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# DELIVERABLE 2.4

## THE DEVELOPMENT OF CONCRETE BLOCKS THAT INCREASE THE BIODIVERSITY IN A MUSSEL FARM

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## 1. BACKGROUND

The degradation of marine ecosystems due to anthropogenic activities such as overfishing, habitat destruction, and climate change has necessitated the development of conservation strategies. Artificial reefs have been implemented in various marine environments to promote biodiversity, restore fisheries, and protect coastal areas from erosion (Seaman, 2007). Their effectiveness depends on factors such as material composition, structural complexity, and site-specific oceanographic conditions (O'Reilly & Willerth, 2024).

The Baltic Sea presents unique ecological challenges due to their varying salinity levels, water temperatures, and hydrodynamic conditions. The Baltic Sea, a semi-enclosed brackish water body, has limited natural hard substrates, making artificial reefs particularly beneficial for sessile organisms and reef-associated species.

### 1.1 Artificial reefs and biodiversity

Artificial reefs function as habitat-enhancing structures that facilitate the recruitment and settlement of marine organisms. Studies in the North Sea have demonstrated that artificial reefs act as steppingstones for benthic species, increasing connectivity between fragmented habitats (Coolen, 2017). In the Baltic Sea, where natural hard substrates are scarce, artificial reefs can provide crucial attachment surfaces for sessile organisms such as bivalves and macroalgae. (Bettoso et al., 2023).

Artificial reefs can enhance local biodiversity by providing refugia and breeding grounds for a range of marine species. Research in the Wadden Sea showed that biodegradable artificial reefs increased species richness by 76% and density by 15% compared to control sites (Nauta et al., 2023) (figure 1).

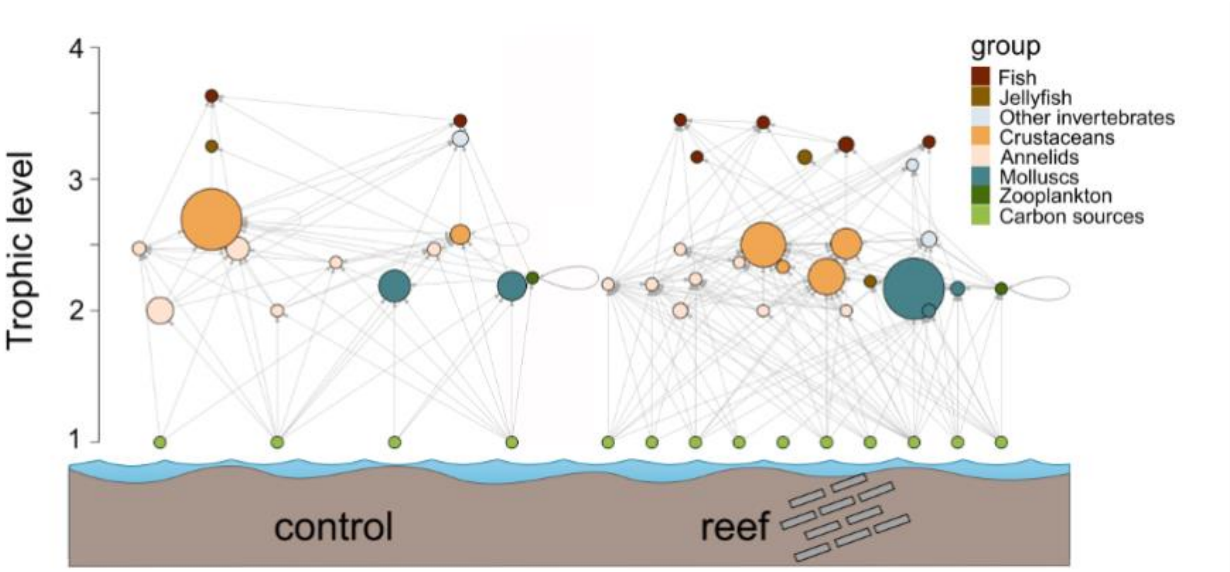


*Figure 1: A study in the Wadden Sea with biodegradable artificial reefs deployed next to a control area showed that the AR supports more complex food webs. The nodules indicate the presence and number of species (Nauta et al., 2023).*

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In the North Sea, studies indicate that artificial reefs support diverse epibenthic communities, including fish, crustaceans, and mollusks (Coolen, 2017). Similar results have been observed in oyster reefs, which serve as keystone structures enhancing biomass and species richness (Chan et al., 2022).

