Elodea species in the northern Gulf of Bothnia

Removal- and Monitoring methods tested in the SeaMoreEco project

Interreg Aurora

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SeaMoreEco
Seamless Monitoring, Restoration and Conservation in the northern Gulf of Bothnia

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Preface

The shallow coastal areas of the northern Gulf of Bothnia represent ecologically important areas, distinguished by their rich biodiversity and unique habitats. However, these areas are increasingly vulnerable to the pressures of human activity and the accelerating impacts of climate change. A challenge for management today is the lack of knowledge of occurring species and habitats and practical solutions on how to improve their conservation status.

SeaMoreEco is a Finnish-Swedish initiative that during the years of 2023 – 2025 brought together expertise in marine biology and geology to map coastal habitats as well as develop, test, and demonstrate methods for monitoring, conservation, and restoration in shallow marine environments in the northern Gulf of Bothnia.

This report is published as one output of the project, with the aim to share the results of the extensive method testing for removal and monitoring of the invasive *Elodea* species *Elodea canadensis* and *Elodea nuttallii*, found in the northern Gulf of Bothnia. Through these efforts, the project aims to strengthen the knowledge of marine habitat and their management and foster long-term resilience in the northern Gulf of Bothnia's shallow ecosystems.

The project was financed by Interreg Aurora and co-financed by Regional Council of Lapland and Swedish Agency for Marine and Water Management.

Participating organisations:

County Administrative Board of Norrbotten
County Administrative Board of Västerbotten
Geological Survey of Finland
Geological Survey of Sweden
Centre for Economic Development, Transport and the Environment in North Ostrobothnia
Centre for Economic Development, Transport and the Environment in South Ostrobothnia

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From Norrbotten we like to thank Linnea Bergdahl for running the project and David Bell, Maja Wressel and Johanna Lycksell for participating in the field work. Thanks go also to Mary Agrér who was project leading SeaMoreEcos during the first year.

We would like to express our sincere appreciation to our colleagues at the ELY Centres in North Ostrobothnia and South Ostrobothnia for their expertise and assistance with various tasks. Our gratitude also goes to Metsähallitus for their support in knowledge exchange and in setting up the jute covers. We further thank the landowners, common land associations, and the private road associations around the test sites for their invaluable help and cooperation throughout the testing process.

During the project we have also arranged two workshops (1.12.2023 and 30.9.2025) to exchange knowledge of *Elodea* species and removal methods. Special thanks go to Kristina Tattersdill (PhD) and all the others presenting and/or participating in the workshops!

Summary

Six different methods for removal of the invasive species Canadian waterweed *Elodea canadensis* were tested in the project. In addition, monitoring both Nuttall's waterweed *Elodea nuttallii* and *E. canadensis* were tested with drones and by snorkelling.

With the short study period in mind (2023-2025) floating cover seems to be a very successful method in supressing all the vegetation including *E. canadensis* just in one summer season. Also, jute cover kept the *E. canadensis* and other vegetation away as long as a new jute cover was added in the spring each year. Plastic cover supressed all vegetation during the whole project period but was hard to keep flat on the sediment because of the gas building underneath. The aquarium experiments showed that *E. canadensis* could be controlled with both dye and salt but only salt treatment seemed to kill the plants (~7 psu). Mechanical removal of *E. canadensis* combined with a suction pump to collect plant fragments was also tested but is not recommended for further use as the suction pump did not manage to gather all the small fragments and the risk of spreading the *E. canadensis* was still high.

Even though some removal methods are cheaper than others, combating *Elodea* species in the field through removal is expensive and the areas for removal measures should be chosen carefully. Removal measures should for example be prioritised in areas where threatened species are in danger to be outcompeted by *Elodea* species. Also, removal measures should be directed in areas where *Elodea* species are not yet the dominating macrophyte species to avoid recolonisation and to succeed in total eradication.

Nevertheless, the priority for the management should be monitoring the shallow coastal areas of the northern Gulf of Bothnia for early detection of the *Elodea* species and the changes in the native macrophytes coverage and species composition, as well as informing the public about how easily *Elodea* species spread and what can be done to avoid this. The drone monitoring of *Elodea* species tested in this project was successful in areas with high coverage of *Elodea* species if the water was relatively clear. The *Elodea* species could indeed be differentiated from other type of vegetation. When *Elodea* species occurred in low coverages, they could not be detected with a drone and therefore other methods such as snorkelling inventories are still needed. Environmental DNA could also be a complementary method for detecting *Elodea* species together with drone.

Keywords: Elodea canadensis, Elodea nuttallii, removal, control, restoration, cover, monitoring, drone

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Background

Elodea species distribution and ecology

Elodea canadensis (Figure 1) and *Elodea nuttallii* (Figure 2), are two invasive alien waterweed species in the Gulf of Bothnia, native to North America (1). A collective name for these two species in this report from here on is *Elodea* species. It is likely that *E. canadensis* was introduced to Europe multiple times, both accidentally with ships when transporting goods (2) but also on purpose to have as ornamental element (1). It was first recorded in Ireland in 1836, likely introduced through ballast water (3). Later it was introduced to Sweden during the 1870's (2) and to Finland in 1887 when it was brought in purpose to the Helsinki Botanical Gardens (4). *Elodea nuttallii* on the other hand, was first encountered in the Europe in 1939 (1). In Sweden, *E. nuttallii* was recorded for the first time as late as in 1992 (5) and in Finland only some years ago, in 2021 (6). *E. nuttallii* was also initially introduced to Europe for ornamental purposes (1). Later, the spread of *Elodea* species has probably been facilitated by birds and boating (7, 8).

Figure 1. Elodea canadensis in Norra Grundfjärden, Västerbotten County. E. canadensis has wider and more oval shaped leaves compared to E. nuttallii. Also, E. canadensis leaves are always in whorls of three at each stem joint.

Figure 2. E. nuttallii in Vargviken, Norrbotten county. In the picture the species is flowering with flowers on thread-like stalks. E. nuttallii can be distinguished from E. canadensis by its narrower leaves that are often twisted.

Both species are found mainly in freshwater but also in coastal areas in Sweden and Finland (Figure 3). Coastal lagoons such as flads and glos are important biodiversity hotspots, but *Elodea* species are also commonly found in these habitats. In Sweden, the southernmost observations of *E. canadensis* in coastal brackish environments (bays, lagoons) are from south of Stockholm in Norrköping (9). Next observation of *E. canadensis* in coastal areas is as far north as Härnösand and Umeå. Most of the observations are from Norrbotten county. The southernmost coastal observation of *E. nuttallii* is also south of Stockholm, in Nyköping. Some more observations of *E. nuttallii* are found in the inner archipelago of Stockholm, between Gävle and Sundsvall, as well as in Västerbotten county. Most of the observations are again from Norrbotten county.

In Finland, most of the coastal observations of *E. canadensis* start at the latitude of Oulu and become more frequent towards the north, but it is also found in the south and west coasts of Finland from Kotka to Merikarvia and again in Luoto, Kokkola and Kalajoki (10). In Finland, *E. nuttallii* has not yet been found in the coastal areas. However, *E. nuttallii* has been observed in lakes and ponds in Southwestern Finland.

In general, observations of *Elodea* species in the Baltic Sea show a clear peak in the Bothnian Bay. *E. nuttallii* is more common of the two species in Norrbotten county (Sweden), whereas *E. canadensis* is the only *Elodea* species present on the Finnish coast. It is likely that the low salinity in the Bothnian Bay explains at least partly the high number of observations of

Elodea species in the area, and that the *Elodea* species distribution is simply restricted by the high salinity in the south. Nevertheless, several other factors are likely to play a role as well, such as introduction history and spatial differences in suitable habitats and in mapping efforts.

To the current knowledge, the populations of both species in Europe consist only of females and therefore only spread vegetatively (11). They spread easily from small fragments of the plant and build new populations (1). Both species are originally freshwater species but tolerate well brackish water. They are fast-growing, taking the space from native species, reducing the biodiversity and building dense meadows (1). *E. canadensis* thrives best in salinity between 0 to 1,2 psu. Salinities above 6 psu are lethal (12). *E. nuttallii* on the other hand seems less sensitive to salinity (13).

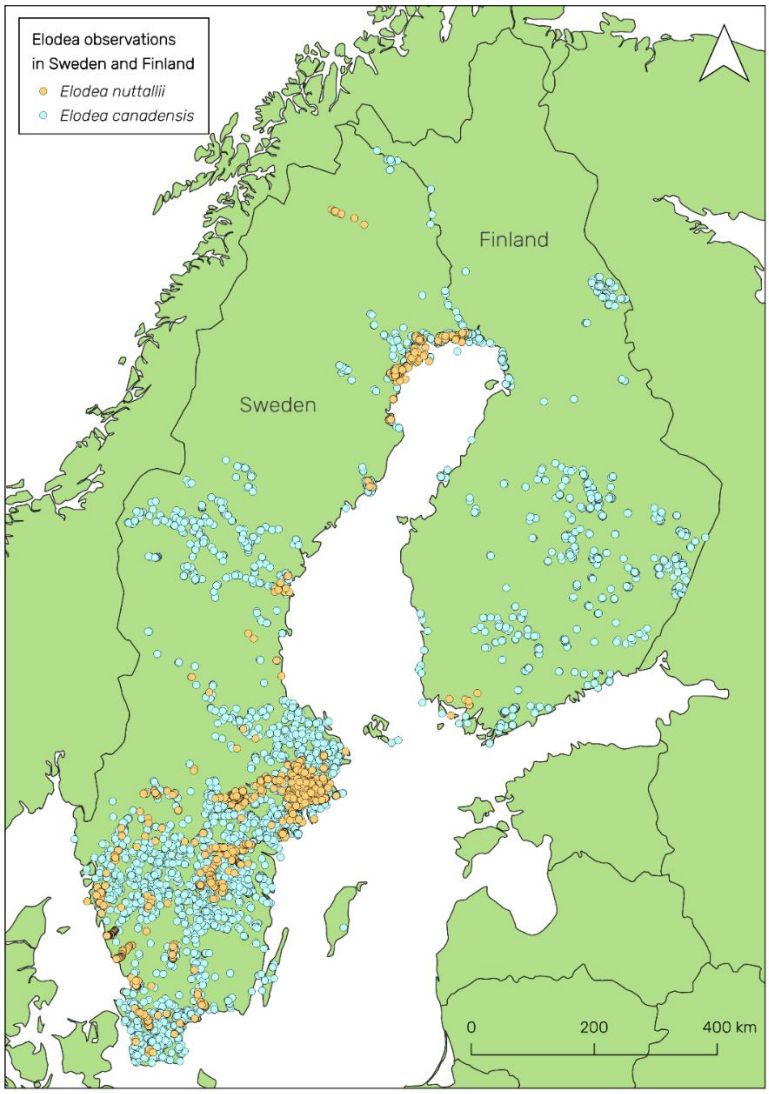

Figure 3. Distribution map of Elodea nuttallii and Elodea canadensis in Sweden and Finland. Observations done in 1990-2025. Data from Artportalen, Swedish Species Observation System and the Finnish Biodiversity Information Facility.

