A

METSÄHALLITUS

METSÄHALLITUKSEN LUONNONSUOJELUJULKAISUJA. SARJA A 256
NATURE PROTECTION PUBLICATIONS OF METSÄHALLITUS. SERIES A 256

A Review of Marine Nature Restoration Work and Methods Used in Finland

Anna Arnkil, Anette Bäck, Fiia Haavisto, Essi Keskinen, Sanna Kuningas, Ari Laine, Aija Nieminen, Irma Puttonen, Henna Raitanen and Sonja Salovius-Laurén

Anna Arnkil, Anette Bäck, Fiia Haavisto, Essi Keskinen,
Ari Laine, Aija Nieminen
Metsähallitus, Parks & Wildlife Finland
firstname.lastname@metsa.fi

Sanna Kuningas
Natural Resources Institute Finland
firstname.lastname@luke.fi

Irma Puttonen, Henna Raitanen, Sonja Salovius-Laurén
Åbo Akademi University
firstname.lastname@abo.fi

Translation: Lingsoft Language Services

Cover photo: Hägnäsfladan. Photo: Jaakko Haapamäki/Metsähallitus

The project has received funding from the LIFE Programme of the European Union. The material reflects the views of the authors, and the European Commission or the CINEA are not responsible for any use that may be made from the information it contains.

ISSN-L 1235-6549
ISSN (online) 1799-537X
ISBN 978-952-377-127-7 (pdf)

Anna Arnkil, Anette Bäck, Fiia Haavisto, Essi Keskinen, Sanna Kuningas, Ari Laine, Aija Nieminen, Irma Puttonen, Henna Raitanen and Sonja Salovius-Laurén

A Review of Marine Nature Restoration Work and Methods Used in Finland

Documentation Page

Published by	Metsähallitus	Publication date	3.7.2024
Sekretessgrad	Offentlig	Diarienummer	MH 3424/2024

Author(s) Anna Arnkil, Anette Bäck, Fiia Haavisto, Essi Keskinen, Sanna Kuningas, Ari Laine, Aija Nieminen, Irma Puttonen, Henna Raitanen and Sonja Salovius-Laurén

Title A review of marine nature restoration work and methods used in Finland

Abstract

The ecological status of the Baltic Sea has deteriorated because of long-standing human activities. The need to protect and restore the Baltic Sea, its habitats, and its species has recently been identified. This is to conserve the valuable ecosystems and functions of the Baltic Sea, which are also of high value to humans. Several preconditions are required to achieve favourable biodiversity status and ecosystem services while fulfilling national and international commitments. These include managing, expanding, and developing the network of protected marine areas and taking active measures to restore, rehabilitate, and improve the status of both the habitats and the species they maintain.

This report contains information on various restoration methods aimed at improving the status of habitats and species in Finnish coastal waters. The report was compiled as part of the LIFE-IP Biodiversea project (2021–2029) to point the way for drawing up a national restoration plan for Finland's coastal area and, by providing examples, to support the selection of restoration measures. Although this report mainly focuses on measures used in Finland, the authors have also striven to incorporate experiences from the entire Baltic Sea and elsewhere in the world that we consider suitable for Finnish conditions. The report emphasises information aimed at facilitating the planning of future restoration measures, which is why it focuses on the lessons learned, experiences, and challenges relating to the methods, in addition to ideas aimed directly at improving or developing them. The report also sums up the costs incurred from various measures to support planning processes.

In this report, we introduce restoration methods from the perspective of both habitats (those listed in the Habitats Directive) and species. Restoration methods are discussed in the section on the habitat type or species of which the most significant amount of experience has been gathered or for which the method was considered the most suitable. Measures relevant to fisheries are presented in the sections on measures associated with species, such as large predatory fish, which, in particular, are vital for habitats. The report additionally includes methods similar to restoration measures. While these measures do not target habitats or species directly, they may be important for improving water quality, marine areas and processes or creating space for species.

Although a selection of tools and measures for restoring marine environments are currently available, efforts to assess their impact are only taking their first steps. As challenges to restoration work, this report highlights marine eutrophication and the poor status of waters, scarcity and fragmentation of research evidence and monitoring data, gaps in Finnish-language restoration terminology, the short duration of restoration projects, ownership of land and water areas, insufficient resources and expertise, and bottlenecks caused by permit processes.

Keywords marine environment, nature conservation, restoration, rehabilitation, restoration methods, nature management, monitoring

Series name and no.	Nature Protection Publications of Metsähallitus. Series A 256		
ISSN-L	1235-6549	ISSN (online)	1799-537X
ISBN (pdf)	978-952-377-127-7		
No. of pages	139 pp.	Language	English
Publishing co.	Metsähallitus, Parks & Wildlife Finland		

Kuvailulehti

Julkaisija	Metsähallitus	Julkaisuaika	3.7.2024
Luottamuksellisuus	Julkinen	Asianumero	MH 3424/2024

Tekijä(t)	Anna Arnkil, Anette Bäck, Fiia Haavisto, Essi Keskinen, Sanna Kuningas, Ari Laine, Aija Nieminen, Irma Puttonen, Henna Raitanen ja Sonja Salovius-Laurén

Julkaisun nimi	Katsaus meriluonnon kunnostustöihin ja -menetelmiin Suomessa

Tiivistelmä

Itämeren tila on heikentynyt pitkäaikaisen ihmistoiminnan seurauksena. Viime aikoina on tunnistettu tarve suojella ja ennallistaa Itämerta ja sen elinympäristöjä ja lajeja, jotta saadaan suojelluksi Itämeren arvokkaita ekosysteemejä ja toimintoja, jotka ovat samalla arvokkaita myös ihmisille. Biologisen monimuotoisuuden ja ekosysteemipalvelujen suotuisan tilan saavuttaminen sekä kansallisten ja kansainvälisten sitoumusten täyttäminen edellyttävät, että mereisen suojelualueverkoston hoidon, laajentamisen ja kehittämisen rinnalla elinympäristöjä ja niiden ylläpitämää lajistoa ennallistetaan, kunnostetaan ja tilaa parannetaan aktiivisin toimenpitein.

Tähän raporttiin on koottu tietoa erilaisista kunnostusmenetelmistä, joiden tavoitteena on parantaa rannikkovesiemme luontotyyppien ja lajien tilaa. Raportti on koostettu osana LIFE-IP Biodiversea -hanketta (2021–2029) ja sen on tarkoitus viitoittaa kansallisen kunnostussuunnitelman laatimista Suomen rannikkoalueelle ja tarjota esimerkkejä kunnostustoimien valintaan. Raportti on pääasiassa keskittynyt Suomessa toteutettuihin toimenpiteisiin, mutta työssä on pyritty huomioimaan kokemuksia koko Itämereltä ja tarvittaessa muualtakin maailmasta, jos ne on arvioitu soveltuviksi Suomen olosuhteisiin. Raportissa on painotettu tietoa, jolla pyritään helpottamaan tulevaisuuden kunnostustoimien suunnittelua ja siksi painopiste on ollut menetelmistä saaduissa opeissa, kokemuksissa ja haasteissa sekä suorissa parannus- tai kehitysideoissa. Lisäksi eri toimenpiteiden kustannuksia on kerätty yhteen suunnitteluprosessien helpottamiseksi.

Kunnostusmenetelmiä esitellään raportissa sekä elinympäristöjen (luontodirektiivin luontotyyppi) että lajien näkökulmasta. Kunnostusmenetelmät on raportissa esitelty sen luontotyypin tai lajin kohdalla, josta on eniten kokemusta tai jossa menetelmä on katsottu sopivimmaksi. Kalataloudelliset toimenpiteet esitellään lajien kunnostustoimien alla, sillä erityisesti suuret petokalat ovat tärkeitä elinympäristöjen kannalta. Lisäksi raporttiin on sisällytetty muita ennallistamisen kaltaisia menetelmiä. Nämä toimenpiteet eivät kohdistu suoraan luontotyyppeihin tai lajeihin, mutta ne voivat olla tärkeitä esim. veden laadun, merialueiden ja prosessien parantamisen tai lajeille tilan luomisen kannalta.

Nykyisin meriluonnon kunnostamiseen on jo työkaluja ja keinovalikoimaa tarjolla, mutta toimenpiteiden vaikuttavuuden arviointi on vasta alkutekijöissään. Kunnostustöiden haasteiksi raportissa nostetaan esiin meren rehevöityminen ja vesien heikko tila, tutkimus- ja seurantatiedon vähäisyys ja pirstaleisuus, puutteet suomenkielisessä kunnostuskäsitteistössä, kunnostushankkeiden lyhytkestoisuus, maa- ja vesialueiden omistajuus, resurssien ja asiantuntemuksen riittämättömyys sekä lupaprosessien aiheuttamat pullonkaulat.

Avainsanat	meriluonto, luonnonsuojelu, ennallistaminen, kunnostaminen, kunnostusmenetelmät, luonnonhoito, seuranta		
Sarjan nimi ja numero	Metsähallituksen luonnonsuojelujulkaisuja. Sarja A 256		
ISSN-L	1235-6549	ISSN (verkkojulkaisu)	1799-537X
ISBN (pdf)	978-952-377-127-7		
Sivumäärä	139 s.	Kieli	Englanti
Kustantaja	Metsähallitus, Luontopalvelut		

Presentationsblad

Utgivare	Forststyrelsen	Utgivningsdatum	3.7.2024
Sekretessgrad	Offentlig	Diarienummer	MH 3424/2024

Författare Anna Arnkil, Anette Bäck, Fiia Haavisto, Essi Keskinen, Sanna Kuningas, Ari Laine, Aija Nieminen, Irma Puttonen, Henna Raitanen och Sonja Salovius-Laurén

Publikation Granskning av restaurering av marin natur och metoder använda i Finland

Sammandrag

Östersjöns ekologiska status har försämrats som en följd av långvarig mänsklig aktivitet. Behovet av att skydda och återställa Östersjön och dess livsmiljöer och arter, vilka också är av stort värde för människan, har blivit allt viktigare. För att främja biologisk mångfald och ekosystemtjänster och för att uppfylla nationella och internationella åtaganden räcker inte skydd och utvidgning av marina skyddade områden. Det behövs också aktiva åtgärder för att återställa, rehabilitera och förbättra livsmiljöer och stärka de arter som lever där.

Den här rapporten innehåller information om olika restaureringsmetoder och målsättningen är att förbättra statusen hos livsmiljöer och arter i finska kustvatten. Rapporten har sammanställts inom projektet LIFE-IP Biodiversea (2021–2029) och är det första steget i att utforma en nationell restaureringsplan för Finlands kustområde. Rapporten sammanfattar redan utförda restaureringar och stöder valet av nya restaureringsåtgärder. Rapporten fokuserar främst på åtgärder som gjorts i Finland, men författarna har också tagit med erfarenheter från hela Östersjön och andra delar av världen när det har ansetts relevant för finska förhållanden. I rapporten finns information som underlättar planering av framtida restaureringsåtgärder. Erfarenheter och utmaningar relaterade till metoderna, samt förslag på hur de kan förbättras eller utvecklas finns beskrivna i rapporten. I rapporten finns också information om kostnader för olika åtgärder för att stödja arbetet med att planera restaureringar.

I rapporten beskrivs restaureringar av både enskilda arter och livsmiljöer (habitatdirektivets naturtyper). Metoderna listas enligt de livsmiljöer eller arter där det finns mest erfarenhet av dem, eller där de anses vara mest lämpliga för användning. Åtgärder som är relevanta för fisk presenteras i avsnitten om åtgärder som är kopplade till arter, tex stora rovfiskar är mycket viktiga i ekosystemen. Rapporten inkluderar även metoder som liknar restaureringsåtgärder. Dessa metoder berör inte direkt livsmiljöer eller arter men kan vara viktiga för att förbättra vattenkvaliteten, gynna havsområden, stödja viktiga funktioner eller skapa utrymme för arter.

Det finns idag ett urval av verktyg och åtgärder för att återställa marina miljöer, men arbetet med att bedöma effekterna av dessa åtgärder är fortfarande i sin linda. Som utmaningar för restaureringsarbetet lyfter rapporten fram övergödning av havet och dåligt vattenstatus, bristfällig forsknings- och övervakningsdata, restaureringsprojektens tidsbundenhet, ägandet av land- och vattenområden, otillräckliga resurser och expertis samt flaskhalsar orsakade av tillståndsförfaranden.

Nyckelord havsnatur, naturskydd, restaurering, återställande, restaureringsmetoder, naturvård, uppföljning

Seriens namn och nummer	Forststyrelsens naturskyddspublikationer. Serie A 256		
ISSN-L	1235-6549	ISSN (online)	1799-537X
ISBN (pdf)	978-952-377-12-7		
Sidantal	139 s.	Språk	Engelska
Förlag	Forststyrelsen, Naturtjänster		

Contents

1 Introduction ... 9

2 Background ... 11
- 2.1 Principles and objectives – national and international strategies and treaties ... 11
- 2.2 Concept of restoration ... 13
- 2.3 Monitoring of restoration measures ... 15
- 2.4 Purpose and objectives of the report and instructions for the reader ... 16

3 Methods by habitat type ... 19
- 3.1 Sandbanks (1110) and Baltic esker islands, including their underwater parts (1610) ... 19
  - 3.1.1 Common eelgrass transplantation ... 19
  - 3.1.2 Restoration of common eelgrass from seeds ... 32
  - 3.1.3 Transplantation of aquatic plants on sand and gravel bottoms in littoral zone ... 35
  - 3.1.4 Sand capping and eelgrass transplantation ... 37
- 3.2 Estuaries (1130) ... 39
  - 3.2.1 Restoration dredging ... 39
- 3.3 Coastal lagoons (1150) ... 43
  - 3.3.1 Sill restoration ... 43
  - 3.3.2 Culvert replacement/removal of a barrier to migration ... 50
  - 3.3.3 Opening a channel ... 56
  - 3.3.4 Catchment restoration ... 61
- 3.4 Large shallow bays (1160) ... 68
  - 3.4.1 Removal of submerged aquatic vegetation ... 68
  - 3.4.2 Removal of the common reed ... 71
- 3.5 Reefs (1170) and Boreal Baltic islets and small islands (1620) ... 74
  - 3.5.1 Reef restoration ... 74
- 3.6 Boreal Baltic narrow inlets (1650) and deep soft bottoms ... 77
  - 3.6.1 Oxygenation of bottoms ... 77

4 Restoration of habitats for species ... 81
- 4.1 Introduction ... 81
- 4.2 Bladder wrack reproduction tests ... 81
- 4.3 Transplantation of charophytes ... 83
- 4.4 Habitat management ... 88
  - 4.4.1 Manipulation of microhabitat of an endangered species ... 88
  - 4.4.2 Causing a deliberate small scale disturbance ... 90
  - 4.4.3 Grazing of shores (large-scale) ... 91
- 4.5 Coastal fisheries restorations ... 93
  - 4.5.1 Fisheries restorations in coastal lagoons ... 93
  - 4.5.2 Pike wetlands ... 98

4.5.3 Restoration of breeding grounds for the sea-spawning grayling 102

5 Methods similar to restoration 105
5.1 Introduction of artificial reefs and other substrates in the seabed 105
5.2 Biomanipulation 108
5.2.1 Vegetation changes 108
5.2.2 Intensive fishing of three-spined sticklebacks 108
5.3 Artificial sandbanks and islands 109
5.4 Acid sulphate soil risk mitigation 110
5.5 Chemical manipulation 111
5.5.1 Phosphorus sequestration in bottom sediment using thermally treated limestone to reduce internal loading 111
5.6 Restoration of silted seagrass meadows 113
5.7 Nutrient removal 113
5.7.1 Use of nutrient-rich brackish water for irrigation 113
5.7.2 Removal of sediment surface layer to reduce nutrients 115
5.7.3 Blue mussel farming and harvesting to reduce nutrients 116
5.7.4 Removal of dead filamentous algae and aquatic plant biomass from the sea 118
5.8 Control measures of invasive alien species 119
5.8.1 Canadian waterweed 119

6 Conclusions 121
State of play – restoration methods and their adequacy 121
Efficiency and impact of the methods 122
Challenges 122
Tips for stakeholders' interest in restoration 125

Acknowledgements 126

References 127

Appendices 139
Annex 1 Suitability of restoration methods for different habitat types 139

1 Introduction

The ecological status of the Baltic Sea has deteriorated due to long-standing human activity. Eutrophication, overfishing, increased maritime traffic, environmental toxins and invasive alien species, in addition to construction in both marine and coastal areas, have directly or indirectly contributed to the degradation of the marine environment, its habitats and its species. The most significant factor that negatively impacts the status of our coastal waters and the open sea is nutrient loading and the eutrophication driven by it, which affects the Baltic Sea. (Korpinen et al. 2018, Laamanen et al. 2021). However, other factors, including coastal construction and dredging, may be locally more significant and radically change the habitat or its functions or lead to species loss, albeit these impacts are often intensified by other elements. A need to protect and restore the Baltic Sea with its habitats and species has been recently identified to conserve the valuable ecosystems and functions of the Baltic Sea, which are also of high value to humans.

The 15th Conference of the Parties to the United Nations Convention on Biological Diversity, held in Montreal in December 2022, made a global commitment to protect 30% of Earth's lands, oceans, coastal areas and inland waters managed by the Parties to the Convention. In addition, the Parties agreed that by 2030, restoration should be completed or underway on at least 30% of degraded terrestrial and aquatic ecosystems. Many other international and national commitments also oblige Finland to take measures to improve the coastal and marine environment (including the Water Framework Directive, the Marine Strategy Framework Directive, the Birds and Habitats Directives, and the Act and Decrees on the Organisation of River Basin Management and the Marine Strategy). The European Commission's Biodiversity Strategy aims to halt biodiversity loss and put biodiversity development on a path of recovery by 2030. On 22 June 2022, the Commission published a proposal for a restoration regulation, or the so-called Nature Restoration Law. The Nature Restoration Law contributes to achieving the objectives of the EU Biodiversity Strategy. This law will create an obligation to manage habitats, including mires, forests, agricultural environments, fells, beaches, the sea and inland waters.

The preconditions for achieving a favourable status of biodiversity and ecosystem services while fulfilling national and international commitments include managing, expanding and developing the network of protected areas and taking active measures to restore, rehabilitate, and improve the status of habitats and the species they support. These measures aim to promote the natural state and representativeness of the sites. In many cases, ecosystems can also recover naturally without targeted restoration measures. Natural recovery is possible if the human impact has been minor or moderate, and conservation measures can reduce pressures (Connell & Slatyer 1977, cited in Kraufvelin et al. 2021b). Natural recovery should always be prioritised where possible. Active restoration is usually a one-off measure targeted at sites that will produce maximum biodiversity benefits. Nature management refers to reviving or maintaining a biotope or habitat suitable for a protected species. It is often necessary to periodically repeat management measures to enable a habitat's typical features to develop or a species to build up its population.

The restoration and management of the marine environment is a relatively young sector, and experiences gained from it in Finland and abroad have only been published in reports and overviews in recent years. Investments in the restoration and rehabilitation of marine nature have been made globally in densely populated and economically important areas, in particular (Kraufvelin et al. 2021b).

The recovery of coastal ecosystems is usually slow and may take several decades (e.g. Borja et al. 2010, Kraufvelin et al. 2021 a and b). Therefore, it is important to remember that preventing environmental degradation and damage in coastal areas is always the first and foremost measure and more cost-effective than restoring the marine environment at a later date, as the success of recovering the structure and functioning of the marine ecosystem through restoration measures is by no means certain. For example, in an article titled *Rebuilding marine life*, the authors (Duarte et al. 2020) estimated that it takes approximately 20 years for marine ecosystems to recover globally. The recovery times vary case by case, between one and sixty years, depending on the habitat type, species, and region. However, restoration measures may never be adequate to recover what was lost. Additionally, we lack an overall understanding of the relationship between anthropogenic activity and impacts on ecosystems, making it difficult or even impossible to target the measures correctly

This review contains information on the different restoration methods used in Finland that may be expected to be suitable for improving the status of coastal habitats and species in the conditions prevalent there. The review is based on compilation reports dealing with the restoration and rehabilitation of the marine environment published in 2021 and produced by various parties both in Finland (Deinhardt et al. 2021) and Sweden (Kraufvelin et al. 2021a) and as part of the HELCOM ACTION project, coordinated by the Helsinki Commission (Kraufvelin et al. 2021b). The review also presents methods still in the planning or testing phase, on which information has been obtained by interviewing experts and other similar means. It was produced as part of the LIFE-IP Biodiversea project (2021–2029) and is intended to point the way for the preparation of a national restoration plan for Finland's coastal area, provide examples for selecting restoration measures, and consequently serve anyone who is planning and carrying out marine nature restoration work. The report aims to broadly examine experiences of, and methods suitable for, the restoration of Finnish sea areas. Restoration and rehabilitation activities are developing rapidly, however, and the information contained in this review will be complemented throughout the project. By contrast, methods that have not been included in the review at this stage but that will come up during the project will be contained in a restoration manual produced as an outcome of the project.

2 Background

2.1 Principles and objectives – national and international strategies and treaties

Due to inadequate action, biodiversity loss and ecosystem degradation are increasing globally, harming people, economies, and the climate. This fact has been widely documented, not only in the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) but also in the progress report on the UN's Aichi Biodiversity Targets. Consequently, the European Commission published a proposal for a restoration regulation known as the Nature Restoration Law on 22 June 2022. The 15th Conference of the Parties to the Montreal Convention on Biological Diversity committed to stopping biodiversity loss by 2030 and actively restoring natural ecosystems.

The European Commission's Biodiversity Strategy, 'Bringing nature back into our lives' (2020), was adopted in June 2021. In this strategy, the Commission set ambitious targets for conserving and restoring nature throughout the European Community territory. The goal is to halt biodiversity loss and to restore nature values in all degraded habitats over the next decade through joint political decisions and programmes binding on the Member States (Ministry of the Environment 2022). In addition, the following EU-level targets were set for restoration measures tackling habitats that are already degraded: 1) There must be no deterioration in the status of conservation values important to the community, ensuring that at least 30% of species and habitats not currently in favourable status show a strong positive trend. 2) Significant restoration will be carried out, especially in carbon-rich and degraded ecosystems.

The Commission also published a restoration regulation proposal, i.e. the Nature Restoration Law, in June 2022. The Nature Restoration Law contributes to achieving the objectives of the EU Biodiversity Strategy. According to a press release of the Finnish Ministry of the Environment (2022), the aim of the proposed Nature Restoration Law is to improve ecological status across a broad range of different environments, both in protected areas and elsewhere. Restoration is comprised of not only protecting but also enhancing nature's values. For example, a site to be restored can remain in commercial use or a part of an urban environment. The general objective of the Nature Restoration Law is to promote long-term and sustainable biodiversity recovery in land and sea areas. The proposal sets binding objectives and obligations related to improving the ecological status of different habitats. The measures should cover at least 20% of the EU's land and sea areas by 2030 and all ecosystems requiring restoration by 2050.

The Water Framework Directive (2000/60/EC), which outlines the Community's water policy, entered into force in 2000. It aims to protect, improve and restore waters, ensuring that their status does not deteriorate and that all water bodies have at least good status throughout the EU by 2027 (the original target year was 2015). The corresponding Marine Strategy Framework Directive (2008/56/EC) entered into legislation in 2008. Its goals include achieving good ecological status in the Baltic Sea by 2027 (the original target year was 2020). The objective of the Marine

Strategy Framework Directive is to create a common framework for the EU Member States' measures necessary for achieving and maintaining a good status of the marine environment (Puharinen et al. 2021).

Council Directive 92/43/EEC, commonly known as the Habitats Directive, was adopted to protect and conserve biodiversity in the European Union. The Habitats Directive covers almost 200 of the most important habitat types within the European Union (Natura 2000 sites). These are habitats within the EU territory whose natural area is minimal or at risk of being lost. They may also be good examples of the six biogeographical regions of the European Union.

The Habitats Directive defines in detail the habitat types to be protected and the species requiring protection within them. The Member States are expected to take the necessary measures to conserve these habitats and, if necessary, restore their favourable conservation status, including restoration measures. Twenty of these habitats are found in Finland's marine and coastal areas, and eight are considered marine habitats. More detailed information on these habitats can be found in Annex I of the Directive. Rather than setting a specific deadline for achieving a good status of the habitats, the Habitats Directive stresses continuous and active management aiming to maintain and improve the conservation status of the habitats and species within the scope of the Directive.

The proposal for an EU Nature Restoration Law notes that the marine Natura 2000 sites listed in Annex I of the Habitats Directive are broadly defined and include a wide range of ecologically diverse subtypes with different restoration potentials, which is why the Member States should use the EUNIS habitat classification levels found in the European Nature Information System. The report from MERIAVAIN project notes that conservation based exclusively on Natura 2000 sites does not afford sufficient protection because habitats are often so extensive that individual projects cannot usually degrade their status (Metsähallitus 2021). By basing the measures on EUNIS habitats, an effort has been made to improve the targeting of protection and measures. However, information on the habitat types of this classification and their occurrence is minimal. While complete distribution maps of marine Natural 2000 habitats are still unavailable, and a large share of the distribution data is based on models, the information available is sufficient, and the habitats are easier to identify. Thus, using them as a foundation for various analyses is easier at this stage.

The descriptions of marine habitats listed in the Habitats Directive, their conservation statuses and trends, the latest assessments of threatened habitats, the most significant threat factors, and threatened and near-threatened species found in the habitats are presented in a report published in Finnish in Metsähallitus' series of nature conservation publications in 2022 (Haapamäki et al. 2022). The report also lists seabed habitats and habitat combinations classified as threatened in a national assessment of threatened habitats (Kontula & Raunio 2018) and other habitats typical of the Natura 2000 site in question. This report also comprehensively describes the anthropogenic pressures on marine nature reserves and measures by which they can be reduced.

Habitats and habitat groups of the regulation on nature restoration (EUNIS classification)

Marine habitat types and groups of habitat types listed in Annex II, Article 5(1) and 5(2) of the proposal for a regulation on nature restoration that are found in Finland's coastal areas:

- Seagrass beds,
- macroalgal forests,
- shellfish beds and
- soft sediments exceeding 1,000 metres in depth.

Annex III marine species whose habitats are covered by the Nature Restoration Regulation:

- Salmon,
- Sea trout.

Species listed in Annexes II, IV and V to the Habitats Directive found in Finland:

- Mammals: grey seal (Annexes II and V), Baltic seal (Annexes II and V), harbour porpoise (Annexes II and IV) and otter (Annexes II and IV),
- Fish and cyclostomes: Baltic grayling, European bullhead (Annex II (var.)), Baltic salmon (Annexes II (var.) and V), sabre carp (Annexes II and V), vendace (Annex V), European river lamprey (Annexes II (var.) and V), spined loach (Annex II (var.)), anadromous whitefish (Annex V) and asp (Annexes II (var.) and V),
- Beetles: Macroplea pubipennis (Annex II) and
- Vascular plants: Najas tenuissima (Annexes II and IV), Persicaria foliosa (Annexes II and IV), Hippuris tetraphylla (Annexes II and IV) and Alisma wahlenbergii (Annexes II and V).

2.2 Concept of restoration

Although ecosystems needing restoration have usually been degraded by human activities, ecosystem restoration may also be necessary after natural disasters, including tsunamis or hurricanes (Komonen & Halme 2014). The recovery of coastal ecosystems is usually slow and may take several decades (e.g. Borja et al. 2010, Kraufvelin et al. 2021a and 2021b). Therefore, it is important to remember that **preventing** environmental degradation and damage in coastal areas is always the first and foremost measure and more cost-effective than restoring the marine environment later, as the success of recovering the structure and functioning of the marine ecosystem through restoration measures is by no means certain.

Key factors in restoration projects to which attention should be paid during the process are the physical and chemical conditions of water, spatial shapes and runoff conditions of water bodies (hydromorphology), and habitats and the species living within them. In some cases, removing the pressure on a species or habitat is adequate as a restoration measure, allowing the **natural recovery process** of the environment to start (Kraufvelin et al. 2021b). This is known as **passive restoration** (Kraufvelin ym. 2021b). Natural recovery is possible if the impact has been slight or moderate, and protection measures can reduce pressures (Connell & Slatyer 1977, cited in Kraufvelin 2021b). In many cases, passive restoration and natural recovery may be the primary options for restoring important ecosystem functions and services. In contrast, **active restoration** measures take second place and are resorted to if the ecosystem recovery is considered to take place too slowly (Jones et al. 2018, cited in Kraufvelin et al. 2021b). In open marine environments, for example, the natural recovery process may be the only and most important method of marine restoration.

Conversely, the literature reviewed for this report generally notes that the natural recovery of a marine environment that has been degraded due to human activity and that measures based on protected areas are usually insufficient to restore a functioning ecosystem. Thus, various restoration measures suitable for marine nature are necessary. Currently, increasing the surface area of protected marine areas alone will not be sufficient to boost the preservation of ecosystem function, habitats, or species. At the same time, climate change, with its direct and indirect impacts and biodiversity loss caused by anthropogenic activities, undermines the status of the marine environment. Humans have altered ecosystems to such an extent that pristine or semi-natural sites may no longer exist (Komonen & Halme 2014), and even if they could be found, protecting the most suitable areas may not be possible due to circumstances related to land ownership. This is a particularly topical issue from the perspective of protecting marine nature in Finland, where, according to a recent study (Virtanen et al. 2018), three-quarters of the most valuable marine natural values are outside the scope of the current conservation area network. Most diverse, shallow, littoral, and archipelagic areas are privately owned in Finland. Consequently, restoration measures are needed alongside protection, as they can be targeted to areas where protection is not possible for one reason or another.

The term **ecological restoration** involves a conceptual controversy about which measures fall within the scope of restoration, which are 'good' and which are 'bad', and whether restoring nature is generally possible (Komonen & Halme 2014). In 2004, the Society for Ecological Restoration's International Science and Policy Working Group (SER) defined ecological restoration as assisting the recovery of an ecosystem that has been degraded with active measures by humans.

In the Baltic Sea area, concepts related to the restoration of marine nature have been discussed in reports by Kraufvelin et al. 2021a and Petersen et al. 2023, among others. Nature restoration is seen as active measures aimed at restoring a habitat or species in an area where the habitat or species in question has disappeared. In addition to the distribution of species and habitats, the measures aim to restore their density, biological mechanisms and hydrological processes (Petersen et al. 2023). According to Kraufvelin et al. 2021a, restoration refers to using physical, and sometimes chemical or biological, measures to restore an ecosystem's natural physical and biological processes damaged or degraded by disturbances. Sometimes, the term can also be used when triggering or accelerating the system's recovery. Although disturbances are usually due to human activity, including direct impacts from emissions or physical exploitation, ecosystem degradation may also be affected by indirect impacts of human activity, such as climate change or invasive alien species (Kraufvelin et al. 2021a).

One of the challenges associated with the concept of restoration is the lack of information: information about the original natural state of an ecosystem is rarely available, which is why, strictly speaking, few measures meet the definition of restoration (Petersen et al. 2023). Humans have influenced the Baltic Sea ecosystem over such a long period and so strongly that it is also justified to ask if restoring habitats and populations of species to their original natural state is even possible (Kraufvelin et al. 2021a). **Rehabilitation** and restoration are parallel concepts. This broader concept includes measures to restore a damaged environment and achieve a targeted state, which may be similar to a natural state (Kraufvelin et al. 2021a). Rather than necessarily aiming to restore the original natural state, the measure's objective is consequently defined by the party implementing it in each case. **As this review contains descriptions of many different methods, the concept of restoration, which mainly covers the measures presented in Chapters 3 and 4, is used.**

In addition to measures aiming for restoration, various actions may be taken in marine areas for such purposes as strengthening/eradicating populations of certain species (biomanipulation, section 5.3), creating new habitats (artificial reefs, section 5.1.) or removing nutrients from the ecosystem (section 5.9) (Kraufvelin et al. 2021a; Petersen et al. 2024). These measures may not always be motivated by the goal of restoring the ecosystem to its natural state or increasing biodiversity. For further discussion, see Chapter 5.

2.3 Monitoring of restoration measures

When planning restoration measures, it is crucial to obtain a clear picture of what the project is trying to restore or improve (Geist & Hawkin 2016, cited in Kraufvelin 2021a). The objective of restoring a site to its natural state is challenging; defining the natural state is not always possible, as nature is dynamic, and the anthropogenic influence has been so long-lasting that the natural state is no longer known or cannot be achieved. According to Kraufvelin (2021a), rather than restoring ecosystems, we should focus on maintaining their key functions and ensuring the continuous provision of valuable ecosystem services.

Appropriately targeted preliminary surveys and monitoring are needed to assess the results of the measures, making it possible to determine if the desired objectives or changes have been achieved. In this way, the effectiveness of different measures and methods can be evaluated, helping to improve the targeting of measures and ensuring that resources are used efficiently. While many restoration measures have already been completed in the Baltic Sea, scientific evidence on the effectiveness of different methods and measures remains relatively scarce (Kraufvelin et al. 2021b). This lack of information significantly hampers work aiming to promote habitat restoration and management, consequently affecting society's ability to carry out rehabilitation measures.

When planning monitoring, its capability of demonstrating whether or not the desired improvement has been achieved should be ensured. The scope of the monitoring may also be broader, making it possible to observe unexpected impacts on other parts of the ecosystem and the services it provides. It is important to remember that the recovery period of an ecosystem may be extended, which is why a sufficiently long monitoring period must be provided.

2.4 Purpose and objectives of the report and instructions for the reader

This report aims to collect the available information on marine nature restoration measures in a single document and, consequently, build up knowledge of the suitability and feasibility of different restoration methods in different habitats and assist future restoration projects. The term restoration is used broadly to refer to measures completed with the aim of improving the conditions of the marine environment. The purpose of these measures is to assist in recovering a degraded environment, i.e., achieve a near-natural state. Restoration can consequently be seen as assisting or managing the recovery of a degraded, damaged or destroyed ecosystem.

This review was produced as part of the Biodiversea project, whose aim is to carry out restoration measures in thirty habitats, twenty habitats of keystone species, and twenty sites important for fish. It is hoped that through the measures completed in the project, the knowledge of various methods and their feasibility in different regions and conditions can be improved through practical restoration pilots and large-scale monitoring, thereby making it possible to assess their actual impacts. The project will also draw up a national restoration plan. Another aim is to support prioritising restoration sites and ensuring cost-effectiveness based on experiences gathered during the project. While this review mainly focuses on the measures used in Finland, the authors have also striven to incorporate experiences from the entire Baltic Sea and elsewhere in the world, if necessary, where they have been regarded as suitable for Finnish conditions.

To support the needs of the Biodiversea project, we present restoration methods from the perspectives of both habitats (habitat types listed in the Habitats Directive) and species in this review. The restoration methods will also facilitate actions not included in the Biodiversea project, as efforts to improve the marine environment are often made with a particular species or habitat in mind. These measures may also aim to have an impact on both a single species and its habitat. The methods are discussed in this review under the section dealing with the habitat or species from which the most significant amount of experience has been gained or for which we have regarded the method as the most suitable. However, it should be noted that the same method may be suitable for many different habitats or species, not only for those discussed in this review. For an indicative classification of the suitability of restoration methods for different habitats, see Appendix 1. Measures relevant to fisheries are presented under the sections on restoration measures for species in this review, such as large predatory fish, which are particularly important for habitats. To complement the report, we have also included a chapter entitled **Methods similar to restoration (Chapter 5)**. While these measures do not target habitats or species directly, they may be necessary to improve water quality, marine areas and processes or create space for species.

The authors have aimed to provide an overview of the methods by highlighting examples of completed rehabilitation measures. We have emphasised information that may facilitate the future use of the methods, which is why the focus has been on the lessons learned, experiences and challenges relating to the methods, and ideas aimed directly at improving or developing them. The report also sums up the costs incurred from various measures to support planning processes and the use of the methods.

In 2021, several compilation reports were produced on the restoration of marine environments with similar objectives to this work. We have consequently used them as a starting point for our report; however, we supplemented the information on the methods and rearranged the report structure to meet our needs. This review has been supplemented with expert interviews to incorporate the most recent information.

Compilation reports on marine environment restoration

Interreg North SeaCOMBO project report 'Restoration in the Bothnian Bay. A review of objectives, targets, methods and risks in coastal and marine environments' (Deinhardt et al. 2021) contains key information on marine environment restoration measures in the Bothnian Bay, regarding the unique features of the Bothnian Bay, factors threatening the area, and its needs. The report also discusses restoration and rehabilitation measures with examples, their costs, and their suitability for the Bothnian Bay and lists possible restoration sites and measures in the area.

The Swedish report *Erfarenheter av ekologisk restaurering i kust och hav* (Kraufvelin et al. 2021a) divides marine environment restoration measures into three categories: 1) biological and physical restoration, 2) restoration and habitat improvement, and 3) other measures similar to restoration. They include compensatory or restoration measures, mitigation of environmental impacts and administration. The report also describes measures that focus on the functions, processes and services provided by ecosystems rather than necessarily targeting the entire ecosystem directly.

The HELCOM ACTION project's summary report (Kraufvelin et al. 2021b) presents 16 measures that can be used to improve the status of Baltic Sea coastal habitats. The measures are divided into three broader categories: 1) restoring the status of or rehabilitating habitats or habitat-forming species, 2) reducing pressures on species and habitats, especially nutrient loading, and 3) protecting habitats or strengthening functionally important species.

For a list of restoration methods discussed in this review by biotopes and habitats of species and other methods similar to restoration

3 Methods by habitat type

3.1 Sandbanks (1110) and Baltic esker islands, including their underwater parts (1610)
- 3.1.1 Common eelgrass transplantation
- 3.1.2 Restoration of common eelgrass from seeds
- 3.1.3 Transplantation of aquatic plants of sand and gravel bottoms and littoral zone
- 3.1.4 Sand capping and eelgrass transplantation

3.2 Estuaries (1130)
- 3.2.1 Restoration dredging

3.3 Coastal lagoons (1150)
- 3.3.1 Sill restoration
- 3.3.2 Culvert replacement/ removal of a barrier to migration
- 3.3.3 Opening of the channel
- 3.3.4 Catchment restoration

3.4 Large shallow bays (1160)
- 3.4.1 Removal of submerged aquatic vegetation
- 3.4.2 Removal of the common reed

3.5 Reefs (1170) and Boreal Baltic islets and small islands (1620)
- 3.5.1 Reef restoration

3.6 Boreal Baltic narrow inlets (1650) and (other) deep soft bottoms
- 3.6.1 Oxygenation of bottoms

4 Restoration of habitats for species

4.2 Fucaceae breeding tests

4.3 Transplantation of charophytes

4.4 Habitat management
- 4.4.1 (Small-scale) manipulation of microhabitat of an endangered species
- 4.4.2 Causing a deliberate disturbance (small-scale)
- 4.4.3 Grazing of shores (large-scale)

4.5 Coastal fisheries restorations
- 4.5.1. Fisheries restoration in coastal lagoons
- 4.5.2 Pike wetlands
- 4.5.3 Restoration of breeding grounds for the sea-spawning grayling

5 Methods similar to restoration

5.1 Introduction of artificial reefs and other substrates in the seabed

5.2 Biomanipulation
- 5.2.1 Vegetation changes
- 5.2.2 Intensive fishing of three-spined sticklebacks

5.3 Artificial sandbanks and islands

5.4 Acid sulphate soil risk mitigation

5.5 Chemical manipulation
- 5.5.1 Phosphorus sequestration in bottom sediment using thermally treated limestone to reduce internal loading

5.6 Restoration of silted seagrass meadows

5.7 Nutrient removal
- 5.7.1 Use of nutrient-rich brackish water for irrigation
- 5.7.2 Removal of sediment surface layer to reduce nutrients
- 5.7.3 Blue mussel farming and harvesting to reduce nutrients
- 5.7.4 Removal of dead filamentous algae and aquatic plant biomass from the sea

5.8 Control measures of invasive alien species
- 5.8.1 Canadian waterweed

3 Methods by habitat type

3.1 Sandbanks (1110) and Baltic esker islands, including their underwater parts (1610)

Conservation status[1]	Trend[1]	Status in 2018[2]	Other points
Sandbanks Unfavourable, inadequate	Stable	Unknown	

Conservation status[1]	Trend[1]	Status in 2018[2]	Other points
Baltic esker islands, including their underwater parts Unfavourable, inadequate	Stable	Unknown	

[1] Assessment of conservation status and trends given in the habitats report referred to in the Habitats Directive 2019
[2] Kotilainen et al. 2018. Threatened habitat types in Finland 2018: the Baltic Sea.

3.1.1 Common eelgrass transplantation

The common eelgrass (*Zostera marina*) is a multiannual submerged plant and the only seed-producing marine plant in the Baltic Sea that lives fully submerged. Eelgrass forms patchy seagrass meadows on shallow sandy or silty bottoms. It attaches to the seabed and absorbs nutrients through its creeping rhizome.

On the Finnish coast, eelgrass only spreads through the vegetative growth of its rhizome and may differ genetically from other common eelgrass colonies in the Baltic Sea (Olsen et al. 2004). The extent of eelgrass meadows varies from smaller patches in the middle and inner archipelago (Boström et al. 2006) to meadows of several hectares (Boström et al. 2003). Eelgrass meadows can form both single-species colonies and mixed meadows with other vascular plants (Boström & Bonsdorff 2000).

On the Finnish coast, eelgrass meadows are usually found at a depth of one to five metres in slightly open areas. Although the species occurs from Rauma to Sipoo (VELMU map service data in 2023), it occurs predominantly in Finland's southwestern outer and middle archipelago in the Åland Islands, the Archipelago Sea and Uusimaa. The key limiting factor of the common eelgrass is salinity, which must not be lower than 5 ‰ (Boström et al. 2003).

Eelgrass is known globally as a keystone species that provides shelter and food for many other organisms. In northern parts of the Baltic Sea, eelgrass meadows form important three-dimensional habitats and biodiversity hotspots on otherwise barren sandy bottoms, and an abundance of algae, invertebrates and juvenile fish live in the shelter of the colony (Figure 1).

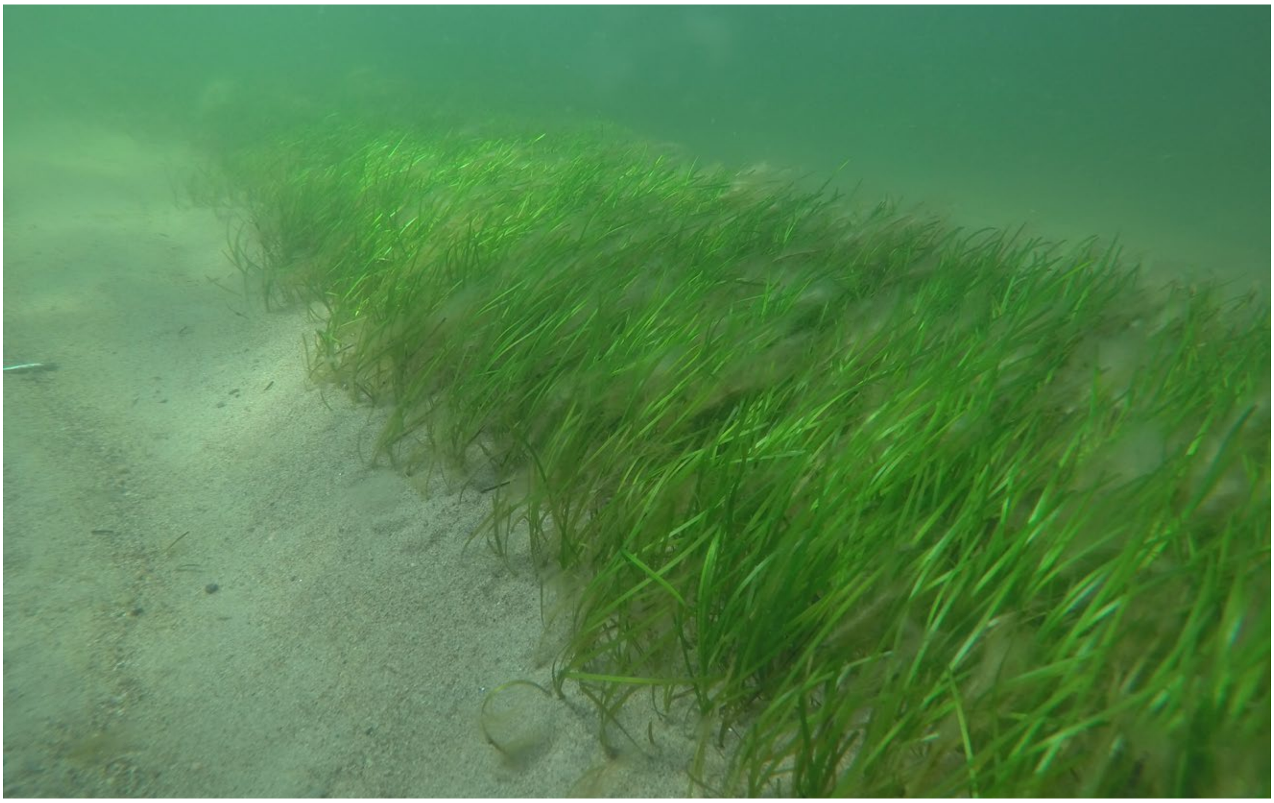


Figure 1. A dense eelgrass meadow south of Hankoniemi. Photo: Aija Nieminen/Metsähallitus.

The main objective of eelgrass transplantation is to restore the species to areas where it has grown in the past. On the western coast of Sweden, for example, approximately 60% of eelgrass meadows have disappeared since the 1980s (Baden et al. 2003). Eutrophication is regarded as one of the reasons for the loss of eelgrass. While the nutrient loads in Swedish coastal waters have decreased and water quality has improved significantly in places, eelgrass has not returned naturally to its historical sites (Nyqvist et al. 2009, cited in Gagnon et al. 2023). This may indicate a regime shift (a dramatic change in environmental conditions); in practice, it means that the bottom sediment has become unstable due to lack of vegetation, increasing sediment resuspension and water turbidity as eelgrass roots no longer bind and stabilise the sediment (Moksnes et al. 2016). A dramatic change in environmental conditions can prevent the spread of the seagrass to its old areas of occurrence, which is why it is justified to help the species to spread by transplanting, and if the current conditions allow the species to return.

