LIFE SURE

Project Report

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The project is carried out by Kalmar Municipality and Linnaeus University.

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List of key-words and used abbreviations

- Sediment uptake
- Resource recovery
- Circular economy
- Beneficial use
- Marine environment
- Shallow waters
- Eutrophication.

BTEX	Benzene, Toluene, Ethylbenzene, Xylenes
COD	Chemical oxygen demand
CEDA	central dredging organisation
DM	Dry matter
DO	Dissolved oxygen
EC	Electrical conductivity
EDDS	Ethylenediamine disuccinic acid
EDTA	Ethylenediaminetetraacetic acid
EU	European Union
HaV	Swedish Agency for Marine and Water Management
KLM	Kalmar Municipality
KM	More-sensitive limit, sediment quality
KPU	Kalmar Produktutveckling, company
LCA	Life cycle assessment
LCIA	Life cycle inventory assessment
LNU	Linnaeus University
LOI	Loss on ignition
MKM	Less-sensitive limit, sediment quality
NN	Nordic Nutrients, company
NPK	Nitrogen – Phosphorous - Potassium
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyls
PIANC	name of the World Association for Waterborne Transport Infrastructure
SedNet	European Sediment Network
SD	Standard deviation
SEPA	Swedish environmental protection agency
SURE	sediment uptake and remediation on ecological basis
TOC	Total organic carbon
TG	LIFE SURE technical group
TM	Techmarket Sweden AB (Teknikmarknad), company
VOS	Vatten och Samhällsteknik, company
WODCON	the global conference organised by CEDA and WODA (World Organisation of Dredging Associations)

Executive Summary

LIFE SURE was a partnership project, originally by Kalmar Municipality (KLM), Linnaeus University (LNU) and the company Techmarket (TM) that ran between 2016 and 2022. However, the latter left the project after just 2 years.

The project was financed by the LIFE programme and the Swedish Agency for Marine and Water Management (HaV)

The overall objective of the LIFE SURE project was to show how to sustainably restore the ecological status and hydro morphology in a eutrophic sea bay and test methods for beneficial use of removed sediments.

The demonstration site of the project was Malmfjärden bay, a shallow bay of the Baltic Sea located centrally in the city of Kalmar, Sweden. In this bay, sediments with relatively high levels of metals and nutrients have accumulated over many years. The bay and the surrounding water bodies suffer from high level of nutrients in the Baltic Sea and therefore do not achieve good ecological status in the Water Framework Directive. Sediment removal from bays and lakes can attribute to a lower load of nutrients and contaminants to the water phase, but only if done without any disturbance to the water phase. If the solution, developed and tested in LIFE SURE, would work, it would be a possible measure to restore many lakes and bays throughout Europe.

The LIFE SURE project's main objective was *to demonstrate an innovative, cost-effective, and ecologically sustainable process to dredge sediments from shallow waters and to use it as a resource*.

During the LIFE SURE project, a prototype for sediment removal was developed and tested. With this new solution, the project has been able to achieve almost all objectives above. LIFE SURE can be as cost effective as conventional techniques. The costs for running a sediment removal project with LIFE SURE was compared to costs in other projects where high demands were set for environmental disturbance.

The LIFE SURE solution has other advantages which were evaluated and confirmed during the project. It can remove soft sediment from shallow water bodies without causing environmental disturbances. The system of sediment removal and dewatering can run automatically, steered by remote control, is movable on trucks and easy to learn and use. The solution is quiet and can be run without fossil fuels. During the project, these parameters were monitored and evaluated. For example, the effects on the marine environment were evaluated by studies before, during and after the projects, confirming that the LIFE SURE solution does not cause turbidity and that plants and animals return to the dredged area within months. The conclusions are also confirmed by the Life Cycle Analysis, analysis of the environmental costs and an evaluation of the socio -economical aspects.

Another promising result of LIFE SURE is that the project has shown that soft sediments from shallow waters can be used beneficially. During the project, the removed sediments were used to final capping of landfills and well as in several pilot studies for innovative sediment uses.

The project tested the removal and reuse of both metals and nutrients from the sediments. These tests were first done on a lab scale, and later in field experiments. The results show that plant nutrients in the sediment can be taken up by amending the sediments with compost and biochar and other soil.

Of these, results from the greenhouse experiments are still under analysis, and a scientific publication is being prepared to be published in 2023.

Next to that, a pilot was run to use sediments in construction and infrastructure. The company NETICS has developed a technique to make blocks using a Geowall press. A recipe for the Malmfjärden sediment was made, to make for example pavement blocks. With higher dewatering rations, other applications could also be possible. Trials provided valuable information on how the Malmfjärden sediments can be used as soil remediation and provide the basis for follow-up projects for developing sediment used for Baltic Sea sediments.

The project recognises several barriers in the large-scale application of sediments removal and use. LIFE SURE recommends developing a BAT document that includes environmental aspects as well as an European scale evaluation on environmental impact assessments for different sediment uses. Member state should be urged to apply the best environmental practices and develop guidelines and instructions for allowing beneficial sediment use.

Finally, the project shared its outcomes with public, politicians, companies, authorities, professionals in Sweden, Europe and even worldwide. Using existing networks, initiating a new network on low-flow dredging and participate in innovation workshops to discuss the possibilities and barriers for the scaling up of the life sure solution to other areas and to allow a wider spread knowledge and application of sediment uses. A business case for the use of the LIFE SURE solution in other areas has been made, as well as suggestions for project financing. This is an ongoing process, as the patent for the prototypes, that KLM has applied for, is pending (Nov 2022).

After the termination of TM in October 2018, the project partners were left with prototypes that were not tested and failed to function, even after a year of tests and improvements. In January 2020, it was decided that a whole new design had to be made and a new prototype (**Mudster**) was built. Also, an innovative steering and operating system was made for the movement of the Mudsters as well as the dewatering of the sediments on the treatment site. Just as the project could finally show a working solution, the COVID19 restrictions made it difficult to disseminate and make contacts for replication and transferring the knowledge from the project. With another year extension of the project, the project team has managed to inform and reach out about the projects results to many target groups which have resulted in continuing sediment removal in Malmfjärden bay and a follow up project on developing sediment use applications. Several other project ideas have been discussed and project applications have been sent out.


Eco-dredging in Malmfjärden bay. (Images: Ulf Rickardsson (left) and Renate Foks (right))

Introduction

Environmental issues addressed

Eutrophication and sediment growth is affecting water bodies and coastal areas. In bays and lakes, polluted sediments can cause environmental problems such as algae bloom and spreading of hazardous contaminants. Traditional dredging methods often cause new problems, such as turbidity (resuspension), disturbance of existing ecosystem and noise. Also, dredged sediments are often dumped, thus adding on societal waste.

LIFE SURE addressed these three main environmental problems in the EU:

1) The problems with overgrowth and internal leakage of contaminants from bottom sediments in shallow aquatic environment within the EU and Baltic Sea,

2) Eutrophication problems in water bodies in the EU and Baltic Sea,

3) The presence of contaminants on shallow waters in the EU and the Baltic Sea Region.

Hypotheses in LIFE SURE

1. The LIFE SURE method will not negatively impact the water environment during operation. The method will contribute that coastal marine ecosystems are able to flourish.
2. The LIFE SURE method is cost-effective and has low environmental impact. The removal and dewatering of sediment often demand a lot of energy and staff. Also, the purification of sediments and reject water is expensive. If successful, it will demonstrate a method that costs less compared to state of the art.
3. The LIFE SURE method will lead to an increase of benefits for both the environment and humans.
4. The LIFE SURE method can be used to solve environmental problems in other water bodies in the EU and globally, that are eutrophicated, contaminated and overgrown. Therefore, the method needs to be movable, easy to use and adaptive to different environments. LIFE SURE will provide an attractive business case for businesses.
5. Furthermore, the LIFE SURE method will demonstrate that more than 70% of the removed sediments can be used beneficially for humans and/or the environment

Description of the innovation concept

The LIFE SURE solution consists of the dredging robot prototypes, its operating system and a dewatering land site. The prototype Mudster consists of two parts: the surface raft and the underwater unit. The surface raft is used to pull the underwater unit. The system is controlled remotely and moves slowly over the seabed (low-flow dredging), therefore does not cause re-suspension of sediments and release of contaminants. The removed sediments are treated and dewatered on site, using a special developed program and dewatering techniques that can operate continuously as well as require minimal electricity. The technology can be handled by non-

professionals after a brief technical introduction. The whole system can be operated 24-hours and can be supervised locally or remotely using wireless communication devices. The sediments produced with the LIFE SURE method can be re-used in different ways, depending on demand and sediment characteristics.

1. *The LIFE SURE method does not negatively impact the water environment during operation.*

The LIFE SURE sediment removal has not shown negative effects on the ecosystem. This was evaluated by monitoring the turbidity and water quality at the dredging site as well as the restoration of marine life and the quality of reject water. The LIFE SURE solution can help restore ecosystem services, when combined with other restoration measures. Also, the reject water from the LIFE SURE dewatering system has high quality and was allowed to be reemitted back to the bay without treatment or filtration.

2. *The LIFE SURE method is cost-effective and has low environmental impact.*

The removal and dewatering of sediment often demand a lot of energy and staff. Also, the purification of sediments and reject water is expensive. The costs for running the LIFE SURE method, as well as the LCA, was compared to other solutions. The LIFE SURE solution can be just as cost efficient and has lower environmental impact than state of the art.

3. *The LIFE SURE method leads to an increase of benefits for both the environment and humans.*

The socio-economical aspects of dredging and the LIFE SURE solution were followed and evaluated. Restored bays and lakes which will be attractive to recreational activities for tourists and inhabitants.

4. *The LIFE SURE method can be used to solve environmental problems in other water bodies in the EU and globally*

The LIFE SURE solution is easy to use and movable: it is estimated that all equipment can be moved using five movements of trucks and trailers. Also, outside of a treatment site and electricity, no special infrastructure is needed.

Possible areas of use of the LIFE SURE solution are water bodies affected by built-up soft sediments (bays, lakes, estuaries, storm water basins, hydropower dams and ditches). The solution is especially interesting for sensitive environments, where normal dredging solutions are not accepted (resuspension, ecosystem disturbance, noise) or where the water level is too low. The solution is also interesting for smaller waterbodies, as many Mudsters can be controlled at once.

The user-friendliness evaluation shows that the system is easy to learn. The initial setup and calibration will be performed by experts, but the day-to-day operation of the equipment can be handled by personnel after instructions.

5. *In LIFE SURE all removed sediments were used beneficially for humans and/or the environment.*

LIFE SURE also demonstrated that there is a growing market and interest for the beneficial use of sediments and therefore can state that most sediments can be reused depending on the dewatering technique and contamination with heavy metals.

LIFE SURE has shown that with the LIFE SURE solution, several beneficial sediment use options are available. Such as Land fill final capping, landscaping, soil remediation (and nutrient recycling) and building blocks for construction and infrastructure.