Overall, the growth cycle of both species starts early in the spring, peaking in the summer in temperatures above 10 °C. Both species can overwinter at least with the help of turions. Nevertheless, slow growth of *E. nuttallii* fragments has been observed in lakes at 4 °C, suggesting that the species might not have any winter dormancy (1).

Challenges in management of Elodea species

Elodea nuttallii is listed as a species of Union concern under the EU regulation on invasive alien species, which makes it illegal to import, sell, cultivate, or release the species into the environment in any EU member country. EU countries are also required to monitor its spread, implement preventive measures, and undertake eradication measures where necessary. In Finland *E. canadensis* is classified as invasive alien species under national legislation, including the National Strategy on Invasive Alien Species (GR 2012) and the Government Decree on Managing the Risk Caused by Alien Species (704/2019, VN 912/2023). In Sweden, *E. nuttallii* is regulated under the EU's invasive species legislation and national legislation (SFS 2018:1939). However, there are currently no legal obligations to manage *E. canadensis*, as it is not included on the Union list and is not subject to specific national restrictions.

Total eradication of the *Elodea* species from the EU is likely to be impossible due to the species' ability to thrive in a wide range of environmental conditions and their effective spreading. This challenge is common among most introduced aquatic species. Nevertheless, if detected early, total eradication might still be possible in a specific area. As a result, the best option is to try to limit further spreading and to find ways to mitigate their negative ecological impacts. Therefore, monitoring has an important role in controlling the Elodea species from spreading to new areas. However, to our knowledge, previous studies have no cost-effective suggestions for a systematic monitoring and mapping of *Elodea* species in aquatic environments.

Examples of earlier removal attempts

There have been several *Elodea* species removal and control experiments during the past decades. Many of these attempts, done in freshwater environments in the USA and Europe, are well summarized and evaluated in a report by Stockan and Fielding, 2017 (14). In Sweden, removal attempts of *Elodea canadensis* have at least been done in Göta canal and lake Roxen (15, 16, 17). Removal or control attempts of *E. canadensis* in Finland have been done especially in freshwater lakes and ponds (4). To our knowledge, only one

documented removal attempt has been done in the coastal brackish environments of the Baltic Sea (18).

Mechanical removal

In France, *E. nuttallii* was removed mechanically in a river through cutting the plants once and twice, which reduced biomass of *E. nuttallii* by 72% and 97% respectively (14, 19). In a laboratory experiment *E. canadensis* was reduced by up to 59 % of the biomass after cutting the plants once (14, 20). On the contrary, another study conducted in a laboratory found that cutting had positive effects on the *E. canadensis* growth (14, 21). In Austria, *E. canadensis* is constantly removed in Old Danube Wienna with the help of 19 truxor machines to keep the biomass low (22). Also in Sweden, in Göta canal and lake Roxen, *Elodea* species has been removed with a Truxor machine (15, 16). The efforts have had some effect on controlling the *E. canadensis* but not removing it totally. In Finland, in a project Elodea II, *E. canadensis* was removed from some lakes with a combination of first cutting *E. canadensis* with a cutting machine and then trawling the material to the shore with a heavy-duty seine net (22, 23). A cutting machine that collects plants directly from water has also been tested (4). With these methods large amounts of biomass have been removed from the lakes but these methods are expensive and do not remove all *E. canadensis* and must be repeated. To our knowledge the only documented removal test of *Elodea canadensis* done in brackish water environment was done in an enclosed lagoon in the Bothnian Bay National Park in 2022. *E. canadensis* was removed by hand and collected in gauze bags. To prevent further spread and dispose of the plant material it was buried in the ground on the shore. Results have only showed an increase of *E. canadensis* in the enclosed lagoon after the treatment (18).

Water level drawdown

In a laboratory experiment, water level drawdown resulted in 100 % mortality of *E. canadensis* after 5-8 days without water (14, 24). *E. nuttallii* on the other hand seems less sensitive especially to natural water level drawdown in the field, but in the laboratory experiment also *E. nuttallii* died after 8 days (14, 24). In addition, parts of Göta canal have been dried of water during winter to remove *E. canadensis* in the canal (17). Water level drawdown together with dredging has also been used in Finland, to get rid of *E. nuttallii* in a pond called Ankkalampi in Paimio. In 2022, divers initially attempted to manually remove the plant from Ankkalampi, but the effort proved only partially effective due to its widespread presence. Following this in 2023, the pond was drained, and the water was directed through a sand filter into the forest floor to prevent further spread to nearby water bodies. The water was eventually channelled into the Paimio River. After draining the water, *E. nuttallii* was manually removed, and the bottom sediments were dredged to eliminate any remaining roots. Clean sand was added to the bottom, and the shoreline was restored. Another invasive species, pumpkinseed (*Lepomis gibbosus*), was also present in the pond, and these were removed using

electric fishing during the final phase of the draining process. The pond was dry during 2024, even during winter, and started to fill up during 2025. Disappointingly *E. nuttallii* was found again in the Ankkalampi pond during summer of 2025 (25, 26).

Shading

In freshwater lakes in Germany, shading with a jute cover reduced *E. nuttallii* by 50-75 % compared to areas without jute matting (14, 27). Polypropylene fabric cover has been tested to control *E. nuttallii* and *E. canadensis* in freshwater in the UK and it took 12 weeks for total control (28). Shading with dyes has previously been tested with *E. canadensis* and *E. nuttallii* and the used doses did inhibit the growth and biomass (29). Reduction and even complete control of *E. canadensis* with dyes has been successful in static waters when applied early in the spring (30). To our knowledge, shading with dyes or with jute matting or other materials has not been tested in Finland or Sweden nor in brackish water.

Non-native herbivorous fish species

Non-native herbivorous fish grass carp (*Ctenopharyngodon Idella*) have been used for removal of *Elodea canadensis* in lakes in the USA. Up to 100% of *E. canadensis* and other vegetation was removed when using grass carp (14, 31, 32). Up to 99% of *E. nuttallii* was removed when using rudd (*Scardinius erythrophthalmus*) in a lake in Netherlands (14, 33). This method is not tested in Finland or Sweden to our knowledge.

Chemical control

Chemical control of *E. canadensis* with herbicide diquat in a greenhouse study (14, 34) and fluridone in Alaskan lakes (14) successfully reduced biomass of *Elodea canadensis* by >90 % (13, 34). Also, high application of lime has been successful in reducing biomass and root growth in a laboratory experiment (14, 35). To our knowledge, no chemical control has ever been tested with *E. nuttallii* (14, 36). Chemical control neither with herbicides, lime nor other chemical compounds has been used in Finland or Sweden for the removal of invasive macrophytes. In EU, usage of herbicides is strictly regulated and at least in Sweden, the Swedish Chemicals Agency does not allow the use of herbicides for the removal of invasive macrophytes (2).

Recommended methods based on previous studies

A good review paper about methods for removal and management of invasive aquatic plants (IIAP) is written by Hussner et al., 2017. The conclusion from them is that there is no one removal or control method that would fit all places and that the best chance for eradication is if the invasive plants are detected at an early stage of invasion and combat them with an integrated management approach (combination of different methods) (36). Stockan and Fielding, 2017 on the other hand recommend more specifically that *E. canadensis* is best controlled with floating plastic covers or dyes to create

shading (14, 30). Nevertheless, it is unclear if floating plastic covers have been tested on *E. canadensis* or *E. nuttallii.* For *E. nuttallii* Stockan and Fielding suggested repeated cutting and benthic matting such as jute based on literature they reviewed (19, 30). Indeed, it might be so that the eradication plans and management of *E. canadensis* and *E. nuttallii* should be species-specific, as they seem to differ in their response to removal methods (14) but also in their tolerance to environmental factors such as salinity, light deprivation (13) and drought stress (14, 24). The Finnish Elodea I and Elodea II projects that have tested mechanical removal methods, conclude that the trawling by hand or with a help of a machine from land to pull in the net, is a good method to remove large amounts of *E. canadensis* and that small fragments of *E. canadensis* stay in the net which makes the risk for spreading small. The machines that cut or cut and collect the *E. canadensis* in the water on the other hand, are expensive and there is a high risk for spreading the species from fragments. Further all these methods do not manage to eradicate the species totally, only to reduce the biomass and in some cases the cutting might even promote the growth of *E. canadensis* (4). The same goes for the Swedish removal tests in Roxen Lake and Göta canal. Removal with their methods only mitigate the negative effects of *E. canadensis* on boating (15).

Aim in the SeaMoreEco project

SeaMoreEco project has tackled some of these challenges by testing removal methods and evaluating snorkelling and drone imagery as a cost-effective method for monitoring *Elodea* species in the brackish water environments of the northern Gulf of Bothnia.

Removal methods tested in the project

The goal was to test removal methods for *Elodea* species to find cost-efficient, effective ways to control the species in the brackish water environments of the northern Gulf of Bothnia. Further, the goal was to test methods in different kind of environments, in areas where *Elodea* species was dominating as well as in areas where it was growing alongside with endangered species. Based on suggestions from earlier studies as well as the characteristics of each study site, floating cover, jute cover, plastic cover, mechanical removal as well as salt and dye treatments were chosen to be tested in the project (see table 1 for a summary on previously tested methods according to literature and how SeaMoreEco contributes).

Table 1. Examples of previous attempts for removal and how SeaMoreEco contributes. F/B = Fresh or Brackish water.

Examples of previous removal and control attempts				**SeaMoreEco 2023-2025**
Method	*Finland*	*Sweden*	*Elsewhere*	*Northern Gulf of bothnia*
Mechanical removal	Yes (F & B)	Yes (F)	Yes (F)	Yes (B), manual removal in combination with a suction pump
Water level drawdown	Yes (F)	Yes (F)	Yes (F)	No
Shading	No	No	Yes (F)	Yes (B) with jute and plastic cover, floating cover and dye
Non-native herbivorous fish species	No	No	Yes (F)	No
Chemical control	No	No	Yes (F)	Yes (B), Salt

Study sites

Four different areas in the northern Gulf of Bothnia, where *E. canadensis* was present, were chosen as study sites (Figure 4).