There is extensive global experience of common eelgrass transplantation, and the method has been tested and used at least in North America since the 1940s, Europe, Oceania (incl. Australia), Southwest Asia, China, Japan, New Zealand and the Pacific Archipelago (Paling et al. 2009). Additionally, extensive international experience has been accumulated from transplanting other seagrass species (including *Posidonia oceanica*, *Cymodocea nodosa*, *Zostera noltii*) (Paling et al. 2009).

In Europe, common seagrass has mainly been planted in the Netherlands, Estonia, and Nordic countries, especially Denmark and Sweden. In Sweden, large-scale eelgrass transplantation has occurred on the western coast in the Kattegat and Skagerrak areas. The *Handbook for Eelgrass Restoration in Sweden – A Guideline* (Moksnes et al. 2016) is based on the results of this work.

Åbo Akademi University has transplanted this species in the Archipelago Sea in Finland (see section 3.1.3, Transplantation of aquatic plants of sand and gravel bottoms). In contrast, Metsähallitus, the John Nurminen Foundation's Meriniitty project, and WWF Finland have carried out small-scale eelgrass transplantation for restoration purposes in the western parts of the Gulf of Finland.

Restoration method

Before going ahead with eelgrass transplantation, it is vital to determine the necessary permissions required. Permission given by the owner of the water area is needed both for the collection and transplantation of eelgrass shoots. In a protected area, additional permission is required from its steward. This is usually from the local Centre for Economic Development, Transport and the Environment (ELY Centre) in private protected areas and Metsähallitus on state-owned lands in Finland. If the restoration measure occurs at a Natura 2000 site, a notification of the measure affecting the site, or a Natura assessment is required. Metsähallitus recommends that new stakeholders planning eelgrass transplantation should contact either the ELY Centre or Metsähallitus before taking any action. Eelgrass meadows are a protected habitat under the updated Nature Conservation Act (chapter 7, section 64).

One key reason eelgrass restoration is not always successful is that the selected site is unsuitable (Moksnes et al. 2016). Consequently, finding a site with appropriate environmental conditions is one of the most challenging tasks associated with eelgrass transplantation. If possible, finding out why the species disappeared from the area in the first place is essential. Metsähallitus has selected potential planting sites based on a data-driven preliminary study, after which thorough field studies are carried out at the sites before making the final selection.

The data-driven preliminary study is underpinned by environmental data collected in the Inventory Programme for Underwater Marine Diversity (VELMU) and other eelgrass observations. The locations of potential planting sites are filtered geographically and based on appropriate bottom quality and depth. Since picking potential planting sites near existing eelgrass meadows is not necessarily desirable, the appropriate distance between them must be determined. Historical eelgrass observations from the Finnish Biodiversity Information Facility´s *Laji.fi* website was also used in the preliminary study. These observations go back as far as the 19th century. Transplantation aims to bring the species back to sites where it has been found in the past but from where it has since disappeared for one reason or another. When selecting the planting sites, the eelgrass distribution model produced by the Finnish Environment Institute was also used.

This data-driven work helps to put potential sites for eelgrass transplantations on the map. They are then examined by a regional expert based on, among other things, aerial photographs, and depth data. Following the expert assessment, areas are marked for field studies at selected sites. The final site selection is never guided by the data-driven preliminary study alone. An initial field survey of a potential transplantation site is always required to determine its suitability for eelgrass.

The field studies should focus on investigating the conditions at potential planting sites regarding the variables known to affect the success of eelgrass. These include light, sediment quality, and the amount of free-floating and epiphytic algae. Drifting mats of bladder wrack (*Fucus vesiculosus*) may dislodge or suffocate eelgrass colonies, hampering both the natural and assisted recovery of the species in these areas (Moksnes et al. 2016). A Danish study found that drifting mats of unattached algae that cover the seabed may interfere with the growth of young eelgrass individuals. This impact is based on shading and preventing water with higher oxygen content from reaching the bottom (Rasmussen et al. 2012). The attachment of drifting algae has been observed to increase as the diversity of aquatic vegetation grows (Gustafsson & Boström 2009).

Åbo Akademi University also found in its planting tests that not only drifting mats of filamentous algae but also storm winds posed challenges to transplantation (Boström, interview on 4 December 2023), as the attachment of newly planted eelgrass roots to bottom sediments is tenuous during the first weeks, making them vulnerable to strong currents and waves.

Test transplantations

Before going ahead with extensive eelgrass transplantation, planting smaller test squares on the selected sites would be advisable. The Swedish handbook describes the issues that should be considered in test planting, which should occur at least one year before actual transplantation to see if the eelgrass will thrive at the planting site (Moksnes et al. 2016).

Donor population

The donor population refers to the eelgrass meadow, where shoots are collected for transplantation. When selecting the donor population, the damage to it should be minimised, while the potential for survival of the shoots removed from it should be maximised.

In Scandinavia, the estimated surface area of eelgrass meadows is around 1,500 to 2,000 km^2, comprising around 6,000 meadows (Boström et al. 2014). In the Baltic Sea, most sites where eelgrass is found are located on the coasts of Norway, Sweden, Denmark, and Germany. Some 1,187 eelgrass observations have been recorded in Finland (VELMU dataset 2023), and the distribution of the species is limited compared to the other cited Baltic Sea countries. Therefore, suitable donor populations are not found in Finland on the same scale as in Western Sweden. To illustrate the difference in scale between locations, an estimated 4,000 vegetative shoots have been used in Finnish eelgrass transplantations since 2020, whereas in Sweden, at least 40,000 shoots were used for planting one hectare alone.

The general guideline for selecting the donor population is that its environmental conditions should be as similar as possible to those of the planting site regarding openness and depth (Fonseca et al. 1998). This similarity is stressed especially in Finnish sea areas where, due to vegetative propagation, common eelgrass meadows are genetically differentiated and usually particularly well adapted to local conditions. The donor population should not be interfered with repeatedly in the same year, and when removing shoots, creating large gaps in the donor colony should be avoided (Fonseca et al. 1998). According to Moksnes et al. (2016), shoots should not be collected from eelgrass meadows with a small surface area (less than 50 x 50 m), as they may be more sensitive to disturbances.

The recommended planting time is in early summer (Moksnes et al. 2016) when the shoots are relatively short (approximately 20 cm) in Finnish waters. Therefore, fully grown shoots are rarely planted in Finland unless transplantation occurs in late summer. In Finnish conditions, it is also important to note the variation in salinity along the coast from west to east and south to north. Salinity is one of the most important factors influencing the distribution of common eelgrass, and Salo et al. (2014, cited in Niemi 2022) found in their study that eelgrass individuals from northern parts of the Baltic Sea were more likely to survive when exposed to higher salinity than southern individuals when exposed to lower salinity. This study shows that transplanting eelgrass shoots from an area with higher salinity to a site with lower salinity is not advisable.

Metsähallitus has used large and stable meadows for its eelgrass transplantations, removing shoots from different parts of the donor colony. This way, creating gaps in the donor population and other disturbances can be avoided. Nevertheless, experience has shown that the location of the donor population matters. The more open the site of the donor population, the more vulnerable it is to prevailing wind conditions and currents driven by the wind, which is relevant to the composition of the bottom sediment. If the seabed mainly consists of fine-grained sand, strong currents tend to compact it, which affects the ease of dislodging eelgrass shoots from the seabed with their roots intact. Eelgrass roots also bind the bottom sediment efficiently, which helps to compact the sand among the roots in open areas. When selecting the donor population, it is advisable to look at the openness of the site and the prevailing wind direction in advance.

The vegetative shoots to be transplanted are usually manually detached from the donor population by divers. The diver grabs the shoot, runs their fingers along it to the bottom, pushes their fingers inside the sediment, and cuts the shoot, ensuring that 5 to 10 cm of roots are retained (Figure 2). Removing the shoots is slower when wearing dry or wet gloves than doing it with bare hands. Metsähallitus recommends that the collected vegetative shoots be planted on the same day.

Transplantation

Two main techniques have been widely used when planting eelgrass shoots: stolons (a long horizontal stem, as of the currants, that grows along the surface of the soil and propagates by producing roots and shoots at the nodes or tip) are planted with or without a plug of bottom sediment. The roots can additionally be 'anchored' to the bottom sediment using different methods, but they can also be planted without anchoring. The planted areas should be clearly marked. Metsähallitus used perforated bricks kept in place by pushing a steel bar through one of the holes into the sediment. The steel bar was bent, and a string with a small buoy tied to it ensured that excessive uplift pressure was not created on the bar.

In Swedish conditions, the *single shoot method* (SSM) is recommended for eelgrass transplantation without sediment or anchor-

Figure 2. Eelgrass shoots collected for planting. The diver should collect the eelgrass shoots in net bags that can be emptied into a container filled with seawater in the boat. Photo: Aija Nieminen/ Metsähallitus.

ing the shoot to the substrate (Moksnes et al. 2016). This method is considered the most cost-effective due to its speed and efficiency. It appears that this is also the most common method in Finland.

Planting of individual eelgrass stolons

Eelgrass stolons for planting are either taken from a donor population or grown from seed in laboratory conditions. The latter method has been used in countries like the United Kingdom.

Divers usually transplant individual stolons. They are planted manually at a sufficient depth in the sediment (approximately 3 to 4 cm), reducing the risk of the planted shoots becoming detached. When using this method, fewer shoots need to be taken from the donor population than, for example, if several shoots were planted together in a bunch.

Based on results obtained in Sweden and other parts of the world, individually planted shoots survive and grow better than those planted using anchoring methods or with sediment (Eriander et al. 2016). In Swedish conditions, an experienced diver can plant 300 to 400 shoots in an hour (Moksnes et al. 2016), whereas, in Finnish conditions, the sea water may be so cold in early summer that gloves are required, which slows down planting. In Metsähallitus' experience, an experienced diver can plant around 100 to 150 shoots in an hour, depending on conditions.

Figure 3. While the work is in progress, eelgrass shoots can be conveniently kept in a net bag, from which the diver can grab a suitable bunch for planting. Photo: Joonas Hoikkala/Metsähallitus.

Other eelgrass transplantation methods in brief

Eelgrass stolons can also be planted using the 'plug method', in which eelgrass shoots and the sediment plug that comes with them are collected using a tube corer (Fonseca et al. 1998). However, this method has more harmful effects on the donor population, as it creates holes in the sediment. While the method has commonly been regarded as the least harmful for planting shoots, it is very time-consuming, expensive, and best suited for planting at low tide in tidal areas. Based on results obtained in Sweden, eelgrass shoots planted using the plug method did not grow as well as those planted without sediment (Eriander et al. 2016).

Various 'anchoring' methods have often been used in connection with eelgrass transplantation to prevent water movements and similar from removing the planted shoots from the sediment (Davis & Short 1997, Fonseca et al. 1998). The most common anchoring methods for planted shoots are (a) the *staple method* and (b) using a planting frame. In the staple method, several planted shoots and their rootstocks are tied together with biodegradable string, and these bunches are anchored to the sediment with a u-shaped 'staple'. For example, a biodegradable bamboo skewer bent in the middle and pressed on top of the roots is adequate as a 'staple' for anchoring a couple of shoots (Davis & Short 1997).

Since the planting frame method requires no diving, volunteers can use it. It is known as the 'TERFsTM' method (T*ransplanting Eelgrass Remotely with Frame Systems*) and uses biodegradable string to attach the shoots to a metal frame lowered from a boat onto the planting site. The frame is left on top of the sediment on the seabed until the shoots have taken root (Chumpong & Fonseca 2001, Short et al. 2002b, cited in Moksnes et al. 2016). Due to its high costs, this method cannot be used for large-scale transplantation.

Monitoring methods

Metsähallitus has monitored eelgrass transplantation sites annually and, in the initial stages, up to twice a year in early and late summer. This monitoring consisted of counting the eelgrass shoots over the planted area and sending divers to estimate their size. A drone method is also being developed to assess the planting area through aerial photography. Due to poor water visibility, the planting area is marked with white buoys using this method. It could also work without the buoys, for example, in the clear water conditions of the outer archipelago.

Monitoring the benthos (infauna and epifauna) would also be necessary before and after planting, primarily based on the excellent results obtained in Sweden and Denmark. In Sweden, Gagnon et al. (2023) found that various planting techniques, which differed in the planting density and plot size, did not affect the speed at which the benthos colonised the plantations. Invertebrate densities already reached 50% to 80% of the control meadow's density during the first growing season with all techniques. After 15 months, the density and diversity of the benthos were similar to those in the control meadow. The findings of Steinfurth et al. (2022) in Denmark were similar, which led to the conclusion that eelgrass transplantation helps the benthos recover quickly in the area.

The colonisation of transplanted meadows by epifauna has been studied in Finland. Among others, Gustafsson & Boström (2009) found in their field tests that, while the epifaunal colonisation of eelgrass transplanted using different techniques took place quickly, no significant difference was observed between multi-species meadows consisting of common eelgrass, *Potamogeton perfoliatus* and *Stuckenia pectinata* or monocultures, and monoculture meadows appear to play an equally important role as multi-species meadows. Metsähallitus divers have observed the invertebrate epifauna and fish in connection with monitoring but not systematically. For example, observations of the broadnosed pipefish, *Syngnathus typhle*, have been recorded in transplantations in Ekenäs Archipelago National Park (A. Nieminen, personal communication on 24 August 2020).

Metsähallitus has also installed light and temperature loggers at some transplantation sites, as recommended in the Swedish handbook (Figure 4). As temperature spikes in summer are becoming increasingly common, installing temperature loggers at transplantation sites makes sense; if the plantations deteriorate or fail entirely over the summer, the logger can be used to determine if the increased mortality was due to higher-than-average temperatures. High temperatures harm eelgrass meadows as they cause hypoxia near the bottom. A temperature of 25 to 30 °C already increases the eelgrass mortality rate significantly, whereas the optimal water temperature for this species is 10 to 20 °C (Nejrup & Pedersen 2008).

The Swedish handbook describes a comprehensive and scheduled monitoring plan covering five to ten years for eelgrass transplantations (Moksnes et al. 2016). This plan can also be used in Finnish conditions as such or where applicable. In the first years, the monitoring plan focuses on measuring shoot density in the transplanted eelgrass meadow and the size of the transplantation area. In contrast, around the mid-point and towards the end of the plan, efforts are made to measure the recovery of ecosystem functions and services produced by the meadow. The techniques for this may include biodiversity measurements, increased fish production or improved water quality.

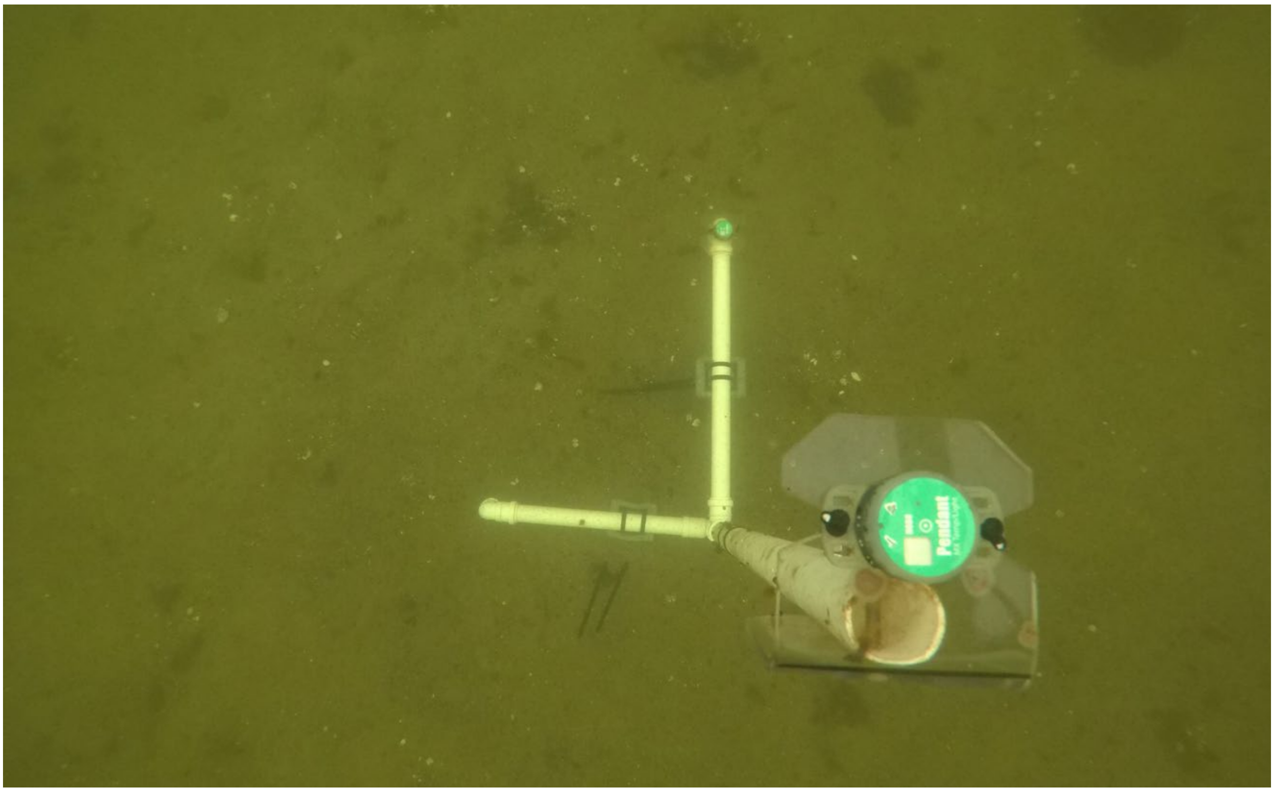


Figure 4. Metsähallitus used Onset HOBO data loggers for eelgrass transplantations to measure light levels and water temperature. The loggers were attached to frames built by volunteer divers from Wärtsilä that were partially embedded in the bottom sediment and stabilised with diving weights. Photo: Joonas Hoikkala/Metsähallitus.

Monitoring of donor populations

No method currently in use in Finland can monitor the harmful effects of shoot removal on the donor population with certainty. This lack of information is hampered by the decentralised collection of shoots from the donor population, possibly by several divers. However, this issue should be given special attention in the future. A database should additionally be compiled on donor populations, in which the number of shoots taken from a donor population and the site where the shoots are transplanted should be recorded.

Experiences of the method

Experiences of the method in Finland

Eelgrass transplantation has only been carried out in Finland for a few years. Åbo Akademi University's first small-scale transplantations in the Archipelago Sea date back to 2009 in an experiment which tested the impact of plant species abundance and species composition on epifaunal colonisation (Gustafsson & Boström 2009). Other vascular plant species were also used in this experiment. Their transplantation is discussed in detail in section 3.1.3 (Transplantation of aquatic plants of sand or gravel bottoms).

Metsähallitus carried out its first transplanting tests in the sea area of Ekenäs Archipelago National Park in 2020, and the monitoring period of this transplantation is the longest on record. These test plantings were successful, which is why Metsähallitus went on to transplant eelgrass at two historical sites of this species near Tvärminne in 2021.

Metsähallitus' planting tests in 2020 took place at two sites (sites 1 and 2), where eelgrass has been found at least since the 1990s (Oulasvirta & Leinikki 1995). The experiment aimed to test transplantation as a method following the instructions given in the Swedish handbook. After preliminary studies, eelgrass was planted at both sites using three techniques at different depths. At site 1, eelgrass was transplanted at depths of 2.2 m, 3.3 m and 3.8 m, and at site 2, at depths of 3.0 m, 3.6 m and 3.9 m.

Preliminary studies at the sites were commissioned to assess their conditions regarding variables known to affect eelgrass success, including drifting and epiphytic algae volumes and the composition of the bottom sediment. Since eelgrass was known to grow at both sites, preliminary studies aimed to obtain background information, and it was assumed that the transplanted eelgrass would thrive at the sites.

The preliminary studies found that the bottom quality at site 1 was more favourable for eelgrass than at site 2 (Leinikki 2020). At site 1, the sediment grain size distribution was as follows: sand 98.10%, clay 0.95%, and silt 0.95%, while at site 2, sand, clay and silt were 42.26%, 31.78%, and 25.97%, respectively. Although many recommendations can be found in the literature regarding bottom quality limit values for transplantation (such as the maximum permitted proportions of clay and silt), eelgrass sometimes grows in unexpected places concerning sediments. Based on results obtained in Sweden, Moksnes et al. (2016) recommend that eelgrass should not be transplanted to areas where the proportions of clay and silt exceed 50%. While Metsähallitus' planting site 2 had 58% clay and silt, the transplantation went ahead, as eelgrass was previously found at that site.

There were large variations in the measurement results for epiphytic algae, and it was difficult to tell which filamentous algae grew along the strings provided as a substrate and which had been drifting around before attaching to them (Leinikki 2020). The epiphytic algae species included *Pylaiella littoralis* and *Ectocarpus siliculosus*. Divers monitored the volume of drifting algae as a visual estimate. On 9 July 2020, little or no drifting algae were found at either site. By contrast, this situation changed over four weeks. On

8 August 2020, long growths of filamentous algae (*Pylaiella littoralis*, *Ectocarpus siliculosus*) appeared at both sites and became entangled in the lower parts of aquatic plants. Their coverage was 70% at site 1 and up to 90% at site 2 (Leinikki 2020). No drifting bladder wrack was observed at the sites.

The 2020 transplantations were carried out in August. One consisted of two planting areas of one square metre in size, in which stolons from two different donor populations were planted (Figure 5). One of the donor populations was located in Hanko, and the other at site 1; in other words, the second donor population was found very close to the intended transplantation sites, while the distance to Hanko was around 20 km, as the crow flies.

In 2021, Metsähallitus used a different technique in its transplantations because, after consulting with a researcher, it turned out that a shoot density of 16 shoots per square metre was too sparse under Finnish conditions. The transplantations of 2021 took place at two sites that did not have existing eelgrass: 100 to 150 stolons were transplanted in an area of approximately 1 to 2 square metres to create a small, compact meadow. Unlike in 2020, the planting took place in June, which is also recommended by Swedish researchers to reduce mortality over winter (Moksnes et al. 2016).

WWF Finland transplanted eelgrass in 2021 and 2023 in its RANKKU 1 and 2 projects. In 2021, the planting took place north of Hankoniemi and in the outer archipelago of Inkoo, whereas in 2023, eelgrass was planted in the outer archipelago of Inkoo at two different sites. The results indicate that two of the three transplantation techniques used in 2021 were highly successful, both occurring in the outer archipelago of Inkoo. WWF collected the shoots to be planted off Hanko, where the distance to the outer archipelago of Inkoo was measured by a direct line distance of more than 50 km.

The first eelgrass transplantations of the John Nurminen Foundation's Meriniitty project also took place in 2023. Metsähallitus, the Foundation's project partner, carried out the work. No monitoring data on these transplantations was available at the time of writing.

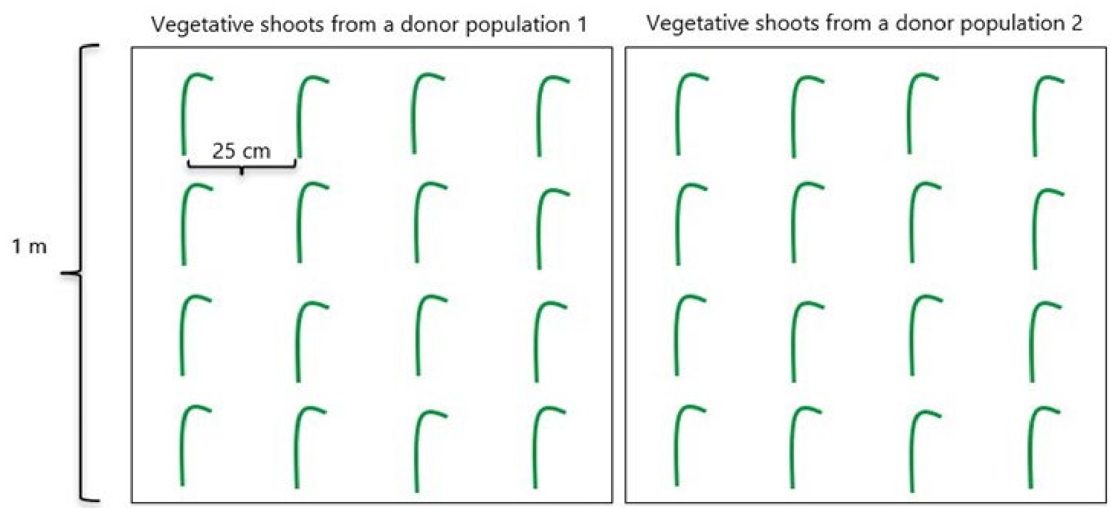


Figure 5. Example of Metsähallitus' planting technique in 2020. Planting tests were carried out following the recommendations of the Swedish handbook by Moksnes et al. (2016). Sixteen vegetative shoots were planted in an area of one square metre with 25 cm spacing, using shoots from two different donor populations. Figure: Aija Nieminen/Metsähallitus.

Experiences of the method in Estonia

Eutrophication has also caused eelgrass to disappear in many places on the Estonian coast, and various innovative methods for assisting its recovery have been tested recently (2017–2019 and 2022–2023) (Kotta, interview on 8 November 2023).

Eelgrass was transplanted at different sites, alone or with blue mussels. Experimenting with a multi-species transplantation of blue mussels and eelgrass was desirable as both species strongly modify their environment. The species were transplanted either using a net buried under the surface sand (either blue mussels and eelgrass together, or eelgrass only) or eelgrass shoots attached to a line.

The blue mussels were washed away from the transplantation site during the first growing season, but the eelgrass shoots grew well during the second season. The line method also produced good results for eelgrass growth at sheltered sites.

The main lesson learned from the transplantation tests in Estonia was that abiotic factors, including the site's openness or shelter and the mobility of sand on the selected transplanting site, strongly impact the viability and propagation of shoots. Estimating the cost of these transplantations is difficult, as some transplanted species did not survive at all (Pajusalu et al. 2023).

Similar tests involving transplanting blue mussels and eelgrass together on the Finnish coast proved that while blue mussels promoted eelgrass growth in laboratory conditions, this did not happen in the wild (Gagnon et al. 2021). Planting eelgrass in an artificial biodegradable tray with blue mussels also negatively affected the survival of eelgrass shoots, whereas using the same tray without the mussels increased their survival rate. These results clearly show that more research is needed.

Outcomes

Monitoring data on eelgrass transplantations has not been gathered for many years, and the longest monitoring period on record concerns Metsähallitus' transplantations of 2020. At both planting sites 1 and 2, two of the three transplantation techniques have been successful until now, even though the shoots were planted sparsely and in August, which was not an ideal time of year.

At both sites, the plants have been least successful at the shallowest sites, and they were covered with filamentous algae on most monitoring visits. The shallowest transplantation sites also had the highest rate of post-planting shoot mortality (Figure 6). The shoot mortality rate in the shallowest area was 40% at site 1 and 50% at site 2, and almost equal

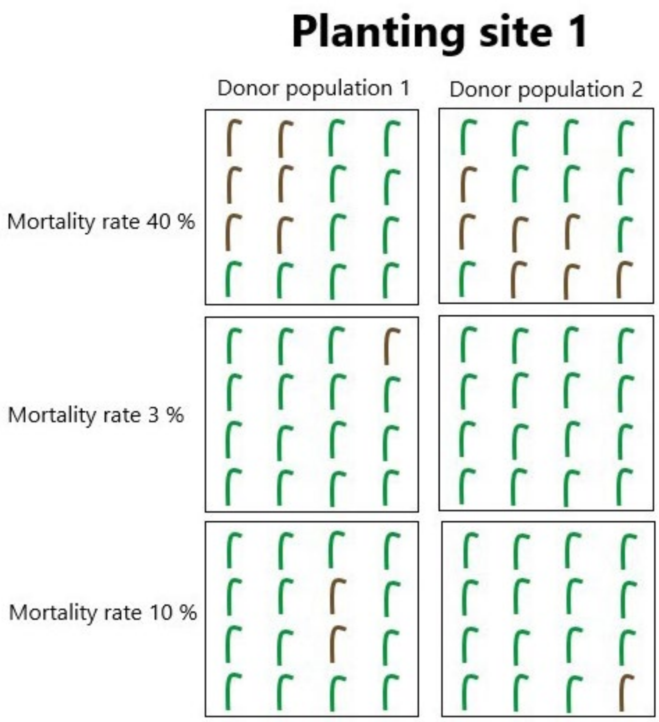


Figure 6. Example of shoot mortality at Metsähallitus' test site 1, planted in 2020. Surviving shoots are shown in green, with dead or lost shoots in brown. The shoot mortality rate was the highest in the shallowest planting areas, whereas, in deeper areas, it was 3% to 10% at both sites 1 and 2. Figure: Aija Nieminen/Metsähallitus.

numbers of shoots perished regardless of their donor populations. At other transplantation sites, the rate of post-planting shoot mortality ranged from 3% to 10%. Although the test was successful in more than half of the planted areas, more attention should be paid, especially to the planting depth in the future, and preliminary studies at different depths may also be necessary.

While the planting tests of 2020 were carried out at sites where eelgrass was previously found, seabed areas devoid of other vegetation were selected for transplantation. Some transplantations were located closer, and others were further away from natural eelgrass meadows. In particular, during the monitoring visit in late summer 2022, some transplanted areas were found to have spread to the extent that it was difficult to tell which shoots had been planted and which had grown naturally (Figure 7). Thus, it is essential to clearly mark the planting squares, especially at sites with pre-existing eelgrass.

Of the two Metsähallitus sites planted in 2021, one is thriving. The bottom type in this area is atypical in that it mainly consists of gravel. Some blue mussels and *Zannichellia* sp. also occur. The area is also known to have little or no boat traffic, which means that anchors cannot damage the transplants. The second site planted in 2021 probably suffered from excessively high temperatures, so it was already struggling in late summer 2022 and had entirely failed by early summer 2023.

Figure 7. A photo of eelgrass transplanted in August 2020 in late summer 2022. The brick attached to the bottom with a steel bar can barely be seen among the plants. The transplanted eelgrass has started growing well and likely merged with the natural eelgrass meadow at the site. Photo: Joonas Hoikkala/ Metsähallitus.

Challenges

Responsible action

As the common eelgrass is an endangered species in Finland, special attention should be paid to responsible action when planning transplantations. The species does not reproduce sexually in Finland. Therefore, the transplantation method currently used is planting shoots taken from existing meadows, which are consequently impoverished. Eelgrass is at the margins of its distribution in Finland, and meadows are sensitive to environmental changes. Eelgrass meadows form a threatened habitat protected under the updated Nature Conservation Act (Chapter 7, section 64), which entered into force on 1 June 2023. Once the ELY Centre has issued a habitat classification and a protection decision, sites with a protected habitat may not be destroyed or degraded (https://www.finlex.fi/fi/laki/alkup/2023/20230009).

As a restoration measure, eelgrass transplantation is still finding its place in Finland as there is not yet enough information on the cost-effectiveness of this method in the Finnish sea area, and the results of pilot studies have varied. Before the effectiveness of transplantation measures can be verified, more information is needed before embarking on more large-scale projects, and monitoring based on standardised methods carried out over more extended periods is required to assess the actual benefits and costs. To obtain sufficient monitoring data concerning the sites, all stakeholders should use the same transplanting techniques. A technique based on Metsähallitus' previous transplantation pilots devised in the Biodiversea project was used by both the WWF and the Meriniitty project in 2023. This enabled the same methods to be used to monitor the success of eelgrass at the transplantation sites.

Climate change will alter the Baltic Sea ecosystem, and according to oceanographic models, changes can be expected in water temperature, salinity and nutrient concentrations (Korpinen et al. 2018). If the salinity of seawater decreases, freshwater species are likely to become more abundant and spread more widely, while the common eelgrass may lost entirely from the Finnish coast.

Increasing temperatures are another future threat. Adverse effects from higher temperatures have already been observed, where a tall eelgrass colony disappeared entirely in August 2021, probably due to a heatwave in July of that year (C. Gustafsson, personal communication on 16 January 2024). The loss of the colony was probably due to multiple factors, e.g. the heatwave may have resulted in a cyanobacterial bloom, which influenced the amount of light on the seafloor.

The Metsähallitus authors suspect that excessively high temperatures destroyed one of its sites planted in June 2021, as the plants were still thriving in June 2022. In contrast, only a few individuals remained in August 2022, and by 2023 had disappeared completely (Figure 8). In his Master's thesis, Niemi (2022) found significant differences in the average temperatures between sheltered and open areas. Higher temperature fluctuations were found in sheltered areas, whereas more open and exposed areas are more stable regarding temperature. This finding is interesting, as the failed transplantation of Metsähallitus described above was in a relatively sheltered area, as was WWF’s equally unsuccessful site north of Hankoniemi.

Globally, fewer than 50% of eelgrass transplantation projects have been successful, usually due to an inappropriate planting site or incorrect techniques (Fonseca et al. 1998). As noted earlier, the most challenging aspect of transplanting eelgrass is finding a suitable location, highlighting the importance of onsite preliminary studies.

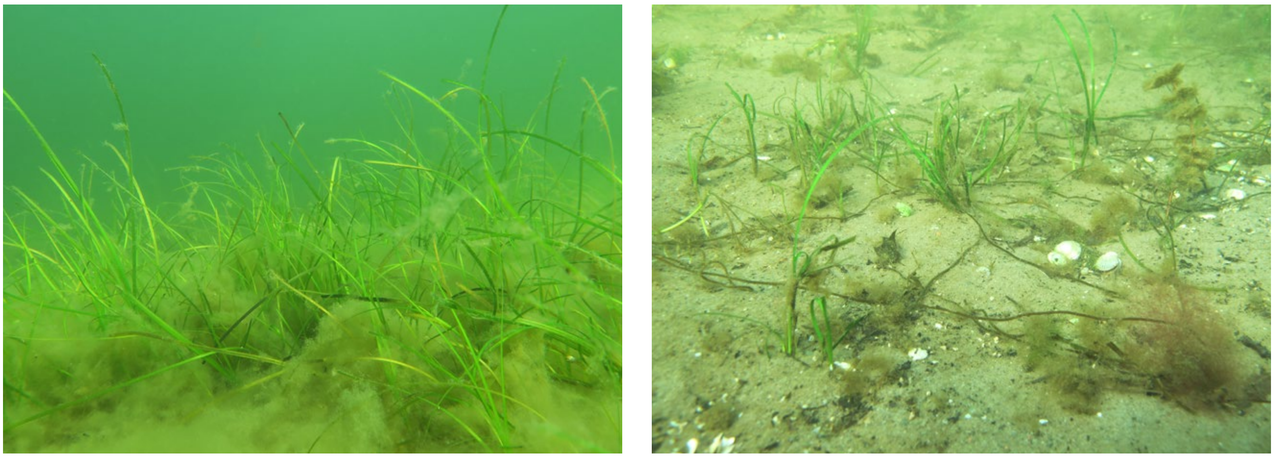


Figure 8. Common eelgrass transplantation site in June 2022 (left) and August 2022 (right). While the plants had started to grow well, as expected in June 2022, they may have been affected by a heatwave during the summer. Unfortunately, there was no automated temperature logger at this site that could have verified the temperature increase. Photos: Joonas Hoikkala/Metsähallitus.

Costs and benefits

In Sweden, an attempt has been made to put a monetary value on an eelgrass meadow one hectare in area. When an eelgrass meadow of this size was compared to a habitat with no vegetation, it was found that the former produces an additional 626 kg of cod and 7,535 percoids (e.g. perch), as well as sequestering 98.6 tonnes of carbon and 466 kg of nitrogen (Cole & Moksnes 2016). It was calculated that, on average, one hectare of eelgrass meadow serves commercial fishing, mitigates climate change and reduces eutrophication by approximately SEK 11,000 annually.

Studies on eelgrass transplantations conducted in other Nordic countries have found that their benefits materialise over a short period (Gagnon et al. 2023, Steinfurth et al. 2022). In a study carried out in Sweden, four sites were planted in squares of 20 x 20 m (Gagnon et al. 2023). Notably, the technique used made no difference regarding the time it took for benthos to colonise the site. Metsähallitus has also noticed a similar increase, especially in epifauna at the planting sites.

3.1.2 Restoration of common eelgrass from seeds

Transplantations and eelgrass restoration from seeds share the same primary purpose of assisting the recovery of the species at its historical sites. Historically, restoration with eelgrass stolons has been the predominant method, rather than restoration from seeds (e.g. Fonseca et al. 1998, van Katwijk et al. 2009, 2015, Moksnes et al. 2016). However, planting eelgrass from seeds has been developed for over 20 years, and this method has proven effective in some areas (Orth et al. 2012, Unsworth et al. 2021). The method has also attracted attention in recent years because it can be used to restore extensive areas cost-effectively (Marion & Orth 2010).

In the Nordic countries, eelgrass restoration from seeds has, for instance, been tested on the west coast of Sweden. Based on more than 20 restoration experiments, the results indicate that eelgrass restoration from seeds is not recommended for reasons including seed loss (Infantes et al. 2016b) and uncertain results (Moksnes et al. 2016). In the experiments carried out in Sweden, less than 1% of the sown seeds developed into seedlings (Moksnes et al. 2016). Despite these failures, eelgrass seed production has been studied, eelgrass seeds have been collected successfully, and a new, more mechanised method for separating large quantities of viable seeds from amongst the collected seed crop has been developed in Sweden (Infantes & Moksnes 2018). The recommendations issued in Sweden regarding this method may change in the future if new methods for restoring eelgrass from seeds are developed further (Moksnes et al. 2016, Infantes et al. 2016b).

Due to the low salinity on the Finnish coast, eelgrass does not flower or produce seeds, except occasionally in the Åland Islands. Since the prevailing conditions are unsuitable, there is no record of eelgrass restoration from seeds having been tested in Finland; the seeds would need to be obtained in Denmark or Sweden, or flowering individuals would need to be grown in Finland in aquaculture basins with a sufficient salinity level. Both methods would be costly without guaranteeing their success.

Restoration method

This method collects flowering shoots with immature seeds from a large donor population. Although flowering shoots are usually collected manually by diving or snorkelling, a mechanical device developed for this purpose is also used in the United States. As the device is towed above a meadow with prolific seed production, it randomly cuts the highest sections of the plants, including shoots containing seeds. With this method, up to 2.5 million seeds may be collected annually, and it has not been found to have adverse effects on eelgrass meadows (Orth & Marion 2007).

Once the flowering shoots with seeds have been collected, they are transported to a potential restoration site or stored under optimal conditions until sown. The storage of seeds is expensive, as they must be manually separated from the flowering shoot, and the seeds may have to be sorted to find the most viable ones (Infantes & Moksnes 2018). The principal storage risks are premature germination, poor viability, or mould. However, viable eelgrass seeds have been stored for up to 8 months in Sweden (Infantes et al. 2016b).

Transporting the seeds directly to the restoration site is considered a more cost-effective method. For example, the collected flowering shoots can be placed in *buoy-deployed seed bags* (BuDS), where the mesh size is small enough to hold the shoots in the bag but large enough to allow mature seeds to fall out. This method was developed in the United States (Pickerell et al. 2005) and has been successfully used in the Netherlands with flowering shoots sourced in Germany (van Duren et al. 2013).

If eelgrass seeds have initially been stored and separated from the flowering shoot, slightly different methods are used to sow and spread them, as individual seeds are sown with no flowering shoot. One of the simplest methods is to deploy divers who sow the seeds in the bottom sediment or attach them to biodegradable tape before they are placed on the bottom. In another method developed in the United Kingdom, eelgrass seeds were mixed with sediment and placed in small hessian bags, which were then attached to a line anchored on the seabed (*Bags of Seagrass Seeds Line*, BoSSLine). Of these bags, 94% produced shoots in 10 months (Unsworth et al. 2019). In the United States, seeds have also been spread using a planting device controlled from a boat.

The advantage of restoring eelgrass from seeds is that, due to the relatively low costs, the method is suitable for large-scale planting projects, and large quantities of seeds can be collected with relatively little negative impact on the donor population. A single eelgrass meadow can produce hundreds of millions of seeds, most of which fail to develop into growing shoots because factors, such as local sea currents, prevent them from spreading to potential growth sites. Thus, in some areas, the surplus production of seeds can be used in various restoration programmes (Unsworth et al. 2021).

Monitoring methods

The same methods are primarily used to monitor eelgrass restoration from seeds and the success of transplantation (see 3.1.1 Common eelgrass transplantation). In addition, the survival of seedlings and seed losses can be monitored.

Experiences of the method

One of the most successful eelgrass regeneration projects from seeds was carried out in the US State of Virginia, where in 1999–2010, 37.8 million eelgrass seeds were sown on 369 individual sites with no vegetation, adding up to 125.2 hectares in four different bays. After ten years, a uniform eelgrass meadow of 1,700 hectares had emerged in the area (Orth et al. 2012).

Despite individual successes, the restoration of eelgrass from seeds involves much more uncertainty than restoration by transplantation. On average, 0.1% to 28% of seeds sown in the sea will develop into full-size growing shoots (Pickerell et al. 2005, Goshorn 2006, Marion & Orth 2011, 2012, Orth et al. 2012, sit Moksnes et al. 2016).

Studies have found that in Scandinavia, large quantities of eelgrass seeds are lost, mainly due to currents, predation pressure from the green shore crab (*Carcinus maenas*) and bioturbation caused by the sandworm (*Arenicola marina*) (Valdemarsen et al. 2011, Infantes et al. 2016a, Infantes et al. 2016b). Field test results obtained in Sweden indicate that some of the sown seeds were lost, especially for the above reasons. In contrast, shoot development was mainly affected by light availability and physical disturbance (Infantes et al. 2016b).

In the hessian bag method used in the United Kingdom (100 eelgrass seeds/bag), one site was hit by a storm, covering the bags with sediment so that none of the seeds germinated (Unsworth et al. 2019). In addition, while germinating seeds developed in most of the hessian bags, on average, only 2.37 ± 2.41 of one hundred seeds grew into a full-sized shoot (Unsworth et al. 2019), which indicates that the method is challenging and further research on germination success is needed.

Swedish researchers found that if seeds sown on the seafloor were covered with a layer of sand two centimetres thick, seed germination rates increased by two to six times compared to uncovered seeds (Infantes et al. 2016b). This improvement was probably due to reduced predation pressure and because fewer seeds were carried away with currents and drifting mats of filamentous algae (Infantes et al. 2016b).

In Denmark, biodegradable coconut fibre mats three centimetres in thickness were tested. They were laid on top of the sediment, and eelgrass seeds were placed on the mat surface. The purpose of this innovative method was to prevent the seeds from being buried too deep in the sediment due to sandworm bioturbation. The results indicate that the fibre mat effectively prevented the seeds from being buried and promoted their germination and the survival of seedlings, as the fibre mat kept the seeds at an optimal depth for germination and also protected small seedlings from being covered (Sousa et al. 2017).

3.1.3 Transplantation of aquatic plants on sand and gravel bottoms in littoral zone

In addition to common eelgrass, other vascular plants or charophytes may be planted in sand and gravel bottoms, shallow coastal waters or moist coastal meadows (for *Chara* transplantations, see section 4.3). Planting laboratory-grown macrophyte shoots or transplantation from another natural population is mainly possible in enclosed basins, including lakes or ponds, and in marine conditions in enclosed lagoons, such as flads or gloe lakes, where the vegetation has been destroyed for one reason or another. In other countries, vascular plants have been transplanted into new, artificial lakes, lakes and ponds where remedial dredging has been carried out or on artificial sandbars (Bakker et al. 2013, Deinhardt et al. 2021).

In the Baltic Sea conditions, the transplantation of vascular plants (other than eelgrass) is mainly an option if, for example, other vascular plants are planted together with eelgrass with the idea that a multi-species seagrass meadow would be more stable or grow better, and/or maintain greater biodiversity or biomass of invertebrates than single-species meadows (Gustafsson & Boström 2009, 2010, 2013, Salo et al. 2009, interview with Boström on 4 December 2023). On the other hand, Gustafsson & Boström (2009) found in their study that, while the abundance and biomass of Gammarus spp. and the number of different taxons were greatest in a monoculture of *Potamogeton perfoliatus*, the differences to other treatments (eelgrass and *Potamogeton pectinatus* together or *Potamogeton perfoliatus* alone) were not significant.

If vegetation is missing from a specific area in the Baltic Sea, there is usually a good reason, such as a mobile seabed, dredging, toxic or acidic run-off. A good seed pool lies in the benthic sediments of the Baltic Sea, and it only takes a small piece of a shoot for many aquatic plants to grow. Currents and ice carry shoots detached from the bottom, and birds transport seeds from one water system to another. Common species transplantations are usually unnecessary (Deinhardt et al. 2021).

Transplanting vascular plants may make sense in order to increase the surface area of the habitat composed of a keystone species (such as eelgrass) or to ensure the survival of a threatened species, at least in some populations within its distribution (Deinhardt et al. 2021). Transplantations in the Baltic Sea have primarily been carried out for the key species eelgrass and for critically endangered species, whose populations have been increased to ensure their survival. Most of the transplanted species are endemic to the Bothnian Bay, have a limited distribution and few known populations, and may be slow to spread. Many of the transplanted endangered plants are species of shallow coastal waters, coastal meadows, estuaries and salt patches that grow along the waterline, benefit from ice erosion and primary succession, and have suffered from reduced grazing of coastal meadows and eutrophication (Deinhardt et al. 2021, Miranto et al. 2017, Markkola 2013, 2016, Siira 2011).

Restoration method

Vascular plants can be transplanted using seeds or shoots, which can be collected in the wild or produced in laboratory conditions.

Monitoring methods

When transplanting vascular plants, monitoring methods should, at minimum, focus on the survival and reproduction of the planted species. Occasionally, the focus should also be on flower and seed production or the biodiversity and/or biomass of invertebrates attracted by the plants.