Expected long-term results from replication and transferability

The project expects to contribute to the European objectives by proposing the use of a more sustainable dredging technology to tackle the problems caused by contaminated sediments and eutrophication in a regional (Baltic Sea Region) and European level. The LIFE SURE solution can be transferred to and implemented not only within EU, but also around the world in areas where there is an urgent need to deal with problems of bottom sediments. Coastal areas, lakes, hydropower reservoirs and stormwater ponds are target "end-users" of this technology.

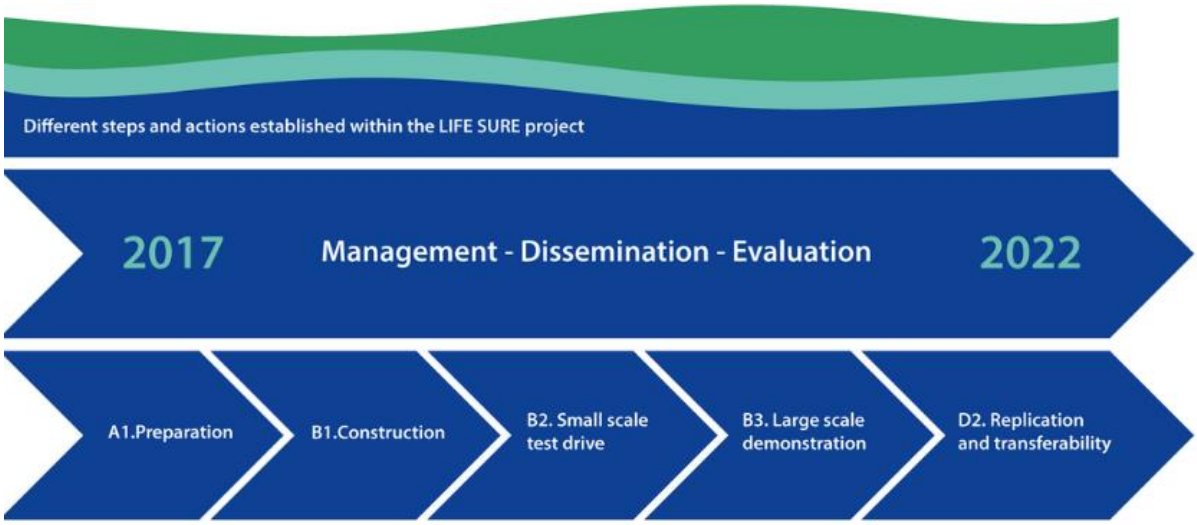
In the long run, we expect the LIFE SURE solution to be one of the facilitating solutions to transform the dredging methods in (sensitive) water bodies. There is a lot of potential in combining these techniques and system solutions with beneficial sediment use.

In LIFE SURE, we have seen that use of Baltic sediments as a soil amendment as well as blocks in infrastructure and construction has big potential, with both high environmental and economic benefits. LIFE SURE shows that not only the sediment uptake, but also beneficial sediment uses offer many business and research opportunities. Finally, LIFE SURE has shown that a LCA is a useful tool to help decision makers to choose the right use of sediments.

LIFE SURE in Action

LIFE SUREs project has been executed along several actions:

- Action A1: Planning and preparations,
- Action B2: Small scale test,
- Action B3: Large scale demonstration,
- Action C1: Monitoring,
- Action D1: Dissemination,
- Action D2: Replication and Transferability



Actions

Action A1 - Planning and preparations

The objective of Action A1 was to perform all necessary planning and technical preparation for the following Actions.

Verification of the chemical and biological status

The objective of sub-action A1.1 is to verify the chemical and biological status of the area to be dredged before the dredging activities takes place. In 2016, field work was done as initially proposed.

The investigations done consisted of:

- Sampling of fish population in 10 different locations,
- Measurements of turbidity, salinity and water temperature in 20 different points,
- Sampling of water in 5 different sampling points for chemical characterization,
- Sampling of bottom sediments at 24 points and bottom layers ranging from 0 to 60 cm,
- Mapping of vegetation within the bay with 149 mapping points used,
- Sediment Characterization – Organic matter (Loss by ignition), moisture, bulk density, metals,
- Pore Water extraction and characterization – COD, TOC, pH and conductivity.

A second characterization of Malmfjärden Bay was carried out in June 2018, consisted of sampling of bottom sediments and surface water at 28 stations from different layers (two control points outside the dredging area) in triplicates (top layer: 0-19 cm; bottom: 20-60 cm) as well as sediment characterization (nutrients, organic compounds, metals, dry matter %, density, LOI (loss of ignition), particle size distribution) and surface water characterization (COD, turbidity, Dissolved Oxygen, conductivity).

Sampling points in Malmfjärden Bay in 2018. Two sampling points, 530 and 529, are outside the dredging area. Images from the sample collecting in 2018. (Source: Stefan Tobiasson, LNU)

The main findings and conclusions regarding the status and baseline of Malmfjärden Bay are:

Vegetation coverage

High incidence of rooted underwater vegetation with coverage of approximately 70% of the total area. Little influence from wind and waves in combination to low depths can bring ideal conditions for the establishment of underwater vegetation.

Benthic Organisms

The main found bottom organisms were highly tolerant to low oxygen conditions.

Fish population

The existing fish community can be related to the high levels of nutrients that are available for absorption. A total of 9 species were found, predominantly carp fishes.

Physico-chemical parameters

The water holds relatively high levels of nitrogen and phosphorous. The levels of dissolved oxygen, turbidity, chemical oxygen demand and pH showed good quality status.

Sediments from Malmfjärden Bay were mainly silt and clay (more than 80%) and showed high content of nitrogen and medium-high content of phosphorous and organic matter. Organic compounds were below detection limits besides PAH-H, PCB 7 and aliphatic compound C16-35, which were near or slightly overpassing the Swedish more-sensitive thresholds. Regarding metals and metalloids, the only elements above the more-sensitive limits were cadmium, arsenic and lead. All parameters were fulfilling the less-sensitive limits, meaning that they can be employed in industry, coverage of landfills or other non-risky uses. Moreover, the sediments presented a similar distribution of element contents in the sampled area. However, comparing the depth, top layers presented higher contents of elements, suggesting that, during more modern times, more contaminants were introduced to the bay. Pore water extracted from the sediments showed higher content of nitrogen and phosphorous compared to the surface water from Malmfjärden Bay. The pH was acid, and metals and organic compounds were below detection limits. The results showed that centrifugation of sediments could cause more contaminated water compared to a more passive dewatering system (like geo bags).

Conclusion

The water bay and sediments presented high content of nutrients. The main pollution concern for the sediments was cadmium. More studies were recommended to determine the availability of metals.

Consequences for sediment remediation and use

Bioleaching was proposed in the project proposal as a solution to extract metals from the sediments. The method was not included in the sediment dewatering system since the material did not require treatment to be used for less-sensitive purposes. The extraction of metals was tested on a laboratory scale to investigate a method that can be used in other projects where the extraction is necessary.

To get an overview of the possible used for the sediments from Malmfjärden Bay, data from the sediment analysis was compared to legislation. Also, to consider the level of local interest, meetings and discussions were done with local companies and institutes.

The following suggested local outlets for sediment use have been determined:

- Expansion and landscape management of golf courses and camping sites
- Defence against extreme climatic conditions and sea-level rise through strategic disposal on near-shore area within Kalmar Municipality
- Lift up of lowlands nearby coastal areas that have been suffering of flooding and sea-level rises
- Agricultural use and recycling of nutrients mainly for energy crops such as raps and willow
- Forestry
- Seedling nursery
- Landfill final cover layer
- Noise barriers and embankments

These results were used as a base-line for further concrete applications. During Action B2 and B3, the project focussed on legal and policy aspects, logistics (transport, volumes, needs, demands), existing costs, benefits, social acceptance and finally the quality of the final product after dewatering.

Permissions and detailed plan

The objective of this sub-action was to handle the process of permission for sediment removal and remediation. The first plan from 2017 was revised in 2018 and used to apply for the necessary environmental and building permits. The application of the environmental permit was coordinated by environmental experts at the company VOS. As part of the obligatory consultation rounds, local clubs and inhabitants were informed about the project, its location and progress. These groups were regularly updated about the project and its activities. Early 2019, the project got a short-term permit for the Action B2. In December 2019, a ten-year environmental permit for Action B3 was granted. Also, the project had to apply for a permit to suspend boat traffic from the working area. This permit had to be renewed and updated every year.

The environmental permits demanded the project to design and perform a control program for monitoring of the effects of the activities. The control programme included monitoring of the bay as well as the reject water quality. Furthermore, to monitor the system, as described in Action C1, LIFE SURE also made a monitoring program for the incoming sludge from the Mudsters and the dewatered sediments. Other important parameters for projects evaluations were continuous measurement of total solids, the flows, pH, turbidity, and electricity-use. The LIFE SURE operating system which was developed in 2019 and 2020, incorporated the monitoring, saving and presenting of this data.

Action B1 - Construction

The objective of Action B1 was the construction of the dredging prototypes and the dewatering system.