Additionally, artificial reefs serve as hotspots for juvenile fish recruitment. Many fish species rely on structured habitats for shelter from predators and as hunting grounds. For example, the German project "Reef Nienhagen", situated in the Baltic Sea (2009-2015, funded by the EU Fishery Fund) aimed to determine the period codfishes spend in the artificial habitats as well as of the migration behaviour of possible local codfish resources. *(https://www.riff-nienhagen.de)*. The project found that the reefs attracted juvenile codfish. The total fish biomass on the NIENHAGEN reef was 30% higher than that of natural areas, and the young cod biomass was almost twice as high (figure 2).

*Figure 2: The figure shows how hard substrate in the sea attract marine benthos and juvenile fish (https://www.riff-nienhagen.de).*

A Danish research study shows that the energy use of Atlantic cod *Gadus morhua* is affected by the surrounding habitat. *G. morhua* saves energy (about 20%) when occupying a stone reef habitat compared to a sand bottom habitat. Accordingly, fish using a sand bottom habitat have an energetic disadvantage that may result in decreased growth rates (Schwartzbach et al., 2020).

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## 1.2 Ecosystem functioning

Artificial reefs influence trophic dynamics by modifying food web interactions. Studies have reported an increase in secondary production and trophic complexity associated with artificial reef (AR) deployments (Nauta et al., 2023). Furthermore, ARs contribute to nutrient cycling and sediment stabilization, which are critical for ecosystem resilience (Seaman, 2007).

Artificial reefs also support filter-feeding communities, which contribute to improved water quality. Mussels, oysters, and other bivalves that colonize artificial reefs can significantly reduce suspended particulate matter, enhance water clarity and foster seagrass and macroalgal growth. This process has been particularly beneficial in estuarine environments where eutrophication and sedimentation are major concerns (Chan et al., 2022).

## 1.3 Material consideration

The choice of materials used in artificial reefs plays a pivotal role in determining their ecological success. While traditionally glacial, environment-friendly sourced stones are used for stone reefs or ripraps, concrete, ceramic, and biodegradable materials have been tested for their biocompatibility and ability to support biofilm formation (O'Reilly & Willerth, 2024). Studies show that porous materials promote microbial colonization, which in turn facilitates the settlement of higher trophic organisms (Yoris-Nobile et al., 2021).

Recent advancements in 3D printing technology have allowed to produce reef structures with complex surface textures that mimic natural reef habitats. These structures have been shown to enhance biofouling, supporting higher recruitment of benthic invertebrates and fish larvae compared to traditional concrete modules (Yoris-Nobile et al., 2021).

Artificial reefs offer a viable strategy for enhancing marine biodiversity and restoring degraded ecosystems in the Baltic and North Seas. Their success is contingent upon site selection, material composition, and structural design. Future research should focus on long-term ecological monitoring to optimize artificial reef applications for marine conservation. Additionally, collaboration between policymakers, marine ecologists, and local stakeholders will be critical in ensuring that artificial reefs fulfill their intended ecological functions without unintended negative consequences.

# 2. THE CONCRETE BLOCKS

In connection with the I3 funded project Baltic MUPPETS, the two project partners, Wittrup Seafood and Blue Research, have developed, demonstrated, and monitored newly designed concrete blocks for deployment in a mussel farm. The farm structure consists of 60 submerged pipes with a length of 122.5 m, with a 3.15 m deep net for mussel production. About 3500 concrete blocks are needed to anchor the structure. Each block weighs approximately 250 kg. Thus, by establishing a mussel farm, the anchoring structures bear great potential to double as an artificial reef.

A normal practice when conducting habitat restoration of, for example, stone reefs or biogenic reefs is that they are established in areas where this habitat type has previously occurred. Nature is thus only restored where it has previously existed. By using the concrete blocks under

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a mussel farm to enhance biodiversity, a habitat type that has likely not existed during the mussel farming before is established. The use of concrete blocks to promote biodiversity can also be justified as several fish populations have been greatly reduced, and the concrete block can help serve as an important habitat for these species.

