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

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1. Introduction

Muddy and easily disturbed sediments that become resuspended due to wave and current movements pose a challenge for eelgrass restoration over large areas in NW coast of Sweden (Moksnes et al. 2018). Similar issues have been observed in Danish waters, particularly within fjord systems where the bottom sediments contain high levels of organic material due to longstanding eutrophication problems (Oncken et al. 2022). To counteract sediment resuspension and improve light and sediment conditions in such areas, sand capping has been proposed and successfully tested in both Sweden and Denmark (Moksnes et al., unpublished data; Oncken et al. 2022).

Sand capping of the seabed is primarily a technique used to cover contaminated sediments with clean sand. This method is widely applied in harbours and disposal sites to reduce pollution leakage from the seabed. Another activity involving large-scale sand placement is beach nourishment, where sand is replenished on beaches affected by erosion. The sand used can originate from land or from dredging operations at sea.

When sand capping is employed to reduce sediment resuspension, it is essential to gather knowledge and data about the target area. This includes measurements of bottom depth, bathymetry, currents, and wave energy. It is also important to map out activities in the area that may be affected by the work, such as boat traffic and recreational use. This information can help determine the most suitable method for a given location.

Below is a description of different sand capping techniques, along with their advantages and disadvantages. Additionally, available sand sources in Västra Götaland County that are suitable for use in sand capping to mitigate sediment resuspension are highlighted. The description of how the materials behave when applied assumes the use of sandy to gravelly sediments with low clay and silt content.

2. Sand capping methods

Much of the literature regarding sand capping of the seabed focuses on covering bottoms with contaminated sediments using a new layer of sand or so-called beach nourishment, where sand is deposited to restore beaches lost due to erosion. Few identified studies aim to place sand to reduce sediment resuspension or improve growth conditions for bottom vegetation, and in these cases, the focus has been on ecological effects rather than sand placement methods. Consequently, the methods described below mainly originate from technical descriptions and reports that focus on covering contaminated sediments (e.g., Bailey et al. 2005; Palermo et al. 1998b; Jarsak et al. 2016). Methods involving materials such as geotextiles or chemical absorbers have been excluded here, as they are not relevant to the purpose of the current sand capping. The type of sand capping described in this report is referred to in English-language literature as "in-situ level-bottom capping" (LBC), which involves placing sediment on an undisturbed seabed, creating a sediment surface higher than the adjacent undisturbed bottom. Other types of sand capping, where dredging has first occurred or where the bottom has been modified, are not addressed in this report.

Sand capping of the seabed can be carried out in various ways, with methods that can also be combined depending on the project's goals, possibilities, and limitations. Similar to dredging, sand placement can be done using mechanical methods, such as excavators that place sand, or hydraulic methods, where sand is mixed with water and sprayed onto the seabed. The loading, storage, and transport of sand to the site, as well as whether it is released at the surface or closer to the seabed, can vary. Alternative solutions are described below for both mechanical and hydraulic methods.

Below is an overview of different types of sand placement methods and equipment, as described in the identified technical reports (e.g., Palermo et al. 1998; Bailey et al. 2005; Rohde Nielsen 2020; Jersak et al. 2016). The advantages and disadvantages of each method are discussed, and finally, each method is ranked based on a set of criteria.

2.1 Mechanical methods

Mechanical sand capping typically involves sand sources that are relatively dry. These originate either from land-based sand extraction sites or from mechanical dredging of the seabed using equipment such as excavators. In this type of placement, the material is released at or below the water surface, and gravity carries it down to the seabed.

2.1.1 Direct mechanical placement

Direct mechanical placement of sand on the seabed can be carried out using various types of excavation equipment, such as digging or grab buckets attached to excavators or cranes. If the area to be covered is located along the shoreline, the material can also be tipped from land.

