Handbook for restoration of eelgrass in Sweden

State of knowledge update 2016-2024

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Handbook for restoration of eelgrass in Sweden

State of knowledge update 2016–2024

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Cover photo: Eduardo Infantes. The image shows densely planted eelgrass shoots at a site in Kosterhavet National Park, where studies are underway to assess whether dense plantings can reduce damage caused by shore crabs.

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Preface

The state of the coastal and marine environment needs improvement. A large number of international and national commitments and decisions require actions to reduce impact and pressure, as well as to restore coastal and marine environments. These include, among others, the EU Water Framework Directive, the Marine Strategy Framework Directive, the Habitats Directive, and the Swedish environmental quality objective *A Balanced Marine Environment, Flourishing Coastal Areas and Archipelagos*.

At the international level, there is currently a strong focus on restoring and rehabilitating damaged ecosystems. The United Nations has declared the period 2021–2030 as the *Decade on Ecosystem Restoration*, and through the *Kunming-Montreal Global Biodiversity Framework*, the UN has established an agreement with concrete targets for ecosystem restoration by 2030. The European Union has adopted a *Biodiversity Strategy for 2030* with the same purpose, as well as a *Nature Restoration Law* with targets for 2030, 2040, and 2050. The Ramsar Convention also includes several resolutions concerning shallow coastal waters, where conservation, restoration, and coastal planning are highlighted as key measures. In 2024, the European Parliament and the Council of Ministers decided to adopt the EU Nature Restoration Law. This regulation mandates that degraded nature, including marine environments, must be restored in all member states, with binding interim targets. As these targets are legally binding, the regulation will have a significant impact on restoration efforts in Sweden.

A key prerequisite for successful restoration is a well-functioning toolbox of scientifically grounded methods. This report provides an updated knowledge base on developments since the first handbook for eelgrass restoration was published in 2016 (Moksnes et al. 2016; SwAM Report 2016:9). The handbook is part of the action program for the Marine Strategy Framework Directive (actions 29, 30, and 31; SwAM Reports 2015:30, 2021:20). The primary target groups for the handbook are environmental officers and managers of marine coastal environments at county administrative boards and municipalities who organize and handle matters related to eelgrass. It is also intended for stakeholders whose activities may negatively impact eelgrass, as well as consulting firms that may carry out practical eelgrass restoration and monitoring work. The handbook may also serve as course material at universities.

Although effective methods for eelgrass restoration are now available for Swedish conditions, restoration remains time-consuming, costly, and associated with uncertainties. Therefore, it is of utmost importance that management efforts primarily focus on protecting the remaining eelgrass meadows, and only as a last resort allow compensatory restoration as a solution in cases of exploitation.

Sincere thanks are extended to everyone who contributed information, materials, and feedback to this work. The report was produced by the research group Zorro from the University of Gothenburg and the County Administrative Board of Västra Götaland. The project manager at the Swedish Agency for Marine and Water Management was Ingemar Andersson.

Gothenburg August 2025,

Johan Kling

Acting Head of Department

Department of Water Resources Management, Swedish Agency for Marine and Water Management

Summary

Restoration of eelgrass constitutes an important measure to restore historical meadows or as a compensatory action when eelgrass is damaged or lost during exploitation. In 2016, a detailed technical guideline for seagrass restoration in Sweden was published (Moksnes m.fl. 2016). This handbook describes all the important steps in the restoration process, from evaluation and site selection, consultation and permits, harvesting and planting, to monitoring and evaluating the results. Since then, the methods described in the handbook have been tested in various projects at several locations along the Swedish coast, and ongoing studies in Bohuslän have led to new knowledge and the development of restoration methods. In this report, which is a supplement to the handbook, new knowledge about eelgrass restoration is compiled based on these experiences from the Baltic Sea and the North Sea between 2016–2024. It also includes results from several restoration projects in Bohuslän conducted by researchers at the University of Gothenburg in collaboration with the County Administrative Board of Västra Götaland, where the goal has been to develop new restoration methods.

The compilation of restoration projects in Sweden shows that eelgrass restoration has evolved from small-scale, experimental studies to a functioning large-scale measure over the past 8 years. During the period 2016-2024, eelgrass restoration has been carried out at a total of 59 planting sites across 37 different locations, where over 500,000 shoots have been planted over an area of 5.2 hectares. The majority of the plantings consisted of smaller test areas of a few square meters, but 15 were classified as large-scale since they covered over 1000 m². The compilation shows that the planting of eelgrass shoots using the recommended single shoot method was used in all projects and that it works well also in the Baltic Sea. Perennial survival was observed in 64% of the plantings, with 39% showing positive shoot growth. A total area of 2.3 hectares of eelgrass beds has been created over the past 8 years, where more than 3 million shoots are currently growing. In Bohuslän, poor water quality where the eelgrass has disappeared poses a significant challenge for finding locations where eelgrass can grow, and sand capping may be necessary to carry out a restoration. In the Baltic Sea and along the exposed coast of Skåne, the growth was high and comparable to the Swedish west coast, with fewer biological disturbances such as crabs and algal mats. The problems here mainly consisted of physical disturbances in the form of exposure and bottom erosion, where planting several shoots in a bouquet worked better in certain locations.

In management and restoration of eelgrass, it is important to have an understanding of eelgrass's genetic diversity as well as how different meadows are interconnected through the dispersal of drifting flowering shoots. In management it is important to protect both meadows with high genetic diversity and high dispersal capacity, as well as isolated and vulnerable meadows with low genetic diversity. During restoration, areas with high dispersal capacity should be selected, and large meadows or meadows with high genetic diversity near the restoration area should be chosen as donor material. In the Swedish part of the Baltic Sea, eelgrass does not reproduce sexually, and thus the genetic diversity is lower, which can increase the risk of restoration failures in the long term. This makes the choice of donor meadows even more important, and shoots from several donor meadows with environmental conditions similar to the restoration site should be used.

Shore crabs (*Carcinus maenas*) constitute a significant problem in the restoration of eelgrass in certain areas on the west coast, where they have caused extensive damage and losses of entire plantings. Studies have shown that losses can be reduced by planting the shoots more densely in smaller groups and through reduction fishing of crabs. Crab damage has also been detected in natural meadows, where the proportion of cut shoots can constitute 40% during the fall. Further studies are needed to investigate whether crabs can also lead to losses of natural meadows and how the problems with crab damage can be reduced to enable the restoration of eelgrass in affected areas.

Sand-capping of the seabed has proven to be a promising method for improving growth conditions for eelgrass in coastal areas where historical eelgrass losses have led to sediment resuspension and turbid water, preventing restoration and recolonization. In Bohuslän, large-scale sand-capping and seagrass planting on one hectare have dramatically improved light conditions and seagrass growth, with a 26-fold increase in shoots found after three growing seasons. Based on these experiences, a detailed guide is presented here for all steps in the restoration process, with sand capping recommended for other areas where turbidity issues caused by sediment resuspension prevent the return of eelgrass.

Eelgrass restoration is expensive, but the results from the large-scale restoration projects conducted in Sweden in recent years show that the variation between projects is significant, with the cost of harvesting and planting ranging from 16 to 110 SEK per shoot. Planting in checkerboard patterns to reduce the number of shoots and thus the cost of restoration shows promising results from studies on the West Coast, where unplanted areas of 1x1 meter regrow after 3–4 years.

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1 Introduction

The “Handbook for restoration of eelgrass in Sweden” was published in 2016 and was produced by researchers within the interdisciplinary research program Zorro (https://www.gu.se/en/research/zorro) at the University of Gothenburg, in collaboration with the County Administrative Board of Västra Götaland, commissioned by the Swedish Agency for Marine and Water Management. Since then, knowledge about eelgrass restoration has continued to evolve through restoration projects and method development carried out at several locations along the Swedish coast. This report serves as a supplement to the handbook and presents new knowledge compiled from several restoration projects conducted within the Zorro research program in collaboration with the County Administrative Board of Västra Götaland. It also includes more comprehensive guidance on sand capping of the seabed as a measure to enable restoration in environments where local sediment resuspension and turbidity hinder eelgrass growth.

Each section on restoration begins with a summary of the key points covered. The report also initially compiles experiences from eelgrass planting efforts carried out in the Gothenburg archipelago, Stockholm, Kalmar, Blekinge, and Skåne counties, as well as from neighbouring countries between 2016 and 2024.

The primary target audiences for this report are environmental officers and managers of marine coastal environments at county administrative boards, municipalities, and other authorities from Sweden involved in management or handling of eelgrass-related matters. It is also intended for stakeholders whose activities may negatively impact eelgrass, as well as consulting firms that may carry out practical work related to eelgrass restoration and monitoring. The English translation is also intended for managers, practitioners and researchers of seagrass restoration in other countries where the presented methods and data may be of interest.

The guidance is intended for large-scale eelgrass restoration (i.e., 1,000 m² or more), where the goal is the long-term recovery of a larger eelgrass habitat and its ecosystem services within a coastal area. Throughout the report, references to “the handbook” always refer to Moksnes et al. (2016). To fully understand the restoration process and place the content of this report in the correct context, readers are encouraged to first read the *Handbook for restoration of eelgrass in Sweden*, as this supplement only highlights those parts of the restoration process where new knowledge is available. The term “eelgrass” always refers to the seagrass species *Zostera marina*.

2 Eelgrass restoration 2016–2024

2.1 Eelgrass restoration in Sweden

Since 2016, several eelgrass planting efforts have been carried out through various projects and initiatives along the Swedish coast. These efforts reveal significant regional differences in survival and growth, providing crucial insights for future eelgrass restoration attempts.

A total of 59 individual planting efforts of eelgrass (i.e. active restoration of eelgrass separated in time or space) were identified, conducted at 37 sites along the Swedish coast between 2016 and 2024 (Figure 2.1, Table 2.1). The majority of these plantings consisted of small experimental plots of just a few square meters, with a median size of 31 m^2. At 15 sites, continuous areas exceeding 1,000 m^2 were planted (Table 2.2). In total, approximately 500,000 eelgrass shoots were harvested and planted over an area of 5.2 hectares.

Of the 59 plantings carried out, 23 (39%) showed an increase in shoot density at the final monitoring time. The fact that many projects showed low survival is not entirely surprising, as several were test plantings aimed at assessing whether the environment was suitable for growth. Despite the fact that many plantings experienced shoot and area loss, total shoot density increased significantly in several cases. At the final monitoring, more than 3 million shoots were recorded in total—representing an approximate 500% increase compared to the number initially planted across all projects.

This positive outcome is largely driven by a few larger plantings that demonstrated very high growth, including sites at Lilla Askerön, Gåsö, and the northern archipelago of Gothenburg in Västra Götaland, as well as smaller projects in Skåne, Blekinge, and Kalmar counties (Table 2.2). Based on the final monitoring results from the various projects, an eelgrass area of approximately 2.3 hectares has been established (Table 2.2).

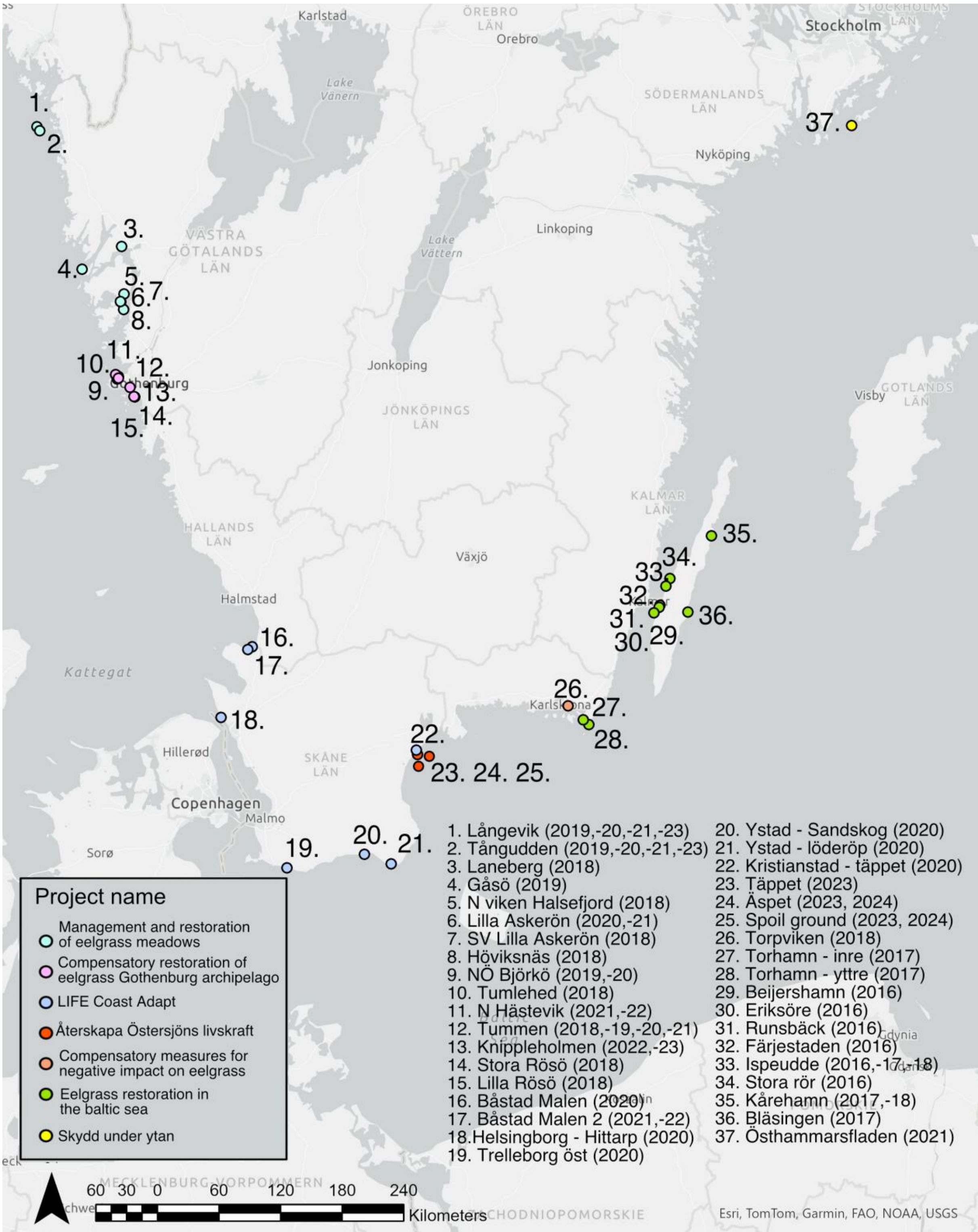


Figure 2.1 The map shows all locations where eelgrass planting took place between 2016 and 2024, based on identified projects. The year(s) of planting are indicated in parentheses. The color coding shows which locations are part of the same project (see legend). For more detailed information about the individual projects, see Table 2.2.

Table 2.1 Location names and coordinates (WGS 84, decimal) where eelgrass plantings were carried out in Sweden between 2016 and 2024.

Location	County	Lat	Long
1. Långevik	Västra Götaland	58,88354	11,00444
2. Tångudden	Västra Götaland	58,8652	11,02828
3. Laneberg	Västra Götaland	58,3366	11,7456
4. Gåsö	Västra Götaland	58,23305	11,39913
5. N. Halsefjorden	Västra Götaland	58,118	11,7671
6. Lilla askerön	Västra Götaland	58,0839	11,73386
7. SV Lilla Askerön	Västra Götaland	58,0812	11,7405
8. Höviksnäs	Västra Götaland	58,047	11,7648
9. NÖ Björkö	Västra Götaland	57,74279	11,694
10. Tumlehed	Västra Götaland	57,73449	11,71941
11. Norra Hästevik	Västra Götaland	57,7262	11,71658
12. Tummen	Västra Götaland	57,72323	11,70632
13. Knippleholmen	Västra Götaland	57,68426	11,81777
14. Stora Rösö	Västra Götaland	57,64095	11,85425
15. Lilla Rösö	Västra Götaland	57,63883	11,86275
16. Båstad Malen	Skåne	56,44745	12,88873
17. Båstad Malen 2	Skåne	56,435345	12,851579
18. Helsingborg Hittarp	Skåne	56,10513	12,61526
19. Trelleborg öst	Skåne	55,36295	13,1935
20. Ystad Sandskog	Skåne	55,43083	13,86963
21. Ystad Löderup	Skåne	55,38303	14,10553
22. Krstd Täppet	Skåne	55,94503	14,32733
23. Täppet	Skåne	55,942217	14,326950
24. Äspet	Skåne	55,910833	14,309167
25. Spoil ground	Skåne	55,937217	14,336950
26. Torpviken	Blekinge	56,16136	15,65352
27. Torhamn inre	Blekinge	56,09236	15,78682
28. Torhamn yttre	Blekinge	56,06973	15,8355
29. Beijershamn	Kalmar	56,61271	16,40608
30. Eriksöre	Kalmar	56,63882	16,45201
31. Runsbäck	Kalmar	56,63961	16,45306
32. Färjestaden	Kalmar	56,64804	16,45822
33. Ispeudde	Kalmar	56,74062	16,51026
34. Stora Rör	Kalmar	56,77732	16,54672
35. Kårehamn	Kalmar	56,98083	16,90831
36. Bläsingen	Kalmar	56,61602	16,70259
37. Östemarsfladen	Stockholm	58,88915	18,13572

Table 2.2 Eelgrass plantings in Sweden between 2016–2024. Project: [1] Management and Restoration of Eelgrass Meadows, [2]Compensatory Eelgrass Restoration in the Gothenburg Archipelago, [3]LIFE Coast Adapt, [4]Återskapa Östersjöns livskraft, [5]Compensatory Measures for Negative Impacts on Eelgrass, [6] Eelgrass Restoration in the Baltic Sea, [7]skydd under ytan. References: [A]Moksnes et al. unpublished, [B]Andersson 2023, [C]Gai et al. 2021, 2022, 2023, [D]Tannergård 2023, [E]Strandberg and Nilsson 2020, [F]Nilsson and Jönsson 2019, [G]Personal communication Cecilia Wibjörn, Skärgårdsstiftelsen. Green cells indicate plantings >1000 m^2 and those with positive shoot growth at the final monitoring. Letters under planting method represent: S = Single shoots, r = checkerboard planting pattern, Sand = sand capping of the seabed before planting, a = anchoring of shoots, p = shoots in sediment plugs, j = shoots attached to jute fabric, b = shoots planted in bundles.* *Number of shoots and area at final monitoring have been estimated by the authors of this report based on reported survival rates and/or shoot growth from the respective projects.*

CountyLocation	Year	Project owner	shoots planted	Method	shoots per m² planted	m² planted	follow-up	shoots on follow-up	m² follow-up	% change in shoot no.
Västra Götalands										
1. Långevik	2019	Lst VG/GU[1A]	128	s	16	8	-20	80	8	-38
1. Långevik	2020	Lst VG/GU[1A]	5 760	s	16	630	-21	0	0	-100
1. Långevik	2020	Lst VG/GU[1A]	32 000	s,r	16	4000	-21	320	20	-99
1. Långevik	2021	Lst VG/GU[1A]	270	s	33	8	-21	180	3	-33
1. Långevik	2023	Lst VG/GU[1A]	1 134	s	16,64,256	10	oct-23	344	0	-70
2. Tångudden	2019	Lst VG/GU[1A]	128	s	16	8	-20	104	8	-19
2. Tångudden	2020	Lst VG/GU[1A]	5 760	s	16	630	-21	10	2	-99
2. Tångudden	2020	Lst VG/GU[1A]	32 000	s,r	16	4000	-21	5	1	-100
2. Tångudden	2021	Lst VG/GU[1A]	100	s	33	3	-21	10	1	-90
2. Tångudden	2023	Lst VG/GU[1A]	1 134	s	16,64,256	10	oct-23	189	0	-83
3. Laneberg	2018	Lst VG/GU[1A]	272	s	4,16	16	sep-18	41	0	-85
4. Gåsö	2019	Lst VG/GU[1A]	16 128	s,r	16	1600	oct-24	361 200	1400	2 140
5. N. Halsefjorden	2018	Lst VG/GU[1A]	272	s	4,16	16	sep-18	3	0	-99
6. Lilla askerön	2020	Lst VG/GU[1A]	256	s	16	16	-20	90	6	-65
6. Lilla askerön	2021	Lst VG/GU[1A]	177	s	16	10	-21	240	8	36
6. Lilla askerön	2021	Lst VG/GU[1A]	80 000	s,r,sand	16	10000	oct-24	2 047 484	5027	2 459
7. SV Lilla Askerön	2018	Lst VG/GU[1A]	272	s	4,16	16	sep-18	37	0	-87
8. Höviksnäs	2018	Lst VG/GU[1A]	272	s	4,16	16	sep-18	0	0	-100
9. NÖ Björkö	2019	Göteborgs hamn AB[2B]	275	s	4,16	25	june-20	22	0	-92
9. NÖ Björkö	2020	Göteborgs hamn AB[2B]	15 600	s	4,7,16	1700	-21	0	0	-100
10. Tumlehed	2018	Göteborgs hamn AB[2B]	250	s	4,16	16	maj-19	0	0	-100
11. Norra Hästevik	2021	Göteborgs hamn AB[2B]	2 200	s	4,16	200	-21	25	0	-99
11. Norra Hästevik	2022	Göteborgs hamn AB[2B]	10 000	s	4,16	1500	-23	0	0	-100
12. Tummen	2018	Göteborgs hamn AB[2B]	250	s	4,16	16	maj-19	4	0	-95
12. Tummen	2019	Göteborgs hamn AB[2B]	2 000	s	4,16	200	-23	60 000	400	2 900
12. Tummen	2020	Göteborgs hamn AB[2B]	20 800	s	4,7,16	2400	-23	67 200	600	223
12. Tummen	2021	Göteborgs hamn AB[2B]	40 100	s	4,16	5820	-23	15 372	2520	-62
13. Knippleholmen	2022	Göteborgs hamn AB[2B]	5 000	s	4,16	500	-23	94 400	400	1 788
13. Knippleholmen	2023	Göteborgs hamn AB[2B]	42 750	s,r	2,16	4750	-23	166 250	4750	289
14. Stora Rösö	2018	Göteborgs hamn AB[2B]	250	s	4,16	16	maj-19	0	0	-100
15. Lilla Rösö	2018	Göteborgs hamn AB[2B]	250	s	4,16	16	maj-19	0	0	-100
Skåne										
16. Båstad Malen	2020	Region Skåne[3C]	529	s,a,p,j	4,16	31	oct-20	195*	12*	-63*
17. Båstad Malen-2	2021	Region Skåne[3C]	12 000	s,r	16	1500	oct-21	1560*	195*	-87*
17. Båstad Malen-2	2022	Region Skåne[3C]	20 384	s,r	16	1898	oct-22	28 818*	1723*	41*
18. Hbg Hittarp	2020	Region Skåne[3C]	529	s,a,p,j	4,16	31	oct-20	31*	0*	-94*
19. Trelleborg öst	2020	Region Skåne[3C]	529	s,a,p,j	4,16	31	nov-20	259*	15*	-51*
20. Ystad Sandskog	2020	Region Skåne[3C]	529	s,a,p,j	4,16	31	nov-20	2*	0*	-99*
21. Ystad Löderup	2020	Region Skåne[3C]	529	s,a,p,j	4,16	31	jan-21	0*	0*	-100*
22. Krstd Täppet	2020	Region Skåne[3C]	529	s,a,p,j	4,16	31	oct-20	1 967*	31*	272*
23. Täppet	2023	Kristianstadkommun[4D]	59 880	s,b	16,25	3000	-24	57 360*	2256*	-4*
24. Äspet	2023	Kristianstadkommun[4D]	19 200	s,b	16	1200	-24	7 020*	293*	-63*
24. Äspet	2024	Kristianstadkommun[4D]	16 000	b	16	1000	-24	?	?	?
25. Spoil ground	2023	Kristianstadkommun[4D]	12 800	b	16	800	-24	13 440*	800*	5*
25. Spoilground	2024	Kristianstadkommun[4D]	39 000	b	16,30	2000	-24	?	?	?
Blekinge										
26. Torpviken	2018	Karlskrona kommun[5E]	800	s	4	200	sep-19	86 250*	300*	10 681*
27. Torhamn inre	2017	Lst Kalmar /Lnu[6F]	102	s	4,16	6	oct-17	918*	6*	800*
28. Torhamn yttre	2017	Lst Kalmar /Lnu[6F]	102	s	4,16	6	oct-17	357*	6*	250*
Kalmar										
29. Beijershamn	2016	Lst Kalmar /Lnu[6F]	306	s	4,16	18	oct-16	2 295*	18*	650*
30. Eriksöre	2016	Lst Kalmar /Lnu[6F]	306	s	4,16	18	oct-16	3 978*	18*	1 200*
31. Runsbäck	2016	Lst Kalmar /Lnu[6F]	306	s	4,16	18	oct-16	1 989*	18*	550*
32. Färjestaden	2016	Lst Kalmar /Lnu[6F]	306	s	4,16	18	oct-16	1 530*	18*	400*
33. Ispeudde	2016	Lst Kalmar /Lnu[6F]	306	s	4,16	18	oct-16	7 191*	18*	2 250*
33. Ispeudde	2017	Lst Kalmar /Lnu[6F]	102	s	4,16	6	oct-17	765*	6*	650*
33. Ispeudde	2018	Lst Kalmar /Lnu[6F]	3 200	s	4	800	aug-18	3 264*	800*	2*
34. Stora Rör	2016	Lst Kalmar /Lnu[6F]	306	s	4,16	18	oct-16	2 754*	18*	800*
35. Kårehamn	2017	Lst Kalmar /Lnu[6F]	102	s	4,16	6	oct-17	1 071*	6*	950*
35. Kårehamn	2018	Lst Kalmar /Lnu[6F]	3 200	s	4	800	aug-18	12 800*	800*	300*
36. Blåsingen	2017	Lst Kalmar /Lnu[6F]	102	s	4,16	6	oct-17	0*	0*	-100*
Stockholms										
37. Östemarsfladen	2021	Skärgårdsstiftelsen[7G]	293	?	?	?	Sep-23	59	?	-80
Sum			**508 065**			**51 678**		**3 049 483**	**22 510**	

2.1.1 Västra Götaland County

Project "Management and Restoration of Eelgrass Meadows"

As part of the project *Management and Restoration of Eelgrass Meadows*, which ran from 2018 to 2022, the County Administrative Board of Västra Götaland, together with the University of Gothenburg, carried out large-scale eelgrass plantings at three sites along the Bohuslän coast. In addition, several smaller areas were planted during this period to, among other things, assess site suitability and the impact of disturbing fauna (see Table 2.2; Figure 2.1; Moksnes, unpublished data).

In 2019, eelgrass was planted over an area of 1,600 m² at Gåsö in Lysekil Municipality. This planting aimed, among other things, to evaluate whether shoot usage could be reduced by creating a checkerboard pattern of planted and unplanted areas (see Section 4.3). A total of approximately 16,000 shoots were planted using the single-shoot method in a checkerboard pattern across four 20×20 meter plots, where the size of planted and unplanted squares varied (continuous, 1×1, 2×2, and 4×4 meters). The shoot density in planted areas was 16 shoots per m². Shoot growth was initially lower than in other trials along the Bohuslän coast (e.g., Eriander et al. 2016), likely due to damage from the large number of shore crabs in the area (see Section 4.4). Despite this, the eelgrass was fully established after four years and has begun to spread beyond the planted area. The unplanted squares in the 1×1 and 2×2 meter checkerboard patterns were almost completely overgrown, effectively doubling the planted area. At the final monitoring in 2024, the average shoot density was 258 shoots per m² across an area of 1,400 m², which is comparable to shoot densities of natural meadows in the region and corresponds to a total of approximately 360,000 shoots (see Section 4.3 for a more detailed description of the results from this study).