Construction of new dredging unit and surface raft

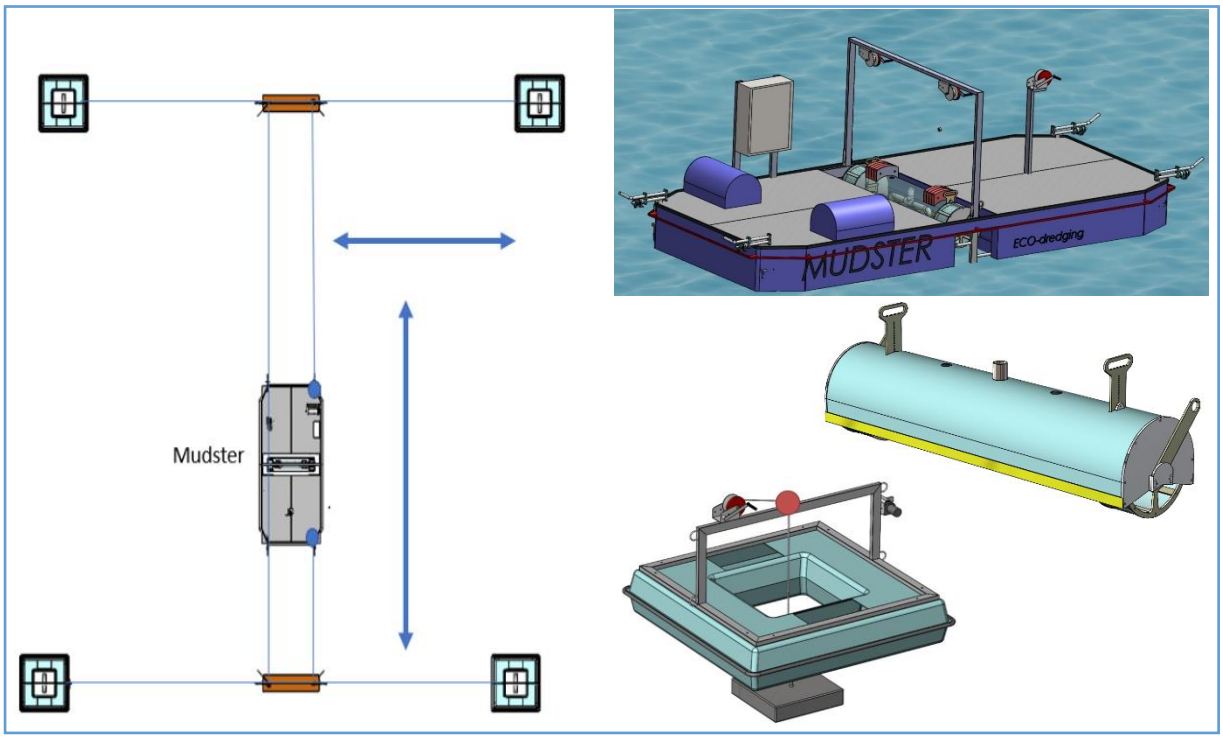
In autumn 2017, TM started to plan and construct the dredging prototypes to make them adapted to the specific conditions of Malmfjärden bay. These prototypes were purchased in 2018 with a written statement of TM that tests would be done to prove functionality. However, when TM suddenly left the project in October 2018, no tests were done in Kalmar. In spring 2019, the prototypes were examined, and KLM also sent a long list of complaints on the construction in a formal written reclamation to NN. Also, an operating program should have been provided, but was never received. The reclamation was denied with the argument that it arrived too late according to the standard contractual conditions (NL09).

Technical drawing Swan prototype (source: NN), picture of Swan-1 with minor adjustments (image: Ulf Rickardsson)

The projects steering group decided to continue the project with the two remaining partners and external experts were hired to test and develop the prototypes. During the year, many improvements and additions were done on the prototype Swan-1. Despite the improvements, the prototype failed to retrieve any sediments nor could be operated remotely. There were substantial problems with the underwater units, the chosen pumps, the wire-system on the rafts, the operating system and the anchors. Finally, the prototype Swan 1 and its solution had to be seen as non-functional and was put aside.

In April 2020, the first all-new prototype Mudster was put to the test in Malmfjärden bay and the first connection with the land site was made and the first amounts of dewatered sediments were produced. In august 2020, Mudster 2 was produced and tested. Other improvements were done on the Mudsters increasing user-friendliness and work safety. An instructions manual and a design document were made and updated consequently.

The Mudster prototypes have a transparent and flexible low-flow underwater unit and are operated using just one wire and one motor. Technicians can control and steer the raft and the dewatering system remotely, using Wi-Fi and internet. As a result of this working invention, and the project's objective to spread the solution to other sites, the steering group decided to apply to a patent to secure the IP-rights for further replication and dissemination of the dredging robots.



Drawings of the movement solution, the Mudster, under water unit and the anchors. (source: Ulf Rickardsson)

Dewatering and treatment equipment

In 2018, the site was prepared to receive a land-based treatment: levelling, piping, energy and water supply, septic tank, staff room and land preparation for heavy trucks to come in and transport the sediments out. However, due to the lack of technical specifications from TM on the solutions that they said had developed for the project, the land-based system could not be finalized. Early 2019, it was decided the project would test passive dewatering solutions in geo-textiles. This solution is more environmentally friendly as the reject water is clean and is much more cost effective.

The limited space of the treatment site did not allow for other common dewatering and treatment solutions, such as large geo tubes or big sedimentation basins. The chosen LIFE SURE solution finally was to dewater the sediments in geo bags in 6 containers. The bags are filled in a certain order. When one geo bag is full (which can be in one day of dredging in the full-scale demonstration), it is left to dewater for a few days before it is collected, emptied, and returned to receive new sediments. This way, a continuous dewatering process is secured.

The dredged masses arrive at the site in an equalisation tank. There, the masses are mixed and analysed. Depending on the total solids (TS), an amount of polymer is automatically added, and the

masses are pumped to the dewatering containers with geo bags. The particles materials remain in the geo bags and clean reject water is released. A final filtration is done through a reed filter before the water enters the bay.

In spring 2019, the site was prepared to receive sludge and dewater the sediments using the techniques above. For the test-phase, also a water filter and buffer tank for the reject water were built (these were no longer necessary in the full-scale demonstration). In August 2019, the infrastructure was ready for the tests and Action B2 could start. During 2020, further investments were done to increase the capacity of the land-based system for Action B3. After Action B2, the site was adapted for the full-scale demonstration, in order to receive incoming flows that correspond to the flow in the Grant agreement (45m3 per hour). This plan included a solution to have 6 collectable containers on site that would dewater sediments onsite.

In 2020, also the site got a new notice board and information signs. The site was completed with sediment use growing experiments and demonstration units.

The operating system and schematic overview of the treatment site, areal image of the site in April 2021 (source: Ulf Rickardsson). Images of the incoming sludge, the dewatering containers, and a full geo bag. (images: Renate Foks)

Action B2: Installation and Minor scale tests

The objective of Action B2 was to install and test the system, before commencing full scale dredging in Action B3. The dredging system need to be installed and calibrated to work autonomously.

Installation

The Mudster prototypes have shown compliance with all the technical demands and challenges. The raft and underwater units were tested separately and calibrated properly. The system was connected to the land site in April 2020.

Testing of equipment

Because of the problems with prototype Swan-1, only small amounts of sediment could be dredged in 2019. However, with the Mudster prototypes, LIFE SURE was able to perform adequate tests, system set-up, calibration and collect performance data both from dredging prototypes and land-based system during April-June 2020. Performance data was then gathered and used as input to modify and adapt the second prototype and scale-up the system for Action B3.

Test for extraction of metals and phosphorus in laboratory scale

The extraction and recovery tests were focused on the removal of metals and nutrients. A summary is provided in action B3 of this project report.

Mudster and the specially developed anchor during the small scale test (images: Renate Foks)

Action B3: Full Scale demonstration

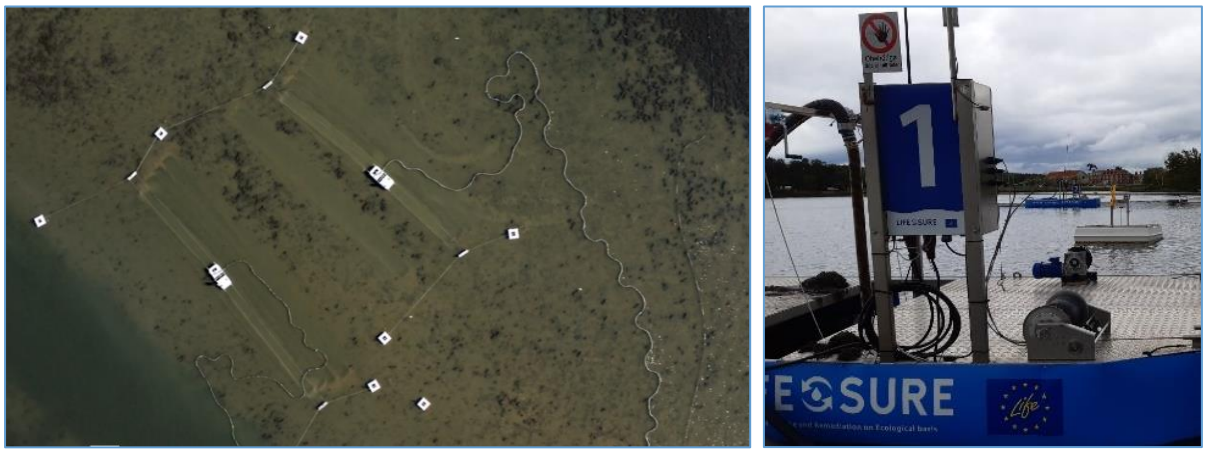
The objective of this action was to demonstrate that the system is well suited to remove sediments from a water body, without causing re-suspension of particles or other detrimental effects.

Sediment removal and dewatering

Since there was a delay in the project, the production period for the full-scale demonstration was limited. This contributed to the total flows being reduced compared to the original plan. Action B3 started in September 2020. In 2020, 1000 m^3 (1-5% dry matter) of wet sediments was taken up. Corresponding to ca. 40 m^3 dried sediments (26-30% dry matter). The demonstration was interrupted on December 15. In 2021 approximately 6800 m^3 of (1-2% dry matter) of wet sediments were removed, corresponding to 225 m^3 dried sediments (25-30% dry matter). Two dredging robots, Mudsters, were employed at the same time, and tests were done to dredge remotely (no staff on site on several days) as well as continuously (from early morning to late at night). Action B3 was abrupted in the first week of December 2021 when temperatures dropped below zero.

Even though the full-scale demonstration was ended in December 2021, in spring 2022, the site and Mudsters were made operational again, but this time for the main reason to demonstrate and share information on the solution during study visits and the final conference. Also, the city-council of KLM decided in December 2021 on a budget that secures a continuation of sediment removal in Malmfjärden bay for 3 years after LIFE SURE has ended. Also, the city council has expressed desire to start same kind of projects in other local coastal areas. KLM also was granted a national funded project (LOVA) to continue research and develop sediment use for soft sediments from the Baltic Sea. This is a follow up of sub-action B3.3. These activities are described in the After LIFE Plan.

Mudster 1 and 2 in Malmfjärden Bay, the day they were put in the water after the winter break (images: Renate Foks)



The Mudsters during the full-scale demonstration in spring 2021 (images: Ulf Rickardsson (left), Johan Persson (right))

During Action B3, a lot of experience was collected on continuous and automatic running of the system. Improvements were done and the polymer dose was automatised. Day to day activities, deviations and corrective actions are stored in a logbook that provides day to day feedback.

Sediment use

The objective of this sub-action was to focus on the clean and dewatered sediments that will be reused in other applications. Contacts with users and companies were made in Action A1 and B2. The projects intention was to use the sediments in soil improvements, construction, landscaping and cover materials. The goal was at least 70% of the sediment would be used this way, LIFE SURE has found useful purpose for all produced sediments and has started new research, innovative applications and business opportunities for use of sediments.

In LIFE SURE, dewatering bags with geotextiles (also called geo bags) nested in movable 20 m^3 containers were used to dewater sediments. The sediments are dewatered on site and transported directly to the user. This way, the treatment site was able to accept and dewater sediments continuously, despite the limited space on the treatment site.

In 2021, LIFE SURE produced 16 geo bags. 15 of the 16 geo bags with dewatered sediment were transported to the municipal landfills Östra Tegelviken and Barkestorp, located circa 10 km from Malmfjärden bay for final landfill covering. At the landfills, the bags were opened, and lime was mixed into the dried sediments and the spread. One geo bag was left on the treatment site and was used in the pilot sediment use projects described below.

