Document title	Measures related to coastal restoration
Code	2
Category	CMNT
Submission date	29.1.2020
Submitted by	Secretariat and Action project

Background

The document contains a summary of measures related to coastal restoration.

An attachment (Document 2 Att.1 HELCOM ACTION WP2.2a Draft list restoration measures revised last version) also provides further information and an approach for evaluating the proposed measures. This latter aspect will be introduced and utilized under Agenda item 5.

Action requested

The Workshop is invited to discuss the information provided.

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Measures related to restoration of coastal habitats

This document contains information on 16 measures of relevance for improving coastal habitats. The content is to be viewed as representing measures for which at least some experience is available today, and is intended to support their further evaluation.

The measures represent three broad categories: i) measures aiming at restoring or rehabilitating[1] habitats or habitat forming species, ii) measures aiming at reducing pressure levels, with a focus on nutrient loading, which is a predominating pressure in many coastal habiatats, and iii) measures focusing on protecting habitats or strengthening functionally important species.

On a generalized level, the different categories are suggested to sort by level of cost-efficiency as: 1) protective measures, 2) measures to improve existing habitats and species and/or to reduce pressures, 3) restoration measures. However, differences in the applicality and need of specific measures within each of these groups affect the total picture.

It should also be noted that different measures may be advisable in different areas, depending on community composition and key species, local characteristics and what local key impacts that are identified, and that a combination of measures is likelyto be the most effective in many cases.

The measures for which information is presented are:

1. Restoration of eelgrass, *Zostera marina*
2. Restoration of soft bottom macrophytes (other than eelgrass)
3. Restoration of brown macroalgae, mainly *Fucus vesiculosus*
4. Restoration of blue mussel reefs
5. Restoration of stony reefs
6. Restoration of soft bottoms free of vegetation
7. Restoration of coastal wetlands
8. Strengthening piscivorous fish to rehabilitate coastal ecosystem function
9. Reducing nutrient loading by farming and harvesting blue mussels
10. Rehabilitation of hypoxic areas by oxygen pumping

[1] In this context, *ecological restoration* involves restoring lost or severly deteriorated habiatats or habitat-forming species to a previous/historical state while *rehabilitation* involves improving the state of existing but deterioratied habitats or habitat-forming species.

11. Reducing internal phosphorus loads by metal bounding
12. Biomanipulation to remove cyprinds and sticklebacks and rehabilitate coastal ecosystem function
13. Rehabilitation of anoxic, nutrient rich or polluted sediments by removal or coverage
14. Rehabilitation of hard bottoms by establishment of artificial reefs
15. Protection of habitats
16. Follow-up and knowledge sharing

Tables 1–15 have been filled in as thoroughly as possible under the general understanding that practical experience is still limited for most of these measures in Baltic Sea coastal areas. Table 16 suggests actions to remediate this limitation in the future by enhancing follow-up and knowledge sharing. The tables synthesise work of the ACTION project and of Kraufvelin et al. 2020[2].

The text was written by Patrik Kraufvelin, Lena Bergström, Jens Olsson, Ulf Bergström and Andreas Bryhn, submitted by the SLU Aqua (Department of Aquatic Resources, Swedish University of Agricultural Sciences) and the HELCOM ACTION project.

ACTION

Co-funded by the European Union

[2] Kraufvelin, P., Bryhn, A., Olsson, J., 2020. Erfarenheter av ekologisk restaurering i kust och hav. Havs- och Vattenmyndighetens Rapport (in preparation). (In Swedish).

Title **1. Restoration of eelgrass, *Zostera marina***
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure Mechanical transplantation of vegetative eelgrass shoots.
Activity: Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material) Extraction of minerals (rock, metal ores, gravel, sand, shell) Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational) Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational) Aquaculture – marine, including infrastructure Agriculture Transport – shipping (incl. anchoring, mooring) Transport – shipping infrastructure (harbours, ports, ship-building) Tourism and leisure infrastructure (piers, marinas) Tourism and leisure activities (boating, beach use, water sports, etc.)
Pressure: *Disturbance of species: Visual, presence, boating, recreational activities, above-water noise* *Extraction of target fish and shellfish species and incidental fish catches* *Physical disturbance to seabed (temporary or reversible and recovers within 12 y)* *Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)* *Changes to hydrological conditions* *Input of nitrogen* *Input of phosphorous* *Input of organic matter — diffuse sources and point sources*
State: In western Sweden, seagrass meadows have decreased in distribution over the last decades. Seabed habitats
Extent of impact: Positive impacts of restoration measures are very local and within coastal waters
Effectiveness of measure From western Sweden (Skagerrak/Kattegat), there are examples of successful results from restoration of eelgrass at the experimental scale. Transplantation of vegetative shoots is the only possibility, sowing does not work. The method is still both expensive and time consuming (Cole & Moksnes 2016, Eriander et al. 2016, Infantes et al. 2016, Moksnes et al. 2016a, b). The measure is only effective provided that the orginal pressures causing the eelgrass loss is also removed, for example related to water quality aspects. Recently, the role of local physical regime shifts shuch as changes in light and sediment condition and how and why these conditions prevent eelgrass recovery have been investigated (Moksnes et al. 2018).
Cost, cost-effectiveness of measure: The estimated costs for western Sweden approach 120 000 – 250 000 euro per hectare restored eelgrass meadow (Moksnes et al. 2016a, b). However, Bayraktarov et al. (2016) give a median prize for the western world of 392 988 euro per hectare restored seagrass and de Groot et al. (2013) present a range of 250 000 – 600 000 euro per hectare for coastal systems including seagrasses.

Feasibility:

The shoot transplantation measure for eelgrass seems to be working in western Sweden (Kattegat/Skagerrak), but the costs are relatively high. For Kalmar Sound and Denmark, only little information is still available (https://www.novagrass.dk/en/home/, Kraufvelin et al. 2020).

Follow-up of measure:

In western Sweden (Kattegat/Skagerrak), eelgrass restorations are followed up (Moksnes et al. 2016ab, 2018)

Background material:

Comprehensive details exist for eelgrass in western Sweden (Kattegat/Skagerrak), but still quite little information from other parts of the Baltic Sea such as Kalmar Sound and Denmark. From the USA, a lot of information is available.

References

Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J., Lovelock, C.E., 2016. The cost and feasibility of marine coastal restoration. Ecol Appl 26:1055-1074.

Cole, G.S., Moksnes, P.-O., 2016. Valuing multiple eelgrass ecosystem services in Sweden: fish production and uptake of carbon and nitrogen. Front Mar Sci 2:121.

de Groot, R.S., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1:50-61.

Eriander, L., Infantes, E., Olofsson, M., Olsen, J.L., Moksnes, P.O., 2016. Assessing methods for restoration of eelgrass (*Zostera marina* L.) in a cold temperate region. J Exp Mar Biol Ecol 479:76-88.

Infantes, E., Eriander, L., Moksnes, P.O., 2016. Eelgrass (*Zostera marina*) restoration on the west coast of Sweden using seeds. Mar Ecol Prog Ser 546:31-45.

Kraufvelin, P., Bryhn, A., Olsson, J., 2020. Erfarenheter av ekologisk restaurering i kust och hav. Havs- och Vattenmyndighetens Rapport (in preparation). (In Swedish).

Moksnes, P.O., Gipperth, L., Eriander, L., Laas, K., Cole, S., Infantes, E., 2016a. Förvaltning och restaurering av ålgräs i Sverige – Ekologisk, juridisk och ekonomisk bakgrund. Havs- och vattenmyndighetens rapport 2016:8, 148 s, ISBN 978-91-87967-16-0. (In Swedish).

Moksnes, P.O., Gipperth, L., Eriander, L., Laas, K., Cole, S., Infantes, E., 2016b. Handbok för restaurering av ålgräs i Sverige – Vägledning. Havs- och vattenmyndighetens rapport 2016:9, 146 p, ISBN 978-91-87967-17-7. (In Swedish).

Moksnes, P.O., Eriander, L., Infantes, E., Holmer, M., 2018. Local regime shifts prevent natural recovery and restoration of lost eelgrass beds along the Swedish west coast. Estuar Coast 41:1712-1731.

https://www.novagrass.dk/en/home/

Title

2. Restoration of soft bottom macrophytes (other than eelgrass)

Submitted by:

SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION

Description of measure

Transplantation and sowing of macrophytes, transplantation of overwintering propagules, harvesting undesired competing vegetation.

Activity:

Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation)
Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational)
Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational)
Aquaculture – marine, including infrastructure
Agriculture
Forestry
Transport – shipping (incl. anchoring, mooring)
Transport – shipping infrastructure (harbours, ports, ship-building)
Waste waters (urban, industrial, and industrial animal farms)
Tourism and leisure infrastructure (piers, marinas)
Tourism and leisure activities (boating, beach use, water sports, etc.)

Pressure:

Disturbance of species: Visual, presence, boating, recreational activities, above-water noise
Extraction of target fish and shellfish species and incidental fish catches
Physical disturbance to seabed (temporary or reversible and recovers within 12 y)
Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)
Changes to hydrological conditions
Input of nitrogen
Input of phosphorous
Input of organic matter — diffuse sources and point sources

State:

Mainly local declines in the distribution of macrophytes (other than eelgrass) have been reported from the Baltic Sea.
Seabed habitats

Extent of impact:

The positive impacts of these restoration measures are supposedly very local and within coastal waters.

Effectiveness of measure

Some success has been achieved for restoration of macrophytes within lake restoration on the European continent. Swedish information is available from lakes and rivers in the report by Degerman et al. (2017), while Torn et al. (2010) have some information about brackish-water charophytes in Estonia. The methods from freshwater systems can potentially be used also in brackish water areas, although they are largely untested (Kraufvelin et al. 2020). Re-establishment of plant communities is, however, a very slow process, often comprising 20–40 years (Hilt et al. 2006, Bakker et al. 2013).

Cost, cost-effectiveness of measure:

Costs per restored hectare of other macrophytes on soft substrate are possibly comparable with those for seagrass or ca 120 000 – 600 000 euro per hektar (de Groot et al. 2013, Bayraktarov et al. 2016, Moksnes et al. 2016ab).

Feasibility:

Too little experience is available for this measure in order to fully judge its feasibility.