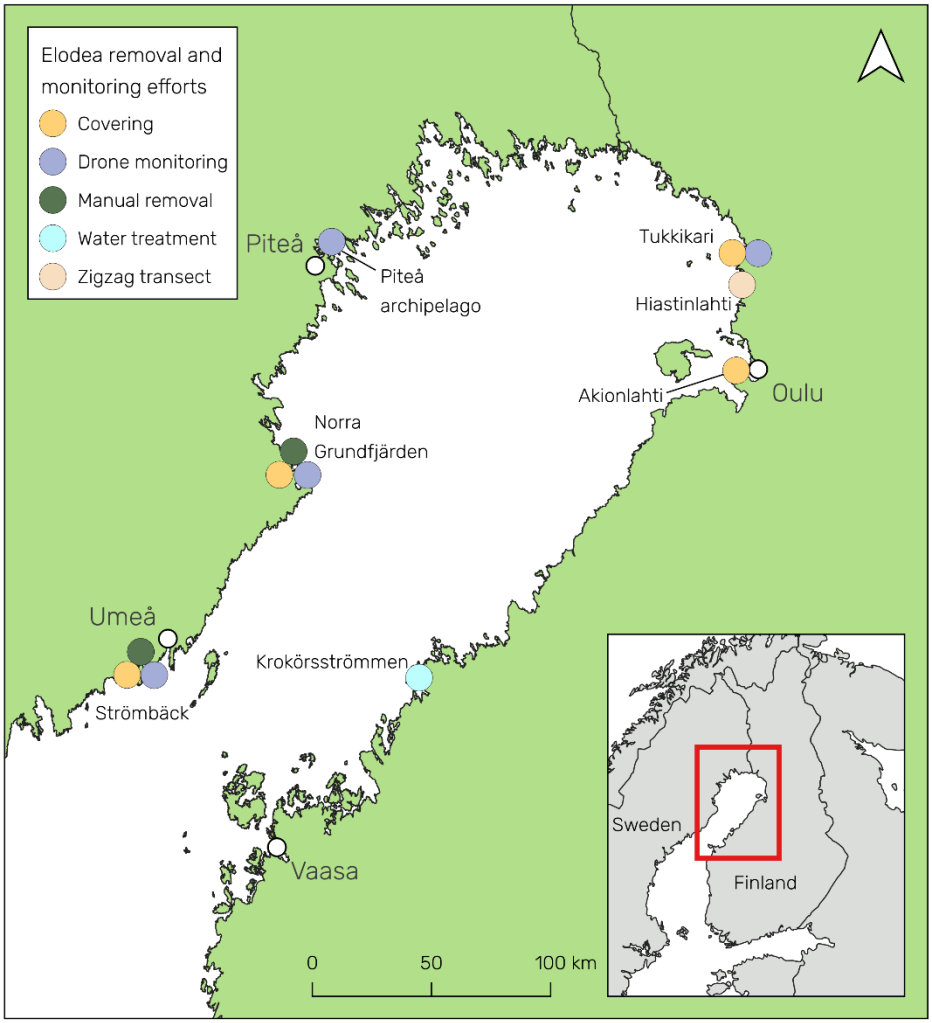

Figure 4. Elodea removal and monitoring efforts in the SeaMoreEco project.

Norra Grundfjärden, Sweden

Norra Grundfjärden in the Skallön Nature Reserve in Västerbotten county, Sweden, is a 5-hectare lagoon with a narrow creek-like opening to the sea. The mean depth in the lagoon is about 0,5 m. The substrate in the lagoon consists mainly of very soft sediment with some sand closest to the shores. There is often bad visibility in the lagoon, partly explained by an upstream creek that flows into the lagoon and transport sediment and organic material to the lagoon. The bad visibility might also be explained by the high occurrence of *E. canadensis*. The underwater vegetation in Norra Grundfjärden was first mapped around 2010. Back then, it hosted a high

diversity of native macrophyte species and no *E. canadensis* was present. In 2019 there was already a lot of *E. canadensis* and in 2021 it was the dominating species. In 2021, some *E. canadensis* could even be found in the bay outside the lagoon. Native species that occur in the area are for example *Sagittaria* natans, *Myriophyllum sibiricum*, *Potamogeton perfoliatus* and *Chara* spp., In Norra Grundfjärden, removal of *E. canadensis* was tested with floating cover, jute cover, plastic cover as well as with the help of manual removal and suction pump.

Strömbäck, Sweden

Strömbäck is a geographical area in close vicinity to Umeå delta estuary in Västerbotten county, Sweden. The chosen study site is in an estuarine bay where Strömbäck folkhögskola has a small harbour. The study site has a clear impact from the Umeå river, with lower salinity and the water often being of brown and red in colour. The native macrophyte species in the area are also typical for freshwater environments such as *Sagittaria natans*, *Sparganium* sp., *Isoetes echinospora*, *Nuphar lutea*, *Equisetum fluviatile* and *Chara* spp. The bay has a soft silty/sandy sediment. The mean depth in the study area is about 0,7 m. The jetty in the harbour is used both by boaters and bathers to get into the water. *E. canadensis* was first time reported in Strömbäck in 2018, but the species has been reported in the estuary area already in 2006 (9). In the beginning of the SeaMoreEco project the vegetation was mapped and the occurrence of *E. canadensis* in the area was patchy. Nevertheless, where the species occurred in the patches the cover was 100 %. In Strömbäck removal of *E. canadensis* was tested with jute cover, plastic cover as well as through manual removal together with suction pump.

Akionlahti, Finland

Akionlahti in Oulu, Finland, is a protected area (Natura 2000 SAC/SPA), important for bird breeding, fish spawning, and recreational use. The Akionlahti glo is shallow, with a maximum depth of around 1,5 m and a surface area of approximately 1,15 km^2. It is affected by nutrient loading, and the water is murky and dark, and the bottom sediment is soft and muddy, with sand underneath. The endangered and protected plant species *Alisma wahlenbergii* has previously been observed in the glo, but it has not been recorded since 2003. *Elodea canadensis* was first documented in Akionlahti in 2016. In inventories made in 2023, it was found at the northwestern and eastern ends of the glo, with coverage reaching up to 90%. Other commonly observed species included *Ceratophyllum* sp. and *Potamogeton* sp. Mechanical removal using a floating draft was planned for the northwestern part in 2024. However, only a small amount of *E. canadensis* was found in suitable areas that year. Most of the plant mass appeared to have shifted to the eastern end and decreased in volume. In Akionlahti removal of *E. canadensis* by shading was tested with jute cover and floating cover.

Tukkikari, Finland

Tukkikari flad in Ii, Finland, consists of three shallow bodies of water. The entire area is very shallow, with water levels fluctuating in response to sea level changes. The water is typically quite clear, and the bottom sediment is mostly silty sand with muddy areas. The endangered and protected plant species *Alisma wahlenbergii* has been found in two of the water bodies as well as along the surrounding seashores. While previous local knowledge indicated that *E. canadensis* was beginning to colonise the flad, the first targeted inventories were carried out in 2023. Actions done in the SeaMoreEco project have focused on the northwestern water body, which has a mean depth of approximately 0,5 m, and where *E. canadensis* can be found, and some *A. wahlenbergii* observations have been made in the other end of the waterbody. The northwestern waterbody has rich biodiversity, and other commonly found species include *Eleocharis* sp., *Potamogeton* sp., *Lemna* sp., and *Chara* sp. In Tukkikari methods tested to remove *E. canadensis* were jute cover and floating cover.

Krokörsströmmen, Finland

Krokörsströmmen is a strait consisting of two distinct flads. The thresholds towards the sea in the north and the south are quite different from each other. In the south there is a two-meter-wide canal through the reed with a depth of about 40 cm. The shallowest point is around 30 cm. In the north the threshold is about 30 m wide and overgrown with reed with a depth of about 30 cm. The flads are only connected at high water levels through a 40 m wide reed belt. At lower levels there is a 30 cm wide stream between the basins through the reeds. In both flads and outside of the in the sea, *E. canadensis* have been observed since 2017. Inside of the flads the *Elodea* species population is large. There is however lush native vegetation in both of them, consisting of many different species. *E. canadensis* has not yet been able to dominate the vegetation and push away the native species, according to observations during the three field seasons of the project. In smaller patches of about 1 x 1 m, *E. canadensis* might dominate, but no larger areas. The other species present are *Stuckenia pectinata*, *Hippuris vulgaris*, *Potamogeton perfoliatus*, *Callitriche hermaphroditica*, *Myriophyllum sp.* and *Nymphea alba*. The shores are covered by a wide reed bed of *Phargmites australis* as well as *Schoenoplectus* sp. *E. canadensis* was first observed in the area by the Velmu programme in 2017.

Floating cover

Methods

Floating cover was tested in 2024 and 2025 in three areas, Norra Grundfjärden in Sweden and in Akionlahti and Tukkikari in Finland.

Material specifications

The floating cover is made of a thick, heavy tarpaulin-like material (polyolefin plastic), orange in colour (bought from Ekeröds Utveckling AB). It is delivered in 6 x 6 m pieces together with a "skirt" in size 1,65 m x 26 m of the same material and a heavy metal chain on the bottom part. The skirt is attached to the sides of the floating cover to stop sunlight from coming from the sides. The floating cover pieces can be connected to each other from all sides with tension straps. At least five of the 6 x 6 m covers can be attached in a row (30 x 6 m) and at least four covers in a row if there are two rows attached next to each other (12 x 24 m). To keep the floating cover in one place, ropes with small anchors can be attached with tension straps on the sides of the cover.

Norra Grundfjärden

In Norra Grundfjärden six covers were attached to each other so that they covered an area of 216 m^2 (12 x 18 m). Small anchors (3 kg each) were attached to each corner of the floating cover as well as one in the middle of the short sides and two anchors on both long sides to keep the cover in place (Figure 5 and 6).

In 2024 the cover was installed in the lagoon on 7th of May. It was placed on top of 100 % coverage of *E. canadensis*. It was removed on 10th of October the same year. The material was transported near by the lagoon during winter and was built together in the water in spring. It was also dismantled in the water in the autumn. Two SUPs (stand up paddle board) were used to transport covers in the water. On top of that there was four people in the water building the cover.

In 2025 the cover was laid in the lagoon on 8th of May and the results were checked on the 15th of September. The coverage of *E. canadensis* before covering was about 70 %. In the spring the floating cover was assembled on the shore and pulled to the water with two SUPs. The skirts and anchors were transported on a SUP to the floating cover and attached to the cover in the water. This method was much faster than building everything together in the water. After checking the results in the autumn 2025 the cover was left on the same spot to see if it can endure winter and ice. The plan is to just to pull it to a new spot in the lagoon in the spring 2026.

Figure 5. Floating cover ready assembled in Norra Grundfjärden in May 2024.

Figure 6. The floating cover in Norra Grundfjärden was visible in the ortofoto from 10th of July 2024 (Lantmäteriet).

Akionlahti & Tukkikari

In Finland, two floating covers (6 m x 6 m / 36 m² each) were tested separately, both with and without skirts. The tests were made in Akionlahti

glo in Oulu and in Tukkikari flad in Ii, where field inventories were made during 2023. Neither site in Finland was easily accessible directly from the shore, so the floating covers were rolled up and towed into place using a small motorboat (Akionlahti) or a paddleboard (Tukkikari). Two people were needed to install the floating covers.