The following trials were executed:

(1) Extraction of metals: Tests were carried out to extract metals from the sediments.

(2) Recovery of nutrients: Cultivation experiments under greenhouse and free land conditions to test the beneficial use of sediments in plant growth substrates and compost experiments.

(3) Trial making construction blocks of the sediments.

Of these, results from the greenhouse experiments are still under analysis, and a scientific publication is being prepared to be published in 2023. A summary of the results of the three trials are shown below. Trials provided valuable information on how the Malmfjärden sediments can be used as soil remediation and provide the basis for a follow-up project for developing sediment used for Baltic Sea sediments.

Extraction of metals

The extraction of metals started with the assessment of the bio-availability by performing the speciation of elements. The results showed that all metals were linked to the residual fraction, suggesting that part of the elements come from natural sources. Lead and zinc were 30% linked to the residual fraction, while cadmium, nickel, copper and iron were at least 50% linked to the same fraction. The contamination factor showed that, on the sediments, lead and zinc were medium contaminated, and the other studied elements presented no contamination. Cadmium results were not possible to analyze since the extracted aliquots presented concentrations below the detection limits. Older studies suggested that cadmium was linked to the residual fraction by only 10%.

Bioleaching was not tested since the low temperatures in Sweden could reduce the efficiency of microorganisms in charge of producing acids to extract metals.

Chemical leaching was selected since it is widely used for other samples like soils and promises good extraction rates for sediments. The method showed satisfactory recovery rates of lead (60-84%), zinc (60-80%), arsenic (50-60%), nickel (28-30%) and copper (50-59%), suggesting the possibilities and even feasibility of using sediments as a secondary source of specific metals for sediments with higher contents of metals. EDTA and EDDS were tested, and both presented similar extraction rates. However, EDTA had higher extraction rates on elements that were highly linked to Fe-Mn oxides since EDDS hardly dissolved this fraction. The tested concentration and pH values also presented similar extraction rates.

Phytoremediation was also tested to evaluate the possibility of removing metals from sediments. The technique employs hyper-accumulator plants to uptake metals from soils/sediments. The uptaken trace elements could be recovered by incinerating the biomass and extracting the metals from the ashes with chemical leaching. The selected plant in the project was alfalfa (Medicago sativa), and the test was carried out under stable conditions in a greenhouse. The plants never grew, and this was attributed to the physical conditions of the sediments since the large content of fine particles did not allow the plants to grow. Photos of the plants are shown below. More experiments to grow plants were carried out, and the results are illustrated in the following section.

Phytoremediation experiment at the greenhouse with alfalfa (left). Lettuce harvested in greenhouse test 1 (right) (Images: Laura Ferrans)

Recovery of nutrients

1st Greenhouse experiment

Phosphorous, nitrogen and other essential elements were recovered by using the sediments from Malmfjärden as a plant growing substrate under greenhouse conditions. The aim of the test was to assess if plants could grow and if they uptake metals. The pre-test was conducted with lettuce and only sediments, and plants did not successfully grow with weights of less than 10 g. Later, the test combined sediments and compost to improve the physical properties and nutrient distribution. Sediments with and without polymer were employed to determine if there were differences in growth. The best lettuces with higher weights were obtained from 100C, 50Sed^{PO}-50C and followed by 50Sed^{LN}-50C (lettuces are shown in the photo above). All lettuces weighed less than 25 g, and the standard weight of a lettuce is around 300 g. The low growth was possibly related to the lack of available nitrogen in the substrates and potential eco-toxicity from elements like cadmium. It was possible to conclude that there were no significant differences in the lettuces from sediments with and without polymer and that using more sediments concluded in a lower weight of the harvested lettuces. Moreover, the lettuces up-took cadmium, and the contents overpassed the European levels. The results showed a slight risk to human health. Therefore, future studies focused on reducing the bio-availability of metals.

2nd Greenhouse experiment

In a second study, dredged sediment growing substrates were successfully used to grow lettuce. The employed 7 substrates combined bark compost and biochar in different amounts. With regards to macronutrient status, all sediment-based substrates were deficient in nitrate-N, the main source of plant available N. Plant available phosphorus (P-Al) was present in sufficiently high contents to sustain plant growth. With regard to the growth of the lettuce plants, fertilization proved to be a bottleneck, and there was an observable difference in growth between fertilized and non-fertilized treatments 30 days into the experiment. No significant differences were observed between growth in fertilized treatments and the control. The biggest individual plants were observed in substrate mixtures with S30C70BC FERT and the commercial potting soil control. In the former individual plants had a fresh weight of up to 322,2 g at harvest, which is comparable to commercially available lettuces and illustrates the potential for growth of lettuces in sediment-based substrates. The photos from all substrates in the second test are shown below.

Plant growth in fertilized and non-fertilized substrate mixtures (S30C70BC)(A) and in the control potting soil (B) 30 days into the second greenhouse experiment. (Images: Frank Schmieder)

Amendment with biochar is a promising and simple method to stabilize cationic heavy metals in grow substrate and to considerably reduce plant uptake of metals. In the present study, Cd leave content in lettuce was substantially reduced with biochar but remained above the critical concentration for leaf vegetables, according to EU regulation. Hence, currently, the recommendation is that sediment-based substrate may be used for ornamental or energy plant cultivation or edibles with a lower tendency to accumulate heavy metals.

As there was an interest to continue with the results from the laboratory tests and there is commercial interest from local stakeholders to use the sediments as a soil improver, several follow up trials were done at the LIFE SURE treatment site. One with direct planning and one with composting.

Cultivation trial at the LIFE SURE treatment site

The cultivation trial with the sediments on the LIFE SURE treatment site was carried out between spring 2021 and summer 2022. The trial included sediment-based growth media of different composition, with biochar, peat, and bark compost as additional components. On these substrates selected plant species, e.g. sunflower and beetroots were cultivated to evaluate growth performance and metal uptake. Plantations were carried out in plastic boxes. All replicates received solid NPK fertilizer amendment (Stroller blå) prior to the experiment start and a second dosage after 8 weeks. In addition, planting boxes with different sediment-based substrates were planted with a multitude of different plant species commonly grown in private gardens for demonstrational purposes and placed visibly for people bypassing the dredging site (see photo below). During the test, all vegetables grew, and the content of metals is still under analysis and will be later reported in a scientific

publication. It also plays an important role in continued collaboration on sediment use in the newly started LOVA project (Activity 2 in the After LIFE plan).

The conclusions of these trials to retrieve nutrients from sediments using plans is that the sediments contained a pool of plant available P that can be utilized to recycle P. Using sediment-based growth substrates remains an attractive beneficial use option that contributes to closing the P cycle in plant production as the need for P fertilization is at least reduced. The sediments used in the study were fresh sediment with less than a month between dredging, dewatering, and final use in the mixture. The growth of lettuce in fertilized substrates was satisfactory. However, allowing the sediment to go through a process of ripening prior to the use in growing media would likely improve plant growth performance.

This trial was done as part of post-doc research and student assignments. LIFE SURE provided facilities on site for this research as well as sediment analysis. For example, boxes that were used for the water filter in Action B2 were reused as growing boxes.

Composting

Also, a composting experiment was carried out to assess if metals could reduce their availability and improve nutrient distribution. In the experiment, beach wreck, green waste, sediments, and biochar were combined. Composting refers to the degradation of organic matter. However, no degradation or change in the distribution of metals and nutrients was detected.

Extraction of phosphorous

Additionally, experiments to extract phosphorous were also carried out since the method could help to produce mineral phosphorous more like the currently used fertilizers. Extractions were performed using citric acid, sulfuric acid, EDTA and sodium hydroxide. The higher extraction rates for the element were found for sulfuric acid at pH 1, where about 40% of the element was removed. Metals were also mobilized, reducing the quality of the final product.

Pilot test growing different plants at LIFE SURE treatment site and Composting experiment with sediments, beach wrack, green waste and biochar (Images: Laura Ferrans)

Construction blocks

LIFE SURE sent out a direct-procurement request to start a pilot for the commercial application of sediments. NETICS AB, a Dutch sediment-use specialist company, won the procurement with their proposal to make a recipe to create compressed construction blocks from the sediments. Applications researched were for example pavements, sound barriers and water permeable parking tiles. 200 kg of dredged sediments was sent to NETICS to make a recipe and demonstration blocks with a focus on pavement stones.

NETICS has developed the GEOWALL®-method. This method focuses on stabilizing dredged materials, using physical, chemical, and mechanical stabilization techniques, into compressed blocks. The feasibility of the GEOWALL®-method has been studied by conducting lab research targeting the requirements for pavement stones. In total four groups of recipes (geopolymers, cement, cement + pozzolans and sustainable cement) have been developed with in total more than twenty different recipes. Additions such as sand, gravel, clay, geopolymer, cement types, fly ash, lime and fibers have been investigated for the goal of stabilizing the Malmfjärden bay material. For every recipe several testing cubes have been produced to test on parameters such as mechanical strength, durability, and quality of mixtures. The material properties of the blocks are studied by analyzing the physical parameters.

The dredged sediment from the Malmfjärden bay was challenging to stabilize because of the high water content, high organic matter content and fine silty composition. Therefore, the maximum compressive strength measured after 28 days was 3.34 MPa which was below the threshold (5 MPa) for pavements stones. However, after 10-28 dry freeze-thawing cycles the blocks were forcefully dewatered which led to a sufficient increase in strength up to 5.87 MPa. The effect of the water content was later confirmed by producing samples with dry Malmfjärden sediment (65% solid content) resulting in strength up to 18 MPa.

Example of the final product, pavement stone of sediments. Test blocks of the Malmfjärden sediment, and a demonstration of the lab scale Geowall during study visit March 2022. (Images: Netics (left) and Renate Foks)

With the target to assess and improve the environmental properties and costs associated with the full dredging chain including the application of the material, an additional analysis was conducted. At first the previously developed recipes were improved in terms of environmental impact by replacing the used Portland cement with Cemvision Ecocement. (Cemvision is a local company in Kalmar working with cement from waste products) By doing this, similar cube characteristics could be achieved confirming the suitability of Cemvision for producing sustainable pavement stones.

However, the susceptibility for water content was again confirmed. The final design recipe consists of up to 40% dredged material compressed into a block element. The results of this study are very promising, and KLM will continue looking for possible funding to further develop the building with sediment stones technique, as described in the After LIFE plan.

Next step was a complete assessment of the full dredging chain using a life cycle assessment (LCA) and cost benefit analysis (CBA). Due to the use of green electricity dredging and the introduction of environmentally friendly applications such as fertilizer replacement and pavement stones, the environmental impact is significantly improved in relation to the reference situation (regular dredging (max. 85% saving) -> dewatering in depots (max. 85% saving) -> land filling (max. 95% saving)/ concrete pavements (recipe: max. 75 % saving)). Moreover, by introducing one or more improvements to the steps in the chain, the environmental savings can hugely be increased which optimizes the outcomes of the LCA and CBA.