In 2020, consultants and the University of Gothenburg planted eelgrass over a total area of 0.93 hectares in two bays (Långevik and Tångudden) within Kosterhavet National Park, Strömstad Municipality. Approximately 75,500 shoots were planted using the single-shoot method in a checkerboard pattern (1×1 meter), with every other square meter planted with 16 shoots. Significant eelgrass losses were observed just three months after planting, despite favourable light and sediment conditions at the sites. By spring 2021, only a few shoots remained. New experimental plantings conducted at the site in 2021 suggest that the main causes of loss were damage and disturbance from shore crabs and various fouling organisms (see Section 4.4). During the summers of 2023 and 2024, further studies were conducted to investigate how shoot density and crab fishing affect the survival and growth of shoots in this area (see Section 4.4.1).

In 2021, consultants carried out sand capping over a 1.0-hectare area of clay bottom at Lilla Askerön, Tjörn Municipality, followed by the planting of approximately 80,000 eelgrass shoots. The eelgrass was planted using the single-shoot method in a checkerboard pattern (1×1 meter), with every other square meter planted with 16 shoots. The seabed was covered with a 10 centimeter thick layer of sand and gravel to reduce resuspension of fine sediment and improve growth conditions at the site (see Section 5). Although eelgrass coverage decreased in parts of the planted area due to disturbance from swans, shore crabs, and winter storms, growth was substantial in surviving areas where the planted squares had largely merged at the final sampling. In the autumn of 2024, approximately 0.5 hectares were covered by a dense eelgrass meadow with an average of 407 shoots per m², comparable to shoot densities in natural meadows. The total number of shoots is estimated to have increased from 80,000 to over 2 million over four growing seasons. In areas where planted eelgrass had disappeared, high densities of blue mussels had instead established on the gravel (see Section 5.8).

Project ”Compensatory Restoration of Eelgrass (*Zostera marina*) in the Gothenburg Archipelago”

As part of the project *Compensatory Restoration of Eelgrass (Zostera marina) in the Gothenburg Archipelago*, the Port of Gothenburg AB carried out eelgrass restoration as a compensatory measure for eelgrass losses associated with port construction. The work was conducted by the consulting firm Marine Monitoring AB. The project ran from 2016 to 2023, and in total, 1.7 hectares of unvegetated seabed were planted with eelgrass at four sites in the northern Gothenburg archipelago (Table 2.2; Figure 2.1; Andersson 2023).

Throughout the process, recommendations from the eelgrass restoration handbook were followed regarding methodology, shoot density, monitoring, and site selection (including sediment and light assessments, as well as methods and sampling frequency for test plantings). Approximately 140,000 shoots were planted during the project. Various planting areas and shoot densities were tested to optimize survival and time efficiency. Plantings were also distributed across time (several years) and space to reduce the risk of failure due to natural variability in environmental factors (e.g., water temperature, nutrient levels, light conditions, storms) and human impact. One of the main challenges in the project was identifying suitable sites for eelgrass planting, and in some cases, plantings failed despite seemingly favourable conditions.

At the final monitoring in 2023, approximately 400,000 eelgrass shoots covered a total of 0.87 hectares across two sites. The project revealed significant variation between sites and years (and in some cases within sites), and identified several factors that may have negatively affected the plantings, such as drifting algal mats, light availability, and exposure levels. The results also showed that planted eelgrass only survived in proximity to natural eelgrass beds. Although the outcomes varied, with several plantings lost, those that survived showed an average growth of approximately 1,300%, and shoot densities were comparable to nearby natural eelgrass meadows. At the site “Tummen,” where eelgrass was planted between 2019 and 2021, the eelgrass survived and grew for several years. At the final monitoring in 2023, high shoot densities were still recorded, but the areal extent of eelgrass had decreased, with eelgrass found on 42% of the originally planted area. A similar reduction in coverage was also observed in nearby natural eelgrass beds. The decline was attributed to the spread of fine filamentous algae in 2022. As with other studies conducted in Västra Götaland, the author emphasizes that eelgrass restoration in the region is both challenging and time-consuming (Andersson 2023).

2.1.2 Skåne county

Project "LIFE Coast Adapt"

As part of the EU project *LIFE Coast Adapt*, led by Region Skåne in collaboration with the City of Helsingborg, Lomma Municipality, Ystad Municipality, Lund University, the County Administrative Board of Skåne, and the municipalities of Skåne, test plantings of eelgrass were carried out between 2020 and 2022 using five different methods at six locations in Skåne County (Table 2.2, Figure 2.1; Gai et al. 2021, 2022, 2023). The aim was to evaluate the potential of eelgrass planting as a measure to protect against coastal erosion.

The work was conducted by consulting firms, and the 2020 test plantings showed positive growth at only two locations. The best growth occurred at the site in Kristianstad on the east coast of Skåne in the Baltic Sea, where the number of shoots increased fivefold after the first growing season using the single-shoot method. No significant differences were observed between the lower and higher shoot densities (4 and 16 shoots per m²). At the site in Båstad, shoot losses occurred in all treatments except the one where shoots were attached to jute fabric. Since this site is more exposed, larger plantings were carried out in 2021 (1,500 m²) and 2022 (1,898 m²) at second site in Båstad in an attempt to reduce erosion (see Table 2.1), using the single-shoot method. The results showed varying growth between the two years. Survival of the shoots planted in 2021 was low (13%), with positive growth observed only in a few plots at the deepest (3-meter) planting depths. The 2022 plantings included both full-coverage plantings in June, which showed high survival and an increase in shoot numbers of 158–232%, and checkerboard-pattern plantings in August, which showed shoot losses ranging from 4–24% (personal communication, Theodor Kindberg 2024).

Project "Återskapa Östersjöns livskraft"

As part of the WWF project *Återskapa Östersjöns livskraft* (eng. *Reviving the Baltic Sea's Vitality)* the Municipality of Kristianstad, through the Kristianstad Vattenrike Biosphere Reserve, planted 146,800 eelgrass shoots over a total area of 5,000 m² in Hanö Bay during 2023–2024 (Table 2.2; Figure 2.1; Tannergård 2023). The planting was carried out by the municipality and consultants in three areas, at depths of 4–5 meters within the wave-exposed bay, referred to as Täppet, Äspet, and Spoil Ground. Täppet consisted of sandy seabed, Äspet of a more heterogeneous bottom with sand, clay, and stones, and Spoil Ground was a former dumping site where eelgrass had not established naturally. The sediment at the dumping site consisted mainly of sand, but also included finer materials such as clay and larger boulders.

Three methods were tested in the project: the single-shoot method from the handbook, where 16 shoots were planted in 1 m² plots (16 shoots per m²); a bundle method where five bundles with five shoots each were planted in 1 m² plots (25 shoots per m²); and a bundle method where one bundle of 16 shoots was planted in the centre of 1 m² plots (16 shoots per m²). The methods were tested on different plot sizes at the three sites (Table 2.2). A total of 91,880 shoots were planted at the three sites in 2023. All planting was done using garden spades, as the sand was too hard for the shoots to be pressed into the sediment by hand.

Eelgrass grew well at all sites during the first year and also showed good winter survival despite severe storms during the 2023–2024 winter season, although survival varied between methods. Planting individual shoots using the single-shoot method was less successful, and at Täppet and Äspet, where this method was tested, all plants had disappeared by the final monitoring in 2024. This is believed to be due to the shoots not having had time to anchor and being dislodged by water movement, which was also observed by divers just days after planting. Instead, the bundle method proved more effective, and at the final monitoring in 2024, 80% of the bundles remained at Täppet, 25% at Äspet, and 100% at Spoil Ground. The remaining bundles showed positive shoot growth, estimated to have increased by 20–30% at Täppet, 50% at Äspet, and 5% at Spoil Ground (personal communication, Ulrika Hedlund, Municipality of Kristianstad). Based on the survival of the different methods and the percentage increase in shoots, approximately 77,800 eelgrass shoots were growing over an area of 3,348 m² at the final monitoring in 2024.

The higher survival of shoots planted in bundles was, according to the practitioners, due to better anchoring in the sediment and easier planting with garden spades in the hard sand. To improve anchoring, the bundles were also planted deep enough that the growth zone was below the sediment surface (personal communication, Ulrika Hedlund, Municipality of Kristianstad), which is not recommended in the handbook as it may increase plant mortality (Mills and Fonseca 2003). However, the shoots showed very good survival and growth, likely due to the sandy sediment allowing good oxygen supply. In line with the handbook, it was noted that winter survival of planted shoots was higher for those planted early in the season (in May) compared to later in the season. In summer 2024, new plantings were carried out at Äspet and Spoil Ground, where a total of 55,000 shoots were planted in bundles of 16 or 30 shoots over an area of 3,000 m². Results from this planting are not yet available at the time of writing.

2.1.3 Kalmar and Blekinge County

Project ”Eelgrass restoration in the Baltic Sea”

Between 2016 and 2018, the County Administrative Board of Kalmar and Linnaeus University collaborated on a project to investigate how well the methods described in the handbook function under the environmental conditions of the Baltic Sea (Nilsson and Jönsson 2019). During the process, the recommendations provided in the handbook were followed regarding site selection for restoration (e.g., sediment and light assessments, as well as methods and sampling frequency for test plantings), planting methods and evaluation.

In 2016, test plantings were carried out at six sites along the western coast of Öland in the Kalmar Sound (Figure 2.1, Table 2.2). At each site, eelgrass was planted at three different depths (1.5 m, 2.5 m, and 4.0 m), with two shoot densities (4 and 16 shoots per m²). Additionally, anchoring of shoots with bamboo sticks was tested according to the handbook's recommendations. The results showed large variation between sites (see Table 2.2), with the greatest shoot growth observed at Ispeudde, where shoot numbers increased by over 2000% in October 2016 and over 1200% in May 2017. The highest shoot growth occurred at the intermediate depth of 2.5 meters, while shoots anchored with bamboo sticks showed poor survival. Test plantings with 4 shoots per m² showed high survival and more than double the shoot growth compared to plantings with 16 shoots per m².

In 2017, eelgrass planting was conducted at a total of five sites: two along the eastern coast of Öland, two in eastern Blekinge (Figure 2.1, Table 2.2), and again at Ispeudde in the Kalmar Sound. Test plantings were carried out using the same two shoot densities, but only at the intermediate depth of 2.5 meters at each site. Results from the October 2017 sampling showed a total loss of shoots at Bläsingen on the eastern side of Öland, likely due to sand movement. At the remaining four sites, shoot density had increased by between 250–950%. As in 2016, significant winter losses occurred, but there was a positive net increase by May 2018. The site with the highest growth was Kårehamn, where shoot density had increased by over 900% in October 2017 (Table 2.2). The 2017 plantings also showed a higher percentage of shoot growth in plots planted with the lower density of 4 shoots per m².

In 2018, the project carried out two larger test plantings at Kårehamn on eastern Öland and Ispeudde on western Öland, which had shown the best growth in 2016 and 2017. At each site, eelgrass was planted over an area of 800 m² with a shoot density of 4 shoots per m², at an average depth of 2.6 m. By August of the same year, shoot density had increased by 350% within the planting area at Kårehamn, while Ispeudde, which had shown the best growth in 2016, had only increased by a few percent, with plants appearing wilted and brown. The poor growth may be explained by the extremely high temperatures (28–29 °C) recorded in the Kalmar Sound during the summer of 2018.

In summary, the three years of planting trials showed varying success between sites and years. Overall, 50% of the plantings were considered successful, highlighting the importance of spreading out plantings in time and space when selecting suitable sites for large-scale restoration.

Project “Compensatory measures for negative impacts on eelgrass”

In June 2018, the Coastal Water Group at Linnaeus University, commissioned by the Municipality of Karlskrona, planted eelgrass as a compensatory measure for negative impacts on eelgrass caused by land reclamation work at the Port of Verkö (Strandberg and Nilsson 2020). A total of 800 eelgrass shoots were planted over an area of 200 m² using the single-shoot method, with a density of 4 shoots per square meter. The results showed very strong growth, with shoot density increasing by approximately 700% just two months after planting. After 14 months, the planted eelgrass had formed a dense meadow that had spread over an area of about 300 m², with 50–75% of the area covered. Shoot density had increased to approximately 460 shoots per square meter, representing a total shoot increase of more than 107 times.

2.1.4 Stockholm County

Project ”Skydd under ytan” (eng. “Protection beneath the surface”)

In 2021, the Archipelago Foundation (skärgårdsstiftelsen) Stockholm conducted planting trials in five, 4-square-meter plots at depths of 5.8–6.8 meters in Östermarsfladen at Nåttarö (personal communication, Cecilia Wibjörn, Skärgårdsstiftelsen). In three of the plots, 81 shoots were planted, and in two plots, 25 shoots were planted. The highest survival was observed in the eelgrass planted at the shallowest depth with the highest shoot density (5.8 meters), where 45 of the 81 shoots remained at the time of sampling in autumn 2023. In the other plots, only a few shoots remained.

2.2 Lessons learnt from eelgrass restoration In Sweden 2016-2024

Since the Handbook for Eelgrass Restoration in Sweden was published in 2016, the methods developed in Bohuslän have been applied in several other locations along the Swedish coast (see section 2.1) and have also been tested in multiple large-scale projects. Even though the success has varied between projects, an estimated 2.3 hectares of new eelgrass meadows have been created during the 8-year period, during which eelgrass restoration has developed from small-scale pilot plantings to a functioning large-scale method. As environmental conditions can differ drastically in terms of, for example, physical exposure, salinity, and associated flora and fauna between areas such as the Swedish Skagerrak Coast, the Kattegat coast of Skåne, and the Baltic Sea, these studies provide a very important complement to the first version of the handbook. Below, we briefly summarize the lessons learnt in Sweden between 2016–2024.

2.2.1 Restoration methods

The single-shoot method, where individual shoots are collected and planted by hand, is currently the recommended method for eelgrass restoration in Swedish waters (Moksnes et al. 2016). The plantings carried out between 2016 and 2024 show that it is a well-functioning method even outside Västra Götaland County on the NW coast, including in more exposed areas along the coast of Skåne and in the Southern Baltic Sea. The handbook also describes restoration methods using seeds, which did not work well in Västra Götaland County, partly due to seed predation by shore crabs. We found no studies testing restoration with seeds between 2016 and 2024. In the Baltic Sea, the low seed production of eelgrass is an additional limitation for using seed-based methods in restoration.

Restoration work in Hanö Bay outside Kristianstad indicates that planting eelgrass in small bundles of 5 or 16 shoots worked better than the single-shoot method in more exposed areas (Tannergård 2023), possibly because grouped plants anchored better in the sediment and were not washed away. Similar indications were found in plantings in the Gothenburg archipelago, where bundles with multiple shoots showed higher survival in exposed environments. When one planting project ended, remaining shoots were planted in bundles outside the designated area, and during a follow-up visit a year later, only these bundles had survived (personal communication, Sandra Andersson, Marine Monitoring AB). This method should be investigated further, both for use in more exposed sites—since anchoring with bamboo sticks has continued to show poor survival (Nilsson and Jönsson 2019)—and also in areas of the Skagerrak where shore crabs currently pose a major problem. New studies indicate that high shoot densities are less vulnerable to crab damage compared to individual shoots (section 4.4.1).

The optimal number of shoots planted per square meter is an important aspect of restoration, as it has a major impact on the cost of a restoration project. Plantings with 16 shoots per m² can still be recommended for eelgrass restoration in the Skagerrak, where problems with crab damage or drifting algal mats are likely to prevent success with plantings of 4 shoots per m² (Moksnes et al. 2016; Moksnes, unpublished data; Andersson 2023). New restoration efforts in Skåne and the Baltic Sea (where shore crabs are not a problem) suggest that planting at low densities may be a better alternative. Plantings along the coast of Skåne show no significant differences between low and high planting densities (Gai et al. 2023), and in the Baltic Sea, a higher proportional growth was observed at 4 compared to 16 shoots per m² (Nilsson and Jönsson 2019). The very high growth rates of planted eelgrass at several sites in the Baltic Sea (approximately 10–30 times increase in shoot density; Nilsson and Jönsson 2019) are comparable to the highest growth rates measured in the Skagerrak, which is surprising given that earlier studies showed significantly lower growth rates of eelgrass in the brackish environment of the Baltic Sea (Baden et al. 2010). The results show that shoot-based restoration is an effective method also for eelgrass restoration in the Baltic Sea.

Planting in a checkerboard pattern has proven to be a successful method along the Bohuslän coast for covering larger bottom areas with fewer shoots, where unplanted areas of 1 m² grow together within three growing seasons (Eriander, unpublished data; see section 4.3 for details). This method was also tested in Båstad with varying results (Gai et al. 2022, 2023).

Results from the compensation restoration in the Gothenburg archipelago and plantings within the project "Management and Restoration of Eelgrass Meadows" suggest that eelgrass plantings are most successful near existing natural eelgrass meadows (Andersson 2023, Moksnes unpublished). In both projects, eelgrass plantings failed in areas where eelgrass had historically disappeared completely. The reasons for planting failures may be various types of external disturbances, which also caused the natural eelgrass to disappear. Shallow areas may, for example, be affected by filamentous algae, drifting perennial algal mats, high crab densities, development, recreational boating, or poor water clarity due to increased runoff or sediment resuspension. After vegetation has disappeared, the environment may have changed so much that it no longer supports eelgrass growth, and support measures may be needed for a planting to succeed, as was the case at Lilla Askerön.

Results from plantings in both Båstad (Gai et al. 2023) and Kristianstad (personal communication, Ulrika Hedlund, Kristianstad Municipality) indicate higher winter survival and growth when eelgrass is planted early in the season (May/June) compared to plantings done in late summer. This supports previous recommendations that eelgrass planting should occur early in the season to give the plants more time to establish and grow before the dark winter season, during which natural shoot loss occurs at this high latitude (Moksnes et al. 2016).

2.2.2 Environmental conditions at the restoration site

Experiences from recent years of restoration trials along Sweden's coasts have provided new insights into the environmental conditions that are favourable for eelgrass growth in different regions. These experiences are summarized below and compared with previous recommendations in the handbook.

Based on results from plantings at several sites and over several years in the Gothenburg archipelago, planting is recommended at semi-exposed sites where filamentous algae and sediment are more easily washed away from the meadows (Andersson 2023). In addition, sites with higher light conditions than those specified in the handbook (25% of surface light; Moksnes et al. 2016) are recommended, especially in areas where other factors such as filamentous algae may cause additional shading of the plants (Andersson 2023). For studies on eelgrass light requirements to be comparable across projects, it is important that light measurement and analysis are conducted in a standardized way. Within the Zorro program, a proposal for a standardized method for light measurements has been developed (see section 4.2).

In areas with poor light conditions, where eelgrass can no longer survive due to sediment resuspension, sand capping of the seabed has proven to be a successful method for reducing turbidity and improving growth conditions. Studies show that natural gravel with a grain size of 0–8 millimetres improves light conditions and visibility by up to 1 m and provides a substrate suitable for eelgrass growth (Moksnes, unpublished data; see section 5 and Appendix B for details). When planting in this coarser substrate and in areas with oysters, planting should be done using thin gardening gloves to avoid finger injuries.

Studies from the Baltic Sea have shown that eelgrass can survive and grow under several classes of wave exposure and sediment types. However, increased exposure was also associated with a higher risk of shoot loss. At particularly exposed sites such as Bläsingen along eastern Öland ("Moderately exposed" according to the wave exposure classification in EUNIS; Swedish EPA 2006), total losses of plantings occurred due to sand burial and erosion. Contrary to the recommendations in the handbook regarding bottom substrate ("*avoid sites with more than 50% clay and silt content*"; Moksnes et al. 2016), studies in the Baltic Sea showed no clear differences in plant growth which was still high in sediments with up to 90% clay and silt (Nilsson and Jönsson 2019). However, competition from other freshwater vegetation was higher on muddy bottoms in some years, and these high-water-content sediments also made planting more difficult due to increased turbidity and poorer anchoring of the shoots (Nilsson and Jönsson 2019). Studies from Kalmar and Blekinge counties also showed that the optimal planting depth is slightly deeper in the Baltic Sea (2.2–3.1 meters; Nilsson and Jönsson 2019) compared to 1.5–2.5 meters on the West Coast of Sweden (Moksnes et al. 2016). Båstad also showed the best growth at a depth of 3 meters, which could be explained by the relatively exposed nature of the site.

Studies conducted in the Gothenburg archipelago, along the coast of Skåne, and in the Baltic Sea show large differences in shoot survival and growth between years and within sites (Nilsson and Jönsson 2019, Andersson 2023, Gai et al. 2023). This is also discussed in Moksnes et al. (2016), and the results emphasize the importance of spreading larger eelgrass restoration efforts across both time and space to reduce the risk that individual weather events or other temporary external disturbances (such as rapid growth of filamentous algae or competition from other vegetation) wipe out entire plantings. In the Baltic Sea, for example, large year-to-year differences were observed in competition from other vegetation (such as pondweeds and charophytes), which led to lower eelgrass growth in some years (Nilsson and Jönsson 2019).

2.2.3 Disturbances

In the trials conducted in Kalmar County, the main disturbances identified included sand erosion, high water temperatures (28–29°C during July in the Kalmar Sound in 2018), sedimentation, and competition from other types of vegetation (Nilsson and Jönsson 2019). The presence of drifting mats of filamentous algae has been noted in plantings in the Baltic Sea. However, no clear damage from these algal mats has been observed in the plantings (Nilsson and Jönsson 2019). The high occurrence of such algal mats along the eastern coast of Öland and in certain areas of the Kalmar Sound and Blekinge suggests that the impact of drifting algal mats is something that may need to be considered when selecting restoration sites in the Baltic Sea as well. The round goby has recently become abundant in the Kalmar Sound, and although no signs of damage from the fish have been observed in the planting trials conducted in the area, their burrowing behaviour in the seabed could potentially pose a problem for future restoration projects (Nilsson and Jönsson 2019).

In Västra Götaland, the main disturbances consist of drifting mats of filamentous and perennial algae (primarily *Furcellaria lumbricalis* and *Fucus serratus*; Moksnes et al. 2016, 2018, Andersson 2023) as well as damage from shore crabs, which can both consume eelgrass seeds and damage shoots (Infantes et al. 2016, Moksnes et al. 2016, Infantes unpublished data). The extensive disturbances from crabs in the Skagerrak may be due to unusually high crab populations caused by disrupted food webs following the collapse of cod stocks (Moksnes et al. 2008; see section 4.4.1 for details).

2.3 Lessons learnt from other European countries

Eelgrass restoration is ongoing in several of Sweden's neighbouring countries, involving both researchers and government agencies. There has been significant interest in the shoot-based restoration methods developed in Sweden and in the Swedish handbook, which was translated to English in 2021 in collaboration with *NatureScot*. Similar restoration handbooks have also been developed in countries such as the United Kingdom and Ireland (Gamble et al. 2021). Below is a brief summary of results and lessons learnt from a selection of restoration studies from countries around Sweden that were published between 2016 and 2024.

2.3.1 Restoration with shoots

Restoration of eelgrass using adult shoots is the most common method in the Nordic countries and the Baltic Sea region. In many areas, wave exposure is considered a challenge, and some form of anchoring is usually used when planting shoots. Below are a few examples of these studies described in more detail so that the methods can be compared with those recommended in the Swedish handbook.

In Denmark, restoration using anchored shoots was successfully carried out in, among other places, Horsens Fjord in 2017 (Lange et al. 2022), where an area of over 1,000 m² was restored. In this study, a thorough preliminary investigation was conducted to identify a suitable restoration site by examining potential disturbances and growth conditions at different locations, as well as through test plantings. Two different methods of anchoring shoots were tested: anchoring with a bent bamboo stick over the rhizome, and shoots where the rhizomes were attached with wire to a nail pressed into the sediment. Across a planting area of ca 4000 m², 190 planting plots of 2×2 meters were placed in a checkerboard pattern with 4-meter spacing. Each 2×2 meter plot consisted of 5 rows with 15 shoots, spaced 0.14 meters apart within rows and 0.5 meters between rows. The shoot density in the plots was 14 shoots per m², and a total of 14,400 shoots were planted. The site depth ranged from 1.2 to 1.4 meters. This planting took 10 people five working days to complete. To reduce damage from algae and shore crabs (*Carcinus maenas* L.), a mesh fence (2 cm mesh size) was installed around the entire planting area, and crabs were continuously removed during the first two months after planting. However, the net was destroyed during winter storms. The plantings showed good survival and growth, increasing from 14 shoots per m² in July 2017 to over 500 shoots per m² after 13 months. After 24 months, shoot densities were comparable to natural meadows (784 shoots per m²; Lange et al. 2022). The planted eelgrass covered a total area of 768 m² in 2017 (about 20% of the planting area). By September 2019, eelgrass covered 1,282 m² (about 30% of the planting area). No differences were observed between the two anchoring methods. Previous pilot plantings in the area showed significantly higher growth in plots protected from crabs using fishing and mesh fencing, but since there were no control plots in the large-scale planting, the effect cannot be measured here. However, the authors suggest that crab reduction may have contributed to the initial success in shoot growth and expansion.

In the coastal waters off Estonia, small-scale eelgrass planting trials were conducted between 2017 and 2019 (Pajusalu et al. 2023). The study investigated whether eelgrass grows better when planted together with blue mussels, which can stabilize the seabed and improve water clarity by filtering, thereby enhancing light conditions for eelgrass. The eelgrass shoots used in the study were attached to a plastic mesh buried in the seabed, and areas with only eelgrass were compared to areas where mussels were distributed among the shoots. The study was conducted at both a wave-sheltered and a wave-exposed site. Each mesh contained 16 eelgrass shoots, and 1 litre of mussels was added to the mussel plots. However, the mussels were washed away during the first growing season, and the authors concluded that this method did not work well on a small scale. The same study also tested the rope method, where shoots are attached to a cotton line using cable ties around the rhizome. The rope was buried in the sediment and secured with metal pins. Both methods showed multi-year survival of the plants, indicating that eelgrass restoration has potential in the area. However, there were large differences in growth between the sites, with eelgrass consistently showing better growth at the wave-sheltered site. These differences are believed to be due to issues with currents, waves, and sand movement at the exposed site (Pajusalu et al. 2023).

Within the EU project MERCES, similar studies were conducted at sites in Denmark, Norway, Finland, and Estonia, where two methods were tested to improve conditions for eelgrass in small-scale restoration (Gagnon et al. 2021). Eelgrass was planted together with blue mussels, similar to the study above. In the second method, planted shoots were surrounded by biodegradable mesh-like structures (BESEs; Biodegradable Establishment Structures), intended to stabilize the seabed by mimicking eelgrass rhizomes. In pre-studies performed in aquaria, growth rates were twice as high for eelgrass planted with mussels, but these differences were not observed in the field experiments. Wave and current exposure proved problematic, limiting the survival of both eelgrass and mussels, especially at the most exposed sites. However, the mesh structures showed potential to both increase eelgrass survival and reduce mussel loss in small-scale restoration (Gagnon et al. 2021).

In the Wadden Sea off the Netherlands, attempts have been made to replant perennial eelgrass beds in the intertidal zone, which had completely disappeared since the 1930s (Rehlmeyer et al. 2024). This study also tested whether sediment stabilization and reduced water movement had a positive effect on planted eelgrass. Stabilization was achieved using biodegradable mesh structures in the sediment (BESE; see above), and sandbags were used to reduce hydrodynamic stress. The study showed that short-term survival increased by 67% when the seabed was stabilized with mesh, while the sandbags led to reduced short-term survival (likely due to turbulence and erosion caused by the bags). No long-term survival was observed in any of the plantings, and the authors concluded that more studies are needed to understand both the causes of shoot loss and how to modify the environment and break negative feedback mechanisms to achieve successful large-scale restoration (Rehlmeyer et al. 2024).