Experiences of the method

Outcomes

In Sweden, the endangered *Alisma wahlenbergii* has been planted with little success (Johansson 2014, cited in Deinhardt et al. 2021). In the third year after planting, not one individual survived out of more than 200 shoots. The recommendation issued for the future is to plant larger individuals at the very beginning of the growing season and to fix their roots to the bottom with stones or similar. In addition, it is advisable to focus on areas where the species is known to have disappeared but where the conditions have since improved.

Further, the critically endangered *Artemisia campestris* subsp. *bottnica*, an indigenous species of the Bothnian Bay, has been transplanted from the only previously known site in Tornio to the Botanical Gardens of the University of Oulu, where plants have been grown from seeds. The seedlings have been transplanted to new areas; the species thrives on shores of sand and shingle. Although the transplantation of germinated shoots was quite successful, transplantation from seeds was poor in the wild, even if the seeds germinated well in experimental conditions (Miranto et al. 2017). Nevertheless, transplantations of this species have managed to expand its distribution and the possibility of the only population disappearing once and for all has been avoided.

The critically endangered *Dupontia fulva* (previously *Arctophila fulva* var. *penduline*) has been transplanted from shoots collected in the wild and grown in a laboratory to new sites and the vicinity of old ones (in sheltered bays and riverbanks liable to flood as well as shallow littoral waters) (Miranto et al. 2017, Markkola 2013). While some of the transplantations thrived and started spreading, others were already destroyed before the next growing season since the particularly unstable habitat of this species in the outermost parts of the estuary was scoured by ice. Nevertheless, new populations have improved the chances of this species being preserved.

The critically endangered *Puccinellia phryganoides* has been transplanted in the Bothnian Bay to increase its population (Siira 2011, Markkola 2016). Shoots were obtained from natural and laboratory-grown (ex-situ) populations and planted close to existing populations and in new areas. Some shoots thrived and started to reproduce, while the erosion effects of ice destroyed others. The habitat of this species (dryer parts of salt meadows and salt patches, grazed meadows) is precarious and often challenging. In the future, more attention should be paid to site selection.

Bakker et al. (2013) published an extensive review article, mainly on vascular plants and other macrophytes planted in German lakes. This article contains a great deal of relevant information for anyone planning to transplant macrophytes.

Challenges

The challenge in the transplantation of vascular plants often lies in shoot mortality and poor reproduction from seeds. Unless the planting site is chosen carefully, the shoots can easily fail, and, as with eelgrass, drifting mats of algae and harsh wind conditions can easily dislodge newly planted shoots (Boström, interview on 4 December 2023). If a species is planted in an area where it has previously disappeared and the pressures that affected it have not been successfully eliminated, the project is guaranteed to fail. Particular attention should consequently be paid to selecting the transplantation site.

Costs and benefits

Planting vascular plants from shoots is labour-intensive manual work requiring a large workforce. Although using seeds is easier, it is more prone to risks. Particular attention should be paid to selecting the planting site to avoid unnecessary costs.

3.1.4 Sand capping and eelgrass transplantation

Both coastal areas and underwater nature can be restored through *sand capping (sand replenishment)*. In Western and Central Europe, sand capping is used to maintain beaches or build dunes in areas with a sand shortage or where human activity has negatively affected natural sediment dynamics. This section focuses on underwater sand capping as a restoration method.

In Sweden, seabed sand capping has been used to promote eelgrass recovery in areas where the species has disappeared due to human activity and unfavourable environmental factors. The loss of eelgrass has resulted in a dramatic change in environmental conditions in the historical distribution of this species in Swedish waters, as eelgrass effectively binds the bottom sediment, thereby reducing water turbidity. Sand capping aims to stabilise the bottom sediment, reducing its resuspension and, consequently, water turbidity, thus improving the chances of eelgrass surviving within its historical range.

Restoration method

The method consists of replenishing sand on the sea bottom in areas where eelgrass has disappeared to create a stable substrate for the plant to grow. In a pilot project at Lilla Askerö, Sweden, a sand layer of 10 cm was added to the bottom at depths of 1.3 to 1.9 m over an area of 1 hectare (100x100 m) in April 2021 (Infantes 2021). To achieve this, approximately 1,800 tons of sand-gravel mix was spread onto the site by an excavator equipped with a precision GPS system, which was transported around the site in a barge. An impressively consistent average thickness of the sand-capped area was achieved in this project (9.3 ± 1.3 cm). After the sand capping phase, 80,000 eelgrass shoots (16 shoots/m^2) were planted manually in every second square metre (forming a 'checkered pattern') in the sand-covered area in May–June 2021.

Monitoring methods

In the pilot at Lilla Askerö, the growth of the transplanted eelgrass will be monitored using various methods, e.g., counting the shoots. In addition, the site's physical characteristics, including changes in wave attenuation, current, turbidity, sedimentation rates and light conditions, will be gauged to assess the impact of sand capping and eelgrass restoration.

Experiences of the method

Outcomes

In the sand capping project at Lilla Askerö, it only took one year for the transplanted 80,000 eelgrass shoots to increase tenfold to 860,000. However, the shoot density in the sand-capped area was inconsistent, and dense patches were found in some areas while others were empty.

While there is no record of such extensive sand capping of the seabed being tested in Finland, Metsähallitus is currently working with the City of Helsinki on a cooperation project which includes plans to cap the seabed with sand close to Lauttasaari Island and to plant eelgrass in this area. According to the web service Laji.fi, common eelgrass was last found at the site in the 1950s. In the summer of 2021, Metsähallitus conducted surveys that included diving and taking sediment samples in this area. While the study found that the seabed here is mainly sandy, it may be difficult for eelgrass to spread to the site naturally, and the replenished sand would ensure that the shoots stay anchored in the sea floor.

The sand used in the project comes from the company MH-Kivi Oy, a subsidiary of Metsähallitus Property Development. The activities of this subsidiary include marine aggregate extraction in the aphotic zone of offshore areas. The sand capping project in Lauttasaari will advance in the summer of 2024 as part of the City of Helsinki's Baltic Sea Challenge Action Plan.

Challenges

Sand capping does not involve restoration per se, even though it has achieved good results in Sweden. If the sand used for restoration is extracted from the seabed, this will have an adverse impact on the extraction site. While the effects of sand extraction on the benthos have been studied little in the Baltic Sea, dredging destroys the seabed habitat at least temporarily, which is why this method may also have devastating impacts on the seabed. A study carried out in Germany's offshore areas found that the numbers of more sensitive benthic animals with slow growth rates or poor ability to spread do not recover to their pre-dredging levels within a year (Krause et al. 2010). In addition, sand extraction and capping increase sediment suspension in the metalimnion and cause turbidity, even if this is only a temporary impact that occurs while the work is in progress.

Costs and benefits

While sand capping and extraction have been found to negatively impact the benthos, these impacts are of short duration (Fröhlich & Rösner 2015, cited in Deinhardt et al. 2021). In the pilot project at Lilla Askerö, Sweden, the impacts of sand capping on the benthos were studied in smaller test squares before extensive sand capping went ahead. The recapped sand was not found to have any negative impacts, and within no more than three months, a similar benthos was found in the capped squares as in the natural sediment of the adjacent area (Moksnes 2021). Based on preliminary studies, sand capping was even considered to have positive effects, as the individual density of the benthos in the capped squares was higher than in the natural sediment. After two years, the abundance of benthic fauna in the capped squares was already three times that found in the natural sediment. Additionally, more species were found in the sand-capped squares than in the natural sediment. It is believed that the positive effects of sand capping on benthic fauna are associated with the higher oxygen content of the replenished sand compared to the natural sediment, which contains clay and is finer (Moksnes 2021).

Generally speaking, sand capping as a restoration method is expensive. Costs are incurred from the mechanical power needed to extract, transport, and deposit the sand upon the seabed. If the site to be restored is far from the sand extraction site, the costs may be even higher.

3.2 Estuaries (1130)

3.2.1 Restoration dredging

Conservation status[1]	Trend[1]	Status in 2018[2]	Other points
Unfavourable, bad	Stable	Endangered	Finland's international special responsibility habitat[2]

[1]Assessment of conservation status and trends given in the habitats report referred to in the Habitats Directive 2019
[2] Kotilainen et al. 2018 Threatened habitat types in Finland 2018: the Baltic Sea.

Throughout history, humans have harnessed rivers for economic purposes, in the interest of which they have been straightened, dredged, dammed and embanked, thereby often also destroying the natural estuary and flood dynamics of rivers. Many pioneer species live in habitats that rely on such phenomena as annual flooding and the sludge it brings, new delta habitats created in the estuary, or habitats maintained by active and natural river dynamics otherwise free from competitors. Many species have also suffered from modifications to estuaries to make them more suitable for boating. Small side channels with a slow flow rate have been blocked to achieve this, and the main channel has been dredged to make it straight and streamlined. This has destroyed areas used by species that need shallower or more sheltered habitats or where water flows more slowly. The restoration dredging of rivers has usually been more associated with flood protection than nature conservation in Finland.

In this section, we also discuss a project in which shallow and overgrown straits at the Pappilansaari Islands in Lupinlahti Bay, Hamina, were opened through suction dredging, to improve water exchange. Lupinlahti is a narrow bay that is very shallow in places and connected to the sea by three narrow straits. While not a river estuary in terms of its habitat type, the same restoration dredging method can also be used in estuaries.

Restoration method

River Temmesjoki

The River Temmesjoki discharges into Liminka Bay in North Ostrobothnia. The river has been altered to improve its flow and later for flood protection. The natural meanders of the river's main channel have been straightened, dredging spoils have been deposited on the banks, and the flow rate is approximately the same on all modified river sections. The upper reaches of the river were restored by Metsähallitus in 2022 by redirecting the water to its original natural meandering channel and recreating counter currents, rocky areas and other natural elements that slow down the flow and maintain variable flow conditions.

In 2019, the River Temmesjoki estuary was rehabilitated and restored by the ELY Centre for North Ostrobothnia, mainly to safeguard the habitats of the endangered pendant grass *Arctophila fulva* var. *pendulina* and to preserve one of the very few populations of this species (Markkola 2013, Markkola 2016, Niemelä 2009, Rautiainen et al. 2007, Siira 2011) [for more information on this species and other conservation measures targeting it, see section 4.6.1. (Small-scale) manipulation of microhabitat for an endangered species.] *Arctophila fulva* var. *pendulina* is a perennial plant that thrives in estuaries, floodplains, and on shallow shores. It has suffered from the clearing and straightening of the river and the dredging spoils deposited on the riverbanks. The natural flood dynamics of the river have also been negatively affected by flood protection measures. The aim was to restore the Temmesjoki River by increasing the water flow into the estuary and safeguarding the preservation of sites where the endangered *Arctophila fulva* var. *pendulina* is found in this area.

Several small side channels were dredged in the estuary of the River Temmesjoki. Rather than discharging into the sea, these channels branch out from the main course and end in the wetland area of the estuary (Figure 9).

Suction dredging in the straits of the Pappilansaaret Islands in Lupinlahti Bay, Hamina

Accelerated reed bed growth in the inner archipelago is often a sign and consequence of eutrophication. It may cause the accumulation of organic matter, local silting, and a reduction in water exchange in naturally shallow areas, all contributing to further overgrowth.

In Hamina, the three narrow straits of the Pappilansaaret Islands connect the enclosed Lupinlahti Bay to Haminanlahti Bay and further to the Gulf of Finland. Lupinlahti Bay is a Natura site, most of which is protected as a nature reserve. It is particularly important as a resting and feeding area for migrating aquatic birds. The expansion of reed beds is evidence of the effects of marine eutrophication in this area. For example, previously open sandy bathing beaches near the straits have been taken over by reed, while the abundance of submerged plants has also hampered boating.

The straits were dredged to combat the harmful effects of eutrophication (Figure 10). Additionally, the edges of the reed beds were mowed. Clearings were created in the reeds and more are planned. The dredging took place in 2021–2023, a different strait each year. The total surface area to be dredged was around 11 hectares. The dredging operation was commissioned by MeriHamina Association (Harri Huuho, personal communication on 10 January 2024).

Suction dredging was also used at this site. The dredged sludge and bottom material were run through a pipe into a special bag-like textile container called a geotube placed on dry land (Figure 11). In the geotube, water-containing sludge gradually settles due to gravity, while a polymer added to the sludge causes water to filter through the geotube's fabric. After this, the sludge can be used for

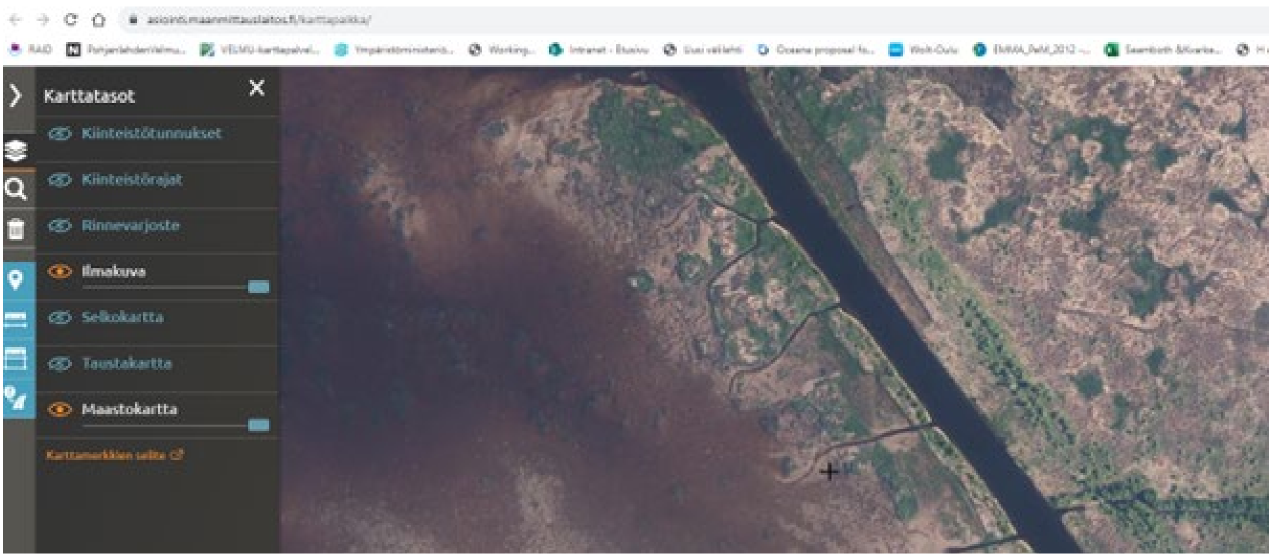


Figure 9. Restoration dredging in the River Temmesjoki estuary can be seen in the aerial photograph as narrow side channels ending in wetland. Photo: National Land Survey of Finland, MapSite.

Figure 10. Suction dredging of the sediment in the straits of the Pappilansaari Islands, Hamina. Photo: Harri Huuho/MeriHamina Association.

Figure 11. Aerial photograph of a geotube field. Photo: Harri Huuho/MeriHamina Association.

landscaping and other similar purposes (Figure 12). The total volume of the dredged spoil was approximately 33,000 m^3.

Monitoring methods

Before dredging started, the site was echo sounded to study its depth structure, the contaminant concentrations in the sediment to be dredged were examined, and nature surveys for the permit application were commissioned. While the dredging work was in progress, the Kymijoki River Water and Environmental Association (Kymijoen Vesi ja Ympäristö Ry) monitored the water quality. While benthic communities were not monitored as part of this project, information on the fish fauna and its changes was obtained by interviewing local fishermen.

Experiences of the method

Outcomes

Dredging increased the depth of the straits by approximately half a metre, which strengthened the current in the area. This has been particularly evident in winter as the straits are less likely to freeze over. The dredging was a one-off measure, and an effort will be made to keep the straits open by mowing the reed beds bordering them. Clearings and small ponds will also be created in the reed beds to improve habitats for fish and birds.

Challenges

The local association carried out the restoration project with a self-financing share of 50%. Getting the self-financing share together for a costly project may be difficult. Obtaining the funding, permit processes, organising a competitive tendering process for the work and carrying it out also requires careful planning, and delays in different work stages may multiply and hamper project completion.

Costs and benefits

The total cost of the project was around EUR 1,793,000, of which the suction dredging and geotubes (EUR 1,085,000), as well as construction and maintenance of the geotube field and transport of the spoils (EUR 523,000) accounted for the largest part. Other costs were incurred from planning, permit processes, various preliminary studies, supervision and monitoring.

Figure 12. Dredged spoil that has solidified within a geotube. Depending on its properties, the spoil can be used in landscaping and for other similar purposes. Photo: Harri Huuho/MeriHamina Association.

3.3 Coastal lagoons (1150)

Conservation status[1]	Trend[1]	Status in 2018[2]	Other points
Unfavourable, bad	Stable	Flads - Threatened gloe lakes - Threatened	Finland's international special responsibility habitat[2]

[1] Assessment of conservation status and trends given in the habitats report referred to in the Habitats Directive 2019
[2] Kotilainen et al. 2018 Threatened habitat types in Finland 2018: the Baltic Sea.

3.3.1 Sill restoration

Dredging is a typical operation in Finland's shallow sea areas. The inlets of flads and gloe lakes have also often been dredged open, and their sills have been lowered or removed altogether. The latest reviews indicate that 28% of Finnish flads and gloe lake sites exceeding one hectare in size have had their inlets dredged (Haapamäki 2021).

Dredging has been carried out to facilitate boating, for example. Land uplift may have caused a bay's sill to rise, and previously accessible routes have become too shallow, preventing access to a sheltered bay or harbour. According to a prevailing view, dredging the inlets has additionally been regarded as a service for nature as it has been considered to improve water exchange and facilitate fish migrations (Blomqvist 1984). Therefore, especially at sites that have reached later stages of their development (gloe-flads and gloe lakes), you often see dredged channels in the archipelago even if there were no settlements or docks nearby. Regardless of the reason, channels have often become both deep and wide, and the natural sill has disappeared.

Removing or lowering the sill exposes the bay to water level fluctuations and may cause the shores or the entire bay to dry out when water levels are low (e.g. Saarinen 2019). As a result, eggs deposited by fish in shallow waters close to shores end up on dry land, and, in the worst case, spawning may fail entirely in certain years. Today, it is understood that the sill and the limited water exchange between the sea and the bay are the specific factors that make the flads and gloe lakes unique and valuable. The sill limits the exchange of water and, consequently, raises the temperature in the bays, especially in spring, reduces salinity by increasing runoff water retention in the flad and, in general, mitigates the effects of wind and waves and provides warm and stable habitats for many species (Pursiainen et al. 2021). Dredging the the inlets of flads and gloe lakes requires careful consideration and is rarely worthwhile because of its adverse effects on the habitat. It may destroy the bay by changing its species composition and ecological function, for example, as a spawning habitat for fish.

So far, few examples of sill restoration projects have been completed in Finland. In the Kvarken flada project (2016–2019), some measures were planned and carried out in Sweden by the County Administration Board of Västerbotten. For a description, see Saarinen 2019. Measures were also planned in Finland, but landowners took a dim view of them, highlighting the issue's sensitive nature. From the landowners' perspective, preventing/slowing down the water flow increases the flood risk and may reduce the usable value of forestry land on the shores. The shores are often steep or consist of wetlands in low-lying areas, and a temporary rise caused by meltwaters, or a high sea level has no effect on vegetation except in the immediate shore area. After the Kvarken flada project, work has been carried out on individual sites under the national HELMI programme, and several areas are currently being planned within the Biodiversea project. The HELMI programme is currently developing a restoration guide for small coastal water bodies, gathering best practices and lessons learned based on existing experiences. The idea is that stakeholders can rely on the restoration guide when surveying small water bodies, planning and carrying out their restoration, and monitoring the sites. The guide was published in 2024 (ELY Centre for South Ostrobothnia 2024).

Restoration method

If the sill is restored to recover natural but limited water exchange between the sea and the bay, the natural conditions, functions and species of the flad will also recover. For example, this report uses the restoration of Halsskärsgraven in Robertsfors and Ytteravan in Kronören Nature Reserve by the County Administration Board of Västerbotten in Sweden. The experiences in Finland concern Långviken in Nykarleby and Kobbfladan managed by the ELY Centre for South Ostrobothnia, as well as Ormskatglon in Replot, where the ELY Centre guides the work. The information was obtained from the final report of the Kvarken flada project (Saarinen 2019), a restoration report on Långviken (Wistbacka 2023) and interviews. In all these examples, the inlets had been excavated in the second half of the 20th century.

Sills with deeper channels

Both Halsskärsgraven and Ytteravan are gloe-flads with deeper channels excavated in their rocky and relatively open inlets. As a result of dredging, the water level in the bays currently follows sea level fluctuations, which has sometimes led to the bays drying out completely as there is no sill to stop the outflow (Saarinen 2019). In addition to drying out, there are signs of more floating algae entering the flad. The number of three-spined stickleback fish has increased, and, in general, the suitability as spawning area in the flad has declined due to increased water exchange and the consequent reduction in the water temperature.

The restoration project aimed to recreate the natural sill and water exchange of the flads. Old aerial photographs were used at the planning stage to get an idea of the natural shapes of the inlets and sills. Excavators were needed at both sites. In Ytteravan, the excavator was transported to the site on a barge to minimise natural disturbance. Only material found on the site was used, as the spoils previously dug out of the channel had been placed nearby. More diverse measures were needed at the Halsskär restoration site, since the channel was used for boating, and there was a dock and a boat ramp in the flad. It was agreed with users that the marina located outside the flad would be improved in connection with the restoration work, and any boats using the moorings in the flad could be moved there. Dredged spoil from building the dock was also used to build the sill (Figures 13 and 14).

Closure of artificial channels and building up of the sill

In the 1990s, two new channels were dug in Långviken in Finland to improve water exchange (Wistbacka 2023a, interview with Wistbacka, 30 October 2023). Since then, water exchange has mainly occurred through these artificial channels rather than through the natural inlet shaped by the area's topography. In the natural development process of flads, without the excavated channels, Långviken would have already reached the gloe lake stage. Since the channels are deeper than the flad, it may occasionally dry out completely.

The goal of the measure was to close two man-made channels and to restore the natural inlet and sill. An excavator was used to carry out the work. While stone material was returned to the sill in the two previous examples, in Långviken, finer-grained materials

Figures 13 and 14. Photos of the sill in Halsskärsgraven before and after restoration. Photo: Anniina Saarinen/Länsstyrelsen Västerbotten.

were used from the area (clay, gravel) as well as transported to the site in a barge (gravel 10–60 mm and 0–30 mm). The channels were filled with the material and closed with a geotextile. Gravel was applied on top of the geotextile to a height slightly exceeding the surrounding ground level as the material was expected to sink (Figures 15 and 16). Once the excavator had completed its work, the shore was restored with stones, the natural inlet was opened out and improved with a scythe and spade, and the sill was improved and reinforced with stones.

Narrowing the channel

The gloe lakes of Ormskatglon and Kobbfladan are located in Replot. Both sites are connected to the sea by streams that were widened in the latter half of the 20th century. The reasons for this are unknown, but the idea may have been to improve migration routes for fish. The dredged spoils were placed along the streambanks. The aim was to restore the original stream channel and to recreate its natural width and water flow. When planning the restoration work, the ELY Centre for South Ostrobothnia used the volume of old dredged spoil to calculate the natural sizes of the streams. An excavator was used to carry out the work using the old,

Figures 15 and 16. In Långviken, the goal of the restoration was to close two man-made channels and to restore the natural inlet and sill. Aggregate, clay and gravel for the work were found in situ and also obtained off-site. Photos: Ralf Wistbacka.

dredged spoil. In interviews from both Wistbacka (30.10.2023) and Nikolajev-Wikström (21.11.2023), they both noted that estimating the size of a stream in its natural state is difficult and that some standardised model should be produced based on factors such as catchment size.

Monitoring methods

Both Halsskärsgraven and Ytteravan were surveyed in the Kvarken flad project, and the monitoring methods are described in reports *Restaurering av grunda kustmiljöer i Kvarken – Erfarenheter, metoder och framtida åtgärder med fokus på flador* (Saarinen 2019) and *Fiskyngelproduktion i grunda avsnörda havsvikar* (Saarinen et al. 2021). The same monitoring methods have also been used after the conclusion of the project.

In Halsskärsgraven, the impacts of restoration were monitored by surveying perch eggs, water temperature and aquatic plants. Samples of fish juveniles were additionally collected after the restoration, as the bay was no longer dry at low water. The results showed a slight increase in the number of perch eggs (from three to four ribbons) and the number of pike juveniles. The vegetation appeared lusher despite being grazed by sea birds. No significant temperature differences were observed. For some unknown reason, there was a large amount of filamentous algae in the old dredged area both before and after restoration, even though the rest of the bay was in excellent condition; the water was clear, and there was plenty of vegetation. Monitoring in Halsskärsgraven continued after the end of the project, and the results have shown that there are plenty of pike juveniles in the area. More information on the initial situation would have been helpful to support monitoring. However, there are indications that the measure was successful.

In Ytteravan, fish samples taken prior to restoration showed that there were perch juveniles in the flad. The vegetation survey showed that the innermost parts were in reasonably good condition, and plenty of vegetation existed. The closer the observations were made to the dredged sill, the more floating filamentous algae there was. The County Administrative Board has included Ytteravan in its continuous monitoring programme after the project's completion to assess the restoration's impacts. The results are vague, and no clear increase in fish numbers or similar has been observed. In general, it can be said that the bay is not optimal for perch or pike.

The thermal sum and water levels have been monitored in Långviken, Ormskataglo and Kobbfladan to observe the impacts of restricting the water flow and the new channel and sill (Nikolajev-Wikström, interview on 21 November 2023). Fish yield has been examined by monitoring perch and pike juvenile densities. Before the restoration, a high density of perch juveniles was observed in Långviken in 2022, and the report notes that monitoring fish migrations and juvenile production in 2024 would be important. Attention should also be paid to the vegetation, including the spread of reed beds and the extent to which raising the water level has been successful in controlling the spread and growth of reeds (Wistbacka, interview on 30 October 2023). In Ormskataglo and Kobbfladan, temperature, water level and fish fauna were monitored in 2022 and 2023, and this monitoring will continue in 2024 (Nikolajev-Wikström, interview on 21 November 2023).

Experiences of the method

Outcomes

The projects in Halsskärsgraven and Ytteravan can be considered successful (Saarinen 2019). Inlets and sills built or restored to a more natural state are expected to lead to natural water levels and exchange between the bay and the sea. Although large numbers of pike juveniles are produced in Halsskärsgraven, as the initial situation was unknown, there is no certainty of how the measure has affected their numbers (Saarinen & Berglund, interview on 23 October 2023). Significant quantities of fish have not been observed in Ytteravan after the restoration, but this may be because the site is not an important perch or pike spawning habitat. The aggregate and gravel materials used for building up the sill have been able to withstand the effects of wind and sea level fluctuations.

It was found that the restoration project in Långviken had succeeded exceptionally well and could set an example for restoration projects in the HELMI programme (Wistbacka, interview on 30 October 2023). The artificial channels were filled in, and the water now flows along a natural channel that enables fish spawning migrations. Today, the area is in a near-natural state. Even the tracks of machines and traces of the measures have almost completely disappeared. The measure's impact on nature values and ecological functions remains to be proven by the planned and completed monitoring. Fish monitoring should focus on juvenile numbers and their changes.

So far, the filled-in channels appear to have withstood erosion caused by wind and waves, water level fluctuations and ice (Wistbacka, interview on 30 October 2023). The success of the restoration project in Långviken was probably due to a long period of low water levels, which allowed the masses to dry before the water level rose, and the filling of gravel on top of blue clay in the channels was almost like concrete. After the restoration, the coastal meadows of Långviken were covered with spring floods and functioned as a habitat for pike juvelines. The water level in the spring used to be -30 cm, whereas after the restoration, it exceeded +10 cm.

The restoration in Ormskatglon and Kobbfladan was only carried out in autumn 2023, so no monitoring results are available yet (Nikolajev-Wiskström, interview on 21 November 2023).

The following lessons were learned during these projects:

- The optimal time for restoration measures depends on the area and location; in Halsskärsgraven, it was noted that the best time for the measure was in the autumn before soil frost causes problems, whereas, in Ytteravan, it was in the summer, a season during which calm weather facilitates the transport of the machinery to the site on a barge. In Långviken, the most suitable time was in the spring to allow the soil masses to dry out while the water level was low. On the other hand, gravel should be spread in winter to avoid leaving traces in nature. The conditions are usually stable between February and May. However, bird nesting sites and the nesting season should be avoided, which also affects site permit processes. In the autumn, the common reed reduces the marks left by machine tracks on site. Careful consideration should be given to different sites' conditions, characteristics and objectives when planning the measures. The best time for most measures is periods during which the water level is low; this is why it is advisable to look at water level statistics from previous years and determine when the conditions usually are the most favourable. On the other hand, water levels are difficult to predict.
- It is essential to determine what the soil on the site is like and which materials should be transported to it. While it was assumed that gravel would be found under the reed bed in Långviken, the soil consisted mainly of silt or clay down to a depth of 1.5 metres (Wistbacka, interview on 30 October 2023). Thorough knowledge of the available materials makes planning and carrying out the work easier.
- It is advisable to use geotextiles and large sacks to stabilise the material when restoring a channel (Wistbacka, interview on 30 October 2023). Unfortunately, few of the more robust materials are biodegradable.
- Materials that can withstand erosion should be selected. It is also a good idea to use coarser material in the top section of the sill/channel and anchor it in place with larger stones. Using a

mix of different gravel sizes rather than gravel with a more consistent structure is important. Materials suitable for the site should always be used (as they look natural) (Wistbacka, interview on 30 October 2023). Sufficient material for the sills is often not found at the restoration sites, or the existing materials are difficult to use and require excavation, which is also not a good idea. As a compromise, material can be transported to the site and mixed with the soil found at the site (Veneranta, interview 23 October 2023).
- It should be noted that closing in a bay (filling in channels, etc.) makes the area more sensitive to water entering from the catchment. Therefore, one should always check the quality of the water flowing in from the catchment before closing a bay to ensure that potential problems with waterquality will not be highlighted due to the restoration measure.
- Monitoring the site based on scientific criteria is not always possible. It would be important to create more straightforward monitoring methods for such stakeholders as landowners (joint property management associations, fishing districts or municipal environmental authorities) to use more extensively.

Challenges

- **Planning the restoration of a natural inlet/channel** may be difficult if the dredging took place long ago and the situation before dredging is not known. Old aerial photographs and reports have been used for planning, and the soil conditions around the site have been examined. Historical aerial photographs can be accessed from the Paikkatietoikkuna website. The catchment size can give an idea of the natural size of the channel/inlet. It would be important to look at different types of catchments and their natural outlets and produce a model to support planning.
- **Conditions**: it is vital to find the most suitable time for carrying out the work, including a suitable water level, the dryest season and the low-water period.
- **Transporting materials and machinery to sites**, with no roads, including outer archipelago sites like Långviken. In 2021, there was no machine contractor in Nykarleby with access to a barge. The transport costs should also be accounted for in the budget.
- **Ownership and attitudes.** Traditionally, excavating channels was considered important, partly because this gave access to the flad, and partly because the excavated channels were thought to improve the living conditions of fish. Consequently, there may be resistance to filling in or narrowing inlets and channels. Investigating measures that can mitigate the harms caused to landowners, such as replacing a dock with one built outside the bay, would be necessary.

Costs and benefits

Most of the construction costs are incurred from excavator use and materials. The costs will increase if the site is located in the outer archipelago and requires transport by barge. Each actor also has their price, as was seen in connection with the work in Ormskataglo and Kobbfladan. The price also depends on the availability of material at the site. Previously excavated material is often located near the channel and forms man-made embankments. In these cases, using such materials is advisable.

- Halsskärsgraven: SEK 230,000 SEK + SEK 20,000 of unexpected costs (ca 23 000 euro + 2000 euro)
- Ytteravan: SEK 109,000 (ca 11 000 euro
- Ormskataglo: EUR 4,500, supervision by the ELY Centre, aquatic plants to be mowed in 2024
- Kobbfladan: EUR 13,500
- Långviken: EUR 17,000 (including planning)

Coastal lagoons are often key spawning habitats for fish, and the juvenile production in individual lagoons may be highly significant. The significance of flads for fish was studied in the Kvarken flad project, which also produced a preliminary estimate of the fish production value as an ecosystem service that a flad may provide.

3.3.2 Culvert replacement/removal of a barrier to migration

The pressure of human activities on the archipelago has increased considerably in recent decades. There is a growing need for infrastructure as coastal construction and settlements increase, alongside other activities such as forestry. The mosaic-like character of the archipelago, with its headlands and bays, is a challenging environment for infrastructure development, and bridges and road embankments have usually been built to span water areas. Occasionally, attempts have been made to preserve water flow, for example, by employing culverts. Unfortunately, such crossings of water areas often affect water exchange, flow conditions and water quality. The possibility of migrating aquatic organisms, such as fish, is also adversely affected. Culverts that were installed at the time of construction may be too small or placed too high, or their slope may be incorrect. They may also shift over time, for example, due to land uplift or water and ice conditions. This may make it difficult or impossible for fish to pass through, especially as the culvert bottom is often smooth and offers no resting places. These factors may stop fish from accessing and spawning in otherwise suitable habitats. Culverts may also cause changes in water quality.

Culvert replacements have been carried out relatively extensively to eliminate barriers to migration. For example, such work has been included in the Interreg projects Rinnande vatten i Kvarken, FLISIK and Kvarken flada, in which some culverts have been replaced and others modified internally to make them more suitable for fish. Similar projects have also been completed in inland areas of Finland; for example, 30 culverts were repaired in the Esteet pois project to improve possibilities for fish migrations. Reports have been produced on the experiences of the Kvarken flad and Esteet pois projects. In addition to work carried out by Metsähallitus, experience in such projects has also been gained from elsewhere, including Sweden and by the County Administration Board of Västerbotten.

Restoration method

This restoration method consists of replacing culverts with structures that better maintain the natural flow and creating channels enabling fish migrations. In all the examples discussed here, the existing culverts were either too small or placed too high, their slope was too steep, resulting in an excessive laminar flow, or they had shifted due to the conditions and no longer did their job. The information has been collected from the projects' final reports and through interviews. As examples for this review, we have selected sites restored in the Kvarken flad project: in Finland, Verkvikfladan in Iskmo (by Metsähallitus) and in Sweden, a flad-gloe complex known as Sladan in Robertsfors (by the County Administration Board of Västerbotten). Examples relating to Korvgräven and Storträsk-Lillträsk sites restored in the FLISIK and Rinnande vatten i Kvarken projects (both by Metsähallitus) are also given. Information for this report was additionally sought in Metsähallitus' guide on restoring culverts that hamper migrations (Karppinen 2020).

While incorrectly placed culverts caused the problems in all these cases, the solutions varied from site to site.

Half culvert

Sladan is a lake connected to the sea by a stream. There was an incorrectly installed culvert close to the lake, which prevented fish migrations to some extent. The culvert was 80 cm in diameter and made of concrete rings that had partially slid apart. The two-part culvert was replaced with a half culvert of the same height, which was placed on a crushed rock bottom and anchored in place. Natural stone was laid on the crushed rock to make the channel as natural as possible. This work took 1.5 days. As the work was carried out, it was noted that while a half culvert is more expensive than a round one, it improves the chances of creating a natural bottom for fish.

A similar-sized culvert dug deeper into the ground

The situation in Verkvikfladan in Iskmo, Finland was similar to that in Sladan. The gloe lake was connected to the sea by a 25-metre stream bisected by a road embankment, under which was a culvert of concrete rings. The culvert was built in the 1990s and placed directly on the bottom of the stream. A crack had later appeared between the two concrete rings, after which the water primarily flowed under them. This reduced the flow inside the rings to a level that was too low for migrating pike, perch and roach for most of the spring. The stream was relatively small, approximately 30 to 40 cm wide and 20 cm deep. A decision was made to replace the old culvert with a new round culvert of the same diameter (80 cm) to minimise changes to the channel. The site was restored in 2019, and the new culvert was installed at a depth of 30 cm into the ground and stabilised to prevent seawater from moving it (Figures 17 and 18). The new culvert was filled with natural gravel and boulders to make the channel as natural as possible. Stones were also added to the channel above and below the culvert to ensure a suitable gradient and the availability of resting and 'staging' areas for fish.

Figures 17 and 18. Vervikfladan culvert before and after restoration: Photo taken before restoration: Maija Haukkala/Metsähallitus 2019, after restoration: Anette Bäck/Metsähallitus 2021.

Replacement with a larger culvert installed deeper in the ground

A similar measure was carried out in a channel leading to Korvgräven in the FLISIK project. The eastern channel of Korvgräven is crossed by a road, under which there was a culvert of 40 cm in diameter (Wistbacka 2013). The culvert was too small and installed too high. It had broken into two in the middle, become compressed and risen higher, preventing all fish migrations to Korvgräven. Consequently, landowners had to manually help pikes get past the culvert during the spring spawning season. In this project, the old culvert was replaced with a new one 1 metre in width, which was installed deeper into the ground and filled with gravel and rocks to achieve the most natural continuation possible for the channel (Figure 19). Stones were also added to the channel below the culvert to create a more natural, meandering stream with resting places for migrating fish.

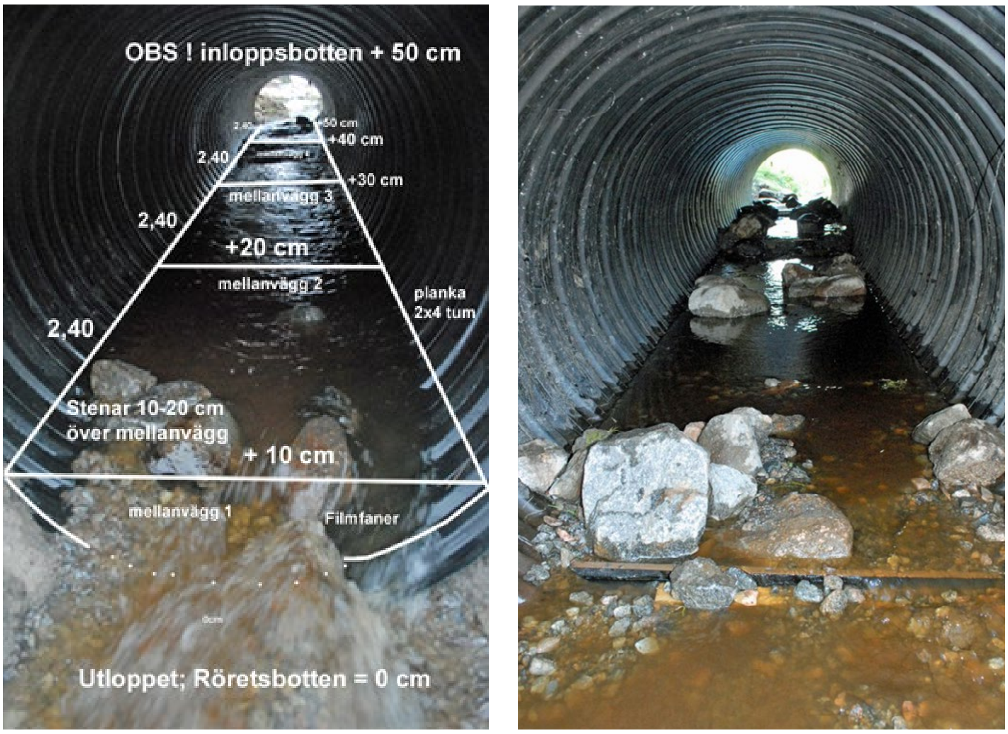
Fish pass in a culvert

A culvert in Storträsk-Lillträsk in Oravais was repaired in the same project. In this case, a culvert that was too small and installed too high was also replaced with a larger culvert installed deeper into the ground (Wistbacka 2009). As the channel had a steep slope, it was decided to build a fish pass inside the culvert and fill it with gravel and rocks, creating a natural, gradual slope where spawning fish could rest and pick up speed. The fish pass was built with waterproof plywood (Figures 20 and 21).

Building a sill

The most common and easiest way to restore an inaccessible culvert is to raise its water level by building a sill in the stream channel below it (Karppinen 2020, Figure 22). This increases the water depth and moderates the slope while also reducing the flow rate in the structure. Stones can be used to eliminate

Figure 19. The culvert was installed deeper into the ground and filled with gravel and stones to create a channel extension that was as natural as possible. Photo of Verkvikfladan: Maija Haukkala/Metsähallitus 2019.



Figures 20 and 21. The channel to be restored had a steep slope, so a decision was made to build a fish pass inside the culvert and fill it with gravel and rocks, creating a natural, gradual slope where spawning fish can rest and pick up speed. The water level is still relatively low in this photo. Photos: Ralf Wistbacka 2013.

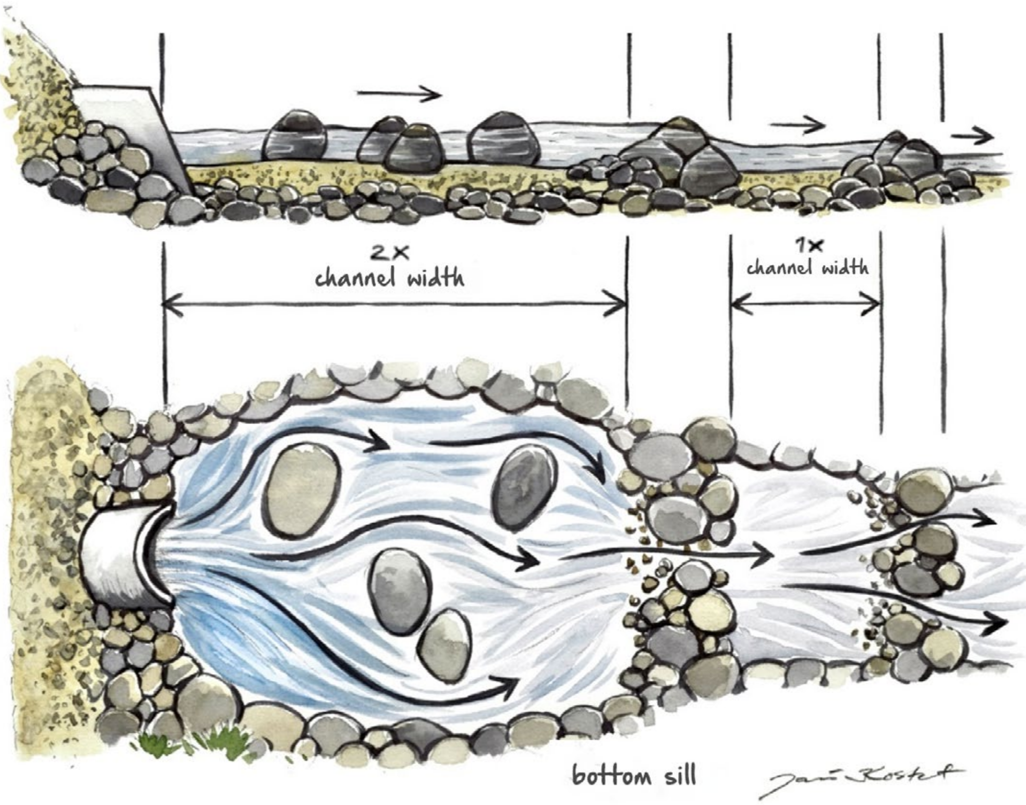


Figure 22. An inaccessible culvert can be restored by building sills with stones and timber in the channel below the culvert. The purpose of the sill is to raise the water level in the culvert and to enable the passage of aquatic organisms through it. Adding stones can also eliminate a fall below the culvert to the channel bottom and/or the water surface. Photo: Jari Kostet/Metsähallitus 2020.

a drop to the channel bottom and/or the water surface below the culvert. For support for replacing culverts and planning, see such documents as the guide to restoring culverts that hamper migrations (Metsähallitus 2020).

Monitoring methods

The selected sites in the Kvarken flad project, including Verkvikfladan, were surveyed for three consecutive years. While the purpose of the surveys was to collect information on seasonal variations, their results were also used to monitor the restored bays. See the report Mikkola et al. (2019) for the methods used.

The vegetation of Verkvikfladan was studied in 2017, 2018, and 2019; in other words, it was studied two years before and one year after the restoration was completed. The surveys and monitoring showed that aquatic plants' species composition and coverage varied, sometimes significantly, from year to year in all the bays studied (Mikkola et al. 2019). This made the impact of restoration on vegetation challenging to interpret in Verkvik. The report notes that "with regard to Verkvikfladan, something happened in 2019 to reduce the vegetation coverage significantly compared to 2018, and charophytes took over the dominant position from vascular plants. The stream leading from this gloe lake was restored in late winter 2019 by replacing a culvert to facilitate the passage of fish. However, this should not have had a significant impact on water quality and is unlikely to be the cause of the change, whereas it may have been a contributing factor." Interviewees from the County Administrative Board of Västerbotten noted that monitoring vegetation is challenging. In this context, it would be important to have a clear picture of which factors can be expected to change and how the actual monitoring should be carried out to obtain data that demonstrate the impacts of the completed measures. These factors and practices remain unclear for now.

The project also examined fish spawning and juvenile production before and after the measure. Pike juveniles were searched for along a specified transect using a scoop net. Perch spawn ribbons were surveyed on specified shore sections, and juveniles were sampled using a tow net. For the methodology used, see the report *Fiskyngelproduktion i grunda avsnörda havsvikar* (Saarinen et al. 2021). Juveniles migrating out to sea were also studied. However, the monitoring studies did not indicate a change in the first year after restoration. Fish were able to access Verkvikfladan before and after the culvert was replaced, which is why it is unlikely that there was any major change for them (Veneranta, interview on 23 October 2023). This lack of change may also be due to fish homing behaviour, which will take two to four years before an increase can be expected. Consequently, conducting new monitoring studies would be important. For more information on the fish fauna and fish reproduction in Verkvikfladan, see "Hauen (*Esox lucius*) ja ahvenen (*Perca fluviatilis*) lisääntyminen sekä poikasten esiintyminen, kasvu ja ulosvaellus kahdessa Merenkurkun rannikon pienvesistössä" (Palo 2020).