Follow-up of measure:

Details are missing

Background material:

For other macrophytes, there is very little information available from brackish water, although some initial attempts have been done in Björnöfjärden in Stockholm archipelago (http://balticsea2020.org/alla-projekt/overgodning/15-oevergoedning-avslutade-projekt/402-restaurering-av-vegetationsklaedda-bottnar)

References

Bakker, E.S., Sarneel, J.M., Gulati, R.D., Liu, Z., van Donk, E., 2013. Restoring macrophyte diversity in shallow temperate lakes: biotic versus abiotic constraints. Hydrobiologia 710:23-37.

Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J., Lovelock, C.E., 2016. The cost and feasibility of marine coastal restoration. Ecol Appl 26:1055-1074.

Degerman, E., Tamario, C., Sandin, L., Törnblom, J., 2017. Fysisk restaurering av sjöar. Aqua reports 2017:10. Institutionen för akvatiska resurser, Sveriges lantbruksuniversitet, Drottningholm Lysekil Öregrund, 105 s. (In Swedish).

de Groot, R.S., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1:50-61.

Hilt, S., Gross, E.M., Hupfer, M., Morscheid, H., Mählmann, J., Melzer, A., Poltz, J., Sandrock, S., Scharf, E.M., Schneider, S., Van de Weyer, K., 2006. Restoration of submerged vegetation in shallow eutrophic lakes – a guideline and state of the art in Germany. Limnologica 36:155-171.

Kraufvelin, P., Bryhn, A., Olsson, J., 2020. Erfarenheter av ekologisk restaurering i kust och hav. Havs- och Vattenmyndighetens Rapport (in preparation). (In Swedish).

Moksnes, P.O., Gipperth, L., Eriander, L., Laas, K., Cole, S., Infantes, E., 2016a. Förvaltning och restaurering av ålgräs i Sverige – Ekologisk, juridisk och ekonomisk bakgrund. Havs- och vattenmyndighetens rapport 2016:8, 148 s, ISBN 978-91-87967-16-0. (In Swedish).

Moksnes, P.O., Gipperth, L., Eriander, L., Laas, K., Cole, S., Infantes, E., 2016b. Handbok för restaurering av ålgräs i Sverige – Vägledning. Havs- och vattenmyndighetens rapport 2016:9, 146 p, ISBN 978-91-87967-17-7. (In Swedish).

Torn, K., Martin, G., Kotta, J., Kupp, M., 2010. Effects of different types of mechanical disturbances on a charophyte dominated macrophyte community. Estuar Coast Shelf Sci 87:27-32.

http://balticsea2020.org/alla-projekt/overgodning/15-oevergoedning-avslutade-projekt/402-restaurering-av-vegetationsklaedda-bottnar

Title **3. Restoration of brown macroalgae, mainly *Fucus vesiculosus***
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure Transplantation of seaweed attached to stones/boulders
Activity: Land claim Coastal defence and flood protection (seawalls, flood protection) Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material) Extraction of minerals (rock, metal ores, gravel, sand, shell) Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational) Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational) Aquaculture – marine, including infrastructure Agriculture Forestry Transport – shipping (incl. anchoring, mooring) Transport – shipping infrastructure (harbours, ports, ship-building) Waste waters (urban, industrial, and industrial animal farms) Tourism and leisure infrastructure (piers, marinas) Tourism and leisure activities (boating, beach use, water sports, etc.)
Pressure: *Disturbance of species: Visual, presence, boating, recreational activities, above-water noise* *Extraction of target fish and shellfish species and incidental fish catches* *Physical disturbance to seabed (temporary or reversible and recovers within 12 y)* *Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)* *Changes to hydrological conditions* *Input of nitrogen* *Input of phosphorous* *Input of organic matter — diffuse sources and point sources*
State: Loss of bladder-wrack, *Fucus vesiculosus*, is considerable along many stretches of the Baltic Sea coastline, especially at the deeper ranges of its former depth distributions. Seabed habitats
Extent of impact: Restoration can at best improve conditions locally in coastal waters, but there is still no evidence of successful restorations of perennial brown algae from the Baltic Sea.
Effectiveness of measure For bladder-wrack in the Baltic Sea, transplantation methods have been tested and used without long-term success (e.g. Engqvist et al. 2000, Berger et al. 2001, Kautsky et al. 2019), but see Krost et al. (2018) from the Kiel bight in Germany. Kautsky et al. (2019) list epiphytic load, light conditions, grazing and type of substratum as factors that need to be taken into consideration in order to achieve successful restoration of bladder-wrack, *F. vesiculosus*.

Cost, cost-effectiveness of measure:

Costs for restoration of *Fucus vesiculosus* in the Baltic Sea have recently been estimated by Kautsky, Schagerström and Qvarfordt (personal communication) and they present time use for various stages connected with transplanting a certain number of bladder-wrack individuals, including a follow-up program. In total 464 h are estimated to be needed planning and actual transplantation and following up the transplantation success for 350 bladder-wrack individuals. De Groot et al. (2013) present a range of 250 000 – 600 000 euro per hectare for coastal systems including perennial macroalgae on rocky shores. Globally, the presented costs for macroalgal restoration, depending on species and geographical region, vary with several orders of magnitudes; from 26 012 euro (Campbell et al. 2014) to 2 285 880 euro per hectare (Carney et al. 2005).

Feasibility:

Restoration through transplantation of bladder-wrack is very difficult and still no real success stories exist from the Baltic Sea (see Kautsky et al. 2019 for details) with some possible exceptions (see Krost et al. 2018).

Follow-up of measure:

All long-term follow-up studies of bladder-wrack transplantation attempts in the Baltic Sea demonstrate failures (Kautsky et al. 2019, Kraufvelin et al. 2020), although the study by Krost et al. (2018) presents some promising results.

Background material:

Restoration of bladder-wrack through transplantation has been tested in Björnöfjärden (Stockholm archipelago, eastern Sweden), in Himmerfjärden (Trosa archipelago, eastern Sweden), in the Kalmar Sound (southeastern Sweden), in the Bay of Gdansk (Poland) and in the Kiel bight (Germany).

References

Berger, R., Malm, T., Kautsky, L., 2001. Two reproductive strategies in Baltic *Fucus vesiculosus* L. Eur J Phycol 36:265-273.

Campbell, A.H., Marzinelli, E.M., Vergés, A., Coleman, M.A., Steinberg, P.D., 2014. Towards restoration of missing underwater forests. PLoS One 9:e84106.

Carney, L.T., Waaland, J.R., Klinger, T., Ewing, K., 2005. Restoration of the bull kelp *Nereocystis luetkeana* in nearshore rocky habitats. Mar Ecol Prog Ser 302:49-61.

de Groot, R.S., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1:50-61.

Engkvist, R., Malm, T., Tobiasson, S., 2000. Density dependent grazing effects of the isopod *Idotea baltica* Pallas on *Fucus vesiculosus* L in the Baltic Sea. Aquat Ecol 34:253-260.

Kautsky, L., Qvarfordt, S., Schagerström, E., 2019. *Fucus vesiculosus* adapted to a life in the Baltic Sea: impacts on recruitment, growth, re-establishment and restoration. Bot Mar 62:17-30.

Kraufvelin, P., Bryhn, A., Olsson, J., 2020. Erfarenheter av ekologisk restaurering i kust och hav. Havs- och Vattenmyndighetens Rapport (in preparation). (In Swedish).

Krost, P., Goerres, M., Sandow, V., 2018. Wildlife corridors under water: an approach to preserve marine biodiversity in heavily modified water bodies. J Coastal Conserv 22:87-104.

Title **4. Restoration of blue mussel reefs**
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure The measure aims to support the natural recruitment of blue mussel (*Mytilus edulis/trossulus*). This can be achieved by deploying mussel shells (for example from mussel farms) or other natural or artificial substrates onto hard bottoms in areas with natural availability of mussel recruits. Alternatively, mussels can be naturally recruited onto (jute or coconut fibre fabric) substrates in the water mass and later transplantaed to the bottom together with the substrate. Direct transplantation of young or adult mussels may be another option.
Activity: Land claim Coastal defence and flood protection (seawalls, flood protection) Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material) Extraction of minerals (rock, metal ores, gravel, sand, shell) Renewable energy generation (wind, wave and tidal power), including infrastructure Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational) Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational) Aquaculture – marine, including infrastructure Transport – shipping (incl. anchoring, mooring) Transport – shipping infrastructure (harbours, ports, ship-building) Waste waters (urban, industrial, and industrial animal farms) Tourism and leisure infrastructure (piers, marinas) Tourism and leisure activities (boating, beach use, water sports, etc.)
Pressure: *Input or spread of non-indigenous species* *Disturbance of species: Visual, presence, boating, recreational activities, above-water noise* *Extraction of target fish and shellfish species and incidental fish catches* *Physical disturbance to seabed (temporary or reversible and recovers within 12 y)* *Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)* *Changes to hydrological conditions* *Input of nitrogen* *Input of phosphorous* *Input of organic matter — diffuse sources and point sources* *Input of other substances (e.g. synthetic substances, non-synthetic substances, radionuclides) — diffuse sources, point sources, atmospheric deposition, acute events*
State: This far, mainly local decrease in mussel abundance has been reported, but in western Sweden (Kattegat and Skagerrak), a larger-scale disappearance of blue mussels is taking place. Seabed habitats
Extent of impact: The positive impacts of restoration measures are local and within coastal waters.

Effectiveness of measure

The used methods for restoration can in Denmark lead to fast re-establishment, within 1–2 years, of functional/harvestable mussel stands (Dolmer et al. 2009). Succesful restoration of biogenic reefs of mussels have been observed to increase the structural complexity and biodiversity of the habitat and associated fauna, which may support an increased fish growth and diversity over time (Kristensen et al. 2015). The restoration may also include many positive side effects, such as habitats for associated organisms and fish, clearer waters and increased coastal protection (Kraufvelin et al. 2020).

Cost, cost-effectiveness of measure:

Blue mussel restoration is probably one of the least costly marine restoration methods, provided that the measures are successful. Still, no cost estimates seem to exist for restoration of blue mussel reefs in the Baltic Sea. For indicative comparison, a median cost of 194 270 euro per hectare restored oyster reef is given by Bayraktarov et al. (2016). de Groot et al. (2013) present a range of 250 000 – 600 000 euro per hectare for coastal systems including rocky shores.

