 (This question was asked from those who answered "YES" or "can't say" in question 5, whether the sea-based measures should be included in water management plans):

In what ways and under what conditions could sea-based measures be included in the water management plans? (**This question not included in Survey for Estonia*).

- **PILOT PROJECTS:** Plans could include the piloting of novel measures to get more information about risks, effects, and cost-efficiency. During the first planning period, sea-based measures could be included as pilot projects and during the following period, we should consider the wider use of the measures.

- **ALLOCATION:** Sea-based measures should be allocated to the most sensitive sea areas with high nature values. Sea-based measures should be allocated to the heavily eutrophic sea areas, where heavy pressure from human actions can be identified.
- **TOGETHER WITH LAND-BASED MEASURES:** Sea-based measures could be used as supporting actions to land-based measures.
- **OTHER ARGUMENTS:**
    - Funding is needed for the measures.
    - Restoration of coastal bays has been mentioned in the existing water management plans, but concrete actions have not yet been included.
    - Sea-based measures should be developed in different parts of the Baltic Sea, not just in the Archipelago Sea.
    - Local authorities should be encouraged to cooperate with neighbouring municipalities.

QUESTION 7 was targeted to "NO" respondents of question 5. Answers (3) are combined with question 5.

Summary of answers for QUESTION 8:

Under which conditions could sea-based measures be advanced?

(**This question not included in Survey for Estonia*)

- **TOGETHER WITH LAND-BASED MEASURES:** The external load to the sea area should be under control before implementing sea-based measures. Sea-based measures must not replace any land-based measure.
- **RISK MANAGEMENT:** The precautionary principle should be taken into account. Sea-based measures could be implemented first in anoxic bottoms, where risks for the ecosystem are lower. Measures must not cause harm to benthic organisms. Nature values, food webs and other ecosystem services like recreational use should be considered in planning and implementing the measures.
- **COLLECTION OF SCIENTIFIC DATA:** Measures should include long-term monitoring and evaluation of the effects. Measures could be implemented only in the areas, where the baseline is well known, and the effects of the measures can be observed. All information and experiences from the pilots must be publicly available.
- **ALLOCATION TO FOCUS AREAS:** Sea-based measures could be used as restrictive actions in the areas, where ecological status is deteriorating. Sea-based measures should be allocated to the most important bird nesting and fish spawning areas.
- **ECONOMIC SUSTAINABILITY:** Sea-based measures could be implemented if they turn out to be as cost-efficient as land-based measures. Funding and permitting of the measures must be in order.
- The sea-based measures should not be implemented at all.

Summary of answers for QUESTION 9:

In what way could your organization contribute to the implementation of these actions in the future? (**This question not included in Survey for Estonia*)

- **SCIENTIFIC WORK:** By contributing to research work. By participating in projects aiming at investigating the state of the sea areas and their weak points.
- **SHARING INFORMATION:** By sharing information about the measures and possibilities. By convening collaboration parties to promote the issue.

- **POLICY MAKING:** Via political guidelines. By acting in the HELCOM MINUTS working group. By including these measures in the national (MSFD) Program of Measures, in the HELCOM Baltic Sea Action Plan and EU funding programmes.
- **OFFERING EXPERTISE:** By offering expertise for planning of the measures and drafting financing applications. By helping with monitoring and supervision of the projects. By making statements.
- **PLANNING:** By developing local action plans for restoration of eutrophic sea bays. By taking proposals for actions to the water management planning processes. By investigating whether we have anoxic bottoms in our municipality's area and finding suitable sites for the measures.
- **PRACTICAL WORK:** By acting as a local coordinator in the projects. By supporting the implementation of measures in practice. By developing new projects to cut the internal load.
- **FINANCING:** By allocating resources to the restoration of the sea. By including measures in the annual budgets. By offering funding. By supporting local operators financially.