The sites restored in the Rinnande vatten i Kvarken and FLISIK projects were surveyed using a method for inventories of streams developed in the project. As the projects mainly focused on streams, no large-scale surveys of gloe lakes were carried out. Landowners used traps to monitor migratory fish (Öja fiskelag and Oravais Fiskargille).

The projects in both Korvgräven and Storträsket-Lillträsket were successful in guaranteeing the spawning migration of the pike and perch (Wistbacka, interview on 30 October 2023).

Experiences of the method

Outcomes

Restoration measures and structures aimed at replacing culverts and removing barriers to migration have proven highly effective, safe and permanent. Fish have been found to move through them effortlessly, using the sheltered areas, basins and fish passes provided to facilitate their migration. Once culverts have been replaced, fish can move freely through them. Fish surveys carried out by landowners confirm that fish can pass through the area and reproduce.

Site users and landowners have been satisfied with the measures taken, as they significantly improve fish production while enabling repairs to road embankment/culvert structures. From the monitoring perspective, priority should be given to fishing and fish production, as they are the most likely and easily identified improvements (Wistbacka, interview on 30 October 2023).

The following lessons were learned while working on the restoration measures:

- It is more expensive to replace a culvert with a half culvert than with a culvert of a similar size. However, a half culvert may be a better option for fish, as a more natural bottom and smaller water flow can be achieved this way. On the other hand, a slightly larger round culvert can often be installed deeper into the ground, making the channel sufficiently broad, and it can be filled with material (gravel and stones) to create a natural continuation for the channel. This is a less expensive option. However, it is advisable to conduct thorough soil surveys in advance. If the bedrock is unsuitable and blasting is required to instal a round culvert into the ground, replacing it with a half culvert may be cheaper (Wistbacka, interview on 30 October 2023).
- If the channel has a slope, the culvert may sometimes have been installed in an inclined position. Where the bottom is smooth, and the flows are strong, it is less likely that soil materials will remain on the bottom. In these cases, using the method employed in Storträsk-Lillträsk is advisable: the culvert is installed horizontally, but a fish pass is built inside it to counteract the slope. The gravel inside the culvert must be sufficiently coarse, i.e. 10 to 60 mm, with stones 20 to 40 cm in diameter, to prevent it from being washed away. The gravel should be anchored with stones both inside and outside the culvert.
- It is also necessary to ensure that the construction of the channel on both sides of the passageway facilitates fish migrations. For good examples, see the report titled 'Esteet pois' (Karppinen, 2020, Figure 22).

Challenges

- The road must be closed when the work is in progress. While a culvert can usually be replaced in a day, the operation still requires active communication with road users. An additional requirement is planning the work so that it has as little impact on road users as possible (including the timing of the work) and anticipation regarding traffic arrangements during the project. The sites are, fortunately, often located in the archipelago and along more minor roads.
- Construction materials typically contain plastic; finding functional plastic-free materials can be challenging.
- The monitoring methods cited in the restoration guide may be too demanding for many stakeholders. In principle, with good timing, fish can be monitored using a trap (Wistbacka, interview on 30 October 2023).

Costs and benefits

Replacing a culvert is often a cost-effective way to secure possibilities for fish migration into gloe lakes and gloe-flads. The costs depend on the size and shape of the culvert, as a half culvert is more expensive than a round one. To carry out the work, an excavator and soil materials to be placed around and inside the culvert are required to achieve a sustainable solution and a natural bottom. As the sites can usually be accessed by roads, transport to the site is relatively fast and trouble-free. The most time-consuming part usually involves discussions with the users of the area and any permit processes, as well as surveying, planning, and monitoring the sites. Appropriate disposal of removed culverts and materials must also be addressed.

The actual costs of culvert replacements on the sites discussed above were:

- Verkvikfladan: EUR 1,900
- Sladan, Robertsfors, Sweden: SEK 128,000 (ca. EUR 13,000)
- Korvgräven: The measure was completed more than ten years ago, and its costs are consequently not comparable to today's price levels.
- Storträsk-Lillträsk: The measure was completed more than ten years ago, and its costs are consequently not comparable to today's price levels.

3.3.3 Opening a channel

The water in a flad is a mixture of saltier seawater and fresh water from the catchment. The species composition in the flad is often diverse, and as flads are connected to the sea, these warm and protected water bodies often serve as ideal spawning grounds for fish in spring. Land uplift slowly raises the threshold and reduces the connection to the sea; at some point, the connection will finally be lost. Due to this natural process, the water quality, species composition and function of the bays will change over time.

Cases can be found, however, where a flad's connection to the sea has been closed 'prematurely'. They may have been closed off by road embankments or connected to the sea by a narrow culvert (see 3.3.2). The connection may have been closed for reasons relating to fishing (including historical fish dams) or for aesthetic reasons to change the water level and to build private pedestrian bridges across waterways. Dense reed beds formed due to eutrophication also impede or slow the water flow, fish migrations, etc.

This review mainly focuses on methods that can be used to restore streams and channels that have become overgrown due to eutrophication, as this is the problem where the most experience has been gained. Overgrowth caused by eutrophication is the most common problem in coastal lagoons. Keeping the channel/water flow connection open between the sea and the bay that is about to become enclosed to ensure fish migrations is not a new invention; on the contrary, it used to be a relatively common measure in the archipelago and part of the annual management of spawning grounds that were important to landowners or users of the area. They removed barriers manually to safeguard their future catches. This tradition has almost disappeared, having been replaced by overgrown waterways or the use of heavy machinery such as excavators, which has led to other problems (see 3.3.1). However, the method has been introduced elsewhere for restoring flads and gloe lakes. For example, it has been used in the Kvarken flada, FLISIK and Rinnande vatten i Kvarken projects and the HELMI programme.

Restoration method

The method aims to open and restore estuaries and channels connecting a bay to the sea, restoring a state that corresponds to the natural water exchange conditions of the flad's development phase. The method aims to restore the connection to the sea and, consequently, restore the natural conditions, species composition and ecological functions within the flad. While the method has been used relatively widely, we have selected as examples Dollosverkan in Björköby (Metsähallitus) and Roliggropen in Korsnäs (ELY Centre for South Ostrobothnia), which are included in the HELMI programme, and Norrfjärden-Flybäcken, which is part of the FLISIK and Rinnande vatten i Kvarken projects (Metsähallitus).

Dollosverkan is a gloe lake in Björköby, Korsholm. This complex is in a relatively natural state, even if fellings and forestry operations have taken place in the catchment area. A forest ditch has been dug that discharges into the gloe lake, and it is likely that minor manual measures have been carried out going back in time to maintain this channel, which is around 150 metres in length. As in many other areas, there is a dense reed bed on the seashore. Because of this zone, the last 30 to 50 metres of the channel have become overgrown, and water now flows over a larger area, as there is no clear channel into which it can be concentrated. The absence of a clear channel and dense vegetation have prevented fish migrations into the gloe lake, and fish are spawning outside it and in the bays surrounding it instead.

While reed beds are part of the natural flora in the area and the connection to the sea is being cut off by land uplift, eutrophication was considered to have accelerated the process at this site. Consequently, Metsähallitus decided to take action. During the restoration project in 2021, the channel was marked with GPS coordinates and cleared manually using hoe forks, scythes and rakes (Figure 23). Reeds were pulled up with their roots in the channel and taken to one side, and the workers walked back and forth in the channel to solidify its bottom. The work was

Figure 23. The channel in Dollosverkan was cleared with a scythe and hoe fork. Photo: Anette Bäck/Metsähallitus 2021.

carried out in June, and a team of five people completed it in half a working day. To prevent the water level in the gloe lake from dropping, stones were placed at selected points in the channel to slow down the water flow and to maintain the same flow rate as before restoration.

Roliggropen, a gloe lake in Korsnäs, is in its natural state; no forest ditches discharge into it, and neither the gloe lake itself nor its channel have been excavated. The gloe lake is connected to the sea by a 130-metre channel (Figure 24). The area is flat, and large coastal meadows have become overgrown by dense and tall reeds. Emissions from fur farms and feed factories have driven eutrophication in the sea area and bottom sediments, which may partly explain the lush reed vegetation (Wistbacka 2023). In previous studies, fish could access the gloe lake for spawning. However, as the reeds grew even more abundant, spawning in the gloe lake ceased; instead, eggs and juveniles were found on the shores and in the inlet of the gloe lake (Veneranta, interview on 23 October 2023). In the planning phase of the restoration project, using an excavator and sealing the channel bottom with a geotextile were considered. However, trying out methods that were as natural and gentle as possible was considered desirable at this site, and a decision was made to mow and pull up the reeds using various hand tools. The vegetation removal was repeated, and the vegetation was monitored for a few years. The work was carried out by volunteers. In the first working party in spring 2022, seven volunteers participated in the work for one day; in spring and autumn 2022 and 2023, two volunteers worked for two to three hours at a time. In 2022–2023, a total of 16 people participated in voluntary work, and the total number of hours worked was 70.

Roliggropen and Dollosverkan are example sites where the vegetation was removed using manual tools, whereas in Norrfjärden, parts of the channel bottom were also covered with stones to reduce the reed bed's capacity to regenerate.

Figure 24. Restored channel of Roliggropen in an aerial photograph. Photo: Anette Bäck/Metsähallitus 2022.

While Norrfjärden in Kristinestad is classified as a bay and an estuary of the Tiukanjoki River, it was included as an example because the Flybäcken stream discharges into it. Flybäcken leads to Storträsket, which has previously offered good spawning grounds for fish. Norrfjärden is shallow and has been strongly affected by water and sediment carried into it by the River Tiukanjoki, so a highly dense reed bed has colonised it. The reeds grow so densely that it is difficult for fish to get to Flybäcken from the sea. In 2010, a fish pass was restored in the FLISK and Rinnande vatten i Kvarken projects to improve the possibilities for fish migration. The actual channel was marked with GPS coordinates and cleared over the summer months using a scythe and a spade. Stones were placed on the bottom of the channel to prevent the recovery of the vigorous reed vegetation. The stones were transported to the site in a snowmobile in winter and placed in piles on ice along the route, saved as GPS coordinates. As the ice conditions were relatively poor, the entire length of the channel could not be covered. The piles of stones sank to the bottom as the ice melted in the spring. The channel was examined in summer, and the stones were moved around in the mowed channel as necessary.

Monitoring methods

Dollosverkan was mainly restored for fisheries purposes, so it was necessary to monitor the numbers of fish entering the spawning area and juveniles migrating out later (Veneranta, interview on 23 October 2023). Natural Resources Institute Finland started monitoring the site before the restoration was carried out and has since continued to follow its development for two consecutive years. The methods used are monitoring fish with a camera trap and catching fry in a net to assess their density. While fish numbers have increased, it should be noted that there is a certain delay in this respect caused by the strong homing instinct of fish. The best idea of the results can only be obtained after two to four years, and the actual results are consequently not yet available. The experiment also produced information on the length of time an open channel will remain open before further action is needed. The results were still satisfactory after two years, even if minor improvements were made during a field visit.

Roliggropen was also surveyed before and after restoration. As a part of Kvarken flada project, vegetation, water temperature and fish fauna were surveyed in 2017. To monitor the impacts of the measures coducted by the ELY Centre, Natural Resources Institute Finland repeated the surveys of spawning fish and juveniles in 2022, and the ELY Centre measured water temperature and levels both inside and outside the flada (Nikolajev-Wikström, interview 21 November 2023). Natural Resources Institute Finland found that the number of spawning fish had increased in the area after the restoration measure. When carrying out measures of this type, to gauge the scale and permanence of their impact, it is important to monitor the channel to see if it remains open or becomes overgrown again. Although both sites have required minor annual improvements as reeds have started growing in the channel in places, the decline of the reeds is still apparent.

In Norrfjärden, fish were monitored using traps. The number of fish showed a clear increase after the measure (Wistbacka, interview on 30 October 2023). More than ten years have passed since the original restoration of Norrfjärden, and the situation has once again deteriorated, which is why the site requires further action. Such sites should be checked and restored every spring to ensure the permanence of the measures.

Experiences of the method

Outcomes

The results were positive in all the examples, and the channels and their function could be restored manually. Monitoring also showed that reed vegetation did not recover to its previous level in the years following the measures. Improvements made in the year following the restoration took much less time than expected. An increase in the number of spawning fish was found, even if it was minor.

- While using a snowmobile to carry stones into the channel has great potential as a method, a good ice winter is needed for it to work.
- Volunteers carried out a large part of the work. This is the advantage of simple methods: anyone can do the work. Simple measures carried out by volunteers have great potential to spread into wider use. They also help to avoid major excavations as the work is carried out by a larger team with hand tools.
- The results show that, whereas clearing the channel may at first require considerable effort, once the initial work has been completed, the vegetation will grow less densely. In the future, minor repeat measures will only be needed annually or every few years.
- Landowners or users of areas could be encouraged to take care of fish spawning grounds that are important to them; the authorities could select the sites and either carry out or support the initial restoration measures. The management of the site could then be handed over to local stakeholders. It would be important to draw up a clear list of sites where such restoration measures can be taken and to ensure that there is no more excavation on sites that have already dried out. The list of sites should be updated regularly, accounting for their natural development and the impacts of land uplift.

Challenges

- Convince local stakeholders that subtle restoration measures (no excavators) are often better, and involve local people in restoration work and checking fish migration routes annually.
- Cleared channels will become overgrown over time without maintenance. Maintenance could consist of repeatedly removing vegetation, adding stones to the channel, or other means of preventing the growth of reeds. However, all require a longer-term commitment to the sites.
- Land uplift and flads and gloe lakes drying out is a natural phenomenon. Restoration is not about restoring water connections that have naturally dried out. Restoration measures aim to restore the connection to the sea/water flow in those channels that, without human intervention, could still be in contact with the sea. This should be ensured by carefully examining the site topography when selecting sites and by ensuring that the channel height is reverted to its natural level during the planning process. This is not a simple equation, however.
- When the channel is cleared, as in Dollosverkan, this can affect the flow. Controlling flows with natural methods requires subtle action, and in order to monitor the flows, information on water levels and flow rates is needed before the measures are carried out.

Costs and benefits

A large part of the costs incurred from measures aiming to restore the channel consists of planning (finding the sites), field visits, planning and applying for permits, and possibly finding a contractor. In contrast, the costs of the actual work in the field are relatively low. For example:

- Dollosverkan: Volunteers from the Finnish Federation for Recreational Fishing

partly carried out the restoration work. Approximately EUR 3,000.
- Roliggropen: EUR 3,400 (including planning and work), implementation EUR 1,100
- Norrfärden: The measures on this site were completed over ten years ago, and the prices are no longer comparable with the current situation.

3.3.4 Catchment restoration

A significant proportion of the water in the Baltic Sea comes from its catchments. The sea shows clear signs of human influence, especially in terms of high concentrations of nutrients from agriculture and forestry. This has led to eutrophication, which is currently the most acute problem faced by the Baltic Sea. The effects of eutrophication are visible throughout the Baltic Sea but especially in coastal and shallower areas, including flads with a low level of water exchange.

The water quality in the Baltic Sea, particularly its shallow areas, clearly reflects the impacts of land use in the catchments. Due to timber harvesting, agriculture and drainage, water containing humus and nutrients flows into flads, causing eutrophication, turbidity and hypoxia and colouring the water brown. This may change the composition of species, accelerate overgrowing, and impair the living conditions of plants and animals. Drainage of acid sulphate soils can also lower the pH and release metals into the water that may damage fish stocks.

Water quality affects the potential of a site to be restored. The restoration will fail if the water quality is not suitable for a particular species or activity. Sometimes, restoration may even enhance the negative impacts. A prominent example of this is the restoration of flads and gloe lakes, where rebuilding a dredged sill may limit water exchanges with the sea and exacerbate the negative impact of the catchment on water quality in the flad.

However, there are few or no examples of restoring an entire catchment to improve the status of a flad or other sea areas so far. In contrast, many examples of catchments restored inland to improve the status of lakes and rivers can be cited. To approach this method, we will rely on experiences gained from restoring the catchments of lakes and rivers, whereas in the handbook to be produced later in this project, we strive to describe the specific catchment restoration experiences of the Biodiversea project.

For example, catchment restoration projects have been carried out in the Freshabit LIFE IP project and projects completed by WWF Finland (including (4K, VALUTA1-2, RANKKU1-2, Metsälähde). The report on the Freshabit LIFE IP project (Härkönen 2022) notes that primarily, efforts should always be made to prevent the root causes of problems, and only after this will restoration be worthwhile. Methods for reducing the impacts of agriculture on waters include controlled subsurface drainage, reduced ploughing in autumn and increased plant cover in winter to prevent erosion, as well as precision farming, which promotes more accurate nutrient use and reduced fertilisation to prevent or decrease nutrient loading (Pesonen et al. 2010, cited in Härkönen et al. 2022). Various soil improvers for agriculture, including lime, gypsum and structural fibres, can also reduce the load of nutrients and solids in water systems by improving soil structure and preventing erosion (Ajosenpää et al. 2022, cited in Härkönen et al. 2022). In forestry and especially in peatlands, efforts to tackle loading and erosion can be made through continuous cover forestry, which can reduce the need for drainage and consequently decrease the load of solids, nutrients and humus (Nieminen et al. 2018, cited in Härkönen et al. 2022).

Restoration method

The outcomes of the Freshabit LIFE IP project, which sought and tested solutions for reducing the negative impacts of catchments on lakes and rivers, are discussed in this review. An example is the measures used to restore the catchment of Lake Puruvesi. We also describe the experiences of WWF Finland, which has engaged in landowner-driven wetland construction in Western Uusimaa since 2018.

While Lake Puruvesi has mainly been assessed as having an excellent ecological status, monitoring has indicated a deteriorating trend. The lake has become eutrophic, resulting in reduced visibility even in the most transparent open water areas and abundant primary production, sedimentation and disturbed ecosystems, particularly in shallow and isolated bays. The water system is impacted by loading from agriculture. In addition, large volumes of solids and nutrients are carried from old urban wastewater treatment plants, pumping plants in fields, and peat extraction areas due to erosion. A significant part of Lake Puruvesi's catchment comprises drained mire forests, and problems in the catchment area are emphasised in an otherwise naturally nutrient-poor water body with slow water exchange.

The Freshabit project tackled the whole area and carried out measures in various parts of the lake. The aim was to use different water management measures in the catchments to reduce the load entering the lake and improve water quality in bays through intensive fishing and mowing of aquatic plants. One project outcome was that building protection structures in the catchment's upper reaches was advisable since preventing and retaining loading is more manageable in smaller upstream sub-catchments (Härkönen et al. 2022). In addition, building several consecutive water protection structures is recommended, especially if the catchment is large or the load is significant.

Wetlands and sedimentation basins

Large-scale wetlands were built in several areas to reduce the transport of solids and nutrient emissions. The key wetland processes comprise the sedimentation of solids and the nutrients bound to them in the wetland bottom sediments, the accumulation of nutrients in wetland vegetation, periphyton and sediment, and nitrogen removal through denitrification (Puustinen et al. 2007, cited in Härkönen et al. 2022).

Soil was excavated to construct the wetlands, and embankments and dams were built. The spoils were spread on adjacent field areas or used for building embankments to reduce proneness to flooding and strengthen the structures. Meandering waterways increased water retention, giving nutrients more time to bind to the vegetation in the basins. Deeper sedimentation basins were built in the upstream parts of the wetlands. In contrast, the downstream parts contained shallower areas with more islands, enabling vegetation to bind nutrients dissolved in the water.

While the report notes that the functioning of a wetland is strongly related to its size and vegetation, the most important is its ability to retain water (Puustinen 2007, cited in Härkönen 2022). Water retention can be promoted not only by making the wetland bigger but also through islands, embankments, stones, and timber stream deflectors that force the water to take a meandering path (Koskiaho 2003, cited in Härkönen et al. 2022). The variation of shallow and deep water areas and islands improves the functioning of the wetlands as a habitat. The recommended wetland size is typically at least 2% of the catchment surface area (Leonardson 1994, Härkönen et al. 2022).

Sedimentation basins are used to slow the flow rate and ensure that solids settle in the bottom of the basin by gravity. They work best where the flow rate is fast, and concentrations of solid matter are high. The basins cannot retain the finest types of solid matter (Joensuu et al. 1999, then Härkönen et al. 2022). Although sedimentation basins may successfully retain some of the total phosphorus and nitrogen bound to the solids (Joensuu et al. 1999, cited in Härkönen et al. 2022), they do not affect dissolved nutrients and dissolved organic carbon concentrations.

The report also mentions sludge sumps which, due to their small size, have poor retention capacity, and the sedimented solids can be washed away, for example, during large flows (Finer et al. 2020, cited in Härkönen et al. 2022).

Overland flow field

In the Lautalahti area, overland flow fields were also built, which corresponded to 0.5% of the catchment surface area. This dimensioning was expected to produce positive results for the water area.

The report shows that overland flow fields have proven the most efficient water protection structures for drained areas (Hynninen et al. 2010, cited in Härkönen et al. 2022) as they can remove up to 70% and even 100% of solid matter. In some cases, they can be used to remove dissolved nutrients from runoff waters. Reducing the volume of solids upstream from the overland flow field is important to avoid filling it up, in which case it may release a corresponding load of solids downstream. Overland flow fields are not suitable for all sites because they require a large surface area (Nieminen et al. 2018, cited in Härkönen et al. 2022).

Erosion protection

In ditches excavated for forestry and agricultural purposes, the water often flows rapidly and can easily transport soil from the channel edges. The purpose of erosion protection measures for channels and ditches is to reduce the amount of solids carried away from them. Based on experience, erosion protection measures were carried out in winter to reduce the washout of solids. Erosion protection in a channel meant strengthening and supporting the eroding channel wall, typically with aggregates. Aggregates prevent the collapse of softer soils into the water flow, significantly reducing the volume of solids in downstream basins, especially during flood periods. In drained areas, the flow was also directed to channels with a lower erosion risk. Diversion dams were built to direct the flow back to the natural stream channel with a lower flow rate. In such areas as Myllypuro, the flow was additionally directed using bottom sills and clearing small silted channels with slower flows.

Bottom weir

A bottom weir was built above the Jouhenjoki wetland to level out the flow of the River Jouhenjoki, especially upstream from the dam. The bottom weir slows down the river's flow during floods and also tends to retain water in the river during dry spells. This reduces erosion and solids washout and helps the downstream wetland function more effectively.

The report additionally refers to dams with a discharge pipe, which have been found to effectively retain solids washed out from peatlands due to drainage (Marttila & Klove 2010, cited in Härkönen et al. 2022). At the same time, phosphorus and nitrogen bound to the solids can be removed. It should be remembered, however, that dam structures do not significantly remove dissolved nutrients or dissolved organic carbon concentrations from runoff waters.

Mire restoration

Drained mires are restored to recover their natural water levels and flows to stop the drying out of the mire, restore the natural water table, and restart peat buildup. In addition to safeguarding biodiversity, the aim of mire restoration may be to improve catchment water retention capacity as well as to reduce loading in waters and CO^2 emissions in the atmosphere caused by peat decompo-

Figure 25. Blocked ditches, Pohtiinsuo. Photo: Maarit Similä 2018.

sition (Juutinen et al. 2020, cited in Härkönen et al. 2022). Methods used in mire restoration projects include filling in and damming ditches, raising the water level, removing or thinning out trees, and clearing ditch lines.

In addition to these structures, the report notes that **buffer zones, two-stage channels and flood plains** can improve channel diversity and retain solids (Puustinen et al. 2019, cited in Härkönen et al. 2022). In the Freshabit LIFE IP project, **intensive fishing and mowing of aquatic plants** were also carried out as restoration measures in the Puruvesi water system.

WWF Finland has constructed wetlands in several projects (4K, VALUTA1-2, RANKKU1-2, Metsälähde). The objectives of the constructed wetlands include better water management, reducing loads carried from the catchment into the sea, increasing biodiversity, adaptation to climate change and improving water quality in general (Kokkonen and Kaasonen, interview on 18 December 2023). The wetlands were constructed by excavating and damming, or both methods were used on privately owned lands mainly composed of clay soils.

Monitoring methods

In an interview, Ilmonen (22 December 2023) emphasised the importance of carefully planning and carrying out the monitoring. At the beginning of the Freshabit project, a hierarchical, comprehensive list was drawn up of monitoring methods suitable for the different types of measures to be carried out. The monitoring was both ecological and technical. However, it has been recognised that in many cases, it is inadvisable to carry out excessively in-depth monitoring, such as surveys extending to the level of individual species, as it requires plenty of competence and resources. Additionally, there often are little or no resources for monitoring. The advice is that whatever the planned measure, determine the site type, identify the problem that needs to be solved and the kind of monitoring that can demonstrate the measure's potential impacts. The indicators to be used should be decided on this basis. Simple indicators should be selected as the first preference, adding some in-depth ones that can be brought into play if appropriate.

Measures taken in the Freshabit project primarily aimed to influence the water quality/loading. Consequently, this variable was the primary one monitored. The water quality monitoring methods in Lake Puruvesi included continuous measurement of nutrients flowing through a monitoring station in a water body into which the waters of a problematic sub-catchment were discharged. The station monitored chlorophyll values, turbidity, dissolved organic carbon, oxygen concentration, conductivity and total phosphorus content.

Other proposed simpler ecological indicators included overgrowth, open water area (also in bird habitats), temperature (also in flads) or the coverage of a specific vegetation type. If necessary, more demanding monitoring can also be carried out, for example focusing on benthic animals or other species.

Creating a monitoring network for wetland restoration would be helpful in facilitating the planning, implementation, and monitoring of future restoration measures. When a larger number of restoration sites are monitored using established methods, a picture of how various types of wetlands respond to different measures can be obtained, giving a good idea of the efficiency and effectiveness of the measures. This at least partly eliminates the need to monitor future restoration projects.

While focused monitoring is not carried out on all WWF project sites, water quality is monitored if funding is in place (Kokkonen and Kaasonen, interview on 18 December 2023). For example, the Pro Litore Association has been monitoring water quality on the Western Uusimaa coast annually. In addition, in a few individual representative wetlands of different ages, water quality has been monitored monthly in the inlet and outlet channels since 2023. This monitoring has only covered such a short period that it has not yet been possible to draw conclusions on the results. However, wetland construction has long been recognised as a viable restoration measure. So far, The results indicate that water retention has increased in constructed wetlands. Many aquatic birds also settle on the sites immediately after completion, with the horned grebe (*Podiceps auritus*) among the rarest observations. On a constructed pike wetland site, the pike spawning has already been successful for two consecutive years.

Experiences of the method

Outcomes

Some of the measures completed in the Freshabit project were successful while others failed. For a more detailed description of the sites, their monitoring and results, see the report titled *Kunnostusten vaikutukset vesistöjen ekologiseen tilaan ja Natura-alueiden suojelutasoon Freshabit LIFE IP-hankkeen kohteilla* (Vuorio et al. 2022).

The wetlands constructed in the catchment of Lake Puruvesi proved that the structures retain water appropriately. Increased biodiversity was observed in the Lautalahti wetland, for instance, and the wetland had many users. The erosion rate remained stable and reduced the erosion of solids during spring flows. On the other hand, Jouhenjoki wetland was not quite as successful; its location was too low in relation to the lake's water level, and it requires remediation.

In most cases, no clear impact on water quality was observed during the project, and in some, an increase in nutrients was even observed. Time is crucial in restoration projects; restored sites and structures need time to evolve before they achieve the intended impact. It should also be noted that long-term monitoring is needed to demonstrate the ultimate impact.

The lesson learned in this project was that correct dimensioning and selecting an appropriate location are essential; the measure should be sufficiently large in scale (such as a wetland), and its location must be selected correctly (Ilmonen, interview on 22 December 2023). The risk of the necessary measures being impossible or not going ahead is often present, for example, due to land ownership relations, which also means that the objectives, or optimal results, will not be achieved. Paying attention to the location of the measures, such as correct elevation, is important. In this context, fluctuations in hydrological conditions and other similar factors should be accounted for, ensuring that the structure will always remain at an appropriate height above the water level and operate continuously. For example, the sedimentation basin built on the River Jouhenjoki was placed too low, sometimes resulting in it being inundated during flooding and failing to work.

The WWF's wetland projects have usually gained good media visibility, landowners have been successfully inspired to engage in water protection measures, and a clear change in attitudes towards wetland measures and actors has been seen in the relevant areas (Kokkonen and Kaasonen, interview on 18 December 2023). The WWF has completed projects on many sites over the past five years, and many others are also awaiting measures. Good cooperation, open communication and catchment-specific coordinators play a key role in landowner-driven wetland construction. Although the importance of monitoring is also emphasised, long-term monitoring may be a challenge in projects with a duration of two to three years. Wetland construction is slowed down by lack of funding and, at times, landowners' opposition.

Challenges

As in most measures, weather conditions are crucial. Freezing weather prevented some measures from going ahead, whereas in others, a lack of soil frost hampered the work and transport of materials. Water levels are also a constant challenge that can neither be controlled nor predicted accurately.

Other challenges included reconciling different values. A protected moor frog (*Rana arvalis*) was found at one site. This meant the plans needed to be changed to avoid negative impacts on this species.

Funding was also sometimes a challenge in projects. For example, the rules of one of the funding instruments used changed while the project was in progress, and new options had to be sought. Funding, particularly that which covers a sufficiently long period, is a constant challenge in restoration projects. In addition, to achieve reliable results, finding the funds for monitoring over a sufficiently long period should also be secured.

Costs and benefits

The total costs of water system and catchment restoration projects are affected by several factors, including the selected restoration methods, the size of the area to be restored, the nature of the problem causing the need for restoration, and the amount of any voluntary work required (Tiusanen et al. 2022). The costs may vary by region and time of year depending on the measures prioritised at each site. Consequently, giving a generalised estimate of the resource requirements is challenging.

During the Freshabit LIFE IP project, the Finnish Forest Centre planned 12 water protection projects in the catchment of Lake Puruvesi (Härkönen et al. 2022). The sizes of the sites varied from large catchments of a few thousand hectares to smaller ones of a few hundred hectares. In this project, around one hundred bottom weirs, dams with discharge pipes and sedimentation basins, and approximately 30 hectares of wetlands and overland flow fields were planned.

The restoration work in Lake Puruvesi catchment cost approximately EUR 700,000 (Härkönen et al. 2022, see Figure 26). This amount covers many measures, including the actual catchment restoration and background studies, monitoring, lake restoration, work supervision and planning of measures.

Although an expert assessment of the benefits of the restoration was conducted, the economic impact of the benefits was not calculated in any of the reports (Marttunen et al. 2022, Härkönen et al. 2022).

Kokkonen and Kaasonen noted in an interview that the costs of the WWF's constructed wetlands vary depending on the methods used, their location and the period, and the current estimate is EUR 25,000 to 35,000/ha.

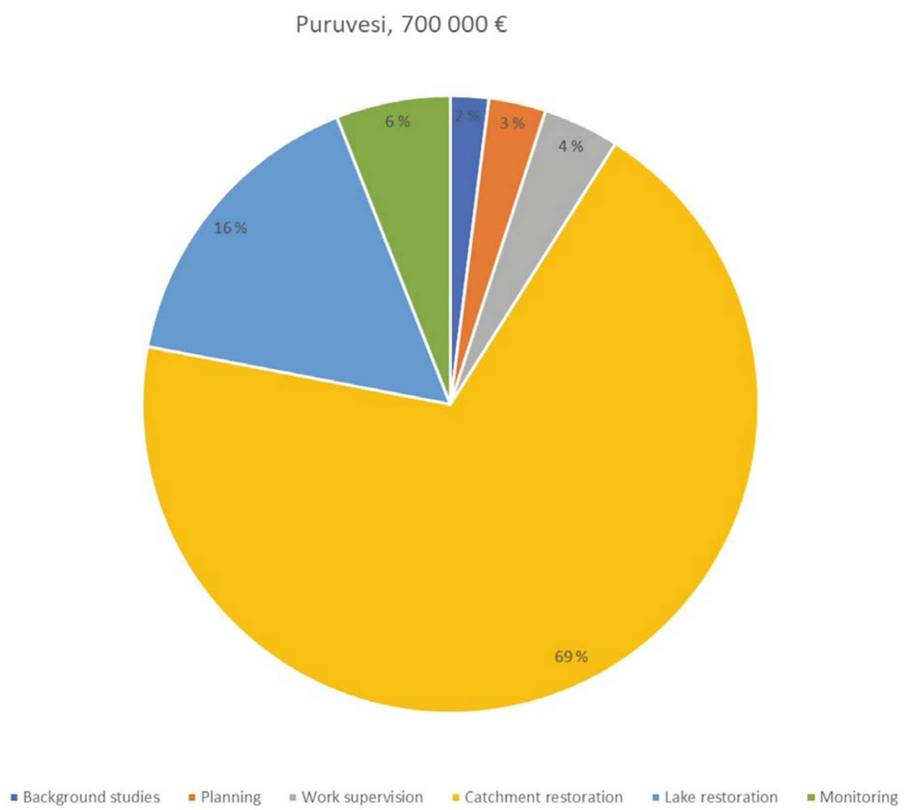


Figure 26. In total, the restoration of Lake Puruvesi catchment cost around EUR 700,000 (Härkönen 2022), divided into different cost types below.

3.4 Large shallow bays (1160)

Conservation status[1]	Trend[1]	Status in 2018[2]	Other points
Unfavourable, bad	Stable	Not included in the assessment	

[1] Assessment of conservation status and trends given in the habitats report referred to in the Habitats Directive 2019
[2] Kotilainen et al. 2018 Threatened habitat types in Finland 2018: the Baltic Sea.

3.4.1 Removal of submerged aquatic vegetation

As eutrophication in the Baltic Sea increases, certain submerged plant species that thrive and spread efficiently in nutrient-rich waters have become abundant in shallow and sheltered sea bays. Dense aquatic plant colonies hinder recreational use (swimming, boating and fishing) and the migrations of juvenile fish (Sandström 2003, cited in Kraufvelin et al. 2021a), while stronger competitors take over living space from original species of the habitat that are more sensitive and less successful in competition. One of these species is Myriophyllum spicatum, which has probably benefited from the gradual eutrophication of shallow bays and possibly also from the warmer sea water and longer growing season brought about by climate change. In Finland, undesirable aquatic vegetation such as *Myriophyllum spicatum* has been removed from lake habitats by mowing, mechanical excavation and suction dredging, especially by lake conservation associations. Similar measures have been taken abroad, for example in North America in the Great Lakes region (e.g. Carpenter & Adams 1977, Carson et al. 2018). Only in recent years such measures have been necessary in sea areas in Finland.

The results of attempts to eradicate *Myriophyllum spicatum* in lake environments have varied; in some cases, the removed vegetation has been replaced by other species, while in others, algae blooms have occurred after its removal. Worldwide, other mechanical methods besides mowing (including manual removal, hoeing, dredging and cutting), biological control (herbivorous fish and insects) and chemical methods (pesticides) have been used to eradicate *Myriophyllum spicatum*. However, the results obtained with all methods have been variable, and no fully effective method has been found (Kumwimba et al. 2020).

Restoration method

The nutrient load accumulated in a bay is removed once or repeatedly by mechanical mowing. The mowed submerged plants are removed from the sea. Removing vegetation improves water turnover, and the site's status will recover naturally. At the same time, an effort is made to improve the natural conditions of the bay and reduce the amount of degradable plant material that may accumulate on the shores, driving eutrophication. Such efforts also facilitate recreational use, which the dense submerged plant zone may hamper.

Metsähallitus CoastNet LIFE project (2018–2025) tested the removal of *Myriophyllum spicatum* by mechanical mowing in a pilot project in Täktominlahti Bay, Hankoniemi, in 2020–2023 (over an area of approximately 8 ha). Before this, a smaller area (approximately 4 ha) was mowed by the local Täktominlahti Management Association (Täktominlahden hoitoyhdistys Ry) in 2017–2019. The plant mass mowed in Täktominlahti Bay in August each year was first laid on the shore to dry

Figure 27. Mowers removing *Myriophyllum spicatum* in Täktominlahti Bay in August 2020. The collected plant mass was allowed to dry on the shore for about a week before being transported to a nearby field. Photo: Asmo Paloniitty.

and later transported to a nearby field for use as fertilizer (Figure 27).

In Veistämönlahti Bay, at the mouth of Heinlahti Bay, in Pyhtää, aquatic plants were mowed in 2021–2023, and funding will be applied to continue the work in 2025. In this shallow area of 1.5 to 2 metres in depth, Myriophyllum spicatum has grown so vigorously that it has even hindered boating. Aquatic vegetation has been mowed across an area of 22 to 28 hectares, and reeds have been mowed from around seven hectares. The work was commissioned by Pyhtää Water Protection Association (telephone interview with Timo Kiiski on 30 November 2023). In 2021, the site was mowed twice, in midsummer and late autumn. When baled, the mowing waste produced 20 to 30 bales of compostable material. In 2022–2023, the plants were mowed in July and August. The mowing work took three weeks. In 2022, the mowing waste amounted to 80 to 90 bags of one cubic metre, while in 2023, the volume was slightly smaller, i.e. 60 to 70 bags. The mowing waste was composted locally to provide raw material for mull.

Monitoring methods

The impacts of removing submerged plants are not yet sufficiently well known, and they vary depending on the site and species, which is why monitoring the impacts of mowing is important. In the CoastNet LIFE project, monitoring was based on standardised diving transects and vegetation squares in Täktominlahti Bay (changes in vegetation and their abundance ratios), monitoring the development of organic matter in bottom sediments, and observing the development of vegetation in the mowed area in aerial photographs.

No monitoring was carried out in connection with mowing in Veistamönlahti Bay, Pyhtää.

Experiences of the method

Outcomes

In Täktominlahti Bay, Hankoniemi, the repeated mowing of submerged vegetation was found to neither significantly reduce nor increase the volume of *Myriophyllum spicatum*. To eliminate this species, a method should be used that removes the plant with its roots, as this perennial submerged plant spreads vegetatively from its roots and other parts. The plant is also an effective competitor, as it secretes plant toxins that prevent or hinder the presence of other plants.

Lessons learned by Metsähallitus about mowing submerged vegetation:

- Before removing submerged vegetation, the nutrient load in the catchment must be addressed!
- Remember to submit a mowing notification to the ELY Centre.
- The work should be performed outside the bird nesting season (1 April – 31 July).
- Remember that *Myriophyllum spicatum* can spread vegetatively from plant parts left behind. If possible, *Myriophyllum spicatum* should be removed repeatedly from the entire area, primarily with its roots.
- Check the reach of the available mowing equipment > a depth over 1.8 m impairs the mowing result.
- Plan a further use for the mowing waste > good fertiliser for fields.
- The bottom quality affects the removal results and should be tested in advance.
- If a species is removed by mowing, efforts to collect the plants must continue for several days, making it also possible to remove the plants that initially sank under the water.
- It is advisable to set aside time and labour resources for follow-up work. Not all mowing waste can be caught immediately from the water column.
- Make use of a wind direction that facilitates the collection of mowing waste.
- Is suction dredging the bottom to remove *Myriophyllum spicatum* possible outside protected areas?
- Can the vegetation be covered and the bottom 're-established' of the bottom with a layer of purified sand/silt?

Based on a visual assessment, overgrowth by aquatic plants in Veistamönlahti Bay, Pyhtää, has slowed due to several consecutive years of mowing. Boating along the channel is easier, and now fishing with a rod and line in the area is also possible and increasing in popularity.

The mechanical removal of vegetation and algae harvesting primarily tackle the symptoms (Kraufvelin et al. 2021a) caused by nutrient loading from the catchment in bays that were always shallow. This is why it is essential to pay attention to and tackle the causes driving eutrophication first when planning restoration measures. The feasibility of measures aimed at eradicating aquatic plants and algae varies depending on the site and external conditions, and their results are usually short-lived. The scientific foundation of such measures is scant or moderate (Kraufvelin et al. 2021a).

Challenges

When considering the removal of submerged vegetation, it is worth remembering that a high level of biological production often characterises the shallow bays of the Baltic Sea, as they warm up faster in spring and early summer than deeper, more open and exposed water areas nearby. Young fish benefit from the higher temperatures in spring and summer by growing faster, making them less vulnerable to predators and starvation in the following winter. Shallow and sheltered bays often have plenty of aquatic plants that shelter juvenile fish and zooplankton from predators while providing large quantities of suitable prey for juveniles. Therefore, such areas are particularly important as habitats for fish spawning and juvenile production

(Sandström et al. 2005, cited in Kraufvelin et al. 2021a). The removal of vegetation can consequently harm fish and some bird species. Aquatic vegetation additionally prevents coastal erosion caused by waves and currents. It retains nutrients and solids originating from the catchment, and the roots of these plants bind the bottom sediments, helping to keep the water clear.

The quality of the work may be inconsistent when mowing submerged vegetation, as the water level and wind direction affect the mowing result and the collection of mowing waste. While the mower contractor used an extended cutter specifically designed for this site and had a longer reach than usual in Täktominlahti Bay, the mowing results were uneven in deeper areas. The pilot project of removing aquatic plants from Täktominlahti Bay showed that mowing is poorly suited for eradicating *Myriophyllum spicatum* and achieving a permanent change. In addition to reproducing sexually, *Myriophyllum spicatum* can propagate asexually from dispersed plant parts, which is why any material left in the water after mowing poses a risk of helping the plant to spread.

Costs and benefits

The costs incurred from mowing in Täktominlahti Bay as part of the CoastNet LIFE project: repeated mowing of the submerged vegetation over a total area of 8 hectares cost EUR 1,100/ha, maintenance of a gravel road leading to the bay EUR 4,000, transport of mowing waste from the area EUR 6,000/year, plus the costs related to monitoring.

In Veistämönlahti Bay, Pyhtää, the total cost of mowing was EUR 50,000 (VAT 0%) in 2023. Volunteers collected mowing waste gathered in bags. An initial funding input of 50% was received from the ELY Centre, and the rest was collected as donations.

3.4.2 Removal of the common reed

The common reed (*Phragmites australis*) is a species that grows naturally on coasts. It benefits from the eutrophication of waters and has spread to many seabays in large colonies. These dense colonies are sometimes seen as spoiling the landscape and potentially hampering the recreational use of the area. As traditional grazing of shores declines, the widespread common reed has additionally taken over living space from the diverse plant species of coastal meadows and bird species that favour open shores, such as waders (Ikonen & Hagelberg 2007). On the other hand, the reed bed binds nutrients from the catchment and prevents bottom erosion. Reed beds also provide shelter and food for many species, including dragonflies, birds, fishes, frogs and bats (Ikonen & Hagelberg 2007).

While the principles of reed bed management vary, one of the objectives is to increase biodiversity in the area. For birds, the result to aim for is to replace dense and homogenous reed colonies with a mosaic of open water areas and reed beds with varying structures, as such habitats have been found to maintain diverse bird populations and a high bird density (Below & Mikkola-Roos 2007). A mosaic created by mowing and excavating ponds also creates free space for aquatic plants (Ulvi & Lakso 2005). Some spring-spawning fish, including pike, favour low vegetation zones that warm up early in the spring for their reproduction habitats, and reed beds are also thinned out to create a mosaic in connection with fisheries restorations, such as the creation of pike wetlands (see section 4.2.2).

Restoration method

In Nisoksenlahti Bay in Lake Lappalanjärvi, Kouvola, restoration was carried out to improve habitats for aquatic birds and *Najas tenuissima*, which have suffered from vigorous reed growth (Tanska and Räihä, interview on 14 December 2023, Figure 28). The area was once used as a pasture for cows, which kept the area open and free of reeds. Due to the lack of grazing and excessive nutrients from its catchment area, Nisoksenlahti Bay has become severely overgrown and eutrophic, and reeds have spread across an increasingly wide area from the shores into the lake. The restoration aimed to create a mosaic-like shallow water area to help the endangered *Najas tenuissima* recover from its natural seed bank and improve aquatic bird habitats.

The work was carried out in October and November 2022 with a long-boom excavator operating from platforms. The aim was to create an open water area ranging from 20 to 80 cm in depth and leave untouched islands of reeds. The excavated spoils were deposited at the site's edges in a dried-out area.

Monitoring methods

No results regarding *Najas tenuissima* are available yet, as monitoring is to start at the earliest in the second summer following the restoration, and the decision on whether or not monitoring will continue will depend on the findings. Pike juvenile production in the area was also surveyed using electrofishing tests in summer 2023, and the plan is to continue this in the future. While pike juveniles were found, their densities were still moderate, as plants have not yet grown back in most parts of the site, excluding the margins.

Figure 28. Nisoksenlahti Bay before and after reed removal. Photos: Ville Räihä/ELY and Laura Tulokas/Vemarak Oy.

Experiences of the method

Outcomes

A press conference was held in the spring following the restoration, and the project in Nisoksenlahti Bay made YLE's local news on radio and television. A news item on the project was published by YLE (Hottola & Tuunila 2023). The joint property management association of the water area also funded building a birdwatching tower with an information board describing the restoration project.

The lesson learned from the restoration work was that flail mowing before excavation speeds up the work significantly in areas of this type. The Nisos area will likely require further management after restoration, including additional mowing of reeds. Although grazing has been discussed with the management association, it is uncertain if this will go ahead. Monitoring will show if the goals regarding *Najas tenuissima* will be reached and, for example, if the number of reed islands left in the area is appropriate or should be higher or if the site should provide even more shelter or additional open areas.

Metsähallitus plans to test a similar method in Ahvenkoskenlahti Bay in Pyhtää which, while heavily overgrown with reeds, is one of the rare sites where *Najas tenuissima* is found.

Costs and benefits

The restoration project of Nisoksenlahti Bay was completed with the help of a water management grant from the ELY Centre and in cooperation with the local property management association of the water area, which led the project. The project's total cost was approximately EUR 48,000, of which excavator work accounted for around EUR 44,000. This made it possible to complete the measures over approximately 3 hectares of the allocated area.