The excavation equipment can be stationed on land or on a barge or platform at the site designated for sand capping. The reach of these methods is determined by the length of the excavation arm, meaning the machine or platform must be able to move if larger areas need to be covered with sand. For mechanical placement, the covering material will likely need to be transported on land via trucks for unloading at the sand capping site or transshipment onto a barge for further transport to the location (Fig. 1). Logistical factors, such as truck accessibility and proximity to a harbour or other suitable transshipment site, must therefore be evaluated. The location where the sand is loaded onto the barge may also require the establishment of work cabins and staging areas for machinery.

Figure 1. Transport of sand capping material on a barge towed by smaller workboats (Blue Orbis 2021).

When the sand capping site is beyond land reach, the excavator must be positioned on a work barge or platform. A so-called jack-up barge can be used, where support legs are lowered to anchor the barge in the correct position. When moving across the sand capping area, the support legs can be winched up to reposition the barge. This type of barge was used for sand placement over 1 hectare of seabed at Lilla Askerön in 2021 (Fig. 2), and inspections of the completed sand capping confirmed that the support legs caused only minimal damage/imprints on the sediment surface (Moksnes, unpublished).

The precision of mechanical sand placement varies depending on the type of bucket and technical equipment used. High precision can be achieved using an excavator with GPS, enabling the operator to maintain accurate positioning of the barge and bucket. A sand spreader bucket that dispenses sand evenly can be used for more controlled unloading. This type of equipment was utilized for sand capping at Lilla Askerön in 2021 and demonstrated very high precision in both sand placement and layer thickness (10 cm ± 2 cm; Moksnes, unpublished).

A similar method was employed in Odense Fjord in 2018, where two areas of 1.0 and 1.4 hectares were covered with a 10 cm thick layer of sand (Oncken et al. 2022). Sand placement was carried out by Odense Port Authorities using an anchoring, floating platform equipped with an excavator that distributed sand from a barge. The bucket used was 2 meters wide and tipped approximately 1 cubic meter of sand at a time over a 5-meter stretch. After four bucket loads, the platform was moved 5 meters. The method worked well, with the entire area being covered seamlessly and achieving a precision of between 7–13 cm (Oncken et al. 2022).