In terms of cost-effectiveness the current method of dredging and dewatering performs similar as regular alternative methods because of the current innovative character. However, some suggested simple improvements are quick wins to improve the method which results in significantly increased cost-effectiveness. These concern mainly the point of intake during dredging, pump capacity, type of flocculant, design of the dewatering containers and type of geotextile.

Conclusion

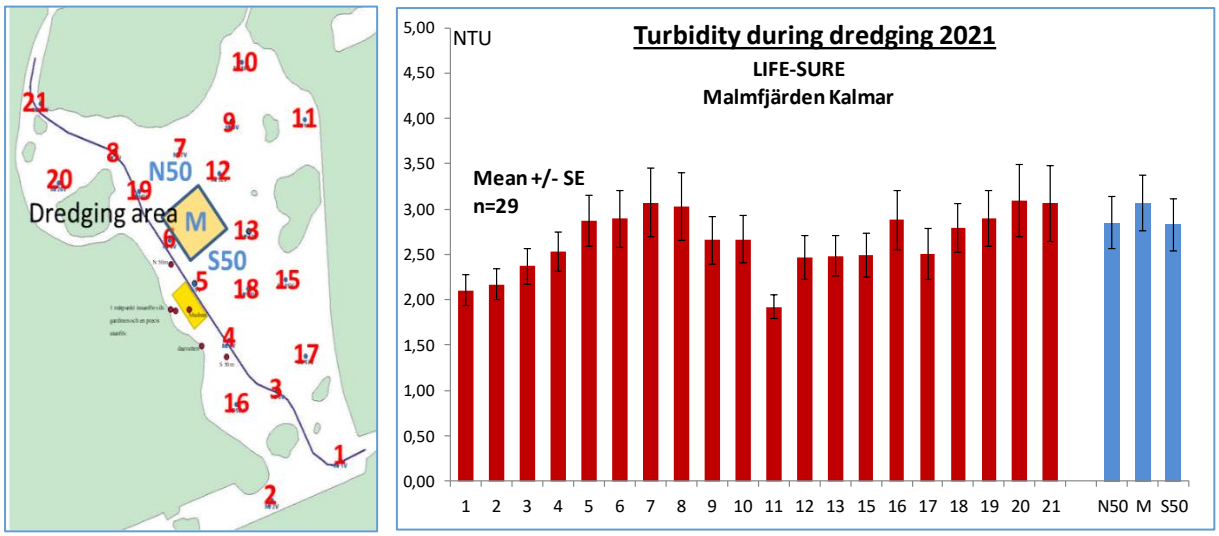
In conclusion, the Malmfjärden sediment is challenging to handle but nevertheless useful in low end applications (fertilizer replacement) and for more high-end applications (pavement stones). To achieve an environmentally friendly and cost-effective method for the beneficial use of sediments, several optimalizations are necessary. Most importantly sufficient dewatering (40-60% of solids) is necessary which can be achieved by optimizing the dredging itself (sucker depth placement, power usage and vegetation removal) and improving the dewatering (improved double wall container design and type of geotextiles combined with more efficient equalization). In case this process is sufficiently optimized the potential for the Mudster electrical dredging in combination with geotextile dewatering and high-end beneficial usage has an unlimited potential for both civil structures as buildings. The current method already acts as an example for further studies on this subject worldwide. The outcomes of present study will be incorporated in the running follow-up with the Mudsters.

Action C1: Monitoring and Evaluation

In Action C1, the activities and results of LIFE SURE project are monitored and evaluated.

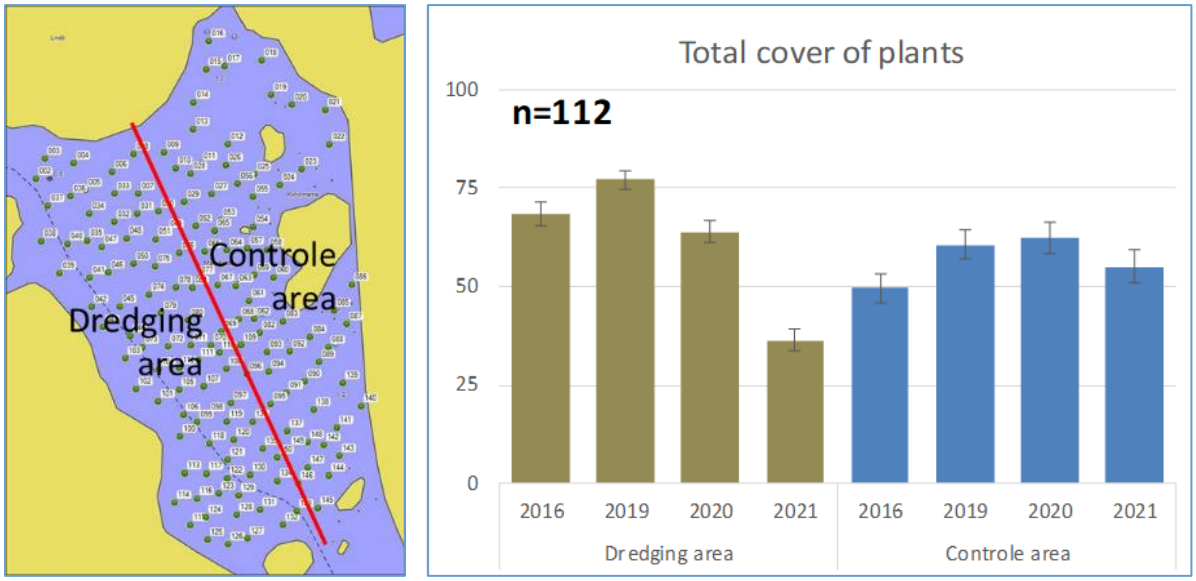
Monitoring and Evaluation of Malmfjärden

The project has examined changes in environmental conditions in the bay. The removal activities did not cause any turbidity or resuspension in the water. Because of the lowered dredging goals and the short time left in the project, only a limited evaluation has been done on monitoring marine life restoration. The sampling stations are shown below, along with the results from turbidity. Red numbers represent the area where dredging was not being carried out, while blue numbers show the area that was being dredged during the time of the measurements.



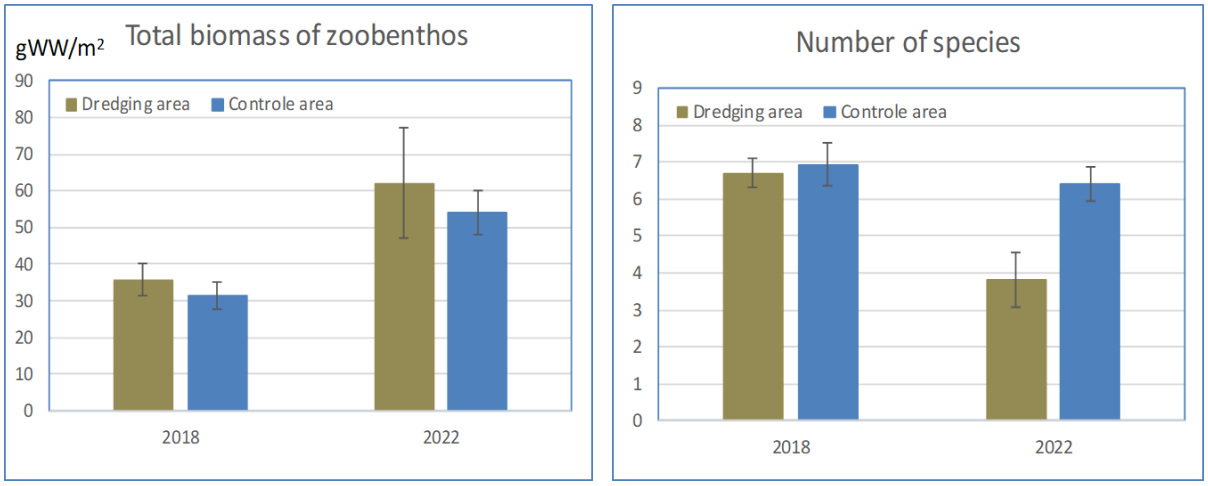
Sampling stations for the measurement of turbidity while dredging (left) and Results of turbidity measured while dredging (right) (red bars: non-dredging area, blue: dredging area). *(source: Stefan Tobiasson, LNU)*

The coverage of vegetation was also measured during the dredging activities. The coverage of plants, as expected, was reduced since the dredging machine removed the plants while extracting sediments. The sampling stations and the percentage of coverage are shown in the figures below. After dredging, some species were re-established after 6 months.



Sampling stations to measure the coverage of plants (left) . Plant coverage in the last years. In 2021, the coverage was reduced since the dredging machine also removed plants. (right) (source: Stefan Tobiasson, LNU)

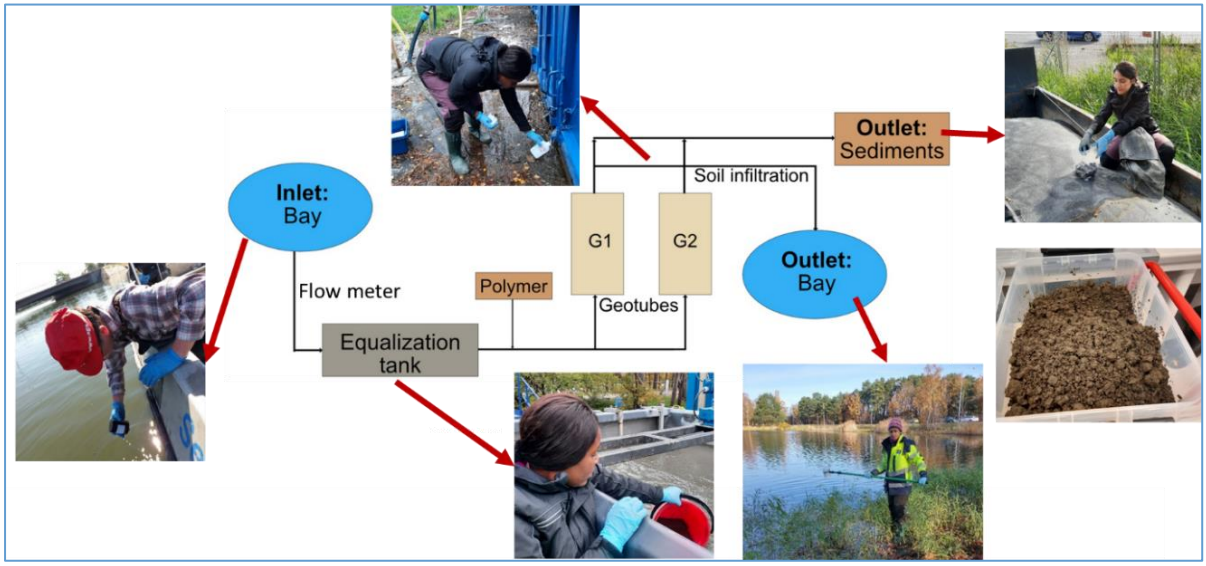
After dredging, the recovery and disturbance of zoobenthos (animals living on the sediment) were analyzed. At 6 months after the dredging activities, there was a visible recovery of the zoobenthos (but not of mussels). Results are shown below. However, the number of species reduced after dredging (see figure below), but a better recovery is expected in the upcoming couple of years. The project partners have secured financing to continue monitoring in Malmfjärden bay after the project.