3.5 Reefs (1170) and Boreal Baltic islets and small islands (1620)

Conservation status[1]	Trend[1]	Status in 2018[2]	Other points
Reefs Unfavourable, inadequate	Stable	Unknown	Included in Finland's special responsibility habitat type: Baltic hydrolittoral rock

Conservation status[1]	Trend[1]	Status in 2018[2]	Other points
Boreal Baltic islets and small islands Unfavourable, inadequate	Stable	Not included in the assessment	

[1] Assessment of conservation status and trends given in the habitats report referred to in the Habitats Directive 2019

[2] Kotilainen et al. 2018 Threatened habitat types in Finland 2018: the Baltic Sea.

3.5.1 Reef restoration

Reefs have mainly been restored in the southern parts of the Baltic Sea, especially in Denmark, where significant volumes of rocks and boulders have previously been removed from reefs as construction material for harbours and breakwaters, impairing the status of this habitat in the relevant areas. All rocks and boulders have been removed from some reefs. In places, aggregates have been extracted from the shallowest parts of the reef, which has increased the impact of erosion and destabilised the reef (Støttrup et al. 2014). The removal of boulders from reefs was prohibited in Denmark in 2010 and Germany in 1974 (Wilms 2021). However, the stone and gravel reserves of the seabed are still being exploited in Denmark. As no reefs have been restored in Finland, the examples presented below are mainly from Denmark.

Reefs are an important habitat for several fish species and provide a substrate for perennial algae and invertebrates. Extracting aggregates from shallow, light-filled areas reduces the coverage of macrophytes performing photosynthesis and the number of sheltered places offered by vegetation and boulders for juvenile fish (Støttrup et al. 2014). The objective of the method is to restore a three-dimensional reef habitat with a hard bottom and its biotic communities to areas where some or all of the stones and boulders that formed the reef have been removed. By restoring reefs, an effort is made to create more suitable feeding and breeding grounds for fish, including the cod, saithe or Baltic herring (Støttrup et al. 2014; Svendsen et al. 2022). Reef restoration aims also include reducing erosion that may have increased after aggregate extraction (Dahl et al. 2016).

Restoration method

In restoration projects, the reef has been partly or fully rebuilt by returning stones or boulders to the area. In 2008, the Blue reef LIFE project restored a reef area of around five hectares at Leasø Trindel reef by introducing approximately 100,000 tonnes of boulders (Dahl et al. 2016). At the restored site, the shallowest point of the reef was at a depth of 1.5 metres. In the area designed to be nine metres deep, the reef was built up to a height of 4 to 5 metres from the bottom. In 2017–2018, reefs that were two metres in height were built at four sites with stones and boulders (0.5 to 1.5 m in diameter, 500 m^3

in volume) in the Flensburg fjord. By building reefs of different sizes, the area could be used to study potential differences in how the biota interact between a single large reef or several small restored reefs (SLOSS theory) (Wilms et al. 2021). In Sønderborg Bay, the restoration of a reef consisting of stones (6 to 30 cm in diameter) was piloted in two areas (Wilms et al. 2021; Svendsen et al. 2022).

Several reef restoration projects are also being planned in Denmark. For example, the construction of a three-reef complex is being planned in Roskilde Fjord in Skjoldungernes Land National Park. The reef in the Veddelev area is closer to the shoreline, and one of the project's objectives is to enable the public to visit the site and engage in education and communication activities related to reef restoration (e.g. Dahl & Göke 2022). For up-to-date information on reef restoration projects and contact points in Denmark, visit: https://marinnatur.dk/projekter/.

Monitoring methods

In the Blue reef LIFE project, benthic animals and plant biomass development were monitored at Læsø Trindel reef from 2008–2012. In this project, changes in fish fauna (2007 vs 2012), as well as the depth of the reef, were also monitored to ensure that the new reef had stabilised (Støttrup et al. 2014; Dahl et al. 2016)

In Flensburg Fjord, an initial survey was carried out in 2016, and reefs were built in December 2017 and January 2018. Monitoring took place six months after the construction work in 2018 (Wilms et al. 2021). The study developed monitoring methods that do not disrupt the species at the site. Remote underwater video cameras, either without bait (RUVS) or baited (BRUVS), were used to monitor the fish fauna at the site, especially the abundance of gadiforms. Monitoring based on eDNA was additionally tested in the area with four fish species (Wilms 2021, Wilms et al. 2022). In Sønderborg Bay, changes in fish fauna, vegetation and invertebrates and the numbers of porpoises were monitored for two years (Svendsen et al. 2022).

Experiences of the method

Outcomes

During the four-year monitoring period, a six to eight-fold growth in biomass and an increase in the number of perennial algal species were observed at the reef restored in the Blue Reef project. The algal species had not yet fully colonised the site during this period. According to a conservative estimate, it would take at least 8 to 10 years before the succession of benthic animals, algae, and plants would reach its endpoint. Both cod (*Gadus morhua*) and saithe (*Pollachius virens*) increased in abundance at the restored reef, with cod observations particularly increasing in the shallow parts of the reefs (Støttrup et al. 2014). Although no change was observed in the numbers of lobsters, these species reproduce slowly, and changes are expected to take place over a longer period (Dahl et al. 2016, Kristensen et al. 2017)

At the reef in Flensburg Fjord, a large proportion of the marine species colonised the new reef within six months. In particular, the reef increased the number of large gadiforms (codfish), Labridae (wrasse species) and Gobiiformes (gobies) on a sandy bottom (Wilms et al. 2021). The study found that some small predatory fish, including Gobiiformes, benefited more from the construction of several small reefs than a single large one (Wilms et al. 2021). Cameras installed on the sea bottom produced reliable monitoring data on habitat use by the seven fish species studied. In the case of cod and whiting, the data obtained with baited cameras (BRUVSs) corresponded to the known habitat use of the species, whereas unbaited cameras did not show a similar link to the habitat. The use of eDNA in monitoring was tested with four different fish species (cod, flounder, plaice and rock cook wrasse). This method produced as many or more species observations than the videos (BRUVS) (Wilms et al. 2022). For local low-mobility species, flounder and rock cook wrasse, the data obtained using the eDNA method was consistent with those obtained with the cameras. For cod, a highly mobile species, and plaice that produced little eDNA material, the eDNA analysis result was inconsistent with the habitat use observed on video (Wilms et al. 2022).

Reef habitat restoration has been found to have a positive impact on the abundance of several fish species important for commercial purposes, including cod, and the retention of top predators in the area (Støttrup et al. 2014, 2017, Dahl et al. 2016, Kristensen et al. 2017, Wilms et al. 2022). On reefs constructed with smaller stones, the abundance of fish increased in three to five months, especially the rock cook wrasse and two-spotted goby proliferated (Svendsen et al. 2022). Many predatory fish feed on these species, and an increase in their numbers may be considered an indicator of food chain recovery (Svendsen et al. 2022).

Planning

- In the planning stage of reef restoration, the necessary seabed surveys should be conducted to ensure that the seabed will carry the weight of the reef and that the structure will stay in place.
- Potential negative impacts should be assessed at the planning stage of the project. Large reef structures may change local current conditions and wave movements, which will be seen as possible changes in sediment transport and seabed morphology. In particular, impacts on protected areas should be accounted for; for example, the project must ensure that the planned reef will not increase sedimentation in a protected area (Kristensen et al. 2017, Støttrup et al. 2017).
- It is important to engage stakeholders and communicate about the project, and these activities should be started early in the project.

Monitoring

- eDNA: The challenge of this method is the degradation and transport of eDNA in a large volume of water, which may make it impossible to obtain a sufficient quantity of eDNA for analysis. When planning the sampling, the target species and their habitat use should be noted (local vs. mobile). Larger volumes (>1L) are advisable when collecting samples, as this increases the likelihood of obtaining sufficient eDNA for quantitative analysis (Wilms 2021).

Challenges

In connection with the Blue reef project, it was found that a new reef creates a shallow area that boaters are not familiar with: sailing boats were observed to navigate very close to the new shallows (water depth less than 1 m). A communication campaign was organised to avoid collisions, and buoys were installed to inform boaters about the new shallow area (Dahl et al. 2016).

Costs and benefits

The project in Læsø Trindel in Denmark restored 7 hectares of reefs and stabilised 6 hectares. The restoration costs in this project amounted to EUR 4,800,000 (Støttrup et al. 2014, 2017).

In the stone reef pilot (stones of 6 to 30 cm in diameter), the surface area of which was 2,600 m^3, the costs of the aggregate, reef construction and seabed studies after construction were DKK 900,000, or approximately EUR 120,650 (excluding VAT) (Svendsen et al. 2022). In the pilot project, the price per cubic metre of material was EUR 47 (Svendsen et al. 2022).

3.6 Boreal Baltic narrow inlets (1650) and deep soft bottoms

Conservation status[1]	Trend[1]	Status in 2018[2]	Other points
Unfavourable, bad	Stable	Not included in the assessment	

[1] Assessment of conservation status and trends given in the habitats report referred to in the Habitats Directive 2019
[2] Kotilainen et al. 2018 Threatened habitat types in Finland 2018: the Baltic Sea.

3.6.1 Oxygenation of bottoms

Anoxia may occur for variable lengths of time in stratified basins with limited water exchange in waters close to the bottom, and this phenomenon is accelerated by eutrophication. Conditions that lead to anoxia and hypoxia have been observed in the Baltic Sea area in some narrow bays with brackish water (Stipa 1999) and more extensively in the Baltic Sea's salinity-stratified main basin (e.g. Carstensen & Conley 2019) and its temperature-stratified basins in the archipelago (Conley et al. 2011). The impact of hypoxia on the bottom ecosystem depends on both its degree and its duration. While mild and short-term hypoxia may cause changes in the structure of the benthic community, complete anoxia and hydrogen sulphide formation will soon lead to the loss of the entire benthos. Bottom-dwelling fish fauna also suffers. Anoxia in near bottom waters also affects nutrient circulation and speeds up internal loading. An attempt can be made to change the situation by oxygenating deep water layers close to the bottom.

Oxygenation of near bottom water has been resorted to on a larger scale in Finnish lakes (e.g. Ulvi & Lakso 2005). In the marine environment of the Baltic Sea, oxygenation has been tested in Pohjanpitäjänlahti Bay, Hanko, in 1995–1996 (Malve et al. 2000), in the Inkoo and Stockholm archipelagos in 2009–2011 (PROPPEN project; Rantajärvi 2012, Lehtoranta et al. 2022) and the Hamina archipelago in 2011–2013 (OXY project; Pöyry Finland Oy). Oxygenation was also tested in a fjord-like bay with a significantly more marine character on the western coast of Sweden in 2010–2012 (Stigebrandt et al. 2015).

Restoration method

Several techniques have been developed for hypolimnetic oxygenation. They are divided into two main types: creating bubbles by pumping air to the bottom or downwelling oxygenated surface water to the bottom. The latter method is considerably more cost-effective (Koweek et al. 2020).

A Mixox oxygenation device has been used in the Finnish sea area to convey oxygen-rich surface water to the hypolimnion (Vesi-Eko 2024, and Figures 29 and 30). For example, in Sandöfjärden, Inkoo, pumps with a capacity of approximately 82,000 m^3 a day were used. The total capacity of the six pumps used for oxidation was 487,000 m^3 a day. Three oxygenation devices were used in Tammionselkä, Hamina. A Mixox device was also used in Pohjanpitäjänlahti Bay.

Monitoring methods

In Sandöfjärden, Inkoo and Lännerstasundet in Stockholm, the impact of oxygenation was monitored by measuring currents, water oxygen content, temperature, salinity and nutrients (nitrogen and phosphorus), as well as the dissolved iron concentration in the water. In Tammionselkä, Hamina, benthic invertebrates, water quality, oxygen content and temperature were monitored.

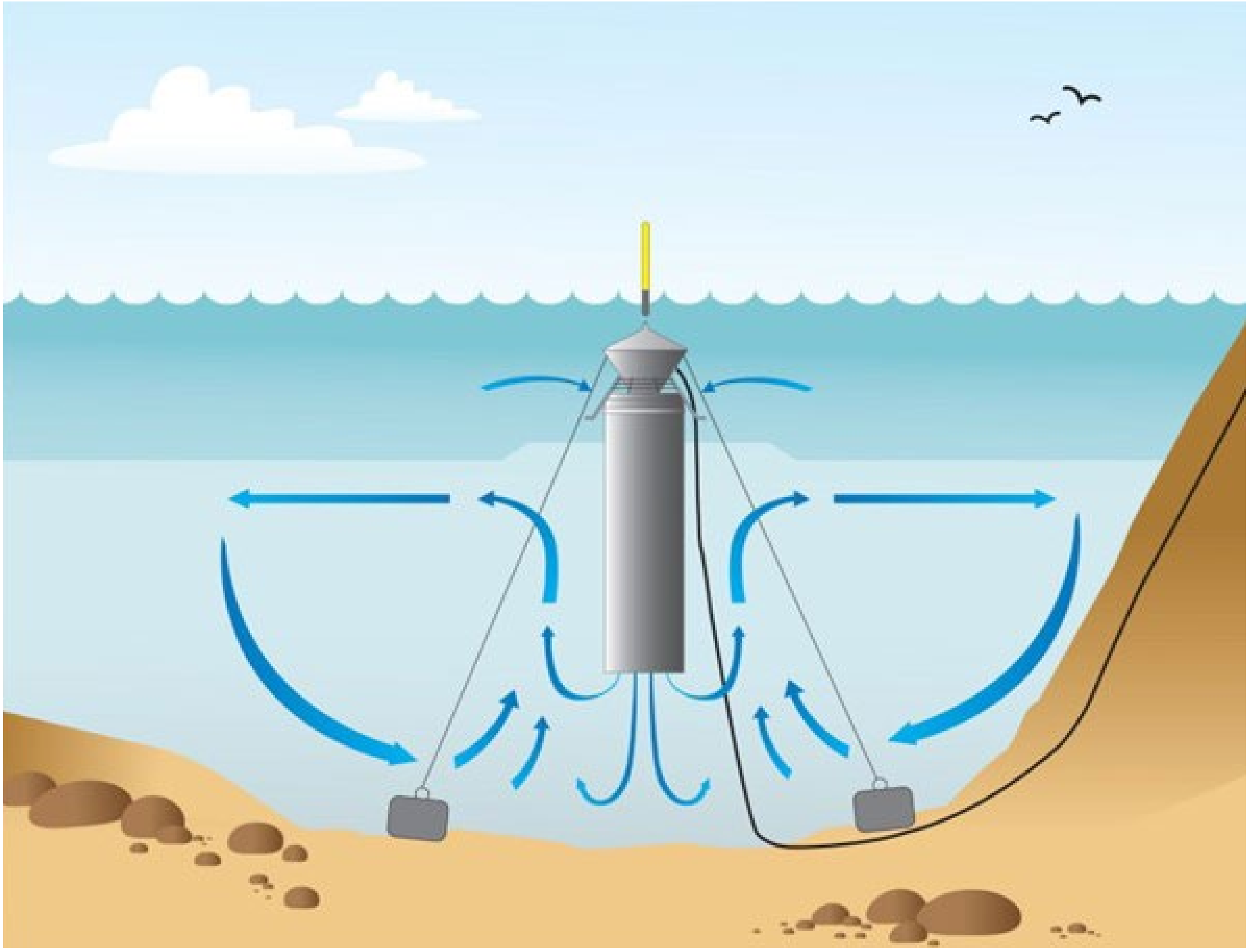


Figure 29. Operating principle of Mixox oxygenation device. Photo: Vesi-Eko Oy. https://www.vesieko.fi/vesisto-palvelut/hapetus-ja-ilmastus/.

Figure 30. Mixox MC 1100 oxygenation device (diameter 110 cm). Photo: Saarijärvi et al. 2012.

Experiences of the method

Outcomes

In Pohjanpitäjänlahti Bay, Hanko, oxygenation increased the oxygen content of near bottom water by 1–2 mg/l, and no release of nutrients from the bottom into the epilimnion was observed. The oxygenation effect is estimated to correspond to approximately one-half of the oxygen consumption in the water and seabed (Malve et al. 2000).

In Sandöfjärden, Inkoo, where anoxia results from stratification by temperature, conveying oxygen-rich surface water to the bottom did not prevent the formation of anoxic areas and the release of nutrients from the sediment, even if the oxygenation should technically have covered the oxygen consumption in the waters close to the bottom.

Close to the pumps, warming of both bottom water and sediment was observed, which may accelerate degradation processes and oxygen consumption. The thermocline was also raised by two metres, which expanded the oxygen-consuming area. These changes may have contributed to the fact that the water pumping was inadequate to improve the area's oxygen situation (Lehtoranta et al. 2022).

In Lännerstasundet in the Stockholm archipelago, which is salinity stratified, oxidation quickly improved the oxygen situation and reduced nutrient concentrations in deep water. One year, oxygenation achieved an improvement in the oxygen situation that lasted for months after the oxygenation had ended. This improvement was due to changes in salinity stratification caused by the oxygenation and increased inflow of oxygen-rich water from the surrounding area. A temperature increase in the water column below the thermocline was also observed here due to oxygenation (Lehtoranta et al. 2022).

As oxygenation improved the oxygen situation, the concentrations of ammonium nitrogen and phosphate phosphorus in the off-bottom water were reduced. However, when oxygenation was discontinued and in anoxic conditions, these concentrations increased once nutrient release restarted.

The results indicate that the success of oxygenation may be influenced not only by the transport of oxygen itself but also by such factors as local changes in temperature, stratification and horizontal currents.

In Sandöfjärden or Lännerstasundet, oxygenation did not enable benthic fauna to recover, probably since the oxygen concentrations nevertheless remained low, and the length of the oxic period was not long enough for recovery (Lehtoranta et al. 2012). The recovery of a normal benthic community often requires several years of oxic conditions.

In an area of significantly higher salinity on the west coast of Sweden, oxygenation for 2.5 years resulted in a significant improvement in the oxygen situation, which also led to the recovery of benthic fauna in the fjord-like bay stratified by salinity (Stigebrandt et al. 2015).

To summarise the results of oxygenation experiments, the success and impact of oxygenation in a sea area are relatively uncertain, and local conditions must be thoroughly known as they have a significant impact on the result. Even when oxygenation succeeds as such, it has only achieved local and short-term improvements in conditions. A permanent change in oxic conditions can only be achieved by influencing the causes of oxygen depletion, of which eutrophication caused by nutrient loading in the sea area is often dominant. Reducing nutrient loading is consequently the most effective way to achieve a more permanent improvement in the oxygen situation of sea beds. Large-scale oxygenation of the Baltic Sea is not considered a realistic and feasible solution to the oxygen problems (Conley et al. 2009).

As a result of climate change, seasonal oxygen depletion in deep-water areas of the archipelago may become more common in the future. Higher temperatures of the water layer near the bottom, which can already be observed, will accelerate degradation processes and oxygen consumption. Warming can also enhance temperature stratification in the summer, further driving oxygen depletion.

Challenges

Continuous oxygenation is usually required to improve the status of the water layer close to the bottom, and oxygen depletion is prone to recur when oxygenation stops. Conveying warm surface water into the hypolimnion may accelerate oxygen consumption and cause changes in stratification, which may increase the need for oxygenation.

Pump corrosion was observed in the oxygenation experiments, which can be avoided by selecting the correct materials. Anti-fouling paints may also be needed for the equipment to prevent biofouling (Saarijärvi et al. 2012). In offshore conditions, organising and securing the electricity supply of the equipment may pose challenges (OXY project).

Costs and benefits

According to Ollikainen et al. (2016), the purchasing price of one Mixox pump was EUR 41,500, while the annual operating costs were approximately EUR 3,000. A cost-benefit analysis of oxygenation shows that the oxygenation of bottoms in the sea area is not a cost-effective way to prevent the adverse effects of eutrophication. It could promote the recovery of bottoms in coastal areas and achieve benefits in a situation where nutrient loading has been significantly reduced. In offshore areas, however, oxygenation of bottoms would not be cost-effective under any circumstances.

4 Restoration of habitats for species

4.1 Introduction

As a rule, the conservation of species should mean protecting their habitats as a whole and ensuring the ability of the ecosystem services to function. However, the situation of some species is so dire that conserving their habitats is no longer enough, and special measures are needed for the in situ conservation of an endangered species.

The ultimate way to protect a species from local or total extinction is ex situ protection, which means conserving the species in a laboratory or other non-natural environments. The ecology of a protected species must be thoroughly known before specific habitat restoration methods targeting a single species can be considered. While the rest of the environment in the vicinity may benefit from restoration and nature management measures targeting a single species, the focus is on protecting the endangered species and improving its habitat.

Even if keystone species are not particularly threatened, their regional protection and improvement of their habitats are nevertheless important, as many other species depend on the services they provide, for instance, as areas for feeding, shelter or breeding, or as food sources. Keystone species often maintain high biodiversity and may provide specific ecosystem services.

Ecosystem services, such as fish spawning are important for preserving species and biodiversity and for the benefits they generate for humans, including fishing. While many marine habitat restoration methods also benefit fish, some of the methods aim to restore or rehabilitate the living conditions or spawning grounds of fish.

4.2 Bladder wrack reproduction tests

The bladderwrack (*Fucus vesiculosus*) is an essential keystone species in the Baltic Sea. The bladderwrack populations in the northern Baltic Sea declined in the 1980s. While the species has returned to several sites, it appears to be struggling to establish itself at sites that would be appropriate, including in southern parts of the Archipelago Sea, where the water quality is reasonably good and the seabed substrate suitable. The spread of the bladderwrack into new areas is limited because instead of drifting to new areas, its gametes are immediately fertilised after release into the water, and the newly fertilised zygote sinks to the bottom, attaches and begins to grow.

The purpose of propagation tests is to promote the reproduction of the species at new sites and establish new viable populations, which will increase the sea's biodiversity and nature values. Factors affecting bladderwrack reproduction on shallow bottoms include water quality and transparency, seabed characteristics, competition with other algae, and the presence of organisms that graze on the bladderwrack.

Lena Kautsky's research team conducted bladderwrack reproduction tests in Sweden as early as the 1990s and later (Kautsky et al. 2019, Kautsky et al. 2020). In Finland, marine biologists at Åbo Akademi University tested the method used by Kautsky et al. in the Archipelago Sea in 2020. Tests were moderately successful, especially in areas with good water quality (middle and outer archipelago near Högsåra). In areas with significantly poorer water quality (inner parts of Paimionlahti Bay), the reproduction of this species was less successful. No report is available on the test performed in the Archipelago Sea.

Restoration method

The method consisted of selecting sexually mature specimens, both male and female, attaching them to a frame or grate, and placing them in a suitable location on shallow rocky bottoms before the bladderwrack gametes were released in spring/early summer. Tiles with a suitable coarse surface were attached to the frame to facilitate the attachment of new zygotes. Before the experiment started, the bottom was cleaned with a brush to remove attached and loose lying algae and provide additional clean surfaces for zygotes to attach to (Figure 31).

Monitoring methods

The test's success was monitored by visiting the sites three times during the same autumn and the following summer to determine if new bladderwrack individuals had appeared. Although small new individuals (approximately 2 mm to 2.5 cm) were observed on all visits, only a few small individuals were observed in the inner parts of Paimionlahti Bay. The new zygotes were attached slightly better to natural stones, which were cleaned before the experiment began, than to the tiles. Most new bladderwrack individuals were still very small (2 to 3 mm) when the test areas were visited the following year. It is unclear if they originated from the previous year's reproduction tests and grew poorly in an unfavourable environment where stress was caused by filamentous algae, sedimenta-

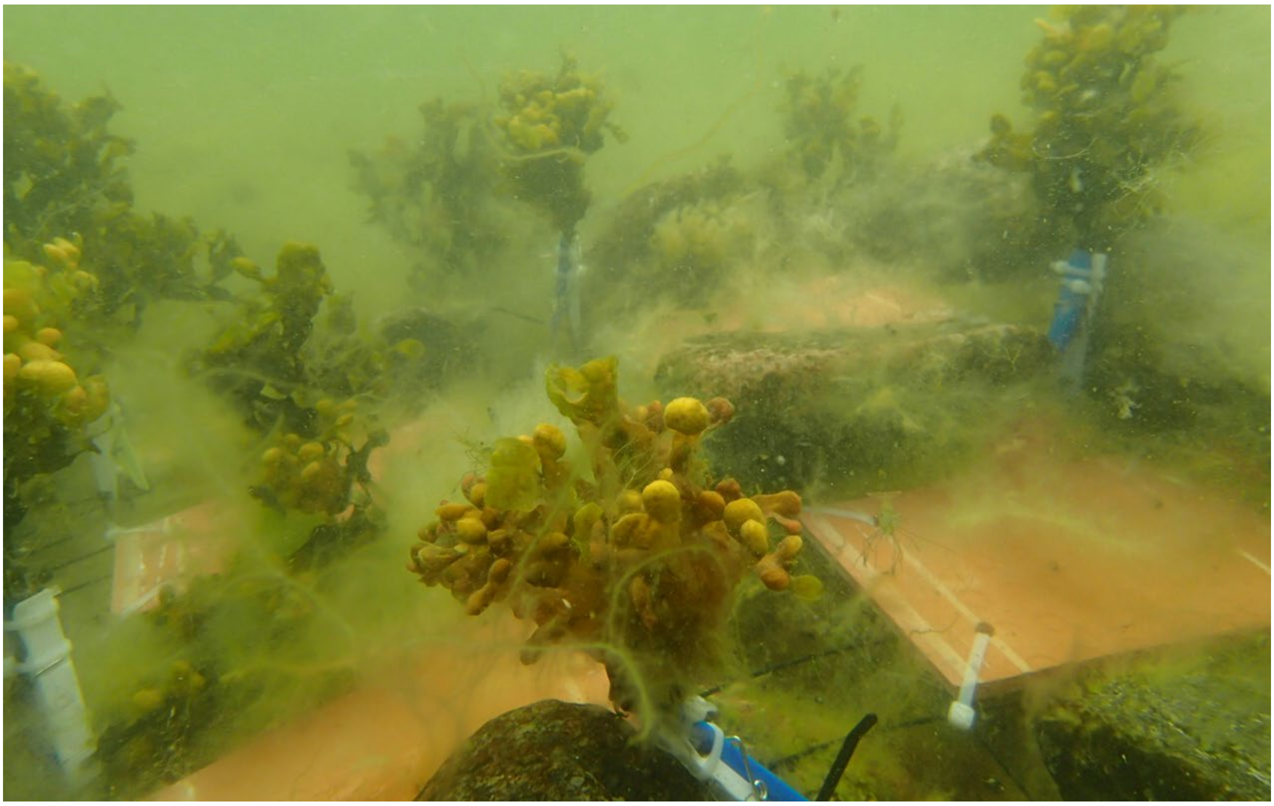


Figure 31. Experiment design for bladderwrack reproduction in the Archipelago Sea in 2020. Photo: Tiina Salo.

tion or herbivores that feed on the bladderwrack. Alternatively, they may have colonised the test sites in other ways (reproduction taking place in autumn, possible bladderwrack individuals drifting along with currents having released their gametes later).

Further monitoring of the test sites would be desirable to determine how the new bladderwrack colonies have grown and developed. If new bladderwrack colonies have developed on these sites, it will be difficult to confirm that this is specifically due to a small test carried out several years ago.

Experiences of the method

Outcomes

The tested method was successful in bladderwrack propagation. New field tests will be conducted in the Biodiversea project to examine the impact of depth, drifting algae, herbivores, and water quality on successful bladder wrack reproduction. Experiments should be carried out on a larger scale in different areas. The bladderwrack is common in shallow areas of the central parts of the Archipelago Sea, especially in areas of good water transparency. Finding suitable shallow rocky bottoms in the middle archipelago where the bladderwrack is not already present is difficult. The species occurs less commonly in the inner archipelago due to poorer water quality and softer substrates.

Challenges

The success of bladderwrack reproduction is likely affected by several factors, including water quality and competition with other algae. In addition, the lack of suitable substrate (rocky bottoms) and poor secchi depth also limit their depth distribution. Species feeding on the bladderwrack may harm the population or destroy new bladderwrack individuals. There is a very short period of approximately two weeks when the sexes of bladderwrack can be distinguished from each other before the gametes mature and are released. Therefore, reproduction experiments with known sex ratios of parent plants need to be conducted quickly. Hence, field tests, which are relatively labour-intensive, must be started precisely during this short period, regardless of the weather conditions.

Costs and benefits

The costs of bladderwrack reproduction tests depend entirely on the scale. While the materials and tools needed for the tests are inexpensive, launching them is relatively labour-intensive, and divers are needed to place them out at sea. Tests must also be carried out under favourable weather conditions in the spring (just before the full moon in May or early June), when most bladderwrack individuals are sexually mature. If reproduction tests are successful, a new three-dimensional habitat is created that is favourable for several other species (algae, invertebrates and fish) and consequently increases biodiversity, functions, production and carbon sequestration throughout the ecosystem.

4.3 Transplantation of charophytes

Charophytes, or stoneworts (Charales), are green algae that grow on sheltered sites with soft bottoms and resemble aquatic plants in their appearance. They provide food and shelter for many groups of organisms, including fishes, invertebrates, and aquatic birds, and are important for biodiversity and juvenile fish production in shallow bays. Stoneworts also reduce water turbidity by slowing the flow rate as particulate matter is sedimented from the water column to the bottom of the bay. Nutrients bound to solids are deposited in the sediment and are not directly bioavailable for phytoplankton. Stoneworts reduce the risk of mass occurrences of cyanobacteria by competing for

Figures 32a and 32b. Charophyte meadow in a sheltered bay. *Chara tomentosa* in a water container. Photos: Roxana Preston and Henna Raitanen.

nutrients in the water column and by excreting allelochemicals that reduce phytoplankton growth.

In Finland, sheltered charophyte meadows are classified as vulnerable (VU), whereas open charophyte meadows are classified as near threatened (NT) (Kontula & Raunio 2018). Both habitats have declined in Finland over the past 50 years. Charophyte meadows are classified as endangered due to their high importance and rare occurrence. The main factors leading to these habitats being endangered are eutrophication and water contamination. Waterborne transport and coastal construction, which disturb or destroy soft sediment bottoms, also play an important role in the decline of these habitats (Kontula & Raunio 2018).

Stoneworts have relatively simple thalli, compared to vascular plants, which have specialised tissues formed by differentiated cells. The stonewort thallus grows from the bottom sediment towards the water surface and has whorls of branchlets that somewhat resemble leaves (Figure 32b). The stonewort's reproductive structures (oogonia and antheridia) appear on these branchlets, while its rhizoids grow in the sediment. Certain stonewort species have starch-filled bulbils in their rhizoids. It is species dependent to what degree these abovementioned structures are used for reproduction and overwintering, and these differences should be accounted for when planning stonewort transplantations.

Four genera belonging to the division Charophyta are found in Finland: *Chara*, *Nitella*, *Nitellopsis* and *Tolypella*. This report focuses on methods that can be used to support the growth and spread of the stonewort species belonging to the *Chara* genus found in the Baltic Sea.

The transplantation of Baltic Sea stoneworts has been tested in field conditions in Sweden (Faithfull et al. 2022) and on a small scale in Finland (Metsähallitus). Elsewhere in Europe and the world, the species have been transplanted with varying successes in freshwater habitats (Blindow et al. 2021). In aquarium and laboratory conditions, stoneworts have been grown in several studies (e.g. Wüstenberg et al. 2011 and Bociąg & Rekowska 2012). Within the framework of the Biodiversea project, researchers from Åbo Akademi University carried out aquarium tests aimed at transplanting Baltic Sea stoneworts. They studied the reproduction strategies of *Chara tomentosa* and *C. baltica* with genetic methods. They determined the environmental and sediment-related requirements of *C. tomentosa* in shallow Baltic Sea bays in the summer of 2023. Their findings will be published over the next few years.

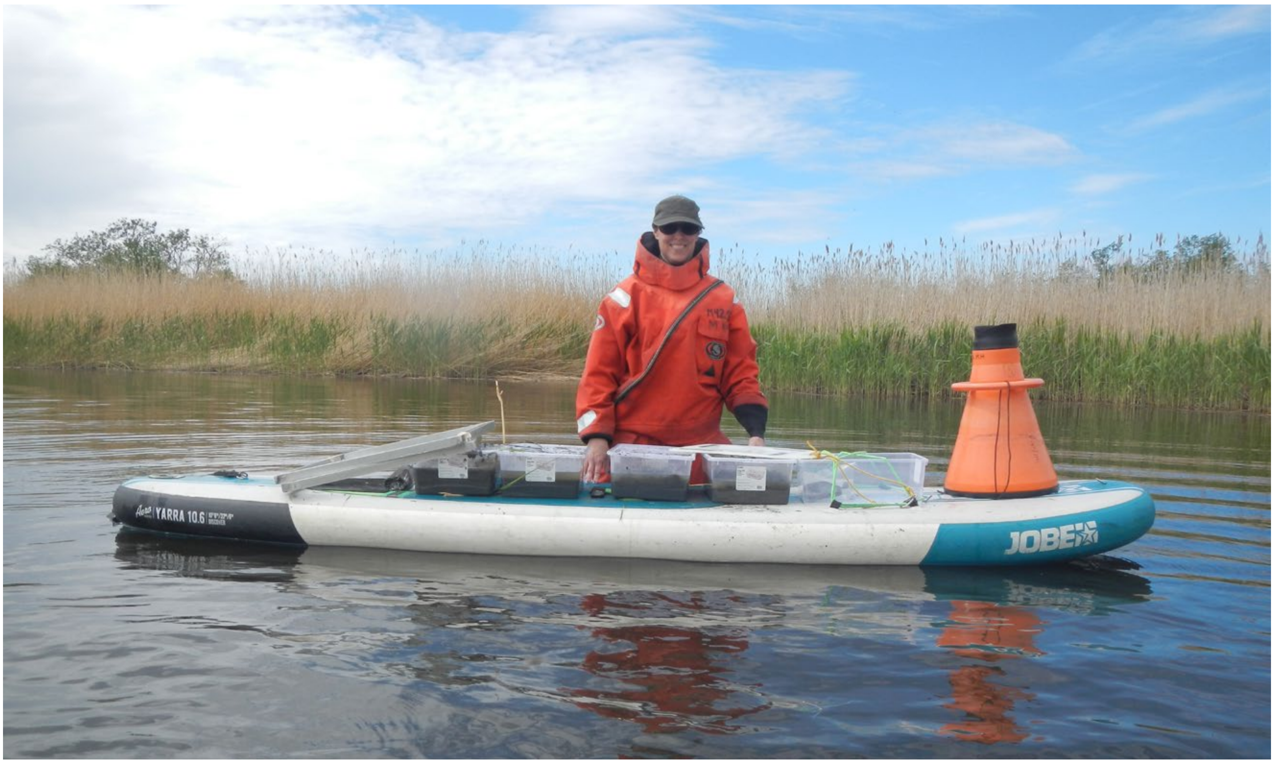
Restoration method

Stoneworts can be transplanted in the Baltic Sea in historical areas where they disappeared if the reasons for their disappearance, such as heavy waterborne traffic, are no longer present. Alternatively, transplantation may also be considered in other areas if the conditions for the growth and reproduction of the species are favourable, and the measure benefits the local ecosystem. Depending on the stonewort species, whole individuals, thallus sections, bulbils, or fertilised oospores (cf. shoots, cuttings, tubers and seeds of vascular plants) may be used for transplantation. Sediment may also be transported with stoneworts or their parts, if necessary.

In Sweden, Faithfull et al. (2022) tested planting whole stonewort individuals in Siviksfjärden Bay on the western coast of the Bothnian Sea (salinity 3.9 to 4.8 PSU). To our knowledge, this was the first recorded attempt to transplant stoneworts in the Baltic Sea area. *Chara aspera* grows naturally across large areas of the bay, whereas in some places, it is not found at all, or the colonies are sparse due to dredged channels for small boats and the disposal of dredged sediments.

The *C. aspera* individuals and a 12-centimetre layer of sediment were lifted from the bay floor, using either a spade or a hollow plastic tube with a cap, and transported from an area of dense stonewort population to the test squares located in the dredging and disposal area within the bay. Three different planting techniques were tested on the transplanting site. 1) The stonewort individuals and sediment lifted from the bottom with a spade were laid down directly in the test squares on the seabed in the bay. 2) Holes were made in a strip of jute fabric for the stoneworts. The stoneworts and sediment were anchored to the bottom of the bay with the strip and stones. 3) Biodegradable, multi-layer BESE-elements© grids made from starch were used to anchor the stoneworts and sediment to the seabed. In addition to the three different planting techniques, the natural spread of stoneworts was examined in control squares where no measures were undertaken. In addition to *C. aspera*, the transplantation of *C. tomentosa*, which also grows in the bay, using a spade and BESE-elements© grids was tested in Siviksfjärden Bay. Both species were transplanted in early summer, and their growth was monitored during the growing season until the end of September.

In early June, Metsähallitus' marine team piloted the planting of stoneworts in the southern part of Quarken. In Roliggropen gloe lake off Korsnäs, *C. tomentosa* was planted over an area of approximately 1.5 square metres with funding provided by the Helmi habitat programme. Spade was the most effective and simple way to transplant charophytes, according to the test done in Sweden. Instead of spades, Metsähallitus used 25 x 40 cm plastic boxes with a cover. One side of the box was cut off, and the box was used as a spade. Sediment and the stoneworts growing in it were scooped into the box and emptied into other boxes used for transport. The idea was to collect stoneworts from neighbouring bays, but due to the late arrival of winter, ice conditions or other unknown reasons, no *C. tomentosa* individuals were found nearby. Therefore, they were collected from a gloe lake in a neighbouring municipality known to have large *C. tomentosa* populations. In total, eight boxes of *C. tomentosa* were transplanted into four separate areas in Roliggropen. The water in Roliggropen is turbid, and the sediment is very soft. The contents of the boxes were emptied and carefully pressed down to the bottom. Metal frames were used to mark the areas of transplanted individuals. The transplantation sites were also marked with GPS coordinates (Figure 33).



Figures 33a and 33b. Metsähallitus transplanted the stoneworts manually. The team were equipped with SUP boards, aquascopes, boxes for collecting charophytes, metal frames, and a GPS device to mark the planting site. Photos: Anette Bäck (upper), Essi Keskinen (lower), Metsähallitus.

Monitoring methods

Very little information is available on stonewort transplantation in the Baltic Sea so far, so monitoring with various methods of transplantation sites that already exists and also those where transplantation will be done in the future is highly important. To assess the success of transplantation tests, monitoring the species' growth should be continued for several years after the restoration measures have been completed, as there are major natural variations in the growth of stoneworts from year to year. In particular, changes in the percentage of stonewort coverage should be monitored at the transplantation site to find out if the transplanted stonewort community has grown denser or started to spread in the bay.

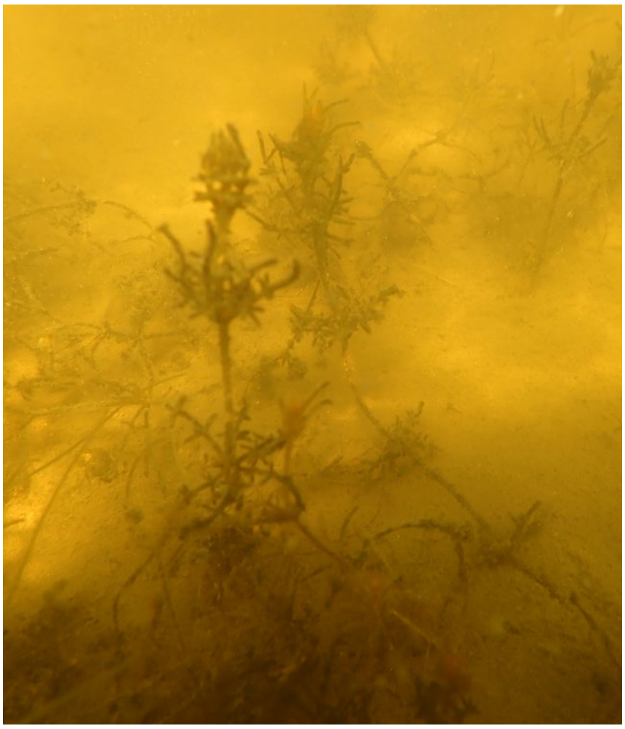
The spread of stoneworts is relatively easy to observe, as many species grow in shallow water. For instance, the situation can be examined from a rowing boat with the help of an aquascope. Snorkelling can often obtain more accurate results than examining the site from the water's surface. Contact with the bottom should be avoided, as the fine sediment typical of many stonewort sites can easily cloud the water column, reducing water transparency for several minutes. Wading through the charophyte meadow and using a motorboat in shallow water may damage the meadow by creating deep grooves.

Surveys were conducted to monitor Metsähallitus' transplantation sites in 2022 and 2023 using SUP boards and aquascopes based on GPS coordinates recorded while planting. The sediment is very soft in this area, and the visibility is extremely poor (Figure 34). This made finding the stoneworts difficult while the monitoring was in progress. The metal frames were found to have sunk into the sediment.

Experiences of the method

Outcomes

In Siviksfjärden Bay, the natural spread of *Chara aspera* in the planting squares and transplantation with a spade were equally



Figures 34a and 34b. Monitoring. Photos: Essi Keskinen / Metsähallitus.

effective. In those squares where jute strips or BESE-elements© grids had been used, the number of individuals was lower at the end of September than in the control squares. Faithfull et al. (2022) noted that using the jute strip was a poor option, as local fish detached stoneworts from the bottom while burrowing under the strip. The BESE-elements© grids had presumably shaded the stoneworts excessively, in addition to which they were expensive. The most efficient and inexpensive option among the three planting techniques was transplantation with nothing but a spade, and considering the amount of labour required for the planting, it, too, was a worse option than the natural spread of the species. However, based on the results obtained in a single growing season, it appeared that transplanting *C. aspera* using spades was possible. This could be an option for a transplantation method at a site where no stoneworts are found if transport from another water area can be arranged.

Transplanting *Chara tomentosa* in BESE-elements© grid was unsuccessful. At the end of September, no *C. tomentosa* individuals remained in the test squares.

Metsähallitus' experiment noted that the planting site must be marked particularly well in areas with very soft bottoms; a combination of a small anchor and a buoy could work. This way, losing the transplanted stoneworts, which makes monitoring the success of the test impossible, due to poor visibility or sediment settlement can be avoided. Despite the difficulties associated with the monitoring, *C. tomentosa* individuals were found in one of the four transplantation sites in Roliggropen in autumn 2022. The individuals planted in the other sites presumably did not survive. Stoneworth was also spotted in the same site in the monitoring carried out in 2023. However, they appeared to be in a relatively poor condition, probably because the site was not optimal for this species.

Challenges

This method is associated with several challenges. Firstly, the conditions must be appropriate for the species to thrive at the site. This means that samples must be collected to assess water quality, and corrective measures in the surrounding catchment area or in the bay may be required if the water quality is found to be unsuitable. In addition, appropriate sites must be found from which stoneworts can be collected and where their numbers are sufficient to ensure that the donor population is not excessively harmed. Transplantation of species involves risks, including the transfer of pathogens. To minimise this, it is advisable to source individuals as close as possible to the transplanting site. Sediments have proven a common cause of problems, as they are frequently so soft that the planted individuals sink into them, and getting the plants to grow is consequently difficult. Turbid water also hinders monitoring.

Costs and benefits

The costs of the transplantation project in Roliggropen were approximately EUR 3,000.

4.4 Habitat management

4.4.1 Manipulation of microhabitat of an endangered species

Protecting an endangered species by manipulating its microhabitat is not unlike gardening – weeds and unwanted plants are pulled up, shading trees and shrubs are removed, and soil is fertilised and irrigated. In situ cultivation in the wild, or protecting an endangered plant species at its original site, can be used to strengthen the species' few individuals or last populations. However, if the tide of an endangered species cannot be turned by other conservation measures, in situ protection may be a safer method than ex situ protection. In the latter case, individuals of the species are transferred to an artificial environment, such as a laboratory (Deinhardt et al. 2021, Miranto et al. 2017).

Small-scale manipulation of the microhabitat of an endangered species may, for example, mean mowing vegetation that shadows or competes with the species to be protected or otherwise making the microhabitat more suitable for the species.

Restoration method

Puccinellia phryganodes (CR) and the native *Dupontia fulva* (previously *Arctophila fulva* var. *pendulina*, EN) grow on the northern Bothnian Bay coasts. The latter is only known to grow on two sites, one in Liminka Bay and the other in the River Tornionjoki estuary. The species is found on riverbanks and seashores liable to flooding and in estuaries on silty, muddy and sandy bottoms. It produces few seeds and mainly reproduces vegetatively. *Puccinellia phryganodes* grows on low-lying coastal meadows with low vegetation, bare silty soils, and depressions between sand dunes and salt patches. This species also produces few seeds and only spreads vegetatively. Almost all the sites on which it is found in Finland are located in the Oulu region, and most of the shoots come from a single population (Markkola 2013, 2016, Niemelä 2009, Rautiainen et al. 2007, Siira 2011). Both species suffer from shores overgrown with reeds and other vegetation, coastal construction and clearing of estuaries, eutrophication and the fact that the shores are no longer grazed and mowed. Some experts also claim that reduced ice erosion and changes in flow conditions caused by the future Oulunsalo-Hailuoto bridge project (Oulunsalo-Hailuoto causeway, Rintamäki 2011) are a threat to certain *Puccinellia phryganodes* populations.

To manage the few populations of both species, competing and taller vegetation (both common reeds and other taller plants) have been mowed, mowing waste has been removed from the site, and soil has been broken up to simulate an earlier succession stage. The reasons for launching the restoration of the natural estuary dynamics of the River Temmesjoki in 2019 (see section 3.2.1 Restoration dredging) also included securing the *Puccinellia phryganodes* populations in Liminka Bay. The habitats of both species are additionally managed by grazing the shores [see section 4.4.3 Shoreline grazing (large-scale)]. The efforts to conserve *Puccinellia phryganodes* were also intensified through ex situ cultivation and transplantation in the ESCAPE Life project in the 2010s (Miranto et al. 2017, Jäkäläniemi 2013).

Monitoring methods

The survival, reproduction and spread of the species are monitored. The proliferation of other species, especially competing ones, can also be monitored at the site.