As part of the German restoration project SeaStore, eelgrass restoration was carried out in 2020 at two sites near Kiel, Germany. A total of 12,288 shoots were planted using the single-shoot method according to the Swedish handbook (Corcora et al. 2021). In 2021, additional plantings were carried out at the Maasholm site in Germany, where shoots were planted in a checkerboard pattern with 1 m² planted and unplanted plots across four 16×16 m areas. Two of the areas were planted with 16 shoots per m² and two with 8 shoots per m². A total of 3,072 shoots were planted. The plantings in these areas have survived and grown over several years, with the lower shoot density of 8 shoots per m² showing the highest growth (Lehmann 2022). Two years after planting, the animal communities in the restored meadows were similar to those found in the donor meadow (Schuster 2023).

2.3.2 Restoration with seeds

Restoration trials using seeds are ongoing in many European countries, including Denmark, the Netherlands, and the United Kingdom (Govers et al. 2022, Cronau et al. 2023). In theory, seed-based planting could reduce the cost of restoration, as large quantities of seeds can be distributed without the need for divers. However, similar to trials in Sweden (Moksnes et al. 2016, Infantes et al. 2016), studies from Denmark and the Netherlands have also reported major losses (>99%) of seeds due to factors such as predation, transport, or burial by bioturbating organisms (Lange et al. 2022, Govers et al. 2022, Cronau et al. 2023, Kwakernaak et al. 2023). As a result, techniques have been developed to try to reduce seed losses.

In the Wadden Sea off the Netherlands, no perennial eelgrass meadows remain in the intertidal zone, and most restoration studies focus on re-establishing annual populations through seed planting in the intertidal zone (Govers et al. 2022). Many of the methods tested in the area have shown very high seed losses and poor establishment (Govers et al. 2022). However, new studies on method development have shown that these losses can be drastically reduced by storing seeds over winter and planting them below the sediment surface. The method uses a new technique called DIS (Dispenser Injection Seeding), where seeds mixed with sediment are injected about 4 centimetres below the sediment surface using caulking guns (Govers et al. 2022, Gräfnings et al. 2023). Using this method, researchers and volunteers have managed to plant seeds over an area of 1 hectare in one week (L. Govers, unpublished data). As in studies from other countries, larger plantings have shown greater success than smaller ones. In one area, seed plantings using the DIS method were particularly successful, and the meadow expanded exponentially between 2018 and 2023 to over 1,250 hectares. However, the structure of these meadows differs from those found in the intertidal zones in Sweden. Since the eelgrass here is annual, there is no clonal growth, and new plants emerge from seeds each spring. The restored meadow is therefore very sparse, with an estimated 0.12 shoots per square meter (1.5 million shoots over 1,250 hectares; L. Govers, unpublished), compared to >500 shoots per square meter in established meadows on Sweden's west coast.

Attempts have also been made to distribute seeds using the so-called BuDS (Buoy Deployed Seeding) method in the same area. This method involves placing flowering shoots with seeds in mesh bags suspended above the restoration area, allowing the seeds to fall onto the sediment surface. This method has also been tested in a study on the Swedish west coast (Eriander et al. 2016), where some seedling establishment occurred. However, a challenge with this method is the increased risk of seed transport compared to methods where seeds are buried, as seen in studies from the Netherlands where seed losses exceeded 99.9% (Govers et al. 2022).

In the United Kingdom, seed-based restoration has been tested in several studies with low and variable success (Unsworth et al. 2019, Unsworth et al. 2022, Unsworth et al. 2024). At a site in Wales, studies were conducted to investigate whether seeds placed in jute fabric bags (50 seeds mixed with clean sand) and buried in the sediment could reduce seed predation and improve the chances of seed development and establishment. A total of 162,000 seeds were planted using three methods (seeds in furrows on the seabed, seeds in bags on the surface, and seeds in buried bags), randomly distributed across nine 10×10 meter planting plots. Germination after 10 months was low (1–4%), with an average of 4 shoots per m^2, ranging from 0–10 shoots per m^2. The study showed that results varied for bags placed on the surface, but that buried seed bags increased the likelihood of seed development into adult plants by a factor of 13 compared to seeds planted in furrows. The positive effect is believed to be a combination of reduced seed predation by shore crabs and the physical protection provided by the jute fabric (Unsworth et al. 2024). Further studies have shown that adding nutrients to the bags can increase seed establishment and plant length, despite high nutrient levels in the environment (Unsworth et al. 2022).

2.3.3 Sand capping to enable restoration

Sand capping of the seabed to stabilize sediments and reduce turbidity has been carried out in Odense Fjord, Denmark (Oncken et al. 2022). In 2018, two areas of 1.0 and 1.4 hectares in Odense Fjord were covered with a 10-centimeter-thick layer of sand. These areas historically supported dense eelgrass meadows but now consist of sediments with high organic content, which provide poor anchoring for eelgrass and easily resuspend, reducing water clarity (Oncken et al. 2022). The sand used came from offshore dredging and had a median grain size of 0.34 millimetres, with a silt/clay content of 1.4%. After the sand was applied, light conditions improved by up to 22%. The number of organisms and species richness in the sediment were higher in the sand-capped area compared to outside at all sampling times. The number of deposit and suspension feeders increased to levels similar to those found in the area between 1998–2002. The abundance of filter-feeding animals also increased significantly. A total of 11 species were found in the sand-capped areas compared to 3 and 6 species outside (Oncken et al. 2022). One year after the sand capping, 6,000 eelgrass shoots were planted using the anchoring method with nails (see description above; Lange et al. 2022). However, these survived only for a few months, and the losses are believed to be due to large amounts of filamentous algae on the leaves and drifting algal mats (Steinfurth et al. 2024). The study did however show, that eelgrass died more slowly on the sand-capped area compared to the muddy sediment outside the capped zone.

These results indicate that while light and growth conditions can be improved by sand capping, other factors may still prevent eelgrass from surviving. See section 5.8 for a detailed description of a similar measure in NW Sweden.

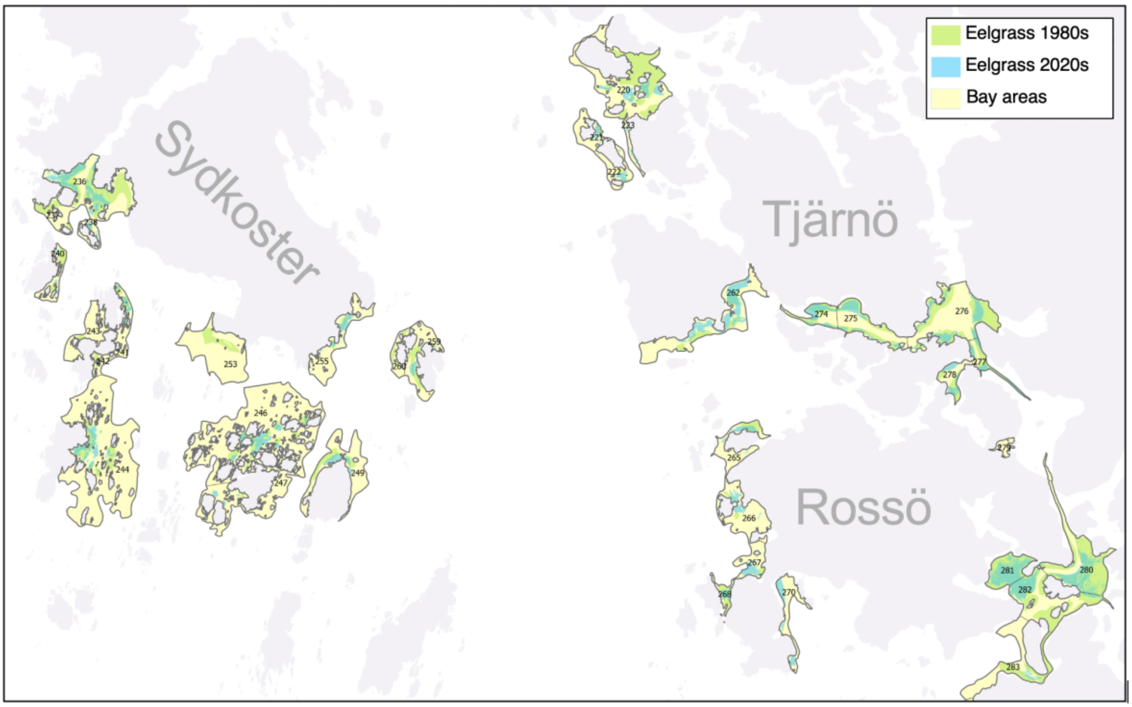
Small-scale sand capping studies from Horten, Norway show that the origin of the sand can affect the ability of eelgrass to grow (Størdal et al. 2023). The study compared commercially available materials in the form of natural sand and crushed stone, as well as natural sediment from the site, in a trial conducted in Horten harbour. The results showed significantly better survival (120%) in natural sediment from the site, compared to both natural sand and crushed stone, which showed similarly low survival (20–25%). However, leaf growth was similar and higher in the natural sediment and natural sand compared to crushed stone. These results differ from similar studies in Sweden, where both better survival and higher growth were found in sand from gravel pits compared to natural muddy sediment from the site (see section 5.8).

2.4 The need for eelgrass restoration in Sweden

In recent years, major changes have taken place in marine environmental policy that affect the need for restoration in Sweden. In 2019, the UN General Assembly declared the years 2021–2030 as the UN Decade on Ecosystem Restoration, with the ambition to scale up the restoration of degraded ecosystems globally. Under the UN Convention on Biological Diversity (CBD), an agreement was reached at the COP15 meeting in Montreal in 2022 to protect 30% of the world's marine areas by 2030, and to restore 30% of all degraded ecosystems. Finally, in 2024, the EU Parliament and Council of Ministers adopted the EU Nature Restoration Law. This regulation requires that degraded nature, including marine environments, be restored in all member states, with binding targets requiring that measures be in place or implemented to restore at least 30% of degraded habitat types by 2030, at least 60% by 2040, and at least 90% by 2050. Since the targets are binding, the regulation will have a significant impact on restoration efforts in Sweden. The implementation of measures is planned individually by each country, and member states have two years to develop a national restoration plan. In this plan, each member state must quantify, for each defined marine habitat type, both the current total area in the country and the area that is not in good condition and needs restoration, based on damage and losses over the past 70 years.

Eelgrass meadows are one of the marine habitat types defined in the regulation, and Sweden must therefore report to the Commission on both current and historical spatial extent, as well as develop a plan for how lost meadows will be restored. Currently, there is no national mapping of eelgrass or other marine habitats in Sweden, which represents a major challenge in meeting the regulation's requirements. However, there is rapid development of methods, including the use of remote sensing to map and monitor vegetation along the coast (Berglund et al. 2022), although accuracy still needs improvement. A recurring problem is the lack of historical data to estimate losses for most habitat types and regions.

An exception is eelgrass, mapped in the 1970s and 1980s in several municipalities in Västra Götaland County and in Kungsbacka Fjord in northern Halland County. A total of approximately 9,400 hectares of seabed were mapped within 152 sampling areas (bays), providing a unique reference dataset on the historical distribution of eelgrass in these counties. The same sampling areas were recently mapped using aerial drones and drop-video during the period 2015–2022, enabling an estimate of losses and restoration needs (Moksnes et al. 2024, Moksnes and Bergström 2025). Within the analysed sampling areas, the spatial extent of eelgrass decreased by a total of 1,377 hectares, from 3,033 hectares in the 1980s to 1,656 hectares in the 2020s—a reduction of 45% (Moksnes and Bergström 2025; Figure 2.2). This loss of approximately 14 km² of eelgrass (1 square kilometre = 100 hectares) represents confirmed losses in these counties and is a minimum estimate, as the mapping is not complete. The total loss can be roughly estimated by extrapolating these values. Analyses of satellite images show that the total area of soft bottom at 0–6 meters depth in Västra Götaland County is approximately 385 km² (Envall 2012). The above-mentioned analysis included about 83.6 km² of soft bottom at 0–6 meters in the same county, corresponding to 21.7%. Assuming that the distribution and loss in the surveyed areas represent the entire county's soft-bottom areas, the total loss of eelgrass can be estimated to approximately 50.4 km² in Västra Götaland County. Together with the reduction in Kungsbacka Fjord, the total estimated loss is 53.5 km² of eelgrass in the study area.



Figur 2.2 The map shows an example of eelgrass loss within 30 bay areas in northern Buhuslän since the 1980s (from Moksnes and Bergström 2025).

According to the Nature Restoration Law, restoration measures must be implemented, that can restore at least 30% of lost habitat types by 2030. For eelgrass meadows in Västra Götaland County and Kungsbacka Fjord, this means that restoration actions must be taken by 2030 that can restore at least 422 hectares of eelgrass (based on confirmed losses) or at least 1,605 hectares of eelgrass (based on estimated losses). Over the past 8 years, just over 1.5 hectares of eelgrass have been successfully restored in Västra Götaland County (<0.1% of the estimated need), and planned projects before 2030 amount to less than 6 hectares (Moksnes, unpublished data). Current methods for eelgrass restoration are relatively costly and slow, and only suitable for small areas (a few hectares per year; Moksnes et al. 2016). It is therefore not realistic to restore the thousands of hectares required by the regulation through active restoration alone (Table 2.3).

Tabell 2.3 Need for eelgrass restoration along the Swedish NW coast: Confirmed and estimated losses of eelgrass (hectares) in Västra Götaland county and Kungsbacka Fjord since the 1980s, and the restoration needs (hectares) according to the targets in the EU Nature Restoration Law from 2030 to 2050."

	Loss	30% 2030	50% 2040	90% 2050
Confirmed	1 407	422	704	1 266
Estimated	5 350	1 605	2 675	4 815

For eelgrass distribution in other parts of Sweden, historical data on spatial extent is lacking, making it difficult to estimate potential losses and the need for restoration. In many areas, eelgrass is still found where it would be expected to grow, indicating that the kind of large-scale losses documented in Västra Götaland county and Kungsbacka Fjord have likely not occurred elsewhere in the country. One possible way to estimate smaller-scale losses in these areas is to map physical exploitation in shallow, wave-sheltered soft-bottom areas where eelgrass likely grew historically. This could provide a rough estimate of historical loss and restoration needs. Currently, mapping of eelgrass and other vegetation is underway in most of Sweden’s coastal counties using remote sensing and field sampling (Berglund et al. 2022). A more complete baseline of the national distribution of eelgrass is therefore being developed, which can be used to quantify future losses and restoration needs.

In summary, restoration alone cannot recover the large historical losses documented along the Swedish NW coast. To achieve lasting recovery of lost eelgrass meadows, management must also focus on halting the ongoing loss of eelgrass, particularly from increasing coastal exploitation and physical impacts that reduce the available habitat for eelgrass. Measures are also needed to improve growth conditions for eelgrass, such as reducing nutrient inputs and implementing actions that increase populations of large predatory fish in coastal ecosystems (Moksnes et al. 2017). Once these steps have been taken, active restoration of eelgrass at strategically selected sites that maximize growth and spread can be an effective measure to accelerate eelgrass recovery and meet the requirements of the Nature Restoration Law, various EU directives, international conventions, and more.

Large-scale eelgrass restoration in Sweden requires significant diving resources, as the eelgrass is planted at 2-3 meters depth by hand, which is time-consuming. Typically, consulting firms need to be hired to carry out the work, with 4–6 divers working simultaneously. Currently, there are only a few consulting firms that have conducted eelgrass planting in Sweden, and to ensure that future restoration efforts are not limited by the availability of consultants, it may be important to raise interest in eelgrass restoration among more companies with diving expertise. One way to do this could be to organize training days where participants also get hands-on experience in harvesting and planting eelgrass.

3 Legislation

When the first eelgrass restoration handbook was written, only small-scale restoration efforts had been carried out in Sweden. Today, however, there is experience from several larger eelgrass planting projects, and the following subsections have therefore been clarified and slightly revised.

The main change is a stronger recommendation for project developers to contact the County Administrative Board or the municipality to determine which permits are required. It is also important to start the process early, as the processing time at the authorities can be long. Preparations should include producing maps showing the location of the donor meadow and the restoration site, and checking whether these areas fall within protected zones, such as shoreline protection areas, nature reserves, or Natura 2000 sites.

For larger planting projects, permission from the water rights holder is also required, and in some cases, an exemption from shoreline protection regulations is required, even if the change is considered positive. The current assumption is that an exemption is likely needed, since all actions that affect natural habitats and plant life must be assessed, and because extensive marking with buoys of the restoration area is often required. The previous version of the handbook stated that eelgrass restoration does not significantly affect Natura 2000 areas and that no permit is needed under the N2000 regulations. It also stated that restoration does not require an exemption in areas protected under habitat protection rules. In the new guidance, this is expressed more cautiously, and project developers are advised to contact the County Administrative Board if the restoration is planned within a protected area.

3.1 Shoreline protection

Both harvesting and planting of eelgrass may require an exemption from shoreline protection regulations if the activity is to be carried out within a protected shoreline area, as the action may significantly alters the living conditions for animal and plant life. Even changes considered beneficial for a species must be assessed under the shoreline protection legislation. Exemptions are applied for through the municipality. If, in addition to shoreline protection, the site is also subject to nature protection (such as nature reserves, national parks, Natura 2000 areas, or habitat protection areas), the exemption must be applied for through the County Administrative Board.

Outside of shoreline protected areas, a notification for consultation under Chapter 12, Section 6 of the Environmental Code (12:6 consultation) may be required if the measure risks significantly altering the natural environment. This assessment is made by the County Administrative Board. It is important to start the process well in advance, as processing times at both the municipality and the County Administrative Board can be long. Applications should be submitted using the forms provided on the authority’s website. Be detailed in the application and include clear maps. A complete application will speed up the processing time.

The *Handbook for Eelgrass Restoration in Sweden* and its appendices describe methods for restoration, how to select donor meadows, and how many vegetative or flowering shoots that can be harvested without damaging the donor meadow. However, this applies to strong and healthy donor meadows. In the shoreline protection assessment, an evaluation of the donor meadow is made to ensure it can withstand harvesting of shoots. Stressed meadows, or meadows near areas where eelgrass has declined, may not be suitable as donor sites. Some meadows may be of particular conservation value, for example genetically, and are therefore unsuitable as donor material (see section 4.1).

3.2 Nature Reserves, National Parks, Nature Conservation or Habitat Protection Areas

If you plan to carry out the activity within a protected area, both harvesting and planting may be controlled by the regulations specific to that area. These regulations are listed in the official decision for the protected area, which can be found on the County Administrative Board’s website. If you wish to apply for a permit or exemption from these regulations, you must do so using the specific forms provided by the County Administrative Board. If you are unsure whether harvesting and planting are covered in the regulations, you can contact a case officer at the County Administrative Board. Even if harvesting and planting are not explicitly mentioned in the regulations for the area, the purpose of the protected area must not be undermined by the activity you intend to carry out.

3.3 Nature 2000 areas

If the planned activity—whether harvesting or planting—is located within or near a Natura 2000 area, it may affect designated habitat types, known as Natura 2000 habitats. These are listed in the conservation plan for the Natura 2000 site. If there is a risk that these habitats may be damaged or negatively affected by the activity, the issue must be assessed by the County Administrative Board. The first step is a consultation, during which the County Administrative Board determines whether a Natura 2000 assessment is required. The outcome of the consultation will either be that the activity does not pose a risk to the Natura 2000 area and may proceed as planned, or that a Natura 2000 assessment is necessary. Activities that have no impact at all or that result in a positive effect do not require assessment under Natura 2000 regulations. A Natura 2000 assessment may be required if the activity damages or risks damaging eelgrass or any other habitat within the Natura 2000 area. If an assessment is needed, the County Administrative Board will evaluate whether the activity is permissible. A Natura 2000 assessment often takes a long time, as it requires the preparation of an environmental impact assessment and a nature value inventory. Such inventories usually need to be conducted during a specific time of year. More information is available on the County Administrative Board’s website.

3.4 Water operations

Harvesting and planting of eelgrass is generally not considered a water operation ("vattenverksamhet"), but you must always contact the County Administrative Board so they can assess whether a notification of water operation is required. If you plan to carry out a water operation, such as sand capping before eelgrass planting, you will likely need to submit a notification to the County Administrative Board or apply for a permit from the Land and Environment Court. Read more about water operations on the County Administrative Board's website. A permit from the Land and Environment Court is required if the water operation is extensive, if the measures may affect valuable natural environments, or if an individual is affected and does not give consent. Permit applications in court can take a long time to process, so submit your application at least one year before you plan to carry out the water operation.

3.5 Right of disposal

Right of disposition ("rådighet") means that you have received permission from the water rights holder to carry out a specific measure. If you are planning a minor action, such as a test planting of eelgrass that is easy to remove, it may be sufficient to simply inform the water rights holder. However, it is important to note that it is the responsibility of the practitioner to assess whether right of disposal needs to be obtained for minor actions.

For larger eelgrass planting projects, written permission must be obtained—this is known as a *consent of disposition* ("rådighetsmedgivande"). To determine who owns the water area, you may need to request a property investigation from Lantmäteriet (the Swedish mapping, cadastral and land registration authority). This can be both costly and time-consuming, as water rights are rarely clearly defined in marine areas. It is far from certain that boundaries in the water can be extrapolated from those on land, and it can be difficult to determine who the water rights holders are. A property investigation will tell you whether the planned measure is located on private or public water. This may also influence where you choose to carry out the measure. Contacting many water rights holders in a joint property association can be time-consuming, so make sure to start early.

If the measure is to be carried out on private water, permission must be obtained from the water rights holder. If the planting is to be carried out on public water, permission must be obtained from the Legal, Financial and Administrative Services Agency ("Kammarkollegiet"). Inform all water rights holders whose area will be affected by the activity and request written consent. Provide information about where the measure will take place and what it entails. The information should include the expected time period during which they may experience noise or boat traffic on their water, as well as whether buoys or other markers will be placed at the site. Naturally, the information should also highlight all the benefits of the restoration.

4 New knowledge – development of methods for eelgrass restoration

Between 2016 and 2024, researchers in the Zorro research program at the University of Gothenburg, in collaboration with the County Administrative Board of Västra Götaland, have carried out several eelgrass restoration trials along the Swedish NW coast (Bohuslän). These efforts have aimed to increase our understanding of the restoration process and to identify new methods in areas where restoration is challenging due to various environmental factors.
Below is a description of the new knowledge that has emerged from these studies.

4.1 Connectivity and genetic diversity in restoration

Summary of recommendations

- Eelgrass meadows that are part of the same dispersal network should be managed as a unit, as they are genetically similar and isolated from other areas.
- Within each network, both valuable meadows with high genetic diversity and high connectivity, as well as vulnerable isolated meadows with low genetic diversity, should be protected.
- Within the network, restoration sites should be selected to optimize the natural dispersal of eelgrass via floating flowering shoots from the restored meadow to other areas in need of restoration.
- Donor meadows should come from the same network as the restored meadow (as they are better adapted to the prevailing environment) and have high genetic diversity (as they are better able to adapt to future changes and lead to ecosystems with better function).
- Choose larger meadows as donor meadows (if measures of genetic diversity are not available), as larger meadows generally have higher genetic diversity and are less inbred than smaller meadows.
- Since meadows near physical disturbances (such as docks, dredging channels, small boat marinas) do not show lower genetic diversity than more undisturbed meadows, they may function well as donor meadows.
- Eelgrass restoration in the Baltic Sea can be challenging due to low dispersal, low genetic diversity, and a lack of seed production. This could, in the long term, lead to lower growth and expansion, as well as a higher risk of failure.
- Due to the low genetic diversity in the Baltic Sea, it is especially important to carefully select donor meadows, for example by conducting test plantings from several potential donor meadows.
- In the Baltic Sea, it is also especially important to spread the effort across time and space to reduce the risk that unexpected environmental conditions wipe out the entire planting.
- In areas where climate change is expected to eliminate existing populations, transplantation of eelgrass plants that are resilient to future climate scenarios may be necessary to save threatened meadows.

Understanding how benthic plants and animals disperse between different areas in the sea, for example via floating seeds and pelagic larvae, is central to understanding the population dynamics of these organisms—that is, why the number of individuals in a population increases or decreases. This connectivity (the degree of interconnection) is therefore crucial for the sustainable management of commercial stocks and biodiversity, for example through networks of marine protected areas (Moksnes et al. 2014, Jonsson et al. 2020), but also for selecting suitable sites for restoration (Moksnes et al. 2016). However, it is notoriously difficult to study how millimetre-sized seeds and larvae are dispersed by ocean currents over weeks to months in the sea, which is why knowledge about the connectivity of marine organisms is generally very limited (Moksnes and Jonsson 2020).

In recent decades, however, there has been rapid development in the study of dispersal and connectivity using oceanographic circulation models and genetic tools (Jahnke and Jonsson 2022), particularly concerning eelgrass in Swedish waters (Jahnke et al. 2018, 2020, Ries et al. 2023, Faus et al. 2025). Since the eelgrass restoration handbook was published in 2016, new knowledge has emerged about how eelgrass spreads along the Swedish coasts, as well as how genetic diversity varies—knowledge that can be directly applied in the management of eelgrass populations and in the selection of restoration sites and donor meadows. Below, we discuss these new findings and how they can best be used, but we begin by discussing new insights into how eelgrass disperses.

4.1.1 How does eelgrass disperse and how is genetic diversity affected?

In areas where eelgrass reproduces sexually, it can spread both through vegetative (clonal) growth, which occurs over very short distances (16–45 centimeters per year; Olesen & Sand-Jensen 1994), and through seed dispersal. The seeds have negative buoyancy, and most seeds released from flowering shoots spread only a few meters from the meadow (Orth et al. 1994). However, storms can likely transport large quantities of seeds over longer distances, which is considered to explain the very rapid development of restored eelgrass meadows (Orth et al. 2012) as well as the natural recolonization of large eelgrass beds (Greve et al. 2005). A smaller number of seeds are regularly dispersed over long distances via floating flowering shoots with seeds. Studies in Bohuslän show that eelgrass inflorescences easily detach when the seeds are mature and that they have positive buoyancy for four to eight weeks, during which they can be dispersed over long distances by surface currents while the seeds detach and sink to the bottom (Källström et al. 2008, Infantes and Moksnes 2018). Although seed production of eelgrass in Bohuslän (on average 140–600 seeds per m²) is nearly ten times lower than that of eelgrass in other parts of the world (Infantes and Moksnes 2018), new genetic studies show that most eelgrass meadows in the Skagerrak and Kattegat have high sexual reproduction (Jahnke et al. 2018, Ries et al. 2023, Faust et al. 2025), suggesting that dispersal via flowering shoots may be an important mechanism in this region. This is supported by studies comparing results from oceanographic circulation models simulating surface-drifting flowering shoots with analyses of the population genetics of eelgrass meadows in the area. The analyses showed very similar results in terms of connectivity and dispersal barriers both on a larger scale between regions and on a smaller scale within fjord areas, supporting that drifting flowering shoots are the dominant dispersal factor for eelgrass (Jahnke et al. 2018, 2020).