Total biomass of zoobenthos before dredging (2018) and after dredging (2022). (left) and Number of species of zoobenthos before dredging (2018) and after dredging (right) (2022). (source: Stefan Tobiasson, LNU)

Monitoring and Evaluation of the sediment treatment and dewatering.

The project monitored several parameters, such as incoming sediment masses, used polymer and electricity as well as pollutants in sediment, rejected water (outlet) and water from the bay. Over the whole project time, rejected water kept below the allowed levels in the permit. A monitoring plan was designed to follow up the system. The scheme of the dewatering system and photos of the sampling procedure are shown below.



Dewatering system and sampling photos in the different stages. (Source: Laura Ferrans)

The mean inlet flows to the dewatering system during the full-scale demonstration (September 2020 to December 2021) varied depending on if one or two Mudsters were used. Or if any problems were encountered, such as storms or technical problems. In total, around 12 000 m^3 entered the system.

Regarding the quality of the reject water, monitoring data shows that levels in the reject water never overpassed the thresholds. It is important to notice that the oil index overpassed the limits at the outlet of the geo bags. However, the system was designed to additionally remove more organics by the last step of the soil infiltration. It is impossible to sample the outlet water once infiltrated into the soil. Therefore, it is recommended to perform a sampling of the soil in a couple of years to verify the degradation of the organics in the soil matrix. Moreover, the quality of the bay was always in good condition, and variations in concentrations were more related to the dynamics of the bay.

Regarding the sediment phase, two different geotextile dewatering bags were evaluated. LIFE SURE tested two suppliers, comparing both the reject water quality and the dewatering speed. The geotubes from TenCate showed the best results.

During the full operation of LIFE SURE, 16 geo bags containing dewatered sediments were taken out of the system with a volume of 22 m^3 (approx. 1 m^3 could not be employed to avoid high weight in the trucks). Additionally, a geo bag of 9 m^3 was extracted in the full operation of 2020. In total, approx. 345 m^3 of sediments (solid content of about 30%) were taken out of the system. If only the solid matter is accounted approx. 105 m^3 (solid content 100%) of solids were treated in the system.

The quality of the sediments in the inlet and outlet was compared to the Swedish maximum permissible limits for soils/sediments used in more-sensitive uses (KM) and less-sensitive uses (MKM). The sediments fulfilled the less-sensitives limits. However, Cd, Pb, As, PAH-H and aliphatic compound 12-16 slightly overpassed more-sensitive limits. Regarding the solid content, the aim of the system was to increase it, and the results were satisfactory since it increased from around 6% in the inlet to around 30% in the outlet.

In conclusion, the dewatering system was effective, and the geo bags generated dried sediments with a solid content of around 30%. Additionally, the bags were effective on electricity consumption since they are a passive system that does not require it. Oppositely, other dewatering techniques, like centrifuges, consume electricity for their operation. The main recommendations after the evaluation of the system were:

- LIFE SURE did not require the removal of pollutants from reject water or sediment phases. However, this can change in other projects depending on the quality of the bay. If the treatment of sediments or water is required, other treatment units shall be added to the system. Possible technologies are filters, coagulation-flocculation, sedimentation, or others according to the requirements
- The geo bags used in LIFE SURE were small due to space limitations. For other projects, it is recommended to employ bigger geo bags since the economic feasibility of the projects can increase. Additionally, it is recommended to use free-standing bags (opposite to those contained in containers) since the dewatering procedure can improve.
- The oil index measured on the water effluent of the system and sediments was related to the addition of polymer. When fine particles are present in the sediment, the polymers are essential to secure the dewatering of the material. Therefore, the recommendation for the polymer is to maintain it to secure the dewatering, but it is always necessary to maintain the dose as low as possible. The optimal doses can be tested using a jar test where several of them can be assessed.
- It is also recommended to analyze the oil index on the soil where the water outlet of the system was infiltrated. It is assumed that the organic compounds can be filtered and degraded over time. However, an inspection in a couple of years could help to prove the quality of the soil.
- The equalization tank has the important task of homogenizing the quality and quantity of the inlet containing water and sediments. Therefore, it is recommended to always ensure a good mix on this tank. When no mix is provided, the quality entering the geo bags can be modified, reducing the efficiency of the polymers. Moreover, sediments can settle on the tank, increasing the need for cleaning.
- The efficiency of the system can be increased if more solids can be brought with the dredging machine. The solid content of the initial material changed over the development of the technique, but it was around 1 to 5%. If more solids are brought to the land system, the dewatering and complete project system could be more efficient.

Monitoring and Evaluation of cost-effectiveness.

The cost effectiveness and life cycle assessment (LCA) were performed as part of the ongoing PhD-research, a master thesis ("How Sustainable is LIFE SURE") and a consultancy from NETICS. Some results of NETCIS evaluation are already mentioned in Action B3.

The cost effectiveness was calculated by comparing LIFE SURE with two different projects. The first project is the dredging project in Örserum, Jönköping, which took place between 2001-2004, and utilized a traditional dredging methodology. The second project occurred in Svartsjön, Hultsfred, and occurred in 2006. It also utilized a traditional dredging methodology. Both projects occurred within relative proximity to Kalmar. Operational costs were adjusted due to inflation. The costs included in this evaluation were focused on operational costs based on the full scale of the dredging operation per month. The costs for registering a new project or developing an innovation technique were not included since these were not available for the other projects. The cost effectiveness of the 3 projects is shown below.

Table comparing cost effectiveness between the LIFE SURE project, Örserum and Svartsjön projects. (Source: Alexander Nilsson, LNU)

Project	Cost-effectiveness (SEK/m^3)
LIFE SURE	3816
Örserum	578
Svartsjön	406

For the LIFE SURE project, the costs were summed for the months of full operation in 2021 (May-Nov 2021) since the operation in 2020 only had one Mudster running at a time. In these cost calculations, the results from LIFE SURE showed higher costs per m3 than the other projects. However, the amount of dredging in LIFE SURE was very reduced by the fact that the technology still was under development. Therefore, to consider stable conditions at operation, an estimation of the theoretical amount of dredged sediments along with the related costs was calculated. Moreover, the main costs of the project were the personnel and geo bags. The LIFE SURE project could only employ small geo bags due to space restriction on the site where the dewatering system is located. However, other projects might have the possibility to use the same dredging and dewatering technology but using big geo bags, reducing the cost of the treatment. Additionally, the personnel used in one project could be employed to carry out 2 dredging projects located in the same area, reducing the cost of salaries. Assuming the new conditions on amount of dredged material, size of geo bags and number of projects carried out by the same personnel, new scenarios were calculated, and the cost effectiveness are shown in the table below.

Monthly cost of scenarios and associated volume of dredged material and cost effectiveness. (Source: Alexander Nilsson, LNU)

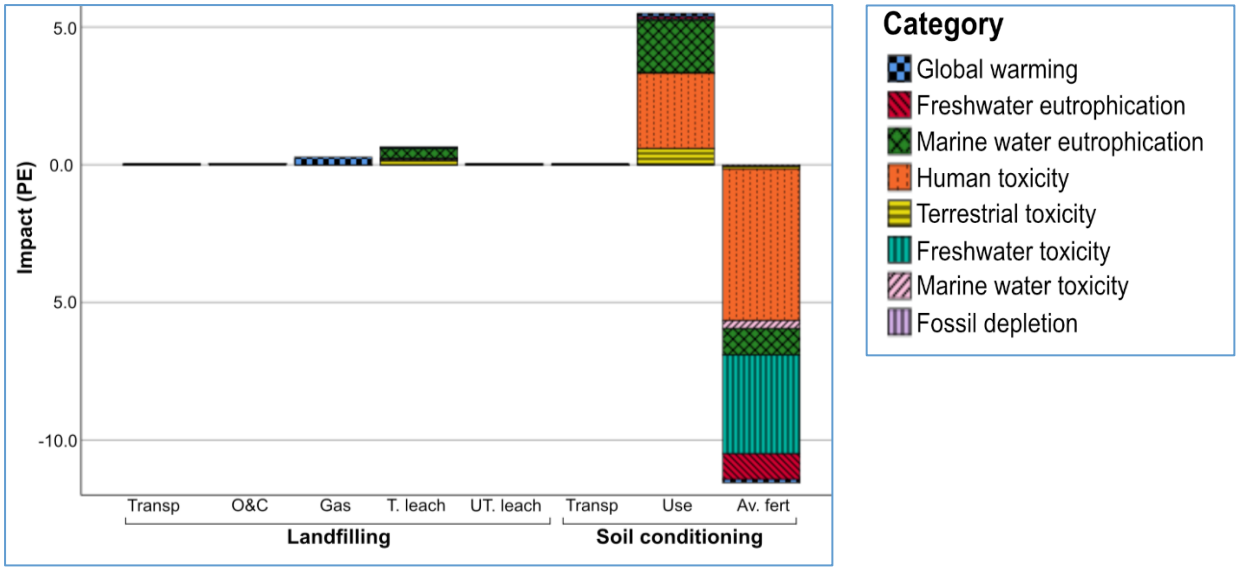
Operational hours	Large geobags	2 projects at a time	Total monthly cost (SEK/month)	Monthly Vol dredged material (m^3/month)	Cost Effectiveness (SEK/m^3)
4	No	No	220,867	101	2,191
8	No	No	292,796	202	1,452
16	No	No	436,653	403	1,083
24	No	No	580,510	605	960
4	No	Yes	296,935	202	1,473
8	No	Yes	440,792	403	1,093
16	No	Yes	728,506	806	903
24	No	Yes	1,016,221	1,210	840
4	Yes	No	181,459	101	1,800
8	Yes	No	213,980	202	1,061
16	Yes	No	279,021	403	692
24	Yes	No	344,062	605	569
4	Yes	Yes	218,119	202	1,082
8	Yes	Yes	283,160	403	702
16	Yes	Yes	413,242	806	512
24	Yes	Yes	543,325	1,210	**449**

It was concluded that similar cost effectiveness values to the other 2 compared projects were found when the system designed in LIFE SURE could operate for 16 or 24 hours, large geo bags are employed, and the operational personnel run 2 projects at a time.