Feasibility:

Restoration of blue mussel reefs, as a measure, is probably relatively easy and cheap compared to many other benthic restoration measures.

Follow-up of measure:

-

Background material:

8-fjordar, Stenungsund (western Sweden); Limfjorden (northern Denmark); Nørrefjord (southern Denmark)

References

Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J., Lovelock, C.E., 2016. The cost and feasibility of marine coastal restoration. Ecol Appl 26:1055-1074.

de Groot, R.S., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1:50-61.

Dolmer, P., Kristensen, P.S., Hoffman, E., Geitner, K., Borgström, R., Espersen, A., Petersen, J.K., Clausen, P., Bassompierre, M., Josefson, A., Laursen, K., Petersen, I.K., Tørring, D., Gramkow, M., 2009. Udvikling af kulturbanker til produktion af blåmuslinger i Limfjorden. DTU Aqua-rapport nr. 212-2009. Charlottenlund. Institut for Akvatiske Ressourcer, Danmarks Tekniske Universitet, 127 p. (In Danish).

Kraufvelin, P., Bryhn, A., Olsson, J., 2020. Erfarenheter av ekologisk restaurering i kust och hav. Havs- och Vattenmyndighetens Rapport (in preparation). (In Swedish).

Kristensen, L.D., Stenberg, C., Støttrup, J.G., Poulsen, L.K., Christensen, H.T., Dolmer, P., Landes, A., Røjbek, M., Thorsen, S.W., Holmer, M., Deurs, M.V., Grønkjær, P., 2015. Establishment of blue mussel beds to enhance fish habitats. Appl Ecol Environ Res 13:783-798.

Title

5. Restoration of stony reefs

Submitted by:

SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION

Description of measure

Restoration and revitalization of stony/boulder habitats is a priority in areas where these habitats have previously been destroyed or lost due to human activities. These measures are undertaken in order to bring back the degraded habitat to a state where it can support biodiversity and also the productivity of fish populations. The measures aim to re-create natural physical hard structures, and are mainly applicable for the southern and southwestern Baltic Sea. Natural or blasted rocks that can serve as underwater stony/boulder reefs, are re-introduced to allow for colonisation of hard bottom macroalgal and macrofaunal assemblages and fish.

Activity:

Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)

Extraction of minerals (rock, metal ores, gravel, sand, shell)

Transport – shipping infrastructure (harbours, ports, ship-building)

This refers to past activities

Pressure:

Physical disturbance to seabed (temporary or reversible and recovers within 12 y)

Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)

Changes to hydrological conditions

State:

The measure is relevant for coastal areas where stony reefs have previously been present, but where they now are depleted, such as in the southern and southwestern Baltic Sea.

Seabed habitats

Extent of impact:

There are mostly local positive effects of the measure, but with combination of the establishment of marine protected areas, some wider scale positive impact could possibly be achieved.

Effectiveness of measure

The measure implies re-introduction of natural or blasted stones that can serve as underwater stony/boulder reefs to allow for colonisation of hard bottom macroalgal and macrofaunal assemblages and fish communities (Kraufvelin et al. 2020). The measure is expected to lead to more habitat for marine organisms, increased biodiversity, increased availability of essential fish habitats, preserved ecosystem services, improved coastal protection against erosion, sequestration of organic material and nutrients and more. Potential negative responses that should be considered during localization are effects on bottom structure and water circulation, and the risk of claiming space from other marine habitats. In areas of predominating soft bottoms introduced hard substrates can serve as stepping stones for non-indigenous invasive species. Promoting the attraction by individuals to certain areas can lead to overharvesting of fish unless fisheries are also managed.

In the Baltic Sea region, a restoration was applied in Denmark to areas where the original hard substrate historically has been removed by stone fishing, leaving a soft, predominantly sandy substrate that could not support the natural biological community including fish. When artificial stone reefs were re-introduced in such areas, it was seen that the biotic community changed as the new structures attracted species with a preference for rocky habitats. Monitoring in such areas have shown increased biodiversity, increased abundances of fish, including increased abundance of larger specimens of certain species of fish (Støttrup et al. 2014, 2017).

Similar effectiveness of the measure can be deduced from monitoring fish close to off shore wind farms in the Sound area, where boulders are deployed as scour protection around the turbine foundations (Stenberg et al. 2015, Bergström et al. 2015). Comparable examples can also be found from areas outside of the Baltic Sea (HELCOM 2018).

In some areas, the restoration of other types of hard substrates may be more relevant. Restoration of biogenic reefs of mussels have been observed to increase the structural complexity and biodiversity of the habitat and associated fauna, which may support an increased fish growth and diversity over time (Kristensen et al. 2015). The long-term effect of the measure is dependent on the persistence of the created habitat, why rocks are assumed to be more persistent, lasting and requiring less maintenance.

Whether the above-mentioned observations are the result of pure attraction effects of the fish or if they also reflect effects at the population abundance level, is to date not established due to a lack of long-term follow-up studies. However, it is relevant to recommend that the measure is combined with protection from fishing to facilitate the rapid re-establishment, and to avoid over-fishing as fish are expected to become easier to catch in areas where they aggregate such as around restored stone reefs.

Cost, cost-effectiveness of measure:

Restoration of 7 hectares and stabilisation of 6 hectares of stony reefs at Læsø Trindel in Denmark cost 4 800 000 euro (Støttrup et al. 2014, 2017). The construction and monitoring of seven stony reefs (more of the artificial reef type, see Table 14 below) at Vinga outside Gothenburg in Sweden cost about 1 200 000 euro (Salonsaari 2009, Wikström et al. 2016).

Feasibility:

The measure is comparably feasible when applied for the restoration of historically lost stony/boulder reefs.

Follow-up of measure:

Increase in commercially important fish species such as cod and saithe (Egriell et al. 2007, Støttrup et al. 2014, 2017, Wikström et al. 2016), increase in shellfish and other benthic life forms (Salonsaari 2009, Pålsson 2009). Restored stone reefs may also attract harbour porpoise (Mikkelsen et al. 2013).

Background material:

Note. This refers to the same measure as included in the set of measures for coastal fish provided separately.

References

Bergström, L., Sundqvist, F., Bergström, U. (2013) Effects of an offshore wind farm on the local demersal fish community. Marine Ecology progress series 485: 199–210. doi: 10.3354/meps10344

Egriell, N., Ulmestrand, M., Andersson, J., Gustavsson, B., Lundälv, T., Erlandsson, C., Jonsson, L., Åhsberg, T., 2007. Hummerrevsprojektet, slutrapport 2007. Konstgjorda rev i Göteborgs skärgård (år 2002–2007). Länsstyrelsen i Västra Götalands län. Rapport 2007:40, 128. (In Swedish).

HELCOM 2018. Status of coastal fish communities in the Baltic Sea during 2011-2016 – the third thematic assessment. Baltic Sea Environment Proceedings N° 161

Kraufvelin, P., Bryhn, A., Olsson, J., 2020. Erfarenheter av ekologisk restaurering i kust och hav. Havs- och Vattenmyndighetens Rapport (in preparation). (In Swedish).

Kristensen, L.D., Stenberg, C, Støttrup, J.G., Poulsen, L.K., Christensen, H.T., Dolmer, P., Landes A., Røjbek, M., Thorsen, S.W., Holmer, M., Deurs, M.V., Grønkjær, P., 2015. Establishment of blue mussel beds to enhance fish habitats. Appl Ecol Environ Res 13:783-798.

Mikkelsen, L., Mouritsen, K.N., Dahl, K., Teilmann, J., Tougaard, J., 2013. Re-established stony reef attracts harbour porpoises *Phocoena phocoena*. Mar Ecol Prog Ser 481:239-248.

Pålsson, C. (ed.), 2009. Inventering av behovet och möjligheterna till restaurering av övergödda havsvikar och kustnära sjöar (Södra Östersjöns vattendistrikt) – redovisning av regeringsuppdrag. Länsstyrelsen i Kalmar län, Kalmar. (In Swedish).

Salonsaari, J., 2009. Övergödda havsvikar och kustnära sjöar inom Norra Östersjöns vattendistrikt – redovisning av regeringsuppdrag, Rapport nr 2009:5. Länsstyrelsen i Västmanlands län, Västerås. (In Swedish).

Stenberg, C., Støttrup, J.G., van Deurs, M., Berg, C.W., Dinesen, G.E., Mosegaard, H., Grome, T.M., Leonhard, S.B., 2015. Long-term effects of an offshore wind farm in the North Sea on fish communities. Mar Ecol Prog Ser 528:257-265.

Støttrup, J.G., Stenberg, C., Dahl, K., Kristensen, L.D., Richardson, K., 2014. Restoration of a temperate reef: effects on the fish community. Open J Ecol 4:1045-1059.

Støttrup, J.G., Dahl, K., Niemann, S., Stenberg, C., Reker, J., Stamphoj, E.M., Goke, C., Svendsen, J.C., 2017. Restoration of a boulder reef in temperate waters: Strategy, methodology and lessons learnt. Ecol Eng 102:468-482.

Wikström, A., Sundqvist, F., Ulmestrand, M., Wennhage, H., Bergström, U., 2016. Ett fiskefritt område för skydd av hummer och rovfisk i Göteborgs skärgård. S. 159-180 i: Bergström m.fl. 2016. Ekologiska effekter av fiskefria områden i Sveriges kust- och havsområden. Aqua reports 2016:20, Institutionen för akvatiska resurser, Sveriges lantbruksuniversitet, Öregrund. (In Swedish).

Title

6. Restoration of soft bottoms free of vegetation

Submitted by:

SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION

Description of measure

"Restoration" of unvegetated soft bottoms can be done through covering the seafloor with new bottom material e.g. after installing cables/pipes or by collection and removal of e.g. drifting macroalgae to re-establish bottoms free from vegetation. The measures may also include natural resedimentation of previously dredged waterways when these are no longer in use.

Activity:

Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation)
Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
Extraction of minerals (rock, metal ores, gravel, sand, shell)
Transmission of electricity and communications (cables)
Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational)
Transport – shipping (incl. anchoring, mooring)
Tourism and leisure activities (boating, beach use, water sports, etc.)