At the start of July 2024, one floating cover was placed in the southeastern part of Akionlahti (Figure 7), where *E. canadensis* had a coverage of 70 %. Another floating cover was placed in the northwestern water body in Tukkikari, positioned over a patch of *E. canadensis* with approximately 80 % coverage. Both covers were equipped with a skirt. To assess environmental effects, temperature and light intensity loggers were installed under the covers and in control areas. The covers remained in place throughout the growing season and were removed in early October 2024.

In 2025, both covers were placed in Tukkikari flad from 4.6. to 29.9.2025. The floating covers were placed in the same northwestern part, but both covers were positioned over new *E. canadensis* patches, while the 2024 spot was left as a control. One of the 2025 covers was tested without the skirt, and both had temperature and light intensity loggers installed beneath them.

Figure 7. One floating cover with the skirt attached in Akionlahti, Finland. In Akionlahti the water colour is dark brown.

Results and discussion

Norra Grundfjärden

The results from the floating cover seem very successful, at least during this short period of testing. There was 0 % vegetation on the covered spot in the end of the summer season 2024, only sediment (figure 8). After the summer season 2025 the results were similar, no vegetation except 1 % coverage of *Lemna trisulca*. When the 2024 covered area was revisited in autumn 2025 it was 100 % covered with vegetation but dominated by native species. *Callitriche hermafroditica* had a coverage of 40%, *Myriophyllum sibiricum* 25%, *Potamogeton perfoliatus* 15% and *Chara* spp. 1%. *E. canadensis* accounted for only 20%.

The floating cover did eradicate *E. canadensis* at least for one summer season. It is uncertain whether some *E. canadensis* parts (such as turions) can have survived in the sediment but there were no visible parts of *E. canadensis* to be found neither 2024 nor 2025. It is likely that the native species had seeds left in the sediment and recolonized the covered area once *E. canadensis* disappeared and the cover was removed. This could explain the high coverage of native species. But it could also just be recolonization from the surrounding macrophyte populations. During 2025 there was generally high coverage of macrophytes in the project area probably due to the warm July.

Figure 8. The picture to the left: E. canadensis next to the covered area in October 2024. Picture to the right: Only sediment under the covered area in October 2024.

Akionlahti & Tukkikari

Individual floating covers in Finland showed results very similar to those of attached covers in Sweden.

In Akionlahti, where *E. canadensis* originally had a coverage of 70 %, a dense growth was observed around the cover at the end of the season, but no plants were detected underneath it during 2024. This cover was equipped with a

skirt and had a temperature and light intensity logger installed beneath it. According to the logger data, no light penetrated under the cover, and the average temperature did not differ significantly from the control.

Similar to results in Akionlahti, in Tukkikari flad, where the first floating cover equipped with a skirt was positioned over a patch of *E. canadensis* with approximately 80 % coverage, when the cover was removed at the start of October, dense *E. canadensis* growth (100 % coverage in places) was observed around the cover (figure 9), but 0 % under the cover. During 2025 both floating covers were placed in Tukkikari and one of the covers was tested without the skirt. The aim was to see if the floating cover would be as effective without the skirt, which would reduce the costs, and the amount of person hours needed significantly. Surprisingly, when the covers were removed at the end of September 2025, no *E. canadensis* was found under either cover. Under the cover without the skirt, a small amount (0,1 % coverage) of free-floating *Lemna trisulca* was detected. Logger data showed that while some light seems to have gotten under the floating cover without the skirt, the amount was insignificant (maximum of 2,78 lux) (figure 10), and no significant amount of light was detected under the skirted cover (maximum of 0,20 lux). Temperature readings were similar across both setups and control.

Figure 9. At the end of the season in 2024, a dense growth of E. canadensis was visible around the floating cover in Tukkikari, but no plants were detected under the cover.

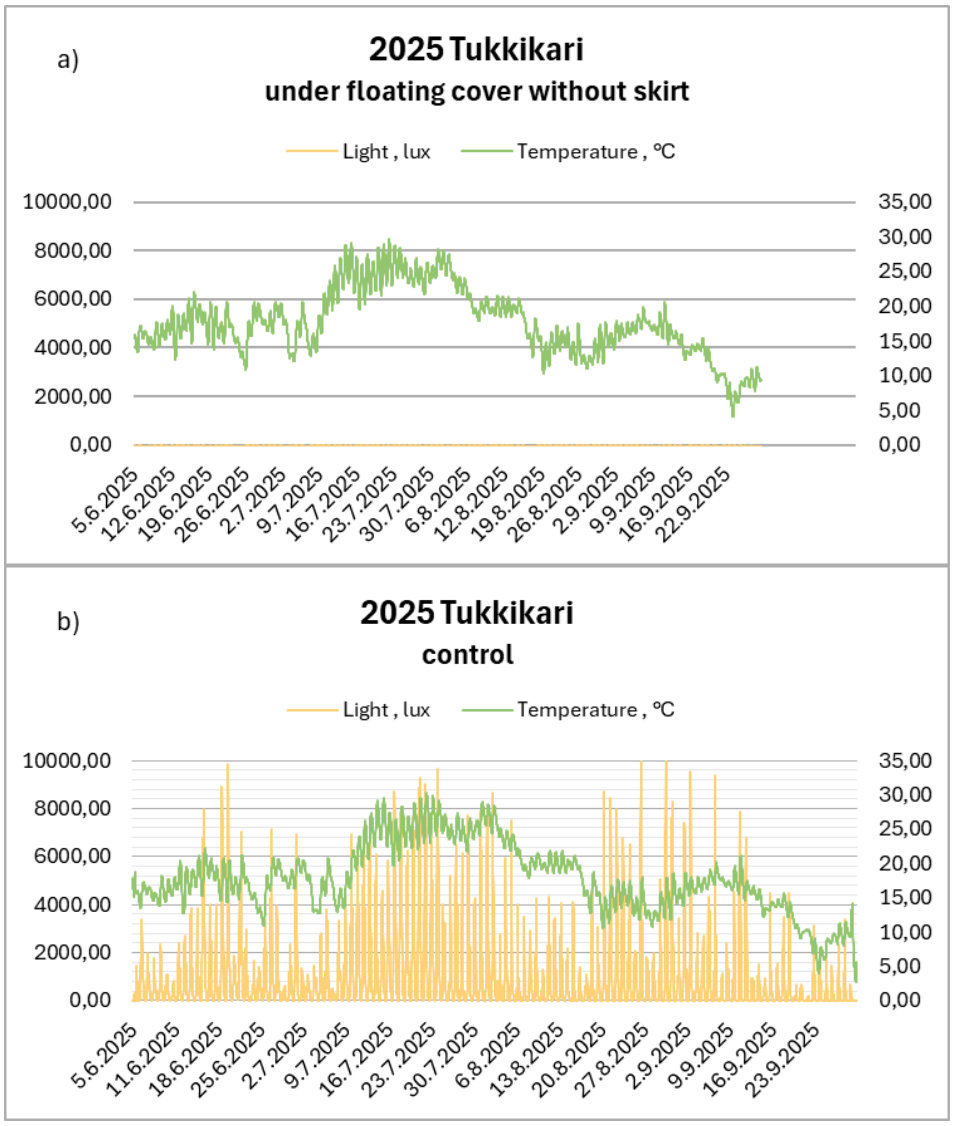

Figure 10. Light intensity (lux) and temperature (°C) at Tukkikari in 2025. Panel (a) shows logger data recorded under a floating cover without a skirt, while panel (b) presents data from the control logger. Light penetration under the cover without a skirt was minimal compared to the control. Temperature followed a similar seasonal pattern in both setups.

In October 2025, the area where the floating cover had been placed during the 2024 growing season was revisited to assess effects. It was found that *Elodea canadensis* had begun to re-establish, with an estimated coverage of approximately 40%. Some individuals of *Potamogeton perfoliatus* were also present.

The site was additionally monitored using drone-based orthophotography, which provided a broader overview of vegetation patterns and confirmed the

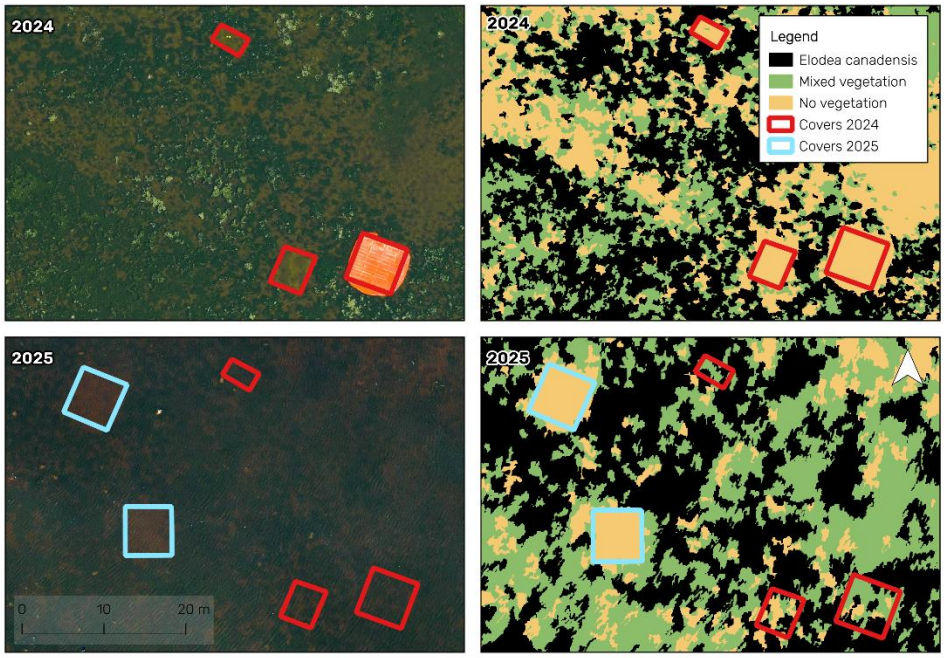

Figure 11. Elodea canadensis removal with jute and floating covers in Tukkikari, Finland.

re-establishment of *E. canadensis*. Classified orthophotos were used to monitor the effect of the removal efforts by calculating vegetation and substrate coverages before and after the covering (Figure 11). Both jute covers and floating covers led to distinct changes in the composition of the treated areas. The results after the first growing season were easy to detect, even without a drone, given the fact that there was nothing growing on the bottom. However, drone-based monitoring was particularly useful to detect the effects after two growing seasons. This method was used to analyse the effects of the coverings conducted in 2024 in Tukkikari flad in Ii.

Floating covers showed a clear reduction in *Elodea* coverage (-44 %) while increasing native vegetation (+46 %). Bare bottom under floating covers showed a slight decline (-3 %). The surrounding reference area displayed an opposing trend. There, *E. canadensis* expanded substantially (+47 %), while bare bottom decreased notably (-39 %). Native vegetation showed only a small decline (-5 %).

Elodea coverage declined consistently in all treated areas, whereas it increased in the reference area during the same period. Also, the suppression of the alien species created space for native vegetation to expand, indicating that the covering method was effective not only in limiting *Elodea canadensis* but also in supporting the recovery of native aquatic plant communities.