The study carried out by NETICS for LIFE SURE, provided even more possible economical improvements: such as increased incoming solids. Based on these calculations, the LIFE SURE solution can even become better cost-effectiveness than traditional dredging methods. NETICS also did a calculation on the environmental costs of LIFE SURE solution, which also shows the solution can achieve lower environmental cost than conventional dredging.

Another LCA was carried out to assess the environmental impacts caused while landfilling and using dredged sediments in soil conditioning. The study evaluated impacts produced after dredging and dewatering, and the functional unit was 22 tons. The assessment was carried out in the software EASETECH from the technical university of Denmark. The impacts caused in each scenario are given in the figure below. The units are personal equivalent, which converts the units of each category into a comparable unit employing conversion factors.

Both scenarios were related to negative impacts in the categories of global warming, toxicity and eutrophication. However, the soil conditioning scenario presented the most positive environmental and economic impacts due to the environmental savings produced by the avoidance of producing and using fertilizers. Due to the inevitable leaching of metals and nutrients, its implementation shall be carefully evaluated to avoid the pollution of very sensitive ecosystems.



Environmental impacts caused during landfilling and soil conditioning of 22 ton of dredged sediments from Malmfjärden. (Source: Laura Ferrans)

Monitoring and Evaluation of the socio-economic impacts.

As part of a Master thesis, LIFE SURE was compared with two other scenarios: baseline and traditional dredging. The results of the study (appendix 15) found that the overall socio-economic impacts of the project were low/negligible regarding negative impact, and low/medium regarding positive effects. The biggest advantages from the LIFE SURE solution from traditional dredging are the effects on natural and recreational areas, boating and the nuisance of the noise and high turbidity during traditional dredging as well as the visual impact, as the robots applied in LIFE SURE melt in the landscape well.

Between 2020 and 2022, students preformed studies and interviewed over 200 persons on the perception of Malmfjärden bay and LIFE SURE. These surveys revealed that, despite the notice boards and communication in the media, LIFE SURE was not very well known among the by-passers. However, Malmfjärden bay was highly valued and the overall view on the project's goals were seen as positive. It is recommended to continue to inform about the project and particularly include younger persons and school students.

Monitoring and Evaluation of user friendliness and movability

During autumn 2021, the monitoring of the user friendliness was done by questionnaires, and the movability and bulkiness were calculated. One main result of this report is that the system is comprehendible for non-experts, but several parts, such as the instructions manual, need to be improved. All equipment is designed to easily be taken up from the water and the site, and transported to a new site by trucks. During the uptakes for winter pauses, LIFE SURE has collected a lot of experience on how to organize and optimize the movability of the different elements. To move the whole site, including all containers and Mudsters, 5 trucks with trailer "movements" are needed.

After the winter stops, the Mudsters were transported from the indoor storage and lifted back in the bay, giving the project important feedback on the practicalities round movability of the system. Images: Renate Foks)

Monitoring and Evaluation of dissemination, replication and transferability

The dissemination and replication activities are constantly registered and evaluated, in Action D1 and D2 the activities are described. The report "dissemination and replication" lists all undertaken activities in detail (appendix 16) Even though, LIFE SURE has met many obstacles such as the fall-out of the business partner and COVID19, the project team is quite satisfied with the outreach and contacts made in the project. It has reached and sometimes even exceeded its goals. One hinder to execute the replication fully, it that the IP rights are not fully secured yet.

Evaluation of the LIFE SURE project

This evaluation puts the conclusions of previous evaluations together: LIFE SURE has succeeded to develop and demonstrate a method to remove and recycle sediments from shallow waters that is relatively cost-effective (at least similar to traditional techniques) and ecological sustainable, i.e. not damaging the marine environment, releasing clean reject water and with low-energy use and providing many opportunities for beneficial sediment use. The solution is easy to use, movable and can be applied in other water with soft sediments, for example in varying depths.

LIFE SURE has also succeeded to finding solutions for beneficial use of the sediments. Naturally, an important part of any sediment removal project would be to make use of the sediment taken up. As metal removal for reuse has not been technically or economically interesting, LIFE SURE has focused on nutrient recycling. The preliminary results of the on-site growing experiment indicate that LIFE SURE has produced a successful recipe for a soil-improver by combining sediments, biochar, and mature compost. The plant growth in these mixtures was good to very good. However, we have not yet received the data from the analysis about the uptake or leakage of heavy metals. This might be a limiting factor, as the Malmfjärden sediments are affected by pollution.

In the other pilot sediments were used for construction and building blocks. The results point to that sediment can be used to replace low-density concrete solutions, such as pavement and parking tiles or sound barriers. This is very exciting news, considering that cement is a finite resource and energy demanding to produce. In the suggested outlet for sediments, it was suggested that the sediments can be used as a construction or landscaping element in geo bags, for instance as flood protection or habitat restoration. LIFE SURE did some general exploration in this area. Another possibility to explore more about using the organic material in sediments to make compost. These kinds of sediment uses will be part of the LOVA follow-up project as described in the After Life plan.

Action D1: Public Awareness

The objective of Action D1 was to disseminate the progress of the project and its results to the identified target groups and end-users in EU, thereby raising public and industrial awareness about the potential to substitute current best available technology with a more environmentally friendly way to take up and take care of semi contaminated sediment.

Several milestones and reports in Action D1 were delayed because of delays in Actions A1, B1 and B2, as well because of COVID19 restrictions, which made it difficult to invite organisations and companies for study visits as well as to spread the projects results.

Dissemination

LIFE SURE has executed this action confirming to the communication plan made in 2018 and updated in 2020.

Channels and materials:

The LIFE SURE website (life-sure.eu) had about 11.000 views between 2018 and August 2022, exceeding the expected 10.000 views. The project had a Facebook page and also sent 11 newsletters to a group of 95 subscribers to inform about updates in the project. LIFE SURE produced the following printed materials: a project brochure (2019), an information card (2020) and the Layman's Report (2022). These items were distributed during arranged events and during participations at conferences/fairs. Also, two roll-ups were produced to put up during fairs and presentations.

Media, advertisements and publications:

On several occasions, LIFE SURE got coverage in the regional newspaper. Also, the local radio did live broadcasts at the LIFE SURE site. In the project plan, the planned result was to have media attention at 20 occasions and to publish at least 6 papers.

At the end of the project LIFE SURE has achieved the following:

- 22 articles and interviews were published in 7 different mass media outlets (radio, tv and newspapers).
- 10 papers were published, of which four in scientific journals and six as conference proceedings

Even though, the Facebook page of LIFE SURE had not many followers (47), some posts were promoted, reaching over 46.000 social media users. The most popular post was the one launching the projects film.

In September 2022, Laura Ferrans successfully defended her PhD which research is based on the monitoring and evaluations of the LIFE SURE project. The defence was attended by a broad audience, as well as in Kalmar as via zoom. The dissertation can be downloaded as full at: http://lnu.diva-portal.org/smash/record.jsf?pid=diva2:1695997.

Already in January 2022, Laura Ferrans, received the prestigious Linnaeus scholarship. The award will help Laura to continue her research on sediment use. It also gave the project media attention.

The local media is interested in the follow-up activities of the project. In October 2022, the local newspaper published an article and the local TV did an interview on the LIFE SURE plans.

Films:

LIFE SURE made several films during the project.

- Animation: The first film was an animation made to inform about the planned actions. There is an English and Swedish version
- Digital study visits**:** In 2020, two films were made to use at conferences, trainings and workshops: one in Swedish and one in English.
- Project film**:** The film was ready in October 2021 and was delayed because of the delays in the project in general. The film has been shown at conferences and workshops, and will continue to play an important role networking and follow up projects. The project film is bilingual and has subtitles.
- Portrets: In 2021 and 2022, the project made three films about the people behind LIFE SURE. The idea was to make attractive content for the web site, newsletter and Facebook.

The animated film and the project film were made by a multimedia company, the English study visit was made by film students and the other films were made by in-house communication officers.

Of the films in the play list, the Swedish film has been most watched. In total, 2300 views are counted for all films.

Link to the play list:

https://youtube.com/playlist?list=PL1um4eayKd5oWxTZhqMWAZ6cmykiN65RI

Presentations and lectures

Conferences and seminars provide opportunities to disseminate the objectives and results of the project. As many of these meetings were cancelled or changed into online events in 2020, at an important stage of the project, the project team adapted its strategy. Online presentations, films and meeting with network and experts on zoom became important tools.

In 2020, LIFE SURE applied for an end-date extension to execute the activities and reach objectives in action D1 and D2. Thanks to the extended deadline, LIFE SURE has organised 5 seminars, co-hosted 3 Eco-tech conferences and organized one final conference, which makes a total of 9 seminars. The project has organised more seminars than the original 4 in the project plan. Furthermore, the seminars in the last two years of the project were the most important to share the results and to discuss concrete actions for replication and the use of the solution in other areas.

LIFE SURE has organised the following seminars:

1. 2016-11, co-organized EcoTech conference with presentations in Kalmar
2. 2018-11, co- organized EcoTech conference with presentations in Kalmar
3. 2018: hosted a local seminar with companies in Kalmar
4. 2019: hosted the national low flow dredging network in Kalmar
5. 2020-11: co-organized EcoTech 2020 with a half-day programme with presentations and discussions on LIFE SURE (online conference)
6. 2021-10: organised a seminar, workshop, study visit for problem-owners in Kalmar
7. 2021-10: organised a seminar, workshop and study visit for companies in Kalmar
8. 2021-11: hosted the national network for low-flow dredging (online and in Kalmar)
9. 2022-06: organised the final conference (online and in Kalmar)

The LIFE SURE project has been presented by members of the project team at in total 46 conferences, workshops and network meetings. Amongst many other events, LIFE SURE has been presented at the Goldschmidt conference, Sednet 2019 and 2021, Wodcon 2022, National Marine Restauration Conferences 2018 and 2020, and during several project site visits in the EU. The project has reached over 1800 researcher, students, stake holders and experts all over the world, which is double the amount expected in the project plan.

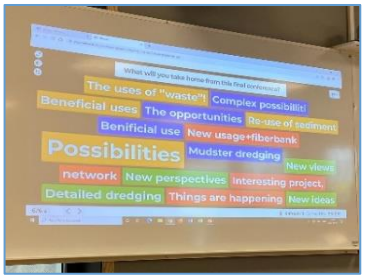
Also, the interest in LIFE SURE continues after July 2022. For example, in September 2022, the project was presented at an ERINN Innovation meeting. In November 2022, results from LIFE SURE will be presented at EcoTech 2022.

Notice Boards

A notice board and several information signs were made in early 2019, by ways of signs connected to the fences. But wind and weather tore the signs. In 2020, therefore, new, updated and stand alone signs were made. The bilingual signs have drawn attention from passing citizens and visitors, as they are located along the popular walk- and bicycle path around the Malmfjärden Bay. These signs will stay in place for as long as the sediment removal will continue at Malmfjärden Bay.