Pressure:

Disturbance of species: Visual, presence, boating, recreational activities, above-water noise
Disturbance of species: Other (e.g. barriers, collission)
Extraction of target fish and shellfish species and incidental fish catches
Physical disturbance to seabed (temporary or reversible and recovers within 12 y)
Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)
Changes to hydrological conditions
Input of organic matter — diffuse sources and point sources

State:

The total damaged area of vegetation-free soft bottoms may be considerable in the Baltic Sea, although there are few restoration efforts going on. Probably natural recovery is the most efficient way to deal with problems, especially on deeper bottoms.
Seabed habitats

Extent of impact:

The positive impacts of these restoration measures are very local and within coastal waters.

Effectiveness of measure

The recovery process depends on which species are present in the area and their respective life cycles, mobility and capability of dispersal (Lewis et al. 2002). Positive responses: re-establishment of previous habitats and bottom substrates for bottom fauna as well as reproductory areas for fish. Negative responses: risks for changed or unnatural sediment composition (as it is very difficult to reconstruct the right proportions of sand, mud and gravel making up the seafloor), risks of removing important species while removing macroalgae.

Cost, cost-effectiveness of measure:

Cooper et al. (2013) calculated restoration costs for a dredged site of 83.9 hectare in the Thames estuary, Great Britain and reached a value of 944 058 euro which meant 11 252 euro per hectare. This amount included cost for restoration (dredging, capping, bed levelling), licensing, carbon footprint and survey costs (one baseline survey and two post-restoration surveys).

Feasibility: -
Follow-up of measure: -
Background material: -
References Cooper, K., Burdon, D., Atkins, J.P., Weiss, L., Somerfield, P., Elliott, M., Turner, K., Ware, S., Vivian, C., 2013. Can the benefits of physical seabed restoration justify the costs? An assessment of a disused aggregate extraction site off the Thames Estuary, UK. Mar Pollut Bull 75:33-45. Lewis, L.J., Davenport, J., Kelly, T.C., 2002. A study of the impact of a pipeline construction on estuarine benthic invertebrate communities. Estuar Coast Shelf Sci 55:213-221.

Title **7. Restoration of coastal wetlands**
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure Recreating wetlands through e.g. impoundments enables periods with flooding keeping the water longer in the system. These wetlands can serve as nutrient traps, improve birdlife, improve habitats for amphibians, and promote the recruitment of pike and perch, but also other fish species. Coastal wetlands are often popular recreational sites for nature enthusiasts. Restoration and revitalization of coastal wetlands as spawning and recruitment habitats for fish are key priorities in areas where wetlands have previously been drained and destroyed, in order to bring back the degraded habitat to a state where it can support biodiversity and also the productivity of fish populations.
Activity: This refers to past activities leading to loss of functions such as natural spawning habitats, nutrient trapping, etc. Land claim Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation) Coastal defence and flood protection (seawalls, flood protection) Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material) Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational) Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational) Aquaculture – marine, including infrastructure Agriculture Forestry
Pressure: *Loss of, or change to, natural biological communities due to cultivation of animal or plant species* *Disturbance of species: Visual, presence, boating, recreational activities, above-water noise* *Disturbance of species: Other (e.g. barriers, collission)* *Extraction of target fish and shellfish species and incidental fish catches* *Physical disturbance to seabed (temporary or reversible and recovers within 12 y)* *Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)* *Changes to hydrological conditions* *Input of nitrogen* *Input of phosphorous* *Input of organic matter — diffuse sources and point sources*
State: Spawning and recruitment habitats in coastal tributaries for coastal fish have undergone substantial deterioration in many regions of the Baltic Sea (Engstedt et al. 2010, Nilsson et al. 2014, Kraufvelin et al. 2018). Seabed habitats
Extent of impact: The measure is relevant for freshwater-spawning coastal fish species in the Baltic Sea and it aims to re-create natural fish spawning habitats in coastal tributaries and wetlands where the availability of natural spawning areas is limited due to human-induced habitat loss. The positive impacts are mainly local, within coastal areas, but with a potential for positive basinwide effects.

Effectiveness of measure

Wetlands can be recreated through e.g. impoundments enabling periods with flooding keeping the water longer in the system. These wetlands can promote the recruitment of pike and perch, but also other fish species such as cyprinids.

Experiences on the effectiveness of restoring wetlands and tributaries to support spawning habitats of coastal fish are available for the Baltic Sea coast of Sweden. Restoration of wetlands as reproduction areas for foremost pike have in many cases shown to result in a strong increase in the production of juvenile pike as a result of optimal spawning conditions, predation refuge and food production (Nilsson et al. 2014, Larsson et al. 2015, Hansen et al. 2019).

Effects on adult pike populations are not yet well established, but some studies are ongoing (Hansen et al. 2019, see also Fredriksson et al. 2013).

Positive responses include maintenance of a high biological production and diversity as well as function as nutrient and sediment traps (buffering zones), promoted fish reproduction ("pike factories", perch), benefits for bird and amphibian life, recreation, etc. Increased number of predatory fish can contribute to decreased eutrophication through an increased predation on smaller fish and other prey species, both in the wetland and in the sea outside. This can in turn increase the amount of grazing zooplankton, crustaceans and gastropods controlling phytoplankton and periphyton and filamentous algae (Östman et al. 2016). Negative responses include potentially disturbed terrestrial ecosystems, alteration of freshwater or marine habitats, potential harmful effects of certain bird species.

Cost, cost-effectiveness of measure:

For Sweden, 281 hectare wetland/coastal lakes were restored between 2010 and 2018 and 2 610 hectares were made accessible for pike by 83 measures/projects by the Swedish Anglers Association (Hansen et al. 2019). The costs for one hectare restored wetland are estimated to 10 000 - 20 000 EUR (including planning and restoration, but excluding monitoring costs afterwards). Globally, de Groot et al. (2013) present a range of 15 000 – 600 000 EUR per restored hectare for coastal wetlands.

Feasibility:

The measures are fairly feasible to carry out and positive effects can probably be maintained with comparably low costs and efforts.

Follow-up of measure:

Measures are rarely followed-up and therefore the knowledge-base needs to be improved by including costs for post-project monitoring and follow-up in future projects.

Background material:

Note. This refers to the same measure as included in the set of measures for coastal fish provided separately

Based on review presented by:

HELCOM 2018. Status of coastal fish communities in the Baltic Sea during 2011-2016 – the third thematic assessment. Baltic Sea Environment Proceedings N° 161 and additional more recent studies.

Measures have been taken in e.g. Björnöfjärden (Stockholm archipelago), Kalmar Sound (southeastern Sweden), Gyldensteen strand (Denmark), pike factories at numerous places along the Swedish Baltic Sea coast (Swedish Anglers Association), etc.

References

de Groot, R.S., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1:50-61.

Engstedt, O., Stenroth, P., Larsson, P., Ljunggren, L., Elfman, M., 2010. Assessment of natal origin of pike (*Esox lucius*) in the Baltic Sea using Sr:Ca in otoliths. Environ Biol Fish 89: 547-555.

Fredriksson, R., Bergström, U., Olsson, J., 2013 *Riktlinjer för uppföljning av fiskevårdsåtgärder i kustmynnande våtmarker med fokus på gädda*. (Guidance for the follow-up of measures to restore freshwater tributaries with a focus on pike). Aqua Reports 2013:7. Department of Aquatic Resources, Swedish University of Agricultural Sciences, Öregrund, Sweden. 52 pp. (in Swedish with English summary).

Hansen, J., Anderson, H.C., Bergström, U., Borger, T., Brelin, D., Byström, P., Eklöf, J., Kraufvelin, P., Kumblad, L., Ljunggren, L., Nordahl, O., Tibblin, P., 2019. *Våtmarker som fiskevårdsåtgärd vid kusten. Utvärdering av restaurerade våtmarkers effekt på fiskreproduktion och kustekosystemet* (Wetlands as a measure to support coastal fish. Evaluation of the effect of restored wetlands on fish production and coastal ecosystems) Report to the Swedish government on development on national environmental objectives. (In Swedish with English summary)

HELCOM 2018. Status of coastal fish communities in the Baltic Sea during 2011-2016 – the third thematic assessment. Baltic Sea Environment Proceedings N° 161

Kraufvelin, P., Pekcan-Hekim, Z., Bergström, U., Florin, A.-B., Lehikoinen, A., Mattila, J., Arula, T., Briekmane, L., Brown, E.J., Celmer, Z., Dainys, J., Jokinen, H., Kääriä, P., Kallasvuo, M., Lappalainen, A., Lozys, L., Möller, P., Orio, A., Rohtla, M., Saks, L., Snickars, M., Støttrup, J., Sundblad, G., Taal, I., Ustups, D., Verliin, A., Vetemaa, M., Winkler, H., Wozniczka, A., Olsson, J., 2018. Essential coastal habitats for fish in the Baltic Sea. Estuar Coastal Shelf Sci 204:14-30.

Larsson P., Tibblin, P., Koch-Schmidt, P., Engstedt, O., Nilsson, J., Nordahl, O., Forsman, A., 2015. Ecology, evolution, and management strategies of northern pike populations in the Baltic Sea. Ambio 44: 451-461.

Nilsson, J., Engstedt, O., Larsson, P., 2014. Wetlands for northern pike (*Esox lucius* L.) recruitment in the Baltic Sea. Hydrobiologia 721:145-154.

Östman, Ö., Eklöf, J., Eriksson, B.K., Olsson, J., Moksnes, P.-O., Bergström, U., 2016. Top-down control as important as nutrient enrichment for eutrophication effects in North Atlantic coastal ecosystems. J Appl Ecol 53:1138-1147.

Title

8. Strengthening piscivorous fish to rehabilitate coastal ecosystem functioning

Submitted by:

SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION

Description of measure

Protection of shallow coastal environments, applying fishing and boating regulations, restocking, stock enhancements, controlling seals and cormorants, etc. in order to restore populations of predatory fish.

Activity:

This refers to past activities leading to loss of functions such as natural spawning habitats.
Land claim
Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation)
Coastal defence and flood protection (seawalls, flood protection)
Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational)
Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational)
Aquaculture – marine, including infrastructure
Agriculture
Forestry

Pressure:

Loss of, or change to, natural biological communities due to cultivation of animal or plant species
Disturbance of species: Visual, presence, boating, recreational activities, above-water noise
Disturbance of species: Other (e.g. barriers, collission)
Extraction of target fish and shellfish species and incidental fish catches
Physical disturbance to seabed (temporary or reversible and recovers within 12 y)
Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)
Changes to hydrological conditions
Input of nitrogen
Input of phosphorous
Input of organic matter — diffuse sources and point sources
Input of anthropogenic sound (impulsive, continuous)
Input of other forms of energy (including electromagnetic fields, light and heat)

State:

The measures are undertaken to counteract decreased abundance and size of predatory fish which are present at a Baltic Sea wide scale.
Fish

Extent of impact:

The positive impacts are mainly local, within coastal areas, but with a potential for positive basin-wide effects.