Outcomes

The mowing of common reeds has been partially effective in protecting populations of *Dupontia fulva*, whereas it has made no essential difference to the conservation of *Puccinellia phryganodes*. Mowing other taller vegetation has helped both species. Especially in the case of *Puccinellia phryganodes*, breaking up the soil has helped the species to survive, while in the case of *Dupontia fulva*, this had an adverse effect (Markkola 2013, 2016, Niemelä 2009, Rautiainen et al. 2007, Siira 2011).

Challenges

Unless the ecology of the species is well known, even light microhabitat manipulation may undermine its living conditions. However, in situ conservation is a gentler method for the species than transplantation or laboratory cultivation: at the very least, the species is known to thrive at its original site, where attempts to improve its microhabitat can be made (Jäkäläniemi 2013, Miranto et al. 2017).

Costs and benefits

The costs are minor and mainly consist of labour. Light mowing, removing the mowing waste from the site, and tilling and breaking up the soil can be carried out by volunteers if they can be taught to identify the species to be protected. The equipment is inexpensive. Supervisors and their competence play a key role in in situ protection and small-scale habitat manipulation if volunteer labour is used.

4.4.2 Causing a deliberate small scale disturbance

Maritime nature is not a stable environment in which the biota would remain unchanged in the same habitat year after year. In addition to the changing seasons, the physical environment varies irregularly, presenting the shore flora and fauna with various disturbances, including ice erosion (Erävuori & Kullberg 2018). Other relatively small-scale disturbances include grazing and floods.

The coasts of the Bothnian Bay, in particular, are shallow and strongly affected by land uplift. Many of this area's indigenous or near-indigenous coastal plants are pioneer species that have adapted to primary succession stage habitats – they are weak competitors that cannot cope with overgrowing by such species as reeds.

Ice erosion shapes coastal vegetation in two main ways. Mechanical ice erosion levels sediments and coastal vegetation when wind pushes fast ice or ice floes against the shore. Thermomechanical ice erosion is where an ice floe freezes fast to the bottom and, as the water rises, lifts bottom sediment and vegetation. When the winds move this ice flow along, sediment, seeds and plant parts are carried to new areas.

Many threatened aquatic and coastal plants of the Bothnian Bay, including *Alisma wahlenbergii* (VU), *Hippuris tetraphylla* (VU), *Dupontia fulva* (EN) and *Puccinellia phryganodes* (CR) cannot cope with competition as their growth strategy is based on colonising vegetation-free land rising from the sea or shallow silty shores or meadows where ice erosion has cleared all competitors. If ice erosion is reduced or ceases due to human activity or climate change, the living conditions of these species will quickly decline. This is because other species, such as the common reed, spread, and the habitat is overgrown along with other taller plants and stronger competitors (Erävuori & Kullberg 2018). Previously, grazing and mowing in coastal meadows have also contributed to the survival of these species.

Restoration method

A permanent connection to replace ferries is planned between Hailuoto, the largest island in the Bothnian Bay, and Oulunsalo on the mainland. It would comprise a causeway approximately seven kilometres long with two larger bridge spans. The environmental impact assessment report found that the causeway would reduce the impact of ice erosion from a minor to a significant extent on nearby Natura sites and could consequently threaten the survival of the populations of some endangered species in the future (Erävuori & Kullberg 2018).

To compensate for reduced ice erosion, simulated disturbance has been proposed, such as mechanical grinding of the shore in the spring immediately after the ice has melted. The idea would be to control the competing species and to simulate a primary succession shore cleared by ice erosion.

Monitoring methods

The programme for monitoring the impacts of reduced ice erosion once the causeway to Hailuoto can be seen at Pohjois-Pohjanmaan ELY-keskus (2018).

Outcomes

The method has not yet been tested in practice. See the dedicated section for other relatively small-scale disturbances created by humans to manage coastal nature, such as grazing (4.4.3). *Puccinellia phryganodes* has benefited from breaking up the soil on its natural sites (Niemelä 2009, Siira 2011, Markkola 2013, 2016, Rautiainen et al. 2007). See also Pohjois-Pohjanmaan ELY-keskus (2010) and Rintamäki (2011).

Challenges

The method has not yet been tested, and there is no knowledge of whether it works. Neither has a decision concerning its technical implementation been made yet.

4.4.3 Grazing of shores (large-scale)

In the past, mowing and grazing coastal meadows were common ways of feeding cattle and keeping the shores open (Figure 35). Many species have adapted to life on grazed coastal meadows, where competing vegetation remains low and the cows' hooves cause small natural disturbances in the microenvironment.

Industrialisation and increasingly mechanised agriculture had dramatically reduced grazing in coastal meadows by the 1950s and 1960s. In the meantime, the increased nutrient load in the Baltic Sea speeded up the overgrowth of the shores, and shrubs took over the coastal meadows.

Especially in North Ostrobothnia, traditional rural biotopes are managed by grazing the shores, which also benefits such species as *Hippuris tetraphylla, Persicaria foliosa, Dupontia fulva, Persicaria foliosa* and *Crassula aquatica* (Huuskonen 2006, 2023, Kontula & Raunio 2018). All these endangered aquatic or coastal plants are weak competitors, and while they cannot cope with shore overgrowth, they benefit from eliminating taller competitors. Coastal meadows are also particularly important for birds. Consequently, many coastal meadows are natura 2000 SPAs, and several are Ramsar sites also.

Figure 35. Cows and sheep graze coastal meadows on shallow shores managed as traditional rural biotopes. Photo: Kevin O'Brien/Metsähallitus.

In North Ostrobothnia alone, approximately four thousand hectares of coastal meadows are grazed. While the main objective of some of the pastures is to manage an endangered traditional rural biotope, others aim to manage *Dupontia fulva* or *Persicaria foliosa* habitats. Grazing also manages bird habitats in coastal meadows (Huuskonen 2006, Katja Raatikainen, Teams discussion on 21–22 November 2023).

Restoration method

Coastal meadows can be grazed by either cattle or sheep. Typically, the farmer makes an agreement with the landowner and grazes their animals on fenced coastal meadows from early summer till autumn. As the growing season progresses, the animals are moved from one pasture to the next as one meadow has been 'managed'. Grazing must be continuous in order to maintain a managed habitat. While grazing stops the vegetation of coastal meadows from growing excessively tall, cows' hooves also break up the soil surface, which benefits at least *Persicaria foliosa* and *Hippuris tetraphylla* (Markkola 2013, Deinhardt 2021).

Further management of a restored site is based on grazing. Sufficient grazing pressure adapted to the site keeps reed growth in check, causing it to decline gradually. The reeds are replaced by low-growing coastal meadow species. Low vegetation, denuded patches and alluvial soil forming at the waterline attract insects and birds, especially migratory and nesting waders.

It has been estimated (LuTu 2018, Kontula & Raunio 2018) that some 12,000 hectares of areas overgrown with reeds could still be restored as coastal meadows. Some of the sites classified as coastal meadows would also require restoration as they have been re-colonised by reeds (approximately 2,000 ha). The area of coastal meadows that have remained open and are maintained by annual grazing is 4,000 hectares (Katja Raatikainen, Teams discussion on 21–22 November 2023).

Monitoring methods

Bird life is monitored relatively well:

- Bird surveys are carried out before and after management starts, for example, in coastal meadows to be restored under the Helmi programme
- Nesting birds: pair numbers, breeding success, resting birds: number of individuals of species
- Especially species listed in Annex IV to the Birds Directive
- Also, a great deal of monitoring by birdwatchers

Other monitoring:

- Rural biotope inventories (status and representativeness of biotopes, management situation and success of management, vegetation)
- In state-owned protected areas, annual monitoring of the management carried out and documentation of management measures (which measures were carried out and when)
- On sites covered by agri-environment schemes, monitoring of implemented management and management journals
- Natura site status assessments, etc.
- In protected areas, a small network of plant testing areas (around ten sites with controls)
- Better and more organised monitoring would undoubtedly be necessary. No information has been collected on the monitoring costs (Katja Raatikainen, Teams discussion on 21–22 November 2023).

Experiences of the method

Outcomes

Coastal meadows have been managed with good results for years, especially in North Ostrobothnia (Katja Raatikainen, Teams discussion on 21–22 November 2023). Grazing has benefited birds, some endangered aquatic plants and traditional rural biotopes alike. Coastal meadows have made relatively attractive pastures for livestock owners as they comprise large areas that can accommodate big herds. Especially suckler cow and beef farms have found that coastal meadows work well as part of the farming operation.

Challenges

Many people are still concerned over the impacts of coastal grazing on water bodies, even if Natural Resources Institute Finland's calculations in 2023 showed that grazing reduces the total amount of nutrients in the coastal meadows of the Bothnian Bay (Huuskonen 2023).

However, Finnish sea areas differ from each other greatly in terms of their ecology. The Bothnian Bay is the only one where phosphorus is the growth-limiting nutrient, whereas it is nitrogen in the other sea areas. The direct impacts of coastal grazing on local water quality have only been studied in the Bothnian Bay (Pesonen 2023), and the Natural Resources Institute Finland's calculations are theoretical. More direct studies on the impacts of coastal grazing on nearby underwater nature in different water bodies are needed.

Costs and benefits

Almost without exception, grazing is based on five-year contracts under the agri-environment scheme. The application is submitted by a farmer with grazing animals. The compensation paid under the agri-environment contract varies according to the area's value; at regional and national sites, it is EUR 610/ha a year, and at others, it is EUR 460/ha a year. Under the agri-environment scheme, a separate one-year fencing or clearing payment can be applied for and included in the agri-environment contract (fencing 1,500 €/ha, clearing EUR 450/ha).

Project funding can also be obtained for fencing and clearing or under such programmes as Helmi, in which the work is carried out by the ELY Centre, Metsähallitus or by the landowner or the party managing the site. The price of fencing depends greatly on the type and location of the fence. The price of clearing also varies a lot.

If the site has been left unmanaged for an extended period, restoration usually needs to start with mowing the reeds before or simultaneously with the grazing. In recent years, the price of flail mowing of reeds has been approximately EUR 700 to 1,000/ha. If the mowed waste is taken away, this will increase the costs. Rotavating the soil surface would also be important for birds at some sites. The price of this operation is similar to the price of flail mowing. Uses have been developed for mowed reeds in recent years. If effective production chains could be created and a market for the pulp was found, the harvesting costs would be reduced (Katja Raatikainen, Teams discussion on 21–22 November 2023).

4.5 Coastal fisheries restorations

4.5.1 Fisheries restorations in coastal lagoons

In the Baltic Sea, spawning areas important for spring-spawning freshwater fish species, such as perch and pike, are mainly located in estuaries, shallow coastal bays, and lagoons (flads and gloe lakes). Fish eggs and larvae are particularly sensitive to changes in the environmental conditions, and mortality is high at these life cycle stages. The spawning areas and their conditions consequently play an essential role in the breeding success of fish. In shallow and sheltered coastal lagoons, water temperature rises faster in spring than in the surrounding sea areas. The higher temperature helps the development of eggs and larvae. Flads and gloe lakes often contain suitable vegetation and zooplankton for egg and juvenile development also.

Coastal flads and gloe lakes are subjected to indirect and direct human pressure. They are influenced by the leaching of nutrients, which drives eutrophication, as well as solid matter washout from agriculture and forestry. Eutrophication in coastal lagoons causes the rapid growth of common reeds, an increase in filamentous algae, and the deterioration of water quality. In many coastal lagoons, increasing reed growth may block the channel leading to the sea, preventing fish migrations to and from their breeding grounds.

On the other hand, a flad's shelter and vital temperature development have often been lost when its channel has been dredged and opened excessively, for example, for boating purposes. Major modifications of the flad's channel increase water exchange and flow, which puts the development of eggs and juvenile at risk. Other construction measures affecting a flad or gloe lake and the channel leading to it, such as building a road across the channel, may have blocked the connection between the sea and the lagoon. A culvert is often placed under the road, but a poorly installed culvert can become a barrier to fish migration. For more information on restoration methods, see section 3.3 Coastal lagoons: 3.3.1 Sill restoration, 3.3.2 Replacement of culvert/removal of barrier to migration, and 3.3.3 Opening of channel.

Fisheries restorations in shallow sea bays and coastal lagoons along the Finnish coast have been carried out by body of a jointly-owned water area. There are major gaps in the information on restoration measures completed decades ago, most of which have gone entirely unreported. Fishery restorations have been carried out in some coastal lagoons since as early as the 1970s (Wistbacka & Snickars 2000). In the 1990s, 18 sea bays or flads/gloe lakes were restored in the Uusikaupunki, Kustavi and Taivassalo areas with FIFG funds (European Community Financial Instrument for Fisheries Guidance). At that time, the typical restoration method believed to benefit fisheries was channel dredging, the aim of which was to maintain or improve the production of juvenile fish. Ten years later, in their report, Härmä et al. (2008) attempted to determine the effectiveness of these measures completed in the 1990s. As the situation of fish juvenile production before the restoration measures had not been reported, assessing the effectiveness of the measures proved impossible. Retrospectively, the scale of channel dredging at these sites was excessive. As a result, the characteristics that support juvenile fish production in sheltered lagoons, such as shelter and higher temperature, were lost.

The Natural Resources Institute Finland has carried out fisheries restorations in the Kvarken flada project in the Quark (Hynninen et al. 2019, Saarinen 2019) and in the European Maritime and Fisheries Fund project titled Environmental Programme for Fisheries (2017–2023) in Ekenäs archipelago and Quarken (Lappalainen et al. 2023, Louhi et al. 2023). In these projects, flad and gloe lake sites have been restored using light mowing of the channels, culvert repairs and other channel restorations.

Similar fisheries restoration projects have been carried out recently along the Swedish coast, primarily to support the natural reproduction of spring-spawning fish species, including pike and perch. The work in the Kvarken flada project carried out in 2016–2020 also extended to the Västerbotten province of Sweden (Saarinen 2019).

Restoration methods

The main types of fisheries restorations in Finnish coastal lagoons are either channel restorations by light mowing of vegetation, or restorations of excessively dredged openings. Some culverts that prevent fish migrations have been replaced, or the water level has been raised to enable the culvert to work as a migration route. In some cases, the channel may have been equipped with fishways (see Figures 36–41). to regulate the water level in a gloe lake or to facilitate fish migrations

(Hynninen et al. 2019). For more information about fisheries restorations carried out by the Natural Resources Institute Finland and the methods used in coastal lagoons, see Hynninen et al. 2019 and Lappalainen et al. 2023.

Figure 36. A fishway leading to a gloe lake helps fish migrate to their spawning grounds in the spring. Photo: Sanna Kuningas/Natural Resources Institute Finland.

Figure 37. Plenty of stones are placed in the channel. Photo: Sanna Kuningas/Natural Resources Institute Finland.

Figure 38. Stones are laid on the bottom of the channel to prevent rapid recolonisation by reeds. Photo: Sanna Kuningas/Natural Resources Institute Finland.

Figure 39. The channel leading to the flad is mowed with a scythe. Photo: Sanna Kuningas/Natural Resources Institute Finland.

Figure 40. After manual mowing, the channel between the flad and the sea is visible in the reed bed. Photo: Sanna Kuningas/Natural Resources Institute Finland.

Figure 41. Backfladan and its restored channel after clearing of reeds. Photo: Lari Veneranta/Natural Resources Institute Finland.

Monitoring methods

Monitoring fish migrations has been based on footage from a camera trap placed in the channel and, in some places, trapping of fish in fyke net. Trapping makes it possible to determine the species, size, and sex distribution of migrating fish. After measurements fish has been released back to water. After perch spawning, egg counts are carried out either by snorkelling or using a rubber boat or a SUP board. The number of perch females that have visited the spawning grounds can be determined based on the number of egg ribbons. Once the young have hatched, juvenile has been caught in a plankton net to assess their density. The number of pike juveniles has been examined by walking approximately 100 metres at a suitable depth among the shore vegetation, counting the number of juveniles caught with a net or using a white plate and/or a scoop. For more information on the monitoring methods used, see Borg et al. (2012) and Lappalainen et al. (2023).

In coastal lagoons where fisheries restoration measures have been carried out, water temperature has typically also been monitored from ice melt until the beginning of July using temperature loggers. This provides information on temperature development in the egg and juvenile stages and the thermal sum of the selected period.

Experiences of the method

Outcomes

There are no reports describing the effectiveness of fisheries restoration measures carried out in previous decades, except for a study on widening the inlet of a flad, in which fish movements were found to increase if the connection to the sea is opened (Blomqvist 1984). Nor is there any documentation on the impacts of flad restorations carried out in the 1990s, which mainly consisted of the excessive dredging of the flad's inlets to increase water exchange. The report on the restoration operations in the Kvarken flada project (Saarinen 2019) describes the project's successes and failures. The report also provides valuable guidance on issues to be accounted for when embarking on similar measures. Under the Environmental Programme for Fisheries funded by the European Maritime and Fisheries Fund, flad and gloe lake sites were restored in the Quarken and Ekenäs archipelagos, and the effectiveness of these measures was monitored. The results were compiled in a Natural Resources Institute Finland report (Lappalainen et al. 2023).

When the vegetation in the channel between the sea and a flad has been gently mowed to enable fish migrations, this has been found to produce positive effects almost immediately. No more than a few weeks after the mowing, fish were found to have reached the spawning grounds. This observation has also been made in connection with ineffective culverts. Immediate positive effects on fish migrations and reproduction success have been achieved by ensuring there is enough water in the culvert.

When the channels of dredged flads were restored, the shelter provided by the flad and its thermal properties were quickly recovered by limiting the water exchange. It has also been shown to have immediate effects on facilitating perch reproduction.

Challenges

Challenges have been identified in different stages of fisheries restoration of flads and gloe lakes. The first challenge is finding suitable sites to restore. In many places, especially along the coasts of the Gulf of Finland and the Archipelago Sea, flads and gloe lakes are already subjected to strong human pressure. This is especially true at sites that were dredged open to facilitate access for boats, and persuading all land and water area owners to agree to the restoration is hugely challenging.

Once a site suitable for restoration has been found, permissions must be obtained not only from landowners but also from the ELY Centre if necessary. In fisheries restorations along the coasts, the greatest challenges arise from finding suitable sites to restore and applying for permits. In permits issued by the ELY Centre, the presence of endangered species at the restoration site or the impact of restoration on the environment considered to be in a natural state is considered. Observations of endangered species may prevent restoration measures.

Specific challenges are also associated with the monitoring methods of restoration projects, many of which are labour-intensive. For experiences of restoration methods, see Natural Resources Institute Finland’s report (Lappalainen et al. 2023).

Costs and benefits

The cost of restoring flads and gloe lakes varies greatly depending on the site. Volunteers can do the light mowing of a channel, with the only costs arising from the tools, such as scythes and digging forks. If machines are needed, the costs will rise to between EUR 5,000 and EUR 25,000 per site for mowing and channel restoration. The price of replacing a culvert is around EUR 5,000 per site.

4.5.2 Pike wetlands

It is likely that floodplains have previously played a major role as breeding grounds for spring-spawning fish along the Finnish coastline. Pike prefer to spawn on shallow shores with vegetation and in flood meadows where the water temperature is favourably high in spring and where there is plenty of vegetation as a substrate for the eggs and shelter for the hatched juvenile (Ljunggren et al. 2011, Nilsson et al. 2014).

In Finland and globally, wetlands have suffered from human activities, including drainage for agriculture and forestry purposes and coastal construction. Modifying river estuaries, such as clearing, has also extensively destroyed natural flood meadows, which have been important breeding grounds for spring-spawning fish. In some places, wetlands may also be threatened by overgrowth driven by eutrophication, and the common reed dominates shore vegetation in many places. The grazing of coastal meadows has been a way to reduce overgrowth and maintain the traditional rural biotopes of the coast. However, grazing may also have a negative impact on water quality. In some places, it has been found to remove littoral vegetation that is important for the success of fish spawning on the shallowest part of the shore.

It has been estimated that the area of coastal meadows has decreased by about 90% along Finland's coasts since the 1960s. Coastal meadows were classified as critically endangered habitats in the latest assessment conducted in Finland (Lehtomaa et al. 2018).

One way of recreating wetlands is partly damming streams that discharge into the sea and flooding a suitable vegetation zone outside the channel. This usually aims to create spawning grounds for the pike, which is why such sites are known as pike wetlands. Mosaic-like gaps can be created in the reed bed or other shore vegetation by mowing if necessary.

Progress has been made in creating pike wetlands in the Baltic Sea region in the 2000s, especially on the Swedish coast, where dozens of wetland restoration projects have been completed (Hansen et al. 2020). Pike wetland restorations in Sweden have been carried out by at least the County Administration Board, the Swedish University of Agricultural Sciences (SLU) and Sportfiskarna association. For information on these projects, see the website of Åtgärder i Vatten (atgarderivatten.lansstyrelsen.se). The effectiveness of the restoration has also been monitored at most sites, and it has been found that pike wetlands can produce significant numbers of juveniles (Nilsson et al. 2014).

In Finland, the Finnish Federation for Recreational Fishing (SVK) has restored a few wetlands known as 'pike factories' in recent years, both on the coast and in inland waters (Figure 42). The Natural Resources Institute Finland has investigated the effectiveness of restoration at a few coastal sites. As part of its Rankku project, WWF Finland restored a wetland whose primary purpose is to reduce nutrient loading in the sea, but it is also hoped to positively impact pike reproduction. In the Åland Islands, the City of Mariehamn created an urban wetland in the Nabben area, including a small pike spawning wetland. Wetlands have also been restored in the Svibyviken area in Åland.

Restoration method

From the perspective of fisheries, the characteristics of a highly productive wetland include offering shelter and being shallow (10 to 70 cm), as this ensures a steady and adequate temperature for egg and juvenile development. Suitable vegetation is also needed, including the common reed, grasses or sedges, which provide substrates for the eggs and shelter for newly hatched juvenile pike. After the yolk sac stage, the developing juvenile fish also need zooplankton to feed on. Pike migrate to their spawning habitats immediately after the ice has melted, and small pike juveniles leave the wetlands for the more open coastal area in early summer. The wetland must remain wet throughout the period between spawning and juvenile migration; otherwise production will be at risk.

Migration channels have been restored, and possible barriers to migration removed in pike wetlands. Regulating dams may also have been installed to ensure sufficient water levels in the vegetation zone during pike reproduction. A suitable bottom weir may be an alternative for a regulating dam if necessary. In some places, aquatic vegetation has been

Figure 42. Pike wetland in Mussalo, Kotka. Photo: Sanna Kuningas/Natural Resources Institute Finland.

removed to create a mosaic-like structure and provide more vegetation border areas. In the pike factory project carried out by the Finnish Federation for Recreational Fishing in Kristinestad, vegetation was removed from the middle of an overgrown gloe lake and its water volume was increased. A sill was built in the stream discharging from the gloe lake to raise the water level during spring overflow. This means that the vegetation along shallow shores remains submerged, and the area suitable for pike spawning and the early stages of the juveniles is greatly extended. As the water level drops, the juveniles move into the open water area and, from there, migrate to the sea along the stream.

Monitoring methods

In some places, the Natural Resources Institute Finland has monitored the spring migration of fish by trapping with fyke net. A camera trap installed above the channel has been used to monitor migrating fish. At specific sites, a white plate, a scoop, or a net have been used to search for pike eggs and/or hatched juveniles among the shore vegetation. Drift nets have been used to estimate the number of young migrating out.

Experiences of the method

Outcomes

No well-documented results can be found on the effectiveness of completed restoration projects in Finland. In the pike wetland restoration projects monitored by the Natural Resources Institute Finland, it was found that pike numbers had increased markedly at sites recently turned into pike wetlands. There has been a primary focus on monitoring in Sweden, and both successes and failures have been recorded regarding pike wetlands (Nilsson et al. 2014). Sufficient wetting of the vegetation during the breeding season and as the young grow and the availiability of suitable vegetation have played key roles in successful wetlands projects and fish production.

Figure 43. Yolk sac pike juveniles in a white scoop. Photo: Sanna Kuningas/Natural Resources Institute Finland.

Challenges

In Sweden, an increase from around 3,000 to over 100,000 juveniles was observed in a pike wetland after restoration (Ljunggren et al. 2011, Nilsson et al. 2014). On the other hand, no corresponding increase in juvenile production was observed at the other two sites restored simultaneously, probably due to a lack of suitable vegetation.

Although the top figures recorded in Sweden have not been achieved in the wetlands restored and monitored in Finland, at least pike reproduction has been found to be successful in the monitored wetlands.

Costs and benefits

The costs of creating pike wetlands vary greatly depending on the site, the scale of the project, the method used, and the amount of external expertise resorted to, including machine work. If volunteers are used and no outsourced work is required, the costs can be reduced considerably.

The cost of building a regulating dam is a few thousand euros. The cost of mechanical mowing per cut is also around the same price. The costs incurred from more extensive excavation work, such as removing reeds, vegetation, or bottom sediments, may amount to more than EUR 20,000.

As with all restoration measures, the focus should be on examining the initial situation before the restoration measures are undertaken and monitoring the situation after the restoration. The success and outcome of the restoration cannot be demonstrated without careful monitoring.

4.5.3 Restoration of breeding grounds for the sea-spawning grayling

The sea-spawning grayling, which used to be common in the Gulf of Bothnia, has declined to the brink of extinction (Keränen 2015). It is currently classified as critically endangered (Urho et al. 2019). While the declining grayling populations were a cause for concern as early as the 1930s (Heusala 1935, cited in Keränen 2015), only in the 21st century was the endangered status of the species fully understood, based on research projects and surveys addressed to fishermen in the Quarken region. It is likely that eutrophication, competition, predation, fishing and climate change have all contributed to the endangered status of the sea-spawning grayling (HAV 2017).

The sea-spawning grayling has declined dramatically and disappeared in some areas, including Quarken and the Sea of Bothnia. As the reasons for the decline of this species are not entirely clear and their combined effects are uncertain, it has not been possible to systematically intervene in the dwindling populations (Keränen 2015). According to the management plan for the sea-spawning grayling, urgent measures must be taken to preserve and strengthen the grayling populations, such as restoring historical spawning grounds and stocking.

As part of the Biodiversea project, the Natural Resources Institute Finland studied the remaining areas important for the grayling by mapping their breeding grounds and monitoring the home range of individuals with acoustic tags. In addition, the Natural Resources Institute Finland is re-establishing the broodstock of sea-spawning graylings and investigating the results of juvenile stocking and factors affecting natural reproduction. The sea-spawning grayling spawns on shallow stone and gravel bottoms, which have primarily become overgrown by filamentous algae due to eutrophication. The Biodiversea project also aims to reduce the amount and coverage of filamentous algae and sediment using different mechanical methods. Suitable methods are discussed in a review article (Baetz et al. 2020).

There are no records of experiments in which seabeds have been cleaned as a restoration method for the sea-spawning grayling or any other species in the Baltic Sea coastal areas. This is why the restoration project was carried out on a small scale. The primary objective was to test different methods and assess their effectiveness, whereas strengthening the existing fish population came second. The restoration tests were carried out at Valsörarna Islands in the Quarken. While there was a robust sea-spawning grayling population in this area in the past, the juvenile surveys carried out in the project and earlier fishing reports indicated that the species no longer exists here. The project will also stock the area to build up the population in the Quarken (carried out by the Natural Resources Institute Finland).

Restoration method

The purpose of mechanically cleaning the sea-spawning grayling's breeding grounds is to reduce the density of filamentous algae in the most important spawning areas. The cleaning measures were part of a pilot study to determine if they work and if their results are permanent. The pilot was carried out at Valsörarna Islands by Metsähallitus; however, it was done in close collaboration with Natural Resources Institute Finland. For a full description of the pilot, see the report titled *Kokemukset ja tulokset meriharjuksen kutupaikkojen kunnostamisesta Valassaarella* (Bäck 2023).

Areas suitable for testing the method were sought, and the work was planned in cooperation with the Natural Resources Institute Finland. The aim was to restore 18 sites of 2 x 10 metres. A control square left untouched for each restored square was also examined to determine the impacts. The work was completed in May 2023, immediately after the ice had melted. Originally, the goal was to use three different techniques, but the third (turning over rocks) was dropped at the planning stage as this method was found to be too time-consuming. The work continued with two methods, both of which were tested at nine sites. These methods were bottom scrubbing and high-pressure washing (Figures 44 and 45).

The areas were located using GPS and marked with buoys. They were cleaned for approximately 40 minutes using either ordinary street brushes or a pressure washer.

Monitoring methods

Each restored square was photographed before and after the measure (Figures 46 and 47). The control squares were also photographed at this time. Ten photographs were taken of each square from the same height using a measuring stick. This made it possible to document both the initial situation and the situation after cleaning the sea bottom, i.e., the immediate effects of the work. In summer, all squares were visited in June, August, and September and photographed similarly.

In the autumn, all photographs were analysed for coverage of filamentous algae. The results showed that filamentous algae reappeared on the sea bed after cleaning (impact and permanence of the measures).

Experiences of the method

- While a temporary reduction in filamentous algae can be achieved by restoration, the algae grow back rapidly and reach the same coverage as in the control squares, usually within a month. It is very difficult to remove the algae permanently. While the decrease in their coverage is probably partly due to their removal, the coverage is likely decreased because the algae were broken and shortened during the work.
- Restoration work should only be carried out in light wind conditions. Strong winds hamper the logistics and the work in general.
- Better or more consistent results were achieved in areas where the stones were mainly smaller and of a more even size. None of the methods were particularly effective. Based on the experiment, their use on a larger scale cannot be recommended. Treating small, essential sites with suitable conditions may be possible, i.e., level and shallow areas too open to allow the build-up of soft sediment. The measures could be developed further by experimenting with higher pressures and a greater volume of water than what could be achieved with the pressure washer used in the experiment, including fire extinguishing equipment

Figure 44 and 45. Brushes and a pressure washer were used to restore spawning grounds for the sea-spawning grayling. Photos: Anette Bäck/Metsähallitus.

used in the archipelago or water scooter propulsion. Various options are currently being explored and can be tested in future years.
- This restoration measure is a very temporary solution. Reducing eutrophication and mitigating climate change are the real, large-scale solutions to the problem. It may also be necessary to impose fishing restrictions during the sea-spawning grayling's breeding season or protect its key range. Studies associated with these measures will be conducted in the Biodiversea project.

Challenges

- The methods were physically strenuous, and rather than being completely removed, the algae were often only broken
- Requires favourable weather conditions
- The seabed is rarely even, and cleaning between stones is difficult
- Transporting large equipment to restoration sites in the shallow archipelago waters is difficult.

Costs and benefits

The material costs of the measures were low: street brushes, pressure washers, buoys and weights. A generator was also needed for the pressure washer and a boat and fuel. Due to the pilot nature of the project, the work started slowly; however, the pace accelerated when effective approaches and division of labour were found. Overall, the work took 24 working days.

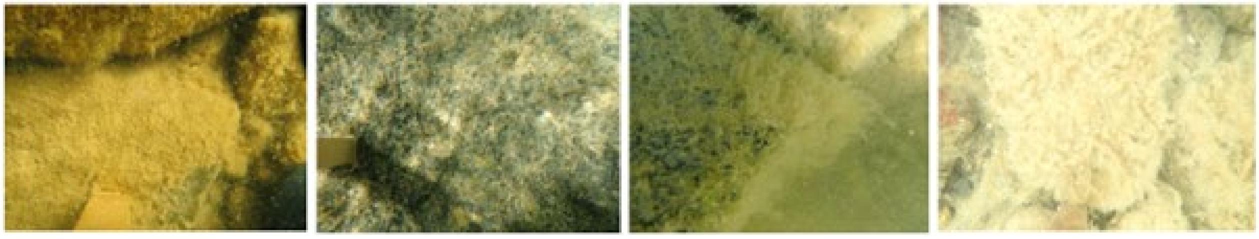


Figure 46. Test site 17.1. From left to right; the initial situation, a restored square, a monitoring visit in June, and a visit in August. The first square shows a sedimented bottom and short filamentous algae. The area was restored using a pressure washer. Although the image after restoration shows less sediment, short pieces of filamentous algae remain, some broken and some untouched. The monitoring photos from June and August show a high coverage of filamentous algae. This is a typical result obtained with a pressure washer. Photos: Anette Bäck/Metsähallitus.

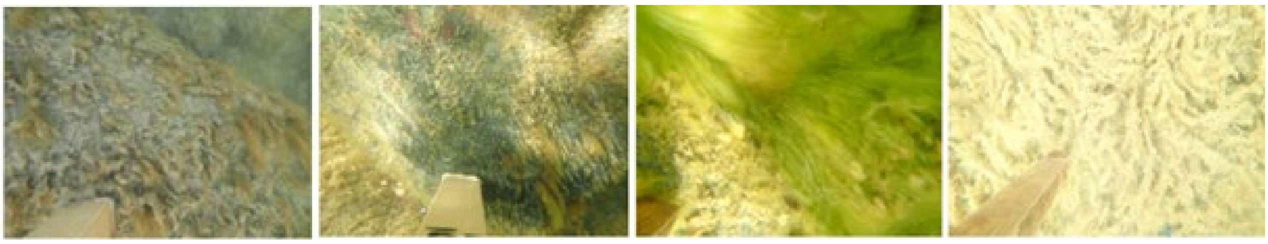


Figure 47. Test site 16.1. From left to right; the initial situation, a restored square, a monitoring visit in June, and a visit in August. The area was restored with a brush, and the photo taken after restoration clearly shows the brush marks. While the volume of sediments and filamentous algae has clearly decreased, they are still visible in the images. Some of the algae are broken. There was abundant vegetation observed on the monitoring visits in June and August. This is a typical result obtained with a brush. Photos: Anette Bäck/Metsähallitus.

5 Methods similar to restoration

5.1 Introduction of artificial reefs and other substrates in the seabed

Artificial reefs are structures consisting of either natural or artificial materials introduced in the seabed to protect, improve and restore different parts of the ecosystem. Artificial reefs include planned and accidental structures, such as wrecks of sunken ships (Kraufvelin et al. 2021). Artificial reefs can be very different depending on their material and the scale of the project. Examples of large projects include the Vinga artificial reef in Sweden, where a stone reef was built in the Gothenburg archipelago on the boundary between the Baltic Sea and the North Sea to compensate for the impacts caused by the extension of the Gothenburg fairway (2003–2004; Kraufvelin et al. 2023). At the other extreme are traditional projects involving introduced spawning habitats made from the branches of coniferous trees. They aim to provide additional spawning substrates, especially for perch and pike-perch, and shelter for juvenile fish (Laakso 1938, Kings et al. 2019). Artificial reefs also include the underwater structures of wind turbines that provide a hard substrate in the water column for macrophytes, mussels and other invertebrates (Bergström et al. 2021).

Artificial reefs are used to improve seabed diversity, for example, by introducing a hard substrate for invertebrates and macrophytes and providing shelter and breeding and feeding sites for fish. Artificial reefs are also built to reinforce the populations of specific target species, including cod (see Baltic waters web site, balticwaters.org), or they may protect sensitive areas from storms, reduce illegal bottom trawling in the area, and provide a setting for scientific research (Kraufvelin et al. 2021). Sensitive natural reefs can also be preserved by directing diving tourism to artificial reefs (Firth et al. 2023).

It should be noted that artificial reefs constructed with rocks differ from the restoration of stone reefs (section 3.5) in that artificial reefs are usually constructed in areas where they may not have existed naturally. This makes the method problematic (Petersen et al. 2023), and special consideration should be given to choosing the site when planning artificial reefs. It is advisable to build artificial reefs in areas where an original reef structure has disappeared, and the use of natural materials is recommended. (Kraufvelin et al. 2021; Petersen et al. 2023).

In the Baltic Sea, artificial reefs have been built e.g., in Kiel and Nienhagen, the River Oder estuary, the Vistula Lagoon, the Gulf of Riga and the Gulf of Finland (Fabi et al. 2011, Kraufvelin et al. 2021). A newly launched project in Skåne, Southern Sweden, aims to build up the cod population by introducing artificial reefs for shelter and feeding environments (The Hanö Cod Reef Project, hanotorskrev.se).

Little experience of artificial reefs has been gained in Finland. Traditionally, additional spawning substrates consisting of conifer branches sunk to the seabed have been used to boost fish production, especially spring-spawning species (Laakso 1938). The significance of introduced spawning habitats for perch reproduction has been studied in the Hanko-Ekenäs area of the Gulf of Finland (Kuningas et al. 2019), and they have been tested in the Finnish Federation for Recreational Fishing's Christmas tree campaigns, as well as in the SEABASED project in Eastern Götaland in Sweden (pdf, seabasedmeasures.eu).

Restoration method

Among other things, artificial reefs have been constructed with rocks and boulders. The Vinga artificial reef was built on a sandy bottom with aggregates produced from blasting operations when the Gothenburg fairway was deepened (800,000 m^3 of stone). A reef structure with seven ridges was built in the area (length 130 to 380 m, width 30 to 40 m, height 4 to 14 m) at depths ranging from 20 to 37 m. For artificial reefs in Germany i.e. Nienhagen (4 ha, at a depth of 11 to 12 metres) and Rosenort (1.2 ha, at a depth of 6 metres), not only natural stone but also different concrete elements were used, and nets and ropes were added to the reefs as substrates for algae and mussels (https://www.riff-nienhagen.de/the_reef_en.shtml).

In 2017-2018, as part of the Environmental Programme for Fisheries, the Natural Resources Institute Finland and the University of Helsinki's Tvärminne Zoological Station investigated if the introduction of spawning substrates improved perch juvenile reproduction in the Hanko-Ekenäs archipelago area. In this experiment, spruce trees were introduced in 16 sea bays (Kuningas et al. 2019).

Figure 48. Introduced spawning substrates are used to increase the success of perch and pike-perch reproduction. Conifer branches provide a substrate for perch egg ribbons. Photo: Mats Westerbom.

Monitoring methods

Artificial reefs are often used to strengthen the populations of predatory fish or large shellfish, and monitoring has frequently focused on these groups. At the artificial reef of Vinga, the abundance and size distribution of lobsters, the cod stock, the numbers of small crustaceans, and changes in the species were monitored as indicators of changes in the predator population. The monitoring initially took place annually for 11 to 12 years, and later, the monitoring exercise was repeated to assess long-term impacts (Kraufvelin et al. 2023). The impact of introduced spawning substrates on the success of perch reproduction was studied in Finland. Divers investigated the number of perch egg ribbons at these sites in the spring, and the number of perch juveniles born in that summer was studied using net fishing (Kuningas et al. 2019).

The impact of spawning substrates on perch juvenile production was studied in the western Gulf of Finland by the Natural Resources Institute Finland. No positive impact on perch juvenile production was observed at the pilot sites over two years (Kuningas et al. 2019). However, Fontell (2001) found in his experiment in Laajalahti that the introduced substrates had served the spawning of both perch and pike-perch. Introduced spawning substrates may have local significance, especially in areas with no benthic vegetation but where the environmental conditions are otherwise favourable for the perch in terms of shelter and warm water in spring.

Experiences of the method

Outcomes

In some cases, artificial reefs have been found to attract fish, mussels and other invertebrates (Fabi et al. 2011). The reef can serve as a substrate for annual and perennial algae in the epipelagic zone and an anchoring substrate for a diverse epifauna community below this zone. Reefs can positively impact the ecosystem, but often in a limited area (Kraufvelin et al. 2021a).

At Vinga stone reef, changes were observed in the lobster population (*Homarus gammarus*): the density of this species increased in 2003–2014 (198%) compared to a reference site (22%), as did the size of females. The number of gadiforms increased over the first four years, after which the differences between the artificial reef and the control area disappeared. Labridae numbers increased during the monitoring period, whereas small crustaceans decreased, probably because of stronger predatory fish populations (Kraufvelin et al. 2023).

Challenges

It has been suggested that artificial reefs would improve the production of fish and mussels. However, it often remains unclear if the reef genuinely increases production or if it only attracts individuals from the surrounding area to the reef. The latter scenario may expose target species to higher fishing or predation pressure as individuals gather in a small area (Kraufvelin et al. 2021a, Petersen et al. 2023).

The impact of artificial reefs on the hydromorphology of the area around it and the benthic communities is poorly known.

So far, little or no research evidence is available on the benefits and disadvantages of artificial reefs in the Baltic Sea. (Kraufvelin et al. 2021a)

Costs and benefits

The costs of building artificial reefs vary considerably depending on the scope of the project and the material used. For example, the construction of a large stone reef and the organisation of monitoring in Vinga, Sweden, cost EUR 1,200,000 (Kraufvelin et al. 2021 b). On the other hand, spawning substrates may be introduced to the seabed at no cost.

5.2 Biomanipulation

5.2.1 Vegetation changes

Eutrophication increases the volume of phytoplankton and turbidity of water and can result in a regime shift in the ecology of the water body (flad, gloe lake, bay) from a plant-dominated habitat with clear water to a habitat with cloudy water dominated by cyprinid fish and phytoplankton. The amount of nutrients in the water system should be reduced so that the plant-dominated ecosystem with clear water can recover. Moreover, even without reducing nutrients, biomanipulation can be used to try to achieve the same result.

This method has been tested for decades, especially in Germany and elsewhere in continental Europe, with both good and bad results.

Restoration method

In this context, biomanipulation refers to such measures as reducing phytoplankton, catching cyprinids that root in the bottom sediment, and planting vascular plants and/or stoneworts to bind the bottom sediment and clear the water. Attempts to reduce phytoplankton can be made by introducing *Cladocera* or *Cnidaria* into the water body. Other measures include catching cyprinids. Once the water has cleared somewhat, planting vascular plants and/or stoneworts that bind the bottom sediment and consume nutrients in the water further reduces turbidity (Deinhard et al. 2021).

Monitoring methods

Since these kinds of restorations have not (yet) been performed in the Baltic Sea, the best monitoring methods can be found in, for example, Hilt et al. 2006 and 2018.

Experiences of the method

Decades of experience in biomanipulation has been accumulated relating to lakes in Germany, in particular. These methods and their results have been explained widely, for example, in Hilt et al. 2006 and 2018.

Outcomes

Decades of experience in biomanipulation has been accumulated relating to lakes in Germany, in particular (see review articles: Sabine et al. 2006, 2018, Bakker et al. 2013).

Challenges

Biomanipulation may fail for several reasons. If the removal of nutrients fails, the water body may quickly revert to its original state. Vascular plant species, such as *Potamogeton* or *Myriophyllum*, rather than stoneworts, may also take over from microalgae in the vegetation, reducing the recreational value of the area. As the method has not been tested in Finland, there is no evidence of whether or not it would be effective in the conditions of the Baltic Sea. Additionally, potential hypoxia and ice cover in winter may not have been critical factors in the areas where biomanipulation of vegetation has been successfully tested (Deinhardt et al. 20221).

5.2.2 Intensive fishing of three-spined sticklebacks

The EU Interreg Central Baltic SEABASED project led by the John Nurminen Foundation has assessed and sought ways of removing phosphorus accumulated in the sea. This information has been packaged into guidelines that can support future efforts to protect the Baltic Sea. In the Åland Islands, the project piloted the intensive fishing of three-spined sticklebacks to support predatory fish populations. Fishing has previously been used to remove nutrients, especially in lakes. The idea of intensive fishing is to reduce eutrophication by catching fish and, along with them, removing biomass and nutrients from the lake/sea. Fish studies conducted on the west coast of the Baltic Sea indicate that a gradual regime shift is taking place, in which the decline in perch and pike populations leads to increasingly large areas dominated by sticklebacks, ultimately threatening the entire ecosystem structure of the Baltic Sea. It has been estimated that catching a dense population of a fish species that feeds on zooplankton and the eggs of predatory fish, together with other measures supporting predatory fish populations, could lead to an improvement in the status of the marine environment.

Restoration method

The idea of intensive fishing is to reduce eutrophication by catching fish and, along with them, removing biomass and nutrients from the lake/sea. In the pilot project carried out in the Åland Islands, a purse seine net was used to catch sticklebacks.

Experiences of the method

Outcomes

The results of the pilot project carried out in Åland were relatively modest. Finding the fish to catch was difficult; choosing the right equipment required fine-tuning.

Challenges

Finding the right time and place for catching the fish may be difficult. A certain type of special equipment is needed to catch sticklebacks: for example, a small mesh size net suitable for catching little fish is heavy to pull with small traction devices.

Costs and benefits

Unknown.

5.3 Artificial sandbanks and islands

In connection with major construction projects, islands and their ecosystems may have been lost or destroyed, or artificial islands may be built for ecological compensation purposes. While examples of artificial islands can be found worldwide, they are usually built for human activities, including housing, airports or landfills. Islands or sandbanks can also be built to dispose of dredged spoils. The Netherlands is an example of a country where artificial islands have been built purely for nature conservation purposes. If land uplift stops in the future due to the rising sea level, this method could also come into play in the Baltic Sea to enable the development of a primary succession ecosystem.

Restoration method

Marker Wadden, a large lake of 700 km^2, was created in the Netherlands in connection with coastal flood protection measures. The problems associated with this extensive lake were the small length of shoreline compared to the water area, turbid and eutrophic water, and declining bird and fish populations. To deal with these problems, significant amounts of bottom material were dredged from the lake. This material was used to build two islands of 5 and 10 km^2 in 2016–2017, plus additional islands in 2020. Relatively quickly, pioneer species began to grow on the islands and in their shallow littoral waters, and primary succession was able to colonise the islands. The spread of vegetation was also sped up by transplantations. Today, numerous bird species nest on the islands, including endangered ones, and fish spawn on their shallow shores. The islands are also used for busy recreational and nature education activities.

Monitoring methods

The species in this area have been monitored.

Experiences of the method

Outcomes

In the lake in the Netherlands in question, the construction of artificial islands has been successful, and nature has taken them over. This example is difficult to relate to the problems of the Baltic Sea; however, the lack of islands and shallow shores is not precisely a relevant problem here. The idea could potentially be used in connection with extensive dredging or construction projects, for example, where the volume of spoils that need to be disposed of (and that are suitable for disposal in the sea) is large enough to make it worthwhile to build a new island or sandbank, rather than dumping the spoils in the sea or on land. However, this method is likely to be primarily theoretical in the context of the Baltic Sea unless someone proposes using it as ecological compensation (Deinhardt et al. 2021).