Based on these tests, floating covers appear to be effective in suppressing *E. canadensis* in small, shallow areas over short periods, even without the use of the skirt blocking light from the sides. During the 2024 growing season, both test sites, Akionlahti glo and Tukkikari flad, showed a clear reduction in

E. canadensis biomass beneath the covers. However, in cases where *E. canadensis* remains present in the surrounding habitat, the effects may be short-lived, and regrowth can occur within a year after removal. These findings highlight the potential of floating covers as a targeted management tool for small-scale interventions, especially in sensitive or protected habitats where other methods may be unsuitable and in areas where *E. canadensis* is not yet established. Further tests are needed to evaluate the optimal duration of cover placement, the role of environmental conditions in regrowth, and the potential impacts on native species. Additionally, understanding the role of environmental factors such as water temperature, nutrient levels, and hydrology will be crucial in predicting treatment outcomes and improving eradication success.

Risks for spreading *E. canadensis*

Floating cover, when ready assembled and passively lying in the water, seems to be an excellent method for removing of *E. canadensis* without risking the spreading of the species. To our understanding the *E. canadensis* must have decomposed under the cover during the summer season as the skirts prevented vegetation to drift away and all that could be found under the covers in the autumn was sediment. The highest risk for spreading *E. canadensis* is when transporting and assembling the floating cover in the water in spring and when dismantling it in winter. All tramping around by foot results in detached *E. canadensis* fragments and should be avoided. Therefore, during autumn 2025, the floating cover was left in the lagoon in Norra Grundfjärden over winter to avoid the negative impact of disassembling and reassembling it again. In spring, the plan is to pull the cover to a new spot in the lagoon, with a maximum of two persons in the water.

Jute and plastic covers

Methods

Material specifications

Dense 275-280 g/m^2 jute fabric was used for the covering experiments. The sizes of the covers were 3 x 5 m and 6 x 6 m. The jute fabric was sold in width of 1,5 m, so to achieve large enough areas, the fabric was first sewn together using jute twine (figure 12).

Plastic covers used were also 3 x 5 m with one exception (one larger cover about 6 x 10 meters used in Strömbäck). Plastic covers were made of heavy tarpaulin like material used in covering invasive plants (bought from Invasiva AB). They were delivered in size of 6 x 10 meters and cut to smaller pieces (figure 13).

Figure 12. Jute cover is light material, that is easy to work with. Here jute cover is being placed on top of the E. canadensis in Akionlahti.

Figure 13. The plastic covers are heavy to work with but do not let any light through. This plastic cover has just been lifted from the water from Strömbäck.

Norra Grundfjärden

On 12th of July 2023 7 jute covers, and 5 plastic covers were placed in the Norra Grundfjärden lagoon (see attachment 1 for the placement of the covers). Some of them were placed in the middle of the lagoon where *E.*

canadensis coverage was 100 % and others were placed closer to the shore where there were some native species in the covered area but also next to the covered area. The coverage of different species was estimated both in the area where cover was going to be placed as well as next to the area that was going to be covered to see what species could possibly recolonize the covered areas (data not included in this report). Each cover was weight down with 6-8 bricks. Material was transported on SUP boards and snorkelers placed the covers and bricks on the right spots. In mid-august the covers were revisited and noticed that especially the plastic covers had partly lifted from the bottom because of gas formation in the decomposition process. Small holes were made into the plastic covers and extra bricks laid on top of them.

On 22nd of May 2024 the covers were revisited after the winter. They were still in place, and no vegetation was growing on them. All jute covers were strengthened with an extra layer of the same jute fabric. All covers were anchored also with four rebars in each corner which turned out to be a good method for anchoring and marking the covers.

On the 8th of May 2025 the covers were revisited again. Still, there was no vegetation on the covers. One plastic cover and two jute covers were removed to see if these areas would be recolonized during the summer. On the 15th of September the covers were revisited again and the macrophytes were mapped in the same way as in the beginning of the study. All remaining plastic covers and anchoring equipment were removed from the lagoon. Only the jute covers were left to decompose. In addition to snorkelling, the study area has been photographed with drones on several occasions to document the results from the removal.

Strömbäck

On the 13th of July 2023 4 jute covers, and 3 plastic covers were placed in the Strömbäck study area (see attachment 1 for the placement of the covers). As the coverage of *E. canadensis* was patchy in Strömbäck, the covers were chosen to be put in areas where there was close to 100 % coverage of *E. canadensis*. Some covers were placed close to the shore and some in deeper waters (0,3-1,5 m depth). The covers were anchored the same way as in Norra Grundfjärden and when revisited in the 11th of august they were looking quite good. Still, some bricks were added as weight and holes were poked into the plastic covers to let out the gasses. Also, an additional larger plastic cover (6 x 10 meter) was placed next to the jetty.

On the 15th of May 2024 all of the jute covers in Strömbäck were strengthened with a new layer of jute except one that could not be found. By this time no vegetation was growing on the covers. No rebars were used for anchoring as the study area has a lot of boat and other leisure activity.

On 9th of May 2025 the covers were revisited again, and they all were still free of vegetation. The one, most southern jute cover was still not found. The large plastic cover that had been next to the jetty since the august 2023 was

removed to see if there would be any recolonization during the summer 2025. Also, the northernmost jute cover was removed for the same reason. On the 9th of July two more plastic covers were removed also to study the recolonisation process.

On the 17th of September 2025 vegetation was mapped in all the treated areas and next to them in the same way as in the beginning of the study. The jute cover that was missing was recovered. The last remaining plastic covers as well as all the bricks were collected. The jute covers were left to decompose. In addition to snorkelling, the study area has been photographed with drones on several occasions to document the results from the removal.

Akionlahti & Tukkikari

In early June 2024, a total of six jute covers were installed at two test sites in Finland, in Akionlahti glo in Oulu and Tukkikari flad in Ii. Each site had three covers, two measuring 3 x 5 m and one measuring 6 x 6 m. Only one layer of jute was applied in 2024, and no additional layer was added in 2025.

At Akionlahti, the smaller covers were placed in the northeastern and southeastern parts of the glo, while the larger cover was installed at the eastern end. All covers were positioned in shallow areas near the reed belt along the shoreline, where *Elodea canadensis* coverage ranged from 40 % to 70 %.

In Tukkikari, the covers were placed in the southwestern water body. The two smaller covers were installed in the southern and northern sections, and the larger cover was placed in the middle. Here, *E. canadensis* coverage was higher, ranging from 80 % to 100 %.

Due to limited shore access, the jute covers were rolled up and transported to the sites using a stand-up paddleboard (SUP). Installation was carried out by teams of two to four people. Once positioned on the bottom, natural stones were placed on top of the covers to ensure they remained submerged and stable. To alert recreational users to the presence of the test, each jute cover was marked with a tile featuring a small buoy and an informational sign placed at its centre.

Results and discussion

Norra Grundfjärden & Strömbäck

In general, it can be stated that the plastic covers with one exception (the deepest laying cover in Strömbäck) were vegetation free during the three-season trial from July 2023 to September 2025. The plastic covers that were removed in May and July 2025 on the other hand, were recolonised by *E. canadensis* and native species by September 2025 (Figure 14).

Plastic covers could be used in smaller patches of *E. canadensis* to suppress and eradicate the species from that patch to then remove the plastic after some years. The problem with plastic is the gas building underneath. Plastic needs to have holes for the gas to escape, also it needs to be controlled every year to see that it sits right and most importantly is not lost and littering the area. The plastic covers are also heavy to work with. Also, when the plastic is removed the sediment is disturbed and has a negative impact on the surrounding vegetation because of the sedimentation.

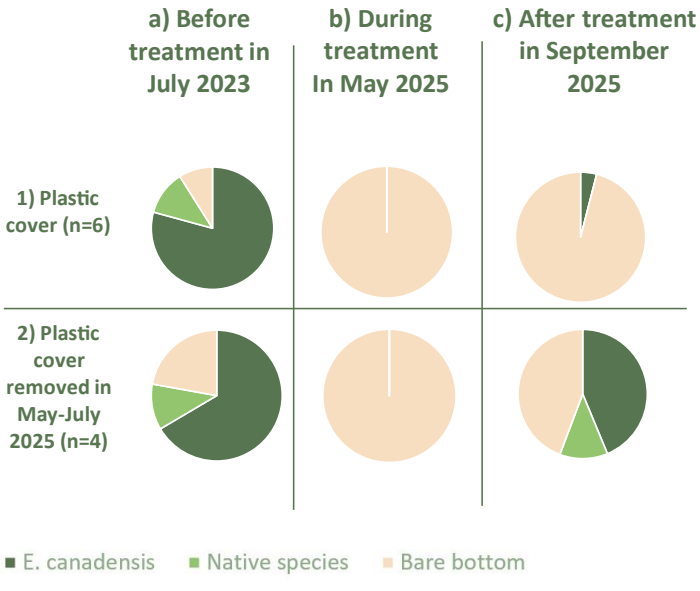

Figure 14. The pie charts are showing the relative abundance of E. canadensis (dark green), native species (light green) and bare bottom (light red) in the covered areas a) before the plastic treatments in July 2023, b) during the treatments in May 2025, and c) after the treatments in September 2025. The different treatments where 1) Plastic cover 2) Plastic cover that was removed between May-July 2025.

Jute cover seems much more environmentally friendly way to cover *E. canadensis* as it is natural material that breaks down fast and can therefore be left to decompose. It is also much lighter material than the plastic and therefore easier to handle. Most importantly jute cover seems to keep all vegetation away as long as a new layer of jute is added in the spring (Figure 15). When the jute covers were not strengthened with a new layer in the spring of 2025, all the treated areas were recolonized by both native species and *E. canadensis* during the same summer. The jute fabric had started decomposing and was falling apart. Also, sediment had accumulated on top of the covers (Figure 16). As mentioned, it is unknown how long turions of *E. canadensis* survive and therefore unclear for how many years in a row the jute cover should be strengthened.