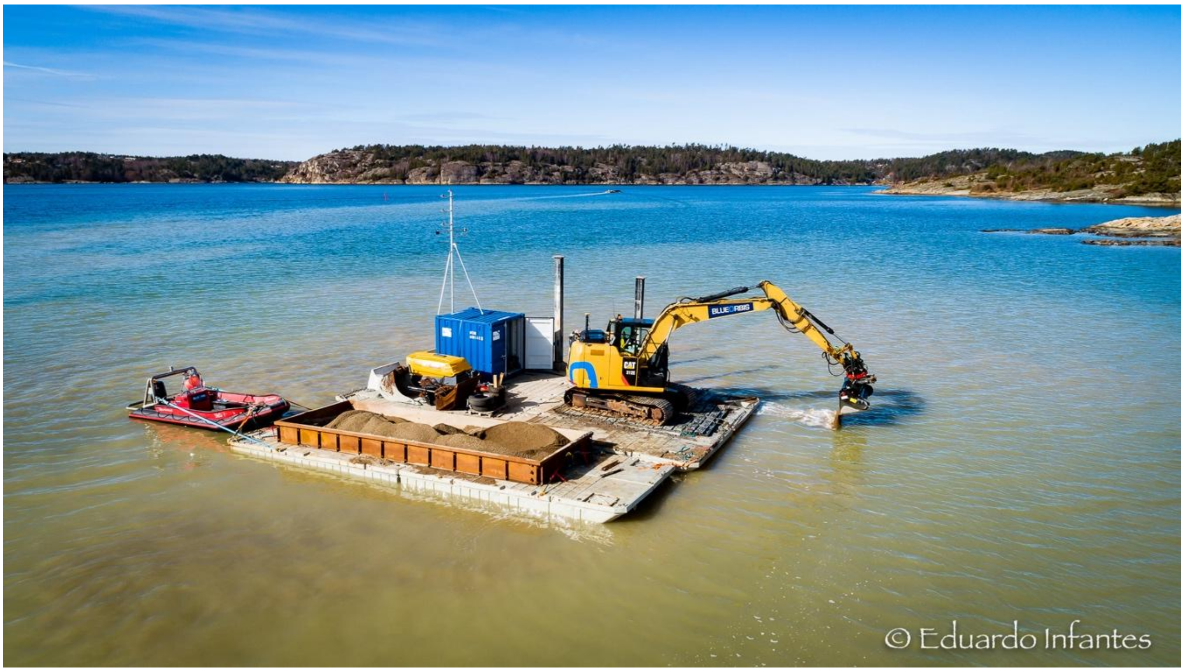


Figure 2. Sand capping through surface release using an excavator from a barge. The images were taken during the 1-hectare sand capping conducted at Lilla Askerön in 2021 (Moksnes et al., unpublished). A similar method was used in Odense Fjord, Denmark, in 2017 (Flindt et al. 2022). Photo by Eduardo Infantes.

The advantage of this method is that barges allow work in very shallow areas (down to 1.5 m depth, depending on equipment and bucket reach) without the risk of grounding. Since relatively dry material is used, sediment resuspension during placement is minimal, making turbidity control measures such as silt curtains likely unnecessary. However, the method involves multiple steps requiring various types of machinery and possibly more than one contractor if the covering material first needs to be transported and loaded on land. Due to limited cargo space on the barge, frequent transport between the transshipment site and the sand capping area may be necessary, leading to extensive vessel movement in the region and potential noise issues. This also makes the method slower compared to sand capping from larger dredging vessels with greater cargo capacity. Weather conditions can also affect the process—stronger winds above 6-7 m/s slow down the work, and damage from support legs may increase (Blue Orbis 2021). However, the advantage is that large vessels and dredging equipment are not required, making this type of placement method appealing for smaller projects.

2.1.2. Surface release from barge or Hopper dredge

Surface release of dry or dewatered sand masses can be carried out using bottom-emptying cargo barges or hopper dredges. These vessels can transport large quantities of sand at a time (100–500 m^3), making this method advantageous for covering large areas or applying thick layers of sand. The material falls quickly to the seabed, generating relatively little turbidity compared to hydraulically dredged material used with the same technique (Bailey et al. 2005).

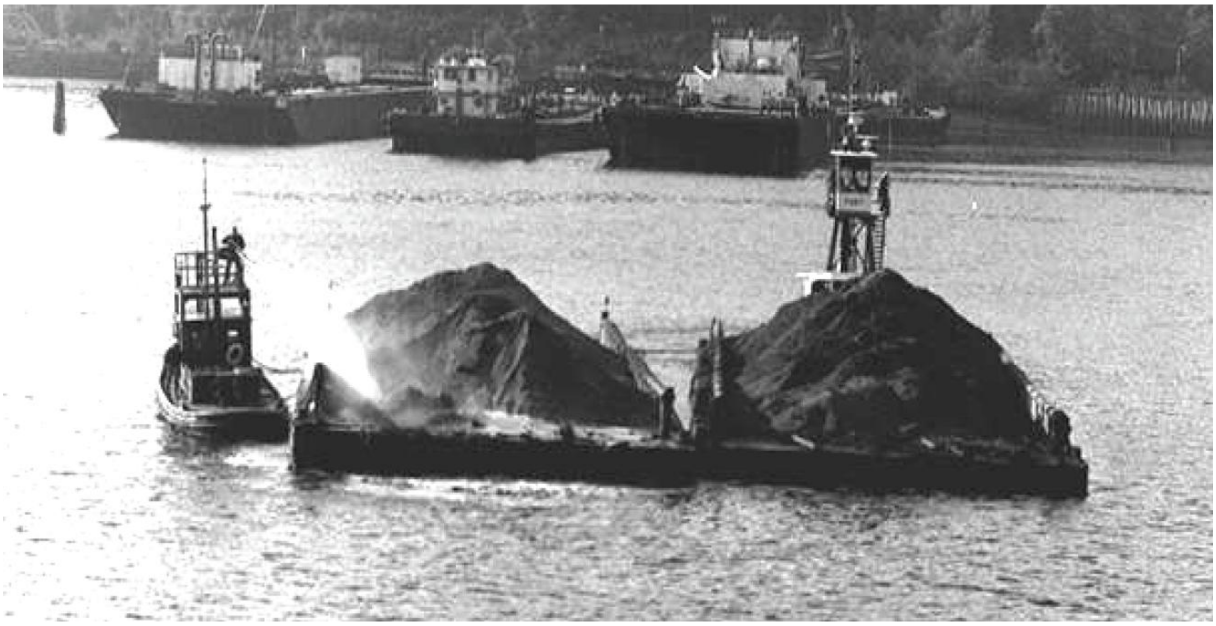
For this method to effectively cover a larger area with thin sand layers, the opening and movement of the barge must be controlled or supplemented with equipment that allows gradual and controlled release of the material. For example, there are bottom-emptying barges where the sand is compartmentalized, and by gradually opening the bottom, the material can be slowly distributed over the seabed while the barge moves across the area with the help of a tugboat (Fig. 3).