- https://www.natuurmonumenten.nl/projecten/marker-wadden/english-version
- https://rewildingeurope.com/news/marker-wadden-project-reaches-milestone-with-island-opening/

Challenges

The method is costly and, at least for the moment, does not appear necessary in the Baltic Sea. Artificial islands built by depositing soil destroy the entire ecosystem left under them. They also change the conditions of currents and sedimentation. In the wrong places, artificial islands or sandbanks may also potentially function as stepping stones for invasive alien species that need shallow water and few competitors to move to a new area (Deinhardt et al. 2021).

Costs and benefits

In the Netherlands, the construction of the islands has cost EUR 75 million so far.

Fish found spawning grounds on the shallow shores of the artificially created islands.

5.4 Acid sulphate soil risk mitigation

Acid sulphate soils have typically been used for arable farming in Finland. These soils are also found in mires, peaty forestland and under small mires forming in low-lying areas. When acid sulphate soils come into contact with oxygen (as in the case of inadequately covered excavation spoils), acid runoff negatively impacts the water system and biota in the immediate vicinity of the catchment area (Autiola et al. 2022). The mobilisation of heavy metals caused by acidification may impair the chemical and ecological status of surface waters (and cause fish kills), adversely affect plant biodiversity, and contaminate the groundwater.

When planning wetland construction, for example, acid sulphate soils must be accounted for using soil samples and careful planning.

Reducing the negative impacts of acid sulphate soils is a routine measure, especially on the coasts of Ostrobothnia, where such soils are common.

Restoration method

Identifying acid sulphate soils promptly before the harmful acidification effects begin is vital. Before launching a project, examining the distribution map of acid sulphate soils produced by the Geological Survey of Finland (gtkdata.gtk.fi) is advisable. If there is even the slightest suspicion that a planned wetland or similar is located in an area of acid sulphate soils, a sufficient number of samples should be taken from the project site, and methods for mitigating the harmful impacts of these soils should be planned well in advance.

Acid sulphate soils can be identified by taking soil samples. The crucial factors in determining the possible mitigation methods include the pH, groundwater depth and depth of acid sulphate soils on the site. Excavated masses can be treated with lime, neutralised and stabilised, the excavation depth can be controlled, and the groundwater level can be regulated to prevent any acidic runoff.

Monitoring methods

A monitoring programme is drawn up to prevent the harms caused by acid sulphate soils, at the centre of which is measuring the pH value of the water. In addition, the conductivity of water and the amounts of heavy metals can be measured.

Experiences of the method

If acid sulphate soils are identified in time, reducing the harm they cause is usually a straightforward, albeit costly, operation.

Outcomes

Results from acid sulphate soil risk mitigation can be found widely in Autiola et al. 2022. Acid sulphate soil's adverse effects can be managed if the situation is recognized early on and mitigation measures are taken.

Challenges

Treating acid sulphate soils with lime is expensive. Collecting and testing samples (EUR 1,500 to 2,000 per sample) is relatively expensive. If acidification does occur, however, repairing the damage afterwards is even more expensive, if not nearly impossible in practice.

Costs and benefits

Lime treatment is expensive if the area to be neutralised is large. Reducing the excavation depth where possible is a less expensive solution. Reducing the harmful effects of acid sulphate soils is a routine measure considered in all excavation and water management projects in such soils.

5.5 Chemical manipulation

5.5.1 Phosphorus sequestration in bottom sediment using thermally treated limestone to reduce internal loading

Aluminium and iron compounds have been used for phosphorus sequestration in sediment to reduce the nutrient content of water in lakes (including Kirkkojärvi in Rymättylä in 2002 and 2005, Kallträsk in 2006, Kirkkolampi in Heinola in 2012, Littoistenjärvi in Kaarina in 2017, and Ahmonlampi in Siilinjärvi in 2019) (Sarvala et al. 2020). The EU Interreg Central Baltic SEABASED project led by the John Nurminen Foundation (2018–2020) assessed and sought ways of removing phosphorus accumulated in the sea. The project tested the use of a product refined from marl, which is obtained as a limestone extraction by-product in Gotland, to bind phosphorus to the sediment in the marine environment in eutrophic coastal areas where phosphorus is released from sediment into water. Phosphorus sequestration in sediment was tested in Kolkka, Rymättylä in Finland and in the inland bays of Kyrkviken, Djuröfladen and Farstaviken in Sweden.

Restoration method

The objective of the pilot project was to reduce the internal phosphorus loading in the Baltic Sea using a sorbent based on crushed rock/rock remnants, which can sequester phosphorus in the bottom sediment. The project had three pilot sites, where thermally activated limestone was applied to phosphorus-rich bottoms in coastal bays of Sweden and Finland. The pilot project consisted of a development phase, risk assessments and selection of pilot sites, after which the measure was carried out. The exact application volumes of crushed rock were determined in the development phase. Laboratory tests showed that thermally treated crushed rock with a particle size of less than 2 mm was suitable for this purpose. This material is known as activated limestone, and its phosphate sorption capacity is approximately 500 times higher than that of untreated crushed rock. Based on the results of the laboratory tests, it was estimated that 100 g of activated limestone per square metre is sufficient to sequester one gram of phosphorus per square metre.

Pre-treated marl was applied to the test sites from a helicopter to sequester phosphorus in the sediment (Figure 49). The surface area of the sites was 80,000 to 90,000 m^2, and the sorbent dose varied from 100 to 130 g/m^2. The water quality was monitored by testing water samples and automatic water quality monitoring before, during and after the application of the activated limestone.

Figure 49. Application of marl in Kolkka, Rymättylä in 2020. Photo: Irma Puttonen/Åbo Akademi.

Experiences of the method

Outcomes

The activated limestone used in the SEA-BASED project did not significantly increase phosphorus sequestration in the sediment or impact the water quality. However, there were indications in both bays in Sweden that the phosphate concentrations in the water layer near the bottom changed almost immediately after the treatment. Nevertheless, this impact disappeared within hours or days of the treatment. The product has shown a good performance in absorbing phosphorus from water in laboratory tests. The application of the product was successful, and its use was not found to have caused any environmental damage.

Challenges

The field test showed that limestone treatment did not succeed in sequestering phosphorus with sufficient efficiency. Application from a helicopter can be expensive. However, the development of phosphorus treatment continues in Sweden (Levande Hav AB).

Costs and benefits

Unknown.

5.6 Restoration of silted seagrass meadows

In the early 2010s, a multi-species seagrass meadow still existed on a sandy bottom to the south of an island called Maasarvi in the Bothnian Bay National Park. The meadow became silted over ten years, perhaps due to the combined effect of a nearby fairway, increased engine sizes and speeds, and the general trend of eutrophication. The sandy bottom was covered with soft silt, and more than a dozen different species of aquatic plants were replaced by an almost monocultural meadow of filamentous alga species called Vaucheria. The size of the meadow is around two hectares.

Restoration method

It has been suggested that the soft top layer of the present Vaucheria meadow should be suction dredged down to the level of a clean sandy bottom. After this, the plant species previously found at the site could be transplanted into the meadow or allowed to spread naturally from nearby areas.

Monitoring methods

Diversity of aquatic vegetation in the meadow, number of species.

Experiences of the method

Challenges

The proposed method is very invasive, expensive and experimental. There are no experiences with it yet.

5.7 Nutrient removal

5.7.1 Use of nutrient-rich brackish water for irrigation

To reduce the loading from the Baltic Sea catchment, irrigating arable lands with nutrient-rich brackish water instead of fertilising the fields has been tested to mitigate the adverse effects of eutrophication. The method was tested in the EU Interreg Central Baltic SEABASED project led by the John Nurminen Foundation (2018–2021) in two eutrophic bays in the Åland Islands (Kaldersfjärden and Ämnäsviken) and in Eastern Götaland, Sweden. The SEABASED project assessed and sought ways to remove phosphorus accumulated in the sea. The irrigation method was tested in the summers of 2019 and 2020.

Restoration method

In the pilot project, nutrient-rich water layers found close to the bottom were extracted from two eutrophic coastal bays that were semi-enclosed, and the possibility of recycling nutrients using this water for irrigating fields was tested. The goal of recycling nutrient-rich water for field irrigation was to reduce the harmful effects of eutrophication by removing nutrient-rich sea water from the layer close to the bottom while using the nutrients contained in irrigation water on local farms.

Monitoring methods

Before the irrigation tests started, sediment samples were taken from both bays and analysed in depth fractions of 0 to 2 cm, 2 to 5 cm and 5 to 10 cm. The sediment samples were analysed for total phosphorus (TP), total nitrogen (TN), total organic carbon (TOC), loss on ignition, polycyclic aromatic hydrocarbons (PAH16), metals (cadmium (Cd), copper (Cu), chromium (Cr), cobalt (Co), mercury (Hg), nickel (Ni), lead (Pb), vanadium (V), zinc (Zn) and arsenic (As)), as well as tributyltin (TBT). The ongoing regular sampling of the bays was complemented by enhanced monitoring during the SEABASED project. Samples were taken from both bays every two weeks between May and August in 2019 and 2020. The water samples were analysed for salinity, temperature, oxygen, total nitrogen (TN), ammonia ($NH4+$), nitrite and nitrate ($NO2 + NO3$), total phosphorus (TP), phosphate ($PO43-$) and chlorophyll-a. To determine the quality of irrigation water applied to the fields, the farmers took water samples directly from the irrigation equipment every time it was used. These samples were analysed for salinity, chloride, conductivity, total nitrogen, ammonia, nitrite and nitrate, total phosphorus, iron and aluminium. The farmers calculated the yield, or the crop harvested per unit of surface area, after each harvest in 2019 and 2020 in both pilot and control areas. Silage was analysed for qualities such as dry matter, sugar content, chloride, and several minerals. Soil samples were analysed for soil type, humus content, conductivity, chloride, pH, calcium, total phosphorus, phosphate, sodium (Na), aluminium (Al), iron (Fe), magnesium (Mg), potassium (K), copper (Cu), manganese (Mn), zinc (Zn) and boron (B). Repeated groundwater samples were taken in one of the test areas.

Experiences of the method

Outcomes

More nutrients could be removed using brackish water from the layer close to the bottom to irrigate fields than by extracting irrigation water from the surface layer of the sea. This means that the separate application of fertilisers to arable land can be reduced accordingly.

During the project, the water quality in the bays from which water was extracted, the irrigation water quality, the growing crop (grass), soil and groundwater were monitored. The nutrient amounts removed from the water correspond to 1% to 6% of the targets set for phosphorus and nitrogen reduction to achieve a good ecological status. No changes were observed in the quality or quantity of the crop. The salinity of groundwater increased somewhat as a result of the irrigation.

For a comprehensive final report of the experiment and more detailed recommendations, see Government of Åland (2021).

Challenges

The use of brackish water for irrigation carries the risk of salinisation of soil and groundwater if this method is used repeatedly for several years. During rainy periods, the additional irrigation of fields is harmful.

Costs and benefits

Unknown.

5.7.2 Removal of sediment surface layer to reduce nutrients

The EU Interreg Central Baltic SEABASED project led by the John Nurminen Foundation (2018–2020) assessed and sought ways of removing phosphorus accumulated in the sea. The project examined the possibilities of removing the surface layer of sediment to reduce nutrients and the internal phosphorus load. This method has been used in Sweden to control internal nutrient loading in lakes. In Sweden and Norway, equipment have been developed for removing the sediment surface layer using a low-flow suction dredging method, which causes very little turbidity (Figure 50). While dredging with conventional equipment has been used to restore lakes worldwide, less experience has been gathered concerning sea areas.

Restoration method

The purpose of the method is to remove a 10-centimetre layer from the sediment surface by suction dredging, minimising any harm. While the main objective is to remove nutrients from the seabed, other goals include reducing organic oxygen consumption in the sediment, which decreases the release of phosphorus from anoxic sediment into the water body.

Removing the sediment surface layer using the low-flow technique or other similar methods to avoid sediment re-suspension and turbulence exceeded the budget of the SEABASED project when tenders were requested for testing the method in the field. This is why a decision was made in the project to carry out a laboratory test commissioned by the ELY Centre for Southwest Finland to exam-

Figure 50. Sediment removal in Jönköping, Sweden (Barnarpasjön) 2018 with low-flow suction dredging equipment. Photo: Irma Puttonen/Åbo Akademi.

ine the likely effects of sediment removal on sediment oxygen consumption and nutrient flows between the sediment and the water above it. The suitability and potential of the measure for the protection of the Baltic Sea were assessed, especially regarding anoxic coastal seabeds, which have historically been subjected to high nutrient loads and offer little chance of survival for significant flora or fauna.

In the SEABASED project, layers of different thicknesses were removed from the sediment surface in the laboratory, and changes in oxygen consumption and nutrient concentrations in the water layer above the sediment were monitored. The method's effectiveness was assessed through a laboratory incubation test.

Experiences of the method

Outcomes

The laboratory test carried out in the SEABASED project showed that sediment oxygen consumption was slightly lower when the surface layer was removed from the sediment. Since new organic matter that consumes oxygen as it decomposes sinks onto the sediment surface every year, it was noted that oxygen consumption would probably return to its previous level. Removing the sediment surface layer would have to be repeated annually to keep oxygen consumption at a moderate level and ensure that the sediment can sequester nutrients better.

The technology needed to remove and use the sediment requires improvement. External nutrient loads must be brought under control first before the measure can be expected to affect internal nutrient stores. Numerous uses can be found for the removed sediment (Welch et al. 2016).

Challenges

Where the aim is to improve the functioning of the biotic community and to mitigate eutrophication, dredging must be carried out using a method that causes as little harm as possible. In the sea, the challenges include the scale, suitability of the available technology, high cost, and nutrient loading from the catchment and nearby sea areas. In addition, fresh degradable organic matter sinking to the bottom would replace the removed sediment, making the impacts of the operation short-lived.

Costs and benefits

The costs incurred from sediment removal over two hectares and its disposal at the site examined in the SEABASED project in the Archipelago Sea would have exceeded EUR 500,000. The costs depend on the location and size of the site and the further treatment of the removed sediment. Any contaminants in the sediment will increase costs.

5.7.3 Blue mussel farming and harvesting to reduce nutrients

Eutrophication and the resulting turbidity of water are some of the biggest problems in the Baltic Sea. The farming of algae and mussels has been tested as a method of reducing nutrients and improving water quality. The biomass of algae and shellfish binds nitrogen and phosphorus, and by increasing and harvesting this biomass, nutrients that have ended up in the Baltic Sea can be removed from the ecosystem. In addition, the blue mussel (*Mytilus trossulus*) filters water at a rate of approximately two litres per hour in the Baltic Sea, removing particles from the water column and clearing the water. (Kautsky & Wallentinus 1980, Kraufvelin & Díaz 2015, Kotta et al. 2020a).

Blue mussel farming has already been piloted in several projects in the Baltic Sea. The report on the Baltic Blue Growth project (Minnhagen 2017) provides information on pilot projects carried out between 2007 and 2016 in the Baltic Sea, and the report compiled by Kraufvelin et al. (2021a) also describes more recent projects completed before 2020. In Finland, blue mussel farming was piloted between 2007–2012 in the Åland Islands, for example, in the Baltic Ecomussel project (Minnhagen 2017, Díaz & Kraufvelin 2013).

Restoration method

The farming of blue mussels is based on larvae from natural populations attaching themselves to various substrates introduced into the water column, including lines and nets, where they grow into adult individuals. The farmed biomass is usually harvested one to two years after the start (Kraufvelin & Díaz 2015). Among other things, blue mussels and zebra mussels have been farmed on posts, lines, nets or permanent breakwater/reef-type structures. In a Finnish blue mussel farming pilot carried out at Kumlinge, in the Åland Islands, growing blue mussels in a plastic net was tested in 2007–2009. In Syderstö in the same area, a pilot project was launched in 2010 with the aim of examining the farming of blue mussels in growing nets produced by Smartfarm (Smartfarm A/S) (Minnhagen 2017).

Monitoring methods

In the blue mussel farming pilot conducted in the Åland Islands, water quality (transparency, phosphorus and nitrogen content, and chlorophyll-a) was compared between the farming site and six control sites. Additionally, the volume of organic matter in the seabed and the numbers and species composition of benthic animals were examined at the farming site and compared to two control sites. Samples were taken once in August 2012 (Díaz & Kraufvelin 2013).

Experiences of the method

Outcomes

In the pilot projects in the Åland Islands, mussels attached and grew in the nets and the pilot was technically successful, despite challenging winter conditions. The shellfish biomass, which totalled 14.4 tonnes, was harvested 2.5 years after the launch of the project (November 2012). However, the harvested biomass was smaller than expected (the target was 20 to 28 tonnes). This was partly due to the harvesting method used, in which small mussels were left behind. (Minnhagen 2017). The calculated nutrient removal in the pilot project was 83 kg of nitrogen/ha and 6.4 kg of phosphorus/ha (Kotta et al. 2020). The impacts of the small-scale pilot on water quality and benthos were mainly positive. A smaller total phosphorus and chlorophyll-a content was found at the farming site than at the control sites. The abundance of benthic animals and the number of species were higher at the farming site than at the control sites. No seabed anoxia was observed at the farming site (Diaz & Kraufvelin 2013, Kraufvelin & Díaz 2015).

Since the pilot project, blue mussel farming has not been developed further in the Åland Islands (see challenges).

Challenges

The costs and benefits of blue mussel farming in the Baltic Sea area have been a subject of scientific debate in recent years (Kotta et al. 2020a and 2020b, Wikström et al. 2020). There are several challenges to cultivating blue mussels in the northern parts of the Baltic Sea (Hadberg et al. 2018). First, the slow growth of the mussels (on average, a few millimetres per year in natural conditions) and second, the uncertainty of their reproduction set limitations to economically viable farming (Interview with Mats Westerbom on 3 November 2023). Due to the small size and slow growth of the blue mussel, achieving sufficient biomass that would positively impact water quality in the area is difficult. In addition, the amounts of nitrogen and phosphorus bound to biomass are considerably lower in the northern Baltic Sea compared to the western coast of Sweden, where cultivating mussels for human consumption is profitable (Hadberg et al. 2018). Additionally, recruitment does not happen annually in the Finnish sea area, and reproduction success depends on several environmental variables (Westerbom et al. 2021).

Blue mussel cultivation could work locally to curb point-source loading, for example, in connection with fish farms (Kotta et al. 2022). No adverse impacts on the status of the seabed were observed in the small-scale farming pilot in the Åland Islands (Kraufvelin & Díaz 2015). Larger and denser farming sites could potentially increase anoxia in the bottom and release nutrients from the bottom sediment due to the accumulation of mussel faeces and other organic matter on the seabed (e.g. Wikström et al. 2020). Little is known about these impacts in the Baltic Sea (Hadberg 2018, Wikström et al. 2020). Harmful substances also accumulate in mussels, which may restrict biomass use for human or animal consumption. Currently, biomass use is not generally advanced enough to make farming on a larger scale economically viable and attractive to different operators (Žilinskaite et al. 2021). In the Finnish pilot project carried out in the Åland Islands, the costs of farming in relation to the nutrients removed were high compared to experiments in the central and southern parts of the Baltic Sea (Kotta et al. 2020a). The region also lacks the necessary infrastructure for using biomass, and neither is funding available for developing it in place (Linsén 2016). When examining blue mussel farming from the perspective of cost efficiency, the impacts of climate change should also be factored in: a reduction in the salinity of seawater to less than 5.5 per mille will impair the status of blue mussel communities considerably (Westerbom et al. 2019, Jaatinen et al. 2021). Consequently, the Finnish sea areas will likely become less suitable for farming certain marine species in the future.

Costs and benefits

The costs of blue mussel farming are usually estimated as euros per kilogram of nutrients removed. In the Finnish pilot projects in the Åland Islands, the cost of nitrogen and phosphorous removal was EUR 1,683 and EUR 21,300 per kilogram, respectively (Kotta et al. 2020a).

5.7.4 Removal of dead filamentous algae and aquatic plant biomass from the sea

Higher nutrient loads in water bodies increase primary production, which can be seen as the abundance of planktonic and macroscopic algae, especially annual filamentous algae and aquatic plants. When filamentous algae die, they detach from their substrate, and waves and currents often build them into larger masses. Dead filamentous algae are found in surface waters, on the bottom, and in the water layer close to the seabed.

Masses of dead algae drifting in surface waters are often pushed close to the shore, for example, in small sea bays, or accumulate in deeper water areas. The decomposing algae mass releases nutrients that cause local eutrophication. Decomposition consumes oxygen; as a result, oxygen is consumed within the algae mass and often also in the water and seabed below it. While the accumulation of dead plant masses on shores is a natural process, eutrophication has increased the volume of such masses to impact the entire local habitat and its biodiversity negatively, and many sensitive species may suffer from it. Over time, dead organic matter accumulating on the shore and in shallow waters may completely change the habitat. For example, many bays with sandy bottoms and beaches have become overgrown, resulting in a regime shift. Algae masses drifting onto the shores and shallow waters also hamper recreational use.

The aim of removing algal and aquatic plant biomass is to maintain original biotopes and habitat diversity, remove nutrients from the sea and recycle them, for example, by composting, and improve the properties that promote the recreational use of shores. This can be achieved by activating private shore owners and holiday house residents to collect and remove algae and developing a mechanical method suitable for algae disposal in larger areas.

Restoration method

Removing biomass consisting of dead filamentous algae and aquatic plants from the sea is one of the measures listed in the National Programme of Measures of Finland's Marine Strategy (Laamanen et al. 2021). While various projects are developing this method, it has not yet been systematically tested (Janne Suomela, ELY Centre for Southwest Finland). Ordinary landowners have collected algae from their shores, and their enquiries have given additional motivation for developing the method.

Experiences of the method

Challenges

- Persuading ordinary landowners to remove algae masses
- Obtaining funding for mechanical removal
- Potential adverse effects of algae mass removal.

Costs and benefits

No costs are incurred from collecting algae from the shores manually if the landowner carries out the work. A mechanical method is being developed to remove biomass from larger water areas. While its costs cannot yet be estimated, they will likely be in the same range as those of mowing aquatic vegetation and similar mechanical work.

5.8 Control measures of invasive alien species

5.8.1 Canadian waterweed

The Canadian waterweed (*Elodea canadensis*) is a pretty, fast-growing ornamental species that was planted in Kaisaniemi Botanical Gardens in 1884. From there, it began to spread rapidly around Finland, and this alien species has even reached the Käsivarsi area in Lapland. As an invasive alien species, the Canadian waterweed has taken hold of many lakes of inland Finland, where it dominates over other vegetation. The Canadian waterweed is a tough competitor and can easily take over from other species. Enclosed water bodies with abundant Canadian waterweed sometimes experience strong pH fluctuations, and the dying plant mass may use up all oxygen while covering all other vegetation. Where it is found in large numbers, the Canadian waterweed may also disrupt fish spawning. Plentiful occurrences of the species also hamper a water body's recreational use.

While the Canadian waterweed is a freshwater species, it has spread into estuaries, bays, and some flads and gloe lakes in the Baltic Sea. The species is spread not only by humans but also by birds and other animals. It can propagate even from small pieces.

Such methods as seine nets have been used to remove Canadian waterweed from lakes in Finland in various projects (e.g. ELODEA and ELODEAII projects coordinated by the Finnish Environment Institute). Seine netting succeeds in removing Canadian waterweed biomass temporarily, but as the species can propagate even from small shoot sections, eradicating it is practically impossible.

While the ultimate goal of eradicating the Canadian waterweed from a water body can no longer be achieved, biomass removal may help the survival of other species and facilitate the recreational use of water bodies, at least momentarily.

Restoration method

Metsähallitus and the ELY Centre for North Ostrobothnia tested Canadian waterweed removal in Pensaskari gloe lake in the Bothnian Bay National Park in 2021–2022. The aim was to eradicate this invasive alien species from the gloe lake altogether, or at least to reduce its volume, preventing it from dominating the vegetation. The protected *Alisma wahlenbergii* and near-threatened *Potamogeton friesii* are found in this gloe lake, which is why neither mechanical removal nor seine netting were possible. The experiment was underpinned by the idea that if the species could be eradicated from the gloe lake, it would at least take a while before it spread there again, as it is located on an island in the middle of the sea, and Canadian waterweed cannot tolerate even low-saline brackish water in the northern parts of the Bothnian Bay. It could only spread to the area again from shoots carried by birds.

Volunteers worked to remove the plant by wading through the water in survival suits and using an aquascope or snorkelling and diving. An effort was made to remove the plants whole with their roots. The plants were collected in gauze bags and then emptied in sieves held by assistants on SUPs, taken to land and buried in the ground.

The work was organised by dividing the gloe lake into sections with a white sink rope, then working in one section at a time to remove the plants.

Monitoring methods

The results of the measure have been reviewed once a year, and the increase in the number of shoots has been estimated compared to the previous year's situation.

Experiences of the method

Outcomes

Removing the Canadian waterweed manually or by other methods does not entirely eradicate the species from the water body. Removing its shoots can only hope to reduce the adverse effects of the species. See Elodea II project (syke.fi).

Challenges

If there are more than a few shoots of the species, manual removal of the Canadian waterweed is not possible, even in a small water body. The species propagates even from small shoot sections, meaning it cannot be eliminated without recovering every piece of shoot and root.

The species was first observed in Pensaskari gloe lake in 2011. Had the know-how existed to start eradicating the plant as soon as it had arrived, it might still have been possible to save the day. As restoration measures were undertaken too late, the species had already spread all over the four-hectare gloe lake, even if it had not yet reached a dominant position.

The shoots collected from a water body by netting or other means must be disposed of appropriately. Any shoots or shoot sections carried back into the water system will continue to grow. Neither can the plant mass be directly spread anywhere or used as a feed. The Finnish Environment Institute considered the final disposal of Canadian waterweed biomass in its ELODEA projects (Karjalainen et al. 2017). Early intervention is probably the only way to eradicate the Canadian waterweed.

Costs and benefits

The cost of Canadian waterweed removal by netting ranges from thousands to tens of thousands of euros, depending on the size of the water body. If the work is carried out manually, the only costs are incurred from the workers (such as volunteers) and their equipment (a few SUP boards, aquascopes, survival suits, diving suits and/or snorkelling equipment).

6 Conclusions

This report was written by key persons of the LIFE-IP Biodiversea project actions A9 - Planning the restoration of underwater habitats and C6 - Piloting new conservation and restoration measures. Some authors represent the research community, while others look at restoration from the perspective of administrating protected areas. Once the report had been produced, the authors came together at a workshop to summarise their experiences reviewing the methods and restoration experiments described in the report. These conclusions comprise the group's experiences of the state of play, challenges and needs of marine restoration in Finland.

State of play – restoration methods and their adequacy

The initial section of the report stresses that the Baltic Sea is affected by a wide range of human activities, of which eutrophication has the most significant impact on its ecosystem. In a marine environment, water as a soluble element carries nutrients far from the point sources, which is why changes and degradation are visible across a wide area, and identifying causal relationships and intervening in them is difficult. Internal loading, which refers to nutrients accumulated in bottom sediments over decades, will continue to have an impact for a long time after all current point sources have been brought under better control. This is why there are few rapid solutions for improving the status of marine areas. As long as the water quality remains poor, carrying out full-scale restoration measures will be pointless. In addition, the applicability and cost-effectiveness of restoration work have their limitations, and such work cannot exclusively solve the problems caused by extensive eutrophication, for example. Marine environment restoration measures should consequently be looked at in the broader context of water and marine protection, in which restoration methods are one among several other measures and programmes (including the water and marine resources management programmes and HELCOM Baltic Sea Action Plan BSAP) aimed at achieving a good status of the sea and waters.

Marine environment restoration experiments have reached a point where a relatively versatile range of tools and measures are already available. However, efforts to assess the impact of the measures are only taking their first steps, as there has been little or no long-term and consistent monitoring of and research on the impacts of the measures on marine nature, or the evidence has only been accumulated over a short period. Diverse restoration measures have been tested and carried out in individual projects and isolated sites, meaning the existing information is fragmented. The group participating in the workshop noted that prioritising or assessing restoration measures, let alone evaluating their cost-effectiveness, is not yet possible at this stage. There is a particular need for research to gather and analyse data concerning restoration and monitoring systematically. It should also be noted that the selection of restoration methods in this and previous compilation reports covers a relatively narrow range of marine species and habitats.

Based on this compilation report, the idea is to continue piloting restoration methods in the Biodiversea project. It is already evident that when transplanting species, for example, a single technique can be applied in several different ways, enabling further development and research in existing methods. The plan is that anything new learned during the project can be disseminated widely. The timing of the project is also interesting, as the EU Nature

Restoration Regulation is likely to enter into force during the project period. The resources needed for restoration must be determined in connection with this legislation, enabling each EU Member State to respond to its requirements.

Efficiency and impact of the methods

As the efforts to define marine ecosystem services remain incomplete both in the international and the national context, few results that can be measured in financial terms regarding the impacts of marine restoration are available. In order to assess ecosystem services, monitoring data on the situation before and after restoration measures are also needed. Even in the case of economically important fish, only rough and indicative estimates can be given, and significant financial investment and methodological input would be needed to calculate the more detailed ecosystem benefits. In certain areas, eelgrass meadows play a significant part in carbon sequestration in the sea, and estimates of the value of the ecosystem services they provide have been produced internationally. On Finnish coasts, the carbon sequestration of patchy eelgrass meadows plays a minor role, whereas eelgrass itself is a vital keystone species that maintains a wide range of biodiversity. Consequently, it should not be forgotten that nature has an intrinsic value and that all measures aiming to increase and boost biodiversity are useful. The perspective of ecosystem services and assigning a financial value to restoration measures can also create problems, as this tends to direct the measures towards habitats and species that offer tangible or intangible benefits to humans.

Challenges

As challenges to restoration work, the group of authors highlighted the eutrophication of the sea and poor ecological status of waters, the scarcity and fragmented nature of research evidence and monitoring data, gaps in the Finnish-language restoration terminology, short-term nature of projects, ownership of land and water areas, insufficient resources and expertise, and factors associated with permit processes.

Eutrophication and water quality

Anthropogenic eutrophication of the Baltic Sea looms large in the background of degraded marine habitats and species. No large-scale improvement in their status will be possible before the nutrient load from the catchment ending up in the seas can be significantly reduced. Additionally, the status of the sea will only improve with a delay once the loading has ended. As noted in the introduction to this report, the prevention of environmental degradation and damage in coastal areas is always the first and foremost measure and more cost-effective than restoring the marine environment at a later date, as the success of recovering the structure and functioning of the marine ecosystem through restoration measures is by no means certain. This is why a sharper focus is needed on catchment rehabilitation and restoration measures. It should be understood that proactive work is less expensive and more effective than dealing with a problem once it has already been caused. Eutrophication also hampers the targeting of restoration measures and undermines their permanence. In the outer parts of the Archipelago Sea, for example, sandy bottoms have become covered with carpets of filamentous algae as the load from the catchment and its impacts have spread to the outer archipelago. While filamentous algae could be removed from bottoms in theory, the methods remain undeveloped and would probably be expensive, while their impacts would be temporary. Restoration is ineffective in practice if the factors that caused a change are far from the habitat they affect.

Fragmentation of data and restoration based on short-term projects

The planning phase of restoration sites is often labour-intensive because background data are available to variable degrees. Large volumes of data have been collected in the Laji.fi database of the Finnish Biodiversity Information Facility, which also contains information on VELMU surveys carried out over the past twenty years. It is worth remembering, however, that much of the older historical species data may still only be found in printed publications, as the observations have not been transferred to databases. Monitoring data describing actual changes are scarce and fragmented. When restoration measures are carried out as projects, the existing monitoring data related to them usually only cover a limited period, which impairs their quality and prevents the accumulation of monitoring data over a longer term, for which there would be an urgent need due to the complex ecological connectivity of the marine environment. This is why the planning phase of restoration measures usually also requires field visits, additional inventories, determination of the initial situation, searching for information from different sources and consultations with local residents, who often have highly valuable local knowledge that may reach back over long periods. The project-like nature of restoration measures and fixed-term funding also hamper the continuous management of sites. For example, several consecutive LIFE projects cannot fund an individual restoration site due to the requirements of the financial instruments, and work on many sites suitable for longer-term restoration will consequently not go ahead.

Lack of definitions of Finnish concepts

The introduction to the report briefly discusses the terminology and concepts related to restorations. No established terminology yet exists in Finland that could unambiguously define different measures relevant to restoration and rehabilitation in one way or another. Clearer concepts and terms would be needed to illustrate the principles and purpose of restoration to all stakeholders. For example, it is advisable to determine if the idea is to restore a habitat to a more natural-like condition or to otherwise improve or increase a particular habitat. The need to develop Finnish terminology will be topical at the latest when the Nature Restoration Regulation enters into force, and cooperation between a broad-based group of experts will be needed to harmonise the definitions.

Ownership of land and water areas

The ownership relations of land and water areas in Finland, which are exceptional by international standards, are another challenge. The shallow coastal areas in Finland are mainly under private ownership, while land and water areas and alluvial lands are often under joint ownership of dozens of partners. A shared intent is required to carry out restoration measures in such areas, which, depending on the measure, may be hard to achieve and is likely to be more difficult the larger the number of individual owners. Contacting estates and owners living abroad to obtain their consent is also labour-intensive and sometimes impossible, and this preparatory work while searching for sites and in the planning phase is time-consuming.

Few sites will eventually proceed from the planning phase to actual restoration. The high costs of restoration measures additionally hamper the finding of suitable sites.

One solution for inspiring and engaging private owners in restoration projects is investing in intensified communications, as raising awareness and sharing positive restoration experiences can help inspire locals and persuade them to have positive attitudes towards restoration measures on new sites, too. However, in the current situation, sharing successful experiences involves the problem that, as the experience of restorations is scarce, it is challenging to market and communicate about measures whose success is uncertain.

Lack of resources

Marine environment restoration is a relatively resource-intensive sector. Measures in the marine environment are costly, and, as an aquatic environment, special equipment and expertise are required in many areas. Moreover, as this is an emerging sector, sufficient resources should be secured in the future to develop restoration capabilities. It is worth remembering that funding and pairs of hands are also needed for carrying out other water and marine resource management measures, as the purpose of achieving a good marine ecological status will also make it easier to carry out these other restoration measures.

Permit processes

The new Nature Conservation Act (9/2023) brought eelgrass meadows and sheltered charophyte meadows within the scope of protection, which is why a permit issued by the ELY Centre is required for any measures targeting these habitats once the sites have been identified under a protection decision. For such measures as mechanical mowing of aquatic plants and dredging, for example, an advance notification must be submitted to the ELY Centre, which will assess if a permit is needed for the measure in question and provide more detailed instructions for carrying it out if necessary. Under the Water Act (587/2011), a permit must be applied for to undertake any measures targeting small water bodies (natural flads of no more than ten hectares in size, gloe lakes or springs, streamlets outside the province of Lapland, or ponds and lakes up to one hectare in size). A Natura notification must be submitted stating any measures that will be taken on Natura sites or measures that will affect these sites and their impact areas. Contacting the competent authorities or submitting an advance notification is a minimum requirement for measures taking place in other protected areas.

It is advisable to account for the permit process in the plans and set aside sufficient time for this process and information exchanges, ensuring that fieldwork and similar can be carried out on schedule. Not all planned restoration sites and/or methods can go ahead if they breach the guidelines issued by the competent authorities or if their degrading effects on species or habitats cannot be ascertained or excluded.

Cooperation relating to information exchanges can be stepped up. The National Water Management and Restoration Network (www.vesi.fi) is an excellent platform open for all interested in water bodies' well-being and restoration. Its work involves communities, research institutes, companies, authorities and citizens. The network provides up-to-date information on the restoration of water systems and catchments and funding opportunities for restoration work. It organises open and free events and provides a window into international water restoration work. By also strengthening the role of the competent authorities on this platform, planning processes could probably be streamlined in the future, as issues could be discussed openly already at the pre-planning stage.

Tips for stakeholders' interest in restoration

To conclude, the authors discussed the advice they would like to give to individuals or organisations interested in marine environment restoration work. They found this a difficult task as there are numerous restoration methods, and their suitability greatly depends on the site to be tackled. This report contains lists of concrete tips associated with the methods with which the authors have experience. In general, however, it can be said that the restoration method toolkit is still under development, and giving general instructions is difficult. An effort will be made to collect more detailed advice for restoration projects in the restoration manual, which will be prepared later in the Biodiversea project.

It was generally noted that water quality is one of the key factors and also threats to species and processes in the relevant area. Impaired water quality is often the reason for the loss of species or natural processes. The most important advice was consequently highlighted, i.e. studying the conditions and water quality at the planned restoration site to determine if restoration is possible or if other measures should be taken first to create suitable conditions for recovery. As pointed out in this report, large-scale measures are often required to improve water quality, and the recovery of ecological status is a slow process. In such eclosed basins as gloe lakes and flads, on the other hand, water quality can be improved more easily through on-site measures.

Defining the objectives of the measures at the very start of the project is important; what do we want to impact, and what is the targeted status? Is it restoring the site to its natural state or rehabilitating it for some other purpose, or is the measure's purpose to promote recreational use? What kind of changes can be expected, hoped for and measured? It is essential to consider monitoring early to ensure that the data needed to assess the effectiveness of the measures and achievement of the targeted values will be collected. Currently, insufficient information is available on the effectiveness of different methods and measures. This is why monitoring data needs to be collected to support the planning of measures, justify funding applications, and enhance the commitment of landowners and other stakeholders. The interviews conducted for the report showed, however, that less resource-intensive or scientific methods are also needed for monitoring the success of restoration methods. One of the proposals brought up consequently involved considering the level at which monitoring is possible, ensuring adequate expertise and carrying out sufficiently resource-efficient monitoring to identify long-term impacts.

When planning and carrying out restoration work in the marine environment, safety must also be considered when moving and working on water. All work in the marine environment usually requires special expertise; this also applies to nature restoration work. The marine environment's requirements and prevailing conditions must be accounted for at the planning stage when considering such details as the timing and duration of the work as well as the required personnel and fleet.

Currently, the development and testing of marine environment restoration methods are progressing at an increasing pace, and experiences of the effectiveness and efficiency of different restoration methods are constantly growing. As more information is accumulated, producing an update of this review would be justified.

Acknowledgements

For their participation in the expert interviews and information gathering, we would like to extend our thanks to Johnny Berglund, Christoffer Boström, Harri Huuho, Jari Ilmonen, Timo Kiiski, Viivi Kaasonen, Iiris Kokkonen, Jonne Kotta, Leena Nikolajev-Wiskström, Katja Raatikainen, Ville Räihä, Anniina Saarinen, Janne Suomela, Tuula Tanska, Lari Veneranta, Mats Westerbom and Ralf Wistbacka. This report was produced as part of the LIFE-IP BIODIVERSEA project (LIFE20 IPE/FI/000020 LIFE-IP BIODIVERSEA).

References

Autiola, M., Suonperä, E., Suvantao, S., Napari, M., Nylund, M., Kupiainen, V., Vienonen, S., Forsman, J., Suikkanen, T., Auri, J., Boman, A. & Mattbäck, S. 2022: Happamien sulfaattimaiden kansallinen opas rakennushankkeisiin – Opas happamien sulfaattimaiden huomioimiseen ja vaikutusten hallintaan. – Ympäristöministeriön julkaisuja 2022:3. 152 pp.

Baden, S., Gullström, M., Lundén, B., Leif, P. & Rosenberg, R. 2003: Vanishing Seagrass (*Zostera marina*, L.) in Swedish coastal waters. – Ambio 32: 374–377.

Baetz, A., Tucker, T. R., DeBruyne, R. L., Gatch, A., Höök, T., Fischer, J. L. & Roseman, E. F. 2020: Review of methods to repair and maintain lithophilic fish spawning habitat. – Water 12 (9): 2501.

Bakker, E., Sarneel, J., Gulati, R., Liu, Z. & Donk, E. 2013: Restoring macrophyte diversity in shallow temperate lakes: Biotic versus abiotic constraints. – Hydrobiologia 710. 10.1007/s10750-012–1142-9.

Below, A. & Mikkola-Roos, M. 2007: Ruovikoiden ja rantaniittyjen hoidon merkitys linnuille. – In: Ikonen, I. & Hagelberg, E. (eds), Ruovikot ja merenrantaniityt. Luontoarvot ja hoitokokemuksia Etelä-Suomesta ja Virosta. Lounais-Suomen ympäristökeskus, Turku. Suomen ympäristö 37: 24–29.

Bergström, L., Öhman, M. C., Berkström, C., Isæus, M., Kautsky, L., Koehler, B., Nyström Sandman, A., Ohlsson, H., Ottvall, R., Schack, H. & Wahlberg, M. 2021: Effekter av havsbaserad vindkraft på marint liv. En syntesrapport om kunskapsläget 2021. – Naturvårdsverket, Stockholm. 113 pp.

Bergström, U., Olsson, J., Casini, M., Eriksson, B., Fredriksson, R., Wennhage, H. & Appelberg, M. 2015: Stickleback increase in the Baltic Sea– A thorny issue for coastal predatory fish. Estuarine, Coastal And Shelf Science 163: 134-142. Doi: 10.1016/j.ecss.2015.06.017.

Blindow, I., Carlsson, M. & van de Weyer, K. 2021: Re-establishment techniques and transplantations of Charophytes to support threatened species. – Plants (Basel) 10 (9): 1830.

Blomqvist, E. M. 1984: Changes in fish community structure and migration activity in a brackish bay isolated by land upheaval and reverted by dredging. – Ophelia 11–21.

Bociąg, K. & Rekowska, E. 2012: Are stoneworts (Characeae) clonal plants? – Aquatic botany 100: 25–34.

Borg, J., Mitikka, V. & Kallasvuo, M. 2012: Menetelmäohjeisto rannikon taloudellisesti hyödyntämättömien kalalajien lisääntymis- ja esiintymisalueiden kartoittamiseen. – Riista- ja kalatalous. Tutkimuksia ja selvityksiä 4/2012.

Borja, A., Dauer, D. M., Elliott, M. & Simenstad, C. A. 2010: Medium and long-term recovery of estuarine and coastal ecosystems: patterns, rates and restoration effectiveness. – Estuar Coast 33: 1249–1260.

— & Bonsdorff, E. 2000: Zoobenthic community establishment and habitat complexity – the importance of seagrass shoot-density, morphology and physical disturbance for faunal recruitment. – Marine Ecology Progress Series 205: 123–138.

— , Baden, S. P. & Krause-Jensen, D 2003: The seagrasses of Scandinavia and the Baltic Sea. – In: Green, E. P. & Short, F. T. (eds), World Atlas of Seagrasses. University of California, Berkeley. Pp. 27–37.

— , O'Brien, K., Roos, C. & Ekebom, J. 2006: Environmental variables explaining structural and functional diversity of seagrass macrofauna in an archipelago landscape. – Journal of Experimental Marine Biology and Ecology 335: 52–73.

— , Baden, S., Bockelmann, A., Dromph, K., Fredriksen, S. & Gustafsson C. 2014: Distribution, structure and function of Nordic eelgrass (*Zostera marina*) ecosystems: implications for coastal management and conservation. – Aquatic Conservation: Marine and Freshwater Ecosystems 24: 410–434.

Boström, C., Åbo Akademi. Personal interview 4.12.2023, interviewed by Aija Nieminen. memo held by the author.

Bäck, A. 2023: Kokemukset ja tulokset meriharjuksen kutupaikkojen kunnostamisesta Valassaarella. – Unpublished report.

Carpenter, S. R. & Adams, M. S. 1977: The macrophyte tissue nutrient pool of a hardwater eutrophic lake: Implications for macrophyte harvesting. – Aquatic Botany 3: 239–255.

Carson, B. D., Lishawa, S. C., Tuchman, N. C., Monks, A. M., Lawrence, B. A. & Albert, D. A. 2018: Harvesting invasive plants to reduce nutrient loads and produce bioenergy: an assessment of Great Lakes coastal wetlands – Ecosphere 9(6): e02320. 10.1002/ecs2.2320.

Carstensen, J. & Conley, D. J. 2019: Baltic Sea hypoxia takes many shapes and sizes. – Limnology and Oceanography Bulletin 28(4): 125–129.

Cole, G. S. & Moksnes, P.-O. 2016: Valuing multiple eelgrass ecosystem services in Sweden: fish production and uptake of carbon and nitrogen. – Frontiers in Marine Science 2: 121.

Conley, D. J., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B. G., Hansson, L.-A., Rabalais, N. N., Voss, M. & Zillén, L. 2009: Tackling hypoxia in the Baltic Sea: Is engineering a solution? – Environmental Science & Technology 43 (10): 3407–3411.

— , Carstensen, J., Aigars, J., Axe, P., Bonsdorff, E., Eremina, T., Haahti, B.-M., Humborg, C., Jonsson, P., Kotta, J., Lännegren, C., Larsson, U., Maximov, A., Rodriguez Medina, M., Lysiak-Pastuszak, E., Remeikaitė-Nikienė, N., Walve, J., Wilhelms, S. & Zillén, L. 2011: Hypoxia is increasing in the coastal zone of the Baltic Sea. – Environmental Science & Technology 45: 6777–6783.

Dahl, K. & Göke, C. 2022: Naturgenopretning af stenrev i Roskilde Fjord. Detaljeret udlægningsplan. – Aarhus Universitet, DCE & Nationalt Center for Miljø og Energi. Teknisk rapport nr. 231. 20 pp.

— , Støttrup, J. G., Stenberg, C., Berggreen, U. C. & Jensen, J. H. 2016: Best practice for restoration of stone reefs in Denmark (Codes of conduct). – Aarhus University, DCE Danish Centre for Environment and Energy. Technical Report from DCE – Danish Centre for Environment and Energy No. 91. 33 pp.

Davis, R. C. & Short, F. T. 1997: Restoring eelgrass, Zostera marina L., habitat using a new transplanting technique: The horizontal rhizome method. – Aquatic Botany 59: 1–15.

Deinhardt, M. 2021: Liminganlahden & Hailuodon vesikasvillisuuden inventoinnit 2021. – SeaCOMBO-project report.