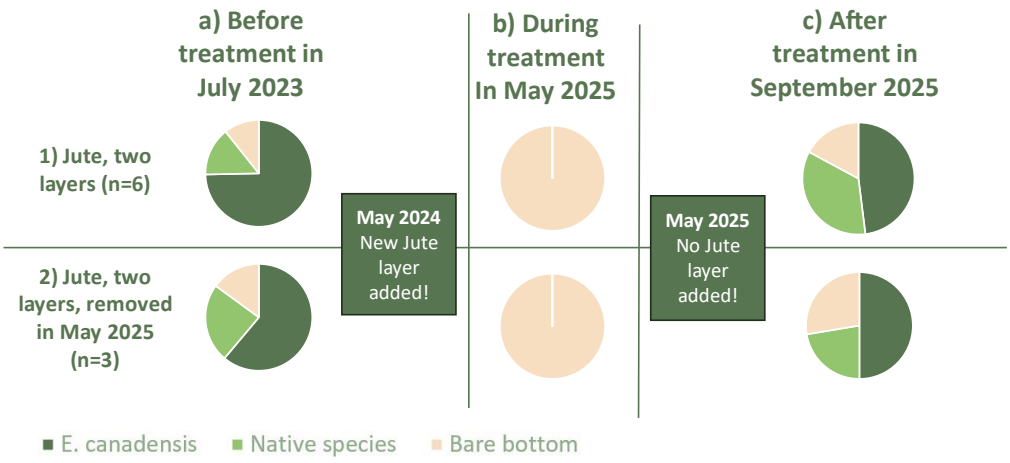

Figure 15. The pie charts are showing the relative abundance of E. canadensis (dark green), native species (light green) and bare bottom (light red) in the covered areas a) before the jute treatments in July 2023, b) during the treatments in May 2025, and c) after the treatments in September 2025. The different treatments where 1) Jute treatment with an extra jute layer added in May 2024, 2) Jute treatment with an extra jute layer added in May 2024 and all jute layers removed in spring 2025.

Figure 16. None of the jute treatments were strengthened in the spring of 2025. This picture taken in Norra Grundfjärden in September 2025 shows how the jute is starting to decompose, sedimentation on top of the jute cover is considerable and E. canadensis and Sagittaria natans are starting to grow on top of the cover.

Akionlahti & Tukkikari

During the summer of 2024, the areas covered with bottom jute covers remained largely free of vegetation, including *Elodea canadensis*. The covers were easy to install if suitable stones were present to use as an anchor and

effectively suppressed plant growth. However, over the course of the season, loose sediment began to accumulate on top of the jute material, some small *E. canadensis* individuals were growing on top and signs of decomposition of the jute were observed.

At the beginning of the 2025 growing season, the covered areas appeared similar to their condition in 2024, mostly clear of vegetation. However, during a follow-up visit in late September 2025, *E. canadensis* was observed beginning to recolonise the surface of the jute covers.

Tukkikari site was additionally monitored using drone-based orthophotography (figure 11). Classified orthophotos were used to monitor the effect of the removal efforts two growing seasons after the covering. It was done by calculating vegetation and substrate coverages from classified orthophotos that were taken before and after the covering. These analyses indicate that in areas with jute covers, coverage of *Elodea canadensis* decreased notably (-32 %), while bare bottom (+7 %) and mixed vegetation (+25 %) increased.

The results from Akionlahti and Tukkikari are similar to the results from the Swedish sites. As no new jute layers were added in the spring 2025, the vegetation started to recolonise the areas where jute cover was placed in 2024. Without adding new layers of jute each spring, this treatment only provides short-term suppression of vegetation, and the effectiveness diminish over time as the material degrades.

These findings indicate that jute covers may be an inexpensive, easy to install and useful tool for temporary control of *E. canadensis* in shallow sensitive habitats, but they are unlikely to provide long-term eradication without follow-up measures such as adding new jute layers each spring. Continued monitoring and potentially repeated treatments may be necessary to prevent regrowth.

Risks for spreading *E. canadensis*

All the tramping around when placing and removing the covers is risking that pieces of *E. canadensis* are fragmented and float away. Therefore, there is a need to find another way to place the covers on top of the *E. canadensis* without disturbing the sediment. If the depth is good (1-1,5 m) it is relatively easy to snorkel and/or use stand-up paddle boards to place the covers without disturbing the bottom too much. If *E. canadensis* is growing next to a jetty, the cover could be applied from the jetty to avoid tramping on the bottom.

Manual removal combined with suction pump system

Methods

On 7-10th of august 2023 and on 12-16th of august 2024 manual removal combined with a suction pump developed and operated by a consultant was tested in Norra Grundfjärden and on 11th of august 2023 in Strömbäck. A suction pump was used to collect the *E. canadensis* that was pulled by hand by 3-4 persons standing in the water next to the jetty (Figure 17 and 18). The areas in Norra Grundfjärden chosen for the removal had a coverage of 70-100 % *E. canadensis*. In Strömbäck the coverage was similar. One person was operating the suction pump that was placed on a floating jetty. *E. canadensis* that was pulled up by hand was fed to the suction pump that collected the material into jute sacks. The jute sacks were then transported to the shore with SUP boards. The treated areas were revisited in autumn 2023, spring 2024 and in autumn 2025 to evaluate how long lasting the effects of removal were.

Figure 17. The water suction pump was placed on a floating jetty and anchored with a metal pole (Bellona AB).

Figure 18. E. canadensis was pulled up by hand and fed to the suction pump hose (Bellona AB).

Results and discussion

In total, an area around 1200 m^2 was emptied of *E. canadensis* during the two years 2023and 2024. This corresponds to approximately 1500 kg of *E. canadensis* (wet weight) that was removed and transported away to be properly handled as combustible waste at a recycling centre (figure 19).

On 14th of September 2023 the area in Norra Grundfjärden where *E. canadensis* was removed in the spring 2023 was revisited and it was still mainly empty of all vegetation. Already in the 7 th of May 2024 was the treated area covered by *E. canadensis*. The treated area was still fully covered by *E. canadensis* on 15th of September 2025. The area where *E. canadensis* was removed in 2024 was also revisited on 15th of September 2025 and *E. canadensis* covered now 50 % of the area and native species 50 %. In Strömbäck the area where *E. canadensis* was removed in 2023 was revisited on 16th of September 2025 and the coverage of *E. canadensis was* 50-70 % which is a bit lower than it was before the removal.

This method included a consultant with a heavy machine that needed to be transported to the shore (several people were needed to carry the parts of machine and jetty). This method also included 4-5 persons working full days, several days in a row to manage to remove *E. canadensis* from the test areas. Even though with this method a large biomass of *E. canadensis* was removed, the treated areas were quickly recolonised by *E. canadensis*. In other words, this method is rather time consuming, expensive, and the results are not long lasting.

Figure 19. E. canadensis was moved from the jute sacks to plastic sacks and transported to recycling station to be properly handled as combustible waste.

Risks for spreading *E. canadensis*

It comes without saying that this method risks spreading *E. canadensis* when the species is pulled up and small fragments can float away even though the suction pump was there to minimise this effect. Nevertheless, it is likely that all the people in the water tramping around and pulling *E. canadensis* must have resulted in a considerable amount of loose *E. canadensis* not captured by the suction pump. Therefore, in conclusion, this method is not recommended for further use.

Salt and dye treatment in field aquariums

Methods

In this test the aim was to see the effects of raised salinity and light deprivation through adding salt and dye on *E. canadensis*, in a natural environment.

Sites were selected in the flad in Krokörsströmmen, where both large populations of *E. canadensis* were found as well as other vegetation, to see the effect on both *E. canadensis* and native species.

For this test 6 semi-enclosed aquariums with the size 1,5 x 1,5 x1,5 m (3,4 m^3) was acquired (figure 20). They were placed in about 0,5 m water depth in Krokörsströmmen, Larsmo for two seasons. Two aquariums functioned as controls, salt was added in two aquariums, blue dye was added in another two aquariums. Salinity loggers were added to the salinity aquariums and light loggers were added in the dye aquariums. Light loggers were only available in 2025.

The salt that was used was common sea-salt (NaCl) and the dye used was Dyofix PondBlue. The amount of water was calculated as 1,5 x1,5 x0,5 m (1,1 m^3). The salinity in the flad was 2 psu. The critical limit for *E. canadensis* according to Martemyanov & Tikhonenkov (2022) (39) is 6 psu. The salinity level aimed for was 7 psu to be certain of reaching above the tolerance level. The amount of salt added was calculated through the formula (desired psu – previous psu) x the volume of water (l)= the mass of salt (g) needed to raise the salinity by 1 psu, since 1 psu = 1 g salt/l water. Since the volume of the water in the aquariums was approximate, this level of certainty was satisfactory.

The amount of dye added followed the upper recommendations of the producers of PondBlue dye, Dyofix. In practice this meant 2,5 teaspoons of dye powder for each aquarium.

In 2024 the test started in July and stopped in August. In 2025 the test was longer, from July to September. In 2024 salt and dye was added once at the start of the test. In 2025 substances were added at the start and additionally twice during the test. This was done because in 2024 it was noted that the there was enough leakage in the aquariums to dilute the colour and salinity during the test. Also, in 2025 the test time was longer and so the dilution was greater.

Figure 20. Moving the test aquariums into the water.

Results and discussion

The results from 2024 and 2025 supported the same conclusion, that salt treatment was a more efficient method compared to the dye treatment.

In 2024 neither method completely eradicated *E. canadensis*. Both methods affected the *E. canadensis* negatively, but the plants exposed to greater salinity were more affected. In 2025, Elodea plants in the salinity aquariums seemed dead while the plants in the colour aquariums seemed quite healthy. At both revisits during the test addition of colour and salt was needed to reach the desired level of light deprivation and salinity.

In the right settings, both methods could be efficient to eradicate *E. canadensis*. Our tests suggest however that if the level of the substance can't be constantly regulated and thereby at a sufficient level, salt is more effective (figure 21). If light deprivation is not constant the plants will be able to recover enough to survive, while a period of high salinity is enough to kill the plants.

Both methods affect plants and animals negatively in the water body. The idea behind these methods however is that since *E. canadensis* can only reproduce through living plant parts, once it is eradicated it is gone. The native plants on the other hand can reappear through seed banks or migrate back in from areas outside of the eradication area. Animals as well are able to of migrate back. This situation however limits the use of these methods in sensitive areas. If threatened species live in the area or if the environment type is threatened, these methods need to be reconsidered.

Figure 21. During one field season, 25 kg salt was needed for each aquarium to reach >6 psu salinity.

A downside for both methods is that there must be no water exchange in the basin where eradication takes place. If eradication is done in bays or flads, a threshold must be constructed to achieve this, which itself is an invasive procedure. The eradicator must make the judgment call on the trade off on the disruption of building a temporary threshold or having *Elodea* species present.

The advantage of salt as eradication substance is that it is a fully natural substance, and it will be diluted to a natural level over time. The effect on other plants is also limited in brackish water areas where many plants are capable of living in salinity conditions required to kill *Elodea* plants. While some plants survive the treatment, a downside is that some plants and invertebrates will not. Another downside is that large amounts of salt is needed which requires accessibility for an adequate mode of transportation.

The advantage of dye as eradication substance is how easy it is to apply (figure 22). Small amounts of powder will colour large volumes of water. Another positive aspect is that the dye is biodegradable, and it will dissolve and disappear over time. The downside is that all plants will die due to light deprivation. Even though the substance is not toxic, light deprivation and lack of vegetation will likely lead to the death of many invertebrates as well.

Figure 22. An aquarium with dye added.