Although various techniques can enhance the precision of this method, it is likely less accurate than mechanical placement using a bucket. This method is not suitable for water depths shallower than 3.5 m, as the bottom hatches must be able to open (Vägverket 1987). If a tugboat is used, propeller movements may also cause sediment resuspension in shallower depths. Depending on cargo capacity, the barge may need to be refilled multiple times, requiring transport to a transshipment site.

Figur 3. Example of sand capping using a bottom-discharging barge towed by a tugboat (image from Bailey et al. 2005).

2.1.3 Hydraulic washing of coarse sand

A less common method for distributing dry sand masses involves flushing the material into the water using a high-pressure sprayer (Fig. 4). The sand masses are placed in a large pile on flat work barges, from where they are sprayed overboard into the water. This leads to a gradual buildup of sand as thin layers settle on the seabed. This type of platform can be used at shallower depths than bottom-discharging barges (shallower than 3 m; Bailey 2005), but controlling the thickness of the sediment layer can be challenging. Turbidity is expected to be significant, as the material is dispersed using a high-pressure sprayer, and since this occurs in thin layers, the method can be time-consuming if large areas of the seabed need to be covered.



Figur 4. Hydraulic wasing of coarse sand into the water from sand piled on top of barges (figur från Bailey m.fl. 2005).

2.2 Hydraulic methods

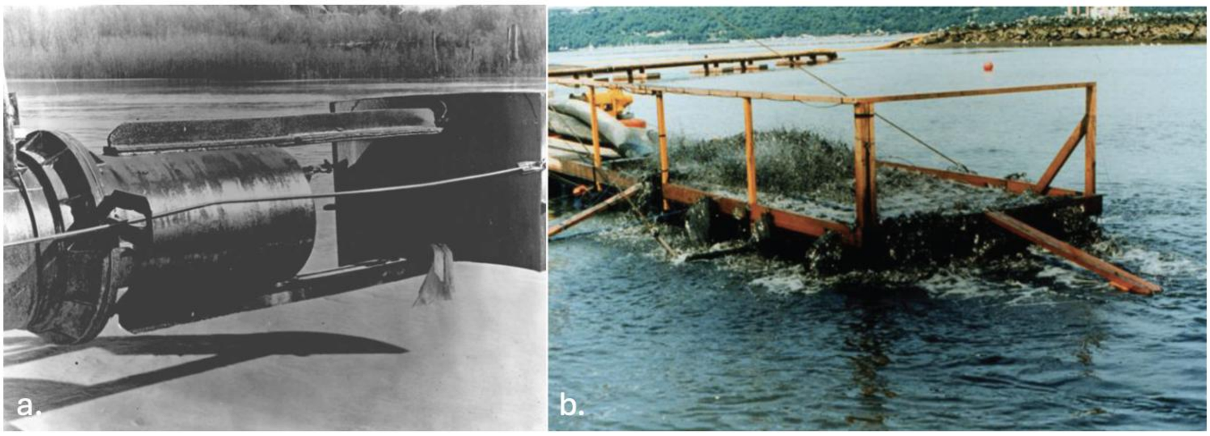
In hydraulic placement, the sand is first mixed with water. The sand can originate from land-based extraction sites, mechanical dredging, or hydraulic dredging, where sand is suctioned from the seabed and naturally mixed with water. The slurry of water and sand can then be distributed onto or below the water surface using various methods.