The high sexual reproduction and effective dispersal of flowering shoots in the Skagerrak and Kattegat result in relatively high genetic diversity in eelgrass along the Swedish west coast, comparable to eelgrass in other parts of the Atlantic (Jahnke et al. 2018, Ries et al. 2023, Yu et al. 2023). These results suggest that the extensive losses of eelgrass in Swedish Skagerrak and northern Kattegat (Baden et al. 2003, Moksnes et al. 2024, Moksnes & Bergström 2025) have not led to a loss of genetic diversity (Jahnke et al. 2020). However, new studies have shown that populations in the Atlantic have several times higher genetic diversity than eelgrass in the Pacific, which may limit the ability of eelgrass to adapt to future environmental changes in the Atlantic (Duffy et al. 2022, Yu et al. 2023). It is therefore important to preserve the genetic diversity of eelgrass in Sweden.

In the Swedish parts of the Baltic Sea, new genetic studies show that sexual reproduction in eelgrass is generally very low and that several eelgrass meadows consist of clones that grow only vegetatively (Ries et al. 2023). The lack of seed production likely imposes a major limitation on the dispersal potential of eelgrass and the ability of lost meadows to naturally recolonize, as well as for restored meadows to spread to new areas. This makes the meadows in the Baltic Sea more vulnerable, and large-scale restoration more challenging. However, new studies indicate that eelgrass can also spread and establish via floating vegetative shoots (without seeds) that can sink to the bottom, for example with the help of epiphytic organisms (Jahnke, unpublished data). Dispersal of vegetative shoots that have been detached from the bottom, for example during storms, may therefore potentially be an important dispersal mechanism, especially in areas lacking sexual reproduction. More studies are needed to confirm this.

In recent years, the genetic diversity of eelgrass along Sweden’s coasts has been monitored through a new national environmental monitoring program and through regional initiatives. Today, a baseline for the genetic diversity of eelgrass has therefore been established, making it possible to detect future changes (Ries et al. 2023, Faust et al. 2025). These data can also be of great use in eelgrass restoration.

4.1.2 Examples of application in restoration

Information about connectivity and genetic diversity has several important applications in restoration, both in large-scale management at the landscape level, and in the selection of sites for harvesting and planting eelgrass. Below, we present some real-world examples from the Swedish coastline.

The Skagerrak and Kattegat

In Skagerrak and Kattegat, high-resolution oceanographic circulation models and genetic studies show consistent results indicating that eelgrass dispersal is limited by the coastal topography, which creates dispersal barriers and networks of interconnected meadows within certain fjord areas. For example, connectivity is high between the meadows within Gullmarsfjorden, Brofjorden, and Åbyfjorden, but low between the three fjords, creating three separate networks of eelgrass meadows (Jahnke et al. 2020; Figure 4.1). The meadows within these networks should be managed as separate units because they are more genetically similar and relatively isolated from other areas. For instance, larger meadows within each management unit (eelgrass network) should be protected, and restoration should be carried out in units that have lost large eelgrass populations. In restoration efforts, donor meadows should primarily be selected from within the same network, as eelgrass within the network is potentially better genetically adapted to the local environment, and to reduce the risk of introducing foreign genetic types that could compromise this adaptation. In the mentioned fjord areas, however, the need for eelgrass restoration is not great, as historical losses have been limited and large meadows are found in most bay areas (Moksnes et al. 2024). It should be noted, however, that the eelgrass network in Brofjorden currently lacks any area protection, which is not recommended for a management unit (Figure 4.1).

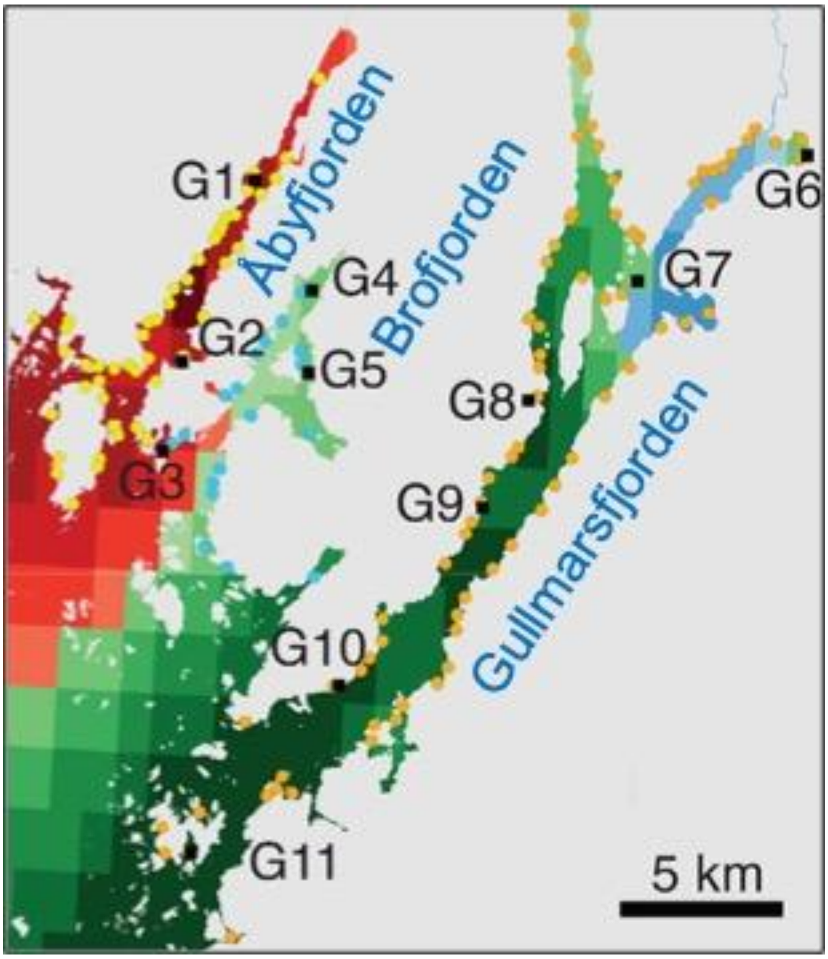


Figure 4.1 Connectivity of eelgrass around the Gullmarsfjord area. The figure shows modelled oceanographic connectivity of drifting flowering shoots (colored dots) and connectivity based on genetic analyses of eelgrass (colored water surfaces) within three fjord areas in Bohuslän. Dots and colored areas with the same color indicate high connectivity; color changes indicate dispersal barriers. The dots mark known eelgrass meadows. Black boxes with codes indicate where genetic samples were taken (from Jahnke et al. 2020).

Another example of different networks of eelgrass meadows is found in the fjord areas inside Tjörn and at the Nordre River estuary (Figure 4.2). Here, over 1,000 hectares of eelgrass have disappeared since the 1980s, corresponding to more than 90% loss in certain areas (Moksnes et al. 2018, 2024). Similar studies here show that eelgrass dispersal is relatively high between the meadows in the fjord area inside Tjörn (in Hakefjorden and Älgöfjord), but not southward inside

Marstrand, where a strong dispersal barrier is found, creating a separate network in the Sälöfjord area (Jahnke et al. 2020; Figure 4.2a). The eelgrass meadows in the Sälöfjord area were historically among the largest in Västra Götaland County, but today more than 98% have disappeared, leaving only very small meadows in the area (Moksnes et al. 2024). Since dispersal studies show that the meadows in the Sälöfjord area have very low connectivity with surrounding areas (Jahnke et al. 2018, 2020), this creates a difficult management situation, as natural recovery through dispersal from surrounding meadows cannot be expected. Restoration may therefore be necessary to recover lost populations in this area. Fortunately, studies show that genetic diversity is still relatively high in the surviving meadows (Jahnke et al. 2020), meaning that the meadows could recover without loss of genetic diversity. Using oceanographic circulation models of the dispersal of floating flowering shoots between the historical meadows, areas in the Sälöfjord network with the highest connectivity to the lost meadows in Ryskärsfjorden and Myggstaviken can be identified (Jahnke et al. 2020; Figure 4.2b). These sites should be prioritized for restoration, as they can facilitate the dispersal of flowering shoots and the natural re-establishment of eelgrass in other areas within the network.

Within the eelgrass network in Hakefjord–Älgöfjord, losses have mainly occurred on the mainland side, while relatively healthy meadows are still found on the western side of the fjord. Here, the dispersal models have identified both the most important bay areas with lost eelgrass meadows to restore (south of Nordön and Lökebergskile) and the most important existing meadows to optimize natural dispersal of eelgrass via floating flowering shoots from the restored meadow to other areas in need of restoration, which are mainly found on the Tjörn side of Hakefjorden (Jahnke et al. 2020; Figure 4.2b). It should be noted that the natural meadows on the western side of Hakefjorden currently lack area protection, which is unfortunate as they constitute the most important seed sources in the network for natural recovery.

New genetic studies of eelgrass comparing genetic diversity between different types of eelgrass meadows in Västra Götaland County show results with important implications for restoration (Faust et al. 2025). The studies showed that smaller meadows generally had lower genetic diversity and were more inbred than larger meadows, making them less suitable as donor meadows. If data on genetic diversity are lacking in a restoration area, it may therefore be better to harvest eelgrass from larger meadows. The results also suggest that it is especially important to protect and restore larger meadows to preserve genetic diversity. However, the study found no difference in genetic diversity between meadows located near small boat harbours and dredged areas and nearby more undisturbed meadows. The results therefore indicate that meadows exposed to physical disturbance may function well as donor meadows in terms of genetic diversity (Faust et al. 2025).

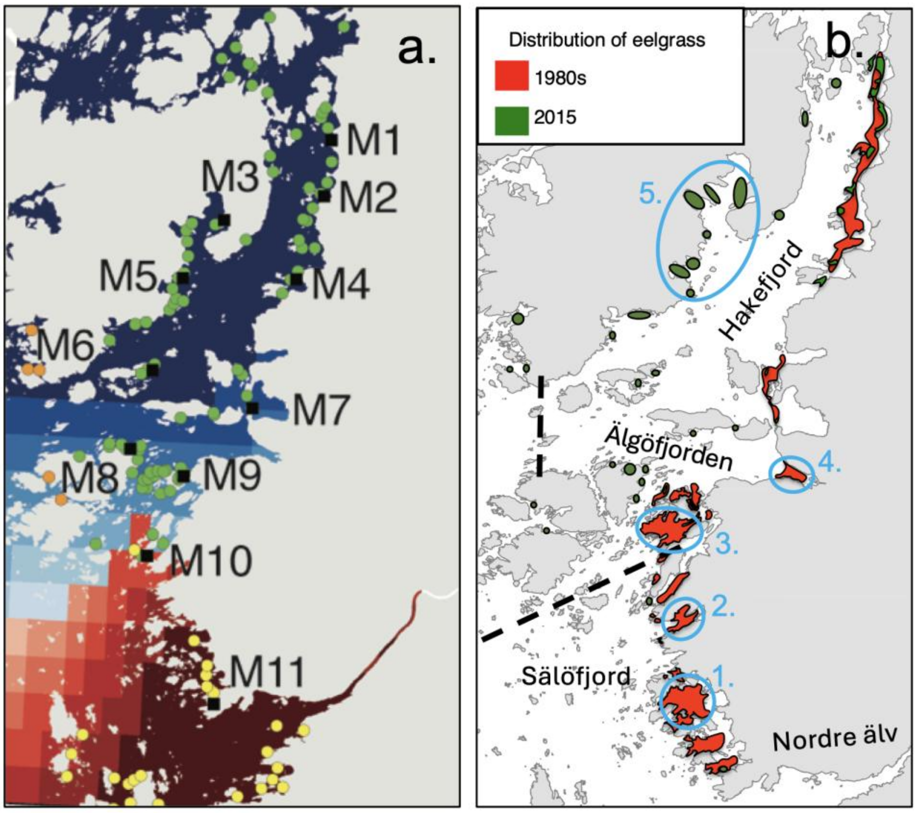


Figure 4.2 Connectivity of eelgrass around the Hakefjord–Sälöfjord area.(a) The figure shows modelled oceanographic connectivity of drifting flowering shoots between historical eelgrass meadows (colored dots) and connectivity based on genetic analyses of existing eelgrass (colored water surfaces) within three fjord areas in Bohuslän. Dots and colored areas with the same color indicate high connectivity; color changes indicate dispersal barriers. The dots mark known eelgrass meadows. Black boxes with codes indicate where genetic samples were taken (from Jahnke et al. 2020). (b) The figure shows existing (green) and lost eelgrass meadows (red areas) in the same fjord areas, where dashed lines indicate dispersal barriers based on the results mentioned above. Blue-colored circles mark the lost eelgrass meadows with the highest connectivity within the Sälöfjord network (1 = Ryskärsfjorden, 2 = Myggstaviken) and the Hakefjord–Älgöfjord network (3 = Nordön, 4 = Lökebergskile), which should be prioritized for restoration. Circle 5 marks the existing meadows with the highest connectivity in the Hakefjord–Älgöfjord network, which are most important to protect for the preservation of the network and to facilitate natural recovery of lost meadows within the network.

The Baltic Sea

In the Baltic Sea, the lack of seeds, low connectivity, and low genetic diversity present several challenges for restoration. The lack of seed production means that restored meadows do not have seeds in the sediment as a backup if the shoots die due to poor environmental conditions, which increases the risk of restoration failure. They also lack the seeds' ability to spread rapidly beyond the planting area, as described in some projects (Orth et al. 2012). Furthermore, the absence of drifting flowering shoots means that connectivity is severely limited, making natural recolonization of lost meadows less likely and giving restored meadows much less potential to spread to other areas in need of restoration (even though drifting vegetative shoots could contribute; see earlier discussion above). Finally, the low genetic diversity, where clones can dominate entire meadows, means that the Baltic Sea's meadows have reduced capacity to withstand disturbances and adapt to future environmental conditions, such as increased water temperature and decreased salinity (Ries et al. 2023). It is therefore especially important to select good donor meadows in the Baltic Sea that come from similar environmental conditions as the restoration site and with as high genetic diversity as possible. It may therefore be important to conduct test plantings from several potential donor meadows.

Taken together, this means that the meadows in the Baltic Sea may be more vulnerable, and that large-scale restoration may be more challenging, with lower growth and spread of planted meadows to be expected. These challenges need to be considered in restoration efforts in the Baltic Sea, for example by planting shoots at higher density and spreading the effort across time and space to reduce the risk that, for example, unexpected environmental conditions wipe out the entire planting. However, the restoration trials conducted so far in the Baltic Sea show that vegetative growth of shoots can be high in several locations (see section 2.1). This high growth may possibly be due to the genetically similar shoots in the area being very well adapted to current environmental conditions. Furthermore, the absence of reproductive shoots may mean that more energy is available for vegetative growth in the Baltic Sea, which partly compensates for the lack of seeds. However, the high vegetative growth does not change the fact that these meadows lack a seed reserve that could enable recovery after temporarily poor environmental conditions, such as a heatwave.

In addition to the challenges mentioned above, eelgrass restoration in the Baltic Sea is further complicated by expected climate change, where both increasing water temperatures and decreasing salinity threaten to eliminate existing eelgrass populations in the northern parts of the Baltic Proper (Ries et al. 2023). Restoration in these areas therefore needs to consider future environmental conditions when selecting donor plants and may need to choose genetic individuals (genotypes) that are adapted to conditions different from those currently present at the site. Within the Zorro research program, ongoing research is being conducted to identify eelgrass genotypes that are resistant to future climate scenarios and whether transplantation of these plants can help save threatened meadows in the Baltic Sea.

4.2 Monitoring and analysis of light conditions

Summary of recommendations

- Light meters are placed at two different depths: 20 and 120 centimeters from the bottom
- Lux meters are calibrated against a PAR meter
- Lux meters in the field are cleaned every other week
- Poor or incorrect data is excluded before analysis
- Kd, Dmax, and daily Mol PAR reaching the bottom are calculated
- The results are compared with the handbook's recommendations regarding light requirements

One of the most important components for a successful eelgrass restoration is ensuring that the restoration site has environmental conditions that allow eelgrass to survive at the location. This type of investigation should begin at least one year before a large-scale restoration and should include, among other things, test planting of eelgrass and monitoring of light conditions (Moksnes et al. 2016). The 2016 handbook discusses several physical and biological factors that can affect the suitability of the environment and how these can be monitored. Often, light conditions are the limiting factor for eelgrass and determine whether a site is suitable and at what maximum depth planting can occur. Therefore, light conditions should be examined during the selection process by logging light during the summer months.

Eelgrass light requirements vary in the literature, but on average, the plants are said to need 20% of surface light to survive (Dennison et al. 1993, Duarte et al. 2007). Research on eelgrass restoration in Sweden has shown similar light requirements (25%; Moksnes et al. 2018), and studies under laboratory conditions show that vegetative growth decreases when light levels fall below 5 mol PAR (photosynthetically active radiation) per m^2 per day, although the plants can survive at light levels as low as 3 mol PAR per day (Eriander 2017). Therefore, when selecting sites for restoration, measuring light conditions is an important part of evaluating environmental conditions and understanding why a test planting may have failed. It is recommended to calculate the light attenuation coefficient (Kd) and the total amount of light reaching the bottom per day (mol PAR per m^2 per day) in the water (Moksnes et al. 2016).

However, there has been a lack of a standardized description of how collected light data should be analysed and interpreted, which is important to ensure that results are comparable between different restoration projects and studies of eelgrass light requirements. Below is a brief description of all steps in a standardized method for light analysis, and appendix A provides a more detailed description along with examples of real data analysis. It is important to note, however, that factors other than light can also limit eelgrass survival at a given site (see sections 4.4 and 4.5 below, as well as section 2 in Moksnes et al. 2016), which is why large-scale plantings should always be preceded by smaller test plantings.

4.2.1 Collection of light data

The light meters used during the development of the method are Lux meters of the brand Onset HOBO, but the methods described for sorting data and calculating light variables are also applicable to other types of light meters that can store data. Onset HOBO is available in two models: the older UA-002-64, which can only be programmed to take instantaneous Lux values, and the newer model MX2022, which can log light values every 30 seconds, after which an average value is calculated for a selected time interval. The latter model is recommended, as these meters provide more stable data with fewer outliers.

Light can be measured continuously during the eelgrass growing season (May–September) if the meters are cleaned at intervals of 1–2 weeks depending on the degree of fouling. Alternatively, light can be measured during a 2-week period at the beginning of the growing season, for example in June/July, and again in September. At sites where, for example, runoff from land or resuspension of sediment from the bottom may negatively affect light levels, longer or more frequent measurement periods may be recommended to identify any periods of poor light that could negatively impact the eelgrass.

Light meters must be placed at two different depths at the same location at the potential restoration site in order to calculate the light attenuation coefficient (kd) in the water. The attenuation coefficient can then be used to calculate the theoretically maximum depth distribution for eelgrass at the site (Dmax). The two meters should be placed ca one meter apart, with the deeper meter 20 centimetres from the bottom, and the shallower 120 centimetres from the bottom so that the depth difference between the meters is 1 meter. It is important that the depth difference between the meters is measured precisely, as small differences have a significant impact when calculating the attenuation coefficient. The shallower meter s also used to calculate of the total amount of light (mol PAR per m^2 per day) reaching the planted eelgrass each day.

The meters are programmed to register light every 30 second, and to estimate an average value every 15 minutes to achieve high data resolution throughout the day while minimizing the risk of the meter's memory becoming full (this applies to loggers of the Onset HOBO brand). To maximize the amount of usable data, the meters should be cleaned at least every other week. Experience from several years of light measurements shows that fouling is generally not a problem during the first two weeks.

4.2.2 Conversion of light from lux to PAR

The Onset HOBO light meters record light in the unit lux, and to convert this value to photosynthetically active radiation (PAR), they are calibrated against a PAR meter by performing linear regressions between PAR and lux for each light meter individually (see Appendix A for details). This calibration is also important to compensate for differences between various lux meters and to calibrate them to each other. The MX2022 meters generally show less variation between units than the older UA-002-64 meters, but if possible, all types of light meters should always be calibrated.

If calibration of the light meters is not possible for any reason, the average formula established for the old and new light meters, respectively, can be used.

Mean formula for UA-002-64 (old meters): $PAR = lux * 0{,}0090 \quad R^2 = 0{,}998$ *Formula 1.*

Mean formula for MX2022 (new meters): $PAR = lux * 0{,}0164 \quad R^2 = 0{,}999$ *Formula 2.*

4.2.3 Exclusion of incorrect data

After calibration and conversion of the light data to PAR, the data is examined to exclude incorrect values caused, for example, by fouling on the sensors or by animals or drifting algae shading the meters. By studying the light at both the deep and shallow meters, as well as the ratio between them, it is possible to assess whether the data indicates fouling or is merely a result of changes in light input or water turbidity. To evaluate this, the average daily light at the surface and bottom is plotted together with the ratio between the average light values (deep/shallow; see Appendix A for details). In general, turbidity is expected to cause more synchronized, transient effects on the ratio compared to fouling.

Before the analysis begins, any incorrectly recorded, unreasonably high PAR values are also excluded. This is important because the sum of all values over a day is used in the calculation of Kd (see below), meaning that erroneously high values can have a significant impact. These are identified by plotting all recorded values against time, or alternatively by sorting the data by light value (see Appendix A for details).

4.2.4 Calculation of Kd, Dmax and daily amount of light at the bottom

To calculate the light attenuation coefficient (Kd), all calculated PAR values per day from the light meters at the surface and bottom are first summed (see example in Appendix A). This is done to stabilize the data and avoid individual high or low ratios between the meters having too much influence. Kd is then calculated per day using these summed values according to the formula:

$$Kd = -\ln(PAR_{deep\ meter\ dayX} / PAR_{shallow\ meter\ dayX}) / \text{Depth difference between meters} \qquad \text{Formel 3.}$$

Based on the Kd values, the theoretically maximum depth distribution at the site (Dmax; assuming that eelgrass requires 20% of the surface light) can be calculated for each day or for a selected period using the formula:

$$Dmax = \ln(0.2)/-kd \qquad \text{Formel 4.}$$

When calculating the daily amount of light (mol PAR per square meter) that reaches the depth where eelgrass grows, or where restoration is planned, the measurements recorded by the meter closest to the bottom are analysed. Calculations of the total amount of light reaching the bottom provide an ecologically relevant measure of actual light conditions, and since this value is not affected by the light measured by the surface meter, it also provides an independent measure of light (see Appendix A for details).

4.3 Planting in a checkerboard pattern to increase cost-effectiveness

Summary of recommendations

- Plant the shoots in 1x1 meter squares with 16 shoots per m² in a checkerboard pattern across the entire planting area.
- Use a planting frame to facilitate the work and navigation underwater.
- Unplanted areas will naturally fill in within 3–5 years under normal conditions.
- Planting in squares does not take more time than continuous planting, which means the method reduces project costs by approximately 50%.

In the restoration of eelgrass in Sweden, the single-shoot method is still recommended. This method involves manually collecting individual vegetative shoots from a donor meadow and planting them one by one at a shoot density of 4–16 shoots per m² (Moksnes et al. 2016). This method requires diving and is time-consuming and costly, which is why studies aimed at developing, improving, and streamlining eelgrass planting using the single-shoot method are important.

To develop new methods that can reduce the number of shoots needed and the cost of restoration, a large-scale restoration study was conducted in Kalvhagefjorden at southern Gåsö in Bohuslän between 2019 and 2024, where shoots were planted in various checkerboard patterns across the planting area. By planting eelgrass only in every other square, the need for shoots is reduced by half, with the idea that the open spaces between the squares will fill in over time. The study began in June 2019, when four different planting patterns were compared in 20x20 meter planting plots, covering a total of 1600 m². In three of the treatments, eelgrass was planted in a checkerboard pattern with equal-sized planted and unplanted areas, but with different square sizes in the three plots (1x1, 2x2, and 4x4 meters). In the fourth treatment, eelgrass was planted across the entire area (no squares) as a control. The same shoot density was used within the planted squares (16 shoots per m²; see Figure 4.3). The aim of the study was to investigate whether and how the size of the squares affects planting time, growth and survival of eelgrass shoots, the time it takes for the open areas to fill in, and the animal community found in the planting. The purpose of the study was to identify the most efficient planting method that provides the highest survival and growth with the least amount of labour.

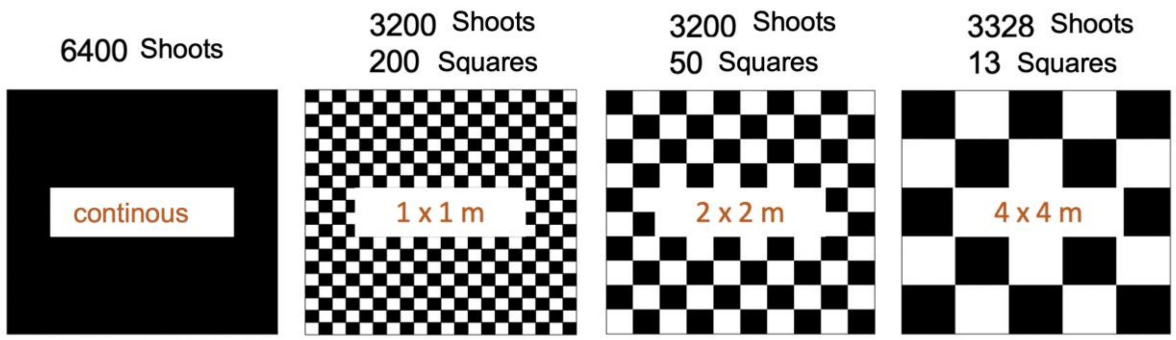


Figure 4.3. Experimental design with 4 planting patterns investigated in 20x20 m² planting plots at Gåsö from 2019 to 2024. All filled squares have a shoot density of 16 shoots per m². Above, the number of shoots used and the total number of squares planted for each method are indicated.

The plantings initially showed poor growth due to disturbances from shore crabs, but after three years, there was a strong increase in growth when the unplanted squares started to fill in, faster in treatments with smaller squares. During the first three growing seasons (2019–2021), eelgrass grew more slowly than expected due to extensive damage from crabs, which significantly reduced shoot density in the fall, despite good growth during the summer months. During this period, shoot density remained around 150 shoots per m², and no clear expansion beyond the squares could be observed (Figure 4.4, 4.5). It was not until the summer of 2022 that the planted squares showed a shoot density similar to that of nearby natural meadows (approximately 230 shoots per m²), as crab damage no longer seemed to affect growth, and the empty squares began to fill in rapidly. The gaps between the squares filled in fastest in the 1x1 meter treatment, which by the summer of 2022 was largely merged. By the summer of 2023, both the 1x1 and 2x2 meter treatments were mostly merged and resembled the treatment where eelgrass was planted continuously in terms of shoot density and spread (Figure 4.4, 4.5). However, the 4x4 meter treatment had still not filled in by the summer of 2024. Shoot density in the checkerboard treatments showed greater variation between 2022 and 2024, likely because the original squares could no longer be visually identified or sampled, and samples taken between them resulted in lower densities (Eriander unpublished data).