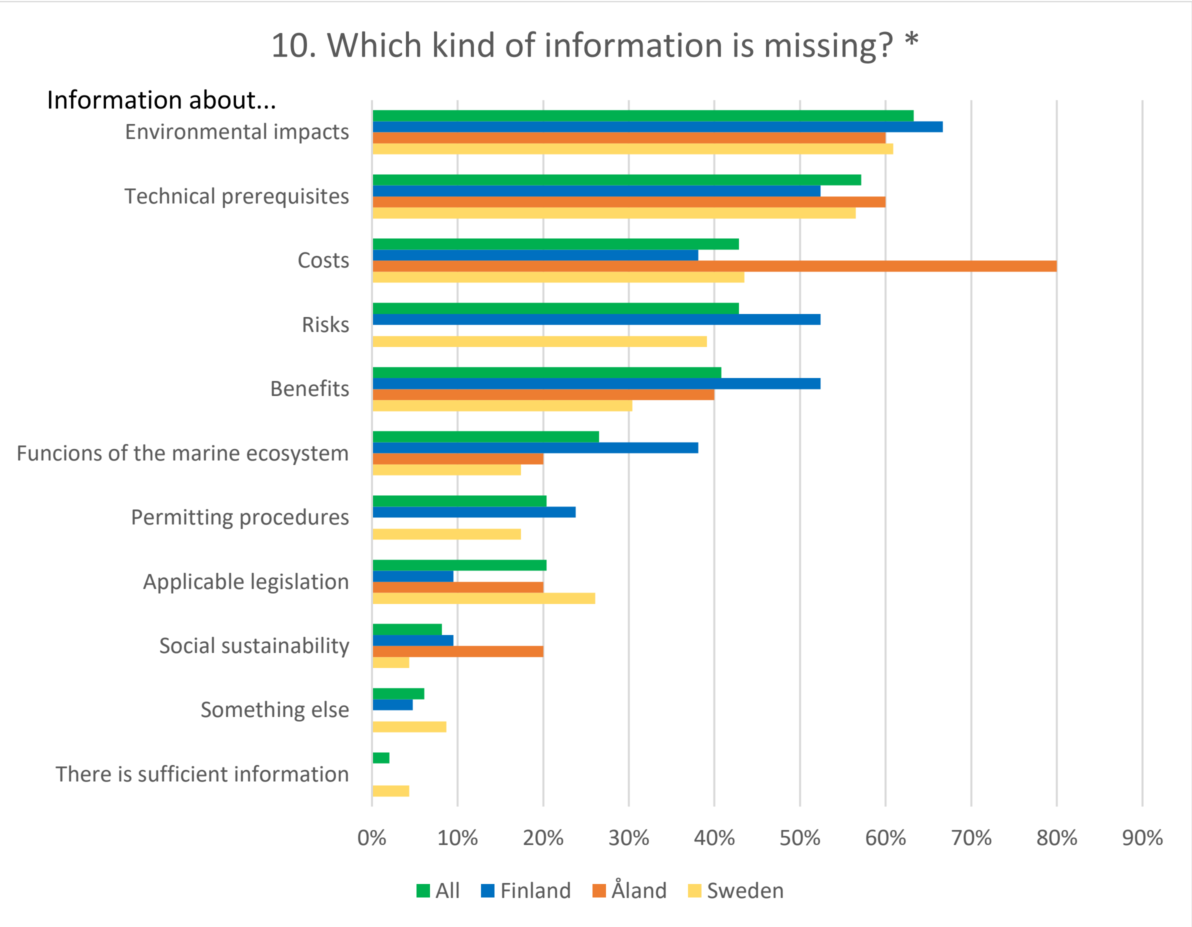


*Fig. 8. Information needs related to the use of sea-based measures. (*question not included in Survey for Estonia*)

<u>Summary of answers to "Something else, please specify":</u>

- Targeted habitat information from different the sea areas
- Sedimentation processes
- Long-term cost-efficiency

Other arguments:

- Actually, all kind of information mentioned is missing.
- Costs, efficiency and benefits are the most important information for policymaking.