2.2.1 Surface release from barge or hopper dredge

Just like the method where dry materials are released from bottom-emptying barges, water-mixed masses can be discharged from barges or directly from hopper dredges. Since these vessels are large, the method is best suited for deeper waters and areas where large quantities of material need to be placed at a single location. If the material needs to be distributed in thinner layers over a larger area with higher precision, as previously mentioned, the hull must only be partially opened, and the dredge must move slowly over the area designated for sand capping. However, unlike dry materials, controlling the discharge of sand in a water mixture can be more challenging, even if the barge’s opening can be adjusted. Various adaptations of bottom-discharging dredges have demonstrated that the method works but that the covered area may become uneven (Bailey et al. 2005). Since the material is in liquid form, it does not settle as quickly as dry or dewatered masses, which likely leads to increased turbidity during placement operations.

2.2.2 Hydraulic surface release via pipelines with a distribution system from a barge or dredge

Material extracted through hydraulic dredging is in a liquid form and can therefore be transported via pipelines and sprayed onto the surface, either directly from the dredger or from material that has been transported to the sand capping site on a barge. To ensure a more even seabed coverage, various energy-dissipating devices can be mounted on the pipe to distribute the water-bound sand. Examples of such devices include a "baffle plate" or a "sand box." A baffle plate consists of a panel positioned a short distance from the pipe opening. When the water jet hits the panel, its velocity decreases, and the water is dispersed vertically toward the surface (Fig. 5a). A sand box functions similarly, with side panels that slow down the water jet. The box itself is equipped with holes or grates at the bottom to allow the material to settle as evenly as possible over the sand capping area (Fig. 5b).



Figur 5. Hydraulic surface release of sand via pipelines using two different devices designed to dissipate energy and distribute the sand during placement. a) shows a baffle plate and b) a sand box (Images from Bailey et al. 2005).

Both of these methods are well-suited for spreading thin layers of sand over large areas. The method could also be adapted for shallower waters if the material is loaded onto smaller dredging barges. The dredging barge can then be towed to the placement site, where the sand is pumped and sprayed across the area. By operating closer to the target site, placement precision can be improved, although it is still likely lower than mechanical sand placement. There are also solutions involving floating hoses, where a smaller boat manoeuvres the hose and controls sand distribution, which can enhance accuracy and allow sand placement at shallow depths (1.5–2 m; Rohde Nielsen 2020). According to this method, it would take an estimated 3–4 weeks to cover 5 hectares of seabed with a sand layer of 0.2–0.5 m (Personal communication, Christopher Rohde, Rohde Nielsen).

As previously mentioned, the limited cargo capacity of dredging barges likely necessitates multiple vessel transports to replenish materials from a dredger or larger cargo barge stationed in deeper waters. Hydraulic pumping also generates noise, but since the method is faster than mechanical placement, the noise disturbance lasts for a shorter period. Hydraulic placement may be challenging if the sediment consists of mixed grain sizes (e.g., 0–8 mm, as used in the sand placement at Lilla Askerön). There is a risk that sediment sorting occurs during the process, which could result in finer sediments being discharged first (Personal communication, Bengt Mårlind, Undeko AB).