Effectiveness of measure

The goals are strengthened populations of predatory fish and of large individuals, which may also relieve eutrophication symptoms and serve to strengthen habitats through re-establisment of trophic control (see e.g. Östman et al. 2016 and references therein). Several measures can be considered out of which not all have been rigorously tested. For example, fisheries no-take areas can lead to strengthened populations of predatory fish (Egriell et al. 2007, Wikström et al. 2016, Bergström et al. 2019).

Cost, cost-effectiveness of measure:
Costs for protection measures by creating no-take areas are very low. Principally they can be established more or less for free unless bought land and water areas are included or some compensation fees need to be paid to former users.
Feasibility:
Highly feasible in combination with fisheries management
Follow-up of measure:
-
Background material:
-

References

Bergström, L., Karlsson, M., Bergström, U., Pihl, L., Kraufvelin, P., 2019. Relative impacts of fishing and eutrophication on coastal fish assessed by comparing a no-take area with an environmental gradient. Ambio 48:565-579.

Egriell, N., Ulmestrand, M., Andersson, J., Gustavsson, B., Lundälv, T., Erlandsson, C., Jonsson, L., Åhsberg, T., 2007. Hummerrevsprojektet, slutrapport 2007. Konstgjorda rev i Göteborgs skärgård (år 2002–2007). Länsstyrelsen i Västra Götalands län. Rapport 2007:40, 128. (In Swedish).

Wikström, A., Sundqvist, F., Ulmestrand, M., Wennhage, H., Bergström, U., 2016. Ett fiskefritt område för skydd av hummer och rovfisk i Göteborgs skärgård. S. 159-180 i: Bergström m.fl. 2016. Ekologiska effekter av fiskefria områden i Sveriges kust- och havsområden. Aqua reports 2016:20, Institutionen för akvatiska resurser, Sveriges lantbruksuniversitet, Öregrund. (In Swedish).

Östman, Ö., Eklöf, J., Eriksson, B.K., Olsson, J., Moksnes, P.-O., Bergström, U., 2016. Top-down control as important as nutrient enrichment for eutrophication effects in North Atlantic coastal ecosystems. J Appl Ecol 53:1138-1147.

Title **9. Reducing nutrient loading through farming and harvesting blue mussels**
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure The measure comprises enabling natural recruitment of blue mussels onto artificial farming substrates such as ropes (longlines) or nets hanging vertically in the water mass. Natural mussel growth and eventual harvest of mussels lead to nutrient removal (Kraufvelin & Díaz 2015).
Activity: Not applicable
Pressure: *Input of nitrogen* *Input of phosphorous*
State: Eutrophication of coastal water bodies calls for measures targeting internal nutrient loading and excessive nutrients available in the water column. Nutrients
Extent of impact: The positive effect of the measure is mostly local (Kraufvelin & Díaz 2015), although many farms could have cumulative positive effects (Kotta et al. 2020). Negative impact can occur especially below the mussel farms (see e.g. Stadmark and Conley 2011, Hedberg et al. 2018) and due to this, the relevancy of blue mussel farming activities to remove nutrients is being debated.
Effectiveness of measure Farming and harvesting of blue mussels may lead to removal of nutrients and clearer waters. Negative environmental impacts are restricted in the case of small mussel farms and farms that are located in areas with a efficient water exchange rate (see Kraufvelin & Díaz 2015 for references), although Hedberg et al. (2018) raise concern about negative impacts in connection with big and dense farms (see below). Farming and harvesting of marine organisms is one of few methods available that are capable of direct removal of nutrients that already are present in the marine ecosystem (see also tables 9–11). Positive responses summarised: nutrient removal at harvest (one of few methods available to remove nutrients already present in the sea), clearer waters and blue mussels constitute a marine resource. Negative responses summarised: local accumulation of nutrients, organic load and possibly oxygen deficiency beneath the farm, unwanted plankton blooms, possible conflicts with boat navigation, use of water areas at the expense of other potential activities.
Cost, cost-effectiveness of measure: Information is available on the costs for removing 1 kg of nitrogen and 1 kg of phosphorus through farming and harvesting blue mussels (e.g. Lindahl 2012, Carlsson et al. 2009, Kotta et al. 2020). The latest information by Kotta et al. (2020) reports a cost of 38 – 278 euro per kg N and 924 – 3 854 euro per kg P.
Feasibility: Mussel-farming is presented as a feasible measure for reducing internal nutrient loads by Kotta et al. (2020), although the measure has also faced considerable criticism (Stadmark & Conley 2011, Hedberg et al. 2018).
Follow-up of measure: See e.g. Kraufvelin & Díaz (2015) and Kotta et al. (2020)

Background material:

Farming data available from e.g.: Kumlinge, Åland Islands, Finland (inner Baltic); Sankt Anna, Southeastern Sweden (central Baltic); Kiel Bay, Germany (outer Baltic); Limfjorden, Denmark; Settlement and growth data available from numerous areas (see Kotta et al. 2020).

References

Carlsson M.S., Holmer M., Petersen J.K., 2009. Seasonal and spatial variation of benthic impacts of mussel long-line farming in a eutrophicated Danish fjord, Limfjorden. J Shellfish Res 28:791-801.

Hedberg, N., Kautsky, N., Kumblad, L., Wikström, S.A., 2018. Nutrient removal capacity and potential ecological consequences of blue mussel farms for nutrient abatement in the Baltic Sea. Stockholms universitet, 28 s. https://balticeye.org/globalassets/fokusomraden/overgodning/musselfarming/nutrient-removal-capacity-and-potential-ecological-consequences-of-blue-mussel-farms-for-nutrient-abatement-in-the-baltic-sea.pdf

Kotta J, Futter M, Kaasik A, Liversage K, Rätsep M, Barboza FR, Bergström L, Bergström P, Bobsien I, Díaz E, Herkül K, Jonsson P, Korpinen S, Kraufvelin P, Krost P, Lindahl O, Lindegarth M, Moltke Lyngsgaard M, Mühl M, Nyström Sandman A, Orav-Kotta H, Orlova M, Skov H, Rissanen J, Šiaulys A, Vidakovic A, Virtanen E (2020) Cleaning up seas using blue growth initiatives: Mussel farming for eutrophication control in the Baltic Sea. Sci Total Environ 709:136144

Kraufvelin, P., Díaz, E.R., 2015. Sediment macrofauna communities at a small mussel farm in the northern Baltic proper. Bor Environ Res 20:378-390.

Lindahl, O., 2012. Mussel farming as an environmental measure in the Baltic. Final Report BalticSea2020, 18 pp.

Stadmark, J., Conley, D.J., 2011. Mussel farming as a nutrient reduction measure in the Baltic Sea: Consideration of nutrient biogeochemical cycles. Mar Pollut Bull 62:1385-1388.

Title **10. Rehabilitation of hypoxic areas by oxygen pumping**
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure Combating hypoxia through oxygen pumping has been suggested as a measure to improve the conditions of the Baltic proper and in hypoxic coastal waters (see e.g. Stigebrandt & Gustafsson 2007).
Activity: Not applicable
Pressure: *Input of nitrogen* *Input of phosphorous*
State: Eutrophication of coastal water bodies calls for measures targeting internal nutrient loading and excessive nutrients available in the water column. Nutrients
Extent of impact: Possible positive impact may mainly be expected at the local scale and within coastal waters.
Effectiveness of measure The oxygen pumping method has only been tested at small scales, inner-bay-level, in Sweden and in Finland. In Byfjorden, western Sweden and in Lännerstasundet, in the inner Stockholm archipelago, there were positive short-term effects leading to decreased phosphorus levels, but in Sandöfjärden in Raseborg in Finland, there were even negative results (http://mmm.multiedition.fi/itameri/uutiskirje/2011/1-2011/sv/3.php, Lehtoranta et al. 2012, Pitkänen et al. 2012, Bendtsen et al. 2013, Stigebrandt et al. 2015, Ollikainen et al. 2016). Oxygen pumping to reoxygenize bottom waters and sediments on accumulation bottoms through artificial mixing of the water column demands hypoxia in the bottom water in order to work. The idea is that the oxygenisation will prevent leakage of particle bound phosphorus to the water mass. In addition, habitats for bottom living organisms will be improved (www.havochvatten.se/download/18.b62dc9d13823fbe78c80003223/1348912824427/evaluation-box-and-proppen-projects-english.pdf). These kind of methods have, however, been criticized in the literature (e.g. Conley et al. 2009, Håkanson & Bryhn 2010, Reed et al. 2011) as they come with unknown, but potentially large risks. For the oxygen pumping in Sandöfjärden, the bottom water stayed oxygenized until the end of summer, but the pumping capacity was not sufficient to keep the entire area of 4.75 km^2 oxygenized during the entire experimental period; with oxygenized water, the P-level is low, but when oxygen drops, the P-level increases to former levels. In Lännerstasundet, which had a smaller anoxic area of 0.26 km^2, a higher pumping capacity was used and the bottom water was oxygenised within a few weeks and the P-level was significantly lower than in a reference area. Similar results have been seen from corresponding experiments in lakes (Hupfer & Lewandowski 2008). Positive long-term effects on phosphorus leakage do not occur (http://mmm.multiedition.fi/itameri/uutiskirje/2011/1-2011/sv/3.php, Pitkänen et al. 2012) and in Sandöfjärden, there was even a nitrogen release and negative end results (Ollikainen et al. 2016). This restoration measure is spurious in lakes, and possibly in Baltic Sea coastal areas too, due to eutrophication leading both to oxygen deficiency and leakage of phosphorus, seemingly independently (Hupfer & Lewandowski 2008). As there always will be sediment depths with anoxic conditions, oxygenization will only lead to leakage of phosphorus a few cm deeper in the sediment.