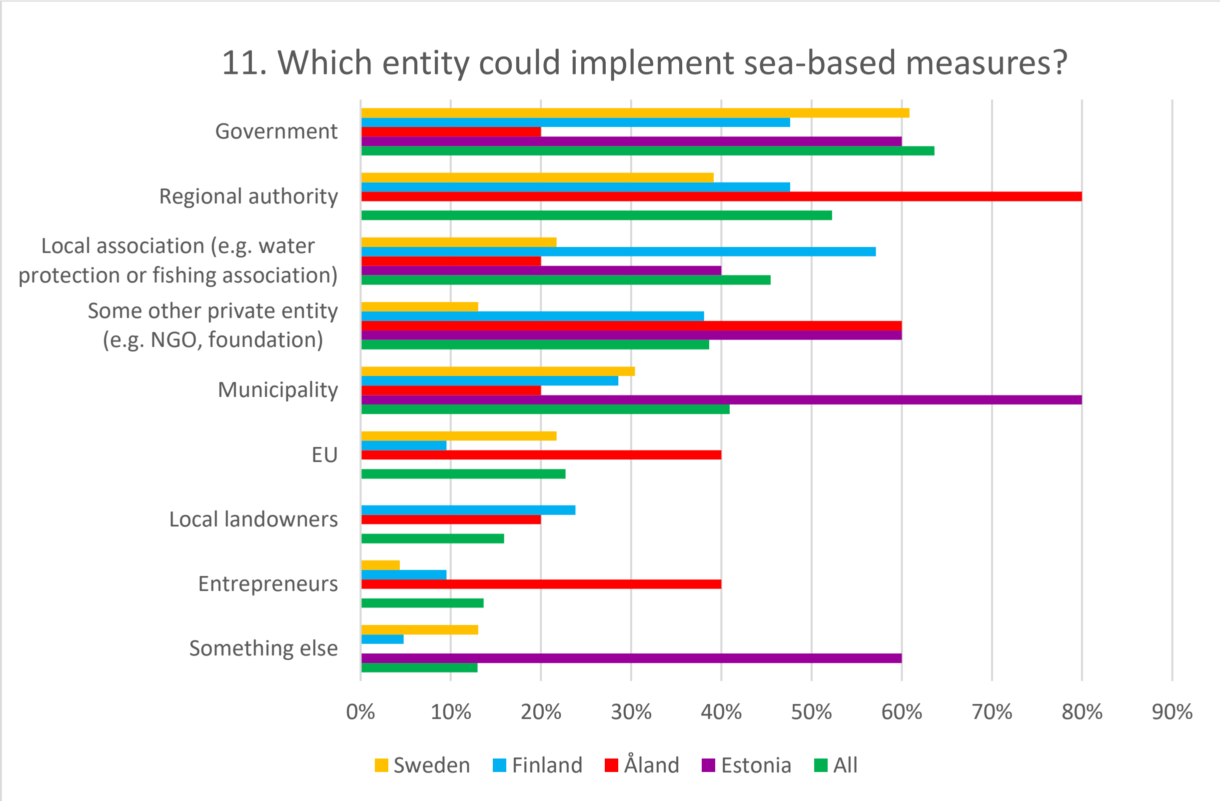


Fig. 8. Authorities' views on the entities that were preferred to be implementing the sea-based measures. (SEABASED Sustainability Survey for environmental authorities in 2020, N=54)

Summary of the answers and views given in open field:

- **COOPERATION**: Different entities and countries in a cooperation. Cooperation between different levels and organisations is needed. Measures could be implemented in a cooperation with different entities, but the governmental authorities could have the responsibility to call all the organisations to join the project. The government and the municipalities should be involved, but the private organisations should take care of the practical implementation.
- **NATIONAL AUTHORITY:** Internal load is a consequence of long-time nutrient load from different sources and from geographically wide areas, so it is difficult to point out any other entity except the government to take care of it. The government has the authority to allocate the resources needed in the implementing bigger projects. The financing could come from the private sector, but also from the government and EU.
- **REGIONAL AUTHORITY:** The responsibility must keep on the regional level. Regional authorities can coordinate the actions also on the local level. We need at least regional coordination, because to be efficient, we need implement the measures in wider areas. The control of the projects must be in enough high level so that there is enough expertise to lead the project.
- **LOCAL AUTHORITY:** A big part of the water areas is owned by cities and municipalities, so they might be the right entities to implement the project. Local entrepreneurs can do the practical work, but the order of the work could be some local organisation.
- **OTHER ARGUMENTS:** It depends on the scale: Local association can implement the smaller projects, but the larger projects need a national authority to lead them. It is good if the local people are involved, but they need support and financing from the higher levels.