— , Saarnio, S., Bergdahl, L., Bystedt, D., Timonen, S. & Lampinen, E. 2021: Restauration in the Bothnian Bay – A review of objects, targets, methods and risks in coastal and marine environments. – SeaCOMBO project report.

Díaz, E. R. & Kraufvelin, P. 2013: Methodology for monitoring and evaluation. – The Baltic EcoMussel project final report.

Duarte, C. M., Agusti, S. & Barbier, E. 2020: Rebuilding marine life. – Nature 580: 39–51.

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. – Journal of Experimental Marine Biology and Ecology 479: 76–88.

Erävuori, L. & Kullberg, J. 2018: Hailuodon kiinteä tieyhteys – Tarkkailuohjelma Jääeroosion ja luonnonympäristön tarkkailut. – Sito.

Etelä-Pohjanmaan ELY-keskus 2024: Rannikon pienvesien kunnostusopas – fladat, kluuvi-fladat ja kluuvit sekä niiden laskupurot. – Etelä-Pohjanmaan ELY-keskus.

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. – Brazilian Jounal of Oceanography 59: 155–166.

Faithfull, C., Kraft, E., Tamarit Castro, E. & Nordling, P. 2022: Restaurering av kransalgsängar - test av metoder med borststräfse (*Chara aspera*) och rödsträfse (*C. tomentosa*). – Aqua reports 2022: 4.

Firth, L. B., Farnworth, M., Fraser, K. P. P. & McQuatters-Gollop, A. 2023: Make a difference: Choose artificial reefs over natural reefs to compensate for the environmental impacts of dive tourism. – Science of The Total Environment 901: 165488.

Fonseca, M. S., Kenworthy, W. J. & Thayer, G. W. 1998: Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. – NOAA Coastal Ocean Program, Decision Analysis Series No. 12.

Fontell, E. 2001: Kuhan & ahvenen kutualuetutkimus Helsingin ja Espoon välisellä merialueella 1999. – Limnologian & ympäristösuojelun laitos, Helsingin yliopisto. 24 pp.

Gagnon, K., Christie, H., Didderen, K., Fagerli, C. W., Govers, L. L., Gräfnings, M. L. E., Heusinkveld, J. H. T., Kaljurand, K., Lengkeek, W., Martin, G., Meysick, L., Pajusalu, L., Rinde, E., van der Heide, T. & Boström, C. 2021: Incorporating facilitative interactions into small-scale eelgrass restoration – challenges and opportunities. – Restoration Ecology 29 (5).

— , Bocoum, E.-H., Chen, C. Y., Baden, S. P., Moksnes, P.-O. & Infantes, E. 2023: Rapid faunal colonization and recovery of biodiversity and functional diversity following eelgrass restoration. – Restoration Ecology 21, e13887.

Government of Åland 2021: Nutrients from sea to field. Compilation report for SEABASED pilot. – Ålands landskapsregering. <seabasedmeasures.eu/wp-content/uploads/2021/05/nutrients-from-sea-to-field-seabased-pilot-report.pdf>. 130 pp.

Gustafsson, C. & Boström, C. 2009: Effects of plant species richness and composition on epifaunal colonization in brackish water angiosperm communities. – Journal of Experimental Marine Biology and Ecology 382: 8–17.

— & Boström, C. 2010: Biodiversity influences ecosystem functioning in aquatic angiosperm communities. – OIKOS 120 (7).

— & Boström, C. 2013: Influence of neighboring plants on shading stress resistance and recovery of eelgrass, *Zostera marina* L. – PLoS ONE 8 (5): e64064.

Haapamäki, J. 2021: Protection of the Natura 2000 habitat coastal lagoons and glolakes in Finland. – Thesis for a Master of Natural Resources, Novia. 34 pp.

— , Haavisto F., Hoikkala J. & Riihimäki A. (eds) 2022: Suomen meriluonnonsuojelualueiden hoidon tehokkuuden arviointi – Menetelmän pilotointi. – Metsähallituksen luonnonsuojelujulkaisuja. Sarja A 238. 79 pp.

Hadberg, N., Kautsky, N., Kumblad, L. & Wikströmi, S. A. 2018: Limitations of using blue mussel farms as a nutrient reduction measure in the Baltic Sea. – Stockholm University. Baltic Sea Center Report 2/2018.

Hansen, J., Andersson, H. C., Bergström, U., Borger, T., Brelin, D., Byström, P., Eklöf, J., Kraufvelin, P., Kumblad, L., Ljunggren, L., Nordahl, O. & Tibblin, P. 2020: Våtmarker som fiskevårdsåtgärd vid kusten. Utvärdering av restaurerade våtmarkers effekt på fiskreproduktion och ekosystemet längs Östersjökusten. – Stockholms universitets Östersjöcentrum, rapport 1/2020.

HAV 2017: Harr i Bottniska viken – en kunskapssammanställning. – Havs- och vattenmyndighetens rapport 2017:30.

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(3): 155–171.

— , Alirangues, N. M. M., Bakker, E. S., Blindow, I., Davidson, T. A., Gillefalk, M., Hansson, L.-A., Janse, J. H., Janssen, A. B. G., Jeppesen, E., Kabus, T., Kelly, A., Köhler, J., Lauridsen, T. L., Mooij, W. M., Noordhuis, R., Phillips, G., Rücker, J., Schuster, H.-H., Søndergaard ,M., Teurlincx, S., van de Weyer, K., van Donk, E., Waterstraat, A., Willby, N. & Sayer, C. D. 2018: Response of submerged macrophyte communities to external and internal restoration measures in north temperate shallow lakes. – Frontiers in Plant Science 9/2018.

Hottola, H. & Tuunila, M. 2023: Erittäin harvinainen vesikasvi hävisi entisiltä laidunmailta – nyt pelastusjoukko odottaa hentonäkinruohon paluuta. – Yleisradio 24.5.2023. <yle.fi/a/74-20032995>.

Huuskonen, A. (eds) 2006: Maisemalaiduntaminen luonnon monimuotoisuuden lisääjänä – tasapaino monimuotoisuuden ja tuottavuuden välillä. – Maa- ja elintarviketalous 79. 418 pp.

— 2023: Ravinnekierto merenrantalaitumilla. – Rantalaidun-hankkeen raportteja.

Hynninen, M., Veneranta, L. & Lappalainen, A. 2019: Fladojen, kluuvien ja kluuvijärvien kalataloudelliset kunnostukset Merenkurkun rannikolla: Mallilajeina ahven ja hauki. – Luonnonvara- ja biotalouden tutkimus 57/2019. 44 pp.

Hyvärinen, E., Juslén, A., Kemppainen, E., Uddström, A., & Liukko, U-M. (eds) 2019: Suomen lajien uhanalaisuus – Punainen kirja. – Ympäristöministeriö & Suomen ympäristökeskus, Helsinki. 704 pp.

Härkönen, L., Ilmonen, J., Tolonen, K., Vuorio, K., Ahola, M., Vaso, A., Käki, T., Lehtovaara, V., Haapalehto, S., Koljonen, S., Hautamäki, J., Olli, P., Leinonen, K., Tiusanen, M., Leinonen, A., Myllykangas, N. & Hellsten, S. 2022: Vesistö- ja valuma-aluekunnostukset Natura 2000 -alueilla: suunnittelun toimintamalli. – Suomen ympäristökeskuksen raportteja 37/2022.

Härmä, M., Auvinen, H. & Hudd, R. 2008: Kunnostettujen mataloituneiden merenlahtien kalanpoikasyhteisöt. – Riista- ja kalatalous. Selvityksiä 16/2008. 29 pp.

Ikonen, I. & Hagelberg, E. (eds) 2007: Ruovikot ja merenrantaniityt. Luontoarvot ja hoitokokemuksia Etelä-Suomesta ja Virosta. – Lounais-Suomen ympäristökeskus, Turku. Suomen ympäristö 37.

Ilmonen, Jari, Metsähallitus. – Teams-interview 22.12.2023, interviewed by Anette Bäck. Memo held by the author.

Infantes, E. 2021: Sand capping to promote eelgrass restoration. <eduardoinfantes.com/sand-capping-eelgrass-restoration>, viitattu 13.1.2024.

— & Moksnes, P.-O. 2018: Eelgrass seed harvesting: Flowering shoots development and restoration on the Swedish west coast. – Aquatic Botany 144: 9–19.

— , Crouzy, C. & Moksnes P.-O. 2016a: Seed predation by the shore crab *Carcinus maenas*: A positive feedback preventing eelgrass recovery? – PLoS One 11, e0168128.

— , Eriander, L. & Moksnes, P.-O. 2016b: Eelgrass (*Zostera marina*) restoration on the west coast of Sweden using seeds. – Marine Ecology Progress Series 546: 31–45.

Jaatinen, K., Westerbom, M., Norkko, A., Mustonen, O. & Koons, D. N. 2021: Detrimental impacts of climate change may be exacerbated by density-dependent population regulation in blue mussels. – Journal of Animal Ecology 90: 562– 573.

John Nurmisen Säätiö 2024: Facts and materials. – <seabasedmeasures.eu/facts-and-materials/papers-publications>.

Jäkäläniemi, A. 2013: ESCAPE (LIFE BIO/FI/917, 1.9.2012-30.8.2017), Hoitosuunnitelma (Management plan, A3), (toimenpiteet C6, C7, C8, C9, D2).

Karjalainen, S. M., Välimaa, A.-L., Hellsten, S. & Virtanen, E. (eds) 2017: Vesiruton hyötykäyttö biotaloudessa – järvien riesasta raaka-aineeksi. Elodea-hankkeen loppuraportti. – Suomen ympäristökeskuksen raportteja 18/2017. 125 pp.

Karppinen, A. 2020: Esteellisen vesistörummun kunnostamisopas. – Esteet pois II -hankkeen loppuraportti, Metsähallitus, Vantaa. <eraluvat.fi/media/dokumentit/esteet-pois/esteellisen-vesistorummun-kunnostamisopas_esteetpoisii.pdf>. 25 pp.

Kautsky N. & Wallentinus I. 1980: Nutrient release from a Baltic Mytilus-red algal community and its role in benthic and pelagic productivity. – Ophelia Supplement 1: 17–30.

— , Qvarfordt, S. & Schagerström, E, 2019: *Fucus vesiculosus* adapted to a life in the Baltic Sea: Impacts on recruitment, growth, re-establishment and restoration. – Botanica Marina 67 (1): 17–30.

— , Qvarfordt, S. & Schagerström, E. 2020: Restaurering av blåstångsamhällen i Östersjön. – Stockholms universitet. ISBN 978-91-982382-3-5. 60 pp.

Keränen, P. 2015: Meriharjuksen hoitosuunnitelma. Osa 1. Meriharjuskannan hoidon ja suojelun tausta. – Metsähallitus, Vantaa. 97 pp.

Kokkonen, Iiris ja Kaasonen, Viivi, WWF Suomi. – Personal interview 18.12.2023, interviewed by Aija Nieminen. Memo held by the author.

Komonen, A. & Halme, P. 2014: Luonnon ennallistaminen on käsitteenä aikansa elänyt. – Tieteessä Tapahtuu 32(5). <journal.fi/tt/article/view/47933>.

Kontula, T. & Raunio, A. (eds) 2018: Suomen luontotyyppien uhanalaisuus 2018: Luontotyyppien punainen kirja. Osa 2: Luontotyyppien kuvaukset. – Suomen ympäristö 5/18.

Korpinen, S., Laamanen, M., Suomela, J., Paavilainen, P., Lahtinen, T. & Ekebom, J. 2018: Suomen meriympäristön tila 2018. – SYKE:n julkaisuja 4/2018. – Suomen ympäristökeskus SYKE.

Kotilainen, A., Kiviluoto, S., Kurvinen, L., Sahla, M., Ehrnsten, E., Laine, A., Lax, H-G., Kontula, T., Blankett, P., Ekebom, J., Hällfors, H., Karvinen, V., Kuosa, H., Laaksonen, R., Lappalainen, M., Lehtinen, S., Lehtiniemi, M., Leinikki, J., Leskinen, E., Riihimäki, A., Ruuskanen, A. & Vahteri, P. 2018: Itämeri. – In: Kontula, T. & Raunio, A. (eds), Suomen luontotyyppien uhanalaisuus 2018. Luontotyyppien punainen kirja – Osa 2: luontotyyppien kuvaukset. – Suomen ympäristökeskus ja ympäristöministeriö, Helsinki. Suomen ympäristö 5/2018. Pp. 15–98.

Kotta, J., Tarton yliopisto. Personal interview 8.11.2023, interviewed by Aija Nieminen. Memo held by the author.

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

— , Futter, M., Kaasik, A., Liversage, K., Rätsep, M., Barboza, F. R., Bergström, L., Bergström, P., Bobsien, I., Díaz, E., Herkül, K., Jonsson, P. R., Korpinen, S., Kraufvelin, P., Krost, P., Lindahl, O., Lindegarth, M., Lyngsgaard, M. M., Mühl, M., Nyström Sandman, A., Orav-Kotta, H., Orlova, M., Skov, H., Rissanen, J., Šiaulys, A., Vidakovic, A & Virtanen, E. 2020b: Response to a letter to editor regarding Kotta et al. 2020: Cleaning up seas using blue growth initiatives: Mussel farming for eutrophication control in the Baltic Sea. – Science of the Total Environment 739: 138712.

— , Stechele, B., Francisco R. Barboza, F. R., Kaasik, A. & Lavaud, R. 2023: Towards environmentally friendly finfish farming: A potential for mussel farms to compensate fish farm effluents. – Journal of Applied Ecology 60: 1314–1326.

Koweek, D. A., García-Sánchez, C., Brodrick, P. G., Gassett, P. & Caldeira, K. 2020: Evaluating hypoxia alleviation through induced downwelling. – Science of the Total Environment 719.

Kraufvelin, P. & Díaz, E. R. 2015: Sediment macrofauna communities at a small mussel farm in the northern Baltic proper. – Boreal Environment Research 20: 378–390.

— , Bryhn, A., Olsson, J. 2021a: Erfarenheter av ekologisk restaurering I kust och hav. – Havs- och vattenmyndigheten rapport 2020:28. 180 pp.

— , Olsson, J., Bergström, U., Bryhn, A. & Bergström, L. 2021b: Restoration measures for coastal habitats in the Baltic Sea: cost-efficiency and areas of highest significance and need. – HELCOM ACTION 2021.

— , Bergström, L., Sundqvist, F., Ulmerstrand, M., Wennhage, H., Wikström, A. & Bergström, U. 2023: Rapid re-establishment of top-down control at a no-take artificial reef. – Ambio 52: 556–570.

Krause, J. C., Diesing, M. & Arlt, G. 2010: The physical and biological impact of sand extraction: a case study of the Western Baltic Sea. – Journal of Coastal Reseach 51: 215–226.

Kristensen, L. D., Støttrup, J. G., Svendsen, J. C., Stenberg, C., Højbjerg Hansen, O. K. & Grønkjaer P. 2017: Behavioural changes of Atlantic cod (*Gadus morhua*) after marine boulder reef restoration: implications for coastal habitat management and Natura 2000 areas. – Fisheries Management and Ecology 24: 353–360.

Kumwimba, M., Mawuli, D. & Xuyong, L. 2020: Potential of invasive watermilfoil (*Myriophyllum* spp.) to remediate eutrophic waterbodies with organic and inorganic pollutants. – Journal of Environmental Management 270: 110919.

Kuningas, S., Veneranta, L., Ojanen, H., Kallasvuo, M. & Lappalainen, A. 2019: Ihmistoiminnan vaikutukset rannikon kalojen lisääntymisalueisiin ja mahdollisuudet kunnostuksiin. – Luonnonvarakeskus, Helsinki. Luonnonvara- ja biotalouden tutkimus 27/2019. 60 pp.

Laakso, U. 1938: Havuturojen merkityksestä kalastuksessa ja kalavesien hoidossa. – Suomen Kalastuslehti 45/3: 50–51.

Laamanen, M., Suomela, J., Ekebom, J., Korpinen, S., Paavilainen P., Lahtinen, T., Nieminen, S. & Hernberg, A. 2021: Suomen merenhoitosuunnitelman toimenpideohjelma vuosille 2022–2027. – Ympäristöministeriön julkaisuja 2021:30. 403 pp.

Lappalainen, A., Kuningas, S., Veneranta, L. & Westerbom, M. 2023: Fladojen ja kluuvien kunnostus kalojen lisääntymisalueiksi: Kokemuksia kunnostuksista ja tuloksellisuuden mittausmenetelmistä. – Luonnonvara- ja biotalouden tutkimus 36/2023. 59 pp.

Lehtomaa, L., Ahonen, I., Hakamäki, H., Häggblom, M., Jantunen, J., Jutila, H., Järvinen, C., Kemppainen, R., Kondelin, H., Laitinen, T., Lipponen, M., Mussaari, M., Pessa, J., Raatikainen, K. J., Raatikainen, K., Tuominen, S., Vainio, M., Vieno, M. & Vuomajoki, M. 2018: Perinnebiotoopit. – In: Kontula, T. & Raunio, A. (eds), Suomen luontotyyppien uhanalaisuus 2018. Luontotyyppien punainen kirja, Osa 2: Luontotyyppien kuvaukset. Pp. 663–757.

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. (eds), Controlling benthic release of phosphorus in different Baltic Sea scales. Final Report on the Results of PROPPEN Project. Pp. 74–81.

— , Bendtsen, J., Lännergren, C., Saarijärvi, E., Lindström, M. &Pitkänen, H. 2022: Different responses to artificial ventilation in two stratified coastal basins. – Ecological Engineering 179: 106611.

Leinikki, J. 2020: Taustatietojen kartoitus meriajokkaan istutuskoealueilla Tammisaaren saaristossa 2020. – Alleco Oy raportti, n:o 16/2020.

Linsén, J. 2016: Musselodling för livsmedelsproduktion i landskapet Åland. Förutsättningar och krav enligt unionslagstiftning. – Ålands Landskapsregeringen.

Ljunggren, L., Olsson, J., Nilsson, J. & Stenroth, P. 2011: Våtmarker som rekryteringsområden för gädda i Östersjön. – FINFO 2011:1 Våtmarker som rekryteringsområden för gädda i Östersjön.

Louhi, P., Hyvärinen, P., Huusko, A., Kuningas, S., Ruokonen, T., Korhonen, P. K., Härkönen, L. S. & Lappalainen, A. 2023: Kalatalouden ympäristöohjelma: loppuraportti. – Luonnonvara- ja biotalouden tutkimus 63/2023. 65 pp.

Luonnonsuojelulaki 9/2023.

Malve, O., Virtanen, M., Villa, L., Karonen, M., Aakerla, H., Heiskanen, A.-S., Lappalainen, K. M. & Holmberg, R. 2000: Artificial oxygenation experiment in hypolimnion of Pojo Bay estuary in 1995 and 1996: Factors regulating estuary circulation and oxygen and salt balances. Pohjanpitäjänlahden syvänteessä vuosina 1995 ja 1996 toteutettu hapetuskokeilu – veden vaihdunta sekä happi- ja suolataseet. – SYKE-JULK-377. 163 pp.

Marion, S. R. & Orth, R. J. 2010: Innovative technique for large-scale seagrass restoration using *Zostera marina* (eelgrass) seeds. – Restoration Ecology 18: 514–526.

Markkola, J. 2013: Pohjansorsimo *Arctophila fulva* var. *pendulina* ja rönsysorsimo *Puccinellia phryganodes* – Esiintymien tila 2013 – Ekologia, suojelu, hoito ja seuranta. – Pohjois-Pohjanmaan ELY-keskus.

— 2016: Rönsysorsimo *Puccinellia phryganodes* – esiintymien tila 2016, hoito ja seuranta. – Raportti. 19 pp.

Marttunen, M., Turunen, V., Tordorovic, S. & Lehtoranta, V. 2022: Freshabit LIFE IP: Socioekonomisten vaikutusten arviointi.

Meristratgiadirektiivi: Euroopan Parlamentin ja Neuvoston direktiivi 2008/56/EY, annettu 17 päivänä kesäkuuta 2008, yhteisön meriympäristöpolitiikan puitteista.

Metsähallitus 2021: Suomen merenalaiset avainluontotyypit ja ekosysteemipalvelut. 16 pp.

Mikkola, R., Bäck, A., Saarinen, A., Haapamäki, J. & Berglund, J. 2019: Kvarkens flador och deras tillstånd. – Delrapport Interreg Botnia-Atlanticaprojektet Kvarken flada. 52 pp.

Minnhagen, S. 2017: A farming of blue mussels in the Baltic Sea. A review of pilot studies 2007–2016. – Kalmar Kommun. 29 pp.

Miranto, M. J., Hyvärinen, M.-T., Ryttäri, T., Ruotsalainen, A., Väre, H. U., Laaka-Lindberg, S., Edesi, J., Virnes, P., Hämäläinen, A., Kulmala, P. & Tiiri, M. 2017: Etäsuojelijan opas. – Luonnontieteellinen keskusmuseo LUOMUS, Helsinki. Norrlinia 32. 64 pp.

Moksnes, P.-O. 2021: Resultat från studier av Lilla Askerön 2018–2019. – Underlag för tillstånd för sandtäckning 2021, Institutionen för marina vetenskaper, Havsmiljöinstitutet, Göteborgs universitet. 12 pp.

— , Gipperth, L., Eriander, L., Laas, K., Cole, S. G. & Infantes, E. 2016: Handbook for eelgrass restoration in Sweden – national guideline. – Swedish Agency for Marine and Water Management, Gothenburg, Sweden.

Nejrup, L. B. & Pedersen, M. F. 2008: Effects of salinity and water temperature on the ecological performance of *Zostera marina*. – Aquatic Botany 88: 139–146.

Niemelä, M. 2009: Biotic interactions and vegetation management on coastal meadows. – Acta Universitatis Ouluensis A Scientiae Rerum Naturalium 529: 1–68.

Niemi, N. 2022: Testing the impacts of a marine heatwave and freshening event on populations of *Z. marina* from the Swedish west coast. – Pro gradu -tutkielma, Åbo Akademi, Luonnontieteiden ja tekniikan tiedekunta, Turku. 57 pp.

Nikolajev-Wikström, Leena, EPO-ELY. Teams-interview 21.11.2023, interviewed by Anette Bäck. Memo held by the author.

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

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 Resources and Economics 16: 28–38.

Olsen, J. L., Stam W. T., Coyer, J. A., Reusch, T. B. H., Billingham, M., Boström, C., Calvert, E., Christie, H., Granger, S., la Lumière, R., Milchakova, N., Oudot-Desecq, M.-P., Proccacini, G., Sanjabi, B., Serrao, E., Veldsink, J., Widdicombe, S. & Wyllie-Echeverria, S. 2004: North Atlantic phylogeography and large-scale population differentiation of the seagrass *Zostera marina*. – Molecular Ecology 13: 1923–1941.

Orth, R. J. & Marion, S. R. 2007: Innovative techniques for large-scale collection, processing, and storage of eelgrass (*Zostera marina*) seeds. – Submerged Aquatic Vegetation Technical Notes Collection, ERDC/TN SAV-07-2. US Army Engineer Research and Development Center, Vicksburg, M.S.

— , Moore, K. A., Marion, S. R., Wilcox, D. J. & Parrish, D. B. 2012: Seed addition facilitates eelgrass recovery in a coastal bay system. – Marine Ecology Progress Series 448: 177–195.

Oulasvirta, P. & Leinikki, J. 1995: Tammisaaren saariston kansallispuiston vedenalaisen luonnon kartoitus – osa II. – Metsähallituksen luonnonsuojelujulkaisuja. Sarja A 41. 84 pp.

Pajusalu, L., Boström, C., Gagnon, K., Kaljurand, K., Kotta, J., Püss, T. & Martin, G. 2023: The restoration of eelgrass (*Zostera marina*) in Estonian coastal waters, Baltic Sea. – Proceedings of the Estonian Academy of Sciences 72: 41–54.

Paling, E. I., Fonseca, M., van Katwijk, M. M. & van Keulen, M. 2009: Seagrass restoration. – In: Perillo, G. M. E., Wolanski, E., Cahoon, D. R. & M. M. Brinson (toim), Coastal wetlands: An integrated ecosystem approach. Elsevier, Amsterdam. Pp. 687–713.

Palo, R. 2020: Hauen (*Esox lucius*) & ahvenen (*Perca fluviatilis*) lisääntyminen sekä poikasten esiintyminen, kasvu ja ulosvaellus kahdessa Merenkurkun rannikon pienvesistössä. – Pro gradu -tutkielma, Jyväskylän yliopisto. 71 pp.

Pesonen, E. 2023: Epifyyttisten rihmalevien käyttökelpoisuus rehevöitymisen bioindikaattorina sekä rantalaidunten ja muiden ympäristötekijöiden vaikutus vedenlaatuun Perämerellä. – Pro gradu -tutkielma, Oulun yliopisto.

Petersen, J. K., Jørgensen T. B., Flindt, M., Stæhr, P. A. U. & Dahl, K. 2023: Concepts in relation to marine nature restoration. – Scientific report from the Danish Center for Marine Restoration.

Pickerell, C., Schott, S. & Wyllie-Echeverria, S. 2005: Buoy-deployed seeding: Demonstration of a new eelgrass (*Zostera marina* L.) planting method. – Ecological Engineering 25: 127–136.

Pohjois-Pohjanmaan ELY-keskus 2010: Ympäristövaikutusten arviointiselostus. Ympäristövaikutusten arviointimenttely. Hailuodon liikenneyhteys. – Pohjois-Pohjanmaan elinkeino-, liikenne- ja ympäristökeskuksen julkaisuja. 238 pp.

— 2018: Hailuodon liikenneyhteyden kehittäminen. – Verkkosivusto. <ely-keskus.fi/hailuodon-liikenneyhteyden-kehittaminen?p_l_back_url=%2Fsearch%3F_com_liferay_portal_search_web_search_bar_portlet_SearchBarPortlet_INSTANCE_elySearch_formDate%3D1708507600157%26_com_liferay_portal_search_web_search_bar_portlet_SearchBarPortlet_INSTANCE_elySearch_emptySearchEnabled%3Dfalse%26q%3Dhailuodon%2Bkiinte%25C3%25A4%2Byh%26_com_liferay_portal_search_web_search_bar_portlet_SearchBarPortlet_INSTANCE_elySearch_scope%3D>.

Puharinen, S.-T., Hakkarainen, M. & Belinskij, A. 2021: Suomen merenhoitolainsäädännön toimivuustarkastelu: Merenhoidon tavoitteet ja niistä poikkeaminen. – Ympäristöministeriön julkaisuja 2021:14. 97 pp.

Pursiainen, A., Veneranta, L., Kuningas, S., Saarinen, A. & Kallasvuo, M. 2021: The more sheltered, the better – Coastal bays and lagoons are important reproduction habitats for pike in the northern Baltic Sea. – Estuarine, Coastal and Shelf Science 259, 107477.

Raatikainen Katja, Metsähallitus. Teamskeskustelu 21-22.11.2023, haastattelijana Essi Keskinen. Tekstit Teams-keskustelussa.

Rantajärvi, E. (eds) 2012: Controlling benthic release of phosphorus in different Baltic Sea scales. Final Report on the result of the PROPPEN Project (802-0301-08) to the Swedish Environmental Protection Agency, Formas and VINNOVA. – Suomen ympäristökeskus. 179 pp.

Rasmussen, J. R., Olesen, B. & Kruse-Jensen, D. 2012: Effects of filamentous macroalgae mats on growth and survival of eelgrass, *Zostera marina*, seedlings. – Aquatic Botany 99: 41–48.

Rautiainen, P., Björnström, T., Niemelä, M., Arvola, P., Degerman, A., Erävuori, L., Siikamäki, P., Markkola, A., Tuomi, J. & Hyvärinen, M. 2007: Management of three endangered plant species in a dynamic landscape of seashore meadows. – Applied Vegetation Science 10: 25–32.

Rintamäki, H. 2011: Jääeroosioselvityksen täydentäminen – Selvitys liittyy Oulunsalon ja Hailuodon välille suunnitteilla olevan tuulipuiston ja liikenneyhteyden kehittämisen vaikutusten arviointiin sekä alueen osayleiskaavojen laatimiseen. – Pohjois-Pohjanmaan elinkeino-, liikenne- ja ympäristökeskuksen julkaisuja. 91 pp.

Saarijärvi, E., Lehtoranta, J. & Lappalainen, K. M. 2012: Coastal pilot studies and laboratory experiments. – In: Rantajärvi, E. (eds), Controlling benthic release of phosphorus in different Baltic Sea scales. Final Report on the result of the PROPPEN Project (802-0301-08) to the Swedish Environmental Protection Agency, Formas and VINNOVA. Suomen ympäristökeskus. 179 pp.

Saarinen A. 2019: Matalien rannikkoympäristöjen ennallistaminen Merenkurkussa – Kokemuksia, menetelmiä ja tulevaisuuden toimenpiteitä fladaympäristöissä. – Interreg Botnia Atlantican Kvarken Flada -hankkeen osaraportti. 57 pp.

— , Veneranta, L., Berglund, J., Bergström, U., Donadi, S., Bäck, A. & Långnabba, A. 2021: Fiskyngelproduktion i grunda avsnörda havsvikar – Metoder och resultat från projektet Kvarken flada. – Delrapport inom Kvarken fladaprojektet. 153 pp.

— , Berglund, J. Länsstyrelsen Västerbotten. Teams-interview 23.10.2023, interviewed by Anette Bäck. Memo held by the author.

Salo, T., Gustafsson, C. & Boström, C. 2009: Effects of plant diversity on primary production and species interactions in a brackish water seagrass community. – Marine Ecology Progress Series 396: 261–272. 10.3354/meps08325.

Sandström, A. 2003: Restaurering och bevarande av lek- och uppväxtområden för kustfiskbestånd. – Fiskeriverket informerar 2003:3. 26 pp.

— , 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.

Sarvala, J., Helminen, H. & Heikkilä, J. 2020: Invasive submerged macrophytes complicate management of a shallow boreal lake: a 42-year history of monitoring and restoration attempts in Littoistenjärvi, SW Finland. – Hydrobiologia 847: 4575–4599.

Siira, J. 2011: Rönsysorsimo (*Puccinellia phryganodes*) ja pohjansorsimo (*Arctophila fulva* var. *pendulina*) Perämerellä 1900-luvulla. – Suomen Ympäristö 6 / 2011.

Sousa, A. I., Valdemarsen, T., Lillebø, A. I., Jørgensen, L. & Flindt, M. R. 2017: A new marine measure enhancing *Zostera marina* seed germination and seedling survival. – Ecological Engineering 104 (Part A): 131–140.

Steinfurth, R. C., Lange, T., Oncken, N. S., Kristensen, E., Quintana, C. O. & Flindt, M. R. 2022: Improved benthic fauna community parameters after large-scale eelgrass (*Zostera marina*) restoration in Horsens Fjord, Denmark. – Marine Ecology Progress Series 687: 65–77.

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.

Stipa, T. 1999: Water exchange and mixing in a semi-enclosed coastal basin (Pohja Bay). – Boreal Environment Research 4: 307–317.

Støttrup, J. G, Stenberg, C., Dahl, K., Kristensen, L. D. & Richardson, K. 2014: Restoration of a temperate reef: Effects on the fish community. – Open Journal of Ecology 4: 1045 –1059.

— , Dahl, K., Niemann, S., Stenberg, C., Reker, J., Stamphøj, E. M, Göke, C. & Svendsen, J. C. 2017: Restoration of a boulder reef in temperate waters: Strategy, methodology and lessons learnt. – Ecological Engineering 102: 468-482.

Svendsen, J. C., Kruse, B. M., Wilms, T., Dahl, K., Buur, H., Andersen, O. G. N., Bertelsen, J. L. & Kindt-Larsen, L. 2022: The importance of reef habitats for fish, harbor porpoise and fisheries management. – DTU Aqua. DTU Aqua-rapport No. 371–2020.

Tanska, Tuula ja Räihä, Ville, Kaakkois-Suomen ELY-keskus. Personal interview 11.12.2023, interviewed by Aija Nieminen. Memo held by the author.

Tiusanen, M. 2022: Freshabit LIFE IP: Sosioekonomisten vaikutusten arviointi – In: Härkönen, H. (toim), Vesistö- ja valuma-aluekunnostukset Natura 2000 -alueilla: suunnittelun toimintamalli. – Suomen ympäristökeskuksen raportteja 37/2022.

Ulvi, T. & Lakso, E. 2005: Järvien kunnostus. – Suomen ympäristökeskus, Helsinki.

Unsworth, R. K. F., Bertelli, C. M., Cullen-Unsworth, L. C., Esteban, N., Jones, B. L., Lilley, R. J., Lowe, C., Nuuttila, H. K. & Rees, S.C. 2019: Sowing the seeds of seagrass recovery using hessian bags. – Frontiers in Ecology and Evolution 7: 311.

— , Rees, S., Bertelli, C., Collins, K., Furness, E., Jackson, E., Jayes, A., Nolan, E., Nuuttila, H. & Preston, J. 2021: Seagrass restoration in practice. – In: Gamble, C., Debney, A., Glover, A., Bertelli, C., Green, B., Hendy, I., Lilley, R., Nuuttila, H., Potouroglou, M., Ragazzola, F., Unsworth, R. & Preston, J (eds), Seagrass Restoration Handbook. Zoological Society of London, UK. Pp. 40–54.

Urho, L. Koljonen, M.-L., Saura, A., Savikko, A, Veneranta, L. & Janatuinen, J. 2019: Kalat. – In: Hyvärinen, E., Juslén, A., Kemppainen, E., Uddström, A. & Liukko, U.-M. (eds), Suomen lajien uhanalaisuus – Punainen kirja 2019. – Ympäristöministeriö ja Suomen ympäristökeskus. Helsinki. 704 pp.

Valdemarsen, T., Wendelboe, K., Egelund, J. T., Kristensen, E. & Flindt, M. R. 2011: Burial of seeds and seedlings by the lugworm Arenicola marina hampers eelgrass (*Zostera marina*) recovery. – Journal of Experimental Marine Biology and Ecology 410: 45–52.

van Duren, L. A., van Katwijk, M. M., Heusinkveld J. & Reise, K. 2013: Eelgrass restoration in the dutch wadden sea. – Deltares report 12038902–000.

van Katwijk, M. M., Bos, A. R., de Jonge, V. N., Hanssen, L. S. A. M., Hermus, D. C. R. & de Jonge, D. J. 2009: Guidelines for eelgrass restoration: Importance of habitat selection and donor population, spreading of risks, and ecosystem engineering effects. – Marine Pollution Bulletin 58: 179–188.

— , Thorhaug, A., Marbà, N., Orth, R. J., Duarte, C. M., Kendrick, G. A. & Cunha, A. 2015: Global analysis of seagrass restoration: the importance of large-scale planting. – Journal of Applied Ecology doi: 10.1111/1365–2664.12562.

Veneranta, Lari, LUKE. Personal interview 23.10.2023, interviewed by Anette Bäck. Memo held by the author.

Vesi-Eko 2024: Happikadon katkaisu. – Verkkosivusto, Vesi-Eko Oy, Kuopio. <vesieko.fi/vesisto-palvelut/hapetus-ja-ilmastus>.

Vesipuitedirektiivi: Euroopan parlamentin ja neuvoston direktiivi 2000/60/EY, annettu 23 lokakuuta 2000, yhteisön vesipolitiikan puitteista.

Virtanen, E. A., Viitasalo, M., Lappalainen, J. & Moilanen, A. 2018: Evaluation, gap analysis, and potential expansion of the Finnish Marine Protected Area Network. – Frontiers in Marine Science 5. UNSP 402.

Vuorio, K., Härkönen, L., Tolonen, K., Ruuhijärvi, J., Einola, E., Pekka, S., Vehanen, T., Jyväsjärvi, J. Ilmonen, J. & Hellsten, S. 2022: Kunnostusten vaikutukset vesistöjen ekologiseen tilaan ja Natura-alueiden suojelutasoon Freshabit LIFE-IP -hankkeen kohteilla. – Deliverable D7 Report on ecological status and conservation status of water bodies under restoration, Freshabit LIFE-IP.

Welch, M., Mogren E.-T. & Beeney, L. 2016: A literature review of the beneficial use of dredged material and sediment management plans and strategies. – Center for Public Service Publications and Reports. 34.

Westerbom, M., Luonnonvarakeskus. – Teams-interview, interviewed by Fiia Haavisto 3.11.2023. Memo held by the author.

— , Kraufvelin, P., Erlandsson, J., Korpinen, S., Mustonen, O. & Díaz, E. 2019: Wave stress and biotic facilitation drive community composition in a marginal hard-bottom ecosystem. – Ecosphere 10: e02883.
— Kraufvelin, P., Mustonen, O. & Díaz, E. 2021: Explaining recruitment stochasticity at a species' range margin. – Frontiers in Marine Science 8: 659556.
Wikström, S. A., Hedberg, N., Kautsky, L., Kumblad, E., Ehrnsten, B., Gustafsson, C., Humborg, A., Norkko & Stadmark, J. 2020: Letter to editor regarding Kotta et al. 2020: Cleaning up seas using blue rrowth initiatives: Mussel farming for eutrophication control in the Baltic Sea. – Science of the Total Environment 727: 138665.
Wilms, T. G. 2021: Restoration and non-invasive monitoring of geogenic reefs in temperate waters. – DTU Aqua.
— , Norðfoss, P. H., Baktoft, H., Støttrup, J. G., Kruse, B. M.& Svendsen, J. C. 2021: Environmental DNA reveals fine-scale habitat associations for sedentary and resident marine species across a coastal mosaic of soft- and hard-bottom habitats. – Journal of Applied Ecology 58: 2936–2950.
— , Jacobsed, M. W., Hansen, B. K., Baktoft, H., Bollhorn, J., Scharff-Olsen, C. H., Bertelsen, J. L., García-Argudo García, E., Støttrup, J. G., Nielsen, E. E. & Svedsen, J. C. 2022: Environmental DNA reveals fine-scale habitat associations for sedentary and resident marine species across a coastal mosaic of soft- and hard-bottom habitats. – Environmental DNA 4: 954–971.
Wistbacka, R. 2009: Åtgärdsplan Storträsk och Lillträsk.
— 2013: Restaurering av bäcken från Korvgräven. – Delrapport inom Interreg Botnia-Atlanticaprojektet FLISIK. 9 pp.
— 2023a: Långvikenin työraportti heinäkuu 2023.
— 2023b: Rapport om restaureringen av Roliggropen 2022–2023. 14 pp.
— Teams-interview 30.10.2023, interviewed by Anette Bäck. Memo held by the author.
— & Snickars, M. 2000: Rannikon pienvedet kalojen kutupaikkoina Pohjanmaalla 1997–1998. – Kala- ja riistahallinnon julkaisuja 48/2000.
Wüstenberg, A., Pörs, Y. & Ehwald, R. 2011: Culturing of stoneworts and submersed angiosperms with phosphate uptake exclusively from an artificial sediment. – Freshwater biology 56 (8): 1531–1539.
Ympäristöministeriö 2020: Ympäristöministeriö EU:n biodiversiteettistrategia. <ym.fi/eu-n-biodiversiteettistrategia>, viitattu 11.7.2023.
Ympäristöministeriö 2022: Ympäristöministeriö EU:n ennallistamisasetus. – <ym.fi/ennallistamisasetus>, viitattu 11.7.2023.
Žilinskaitė, E., Malgorzata, B. & Futter, M. 2021: Stakeholder perspectives on blue mussel farming to mitigate Baltic Sea eutrophication. – Sustainability 13: 9180.

Appendices

Annex 1 Suitability of restoration methods for different habitat types

In the table, the habitat types under which the methods are presented in the report and for which they have the most experience and/or for which they are most suitable are indicated by ticks (X). The habitats for which the methods are also considered suitable are marked with an 'O'.

Restoration method suitable for different habitats	Sand banks	Baltic esker islands, under water parts	Estuaries	Coastal lagoons	Large shallow inlets and bays	Reefs	Boreal Baltic islets and small islands	Boreal Baltic narrow islets	Other deep soft bottoms	Comments
Restoration dredging			X	O	X			O		
Sill restoration				X						
Culvert replacement/removal of a barrier to migration			O	X	O					
Opening a channel				X						
Catchment restoration			O	X	O			O		Most effective for habitat types in the affected area of the catchment area.
Removal of submerged aquatic vegetation			O	O	X			O		The removal technique and results depend on the species to be removed. Pay attention to the spreading ability of the species to be removed.
Removal of the common reed			O	O	X			O		Reeds are an important habitat for many birds and an important breeding area for many fish. The reeds reduce bottom erosion and nutrients, and carbon are bound to the vegetation. Removing the reeds does not solve the problem of eutrophication, so the grounds and objectives of the removal should be carefully considered before taking any measures. The removal plan must take into account the importance of the habitat for birds and fish.
Reef restoration						X				
Oxygenation of bottoms								X	X	Improving the condition of near-bottom water usually requires continuous oxidation, and the lack of oxygen is easily restored when the oxidation activity is stopped.

Transplants	Sand banks	Baltic esker islands, under water parts	Estuaries	Coastal lagoons	Large shallow inlets and bays	Reefs	Boreal Baltic islets and small islands	Boreal Baltic narrow islets	Other deep soft bottoms	Comments
Eelgrass	X	X								Sand and gravel substrates. Requires suitable conditions. Beware of weakening the source populations. Populations that may be genetically differentiated from each other and the mixing of genetic material in plantings should be taken into account by favoring source populations close to the planting site.
Bladder wrack						O	O			Hard substrates. Suitable conditions are required (e.g. good water quality).
Stoneworts			O	X	O			O		Requires suitable conditions. Beware of weakening the source populations.
Other vascular plants	X	X	O	O	O			O		Transplanting can be sensible to increase the surface area of the habitat formed by a key species (e.g. eelgrass) or to ensure the survival of an endangered species even in some populations in its range. It can be transplanted where there are natural habitats and suitable conditions for the species, but the results vary.
Modifying the microhabitat of an endangered species			O	?	O			O		The ecology of the species must be well known, so as not to weaken the living conditions of the species.
Intentional creation of minor disturbance		O			O					Coastal meadows and wetlands, river estuaries, low mud and silt banks.
Coastal pasture			O		O			?		More studies of the direct effects of grazing on the underwater nature of the nearby shore in various water bodies are needed.
Fish restorations in lagoons				O						
Pike wetlands			O		O			O		The primary goal of pike wetlands is to strengthen the predatory fish population. When planning measures, possible conflicts of the goal with habitat type and bird protection should be taken into account.
Grayling habitat restorations		?					?			Grayling spawns on shallow rock and gravel bottoms, eutrophication is a large-scale problem and the effects of the measures are therefore temporary.

Most recent Nature Protection Publications of Metsähallitus

Series A

No 250 Stolton, S., Ahlroth, P., Auvinen, A.-P., Dehmel, N., Dudley, N., Hošek, M., Lahti, K., Ross, B. & Leung, Y.-F. 2024: Management Effectiveness Evaluation of Finland's Protected Areas 2023. 195 s.

No 251 Ikkala, L. & Similä, M. (toim.) 2024: Ennallistettujen soiden seurannan kehittämisehdotukset – Hydrologia-LIFE-hankkeessa kertyneitä kokemuksia hoitoseurannan ja hydrologisen seurannan parantamiseksi ja kaukokartoitusseurannan perustamiseksi. 148 s.

No 252 Arnkil, A., Bäck, A., Haavisto, F., Keskinen, E., Kuningas, S., Laine, A., Nieminen, A., Puttonen, I., Raitanen, H. & Salovius-Laurén, S. 2024: Katsaus meriluonnon kunnostustöihin ja -menetelmiin Suomessa. 139 s.

No 253 Ikkala, L. & Similä, M. (eds) 2024: Proposals for developing the monitoring of restored peatlands – Experiences gained in Hydrology LIFE project for developing general and hydrological monitoring as well as setting up monitoring by remote sensing. 151 s.

No 254 Karppinen, A., Nikula, R. & Vierelä, M. 2024: Eräpalvelujen virtavesikunnostukset 2020–2023 – loppuraportti. 64 s.

No 255 Palviainen, H., Tenhunen, T., Tervonen, P., Tolonen, S., Tuovinen, T., Vauramo, A. & Väli-Torala, T. 2024: Kulttuuriperinnön kuva 2023 – Metsähallituksen julkisten hallintotehtävien hallinnassa olevan kulttuuriomaisuuden kuva vuonna 2023. 53 s.

Series B

No 267 Puranen, T. & Mikkola, M. 2022: Torronsuon kansallispuiston kävijätutkimus 2020–2021. 60 s.

No 268 Puranen, T. 2022: Liesjärven kansallispuiston kävijätutkimus 2021. 62 s.

No 269 Tiikkainen, U. 2023: Sallan kansallispuiston ja Sallatunturin alueen kävijätutkimus 2022. 63 s.

No 270 Haverinen, S. 2023: Patvinsuon kansallispuiston kävijätutkimus 2022. 66 s.

No 271 Haverinen, S. 2023: Tiilikkajärven kansallispuiston kävijätutkimus 2022. 64 s.

No 272 Metsähallitus 2023: Suojelualueiden hoidon ja käytön periaatteet. 245 s.

Series C

No 181 Metsähallitus 2022: Selkämeren kansallispuiston ja Natura 2000 -alueiden hoito- ja käyttösuunnitelma. 199 s.

No 182 Metsähallitus 2022: Helvetinjärven kansallispuiston hoito- ja käyttösuunnitelma. 109 s.

No 183 Metsähallitus 2022: Pinkjärven ja Lastensuon hoito- ja käyttösuunnitelma. 99 s.

No 184 Metsähallitus 2023: Koloveden kansallispuiston hoito- ja käyttösuunnitelma. 131 s.

No 185 Metsähallitus 2023: Linnansaaren kansallispuiston hoito- ja käyttösuunnitelma. 157 s.

No 186 Metsähallitus 2024: Seitsemisen kansallispuiston hoito- ja käyttösuunnitelma. 107 s.

METSÄHALLITUS

ISSN-L 1235-6549
ISSN (VERKKOJULKAISU) 1799-537X
ISBN 978-952-377-127-7 (PDF)
JULKAISUT.METSA.FI