Cost, cost-effectiveness of measure:
For Lännerstasundet, the calculated reduction costs of nitrogen equivalents were slightly below 5 euro/kg, while the costs for reducing phosphorus equivalents were between 13–17 euro/kg (Ollikainen et al. 2016)
Feasibility:
The measure is probably not feasible other than at a very local scale under strict control and possible side effects have not been studied. Suggestions to oxygenise whole sea basins have been highly controversial.
Follow-up of measure:
No information
Background material:
Geographical areas where the measure has been tested in the small-scale: Byfjorden, Uddevalla, western Sweden; Lännerstasundet, inner Stockholm archipelago; Sandöfjärden, Raseborg, southern Finland

References

Bendtsen, J., Gustafsson, K.E., Lehtoranta, J., Saarijärvi, E., Rasmus, K., Pitkänen, H., 2013: Modeling and tracer release experiment on forced buoyant plume convection from coastal oxygenation. Bor Environ Res 18: 37-52.

Conley, D.J., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B.G., Hansson, L.A, Rabalais, N, Voss, M., Zillén, L., 2009. Tackling hypoxia in the Baltic Sea: is engineering a solution? Environ Sci Technol 43:3407-3411.

Hupfer, M., Lewandowski, J., 2008. Oxygen controls the phosphorus release from lake sediments – a long-lasting paradigm in limnology. Int Rev Hydrobiol 93:415-432.

Håkanson, L., Bryhn, A.C., 2010. Controlling eutrophication in the Baltic Sea and the Kattegat. I: Ansari, A.A. (red.) Eutrophication: Causes, Consequences and Control. Springer, Berlin, s. 17-67.

Lehtoranta, J., Lännergren, C., Bendtsen, J., Pitkänen, H., Myrberg, K., Kuosa, H., 2012. Effects of oxygenation on the status of the pilot sites. In: Rantajärvi, E. (Ed.), Final Report on the Result of the PROPPEN Project Controlling Benthic Release of Phosphorus in Different Baltic Sea Scales (02-0301-08) to the Swedish Environmental Protection Agency, Formas and VINNOVA, pp 44-72.

Ollikainen, M., Zandersen, M., Bendtsen, J., Lehtoranta, J., Saarijärvi, E., Pitkänen, H., 2016. Any payoff to ecological engineering? Cost-benefit analysis of pumping oxygen-rich water to control benthic release of phosphorus in the Baltic Sea. Water Resour Econ 16:28-38.

Pitkänen, H., Bendtsen, J., Hansen, J.L., Lehtoranta, J., Lännergren, C., Ollikainen, M., Priha, M., Reinikainen, M., Saarijärvi, E., Zandersen, M., 2012. Controlling benthic release of phosphorus in different Baltic Sea scales: Final Report on the result of the PROPPEN Project (802-0301-08), Finnish Environmental Institute, Helsinki.

Reed, D.C., Slomp, C.P., Gustafsson, B.G., 2011. Sedimentary phosphorus dynamics and the evolution of bottom-water hypoxia: A coupled benthic-pelagic model of a coastal system. Limnol Oceanogr 56:1075-1092.

Stigebrandt, A., Gustafsson, B.G., 2007. Improvement of Baltic proper water quality using large-scale ecological engineering. Ambio 36:280-286.

Stigebrandt, A., Liljebladh, B., De Brabandere, L., Forth, M., Granmo, Å., Hall, P., Hammar, J., Hansson, D., Kononets, M., Magnusson, M., Norén, F., Rahm, L., Treusch, A.H., Viktorsson, L., 2015. An experiment with forced oxygenation of the deepwater of the anoxic By Fjord, western Sweden. Ambio 44:42-54.

www.havochvatten.se/download/18.b62dc9d13823fbe78c80003223/1348912824427/evaluation-box-and-proppen-projects-english.pdf

http://mmm.multiedition.fi/itameri/uutiskirje/2011/1-2011/sv/3.php

Title **11. Reducing internal phosphorus loads by metal bounding**
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure Eutrophication combated through phosphorus inactivation by addition of aluminium or iron has been tested at small scales, inner-bay-level, in Sweden (Malmaeus & Karlsson 2013, Huser 2014, Rydin 2014, Rydin et al. 2017, Rydin & Kumblad 2019, Kumblad & Rydin 2019, www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6522-5.pdf?pid=3831).
Activity: Not applicable
Pressure: *Input of phosphorous*
State: Eutrophication of coastal water bodies calls for measures targeting internal nutrient loading and excessive nutrients available in the water column. Nutrients
Extent of impact: Mainly local scale and within coastal waters.
Effectiveness of measure Metal treatment of active sediments (accumulation bottoms) prevents leakage of phosphorus by binding P in particle form instead of leaking out into the water as phosphate iones (Huser 2014, Rydin 2014, Rydin et al. 2017). This method has been tested in Björnöfjärden with aluminium (Malmaeus & Karlsson 2013, Rydin et al. 2017) and in Östhammarsfjärden with iron (Rydin 2014) in eastern Sweden. Rydin et al. (2017) evaluated the tests using aluminium in Björnöfjärden and they demonstrated lowered phosphorus levels in the water as well as an increased water clarity. These kind of methods have, however, been criticized in the literature (e.g. Conley et al. 2009, Håkanson & Bryhn 2010, Reed et al. 2011).
Cost, cost-effectiveness of measure: Rydin (2014) calculated an aluminium cost of 10 euro per kg phosphorus bound to aluminium in the sediment, without application costs, by this method. The total costs for aluminium treatment of Björnöfjärden is calculated to 900 000 euro. In total, it is expected that 4 ton phosphorus can be bound to added aluminium. This corresponds to the entire phosphorus surplus (the "old sins") in Björnöfjärden. When 4 ton of phosphorus is bound, the cost for the measure becomes 225 euro/kg P (Kumblad & Rydin 2019). Håkanson & Bryhn (2010) commented in their criticism that it would be more cost-effective to remove phosphorus in land-based water treatment plants. For phosphorus, Hasselström (2007) presents a cost range of 42–108 euro/kg P.
Feasibility: The measure is probably feasible only at the small and highly controlled scale and not for the basin-scale.
Follow-up of measure: No information
Background material: Geographical areas where the measure has been tested in the small-scale: Björnöfjärden, Stockholm archipelago, eastern Sweden; Granfjärden, Östhammar, eastern Sweden

References

Conley, D.J., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B.G., Hansson, L.A, Rabalais, N, Voss, M., Zillén, L., 2009. Tackling hypoxia in the Baltic Sea: is engineering a solution? Environ Sci Technol 43:3407-3411.

Hasselström, L., 2007. Fördjupade ekonomiska kalkyler kring vattenskyddsåtgärder i skärgårdsområden: Slutrapport. BEVIS (Ett gemensamt beslutstödssystem för effektiva vattenskyddsåtgärder i skärgårdarna Åboland-Åland-Stockholm), fas II. (In Swedish).

Huser, B., 2014. Phosphorus binding by aluminium in sediment: a tool for restoring water quality in the Baltic Sea and other brackish surface waters. IVM Report 2014:5. Sveriges lantbruksuniversitet.

Håkanson, L., Bryhn, A.C., 2010. Controlling eutrophication in the Baltic Sea and the Kattegat. I: Ansari, A.A. (red.) Eutrophication: Causes, Consequences and Control. Springer, Berlin, s. 17-67.

Kumblad, L., Rydin, E., 2019. Levande kusts Vitbok 1.0. Report, BalticSea 2020, 2019-06-18, 124 pp. (In Swedish).

Malmaeus, M., Karlsson, M., 2013. Modellering av gödande ämnen i Björnöfjärdssystemet. IVL rapport B2135. IVL Svenska Miljöinstitutet. (In Swedish).

Reed, D.C., Slomp, C.P., Gustafsson, B.G., 2011. Sedimentary phosphorus dynamics and the evolution of bottom-water hypoxia: A coupled benthic-pelagic model of a coastal system. Limnol Oceanogr 56:1075-1092.

Rydin, E., 2014. Inactivated phosphorus by added aluminium in Baltic Sea sediment. Estuar Coast Shelf Sci 151:181-185.

Rydin, E., Kumblad, L., Wulff, F., Larsson, P., 2017. Remediation of a eutrophic bay in the Baltic Sea. Environ Sci Technol 51:4559-4566.

Rydin, E., Kumblad, L., 2019. Capturing past eutrophication in coastal sediments – Towards water-quality goals. Estuar Coast Shelf Sci 221:184-188.

www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6522-5.pdf?pid=3831

Title

12. **Biomanipulation to remove cyprinids and sticklebacks and rehabilitate coastal ecosystem functioning**

Submitted by:

SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION

Description of measure

Biomanipulation through fisheries targeting mesopredators as cyprinids or sticklebacks aims at re-establishing or affecting trophic structures in ecosystems where these have been altered. The alterations may for example be due to overfishing of large predatory fish, eutrophication or beneficial conditions for mesopredators and lead to a dominance of mesopredators (i.e. small predators in the food web) such as cyprinids and stickleback in the Baltic Sea and wrasses, shore crabs and black goby in Kattegat. The measure can also be undertaken to reduce the amount of nutrients. Biomanipulation of planktivorous fish has been tested as a restoration method in lakes (Hansson et al. 1998, Lammens 2001, Mehner et al. 2004), but biomanipulation is a relatively untested measure in marine systems (but see Jokinen & Reinikainen 2011, Sandström 2011, https://johnnurmisensaatio.fi/en/projects/local-fishing-project/). On a general level, enhancing trophic regulation in coastal fish populations has been suggested as a potential measure for essential seagrass and seaweed areas of the Baltic Sea (Östman et al. 2016).

Activity:

Not applicable

Pressure:

Extraction of target fish and shellfish species and incidental fish catches
Changes to hydrological conditions
Input of nitrogen
Input of phosphorous

State:

Changed trophic structures call for measures to reduce the amount of mesopredators in the ecosystem. Eutrophication of coastal water bodies calls for measures targeting internal nutrient loading and excessive nutrients available in the water column.
Fish
Pelagic habitats
Seabed habitats

Extent of impact:

Mainly local and within coastal waters, but possibly some impacts could be achieved at the sub-basin level.