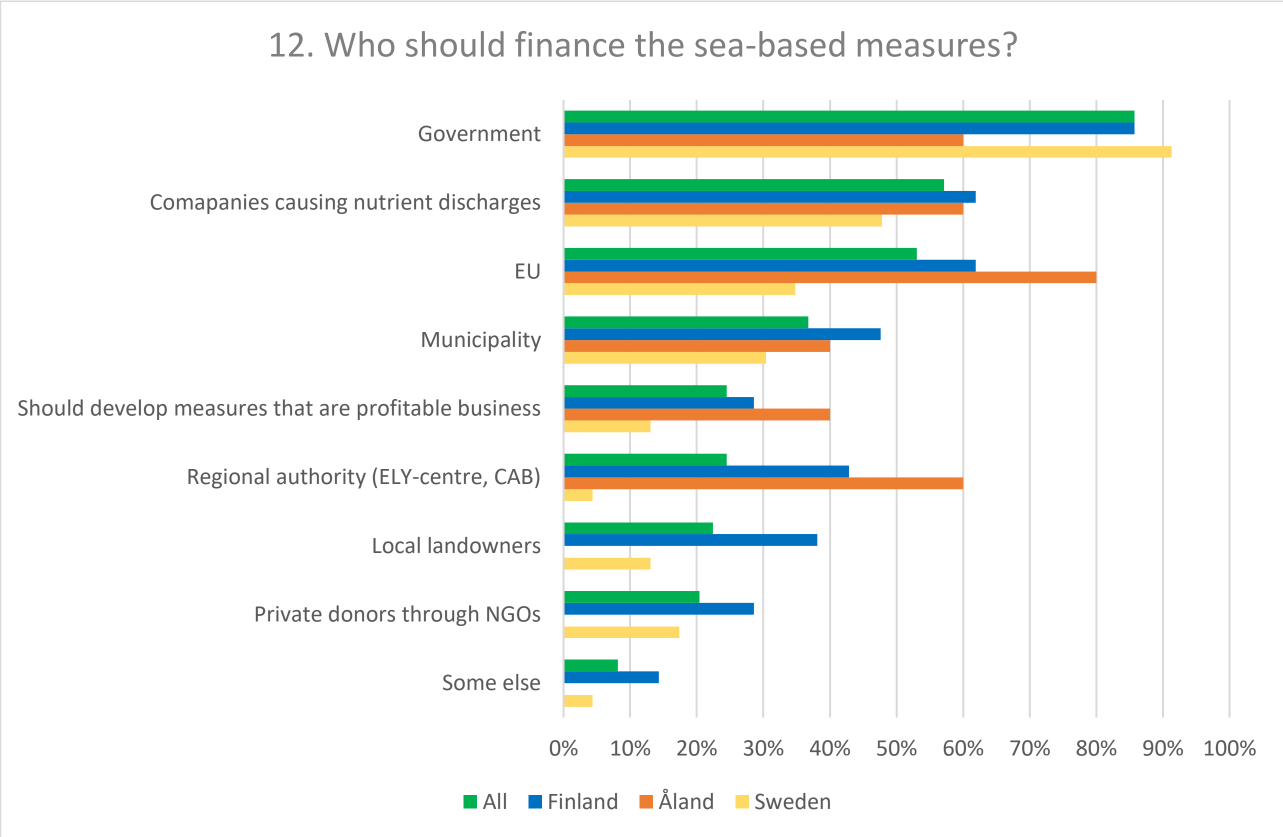


Fig. 9. Public financing was seen the most relevant in implementing the sea-based measures. (SEABASED Sustainability Survey for environmental authorities in 2020, N=54)

Summary or the arguments on financing of the sea-based activities:

- Financing by all the entities which get benefits from the improving water status.
- Any entity which has cause the eutrophication (polluter pays -principle).
- If would be good to get other interest groups involved, too.
- It would be good to have similar fund as we have for oil spill prevention.
- Internal load is a consequence of long-time nutrient load from different sources and from geographically wide areas, so it is difficult to point out “guilty”. Therefore, it would be appropriate that the government funds the measures.

Attachment 2:

SEABASED Local's voice Survey

The project organised local information events related to the implementation of project pilot activities, prior to the planned implementation. At the events, the participants were asked to fill in a survey form, presented in Figure 5, to map their views on the environmental state of the nearby coastal waters, and their attitudes towards the pilot activities to be implemented in SEABASED.