2.2.3 Spraying from a dredger or dredging barge

The sand and water mixture can be sprayed out using a type of sand cannon from a dredger or dredging barge. This method is often referred to as "rainbowing" in literature, as the water jet forms a rainbow-like arc with a range of 50–60 meters (Rohde Nielsen 2020; Fig. 6). This technique is frequently used for beach nourishment, as the extended reach allows the vessel to remain in deeper water while still delivering the sand to the shore. A dredger with its own cargo hold has a very large loading capacity, which would enable rapid work and minimal vessel movement—one of the reasons this method is often more cost-effective compared to direct mechanical placement with an excavator (Langseth et al. 2015). For example, it has been estimated that 1 hectare of seabed could be covered with a 10 cm thick layer of sand in about an hour (according to a bid submitted by Rohde Nielsen AB for the sand capping of Lilla Askerön in 2021; Moksnes et al., unpublished). However, the vessel is constrained by the depth of the site, which, despite the reach of the jet, may limit the applicability of this method and reduce placement precision since the sand must be sprayed from a distance. There are, however, examples of larger vessels with a cargo capacity exceeding 1,000 m^3 that can operate at depths of 3.8 meters when fully loaded (Rohde Nielsen 2020).

Since water-mixed sand is expelled with significant force, turbidity levels in the water become high, and measures may be required to minimize the spread of murky water, such as the use of silt curtains. It is also crucial to monitor water turbidity throughout the operation to ensure that nearby sensitive environments are not negatively impacted. Additionally, there is a risk that this method could cause erosion of the existing seabed when water depths are low and the sediment is fine-grained.

Figure 6. Beach nourishment using the rainbowing method, where sand mixed with water is sprayed from the dredger (Image from Rohde Nielsen 2020).

2.2.4. Placement with automated hydraulic capping barge

There are various types of dredging barges specifically designed to spread sand onto the seabed. These sand-spreading barges were initially developed in the Netherlands to distribute thin layers of sand over contaminated bottoms with loose sediments (Bailey et al. 2005; Fig. 7). The spreading barge is connected to a pump that draws sand capping material from a dredger or dredging barge. With this method, placement can be automated as the spreader follows a pre-programmed path, allowing the thickness of the sand layer to be controlled by adjusting the amount of material released and the speed of the spreader. This method offers high precision, enabling the sand to be placed evenly in layers of 0.3–0.7 m, with rapid application rates of around 1,500 m^3 per hour, depending on the size of the spreading barge.

Figur 7. Automated hydraulic capping barge (picture from Bailey m.fl. 2005).

2.2.5. Subsurface sand distribution

The methods mentioned so far all involve sand being released at or just below the water surface. If reducing sediment dispersion during sand placement is a priority, alternative methods that deposit sand closer to the seabed can be used. These approaches are particularly relevant when high precision is required or when minimizing sediment spread in the water column is crucial. Releasing sand near the seabed allows for better control of material placement and may reduce the amount of cover material needed.

Several methods for near-bottom sand placement exist, but all identified in the literature involve delivering material via pipes. The pipes can be mounted in a fixed vertical position from the barge or at an angle, allowing them to swing from side to side to cover a wider area while the barge moves forward. Spreaders can be attached to the end of the pipe to enable more controlled sand distribution over the seabed. Sand is typically released about 1–3 meters above the seabed, making this method particularly advantageous for sand capping at greater depths where preventing material dispersion is a priority. Similar to other hydraulic methods, the sand masses can be transported to the placement site using dredgers or dredging barges. The sand can be discharged through the pipe either passively, utilizing gravity, or actively, through pumping (Bailey 2005).

2.2 Advantages and disadvantages of each method

The choice of the most suitable sand capping method, or combination of methods, largely depends on the local conditions at the site. Factors such as water depth, wave and current conditions, sediment stability, bottom topography, and maritime traffic influence the decision. Placement via pipes or bottom-discharging barges is most effective in open areas such as harbours and navigation channels. In more confined spaces or locations closer to land, placement from shore or shallow-draft barges may be considered (Jarsek et al. 2016). Table 1 summarizes and rates various sand capping methods based on several factors related to sand placement. The table represents an assessment based on information found in the literature. Where precise data is available, it is included. However, certain factors may be more important when selecting the most appropriate method. For instance, many areas requiring sand capping to reduce turbidity are relatively shallow (<3 m), meaning some methods may not be applicable.