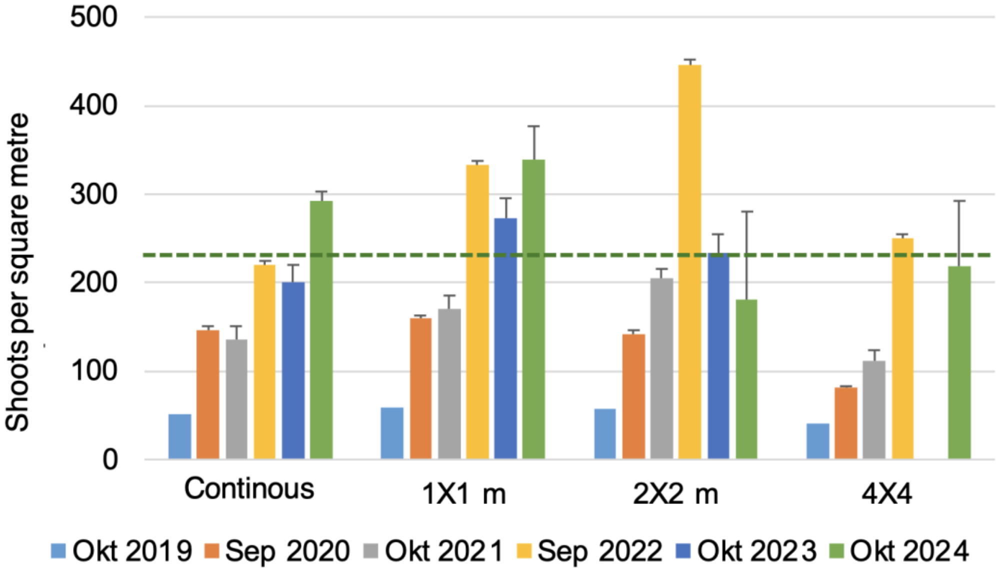


Figure 4.4. Average shoot density (+SE) of planted eelgrass from 2019 to 2024, sampled in autumn within four different planting plots where eelgrass was either planted across the entire area (Continuous) or in a checkerboard pattern with three different sizes (1x1, 2x2, or 4x4 meters). The dashed line shows the average shoot density in a nearby natural meadow in 2022–2023.

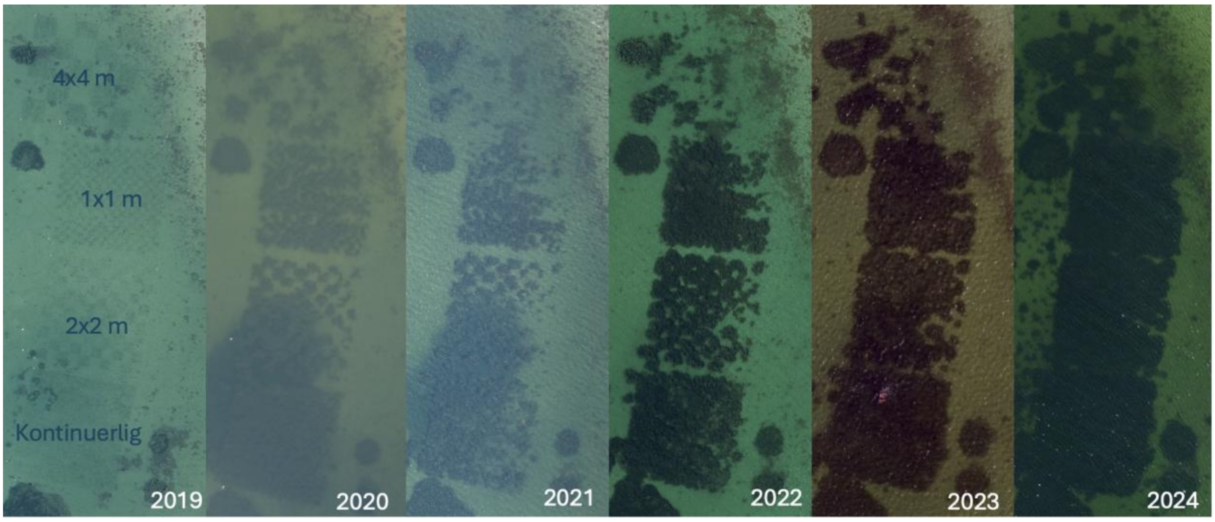


Figure 4.5. Drone photography between 2019 and 2024 of the four 20 x 20 meter planting plots where eelgrass was either planted across the entire area (Continuous) or in a checkerboard pattern with three different sizes (1x1, 2x2, or 4x4 meters). The placement of each method can be seen in the image from 2019.

The results showed that disturbances from crabs can pose a serious problem for eelgrass restoration in the Skagerrak (see section 4.4) but indicate that the problem may decrease once the shoot density exceeds a threshold where growth exceeds the rate of damage. Crab damage had not ceased after 2022, and during sampling in autumn 2024, about 30% of the shoots showed clear crab damage, with blades cut just above the growth zone. Apparently, the planting can withstand this high frequency of damage.

Small mobile invertebrates colonized the planted squares very quickly, and already three months after planting, densities reached 50–80% of those in nearby natural eelgrass meadows. After two growing seasons, both densities and biodiversity were as high as in natural meadows, and no differences could be seen between squares of different sizes (Gagnon et al. 2023). Thus, the biodiversity of small mobile animals recovers very quickly after restoration, and planting in a checkerboard pattern had no measurable negative effects on the animal community compared to continuous planting. Similarly, studies show that the number of species and individuals of fish living among the blades in the planted meadows at Gåsö are comparable to the fish community in the natural meadows at the site after four years (Castro-Fernández et al. 2025).

In summary, the method of planting in a checkerboard pattern worked very well, especially with 1x1 meter squares, where planting was faster than with larger squares and achieved the same planting speed as continuous planting, likely because the frames used made underwater navigation easier. Since the 1x1 meter treatment was the fastest to plant, had the highest shoot density of all treatments after five years, and filled in the fastest, this method can be recommended for future restoration efforts. By planting in a checkerboard pattern, the need for shoots and time required can be reduced by half compared to planting shoots evenly across the entire area. Planting in a checkerboard pattern can therefore nearly halve the cost compared to planting the entire area. In the Gåsö study, it took 4–5 years for the 1x1 meter checkerboard pattern to fill in. In areas with less disturbance from crabs, this could likely occur within 3 years.

When planting according to the recommended method, the diver uses a square frame measuring 1x1 meter (Figure 4.6). The planting area is pre-marked with ropes or measuring tape, and the diver begins by placing the frame in one of the corners of the planting area. Once 16 shoots have been planted using the single-shoot method (Moksnes et al. 2016), the frame is flipped over twice the side, and planting is repeated within the frame. This leaves one unplanted square between each planted square meter. When the diver reaches the rope on the opposite side, the frame is moved down to the next row, and planting continues as before but in the opposite direction. The previously planted row is then used as a guide for continued planting.

Since the 2019 study, plantings using the single-shoot method in a checkerboard pattern with 1x1 meter squares have been used in large-scale plantings in Kosterhavet in 2020 and at Lilla Askerön in 2021 (see chapter 2.1.1). The method has worked well and has been successfully carried out by the consultants performing the planting, with a total of approximately 1.8 hectares of eelgrass successfully planted using this technique.

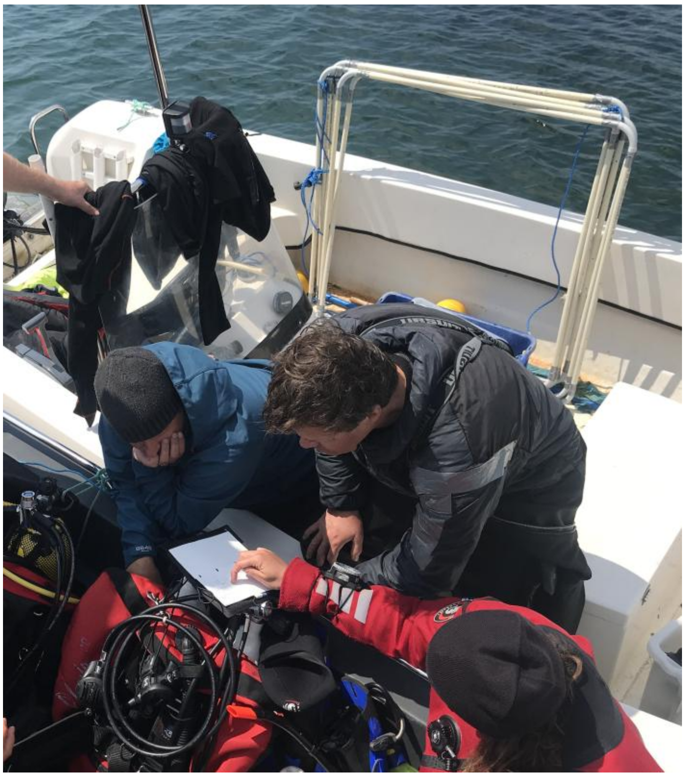


Figure 4.6 Divers planning the day's planting work at Gåsö (in Bohuslän) in 2019. In the background, the 1x1 meter frames used by the divers for checkerboard planting can be seen. Photo: Louise Eriander.

4.4 Disturbance from animals

There are many different types of disturbances, both biological and physical, that can negatively affect eelgrass plantings. Several of these are described in detail in Moksnes et al. 2016. In recent years, knowledge about the effects of several of these biological factors has increased and appears to be crucial for the success of a restoration. The following section describes damage that has been linked to shore crabs and swans in more detail, as well as measures and planting methods that could reduce the impact from these animals.

4.4.1 Damage from shore crabs and methods to reduce impact

Summary of recommendations:

- Plant the shoots in small, dense bundles (9 shoots) to reduce the frequency of damage
- Reduce the number of crabs through intensive fishing.

At the eelgrass plantings carried out at Gåsö (in Bohuslän) in 2019, damage from shore crabs (*Carcinus maenas*) is believed to be the reason for the reduced growth rate of planted shoots (see section 4.3). In a large-scale planting at South Koster in 2020, damage from shore crabs is considered the main reason why the restoration of approximately 0.8 hectares unexpectedly failed (see section 4.5 for details).

The crabs cause distinct damage to the shoots that differs from grazing damage caused by, for example, swans or snails. Often all or most of the blades are affected and cut off with jagged edges (Figure 4.7). The damage is often located at the middle or the top of the sheath, but can also be seen near the shoot’s growth zone at the base of the sheath. According to field observations, the crabs can also pull newly planted shoots completely out of the sediment.

New studies show that extensive crab damage is also found in natural meadows, which means that the abundance of shore crabs may need to be considered in the general management of eelgrass. In natural meadows sampled around South Koster and Gåsö during autumn 2024, between 18–38% of the shoots were damaged by crabs, indicating that crabs could also be a contributing factor to the newly observed losses in eelgrass distribution in these areas (Infantes et al., unpublished data).

Figure 4.7. Image of a shore crab among eelgrass shoots and an example of what damage from a crab can look like.

The number of shore crabs has increased along the West Coast since the 1980s, which is believed to be a result of overfishing and a decline in large predators such as cod in coastal ecosystems (Eriksson et al. 2011). The number of crabs has likely also increased due to the greater occurrence of filamentous algal mats in shallow bays, which benefits the recruitment of shore crabs (Pihl et al. 1995, Moksnes 2024). Despite studies of the crabs' damaging behaviour on eelgrass both in the field and under laboratory conditions (Warwas 2018), it remains unclear why the crabs destroy the eelgrass shoots. It is likely related to foraging, but possibly also due to the crab's aggressive behaviour, which could explain why the damage seems to increase during autumn, when the amount of food in the meadow is likely lower and competition among crabs is greater due to the high densities (Intantes unpublished data).

Methods to reduce damage from shore crabs

In Kosterhavet, where previous years' plantings showed significant shoot losses due to crab damage, studies were conducted in 2023 and 2024 to evaluate methods for reducing damage from shore crabs. Observations from earlier plantings at Gåsö indicated that the frequency of crab damage was lower in areas with high shoot density, compared to newly planted shoots which on the West Coast are normally planted with 16 shoots per m² (Eriander unpublished data). This may possibly be because the crab's behaviour changes with different shoot densities, where individual shoots are attacked to a greater extent. According to this hypothesis, the proportion of shoots attacked would therefore decrease if planting is done with higher shoot density. This was tested in an experiment in 2023 at South Koster, where equally sized plots (0.75x0.75 meters) were planted with three different eelgrass densities (16, 64, and 256 shoots per m²; Figure 4.8). The experiment was repeated at two different sites at South Koster (Långevik and Tångudden). To investigate whether the crab population and damage could be reduced through fishing, crabs were fished at the Långevik site from July to October using 8 baited traps that were emptied at 2–5 day intervals. At Tångudden, no removal fishing was conducted.

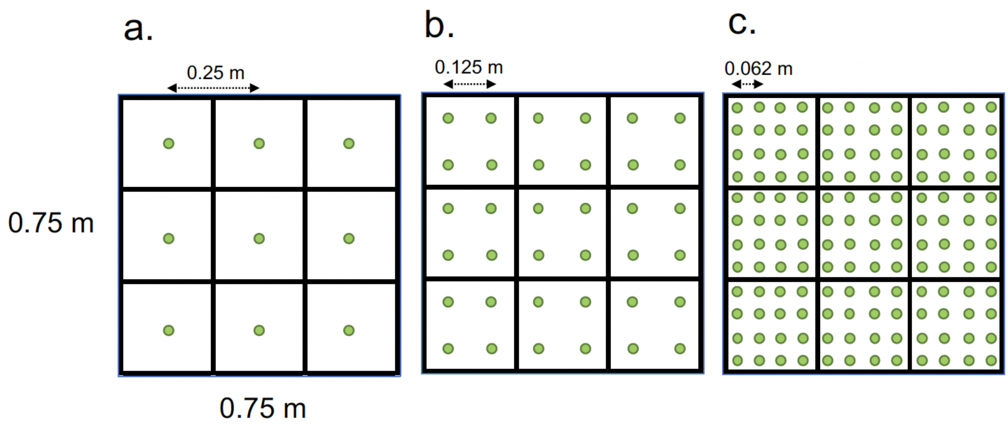


Figure 4.8. A schematic illustration of the three shoot densities included in the study on how shoot density affects damage from shore crabs. A) 9 shoots per planting plot, with 25 centimeters spacing (corresponding to 16 shoots per m²) B) 36 shoots per planting plot, with 12.5 centimeters spacing (corresponding to 64 shoots per m²) C) 144 shoots per planting plot, with 6.25 centimeters spacing (corresponding to 256 shoots per m²).

The results showed extensive crab damage to shoots in all treatments, but the proportion of damaged shoots decreased, and the proportion of surviving shoots increased significantly from 7% to 43% as shoot density increased from 16 to 256 shoots per m² (Figure 4.9). The effect of fishing was more limited, as the number of crabs caught per day increased at both sites from August to October, despite more than 2,600 crabs being removed from Långevik through fishing. However, the total survival of planted shoots was slightly higher in Långevik than in Tångudden (30% and 17%, respectively), which could indicate that trap fishing had some effect on the number of crabs in Långevik (Infantes unpublished data). During a revisit to the plantings in June 2024, surviving shoots were found only in areas planted with the highest density, further supporting the hypothesis that planting at high densities reduces damage from shore crabs.

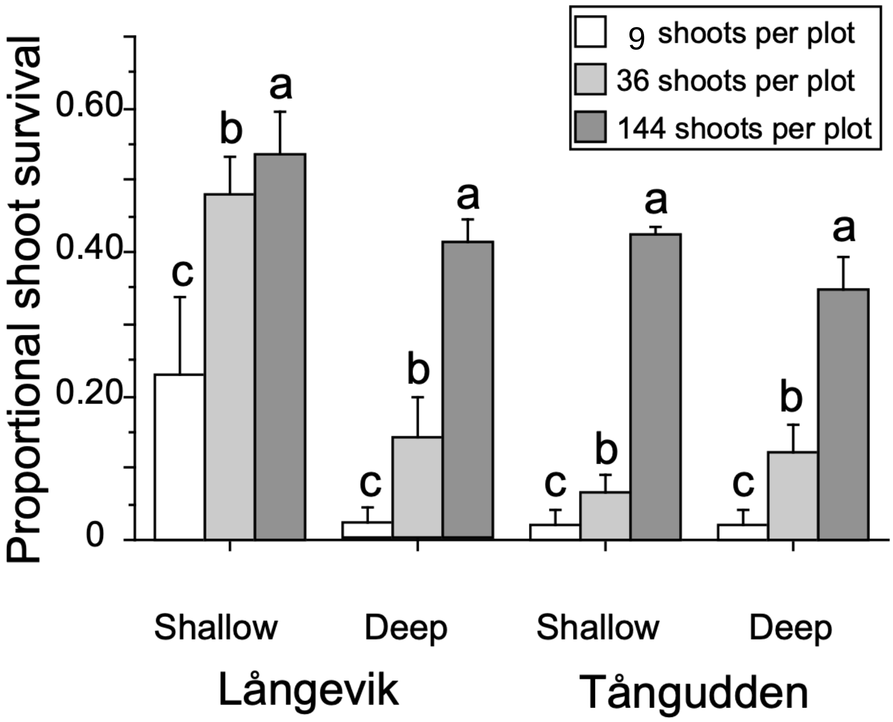


Figure 4.9. Results from plantings in Kosterhavet in 2023 showing proportional shoot survival for the three shoot densities (9, 36, and 144 shoots per plot) at the shallow and deep planting sites in Långevik and Tångudden. Different letters above the bars indicate significant differences.

Since large-scale plantings with 256 shoots per m² would be very costly, new studies were conducted at South Koster in 2024 to investigate whether smaller planting areas with high shoot density could achieve the same effect. In the experiment, the same planting density (256 shoots per m²) was used, but the planting area varied from 0.56 to 0.04 m² and the number of shoots from 144 to 9 shoots per treatment, along with a control treatment planted with 16 shoots per m² (Figure 4.10a). In addition, a method was tested where 9 shoots were tied together with biodegradable thread to a spike, using a commercial planting tube (for planting flower bulbs), where the anchored "bouquet" was pressed into the sediment using the tube (Figure 4.10b). The tube treatment was included to develop methods that allow planting by wading in the water or from a boat after modifications. The experiment was repeated at two different depths at two sites at South Koster, as in the previous experiment.

The results at the end of the growing season showed more extensive crab damage, which varied more between sites than in the 2023 experiment. The proportion of damaged shoots was lower, and the proportion of surviving shoots was higher in all treatments with high shoot density (on average 34%) compared to treatments with 16 shoots per m² (8%). Surprisingly, the highest survival was found in treatments where 9 shoots were planted by hand or with the planting tube (on average 37% and 40%, respectively), which is positive as it would enable more cost-effective planting of small areas with high density. For example, if 3 small areas with 9 shoots are planted per square meter in a checkerboard pattern, a total of 135,000 shoots would be needed to restore one hectare, which is 69% more than if 16 shoots per m² were planted in the same way. That shoots planted with the planting tube showed the highest survival is encouraging, as it opens up possibilities for planting in shallow water without using divers, which would significantly reduce costs. Further studies to develop this type of method are encouraged. However, it is important to emphasize that although high planting densities significantly increased survival from crab damage, losses were still substantial even with this technique (around 60% during the first growing season). This method is therefore not sufficient for large-scale restoration in areas with crab problems. The method thus needs to be combined with other measures, such as intensive removal fishing of shore crabs, at least during the first years of restoration. A more long-term solution would be measures that bring back large predatory fish to coastal ecosystems.

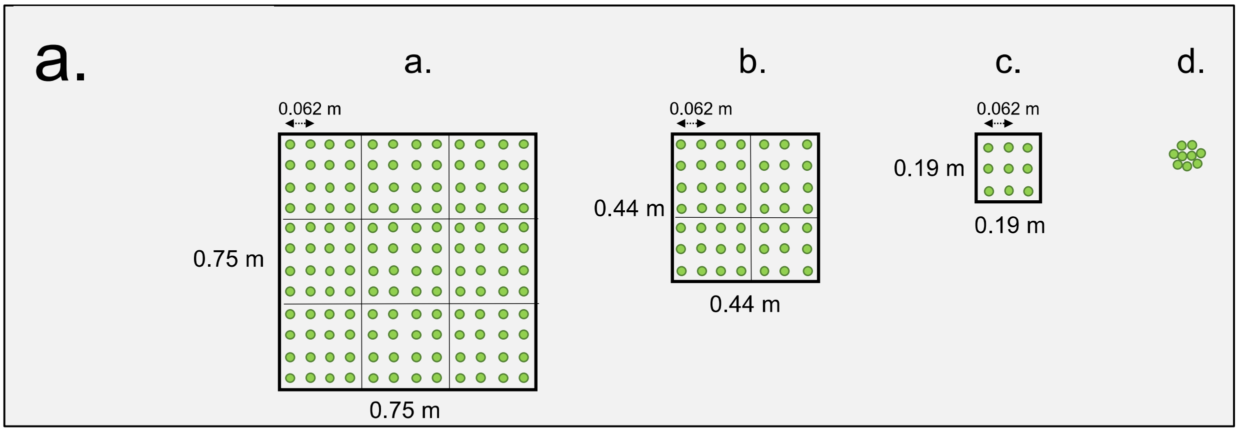


Figure 4.10. (a) Schematic illustration of the four plot sizes with the same shoot density (corresponding to 256 shoots per m²) included in the study on how plot size affects damage from shore crabs. Subfigure d illustrates the treatment where the shoots were planted using a planting tube. The treatment with 16 shoots per m² is not included in the figure. (b) Image of the planting tube and 9 eelgrass shoots tied to an anchoring spike. In the experiment, the shoots were placed with the spike at the opening of the tube and pressed into the sediment using the tube.

4.4.2 Damage from swans and geese and methods to reduce impact

Summary of recommendations:

- Plant the shoots deeper than 1.6 meters.
- Surround the planting area with floating buoys and flag buoys to deter grazing waterfowl.

During the plantings carried out at Lilla Askerön in 2021, problems were noted with swans and geese grazing on the newly planted shoots in the shallow parts of the planting area (swans can reach about 1 meter deep from the surface). This resulted in extensive losses and damage over an area of approximately 250 m². Grazing swans have also posed a problem for planted shoots at restoration sites near the Port of Gothenburg (Andersson 2023). Swans can either graze the shoots, cutting the blades with typical clean cuts (Figure 4.11), or pull up entire shoots from the planting. Eelgrass is a main food source for swans along the West Coast and is therefore a natural occurrence, which normally has a very limited effect in an established meadow with high shoot density (Balsby et al. 2017). However, swans also seem to be attracted to shallow eelgrass restoration sites, where they can quickly cause major damage to planted eelgrass when shoot density is low.

Methods to reduce damage from grazing swans and geese

When the problem was discovered at Lilla Askerön in mid-May, a rope with small floating buoys was placed around the entire planting area, and larger buoys with flags were placed within the planting area to deter the birds. At the same time, the planting work was moved to the deeper part (>1.6 meters) of the area where the swans could not reach the shoots. Although swans were observed at the site even after the buoys were set up, their presence decreased over time, and when the planting work reached the shallow parts of the area in mid-June, the swans were no longer a problem. In sampling conducted in the area in later years, only occasional damage from swans has been found. If damage from swans is a potential problem, it is recommended that planting is primarily done deeper than 1.6 meters and that surface buoys are set up to deter swans if planting is done at shallower depths.

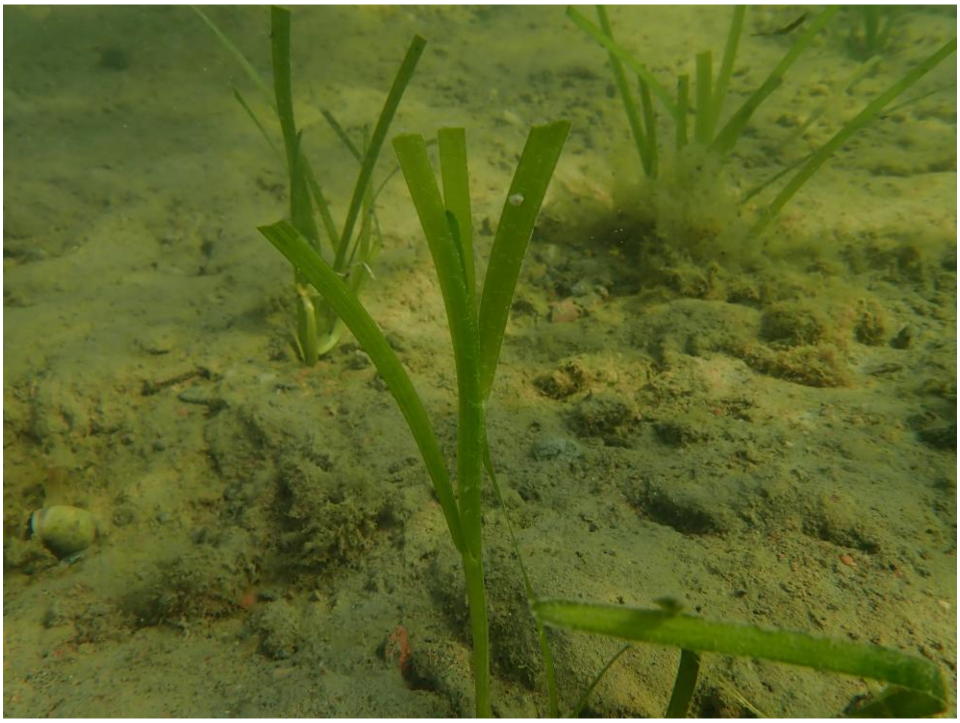


Figure 4.11. The image shows planted eelgrass shoots with typical damage from swans. Photo: Anna Feuring.

4.4.3 Damage from other animals

During eelgrass planting in areas such as Kosterhavet, damage to the blades from other organisms has also been observed. These mainly consisted of various types of grazing damage, either along the edges of the blades (Figure 4.12a) or marks on the blade surface itself. The organisms responsible for this damage cannot be identified with certainty, but the marks on the blade surface could be caused by scraping from snails, while the distinct crescent-shaped damage on the blade edges could be due to grazing by small crustaceans, such as amphipods (which have been observed cutting pieces from the blades in laboratory experiments; Eriander unpublished data). However, extensive damage of this type has never been observed.

The tube-building polychaete *Platynereis dumerilii* is part of the normal fauna in eelgrass meadows but can cause problems if it becomes too abundant. These worms cut pieces from the eelgrass blades and glue them to another blade of the same shoot, thereby creating a tube between the two blades (Figure 4.12b). In studies at South Koster, large occurrences of the polychaete have been observed on planted shoots that were cut and weighed down by the worm’s tube-building, which may have contributed to the large losses observed in the experiment (see section 4.5). Studies of eelgrass restoration in the Netherlands have shown a correlation between the presence of this polychaete and losses of planted eelgrass, which has been explained by the worm’s tube-building reducing the eelgrass’s photosynthetic capacity (Cronau et al. 2022). However, there are no direct studies on the effects of the polychaete on eelgrass in Sweden, nor on measures to reduce its impact. The presence of the worm may possibly have increased due to the decline of large predatory fish in coastal ecosystems (Cronau et al. 2023). The presence of various types of sessile epifauna can also periodically become high in eelgrass meadows, which could pose a problem for the plants. Large amounts of the colonial sea squirt

Botryllus schlosseri are regularly found on eelgrass blades (Figure 4.12c), which can weigh down the blades and reduce the eelgrass's photosynthetic capacity. Similarly, large settlements of juvenile blue mussels can weigh down the eelgrass, which has been observed in natural eelgrass meadows in Byfjorden as well as in a test planting south of Stenungsund on the West Coast in 2024. However, there are no studies on the long-term effects of these events. Since new blades are continuously produced and old ones shed, the plant may possibly recover if the settlement of these organisms occurs only during a limited period.

Since 2018, several potentially pathogenic species of Phytophthora and Halophytophthora have been discovered in eelgrass along the Norwegian coast. However, further research is needed to determine how these species affect eelgrass.