Effectiveness of measure

Biomanipulation measures could be undertaken to counteract increased eutrophication symptoms and problems with trophic cascade effects (Östman et al. 2016). Biomanipulation by removing sticklebacks (http://balticsea2020.org/alla-projekt/rovfisken/12-rovfisken-pagaende-projekt/464-trala-efter-storspigg-i-bottenviken), for instance, could provide positive effects both through the trophic regulation of filamentous algae and decreased stickleback predation on the egg and larvae of predatory fish, although this has not been tested (Byström et al. 2015, Bergström et al. 2015). Biomanipulation targeting cyprinids is another alternative and this has been tested in Finland, however, without much success with regard to a decrease in total biomass of bream nor as improved water quality (Jokinen & Reinikainen 2011).

As biomanipulation of ecosystems is very complicated with high risk of of failures, the effects and possible successes are hard to perceive. Therefore, methods for biomanipulation, if they are considered relevant, should first be tested at a very small local scales. A positive side-effect of targeted biomanipulation would be that nitrogen and phosphorus also are removed from the ecosystem together with the caught fish (Hjerne & Hansson 2002). Biomanipulation through targeted fisheries is one of the few methods available that are capable of direct removal of nutrients already present in the marine ecosystem.

Cost, cost-effectiveness of measure:

There is a general lack of details with regard to biomanipulation costs for Baltic Sea fish, but Sandström (2011) reported a cost of 160 euro per kg P in their biomanipulation study of cyprinid fishing in Östhammar, eastern Sweden. For the cyprinid fishing in the Archipelago Sea in Finland, it is estimated that 8 tonnes of phosphorus can be recycled from the sea on a yearly basis (https://johnnurmisensaatio.fi/en/projects/local-fishing-project/). This cyprinid fishing is also self-sustaining at the moment, i.e. the phosphorus reduction takes place for free as it results in a food product that is consumed by humans. All that was needed to get this going was some initial efforts to achieve a useful product and then find a market for it.

Feasibility:

The measure is probably feasible only at small and highly controlled scales.

Follow-up of measure:

-

Background material:

Geographical areas where the measure has been tested in the small-scale: Pickalaviken, Gulf of Finland and the Archipelago Sea (southern Finland) and Östhammarsfjärden (Eastern Sweden) for testing reduction fishery of cyprinids; Åland (Finland), Gulf of Bothnia and Östergötland (Sweden) for testing biomanipulation targeting sticklebacks.

References

Bergström, 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. Estuar Coast Shelf Sci 163:134-142.

Bernes, C., Carpenter, S.R., Gårdmark, A., Larsson, P., Persson, L., Skov, C., Speed, J.D.M., Van Donk, E. (2015). What is the influence of a reduction of planktivorous and benthivorous fish on water quality in temperate eutrophic lakes? A systematic review. Environ Evidence 4:7.

Byström, P., Bergström, U., Hjälten, A., Ståhl, S., Jonsson, D., Olsson, J., 2015. Declining coastal piscivore populations in the Baltic Sea: Where and when do sticklebacks matter? Ambio 44:462-471.

Hansson, L.A., Annadotter, H., Bergman, E., Hamrin, S.F., Jeppesen, E., Kairesalo, T., Luokkanen, E., Nilsson, P.Å., Søndergaard, M., Strand, J., 1998. Biomanipulation as an application of food-chain theory: constraints, synthesis, and recommendations for temperate lakes. Ecosystems 1:558-574.

Hjerne, O., Hansson, S., 2002. The role of fish and fisheries in Baltic Sea nutrient dynamics. Limnol Oceanogr 47:1023-1032.

Jokinen, H., Reinikainen, M., 2011. Potential ecological effects of cyprinid reduction fishery in Pikkala Bay. Project Report, Tvärminne Zoological Station, University of Helsinki, Helsinki, Finland. 41 pp.

Lammens, E.H.R.R., 2001. Consequences of biomanipulation for fish and fisheries. FAO, Rome (Italy). Fishery Resources Div.

Mehner, T., Arlinghaus, R., Berg, S., Dörner, H., Jacobsen, L., Kasprzak, P., Koschel, R., Schulze, T., Skov, C., Wolter, C., Wysujack, K., 2004. How to link biomanipulation and sustainable fisheries management: a step-by-step guideline for lakes of the European temperate zone. Fisheries Manage Ecol 11:261-275.

Sandström, O., 2011. Reduktionsfiske som metod för att minska övergödningen i Östhammarsfjärdarna. Upplandsstiftelsen, Rapport 2011/2. (In Swedish). http://www.upplandsstiftelsen.se/UserFiles/Archive/5417/Rapporter/2011_2_Reduktionsfiske.pdf

Östman, Ö., Eklöf, J., Eriksson, B.K., Olsson, J., Moksnes, P.-O., Bergström, U., 2016. Top-down control as important as nutrient enrichment for eutrophication effects in North Atlantic coastal ecosystems. J Appl Ecol 53:1138-1147.

http://balticsea2020.org/alla-projekt/rovfisken/12-rovfisken-pagaende-projekt/464-trala-efter-storspigg-i-bottenviken

https://johnnurmisensaatio.fi/en/projects/local-fishing-project/

Title
13. Rehabilitation of anoxic, nutrient rich or polluted sediments by removal or coverage
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure Removal of sediment through various methods of careful dredging and/or coverage of damaged soft bottoms with a clean substrate or active carbon can lower the environmental effects from toxic compounds in polluted sediments, e.g. in harbours, marinas or in industrial recipients (Akcil et al. 2015, Rostmark et al. 2015, Eriksson et al. 2016). Similar methods could possibly be used for removal of anoxic or nutrient rich sediments for example in shallow bays in order to combat macroalgal mats (Hulth & Sundbäck 2009).
Activity: Fish and shellfish processing Aquaculture – marine, including infrastructure Transport – shipping infrastructure (harbours, ports, ship-building) Industrial uses (oil, gas, industrial plants) Waste waters (urban, industrial, and industrial animal farms) Solid waste (land-based disposal of dredged material and, e.g. land-fill) Tourism and leisure infrastructure (piers, marinas) Tourism and leisure activities (boating, beach use, water sports, etc.)
Pressure: *Changes to hydrological conditions* *Input of nitrogen* *Input of phosphorous* *Input of organic matter — diffuse sources and point sources* *Input of other substances (e.g. synthetic substances, non-synthetic substances, radionuclides) — diffuse sources, point sources, atmospheric deposition, acute events* *Input of litter (solid waste matter, including micro-sized litter)*
State: Dead or disturbed sediments due to hypoxia, nutrient enrichment, pollution or litter Seabed habitats Nutrients Hazardous substances Litter
Extent of impact: The positive impacts of these restoration measures are very local and within coastal waters. Removal of some highly toxic substances may, however, be a measure having positive impact even at a Baltic Sea wide scale.

Effectiveness of measure

Recolonisation of plants (in the photic zone) and animals (in the photic and aphotic zone) are typical positive responses. If the surface sediment is removed or altered, however, a biogeochemically active layer with associated functions disappear with possible consequences for the recovery (Hulth & Sundbäck 2009). Experiments have shown that lower levels of bottom living microalgae restrict the recolonisation of macrofauna (Stocks & Grassle 2001).

Full recovery after measures such as dredging is probably restricted both by a slow or seasonal recruitment and by the availability of food (see Norkko et al. 2006 for references). The spatial scale of the disturbance seems to be the most crucial factor for the speed, succession and completeness of the recolonising macrofauna community (Lewis et al. 2002, Bolam et al. 2006, Norkko et al. 2006). The recovery of flora and fauna can possibly be boosted by leaving undisturbed refugia in the treated area that can serve as local banks for a recolonisation (Hulth & Sundbäck 2009).

Cost, cost-effectiveness of measure:

Wasserman et al. (2013) estimated costs around 22 euro per dregded m^3 of polluted sediment and 14 euro per dumped m^3 (Rio de Janeiro, Brazil).

Feasibility:

-

Follow-up of measure:

-

Background material:

-

References

Akcil, A., Erust, C., Ozdemiroglu, S., Fonti, V., Beolchini, F., 2015. A review of approaches and techniques used in aquatic contaminated sediments: metal removal and stabilization by chemical and biotechnological processes. J Clean Prod 86:24-36.

Bolam, S.G., Schratzberger, M., Whomersley, P., 2006. Macro- and meiofaunal recolonisation of dredged material used for habitat enhancement: Temporal patterns in community development. Mar Pollut Bull 52:1746-1755.

Eriksson, J., Foster, A., Lindberg, M., 2016. Applying Freeze Technology for Characterisation of Liquids, Sludge and Sediment (No. NEA-PREDEC--2016).

Hulth, S., Sundbäck, K., 2009. Konsekvensanalys av ett borttagande av ytsediment i grunda vikar. Länsstyrelsen i Västra Götalands län. (In Swedish).

Lewis, L.J., Davenport, J., Kelly, T.C., 2002. A study of the impact of a pipeline construction on estuarine benthic invertebrate communities. Estuar Coast Shelf Sci 55:213-221.

Norkko, A, Rosenberg, R., Thrush, S.F., Whitlatch, R.B., 2006. Scale- and intensity-dependent disturbance determines the magnitude of opportunistic response. J Exp Mar Biol Ecol 330:195-207.

Rostmark, S.C., Colombo, M., Knutsson, S., Öberg, G., 2015. Removal and re-use of tar-contaminated sediments by freeze-dredging at a coking plant Lulea, Sweden. Water environment research: a research publication of the Water Environment Federation.

Stocks, K.I., Grassle, J.F., 2001. Effects of microalgae and food limitation on the recolonization of benthic macrofauna into in situ saltmarsh-pond mesocosms. Mar Ecol Prog Ser 221: 93-104.

Title

14. Restoration of hard bottoms by establishment of artificial reefs

Submitted by:

SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION

Description of measure

Establishing artificial reefs/substrates to allow for colonisation of hard bottom macroalgal and macrofaunal assemblages and fish.

Activity:

Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)

Extraction of minerals (rock, metal ores, gravel, sand, shell)

Pressure:

Physical disturbance to seabed (temporary or reversible and recovers within 12 y)

Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)

Changes to hydrological conditions

State:

The measure should only be considered for areas with historical loss of the substrate that the reef is mimicking.

Seabed habitats

Extent of impact:

Artificial reefs may have positive impact, but mainly locally, within coastal areas.