Risks for spreading *E. canadensis*

Since these methods do not involve physical removal of plants or sediment the risk of spreading Elodea is non-existent. This is the case especially if the method in the future will be used in a whole lagoon or a pond. Nevertheless,

if the aquariums are used for the treatment, some detachment of *E. canadensis* shoots might happen when the aquariums are transported.

Removal costs – a comparison

The different removal and control methods have different costs and life span. In the table below is a rough comparison of the material costs and reusability of each removal method tested in the project (table 2). In addition to the material, the amount of person hours for conducting the work as well as the transport times differ between some of the methods. The floating cover is the most expensive of all the covering materials, it can be used again making the next removal project much cheaper. Also, if the skirt is not needed, the material costs are reduced by more than half. Nevertheless, if the covered area is large, it can take many person hours to assemble and disassemble it as the floating cover is very heavy to work with. The plastic cover is expensive but can be reused. Again, this material too is heavy to work with, and a large cover will take more person hours. Jute cover on the other hand is very cheap and light to work with compared to the other materials, but a new jute layer needs to be applied every year. The highest costs in the salt and dye treatments are the aquariums (~1500 euros for a 1,5 x 1,5 x 1,5 m aquarium) and if the treatments can be done without aquariums the costs for salt or dye are small. The mechanical removal combined with the suction pump is not recommended for further usage but is included in the comparison to present the costs.

Table 2. Material costs for removal of E. canadensis in a 36 m² area during one field season. This comparison does not consider transports or person hours, only the material for the removal itself.

Removal method	**Reusable material**	**Material cost for removal of 36 m²**
Floating cover with a skirt	Yes	~**2100 €** for cover with a skirt (sold in 6 x 6 m pieces)
Floating cover without a skirt	Yes	~**1000 €** for a cover (sold in 6 x 6 m pieces)
Jute cover	No	~10 €/meter ≈ **240 €** for 36 m²
Plastic cover	Yes	~1300 € for 60 m² ≈ **780 €** for 36 m²
Mechanical removal combined with suction pump	Yes	~ **820 €** is the cost for one rental day for the suction pump + operator in 2023 (~150 m² can be removed per day)
Salt treatment	No	~**320 €** (~400 kg salt is needed, 20 €/25 kg)
Dye treatment	No	~**30 €** (one bag of dye is 15 €)

Monitoring methods tested in the project

When doing surveys and monitoring of aquatic vegetation on shallow bottoms, point inventories or transects by diving, snorkelling or drop video is often used. These methods result in varying detailed information of the composition of the vegetation and the method chosen depends on the level of taxonomic detail needed in the survey. What the methods have in common is that, although the taxonomic detail is high, the information is only subjected to the inventory points and does not cover larger areas.

In the SeaMoreEco project area the invasive *Elodea* species usually grows and sometimes thrives in shallow bays where they threaten the native plant communities. The threatened communities consist of many plant species and associated animals important for the coastal ecosystem, including several endangered species. Monitoring of *Elodea* species in these shallow areas would improve the early detection of the species and make it possible to take actions when important ecosystems and endangered species are threatened. Also, the monitoring would give the possibility to learn more of how *Elodea* species effects their environment. The aim in the project was therefore to test and evaluate monitoring *Elodea* species using drones in larger areas in the northern Bothnian bay.

Monitoring Elodea using flying drone

Methods

The methods used are described in detail in the drone flying and analysis manual produced in the SeaMoreEco project (37). In short, a flying drone was used to take photos of shallow sea areas. The same area was also mapped using snorkelling and/or drop video points, creating a ground truth dataset describing the vegetation. The drone photos were compiled into an orthomosaic picture, which was, using knowledge of the vegetation from the ground truth points, analysed using picture analysis tools in ArcGIS Pro or QGIS. The ground truth data and the resulting map were simplified to the level of HELCOM HUB vegetation groups and *Elodea* species. The analysis map was evaluated with the help of the ground truth data set using a confusion matrix to calculate the accuracy of the finished product.

Results and discussion

The drone method worked well in mapping the presence of vegetation in shallow areas and especially for finding dense patches of *Elodea* species.

Drone methods require sunny and calm weather. The *Elodea* species are usually found in sheltered, shallow areas (< 1 m depth). In these conditions, if

the water quality is sufficient, the drone images often capture the bottom conditions well, including the vegetation.

The results from several drone flights and analysis tests can be exemplified by the following figures, one from two areas in Sweden in the Norrbotten archipelago and one from an area in North Ostrobothnia, Finland (figure 23 & 24). The accuracy of *Elodea* species (using a confusion matrix) is well above the limit described in the SeaMoreEco picture analysis method (37), indicating that the maps give a good representation of *Elodea* species in the areas. One of the reasons is that the *Elodea* species often grows in very dense and dark stands, separating it from many other species/groups, which is especially evident when the cover is high.

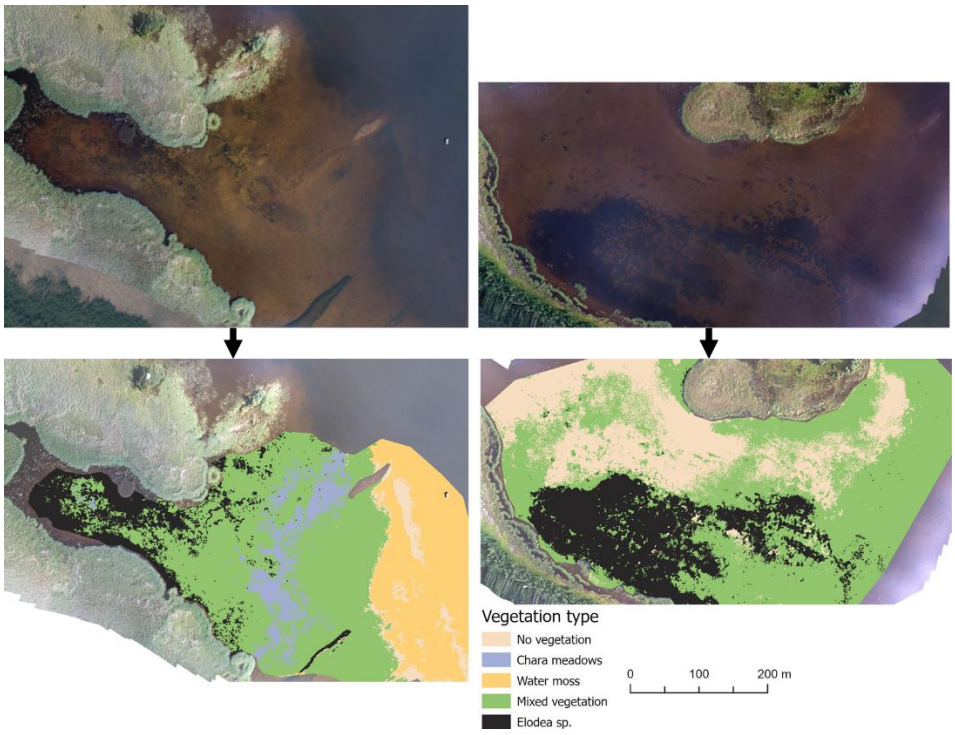

Figure 23. Two shallow areas in the Norrbotten archipelago, including drone picture analysed vegetation types.

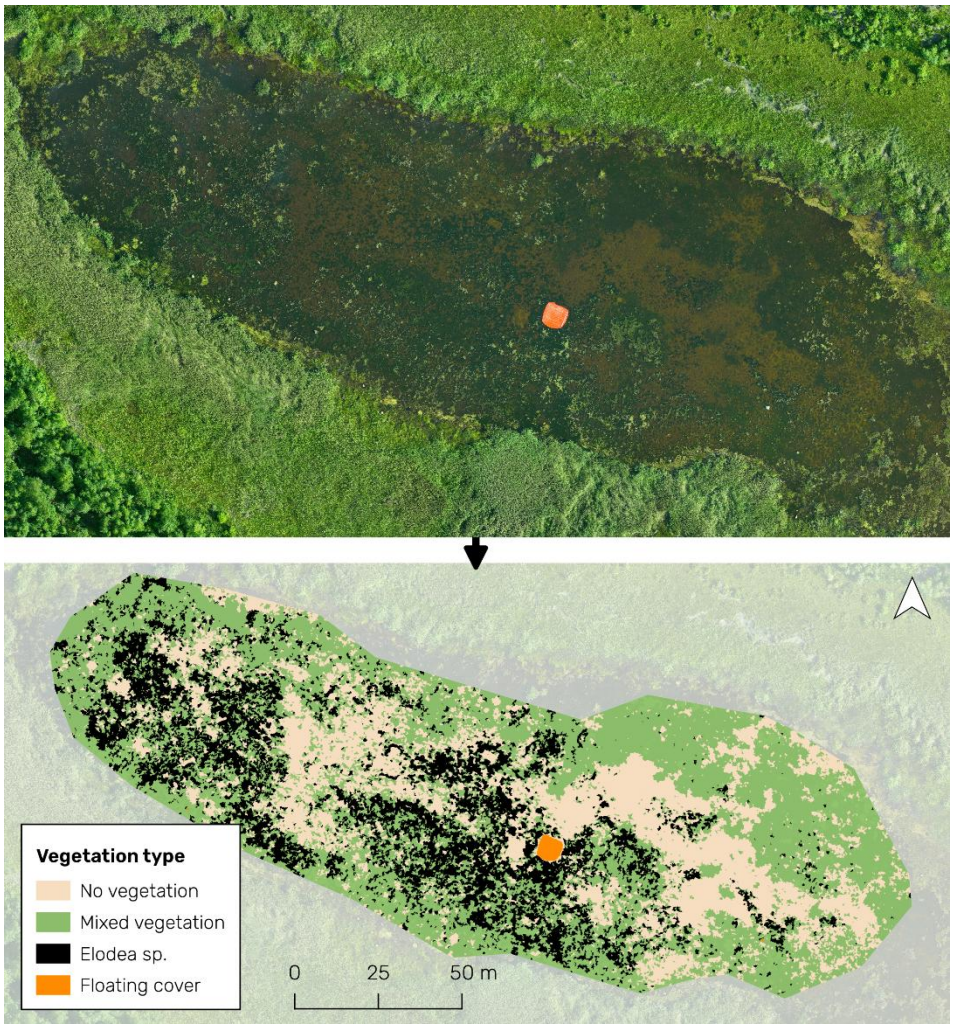

Figure 24. One shallow area visited two years in Ii, including drone picture analysed vegetation types.

The method has been time consuming, especially since many ground truth points needs to be collected in each area. However, the resulting maps covers the whole area, which is very cost effective compared to point inventories, which only gives information from the point itself. If the same area is monitored several years, it is possible that the number of ground truth data points can be lowered since likely vegetation groups on the bottom of the area, and their location is known. In that sense, drone-method makes a cost-effective way to monitor annual change in vegetation. Great synergies would also be possible e.g. collecting ground truth data coordinated with other measures, for example the monitoring of endangered species and/or general monitoring of benthic communities. The drone approach is also helpful when deciding where possible restoration (e.g. *Elodea* species removal) should be prioritised.