Altogether 5 events were organised during the project, and 51 answers to the survey were given at the events. At each of the events, one of the pilot measures of SEABASED was presented, depending on which measure(s) was being planned to the nearby waters of the local community: stickleback harvesting, irrigation of fields with nutrient-rich water (from the bottom of the bay), sediment removal and binding phosphorus to the sediment with marl. The survey included 5 questions. The summary of the answers is presented below.

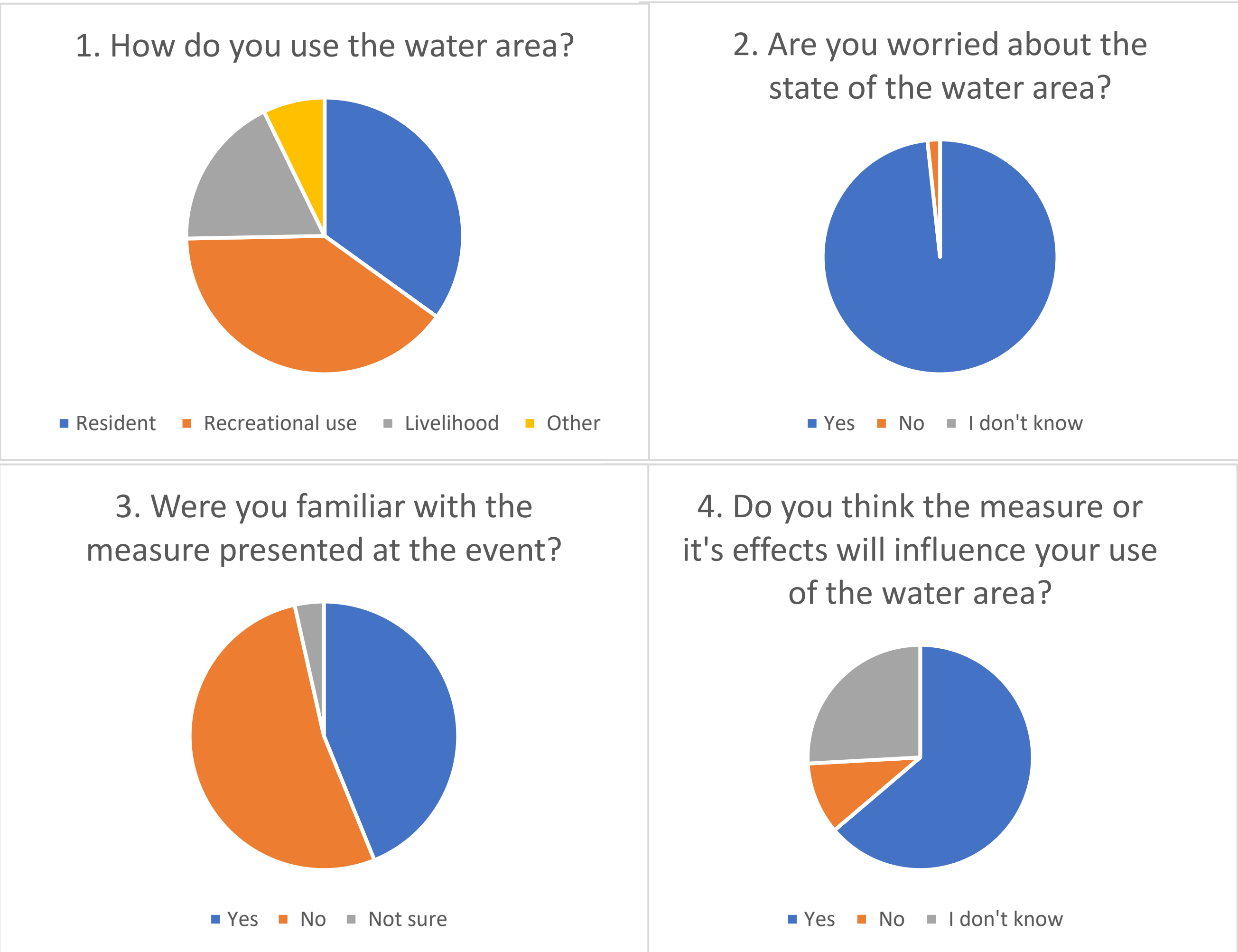


Fig. 1. The summary of answers to questions 1-4 in Local's voice Survey at 5 local information events in 2019 and 2020 (N=51). For the first question, it was possible to select several answering options.