The deployed concrete blocks should be seen in conjunction with mussel farming. There will be sedimentation of feces from the mussels, and there will also be a fall of mussels, especially during harvesting or thinning. The consequence is that the artificial reef on the bottom type with high organic content will have a high occurrence of mussels, which constitute an important food source for, for example, lobster. On the other hand, high organic content in the bottom can lead to low oxygen concentrations, which negatively impact biodiversity on the deployed concrete blocks. However, first tests on benthic oxygen availability underneath the Kieler Meeresfarm showed now significant differences between farm site and reference site (Weinland et al. 2021).

## 2.1 Requirements for the design of concrete blocks

To ensure that concrete blocks are safe for anchoring and can promote biodiversity / function as habitat during mussel farming, there are several requirements that must be met:

1) The blocks must be robust in terms of handling. This means they must be able to unload from a container and boat deck without being damaged.
2) The blocks must be stackable, to streamline and reduce transportation costs.
3) The blocks must be safe to work with. This means they must be able to be handled on deck, without the risk of sliding or moving during transport or deployment.
4) The blocks should be used for the technology for handling blocks that have been developed in connection with Baltic MUPPETS.
5) The blocks should promote biodiversity by providing habitats for a range of sessile and mobile organisms. The concrete blocks should not promote the spread of invasive species.

## 2.2 Design of concrete blocks (bio blocks)

The following design of a bio block was developed (Fig. 3):

- The top and the bottom of the bio block have smooth sides (to allow for stacking and safe handling).
- The bio block is cast with a 3D surface on one side. The 3D side imitates small stones and blue mussel shells. and with 3 sides with smooth surface. These 3 sides have 6-7 holes with a diameter of 6-8 cm that go 9-13 cm into the block.
- The blocks have dimensions of 45 cm - 49 cm - 46 cm (L-W-H).
- The weight of each block is approximately 250 kg.
- At the top of each block, a piece of rope is cast into a short rubber hose to protect the rope from wear.

As a control, blocks with smooth surface on all six sides (traditional concrete blocks) were cast.

The production of bio blocks was approx. 20% more expensive than conventional blocks. This is due to the time required to cast holes and 3D surfaces. The cost of material was the same for bio blocks and conventional blocks.

*Figure 3: shows the design and the surfaces of the bio blocks.*

## 2.3 Test of bio blocks

The newly designed bio blocks were tested against a standard block as a reference at four different locations. At each location, a total of six blocks were placed - three of each type. The blocks were laid out in a row; each tied to a line and a buoy (figure 4).

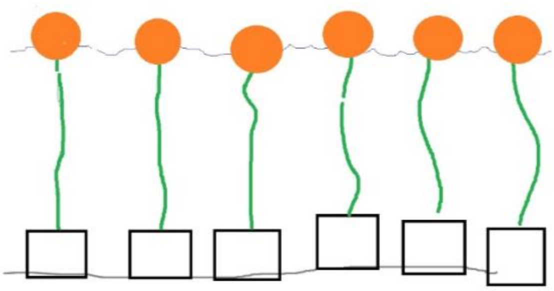

*Figure 4: shows how the blocks are placed on the seafloor.*

The four different locations were chosen to represent varying conditions regarding sediment composition and hydrography such as salinity and current (table 1). The four locations are situated in mussel farming areas in the southern and western parts of the Limfjord and in Horsens Fjord, as well as outside of this in As Vig (figure 5).

*Table 1: Description of the four locations.*

| Location | Type of mussel farm | Seabottom | Depth (m) | Salinity (PSU) |
|---|---|---|---|---|
| 1: Rotholmene | SMARTfarm for resocking production. Farm is submerged during winter. | Mud and sandy mud | 7-10 | 23-28 |
| 2: Sillerslev | Longline farm with production for consumption. | Muddy sand | 6-7 | 23-28 |
| 3: Sælgrund | SMARTfarm. Not in use for last 10 years. | Sand | 5-6 | 18-23 |
| 4: As Vig | SMARTfarm. Not in use for last 10 years. | Sand and moraine deposition | 7-8 | 18-23 |