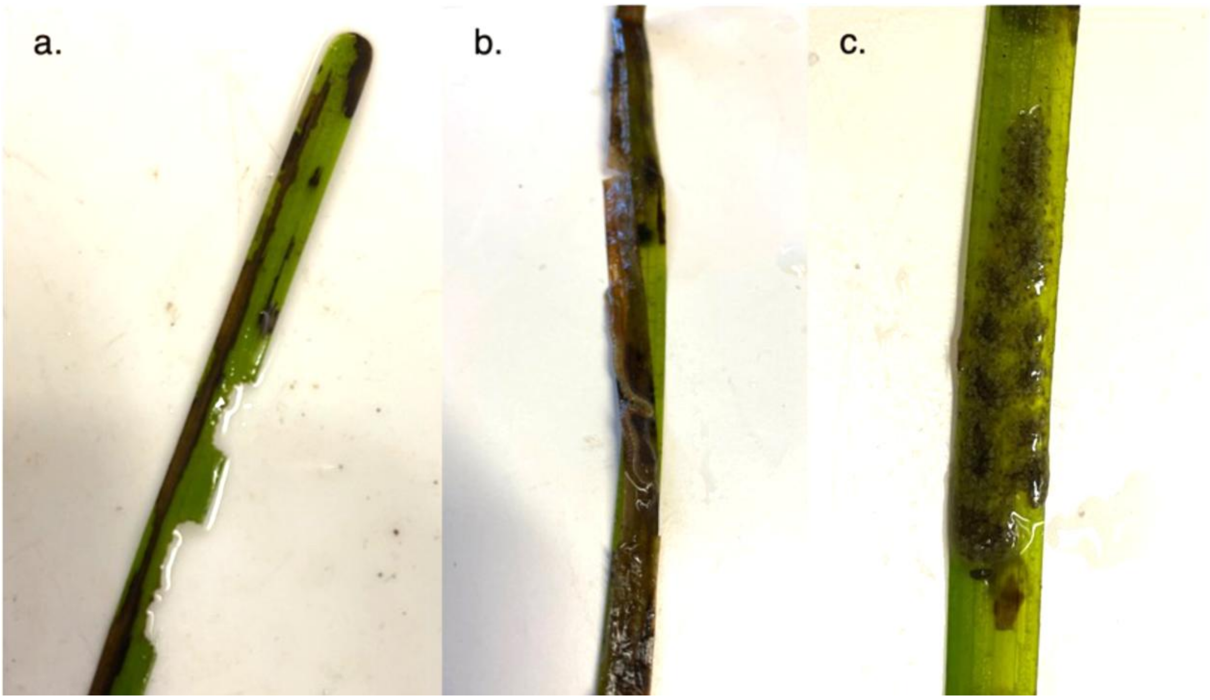


Figure 4.12. The image shows examples of damage to eelgrass blades from a) grazing b) the polychaete *Platynereis dumerilii* and c) the colonial sea squirt *Botryllus schlosseri*.

4.4.4 Spread of invasive species

Restoration of eelgrass that involves the relocation of plants, sediment, and boats may serve as a transport medium for the spread of organisms between areas. This can pose a problem in the presence of invasive species and/or diseases and should therefore be considered when restoring eelgrass. During the planting work at Lilla Askerön in 2021, the consultant's divers encountered problems with high densities of the invasive clinging jellyfish *Gonionemus vertens* in the donor meadow, approximately 1 kilometer from the restoration site. The harvesting work therefore had to be halted, and a new donor meadow was selected for continued work. The risk of spreading invasive species and diseases should therefore be taken into account during restoration, especially if the eelgrass is transported over long distances.

4.5 Monitoring – What to do if the restoration fails?

Summary of recommendations:

- Examine the recorded light conditions during the period (see section 4.2).
- Check whether remaining shoots show damage from, for example, shore crabs (see section 4.4).
- Investigate weather conditions during and shortly after planting.
- Investigate the presence of drifting algal mats.
- Test-plant shoots in open and closed cages, as well as without cages, to determine whether losses may be due to crabs or drifting algae.

Even when following the handbook's recommendations and methods for eelgrass restoration, there is always a risk that a large-scale planting may fail or that the expected shoot growth does not occur. Therefore, follow-up of a restoration is important in order to detect if something goes wrong and, ideally, to gain increased knowledge about factors that may affect eelgrass growth and the chances of a successful planting. If funding is available to continue work at a site where the restoration has not gone as planned, studies can be designed to determine the reasons for the failure. Below is an example of such a situation and how a study to identify the causes can be structured.

Restoration attempt at South Koster 2019–2021

As discussed in section 2.1, a large-scale eelgrass planting (75,500 shoots; 0.93 hectares) surprisingly failed in two bays at South Koster in 2020. This occurred despite the sites having been surveyed in 2019 according to the handbook's protocol, including sediment and light sampling that indicated good environmental conditions, as well as test planting of eelgrass that survived until spring 2020. The eelgrass had been planted by a consultant following the handbook, and during the final inspection of the consultant's plantings on July 16, 2020, the eelgrass appeared healthy and vigorous. However, in October 2020, sampling by divers and drone revealed unexpectedly large losses (50–90%) of eelgrass in both bays. The causes of these unexpected losses could not be explained, as weather conditions during the autumn had been relatively calm. Anchoring bans had been implemented in the bays, and no boats were observed at the restoration sites during inspections. Furthermore, no extensive presence of algal mats was observed that could explain the losses, while crab damage was common among the few surviving shoots. Sampling in May 2021 confirmed that the losses had continued over the winter, with only one living shoot found at Tångudden and only scattered small shoot clusters found at Långevik. One observation was that the majority of surviving shoots were growing close to clusters of living Pacific oysters (*Magallana gigas*).

Based on on-site observations and the literature, six possible factors were identified for the failed planting:

1. Lack of light (mainly in the deeper parts of the planting).
2. Wave exposure uprooting plants (mainly in the shallow parts of the planting).
3. Damage from shore crabs and grazing animals.
4. Drifting seaweed mats that shade and smother the eelgrass.
5. Toxic substances in the sediments.
6. Lack of nutrients.

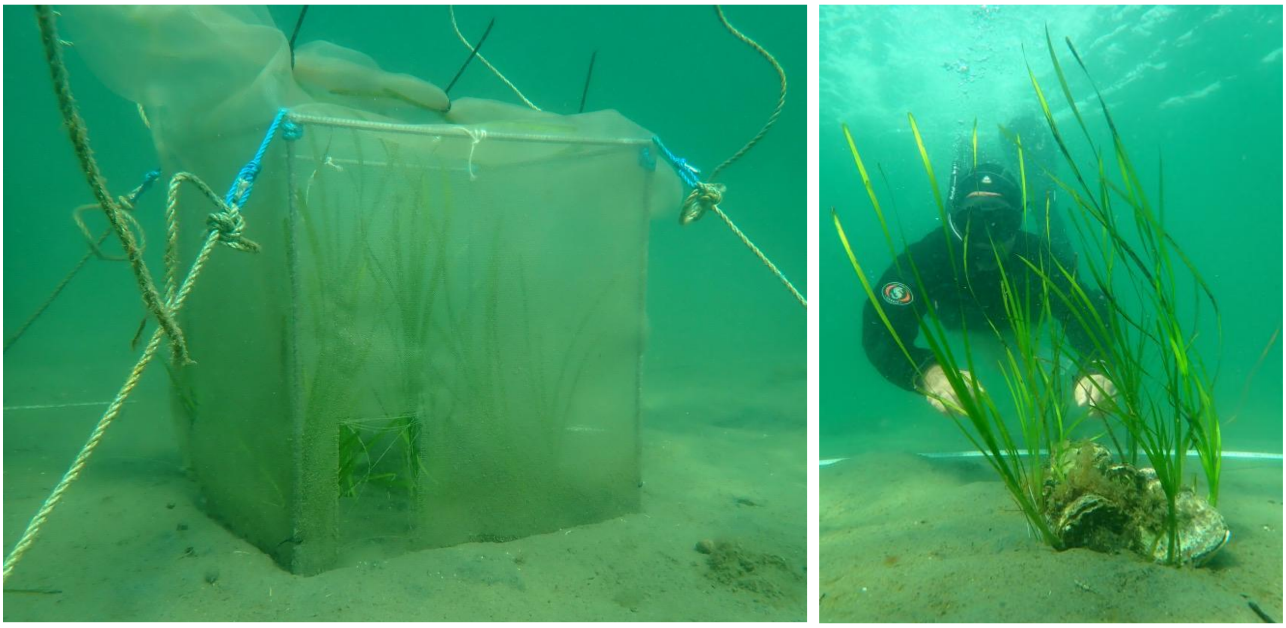


Figure 4.13. Photos from the start of the field experiment in Långevik at South Koster in the summer of 2021. On the left is the cage treatment with holes that allow crabs and other disturbing animals to enter but prevent algal mats from getting in. On the right is the treatment where eelgrass shoots were planted next to living Pacific oysters that occur naturally in the bay. Photo by Eduardo Infantes

To investigate which of these factors may have contributed to the unexpected losses of eelgrass, a field experiment was conducted in the two bays during the summer of 2021. At Långevik, a cage experiment was carried out at two different depths with five different treatments involving planted eelgrass: (1) closed cage with 1-millimeter mesh that prevents all larger grazing and disturbing crustaceans (such as crabs) and snails from entering, (2) “cage control” with 10x10 centimeter holes at the sediment surface that allow larger animals to enter but not algal mats, and that affect light and currents in a similar way to the closed cages, (3) eelgrass without a cage, (4) eelgrass without a cage with 4–6 adult Pacific oysters, and (5) eelgrass without a cage where pelletized flower fertilizer was added to the sediment (Figure 4.13). In each treatment, 9 shoots were planted. The oysters were included both because they may provide protection from disturbing animals and wave energy, and because they may contribute nutrients. By repeating the experiments at two depths in the bay (1.3 and 2.0 meters), it was possible to separate disturbances from waves and light limitations in the different treatments. At Tångudden, where a thick layer of gravel and small stones 20 centimeters below the sediment surface made it impossible to use cages, a smaller experiment was conducted at one depth with only treatments without cages.

The experiment lasted for three months (June 29 to September 29, 2021), and when the experiment ended, both the number and length of shoots differed significantly between the cage treatments, but not between the different depths. In the closed cages, long, healthy shoots were found, without damage, and shoot density had increased to an average of 15 shoots (Figures 4.14, 4.15). In the cage treatments with holes, significantly fewer shoots were found (an average of 8 shoots), and many shoots showed crab damage with cut shoots and shoot tips floating at the top of the cage. Very few shoots were found in the treatments without cages (an average of 1.7–3.2 shoots), which did not differ from each other (Figure 4.14). Surviving shoots in the treatments without cages were in very poor condition, with short leaves, many showing damage from crabs and tube-building polychaetes (Figure 4.15, see section 4.4), or were heavily overgrown by, among others, colonial sea squirts (Figure 4.13c).

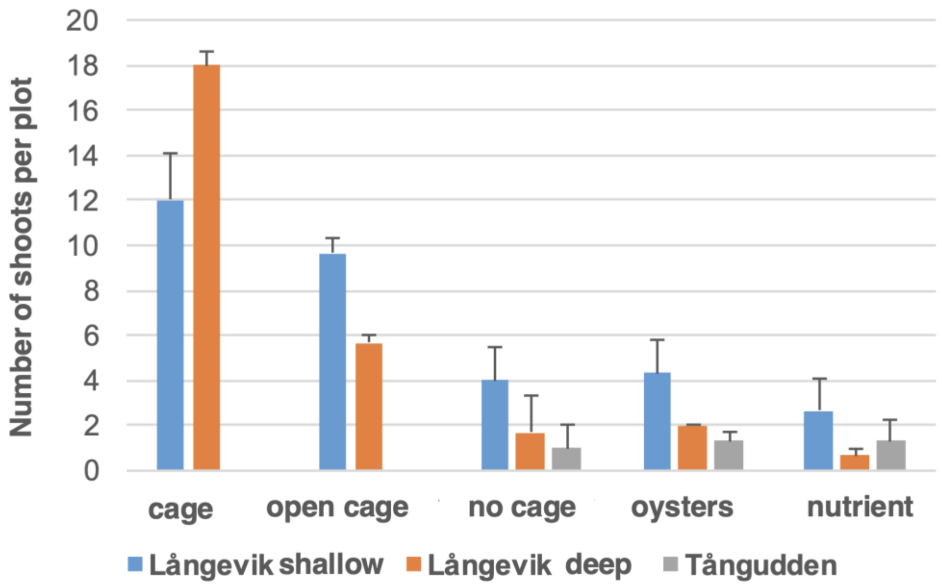


Figure 4.14. Results from the field experiment at South Koster in 2021. Mean number of shoots per plot (+SE) in different treatments after 3 months at two different depths in Långevik, as well as at Tångudden (at South Koster).

Since positive growth of planted eelgrass was only found in the cages that excluded larger animals, the results indicate that disturbance and damage caused by crabs is the main reason for the severe losses and damage to eelgrass in the field experiment, and likely also in the 2020 restoration attempt. It is possible that heavy overgrowth by tube-building polychaetes and sea squirts, as well as grazing snails, also contributed to the losses, as these organisms were less common in the cage treatments. Since the cage mesh likely reduced larval supply of these fouling organisms, this could explain why the open cage treatment showed higher survival than the no-cage treatment. Alternatively, drifting algal mats may have contributed to the losses in the no-cage treatments, as these do not enter cages with holes to any significant extent. However, poor water quality and light limitation can be ruled out, as the highest growth was found inside shaded cages at the deepest site. Likewise, there is no indication that nutrient deficiency or the presence of toxic substances in the sediment is a contributing factor. Furthermore, there is weak support for wave stress being a contributing factor to the losses, as survival was consistently slightly higher at the shallow site in the no-cage treatments, and the difference between treatments with and without cages was strongest at the deep site in Långevik, where wave energy is lower (Figure 4.14). Fewer crab damages were found on shoots growing next to Pacific oysters compared to other treatments without cages, which may explain previous observations of higher survival near oysters, but the effect was too small to significantly influence shoot survival.

In summary, the study at South Koster shows how an experimental approach can separate different explanatory models and identify the most likely factors contributing to eelgrass loss. The results were surprising, as crabs have not caused damage of this magnitude in other locations in Bohuslän, although problems have also been reported at, for example, Gåsö (see section 4.3). Thanks to the identification of the cause of the losses, work is now underway to develop restoration methods that can mitigate damage from crabs (see section 4.4.1).

Figure 4.15. Photos from the conclusion of the field experiment in Långevik on September 29, 2021. On the left are eelgrass shoots that grew inside a closed cage for 3 months, with long (70 centimeters) healthy leaves without damage. In the center and on the right are typical shoots that grew without a cage, with short (20–30 centimeters) leaves showing various types of damage from crabs and polychaetes that build nests from cut leaves. Photo by Per Moksnes

4.6 Monitoring – National database for ”Åtgärder i vatten” (English “Measures in water”)

In Sweden’s waters, a large number of restoration measures are carried out annually in both freshwater and marine environments. The County Administrative Boards handle many cases related to this work, and several projects are funded with government grants. National authorities and researchers have a great need for a comprehensive national overview of implemented measures and the use of public funds. A similar need exists at the regional level among the County Administrative Boards. Information on the socio-economic costs of restoration projects (total costs for planning, implementation, etcetra) needs to be collected (reported), and the measures taken need to be followed up to a greater extent than is currently done in order to gain better knowledge of which measures are cost-effective. In addition, to know when satisfactory restoration levels have been reached, it is important to monitor and evaluate the effects of the restoration measures (so-called adaptive management).

The application *Åtgärder i Vatten* (eng. *Measures in water*) (https://www.atgarderivatten.se/) is currently managed by the Swedish Agency for Marine and Water Management and the County Administrative Boards in collaboration. Since its inception, the goal has been to create a shared database that all involved authorities can use for administration, evaluation, follow-up, and research related to restoration measures. However, to obtain a comprehensive national picture of how the restoration work is progressing, increased contributions of information from various actors are required. It is therefore important that all projects report their implemented measures.

Åtgärder i Vatten currently contains information on:

- Physical and hydromorphological measures carried out in aquatic environments (watercourses, lakes, coasts, and offshore) and in the shoreline zone.
- Biological measures in aquatic environments and the shoreline zone.
- Follow-up of the function and effects of implemented measures.
- The extent and positioning of measures using points, lines, and areas.

5 Guidelines for sand capping to enable restoration in turbid environments

Even though effective restoration methods exist for areas with good water quality, research results show that the environment can deteriorate dramatically as a result of eelgrass meadows disappearing, which has meant that natural recovery or restoration through planting shoots is not possible in many areas (Moksnes et al. 2018). When an eelgrass meadow is lost from an area, its stabilizing effect on the seabed disappears, leading to increased sediment resuspension and deteriorated water quality. In areas where fine-grained, clay sediments dominate the seabed, the resuspension can become so severe that eelgrass and other vegetation can no longer survive in places where they previously grew. When this has occurred, measures are needed to reduce sediment resuspension before eelgrass restoration through planting is possible.

A recently developed method to stabilize bottom sediments, reduce resuspension, and improve water quality to enable eelgrass recovery is to cover the seabed with sand or gravel, known as sand capping (see section 2.3 for examples from Denmark). The porous sand also provides a better substrate for eelgrass growth than compact clay.

This method was successfully tested on a large scale in 2021 at Lilla Askerön in southern Bohuslän, where one hectare of seabed consisting of clay was covered with 10 centimetres of sand and gravel, after which eelgrass was planted on the sand-capped area. Based on the experiences from this work, guidelines are presented below for carrying out large-scale sand capping, along with brief results from the work at Lilla Askerön as an example. The guidelines include all steps in the restoration process, from the selection of sand and site, permit application, procurement, and implementation of the measure, to monitoring. At the end of the section, alternative methods for sand capping and different types of sand sources that could be used for similar measures in the future are also described (see Appendix B for details). All studies below were conducted within the research program Zorro (Moksnes, unpublished data) and by the County Administrative Board of Västra Götaland.

5.1 Selection of sand

When applying sand, the choice of sand source and type of sand (in this text, the term “sand” is used for the material in sand capping even if the grain size includes gravel fractions) is the first step in the process, as the sand is needed in pilot trials when evaluating potential sites (see below). When selecting sand, the following criteria may be important to consider (see also Appendix B).

Critteria for selecting sand:

1. The source should be close to the restoration site to minimize transportation.
2. Must not contain environmental toxins.
3. Must not contain invasive species.
4. Should contain a low proportion of silt and clay to minimize turbidity.
5. Should contain a mixed grain size to reduce the risk of transport and erosion.
6. Should provide a good habitat for infauna.
7. Should serve as a suitable growth substrate for eelgrass.

Exemple of sand selection

During the restoration at Lilla Askerön, a nearby land-based gravel pit (Dunebackens naturgrus) was used as the source, which meets criteria 1–3 for sand selection. Natural drainage gravel (0–8 millimeters) was chosen as the sand type. Grain size analysis showed that the sediment had a relatively even distribution of fractions from fine sand (125–250 micrometers) to gravel (2–8 millimeters), but very little (under 2%) fine sand to clay (<125 micrometers; Figure 5.1), meaning that sand coverage would result in very little input of sediment that could cause turbidity. The sand therefore also meets criteria 4–5 for sand selection. The final criteria are tested in field studies when selecting the site (see below).

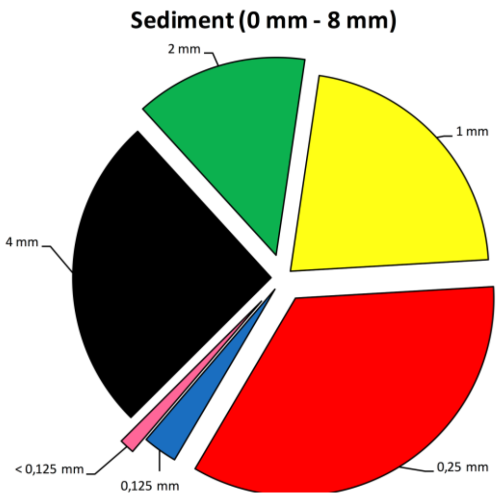


Figure 5.1. Grain size of the sediment used for sand capping (drainage gravel 0–8 mm) at Lilla Askerön in southern Bohuslän.

5.2 Site selection

As with all restoration efforts, the evaluation of potential sites is the first and perhaps most important step in the restoration process. When selecting a site for sand capping, the following criteria are important to consider.

Criteria for selecting a site for sand capping (in order of priority):

1. Eelgrass has previously grown at the site.
2. Turbidity currently prevents eelgrass from growing at the site.
3. The deposited sand does not erode.
4. The deposited sand will not be covered by sediment.
5. The sand-covered area is likely large enough to reduce turbidity in the area.
6. Positive attitude from landowners and local residents toward sand capping.

Exemple of site selection in southern Bohuslän

In the study, four sites in southern Bohuslän were selected, all of which had lost large eelgrass meadows (criterion 1) and currently suffer from significant turbidity issues (Figure 5.2). To test criteria 2–4 as well as 6 and 7 for sand selection, field trials were conducted in 2018. At each site, square meter-sized areas were covered with a 10-centimeter-thick layer of the selected sand type at two different depths (1.5 and 2.2 meters; 3 replicates). Eelgrass was test-planted (16 shoots per m²) on half of the sand-covered areas as well as on natural sediment, and infauna (invertebrates living in the sediment) were sampled on each sediment type and depth (in three replicates).

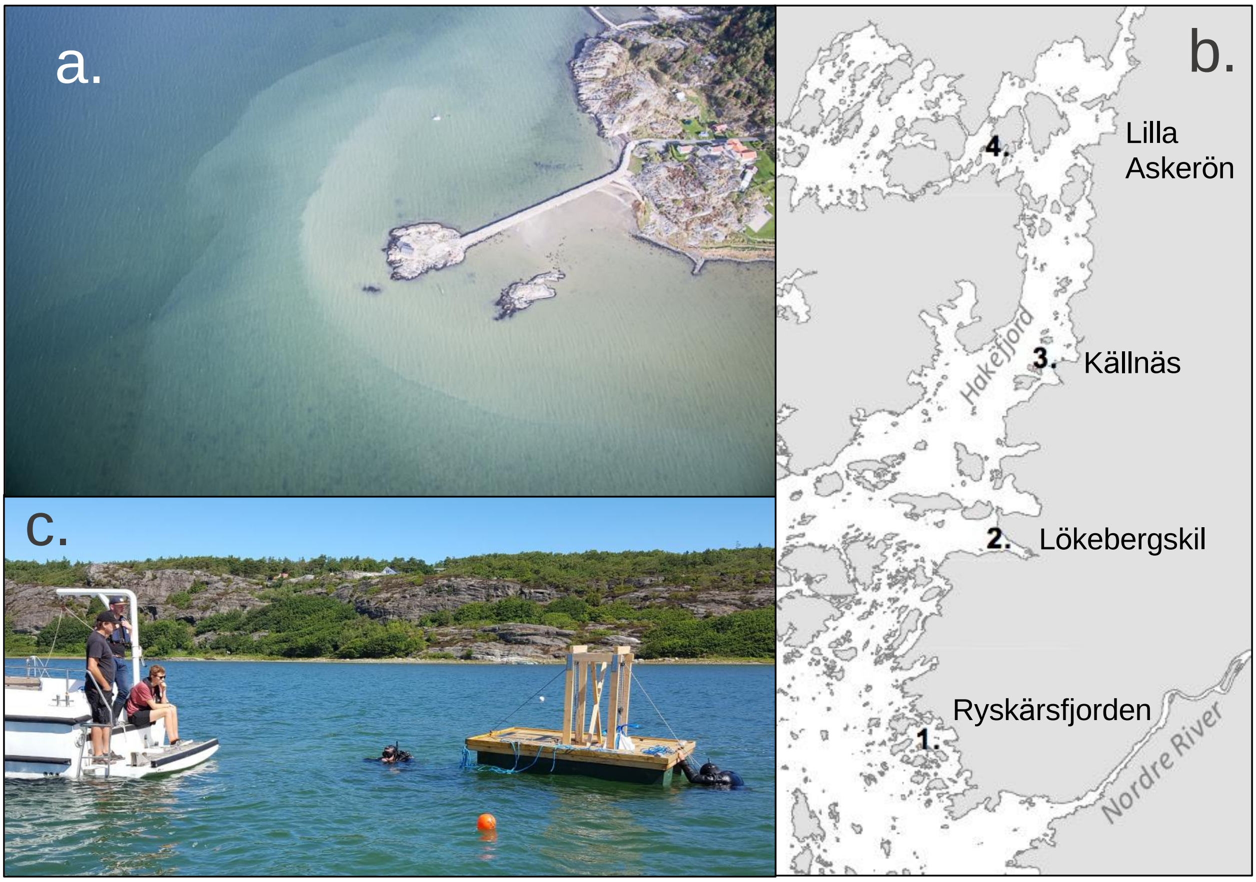


Figure 5.2. (a) Example of turbidity problems caused by fine-grained sediment at site Källnäs in Hakefjorden, southern Bohuslän, after the stabilizing effect of eelgrass on the sediment has been lost. (b) Map showing the four sites investigated for sand capping. (c) Image from the sand deployment during field trials, where a raft was used to transport 100 liters (180 kilograms) of sand to each experimental sand plot.

Sampling in October 2018, four months after the sand was applied, showed three times higher abundance and 30–50% more infauna species on the deposited sand compared to nearby clay sediment, indicating that the sand provides a better habitat for infauna than the natural sediment. As expected, the planted eelgrass died within a year at almost all sites due to poor light conditions, demonstrating that eelgrass cannot be restored without measures to improve light availability. However, eelgrass generally showed higher shoot density on sand than on natural clay, indicating that the porous sand provides a better growth substrate than the compact clay.

This was especially evident at Lilla Askerön, where eelgrass planted at a depth of 2.2 meters had over four times higher growth on sand compared to clay at the same site (Figure 5.3). Interestingly, the eelgrass at 2.2 meters survived just outside the regular turbidity plume in the bay, while the eelgrass planted at 1.3 meters further inside the bay, within the plume, did not survive—highlighting the strong negative effect of turbidity on light availability and eelgrass growth (Figure 5.3).

In the site evaluation, Site 2 (Lökebergskile) was excluded due to high wave exposure that eroded the deposited sand (criterion 3). Site 1 (Ryskärsfjorden) was also excluded due to high sediment dynamics in the area, where deposited sand plots were covered by a 2-centimeter-thick layer of clay sediment after an autumn storm (criterion 4). Both Site 1 and 2 showed favorable conditions for sand application, but Site 3 (Lilla Askerön) was selected for continued work, primarily because the site is smaller, meaning that a one-hectare sand coverage (as allowed by the funding) is more likely to impact light quality. Landowners were also positively inclined toward the measure (criterion 6), and eelgrass growth in deeper water was good.

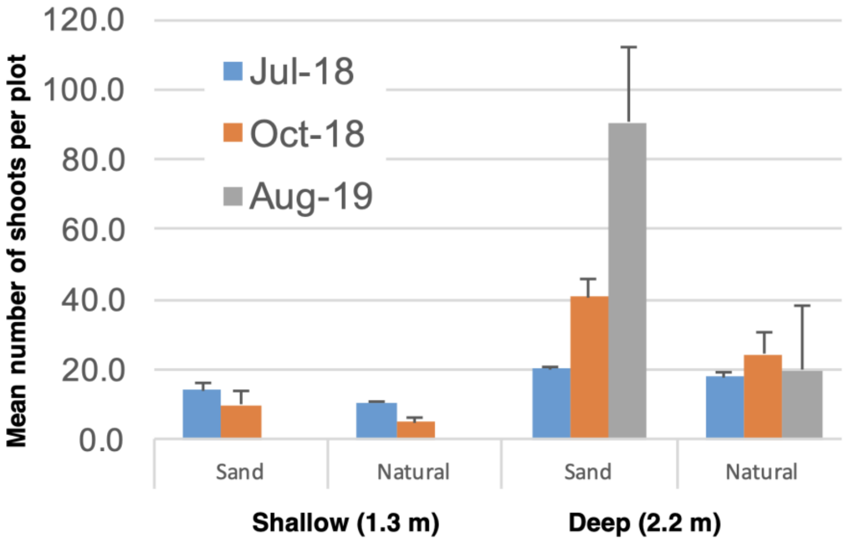


Figure 5.3. Mean number of shoots per plot (+SE) in eelgrass test plantings at Lilla Askerön, where 16 shoots per m² were planted on deposited sand and on natural sediment in June 2018 along the shallow (1.3 meter) and the deep (2.2 meter) transects in the bay. The photo on the right shows the positions of the transects.