Table 1. Compilation and rating of various factors related to sand capping using the different methods highlighted in this report. A single plus (+) means "does not apply at all," two pluses (++) mean "applies well," and three pluses (+++) mean "applies very well." Where precise figures have been found in the literature or previous bids, they are provided. ”shallow” stands for shallow-water capability. "High availability" refers to the accessibility of equipment and contractors capable of performing sand capping using a specific method, while "few operational machines" means that only a limited number of machines, vehicles, or vessels are involved in the placement process.

	Method	**Shallow**	**Low turbidity**	**High precision**	**Fast**	**Low cost**	**Little noise**	**High availabil**	**Few machines**
2.1	**Mechanical placement**								
2.1.1	*Direct mechanical placement*	+++ (1,5 m)	+++	+++ (±2 cm)	+ (0,5-2 month/ha)*	+ (2-3 M SEK/ha)*	++	+++	+
2.1.2	*Surface release from barge or hopper dredge*	+ (3,5 m)	++	++	+++	+++	+++	++	+++
2.1.3	*Hydraulic washing of coarse sand*	++ (<3 m)	+	++	+	++	++	+	++
2.2	**Hydraulic placement**								
2.2.1	*Surface release from barge or hopper dredge*	+	++	++	+++	+++	+++	++	+++
2.2.2	*Hydraulic surface release via pipelines with a distribution system from a barge or dredge*	+++ (1,5-2 m)	++	++ (±15 cm)	++ (<1 week/ha)*	+ (2,5 M SEK/ha)*	++	++	++
2.1.2.3	*Spraying from a dredger or dredging barge*	+ (3,8 m)	+	+	+++ (1 hour/ha)*	+++ (0,5 M SEK/ha)*	++	++	+++
2.2.4	*Automated hydraulic capping barge*	+++	+	+++	++	+	++	+	++

* According to previous bids and communication with contractors. These figures are only examples and may vary depending on factors such as the specific site, sand source, etc.

3. Sand sources

The type of material that has been successfully used for sand capping of eelgrass in Bohuslän consists of fractions ranging from fine sand to 8 mm gravel. If the purpose of sand capping is to improve growth conditions for eelgrass, this must be considered when selecting the sand source and grain size of the material. Currently, there are no studies comparing eelgrass growth on land-sourced sand versus sand dredged from the sea. However, eelgrass exhibited very high growth in the natural gravel (0–8 mm) used for sand capping of 1 hectare of seabed at Lilla Askerön in 2021.

Since the turbidity issue in the study area was caused by high levels of clay and silt in the sediment, it is important to avoid excessive amounts of these fine particulate materials in the sand capping material.

In sand capping projects, a crucial aspect is identifying potential sand sources that can be used. The sand must be free from contaminants and invasive species and may originate either from land-based quarries or offshore dredging. There are primarily three types of sand sources available: land-based quarries, offshore quarries, and offshore dredging conducted to increase depth, such as in harbours. Below is an overview of these sand sources along with their advantages and disadvantages.

3.1 Sand from land in Västra Götaland county

In Sweden, there is a high availability of active sand and gravel quarries on land. The transport distance from the extraction site to the sand capping area significantly affects costs, making it an important factor when selecting a quarry. A review of the County Administrative Board's active sand and natural gravel quarries via NiklTa indicates that there are 53 operational quarries in Västra Götaland alone. This database also provides information on quarry capacity and type. The majority of quarries supply natural gravel, while four quarries in the municipalities of Mark, Hjo, Härryda, and Tidaholm provide sand.