Study visits

In the project plan at least 10 study visits were planned. Between 2019 and July 2022, LIFE SURE has received 15 groups at the site, of which most after July 2021. 190 persons have been accepted at organised study visits. Not included in this number, are the many individual visits and discussions at the site. It happened often that by-passers, employees at Kalmar and LNU, students, and local politicians visited the site and got a personal tour of the site. We can conclude that we have reached around 200 persons through study visits, which equals the target. The study visits continue even after the LIFE SURE project ends.



Notice boards and final conference (images: Renate Foks (above) and Lena Hansson (below))

Networking

Networking has proven to be very valuable for LIFE SURE, such as with stakeholders, scientists, as well as in Sweden as in the EU. Initially, LIFE SURE contacted other LIFE projects mentioned in the proposal. But as the project was delayed and other projects ended, new contacts were made. Even though networking has been difficult during 2020 and 2021, many important contacts were made and developed during the projects time span. Important networking partners were CEDA, PIANC, European Sustainable Phosphorous Platform as well as the national low-flow dredging network.

As the LIFE RichWaters project is also working with a low-flow dredging project, these projects have been sharing a lot of experience. Also, sediment removal and lake restoration activities in the province of Jönköping, as well as knowledge exchange with Race for the Baltic and the Kalmar Sound Commission has been valuable to get important stakeholder feedback.

In the deliverable “networking activities”, which was published in 2021, the networking activities up to 2021 are described. In the last year of the project, the projects network has expanded even more. New contacts were made through the companies, researchers, experts through LIFE SUREs pilot projects for sediment use. In the report on the replication effort, we describe some of these follow up projects that have come from these contacts.

As part of action D2, replication, LIFE SURE has also reached out to municipalities in the south of Sweden, mapping the needs of sediment removal and interest in our project. This led to that several municipalities participated in the projects final conference.

LIFE SURE has not been able to visit other EU projects in the scope that was planned. However, in spring 2022, the project has been able to visit many projects and stakeholder in the Netherland and Germany and made many contacts for continued collaboration, which are discussed in the next action (D2).

After life plan

The partners in LIFE SURE will continue work in the spreading of results and learnings as well as further development and implementation of the LIFE SURE solution. For example, through continue working with the solution in Kalmar and starting several follow up projects for the use of the Mudsters in other areas and for the development of sediment uses. Also, the website will be updated on news from these projects and study visits will continue to be possible in Kalmar. The After LIFE plan can be downloaded from the projects website www.life-sure.eu.

Investigation of best available technology (BAT)

Best available techniques’ (BAT) means the available techniques which are the best for preventing or minimizing emissions and impacts on the environment in a specific subject. In 2020, a first evaluation was done and the deliverable *“Investigation of best available technique (BAT) was made.* The report concluded that there are no documents stating BAT (or at least that not easily available) specifically addressed for dredging equipment and land-based treatment even though this is a common practice all over the world. Also, it concluded that to evaluate whether the demonstrated techniques within the project can get recognition as BAT relies on an evaluation of the overall environmental performance of the techniques used in the project and therefore it can be done only after the project is closed.

At the end of LIFE SURE, the project argues for that the LIFE SURE solution can be recognized as a BAT because it has managed to produce as solution that can cost effectively be compared to state of the art solutions, while at the same time have much less environmental impact and therefore can in much better ways comply to environmental regulations which will be put in the future permits. However, as there is no BAT document on sediment removal nor dredging, LIFE SURE recommends that a BAT document (BREF) is produced for the sediment removal and dewatering of sediments and its environmental impacts. This recommendation is included in the annex: Recommendations to the EU policies.

Action D2: Replication and transferability

The objective of Action D2 was to ensure the cost-efficient replicability and transferability of the actions after the project.

Preparation of a replication strategy

In 2020, strategies for replication and transferability were discussed with C2M-experts and the steering group. Mudster provided a new solution to a technical problem and the IP rights had to be protected. A patent firm was hired, and two patent applications were sent in. A market research for end-users in the Swedish market was done by the project manager and a student from LNU. Also, two students from the Odense Technical University preformed a market research and business case study for the Danish market in 2020 as part of their final thesis.

Verifying transfer of technique to other entities

The LIFE SURE solutions can be used for different water environments up to 8-9 meter deep and with relatively easy technical adjustments can be adapted for increased depths. The underwater units can easily be removed and adapted to other kind of substrates.

The evaluation of funding and financing possibilities conclude that, as eutrophication and ecosystem deterioration continue to be a focus point in many national and European funds, problem owners are likely to be able to partly fund restoration projects with external funding. Also, as part of developments in the dredging industry, future procurements are expected to have a strong focus on low-energy use and avoiding damaging the marine environment. These requirements make it very interesting for businesses to invest in solutions like LIFE SURE. In time, the possibility to apply the sediments as a soil improver or in construction, will make it even more economical to deploy sediment removal projects with the LIFE SURE solutions.

Prepare business cases for application in other sectors

In July 2021, LIFE SURE was assessed by the European Commission's Innovation Radar as classed as Business Ready as it addresses the needs of existing markets / existing customers. A “business case LIFE SURE for use on other areas” was finished. In the LIFE SURE business case, the different parts come together: market research, the possibility for the system to be moved to other area, the LCA and cost-calculations and other evaluations of LIFE SURE, ensuring its positive impact on social and ecological aspects.

Some examples of LIFE SURE discussing sediment uptake and use:

Above: Eems Dollard: sediment uptake combined with clay ripening. (Images: Renate Foks)

Middle: Demonstation of the Geowall to make blocks of sediment. (Images: Renate Foks)

Below: Field for pilot tests on Öland for agricultural use (Images: William Hogland)

In the last years of the project, a lot of contacts have been made to discuss the use of the LIFE SURE solution in other areas. Such as:

- Storm water basins: Kalmar dämme is a large object were sediment needs to be removed, located in Kalmar.
- Shallow bays in the Baltic Sea. The use of the solution around Kullö and Drag in Kalmar and Töölölathi in Helsinki have been discussed.
- Coastal Estuaries: the environmental project Eems-Dollard 2050 was visited in June 2022 and the solution was discussed for use in a shallow area of the estuary.
- Eutrophicated lakes**,** Barnarpasjön in South Sweden and Hornsjön on Öland were visited and discusses by problem owners.
- Urban bays and lagunes: discussions have been started with the University of Rio de Janeiro on using the solution in the urban lagunes of the city**.**

In the field of sediment use, there have also been a lot of contacts and discussions on new applications for sediment use, with companies, farmers/horticulture companies and researchers, in Sweden and abroad.

Analysis of benefits

Environmental benefits

Traditional dredging can have adverse effects for the local environment, habitat disturbance and releasing of buried contaminants. But, with the LIFE SURE solution – this is not the case.

- By removing sediment, LIFE SURE helps restore bays and lakes with problems with water depths and/or leakage of pollutants from sediments
- LIFE SUREs Mudster robots gently sweep the seabed and do not cause any turbidity (and with that leakage of possible pollutants).
- Plants and animals can re-establish at the dredged site within a few months
- Sediment removal occurs without disturbing nesting and foraging birds close to the working area.
- Sediment removal can be done without the disturbance of water borders by excavators or large working docks.
- The sediment removal and dewatering is done without any nuance for inhabitants round the area.
- The clean reject water does not pose a risk for people or the water body.
- Sediment removal and dewatering can be done without fossil fuels, as all systems run on electricity (KLM buys all its electricity from fossil free sources).
- The sediments do not become a waste, but can be reused, as soil-improvers or blocks. This way, the solution also contributes to using fewer final resources such as phosphorous and mineral soils, and less energy consumption for example in producing nitrogen-fertilizers.

Economic benefits

Traditional dredging can be expensive. Manpower, large machinery, and transportation vehicles quickly increase costs and drive the incentive to finish dredging as quickly as possible. This in turn leads to increased ecological impacts. However, the ecological impacts are often not included in dredging cost and will have to be paid by society in a later stage. LIFE SURE is cost efficient and can compete with traditional dredging. Despite utilizing low-flow, advanced autonomous dredging systems, LIFE SURE provides an ecological and economic incentive to re-think how we dredge. LIFE SURE can help the local economy because the constructing of the machines can be done in local workshops and the running of the equipment is user friendly and can easily be taught and shared. Also, because of its remote operating system and movable solutions, it creates an attractive working environment.

Social benefits

Obstruction of narrow water ways and public spaces, noise pollution and generally aesthetic degradation are often commonplace in dredging projects. Social sustainability is important if we wish to create a truly sustainable alternative. If public acceptance is high, it is likely that public actor chooses

that alternative in areas which are prone to opposition. A social impact assessment (SIA) was conducted in the project. By measuring the different impacts of the project, both negative and positive, to a number of social factors – such as recreation, kayaking, property values and visual amenity (amongst others), we have proven that LIFE SURE holds up from a social sustainability point of view.

Replication and transferability

The projects evaluations in Action C1 show that the LIFE SURE solution can be used in other areas

- It is cost effective comparable to conventional techniques
- Technically, the solution can easily be moved, installed, and ran in other areas and it does not require expert knowledge to run the system
- It has low environmental impact, which can even be higher with technical improvements and the right choice of sediment use
- The LCA can be used to choose the most beneficiant sediment use
- There is a high support in society, among inhabitants but also financers who want to support measures to improve the marine and aquatic environments

In July 2021, LIFE SURE was assessed by the European Commission's Innovation Radar as classed as Business Ready as it addresses the needs of existing markets / existing customers.

The likelihood for replication of LIFE SURE is high and is depending on the market. As the technique is still a niche that has not been fully developed yet. The solution can be useful for both companies already working on environmental dredging and for start-ups. The LIFE SURE solution is part of a general paradigm shift from maximizing speed and size, towards a more non-intrusive and cost-effective solutions. The LIFE SURE solution can also be allowed to run year-round and have multiple robots at different places at the same time run by one op, because it does not disturb nesting birds or fish.

New and low-impact technologies in dredging are now high on the agenda. It was the topic of the latest dredging industry conference (WODCON 2022). LIFE SURE was presented during an innovative technology session with about 80 professionals in the audience. During this conference, also four sessions were dedicated to beneficial sediment use.

But LIFE SURE success in replication is also policy depended. Strict environmental policies and regulations will benefit LIFE SUREs low-impact solution. But on the other hand, long and complex permit applications and problems with the beneficial sediment use can cause such delays that it is no longer economically interesting for a commercial business.

A limiting factor can be the chemical contamination of the sediments, or uncertainties around it. Therefore, in new areas, a thorough pre-study must be made on the sediments and a ridged monitoring program must be set up.

It is also important that communication with the local inhabitants, stakeholders and politicians is done prior and under the project. The local support base for such a project is crucial, as it often means a long time to prepare and execute the measure and the effects will not always be visible directly, as ecosystems respond slowly. Therefore, it is very important to have an engaged problem owners who want to drive the measure to its completion.

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