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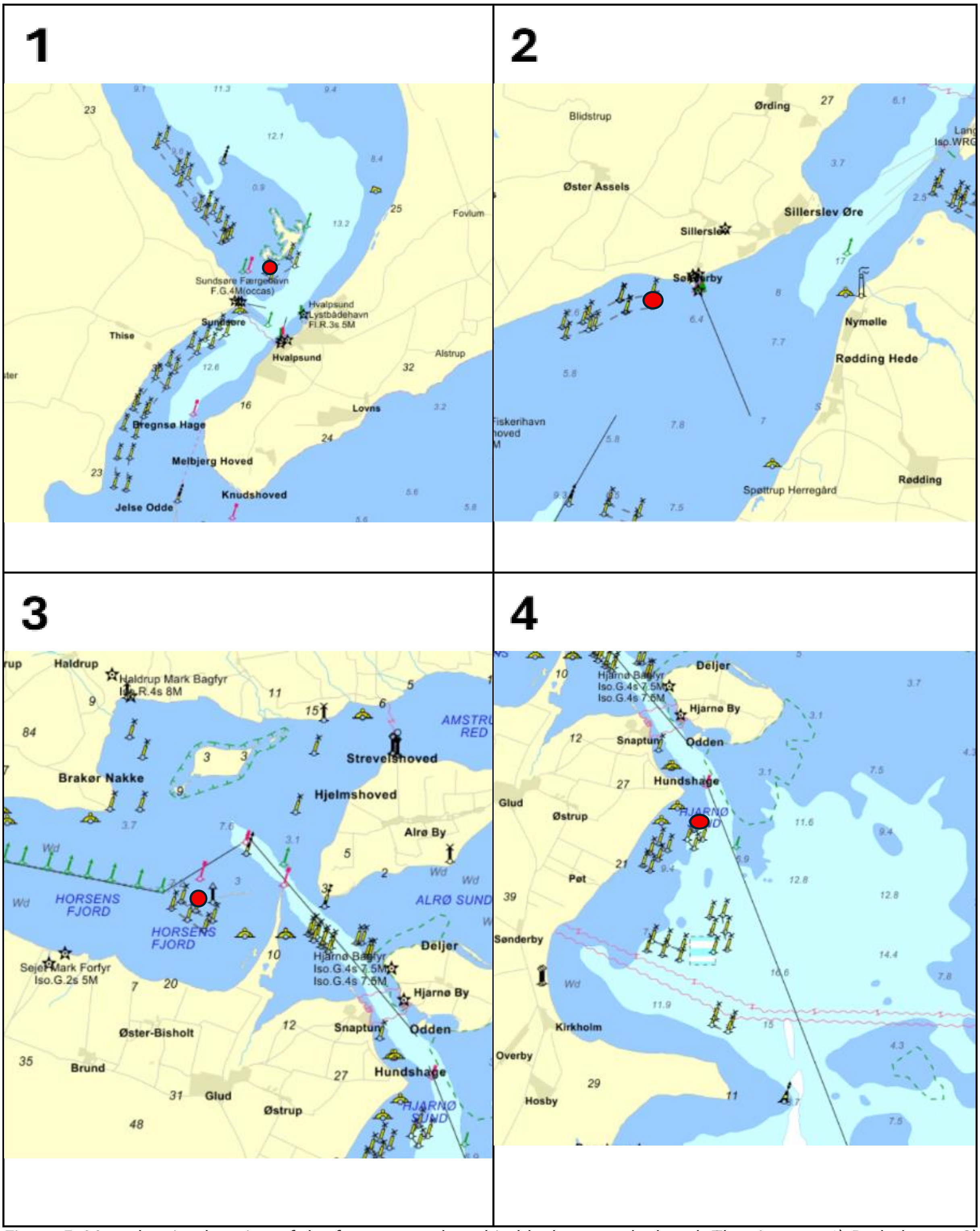


*Figure 5: Map showing location of the four areas where bio blocks were deployed. The sites are 1) Rotholmene, 2) Sillerslev, 3) Sælgrund and 4) As Vig.*

### 2.3.1 List of Materials for deployment at 4 locations

12 concrete bio blocks

12 traditional concrete blocks

Rope for mounting the chains

24 small buoys

## 2.4 Biodiversity monitoring

### 2.4.1 Plan for monitoring of biodiversity

A comprehensive plan for monitoring the biodiversity on the blocks was developed, see Annex 1. Unfortunately, due to unforeseen local conditions as well as adverse wind and weather conditions the original plan had to be adapted and could not be completed in its entirety yet. Instead, where possible video and camera pictures were taken using a ROV at different locations. Localization of lines, buoys and concrete blocks was aided by utilizing a boat equipped with a side scan sonar to enable safe operation of ROV.