5.3 Selection of place and size of the sand capped area

The next step in the process is to determine where the sand capping should be placed within the restoration area and how large the area needs to be in order to have a sufficient effect on the light environment to allow eelgrass growth. Assessing the latter is one of the greatest challenges with sand capping, as it is not possible to test the effect on the light environment on a small scale; i.e. the results can only be observed after a large-scale trial. One way to approach this issue is to model circulation and sedimentation dynamics in the specific area using hydrodynamic models. However, when it comes to selecting the location within the area, the following more general criteria may be important to consider.

Criteria for selecting the location of the sand cap within the site

1. Area where the highest turbidity is generated.
2. Depth where eelgrass can grow.
3. Safe distance from sensitive species within the site (e.g., eelgrass, mussel beds).
4. Area where landowners are supportive of the measure.

Criterion 1 and 2 cannot always be reconciled, as turbidity is often greatest near the shore at shallow depths (<1 meter), where eelgrass restoration is not recommended due to the risk of exposure during low tides and damage from ice in winter (Moksnes et al. 2016). The advantage of placing the sand where eelgrass can be planted is that eelgrass growth can be many times higher on sand compared to clay sediment (Figure 5.3).

Exemple from Lilla Askerön

For the work at Lilla Askerön, a high-resolution three-dimensional hydrodynamic circulation model was used for the area around Lilla Askerön, driven by a large-scale hydrodynamic model of southern Bohuslän. The modelling, conducted in collaboration with DHI, was used to simulate the effect of sand capping on sediment turbidity and light conditions in the bay in order to select the optimal location and size (Figure 5.4ab). The results showed that the optimal location for placing one hectare of sand to improve the average light conditions in the entire bay was in shallow water along the shoreline (Figure 5.4c), while the optimal location for improving light conditions at depths where eelgrass could grow long-term (>1.2 meters) was more central in the bay (Figure 5.4d). The modelling results indicated that one hectare of sand capping at the selected location would reduce turbidity sufficiently for eelgrass to grow at the site.

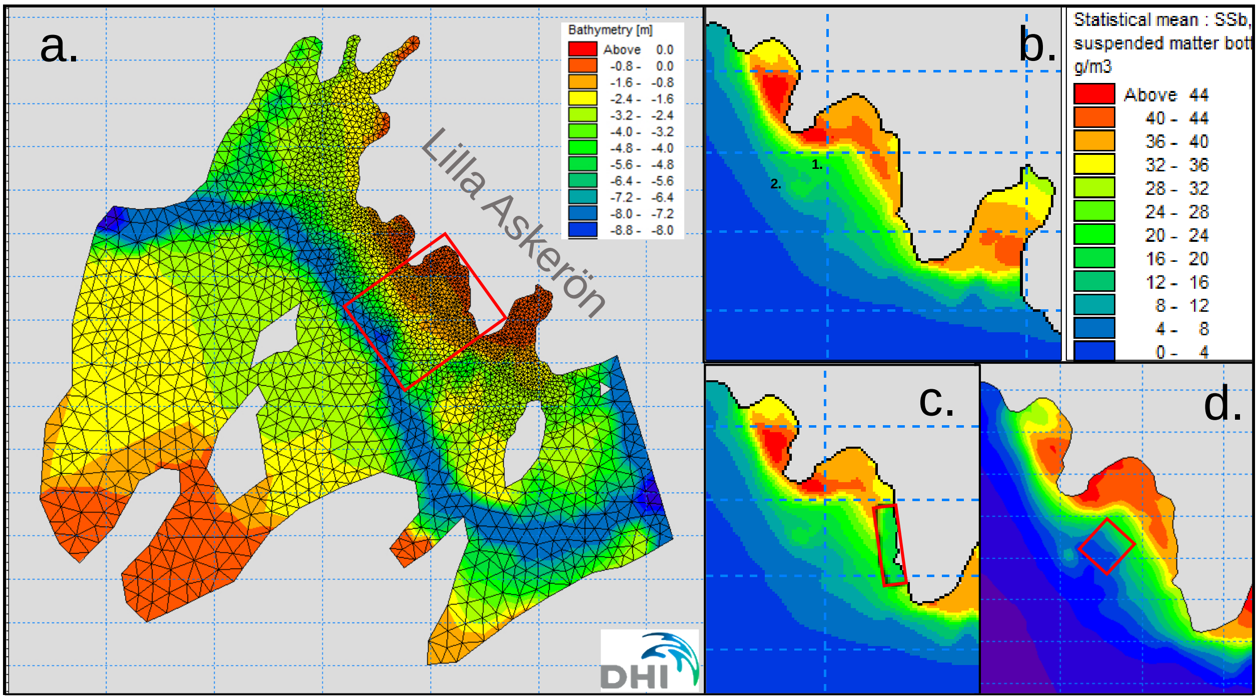


Figure 5.4. (a) High-resolution three-dimensional hydrodynamic circulation model for the area around Lilla Askerön, used to simulate the effect of sand capping on sediment turbidity. (b) Simulated average concentrations of suspended sediment (g/m³) in the bay over the summer months. (c) Example of a model simulation of the effect where one hectare of sand has been placed closest to shore (red box), and (d) when one hectare has been placed in the middle of the bay at a depth of 1.3–2.0 meters.

If modelling tools are not available, areas generating high turbidity can often be identified using aerial drones as gray sediment plumes in the area (Figure 5.5a). These observations can be complemented by mapping turbidity using field turbidity measurements (Figure 5.5b). These field measurements, together with long-term measurements of light conditions at different locations in the bay (see section 4.2), are also important for verifying and calibrating model results. At Lilla Askerön, the model results corresponded well with the field data.

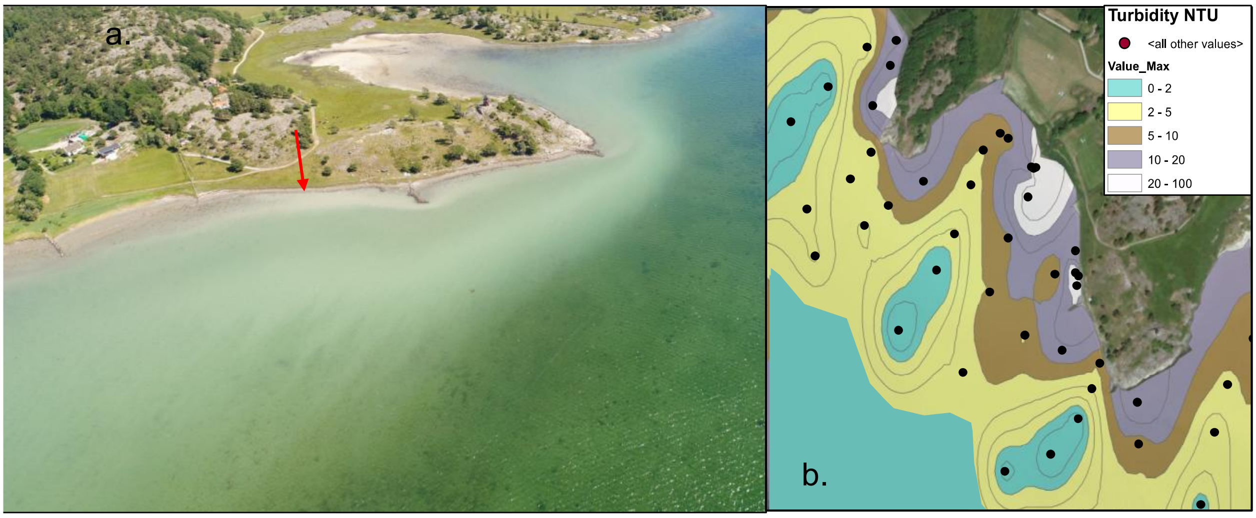


Figure 5.5. (a) Drone photo over Lilla Askerön in 2019 showing a typical turbidity plume covering the shallow parts of the bay. The highest turbidity is seen closest to shore near the stone pier (see arrow), where a sand capping was carried out in 2020. (b) Map based on field measurements of turbidity (NTU) at Lilla Askerön during two hours at midday when sea breeze created turbid conditions (from Möller 2019).

At Lilla Askerön, there was no vegetation of higher ecological value within the bay where sand coverage was planned, and this therefore did not influence the choice of location. However, small mussel aggregations were found in the southern, deeper parts of the bay, which limited the sand coverage area to the central parts. Based on the model results and the four criteria above, it was decided to place a smaller sand coverage (0.22 hectares) near the shore where turbidity was highest (Figure 5.5a), and a larger sand coverage of one hectare in the middle of the bay where eelgrass planting would take place.

5.4 Application for permits and right of disposition

In summary, the following is likely needed for sand capping:

- Notification to the County Administrative Board or permit from the Land and Environment Court for water operations
- Exemption from shore protection regulations
- Permit according to regulations within any area protection
- Written right of disposition from the holder of water rights

Sand capping is considered a water operation because it changes the depth of the water, which is why a notification to the County Administrative Board is required, or alternatively a permit from the Land and Environment Court for water operations under Chapter 11 of the Environmental Code. For smaller fillings, it may be sufficient to submit a notification to the County Administrative

Board. If the seabed area affected by the filling exceeds 3,000 square meters, a permit is instead required. You can read more about this on the County Administrative Board’s website. A monitoring program may also be needed, which is a program to monitor potential environmental effects during the sand placement (see below). When applying, it is important to describe how the sand placement is expected to affect various values and interests.

If the site is covered by any area protection, you may also need other exemptions, such as an exemption from shore protection regulations, or a permit under the area protection provisions (in marine protected areas, for example, dumping is often prohibited). You can read more about this on the County Administrative Board’s website.

Finally, right of disposition from the holder of water rights is also required, which for a larger sand placement must be obtained in writing. All these processes take a long time, so it is important to start the process at least one year before the planned sand capping. It is also worth noting that the notification and permit application affect the later procurement or hiring of a consultant to carry out the sand placement. Since high precision is more expensive, there may be a reason to apply for a slightly larger area and maximum sand capping depth than what is actually planned.

5.5 Procurement of contractors for sand capping and methods

In summary, the following aspects should be considered in procurement:

- The method can be proposed by the contractor
- Desired type of sand.
- The precision required in the thickness of the sand covering
- Minimum depth at the site and sensitivity to turbidity

Sand capping is an expensive measure that, in most cases, is carried out by a contractor. Unlike eelgrass restoration, many companies possess extensive knowledge and experience in covering the seabed with sand with high precision, primarily from work in harbor areas. As discussed in section 5.9 below, there are various techniques for spreading sand, each with its own advantages and disadvantages. Given the expertise among contractors, it may be a good idea to specify the desired outcome in the order or procurement while allowing the contractor to propose a suitable method that aligns with the company's experience and available boats and machinery. However, it is crucial to define the required precision in the thickness of the sand covering, the minimum depth at which the work should be carried out, the area's sensitivity to turbidity, and the acceptable level of turbidity during the operation (see below), as these factors influence the sand capping methods that can be used. Furthermore, it is important to provide information on the type of sand to be used and identify available sites for sand loading, as this affects transportation costs.

5.6 Environmental considerations and monitoring of environmental impact during sand capping

Summary of proposed measures and environmental monitoring:

- To minimize environmental impact, work should be carried out when the water temperature is at its lowest (from November to March).
- If the silt and clay fractions are low in the sediment to be added, and sensitive species are more than 100 meters from the sand placement, silt curtains or bubble barriers are likely not needed.
- Measurements of normal turbidity levels at the sand covering site and nearby areas with sensitive species (such as eelgrass meadows and mussel banks) should be conducted repeatedly under different weather conditions before sand placement begins to identify naturally high turbidity levels in the area.
- A turbidity threshold needs to be established based on naturally high values in the area (e.g., twice the naturally high value). If the threshold is exceeded multiple times or over extended periods (hours) in areas with sensitive species, work should be halted.
- At the start of sand placement, turbidity should be measured at the surface while work is ongoing and along a transect from the sand placement site in the direction of the current until values approach background levels.
- Drone images showing the areal distribution of turbidity plumes constitute a valuable compliment to water turbidity samples.
- If no threshold values are exceeded, measurements should ideally be repeated once a week until the work is completed.
- If threshold values are exceeded, work should be stopped and measures taken to reduce turbidity or sediment dispersion to areas with sensitive species (e.g., reducing sand placement speed or installing silt curtains or bubble barriers).
- After sand capping is completed, the thickness of the sand layer should be inspected, and any damage to the seabed should be assessed to determine if the conditions have been met and if corrective actions are needed by the contractor.
- After sand capping is completed, potential damage or disturbances to sensitive species (such as perennial vegetation, spawning fish, or mussels) in the surrounding area should also be investigated to assess whether further actions or continued monitoring are necessary.
- For more information on turbidity and precautionary measures, see the report "Dredging and Handling of Dredged Material" (SWAM 2018).
- For detailed information on sensitive periods for spawning fish and crustacean species in Sweden, see the *Spawning Period Portal* application (Swedish Agency for Marine and Water Management; https://www.havochvatten.se/arter-och-livsmiljoer/atgarder-skydd-och-rapportering/lektidsportalen.html)

If a monitoring program is required for water operations, the operator must propose and submit it to the supervisory authority, which may provide comments and additional requirements. Each monitoring program is unique to the water operation to be performed, as local conditions vary.

When carrying out sand capping, the main environmental risks are that turbidity and sedimentation from sand placement may negatively affect flora and fauna in the surrounding area, that damage may occur to the seabed or shoreline from the heavy machinery used, or that hazardous chemicals and fuels may leak from machines and boats. To reduce environmental risks, work should be conducted when water temperature and biological activity are at their lowest during the year, which is typically from November to March in southern Sweden. However, it should be considered that shallow marine areas may be ice-covered during this time of year.

Example of environmental monitoring at Lilla Askerön

During sand placement at Lilla Askerön, the monitoring program (turbidity measurements) showed that turbidity did not pose a significant problem due to the low fraction of silt and clay in the sediment (section 5.1), which is why silt curtains were never deemed necessary during the work. Due to extensive preliminary studies at the site, there was ample data on naturally high turbidity values in the area, which was used to set a turbidity threshold of 15 NTU that could not be exceeded at nearby natural eelgrass meadows located approximately 300 meters north and south of the placement site. Turbidity measurements were conducted in transects both north and south of the sand covering site from the start of the work on March 10, 2021, and regularly over two weeks.

High turbidity (up to 50 NTU) was measured at the sand covering site but decreased rapidly with distance. Turbidity values above 10 NTU were never recorded at a distance of 150 meters from the sand covering area. The 15 NTU threshold for turbidity at the eelgrass meadows located 300 meters from the sand covering site was never exceeded (Figure 5.6). In all measurement instances, water circulation was good, and even high turbidity values at the sand covering site returned to background levels within less than 30 minutes after the completion of work.

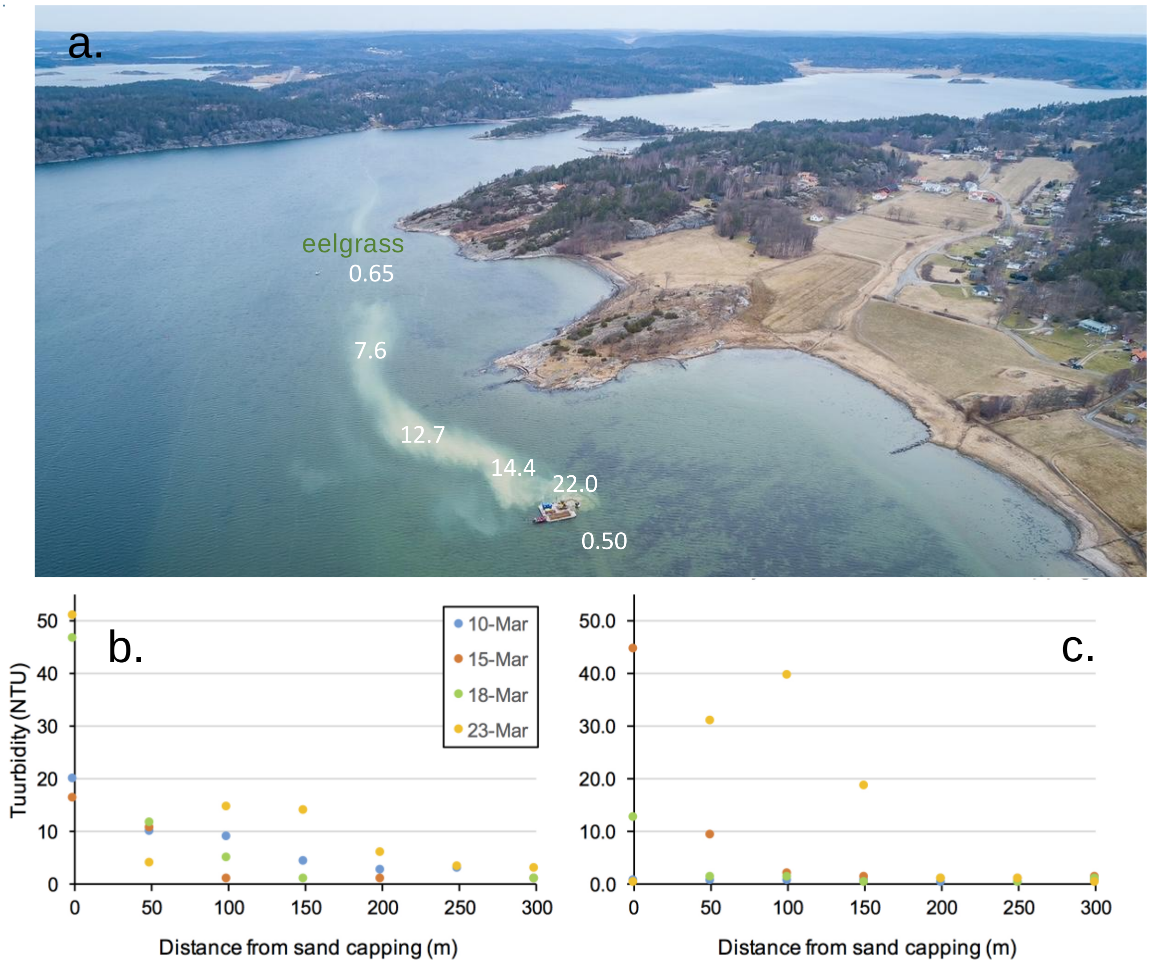


Figure 5.6. Results from turbidity measurements (NTU) in surface water during sand covering work at Lilla Askerön in March 2021. (a) Drone image of a sediment plume being transported toward an eelgrass meadow 300 meters north of the sand placement site, with measured turbidity values indicated at approximate locations. Measured turbidity values on four different dates at various distances from the sand covering work in (b) the northern and (c) the southern direction.

At Lilla Askerön, sedimentation rates were also monitored 50 and 300 meters from the sand covering site using sediment traps both before and during the work. A threshold value of 50 grams per m² per day was used at the eelgrass meadows 300 meters from the sand covering site, based on natural sedimentation rates at Lilla Askerön. The results showed elevated values 50 meters from the sand placement (30 grams per m² per day), but these were within the range of natural sedimentation rates measured in shallower waters in the bay at Lilla Askerön (17–67 grams per m² per day; Moksnes unpublished data). At the eelgrass meadows 300 meters from the site, no elevated sedimentation rates were observed during the sand covering process (Figure 5.7).

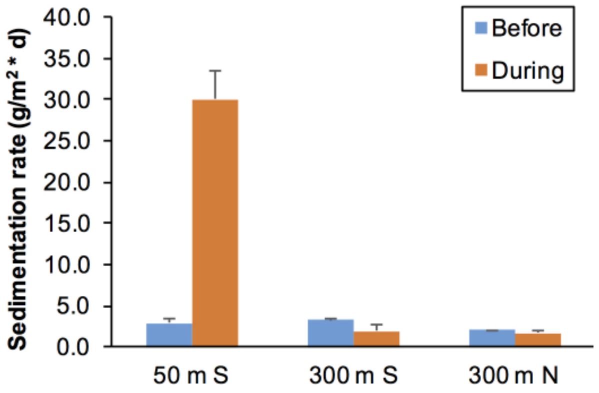


Figure 5.7. Sedimentation rate (mean value + SE) measured 7 days before sand covering began (blue bars) and during three days while sand capping was ongoing (orange bars) at 50 meters and 300 meters south of the sand capping site, as well as 300 meters north of the sand capping site where natural eelgrass meadows were found.

In summary, the effects of sand capping on turbidity and sedimentation during the ongoing work were very limited in both time and space, and no negative impacts could be demonstrated at nearby natural eelgrass meadows.

5.7 Sand capping and eelgrass planting

As discussed above, there are many different techniques for sand capping, each with its own advantages and disadvantages. For shallow areas with loose clay sediments that easily become suspended, and where high precision in the thickness of the sand cover is desired, it may be beneficial to use more careful methods—such as excavators to place the sand one bucket at a time. This technique can also be advantageous when sand with a wide range of grain sizes is used, as hydraulic methods (i.e., where the sand is mixed with water beforehand) may cause the sediment to fractionate by size during the process, with the finer material being released first (see Section 5.9 and Appendix B for details). Often, the contractor has experience and can suggest a method suitable for the local conditions. As previously discussed, sand covering should be carried out in winter or early spring to minimize environmental impact. In some areas, ice formation may pose a challenge that delays the start of the placement. Eelgrass planting can take place during the summer, directly after the sand capping is completed.

Planting eelgrass on sand-capped areas does not differ significantly from planting on natural sediment, and the same techniques recommended in the handbook can be used. The advantage of planting on sand is that the sediment is homogeneous and free from stones, algae, and bivalves (oysters and mussels; if planting occurs soon after sand placement), which simplifies the planting process. A disadvantage, if the gravel fraction in the sand is large, is that it becomes more difficult to press the shoots into the sediment, and gloves may be needed to protect the hands.

Examples of methods for sand capping and eelgrass planting at Lilla Askerön

An initial sand capping at Lilla Askerön was carried out in March 2020, when a smaller area of 2,200 m² was covered along the shoreline in the bay (0–0.5 meters deep). The work was performed by a contractor who proposed that the operation be conducted from land using a long-arm excavator working on logs to protect the ground. A barge was used to transport 380 tons of sand to the bay. The sand was delivered in big bags and then spread by an excavator equipped with GPS in the bucket, allowing for high-precision distribution. When the work was completed, the average sand depth was 11 centimeters (±2 centimeters) on the covered area (Figure 5.8). The purpose of the sand capping was to reduce turbidity and improve light conditions throughout the bay before planting eelgrass in deeper waters. No planting was done on the sand-covered area, as it is too shallow for eelgrass growth.

Figure 5.8. Sand capping at Lilla Askerön in March 2020 using an excavator from land. The right image shows a sediment sample from the sand-covered area, where the placed sand is clearly visible on top of the natural, muddy sediment.

A second sand capping was carried out at Lilla Askerön in March 2021, when a total of 1,800 tons of sand was spread in a 10-centimeter-thick layer over 10,000 m² at a depth of 1.3–2.0 meters in the middle of the bay. The work was performed by a contractor who proposed that the operation be carried out using an excavator on a floating barge, anchored with legs into the sediment. The sand was transported by truck to a nearby marina, from where it was further transported to the excavator using barges (Figure 5.9). Here too, a GPS in the bucket was used, which enabled the sand to be placed with high precision (10 centimeters ±3 centimeters).

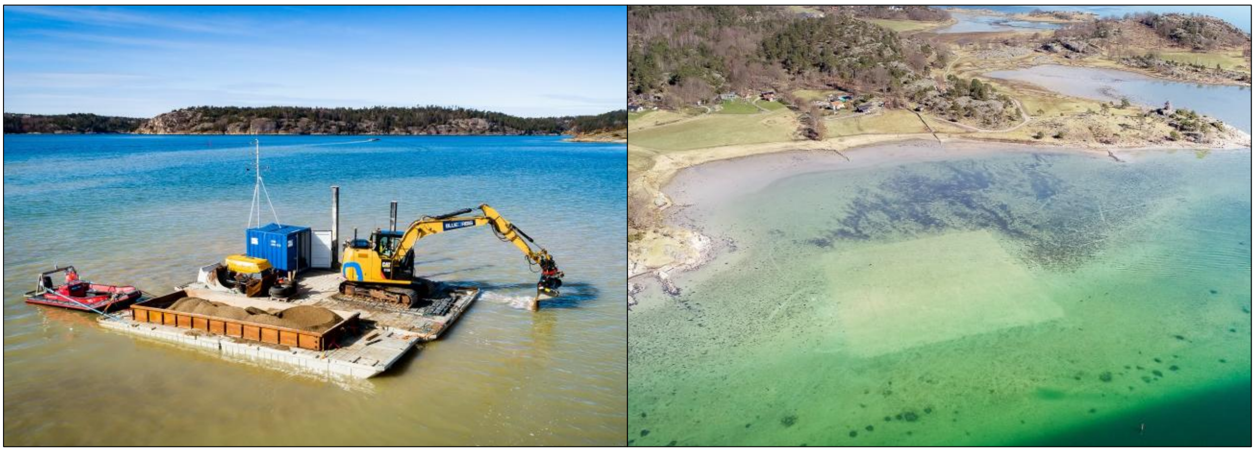


Figure 5.9. Sand capping at Lilla Askerön in March 2021 using an excavator on a floating barge anchored in the sediment with legs. The small barge in the foreground is used to transport the sand to the excavator. To the right is the one-hectare sand-covered area before eelgrass was planted.

Planting of eelgrass began in May 2021 and was carried out by consultants. A total of approximately 80,000 shoots were harvested from a nearby large meadow and planted by divers using the single-shoot method in a checkerboard pattern with 16 shoots per m² (see Section 4.3) across the one-hectare sand-capped area. The work faced challenges in the form of grazing swans and toxic clinging jellyfish (see Section 4.4), but was completed as planned during July 2021.

5.8 Monitoring of light conditions, eelgrass growth and fauna

Monitoring is a central part of the restoration process to determine whether the objectives of the measure have been achieved, as well as to increase knowledge in the event of restoration failure (see Section 4.5). Below is a description of the monitoring of the restoration at Lilla Askerön, where the handbook's protocols were followed.

5.8.1 Light conditions

A main objective of the sand capping was to reduce turbidity and improve light conditions for eelgrass growth in the bay. To monitor this, light conditions (the light attenuation coefficient; Kd) were measured inside and outside the sand-covered area where eelgrass had been planted (see Section 4.2 for methods). The results showed that Kd was significantly lower within the sand-covered area than outside under wind conditions that generate turbidity, corresponding to an improvement in water clarity of over one meter (Figure 5.10).