In the Survey form it was also asked whether the participants felt they got enough information about the presented pilot measure. All participants, except for one, answered "yes", so these results are not presented separately. In question 5, the opinions and feelings towards the presented pilot measures were asked, and the results are presented below (Fig. 2-4). In general, the opinions towards the measures were positive, however, some of the measures also raised some concern and insecurity among the respondents.

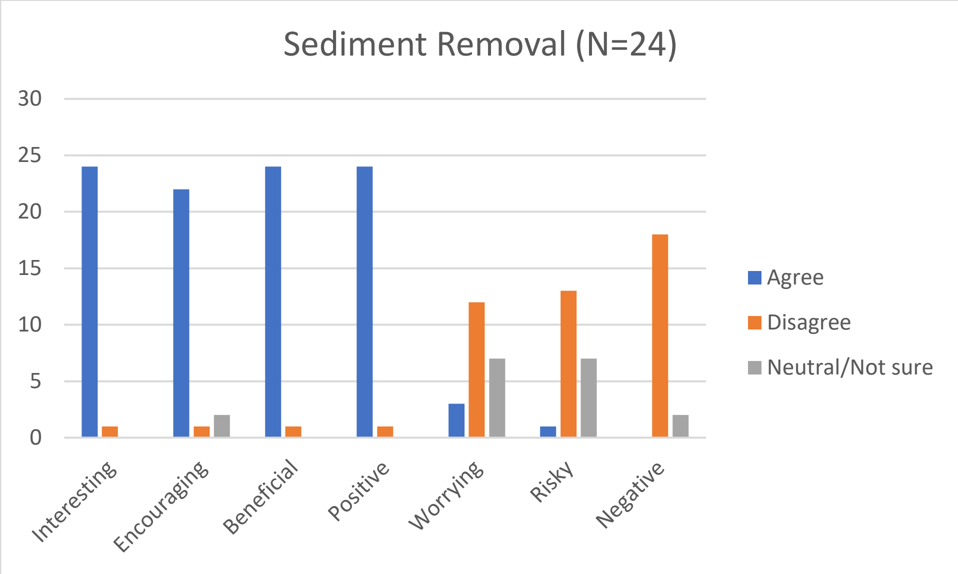


Fig. 2. Combined results from two separate information events which were organised about the planned sediment removal pilot. The opinions towards the measure were positive, and only few respondents found the measure worrying or risky. The respondents were asked to indicate whether they agree or disagree with the given alternatives (N=24, in two events).

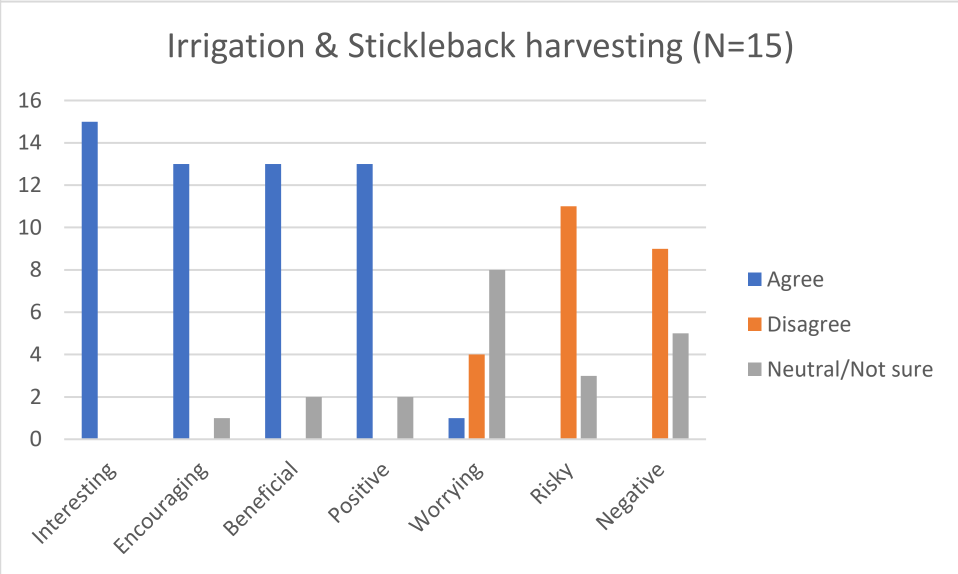


Fig. 3. Two information events were organised about the irrigation of fields and stickleback harvesting pilots. In one event, only irrigation pilot was included, whereas in the other event both measures were presented, but only one survey form was used. Therefore, the results can't be separated and both pilots are presented in the same figure. The respondents were asked to indicate whether they agree or disagree with the given alternatives (N=15, in two events).