Natural gravel is generally available in two size classes: casting sand 0–8 mm and mortar sand 0–2 mm. Casting sand was the type of cover material successfully used for sand capping at Lilla Askerön in 2021. The larger gravel fractions 0–8 mm used at Lilla Askerön also seemed to provide a suitable substrate for blue mussels, which settled and grew in parts of the sand-capped area where eelgrass did not establish. No competition between mussels and eelgrass was observed during sampling at Lilla Askerön in 2024, but this possibility should be considered when selecting materials.

Grain size analysis showed that the material had a relatively even distribution of fractions, ranging from fine sand 125–250 µm to gravel 2–8 mm, while the fraction of very fine sand to clay less than 125 µm only accounted for less than 2 percent. The use of finer sand, known as mortar sand, has not yet been evaluated as a sand capping method. Finer sand particles may be more prone to erosion in wave- and current-affected areas but would likely provide a suitable substrate for eelgrass growth.

The cost of natural gravel is 135–140 SEK per ton in 2024, according to data from the quarry used for sand capping at Lilla Askerön.

Figure 8. Sand and natural gravel quarries in operation in Västra Götaland (source: NiklTa 2024).

If the sand source comes from a land-based quarry, the sediments are dry and can advantageously be released at the surface using mechanical placement methods. If hydraulic methods are to be used, the material must first be mixed with water. One advantage of using sand capping material from land is that the clay and silt fractions are likely lower compared to materials dredged from the seabed. This, in turn, results in less turbidity during sand placement. Another advantage is the greater availability of material on land, meaning more options are accessible and transport distances can be shorter. Sand from land-based quarries is also free from contaminants and invasive species, which can otherwise be a concern when using marine sediments.

The cost of sand per volume is generally higher from land-based quarries than from offshore sources. However, mobilization costs for sand from land quarries are lower than for offshore sources and are also less dependent on weather conditions. On the other hand, transport costs for land-based materials, especially via truck, can be higher, making it important to evaluate environmental and logistical aspects during transport. Additionally, the capacity of land-based quarries may be lower, and natural gravel (such as that used in the sand capping at Lilla Askerön) is a limited resource that may be reserved for other land-based operations. This makes sand from land most suitable for smaller projects (SGU 2020).

3.2 Sand from the ocean

In Sweden, sand extraction in the Öresund has been prohibited since 1982, and only one permit for marine sand and gravel extraction exists in Swedish waters. This location is the Sandhammar Bank, south of Ystad (SGU 2017). It is therefore likely not possible to purchase marine sand from offshore quarries in Sweden, and if this option is considered, sand would need to be sourced from countries such as Denmark, Germany, or Poland.

Another alternative is to use material obtained from offshore dredging operations. This type of dredging is often conducted to maintain depth in harbours and navigation channels. In Denmark, large quantities of sand are regularly dredged to maintain the depth of fairways within estuaries. This sand has been suggested as a suitable source for sand capping in areas where the seabed consists of high levels of clay and organic material (Flindt et al. 2022). However, these materials may potentially be contaminated. Marine sediments dredged from shallow coastal areas can contain high levels of organotin compounds, metals, and PAHs (Moksnes et al. 2019). This makes many sediments unsuitable for use as sand capping material. The threshold for what is considered contaminated differs between Sweden and its neighbouring countries. If marine sand is to be purchased from other countries, its contamination levels must be verified against Swedish regulations. Additionally, moving marine sediments from one area to another carries the risk of spreading organisms and diseases between regions. This is an important consideration and a reason to avoid using marine sand from other countries.

Furthermore, many harbours are located in wave-protected areas, meaning the sediments often contain high levels of silt and clay, which are not suitable for sand capping. Along the Bohus coast, few clean sandy seabeds are found, and dredged materials largely consist of clay and silt, making them less suitable for sand capping. Suitable dredged materials in Sweden are likely to come from dredging projects in more wave-exposed areas of Skåne and Halland counties.

If sand is dredged from an appropriate site and transported directly to the sand capping area, fewer stakeholders may need to be involved compared to transporting and loading materials from land. This can therefore be a more cost-effective alternative compared to using sand from land-based sources.

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