When the cover of *Elodea* species is high, it often grows in very dense and dark stands, separating it from many other species. However, individual *Elodea* species plants are very similar to other sublittoral vascular plants. Individual plants are difficult to identify using drones. This makes *Elodea* species monitoring with drone difficult when aiming to find early signs of *Elodea* species colonization. To find individual plants, traditional inventory methods such as snorkelling, aqua scope, diving or drop video is required. Environmental DNA could work as a complementary inventory method but has its downsides such as quantifying abundance, DNA transport/degradation issues and false positives/negatives.

Zigzag transect

A monitoring method for *E. canadensis* was tested in Iijoki river estuary area, in Hiastinlahti Bay, Ii, Finland. Iijoki river is one of the places in North Ostrobothnia in Finland, where *E. canadensis* is widely spread and forms extensive growths. The method was initially tested in 2018 and repeated along the same transect in 2024. Following the second test, both the methodology and results were reviewed and evaluated.

Methods

The presence of *Elodea canadensis* was surveyed in the Iijoki river estuary area between Hiastinlahti and Hiue (total area of around 1,9 km^2). The aim was to obtain a rough overview of the species' distribution and abundance. The area was examined by conducting a zigzag transect (figure 25) approximately 5000 meters long, starting from the inner part of Hiastinlahti and extending toward the outer border of the Natura 2000 area in the Iijoki River estuary or until the species was no longer observed due to increasing depth. Observations on species presence and bottom substrate were made at approximately 200 m intervals, totalling 25 points. Coordinates were recorded from each point. Other species were not documented, except for identified threatened or invasive species. The transect was done with a small boat and by snorkelling in 2018 and by paddle boards (SUP-boards) and water binoculars in 2024.

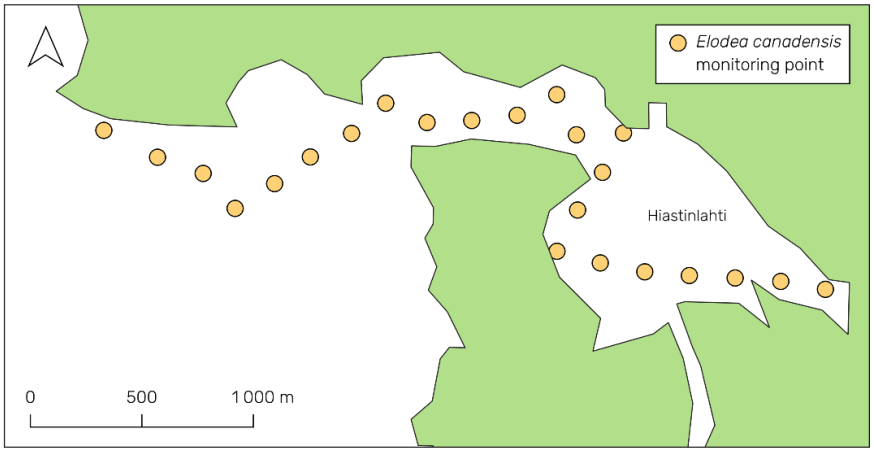

Figure 25. Zigzag transect in Hiastinlahti Bay, with 25 inventory points.

Results and discussion

In 2018 *E. canadensis* was found from eight out of 25 inventory points, mostly from the starting point closest to the river mouth. In these eight inventory points, *E. canadensis* had a coverage of 1-40 %. During the test in 2024 *E. canadensis* was found only in one inventory point with a coverage of 2 %. Average depth of the inventory points was 0,98 m in 2018 and 1,13 m in 2024, with the deepest point being around 2 m. The zigzag transect line was positioned quite in the centre of the Hiastinlahti bay, where a boat way is also present. There is a possibility that most of the *E. canadensis* can be found on shallow parts close to the shoreline. Based on these results, it's impossible to estimate whether the situation with *E. canadensis* in Hiastinlahti had gotten better, or if the results differ, for example, due to yearly variation. For better results, the method should be repeated every year for at least couple of years. After the test in 2018, a consultant stated that the method seemed to be a fairly effective method for gaining a general understanding of the species' distribution across a relatively large area. In less than a day, a broad overview of the situation was achieved. It was left to discussion, if this kind of method would work better in some situations, than randomly selected inventory points.

Concluding remarks

Management suggestions

Monitoring the shallow coastal areas of the northern Gulf of Bothnia for early detection of the *Elodea* species and the changes in the native macrophytes coverage and species composition should be prioritised in management. In addition, informing the public about the *Elodea* species, how easily they can be spread with boats and gear as well as how to avoid that it happens is an important complement to the management measures to further reduce spreading of *Elodea* species.

Nevertheless, removal and control measures are also needed, but should be prioritised in areas where threatened species are in danger to be outcompeted by *Elodea* species. Also, removal measures should be directed in areas where *Elodea* species are not yet the dominating macrophyte species to avoid recolonisation and to succeed in total eradication. If only a small patch is treated in an *Elodea* species dominated area (like in this project, almost all method testing was done in *Elodea* species dominated areas) it is more than likely that it will come back no matter how successful the treatment itself is on the patch. However, many of the removal methods tested in the SeaMoreEco project have good potential to be used further in brackish water environments, where *Elodea* species are not yet dominating. With the short study period in mind (2023-2025) floating cover seems to be very successful method in supressing *E. canadensis* just in one summer season. Also, jute cover kept *E. canadensis* away as long as a new jute cover was added in the spring each year. Plastic cover supressed *E. canadensis* during the whole project period but was hard to keep flat on the sediment because of the gas building underneath. In the end of the study, removing the plastic covers was messy, resulting in sediment blumes. In addition, all these methods do have a risk of spreading *E. canadensis* when the covers are assembled and disassembled. Another negative side of these methods is that they will affect everything underneath the covers, also native flora and fauna.

The aquarium experiments showed that *E. canadensis* could be controlled with both dye and salt but only salt treatment seemed to kill the species. The level of light deprivation was hard to keep on a constant level with the dye and therefore *E. canadensis* managed to survive. There are also other question marks when it comes to using dye and salt treatment in brackish water as the areas treated would need to be enclosed with no water exchange with the sea. Further all the sessile species in the treated area will be affected by the treatment, some more some less depending on the salinity and light deprivation tolerance. Also, huge amounts of salt are needed if the treatment is conducted in a bigger scale. Nevertheless, the salt treatment in small, enclosed lagoons dominated by *Elodea* species or an *Elodea* species

dominated patch delimited by an aquarium wall (as in this study), could be treated with salt with possibility for total eradication.

The only method tested in this project that is not recommended for further use is the large-scale mechanical removal of *Elodea* species, not even with the help of the suction pump, as the mechanical removal in general has a high risk for spreading the fragments of the *Elodea* species. Also, the suction pump did not manage to gather all the fragments. Mechanical removal brings also up another management problem, that all the *Elodea* biomass needs to be taken care off and handled in a proper way to avoid further spreading. If a few *Elodea* plants are present in an area, mechanical removal by hand with a net bag could be an option, but this was not tested in this project.

In the project, all the method testing was done in areas with *E. canadensis*. Nevertheless, it is likely that all the covering treatments would work as well on *E. nuttallii* as they work on *E. canadensis*. The salinity and dye treatments on the other hand, might not work in the same doses on *E. nuttallii* as this species is known to be more tolerant to higher salinities and lower light conditions (1, 13). Further, mechanical removal has earlier been suggested to be more successful on *E. nuttallii* than on *E. canadensis* (14, 19).

The drone monitoring of *Elodea* species tested in this project was successful in areas with high coverage of *Elodea* species if the water was relatively clear. The *Elodea* species could indeed be differentiated from other type of vegetation. When *Elodea* species occurred in low coverages, they could not be detected with a drone and therefore other methods such as snorkelling inventories are still needed. Environmental DNA could also be a complementary method for detecting *Elodea* species together with drone. Still, the eDNA has its limitations such as quantifying abundance, DNA transport/degradation issues and false positives/negatives. Therefore, further development of eDNA methods is needed for reliable results.

Future studies

As SeaMoreEco was a three-year project, there has not been a possibility to study the long-term success of the different *Elodea* species removal methods. The long-term success of *Elodea* species removal by covering depends partly on how long *Elodea* species turions (overwintering parts) can survive in the sediment, without light. To our knowledge this has not been studied but would be crucial for the management to know for how long *Elodea* species need to be covered for total eradication. Also, different jute fabric densities should be tested to see if a thicker jute fabric decomposes slower and could endure two field seasons in a row. If that would be the case, an additional jute layer would not be needed every spring. In addition, evaluating the effectiveness of the floating cover without the skirt across different habitat types would provide important insights for assessing the method's cost-efficiency. In general, the methods tested in this project would need to be developed further so that the assembling and disassembling work in the

water and thereby the disturbance on the sea bottom can be minimised to avoid the spreading of *Elodea* species. This winter for example, the floating cover was left in the Norra Grundfjärden instead of disassembling it to avoid spreading *Elodea* species. If the floating cover survives the winter in ice, it can be gently pulled to a new *E. canadensis* patch in the spring.

To our knowledge it is also unclear whether the whole plant of *Elodea* species can survive from year to year in the Baltic brackish water environments or is it just the turions. In Norra Grundfjärden for example, *E. canadensis* was covering large areas of the lagoon right after the ice was gone in the spring. Some of the *E. canadensis* was loose lying and brownish in colour but it was hard to tell whether it was alive or not. Further studies are needed to determine whether the whole *Elodea* plant can overwinter in our area and keep on growing and spreading. This is extremely important information from the management point of view, when planning the time window for removal attempts. Further, to our knowledge it is unknown how high salinities does *E. nuttallii* tolerate and more over does the turions of both *Elodea* species tolerate higher salinities than rest of the plant. This would be important to know for further development of the salinity treatment.

As *Elodea* species in Europe consist only of females, they can't reproduce with seeds. This gives an advantage to native species to recolonise the area where *Elodea* plants are removed from the sediment below. This is something we suspect that happened in Norra Grundfjärden after the floating cover treatment, but further studies are needed to confirm this.

Lastly, *E. nuttallii* has not yet been recorded in the coastal areas of Finland. A curious thing is that *E. nuttallii* can be found on the Swedish side of the Torneå river, right at the border to Finland. What is the factor keeping *E. nuttallii* away from the Finnish side? What factors affect the spreading of *E. nuttallii* negatively? Could it be the river stream acting as a physical barrier? It could also be as simple as that the *E. nuttallii* has quite recently invaded the coastal areas of Norrbotten and has not yet been detected in Finland. This pinpoints again the most important message to the management, that monitoring the coastal areas for early detection of the *Elodea* and other invasive species, is a crucial part of in the fight against biodiversity loss and should therefore be prioritised.

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Appendix

Appendix 1.

Placement of the Jute (J) and Plastic (P) covers in Norra Grundfjärden (a) and Strömbäck (b).