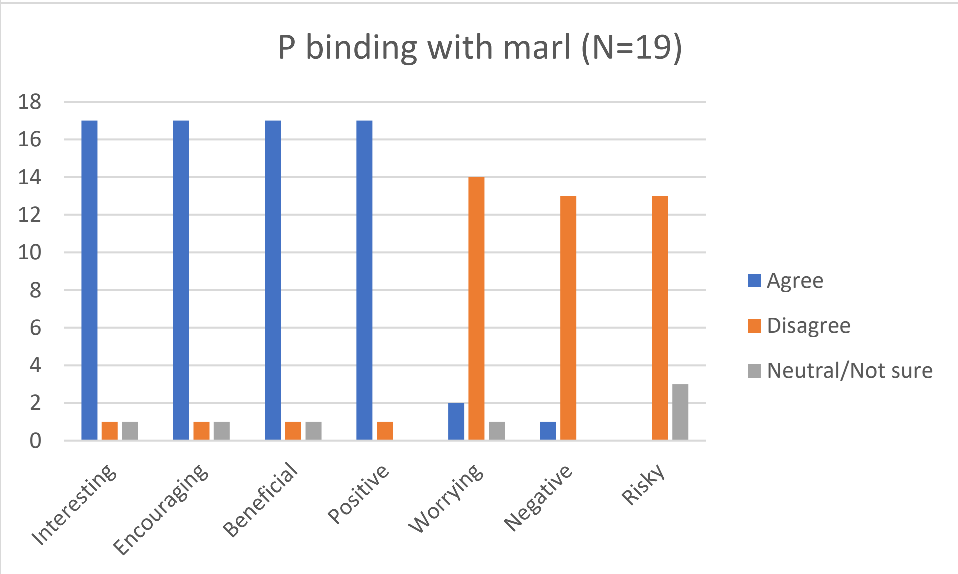


Fig. 4. The results from information event presenting the pilot for binding phosphorus into the sediment with marl. The opinions towards the measure were positive, and only few respondents found the measure worrying or negative. The respondents were asked to indicate whether they agree or disagree with the given alternatives (N=19).

SEABASED /

Locals' voice in the pilot project

The most large-scale problem of the Baltic Sea is eutrophication. While we've been successful in cutting the nutrient load coming from land, nutrients that are stored in the seabed slow down the Sea's recovery. The SEABASED Project will assess measures that improve the status of a marine area by reducing the internal load of the sea. The project will pilot selected measures in the pilot areas in Finland, Åland and Sweden.

This pilot project is one of the pilot projects of SEABASED aiming to test and develop measures to reduce nutrients in the Baltic Sea. We would like to hear your opinions of the pilot project:

1. How do you use the water area?

I am a resident	☐
My livelihoods / work is related to the sea / coast	☐
Recreational use	☐
Other ______________________________	☐

2. Are you worried about the environmental state of your water area? **Yes / No / Not sure**
3. You just heard the presentation of the pilot project, have you heard of the introduced water protection measure before? **Yes / No / Not sure**
4. Do you think the measures, and/or their effects of this pilot project will influence (positively or negatively) your above-mentioned use of the water area? **Yes / No / Not sure**

5. What is your opinion on the measures in the pilot project? **(X)**

I think it is…

	Disagree	**Somewhat disagree**	**Neutral/ Both**	**Somewhat agree**	**Agree**	**I don't know/ Doesn't apply**
	-2	-1	0	+1	+2	
Interesting						
Worrying						
Encouraging						
Risky						
Beneficial						
Positive						
Negative						

In your own words:____

____

6. Did you get enough information? **Yes / No / Not sure**

Thank you!

Fig. 5. SEABASED Local's voice Survey Form, which was used at local information events for gathering participants' views and opinions towards the presented pilot measure(s).