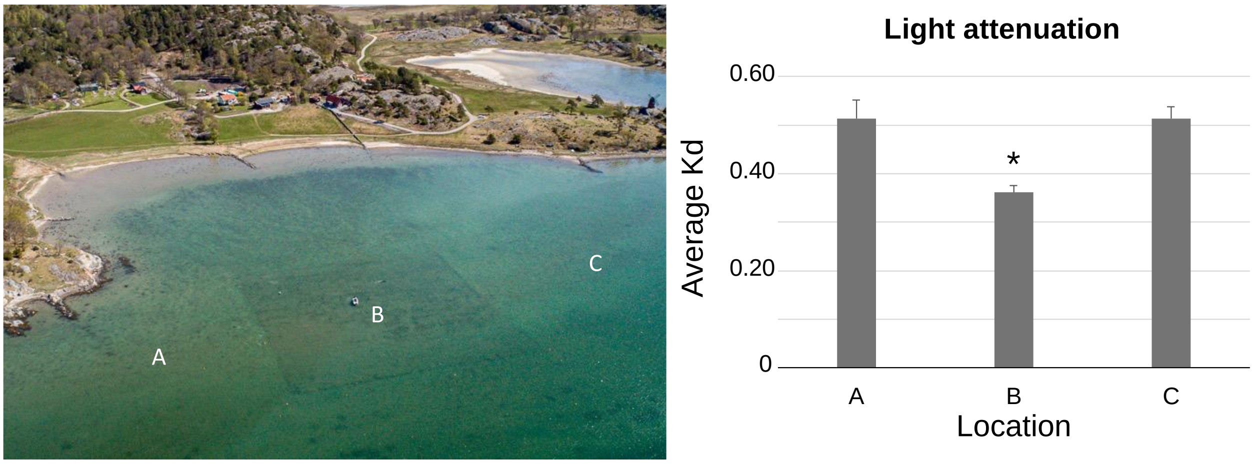


Figure 5.10. Results from light measurements at Lilla Askerön in 2023. The aerial photo on the left shows the positions of paired light sensors, with B located in the center of the restored area. The graph shows the calculated average value of the light attenuation coefficient (Kd) over a two-week period in late May, where the Kd value was significantly lower within the sand-capped area.

That growth conditions had improved was also demonstrated by the high growth of eelgrass in the sand-capped area, where eelgrass had shown negative growth before the measure, but after sand capping increased on average 36-fold in shoot density over 15 months (Figure 5.11). Due to large variation in light measurements over time, the monitoring provided a less clear picture of whether light conditions improved throughout the entire bay after the sand covering. However, this was supported by test plantings of eelgrass in shallow water (1.5 meters) outside the sand-covered area, which showed survival across several years after the measure.

5.8.2 Growth of eelgrass

Eelgrass growth and survival were monitored annually after planting through sampling of shoot density and biomass, as well as by estimating coverage using aerial drone surveys. The results showed both major losses in some parts of the planting area, but also very high shoot growth in areas that survived the first year. The losses mainly occurred in the shallow parts near the shore, where grazing by swans is a likely cause (Section 4.4.2), but also in the northwestern corner where approximately 2,500 m² showed very low shoot density after the first winter. The causes of the losses in this area are unclear, but the planted eelgrass is likely stressed by shore crabs and filamentous brown algae that cover the eelgrass for most of the growing season. It is also possible that shoots were uprooted by waves during rough weather, as shoots hanging only by their roots were observed in this area.

In the areas that survived the first year, however, eelgrass grew exceptionally fast, reaching over 500 shoots per m² after just two growing seasons (Figure 5.11), which corresponds to high shoot density in natural meadows in Bohuslän (Moksnes, unpublished data). During the sampling in autumn 2024, the eelgrass in the surviving planting squares had begun to merge, and the total eelgrass cover was estimated to exceed 5,000 m², which is the same area that was originally planted with shoots in a checkerboard pattern across one hectare. Based on the average shoot density, the total number of shoots was estimated at approximately 2 million, corresponding to a 26-fold increase from the 80,000 shoots planted in 2021.

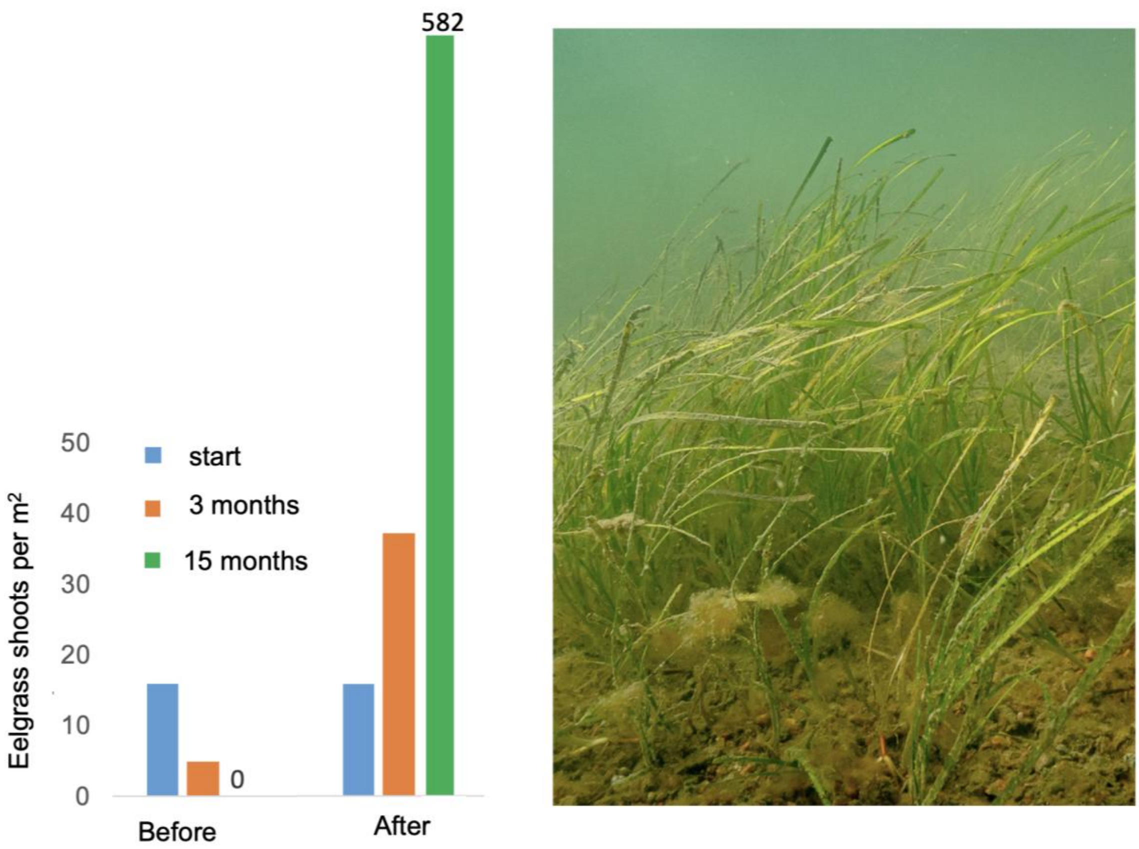


Figure 5.11. Growth of eelgrass (16 shoots per m²) over 15 months at 1.5 meters depth at Lilla Askerön before sand covering (2018–2019) and after sand covering (2021–2022). The right image shows planted eelgrass in 2022.

5.8.3 Recovery of infauna

Sampling of infauna (invertebrates living buried in the sediment) inside and outside the sand-covered area in September 2021 showed that infauna biomass was similar on natural sediment and sand (527 and 492 milligrams per sample, respectively), while the total number of taxa (e.g., genus, family, or order) found in the sand-covered area (26 taxa) was higher than on natural sediment (23 taxa). The number of taxa and biomass of mussel species, and to some extent amphipods, were several times higher on sand than on natural sediment. The number of snail and polychaete taxa was more similar, but the polychaete individuals were larger on natural sediment, likely because the polychaetes on sand mostly consisted of newly recruited individuals. During the sampling of the sand-covered area, several observations were made of live adult blue mussels (*Mytilus edulis*) and oysters (*Ostrea edulis*) on top of the sediment, indicating that they can migrate up to the sediment surface and survive if covered by 10 centimetres of sand.

In autumn 2023, a large number of juvenile blue mussels were observed on the gravel in the vegetation-free corner of the sand-covered area. The mussels were clustered in small groups, and almost covered by larger gravel particles held together by byssal threads (Figure 5.12). Monitoring of the juvenile mussels in 2024 showed very low mortality, which was surprising given that eiders visited the site and there was an abundance of shore crabs in the area. Possibly, the gravel cover provides protection from predators, which may explain the successful recruitment. In autumn 2024, an average of 165 mussels per m² was found in the vegetation-free corner, and it is estimated that over 450,000 blue mussels had colonized the sand-covered area.

Figur 5.12. Examples of "gravel clusters" with juvenile blue mussels found in large numbers in vegetation-free areas of the sand-capped site in October 2023. The gravel clusters are created by juvenile blue mussels attaching their byssal threads to larger gravel particles.

In summary, the results show that sand capping can be an effective method to restabilize and reduce turbidity on clay bottoms that have lost an eelgrass meadow, thereby improving the light environment so that eelgrass can once again grow at the site and enable restoration. Sand capping caused very little negative environmental impact and added a sediment that appears to benefit infauna and mussel recruitment. Sand covering measures are recommended for other areas where turbidity prevents eelgrass recovery.

5.9 Sand capping methods and sand sources

In the following section, a very brief description is provided of methods for sand placement on the seabed, as well as the sand sources available. Appendix B contains a detailed description of various sand placement methods, their advantages and disadvantages, and available sand sources in the county of Västra Götaland in Sweden.

The sand capping methods identified in the literature fall into the categories of either mechanical or hydraulic placement. However, how the sand is loaded, stored, and transported to the site, as well as whether it is released at the surface or closer to the bottom, may vary. Mechanical sand capping usually involves sand sources that are relatively dry. These originate either from land-based sand pits or dewatered marine sediments. In this type of sand capping, the material is released at or below the water surface and gravity carries it to the bottom. This can be done using, for example, an excavator, as was the case at Lilla Askerön in 2021 (see Section 5.8; Figure 4.20). Mechanical sand capping using an excavator is often time-consuming but can be carried out with high precision (± 2 centimetres) and in shallower areas (1 meter; Blue Orbis 2021). Other examples of mechanical methods include dumping material from bottom-emptying barges and hydraulic flushing of material from barges (see Appendix B for a detailed description of mechanical sand placement).

In hydraulic sand capping, the sand is first mixed with water. The sand may originate from land-based pits, mechanical dredging, or hydraulic dredging where the sand is suctioned from the seabed and naturally mixed with water. The slurry of water and sand can then be spread on or below the sea surface using various methods. Placement using hydraulic methods can, for example, be done by pumping the material from smaller dredging barges. There are also solutions where floating hoses are used and a smaller boat manoeuvres the hose and the placement of the sand over the seabed, which can improve accuracy and allow sand to be placed at shallow depths (1.5–2 meters; Rohde Nielsen 2020). Other examples of hydraulic methods include so-called “rainbowing,” where the material is sprayed through the air with high force from a vessel in deep water toward the shore (see Appendix B for a detailed description of hydraulic sand placement).

The method, or combination of methods, best suited is usually dependent on the conditions at the site to be sand capped. The decision is influenced by factors such as water depth, wave and current conditions, sediment stability, bottom topography, and boat traffic in the area. It is also affected by the presence of sensitive species nearby, how easily the sediment becomes suspended, and what human activities are present in the vicinity. Sand capping via pipes or bottom-emptying barges is best suited for open areas, such as harbours and shipping lanes. In areas that are narrower or closer to shore, placement from land or shallow-draft barges may be considered (Jarsek et al. 2016; see Appendix B).

In sand capping projects, an important part is identifying potential sand sources that can be used in the project. The sand needs to be free from contaminants and invasive species and may originate either from land-based pits or from marine dredging. There are mainly three types of sand sources available: land-based pits, marine pits, and marine dredging carried out to increase depth in, for example, a harbour.

Advantages of using sand capping material from land include that the clay and silt fraction is likely lower compared to material dredged from the seabed. This, in turn, leads to less turbidity during sand placement. The type of material that has previously been successfully used for eelgrass sand capping in Bohuslän consisted of fractions from fine sand up to 8 mm gravel (see section 5.1 above). Another advantage may be that the availability of material is greater on land, which means more options are available and transport distances may be shorter. Sand from land-based pits is in most cases also free from contaminants and invasive species, which can otherwise be a problem when using marine sediments. The cost of sand per volume is generally higher from land-based pits than from marine sources. The cost of mobilizing sand material from land pits is lower than from the sea and also less weather-dependent. However, the cost of transporting material by truck on land may be higher, and it is important to consider both environmental and logistical aspects of transport. The capacity of land-based pits may also be lower, and natural gravel (like that used in the sand capping at Lilla Askerön) is a limited resource that may be reserved for other land-based activities, making land-based sand more suitable for smaller projects (SGU 2020). In Sweden, sand extraction in the Öresund has been prohibited since 1982, and only one permit for the extraction of marine sand and gravel exists in Swedish waters. This site is Sandhammar Bank, south of Ystad (SGU 2017). It is therefore likely not possible to purchase marine sand from marine pits in Sweden, and if this option is considered, sand must be purchased from, for example, Denmark, Germany, or Poland (see Appendix B for more information on available sand sources).

6 Cost of eelgrass restoration in Sweden

Eelgrass restoration using the methods that are effective and currently available is time-consuming and therefore costly. Harvesting and planting often need to be carried out by diving, and all work is done manually.

In the handbook (Moksnes et al. 2016), the costs of restoration are estimated based on information available from smaller restoration projects within the research group. However, since 2016, several large-scale eelgrass planting projects have been carried out, where the work has also been procured and performed by consultants. As a result, there is now much new information available for a more accurate calculation of restoration costs.

6.1 Time estimates

The times for harvesting and planting eelgrass shoots presented in Moksnes et al. 2016 still correspond well with the times recorded during larger large-scale plantings. During eelgrass plantings carried out at Gåsö in 2019, the time required for both harvesting and planting was carefully documented. Six divers with varying levels of experience in eelgrass restoration participated in the work. The number of shoots harvested per person and hour initially varied between 180–600 shoots, depending on the individual’s level of experience. Over time, these differences decreased, and one person harvested an average of 400 shoots per hour. Planting shoots takes on average 25% longer, with approximately 300 shoots planted per person and hour. Planting speed also increased over time, which shows that it is important for those performing the restoration to practice both harvesting and planting before starting. During the plantings carried out at Gåsö, additional time was also recorded for tasks such as marking planting areas, transportation, changing air tanks, and more. This “non-diving work time” was significantly greater than what is stated in the handbook’s cost estimates for restoration, and the total working time based on the Gåsö study was 33% longer. According to the handbook, a team of 4 divers and two people on the boat should be able to harvest and plant 4,000 shoots per day. With the higher non-diving work time, the actual number was 2,700 shoots harvested and planted by 4 divers per day. A full dive team with experienced divers might be expected to reach 3,000 shoots per day. This means, for example, that a large-scale planting of 1 hectare of eelgrass using the checkerboard method, requiring 80,000 shoots, would take a total of ca 27 working days, which is about 7 days longer than estimated in the handbook.

According to consultants who have carried out harvesting and planting at several locations along the coast of Västra Götaland, the time required varies between sites. Based on plantings conducted over several years, at different locations and with different personnel, one person harvests and plants an average of 300 shoots/hour (personal communication Sandra Andersson, Marine Monitoring AB). According to experience from the same consultancy, divers can on average work actively with harvesting and planting for about 4–5 hours per day if the same personnel are to be used over a longer period. These times are based on a 12-hour workday, of which 7–8 hours consist of tasks other than harvesting and planting. The workday includes all time from when the staff leave their accommodation until they return in the evening and thus includes transportation, preparation of diving equipment, boat loading, briefings, air refills, and tank changes, etc. Due to logistical differences, however, non-diving work can vary both between projects and between sites within a project. The number of shoots harvested and planted per day by 4 divers was estimated at 2,400–3,000, which is similar to the figures recorded at Gåsö.

In 2020, consultants carried out plantings on a total of 0.8 hectares at two sites at South Koster. The time required for harvesting and planting stated in the final report from this work shows that it took two dive teams (4 divers) a total of 57 hours to harvest 67,192 shoots and 99 hours to plant 65,642 shoots. This corresponds to a harvesting rate of an average of 301 shoots per person and hour and a planting rate of 169 shoots per person and hour. The lower planting rates compared to the handbook are believed to be due to the low water temperature (10°C) when the work began in mid-May. This made the work slower as the divers could not perform the planting with thicker wetsuit gloves or dry gloves. Another factor that slowed down planting was compacted sediment, the presence of sharp oysters and shells.

In 2021, consultants carried out plantings on 1 hectare on a sand-capped area at Lilla Askerön. The time required for harvesting and planting of shoots shows that it took 3 and later 2 dive teams (6 and later 4 divers) 275 hours to harvest 84,177 shoots and 467 hours to plant 80,012 shoots. The report does not specify when the switch from 6 to 4 divers occurred, but if assuming 5 divers throughout the period, the average harvesting rate was 61 shoots per person and hour and the planting rate was 34 shoots per person and hour. This is significantly slower than what was recorded in previous plantings, even by the same consultant. The reason for these low figures is believed to be a number of difficulties discovered during the work. The most critical factor, according to the consultants themselves, was the nature of the sediment. The area had been covered with a 10-centimeter-thick layer of natural gravel in the 0–8 millimetre size fraction before planting. The gravel was described by the consultants as sharp and caused bleeding fingers and infections after prolonged planting work. The surface was also considered uneven, which made planting more difficult. This slowed down the work and led the divers to use gardening gloves. Harvesting also went more slowly, mainly due to the presence of clinging jellyfish, which caused the work to be interrupted several times and eventually led to the use of full-face masks, which slowed down the harvesting work.

Variations in time requirements due to local conditions were also observed during eelgrass restoration in Kalmar County, where it took 4 divers 2.5 days to plant 3,200 shoots at the Kårehamn site, while the same number of shoots were planted in 1.5 days with 3 divers at the Ispeudde site (personal communication Rita Jönsson, County Administrative Board of Kalmar County and Jonas Nilsson, Linnaeus University). The differences were due to the sediment at Kårehamn being hard and compact, and both harvesting and planting took longer.

In summary, the results from Gåsö and time data from consultants show that the time required for harvesting is relatively consistent and varies between 300–400 shoots per person and hour. Based on this, accurate calculations can be made for this part of the restoration work. However, planting work can be more affected by local conditions. If the site has hard sediment, a high presence of oysters, or if planting begins early in the year when water temperatures are low, planting time may need to be adjusted. The most variable factor, however, is the so-called "non-diving work," and individual estimates of this should be made for each new restoration project, where, for example, transportation times, logistics for air refills, and marking of planting areas should be taken into account.

6.2 Cost

For large-scale plantings, it is common for the work to be procured as a service and carried out by consultants. Below is an account of the costs for the various plantings, including a specification of what was included in each assignment. At the end, accounts are also presented for sand capping.

6.2.1 Eelgrass harvesting and planting

In Kosterhavet, the planting was carried out by consultants, and according to the assignment description, harvesting and planting of eelgrass were conducted at two sites near South Koster. A total of 65,642 shoots (0.8 hectares) were harvested and planted in a checkerboard pattern at the two sites. The final cost for this work was SEK 1,000,000, which corresponds to SEK 16 per shoot, or SEK 125 per m^2 (in a checkerboard pattern).

The planting at Lilla Askerön was carried out by consultants. A total of 80,012 shoots were harvested and planted in a checkerboard pattern on the 1-hectare sand-covered area. The final cost for this work was SEK 1,450,000, which corresponds to SEK 23 per shoot, or SEK 145 per m^2 (in a checkerboard pattern). The cost was SEK 100,000 higher than agreed, due to the unforeseen problem with clinging jellyfish, which forced the consultant to purchase full-face masks in order to continue the work.

Within the LIFE Coast Adapt project, consultancy costs for eelgrass restoration work amounted to just under SEK 3,900,000 (personal communication Camilla Greiff, Region Skåne). This includes all measurement efforts carried out by consultants, including all years of planting totalling approximately 35,600 shoots on 2,960 m^2, which corresponds to SEK 110 per shoot, or SEK 1,318 per m^2.

The comparison shows that the price per planted square meter can differ by a factor of 10 between different projects and consultants, which appears to be a greater difference than can be explained by varying difficulty and time requirements between the projects. One possible explanation is that the field is still new, making it difficult both for the consultant to estimate their costs and for the client to know what it should cost. Unit costs generally decrease with increasing planting area size. This means that a test planting is usually more expensive per unit (e.g., per shoot or m^2) than a large-scale planting. Based on the time required for a large-scale planting where 4 divers (with 2 dive supervisors) manage to plant approximately 2,400–3,000 shoots per working day (12 hours, see section 6.1), the cost is approximately SEK 23–28 per shoot. In a test planting, the proportion of downtime is higher because the time for preparations, transport, launching, etc., is only distributed over one working day. In a test planting south of Stenungsund in 2024, 800 shoots were planted on a 10x10 meter area, where every other square meter was planted with 16 shoots per m^2. The cost per shoot for one day of planting with one dive team (1 dive supervisor and 2 divers) was SEK 64, which is about three times higher than for a large-scale planting.

6.2.2 Sand capping

In spring 2020, a sand capping was carried out on 2,200 square meters in the nearshore areas of Lilla Askerön. Consultants placed a total of 380 tons of sand in the bay using an excavator from land, with an average sand depth of 11 centimetres. The final cost for this work was SEK 650,000, which corresponds to SEK 295 per m².

Before eelgrass planting took place at Lilla Askerön, a sand capping was carried out on the 1-hectare area. The sand capping was procured separately from the eelgrass planting. It was carried out by consultants, with the assignment consisting of spreading a 10-centimeter-thick layer of sand (natural gravel 0/8) over an area of 10,000 m², totalling 1,800 tons. The total contractor cost for the sand placement was SEK 2,300,000, which corresponds to SEK 230 per m².

The consultancy cost for assistance with the permit application amounted to SEK 108,000, although a large part of the environmental impact assessment was produced internally. Other costs, such as public fees and information signs that were installed, amounted to a total of SEK 34,960. The monitoring program was carried out by the University of Gothenburg.

7 What can the public do?

All eelgrass restoration in Sweden has so far been initiated by universities, government agencies, and municipalities, as well as by ports as a compensatory measure in connection with development projects, and carried out by professional divers. However, there is growing interest among private individuals and companies who wish to carry out eelgrass planting (personal communication Beatrice Alenius, County Administrative Board of Västra Götaland). Below is some information and advice for those interested in planting eelgrass or in contributing in some way to actions that can improve conditions for these important ecosystems.

7.1 Eelgrass restoration

Start by trying to understand how the restoration process works. As a complement to the 2016 handbook for eelgrass restoration, a number of videos have been produced that explain why eelgrass is important and go through the entire restoration process—from site selection to planting and how best to follow up. These videos can be found on YouTube: https://www.youtube.com/channel/UCPx0jz3gl8VN4Nd8QlBOYLQ (in English)

You can also read more about eelgrass restoration efforts on the website of the Swedish Agency for Marine and Water Management, as well as on the website of the research program Zorro.
SwAM website: https://www.havochvatten.se/en/our-organization/publications/swam-publications/2021-03-16-handbook-for-restoration-of-eelgrass-in-sweden.html
Zorro website: https://www.gu.se/en/research/zorro

There are currently no clear regulations regarding small-scale (1–2 m²) test plantings of eelgrass. However, if you follow the handbook and do not harvest shoots in a way that damages the eelgrass meadow, you generally do not need any permits beyond the landowner’s approval. It is important to note, however, that in protected areas it may be prohibited to collect plants. If the test planting is successful and you wish to plant larger areas, an exemption from the shoreline protection is usually required from the municipality (or from the County Administrative Board if the area is under national protection; see section 3).

Challenges in eelgrass restoration include the fact that meadows or available planting areas often grow at depths greater than 1 meter. If you are not an experienced freediver, this can make it difficult to harvest and plant shoots using snorkelling, and scuba diving may be required. If you want to plant in deeper water using diving but lack the skills, you can try involving a local diving club. It is important to check what rules and insurance requirements apply for diving, whether the planting is done on behalf of a company or privately. Non-profit organizations can apply for funding for this type of action (see section 7.3). However, some co-financing is often required, and voluntary work is rarely reimbursed.

To avoid the need for diving, you can choose to harvest shoots that have drifted ashore (if a small planting is to be carried out) or harvest shoots from a shallow, dense meadow (be careful not to trample the eelgrass or harvest too many shoots from the same spot). Planting at about 1 meter depth can be done with snorkelling, but the water can quickly become cloudy, making it difficult to see after a while. Shallower plantings than 1 meter are usually not suitable due to the risk of ice damage during winter. The Zorro program is presently developing simple restoration methods for potential volunteers, using natural shoots that have stranded on the beach as sources, and planting the shoots on deep water from boats in bundles with weights. Initial studies show promising results (E. Wik unpublished data).

7.2 Other eelgrass-enhancing measures

There are also a number of other positive actions individuals can take to support eelgrass. One very important aspect is spreading knowledge. Many people do not know what eelgrass is or why it is important. By sharing information about eelgrass—for example, with friends, at the marina, or in natural harbours—greater awareness can be raised, and hopefully, more people will be motivated to protect these ecosystems. This is especially important since many human activities that can harm eelgrass (such as dock construction and anchoring) are concentrated in the areas where eelgrass grows (shallow, wave-sheltered bays). The Zorro-program has produced a short video which explains why eelgrass is important (https://www.youtube.com/watch?v=fpNOlmrXMXQ *in Swedish*), which can be shared to knowledge).

If you want to read more about how recreational boating activities and structures affect shallow, wave-sheltered bays, and what can be done to reduce this impact, you can download the report *“Fritidsbåtars påverkan på grunda kustekosystem i Sverige”* (The Impact of Recreational Boats on Shallow Coastal Ecosystems in Sweden; Moksnes et al. 2019): https://havsmiljo.se/media/fritidsbatars_miljopaverkan.pdf (in Swedish with an English summary)

7.3 Financing

On the website of the Swedish Agency for Marine and Water Management, there is a compilation of grants available to county administrative boards, municipalities, water councils, private individuals, and other actors who want to actively work with water conservation, measures, and restoration:

https://www.havochvatten.se/bidrag-utlysningar-och-anslag/hitta-bidrag-for-en-battre-havs--och-vattenmiljo/bidrag-i-sokbar-tabell.html (In Swedish)

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Appendix A Proposed guidelines for light data analysis

Appendix B Sand capping – an overview of methods and sand sources

Handbook for restoration of eelgrass in Sweden

State of knowledge update 2016-2024

The condition of the coastal and marine environment needs to be improved. A large number of international and national commitments and decisions require measures to reduce impact and pressure, as well as to restore coastal and marine environments.

Planting eelgrass is an important measure for restoring historical meadows or as a compensatory action when eelgrass is damaged due to development. In 2016, a detailed technical manual for eelgrass restoration in Sweden was published (Moksnes et al. 2016) (SwAM Report 2016:9). This handbook describes all the key steps in the restoration process, from site evaluation and selection, consultations and permits, to harvesting and planting, as well as monitoring and evaluation of results. Since then, the methods described in the handbook have been tested in various projects at several locations along the Swedish coast, and continued studies in Bohuslän have led to new knowledge and the development of restoration methods.

This report, which serves as a complement to the handbook, compiles new knowledge on eelgrass restoration based on these experiences from the Baltic Sea and the Skagerrak between 2016 and 2024. It also compiles knowledge from several restoration projects in Bohuslän carried out by researchers at the University of Gothenburg in collaboration with the County Administrative Board of Västra Götaland, with the aim of developing new restoration methods.

It is the hope of the Swedish Agency for Marine and Water Management that the handbook can serve as a support for supervisory and permitting authorities, as well as for operators and consulting firms working with eelgrass restoration. The handbook was developed in collaboration between the Swedish Agency for Marine and Water Management, the County Administrative Board of Västra Götaland, and the University of Gothenburg.

The Swedish Agency for Marine and Water Management (SwAM) is a national government agency
in the environmental sector. We work on behalf of the Swedish government to conserve, restore,
and ensure the sustainable use of lakes, watercourses, seas, and fishery resources

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