Effectiveness of measure

Artificial reefs attract e.g. fish and shellfish and they are of interest both for commercial and recreational fisheries and for recreation (Seaman 2007, Fabi et al. 2011), although they can also affect the benthic environments negatively (Bulleri & Chapman 2010, Dafforn et al. 2015, Ruuskanen et al. 2015). The reefs may be placed out intentionally or un-intentionally as ship wrecks in connection with accidents (Ruuskanen et al. 2015, Balazy et al. 2019). Positive responses summarised: more habitat/substrates for marine organisms especially fish and shellfish, increased biodiversity, preserved ecosystem services. Negative responses summarised: altered bottom structure, impact on water circulation, effects on soft bottom organisms, the new habitat may claim space from other marine habitats. Introduced hard substrates in areas of predominating soft bottoms can also serve as stepping stones for non-indigenous invasive species. Promoting "attraction by individuals" ahead of "production" can lead to overharvesting of certain species. Negative impact on existing values should be weighed against the expected ecological improvements beforehand when planning to establish artificial reefs.

Cost, cost-effectiveness of measure:

Costs are highly variable, ranging from almost nothing (zero costs) to more than 100 000 euro. Costs are mostly depending on the type of structures and measures, technique, whether monitoring is included, etc.

Feasibility:

The measure is feasible but the use of artificial reefs may be disputed ethically and environmentally. The measure is only to be considered for areas with historical loss of the substrate that the reef is mimicking. For feasibility scores for this measure, see the ranking in the introduction as well as Appendix 1 at the end of this document.

Follow-up of measure:

The effects of established artificial reefs should always be monitored and evaluated

Background material:

Artificial reefs have been for instance deployed in Kiel and in Nienhagen (northern Germany), in the Odra river estuary, in Puck Bay and in the Pomeranian Bay (Poland), in the Vistula Lagoon (Russia), in the Gulf of Riga (Estonia); in the Gulf of Finland (Russia and Finland) (Fabi et al. 2011).

References

Balazy, P., Copeland, U., Sokołowski, A., 2019. Shipwrecks and underwater objects of the southern Baltic–Hard substrata islands in the brackish, soft bottom marine environment. Estuar Coast Shelf Sci 225:106240.

Bulleri, F., Chapman, M.G., 2010. The introduction of coastal infrastructure as a driver of change in marine environments. J Appl Ecol 47:26-35.

Dafforn, K.A., Glasby, T.M., Airoldi, L., Rivero, N.K., Mayer-Pinto, M., Johnston, E.L., 2015. Marine urbanization: an ecological framework for designing multifunctional artificial structures. Front Ecol Environ 13:82-90.

Fabi, G., Spagnolo, A., Bellan-Santini, D., Charbonnel, E., Cicek, B.A., Goutayer Garcia, J.J., Jensen, A.C., Kallianiotis, A., dos Santos, M.N., 2011. Overview on artificial reefs in Europe. Brazil J Oceanogr 59:155-166.

Ruuskanen, A.T., Kraufvelin, P., Alvik, R., Díaz, E.R., Honkonen, J., Kanerva, J., Karell, K., Kekäläinen, P., Lappalainen, J., Mikkola, R., Mustasaari, T., Nappu, N., Nieminen, A., Roininen, J., Svahnbäck, K., 2015. Benthic conditions around a historic shipwreck: Vrouw Maria (1771) in the northern Baltic proper. Cont Shelf Res 98:1-12.

Seaman, W., 2007. Artificial habitats and the restoration of degraded marine ecosystems and fisheries. Hydrobiologia 580:143-155.

Title

15. **Protection of habitats**

Submitted by:

SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION

Description of measure

The measure aims to protect natural habitats, shores and also spawning and recruitment habitats for coastal fish from further deterioration due to human activities. It is applicable in the designation and management of MPAs, in shore protection as well as in spatial planning.

Activity:

This refers to past activities leading to loss of functions such as natural habitats.
Land claim
Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation)
Coastal defence and flood protection (seawalls, flood protection)
Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material)
Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational)
Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational)
Aquaculture – marine, including infrastructure
Transport – shipping (incl. anchoring, mooring)
Transport – shipping infrastructure (harbours, ports, ship-building)
Urban uses (land use)
Tourism and leisure infrastructure (piers, marinas)
Tourism and leisure activities (boating, beach use, water sports, etc.)

Pressure:

Loss of, or change to, natural biological communities due to cultivation of animal or plant species
Disturbance of species: Visual, presence, boating, recreational activities, above-water noise
Disturbance of species: Other (e.g. barriers, collission)
Extraction of target fish and shellfish species and incidental fish catches
Physical disturbance to seabed (temporary or reversible and recovers within 12 y)
Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)
Changes to hydrological conditions
Input of organic matter — diffuse sources and point sources
Input of anthropogenic sound (impulsive, continuous)
Input of other forms of energy (including electromagnetic fields, light and heat)

State:

Coastal degradation is continuously increasing in coastal areas today, as the effect of physical modifications of seabed, tourism and boating activities, etc. lead to cumulative loss of habitat. Thus, the measure is relevant in all parts of the Baltic Sea coastline.
Seabed habitats

Extent of impact:

The positive impacts are mainly local, within coastal areas, but with a potential for positive basin-wide effects.

Effectiveness of measure

Safeguarding important habitats for maintenance of biodiversity and provision of ecosystem services, for example the recruitment and production of fish (Sundblad et al. 2014, Kraufvelin et al. 2018), can be considerably more effective compared to restoration of deteriorated habitats, in terms of costs and since there is no time lag before the effect of the implementation can be seen. In comparison, restoration is likely to require more resources in terms of cost and time and a has a lower level of certainty in that all original functions and ecosystem services will be recovered.

There is generally a lack of follow-up studies on the effect of habitat protection in the Baltic Sea. However, substantial indirect evidence is provided from studies showing how habitat deterioration reduces fish productivity (Kraufvelin et al. 2018). For example, Sundblad et al. (2014) showed that habitat limitation for early life stages of perch and pikeperch may restrict the abundance of later adult stage fish. There is evidence of long-term negative effects on fish reproduction habitats from physical development, boating and infrastructure related to boating (Sandström et al., 2005, Sundblad and Bergström 2014, Hansen et al. 2018, Sagerman et al. 2020), and studies have shown negative impacts on the habitat and the production of juvenile fish from recreational boating traffic (Sandström et al. 2005). The studies are from Swedish waters but the observed relationships can be assumed to also apply to other countries in the Baltic Sea.

Cost, cost-effectiveness of measure:

Costs for protection measures by creating marine reserves are very low. Principally they can be established more or less for free unless bought land and water areas are included or some compensation fees need to be paid to former users.

Feasibility:

High

Follow-up of measure:

-

Background material:

[*Free text: Clarify choice of background material for the synopses, e.g. does it represent a comprehensive overview of results with regard to the measure or a sub-selection*]

References

Hansen J.P., Sundblad, G., Bergström, U., Austin, Å.N., Donadi, S., Eriksson, B.K., Eklöf, J.S., 2018. Recreational boating degrades vegetation important for fish recruitment. Ambio 48:539-551.

Kraufvelin, P., Pekcan-Hekim, Z., Bergström, U., Florin, A.-B., Lehikoinen, A., Mattila, J., Arula, T., Briekmane, L., Brown, E.J., Celmer, Z., Dainys, J., Jokinen, H., Kääriä, P., Kallasvuo, M., Lappalainen, A., Lozys, L., Möller, P., Orio, A., Rohtla, M., Saks, L., Snickars, M., Støttrup, J., Sundblad, G., Taal, I., Ustups, D., Verliin, A., Vetemaa, M., Winkler, H., Wozniczka, A., Olsson, J., 2018. Essential coastal habitats for fish in the Baltic Sea. Estuar Coastal Shelf Sci 204:14-30.

Sagerman, J., Hansen, J., Wikström, S.A., 2020. Effects of boat traffic and mooring infrastructure on aquatic vegetation: A systematic review and meta-analysis. Ambio 49:517-530.

Sandström, A., Eriksson, B.K., Karås, P., Isæus, M., Schreiber, H., 2005. Boating and navigation activities influence the recruitment of fish in a Baltic Sea archipelago area. Ambio 34: 125-130.

Sundblad, G., Bergström, U., 2014. Shoreline development and degradation of coastal fish reproduction habitats. Ambio 43: 1020-1028.

Sundblad, G., Bergström, U., Sandström, A., Eklöv, P., 2014. Nursery habitat availability limits adult stock sizes of predatory coastal fish. ICES J Mar Sci 71:672-680.

Title **16. Follow-up and knowledge sharing**
Submitted by: SLU Aqua, Swedish University of Agricultural Sciences, Sweden; HELCOM ACTION
Description of measure The measure "Follow-up and knowledge sharing" aims to enhance the evidence-base on efficiency of measures over time by mutual sharing of existing and ongoing experiences among countries. To support an adaptive management, it might also be beneficial to apply measures as test with the dual aim of improving environmental status and learning. The measure "Follow-up and knowledge sharing" is further expected to support engagement and acceptance to measures among the general public and stakeholders concerning the needs of the measures and their objectives, if supported by campaigns dedicated for specific groups.
Activity: Not applicable
Pressure: *Not applicable*
State: Even though a wide range of measures has already been implemented for coastal habitats in the Baltic Sea, there is generally a lack of scientific evaluations and evidence about the effects of many of the measures. This lack of knowledge significantly limits the work with restoring and supporting coastal habitats, through impacts on the capacity of the society to carry out measures. Seabed habitats Nutrients
Extent of impact: Even though a wide range of measures has already been implemented for habitats in the Baltic Sea, there is generally a lack of scientific evaluations and evidence on the effects of many of the measures. This lack of knowledge significantly limits the work with restoring and supporting coastal habitats through impacts on the capacity of society to carry out measures.
Effectiveness of measure Scientific evidence to follow-up on the effectiveness of measures for coastal habitats is only available for a few measures and for some areas. An effective way to support an increased evidence base would be to encourage adaptive learning and the mutual sharing of experiences among countries. To gain stronger support for these measures and for those not yet suggested in this report, it is of outmost importance that past, on-going and future measures for coastal habitats are scientifically evaluated, something that unfortunately is undertaken only rarely. Designed in a proper manner and applied for a specific coastal area, many measures to improve coastal habitats are likely to have positive effects on other parts of the food web.
Cost, cost-effectiveness of measure: -
Feasibility: -
Follow-up of measure: -
Background material: -
References -