### 2.4.2 Expected effect on biodiversity

It was expected that both bio blocks and traditional blocks would be colonized by blue mussels, sea anemones, barnacles and macroalgae, thereby increasing biodiversity and habitat for local species. Also, it was expected that bio blocks would be adopted more readily and faster by sessile organisms and provide a better space for mobile fauna such as crustations and fish that will use the 3D structure for hiding, as resting places and possibly as nesting and rearing ground for their offspring.

# 3. RESULTS

In late winter 2025, 24 concrete blocks were deployed according to section 2.2 in the report. At each location three bio blocks and three blocks with smooth surface were deployed.

Blocks were laid out at locations 1 and 2 on February 18th, 2025.

Location 1 was revisited on June 26th, 2025.

Location 2 was revisited on August 25th, 2025.

Blocks were laid out at locations 3 and 4 on March 6th, 2025.

Location 4 was revisited on May 1st, 2025, and June 25th, 2025.

The four locations are shown on Fig. 5.

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Figure 6 shows the pictures taken at the locations with UV drone and Go Pro camera mounted on the UV drone.


*Figure 6: Pictures of the concrete blocks over a time span of 3-5 months (Photos: Blue Research).*

According to photos and videos taken by UV Drone and Go Pro camera, eight different species were identified across three locations on bio blocks and traditional blocks, see table 2.

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Due to the difficulties in monitoring (see section 4: Conclusions and reflections) no distinct differences could be observed between the different bio block versions and the traditional concrete blocks. However, it could be observed that more species settled and adopted the blocks as living space in comparison to the barren surrounding sediments. Monitoring is ongoing and more conclusive observations are expected.

*Table 2: List of fauna found on the bio blocks after 3-5 months.*

| Species | Type | Location 1 | Location 2 | Location 3 | Location 4 |
|---|---|---|---|---|---|
| Shore crab (*Carcinus meanas*) | mobile | x | x | | x |
| Longlegged spidercrab (*Macropodia rostrata)* | mobile | | x | | |
| Shrimp (*Palaemon adspersus)* | mobile | x | | | |
| Sea star (*Asterias rubens*) | mobile | x | x | | x |
| Sea anemone (*Metridium senile*) | sessile | x | | | |
| Sea squirts (*Ascidia sp.)* | sessile | | x | | |
| Goldsinny wrasse (*Ctenolabrus rupestris*) | mobile | | | | x |
| Broadnosed pipefish *(Syngnathus typhle)* | mobile | | x | | |

## 4. CONCLUSIONS AND REFLECTIONS

The overall conclusion of the deployment of concrete blocks is that solid substrates submerged on the seabed over time will become colonized by algae and act as habitats for both sessile macrobenthos and mobile marine species that can use the blocks as shelter or foraging sites.

Deploying bio blocks under mussel farms shows that concrete structures, which can function as artificial reefs, attract both sessile and mobile fauna. Both types of fauna were found, indicating that artificial hard substrate has a beneficial effect on biodiversity. Concrete blocks provide a habitat for species that require hard surfaces and serve as a place habitat for species that use the blocks as foraging sites or hiding spots. It can therefore be beneficial to use bio blocks in connection with the submersion of the net system in mussel production.

The project has shown that it is possible to use a drone for monitoring, but it is time-consuming in Danish waters due to poor visibility. The operation was possible by letting the drone follow the ropes down to the blocks, but there was a risk of damaging or losing the equipment as it got tangled in the ropes.

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Unfortunately, not all locations were visited due to harsh weather conditions, waves and strong current which complicated the monitoring of blocks with UV Drone. This was mainly due to the way the blocks were attached to their respective ropes leading up to a buoy. Several times, the equipment got caught between the ropes and had to be retrieved by a snorkeler.

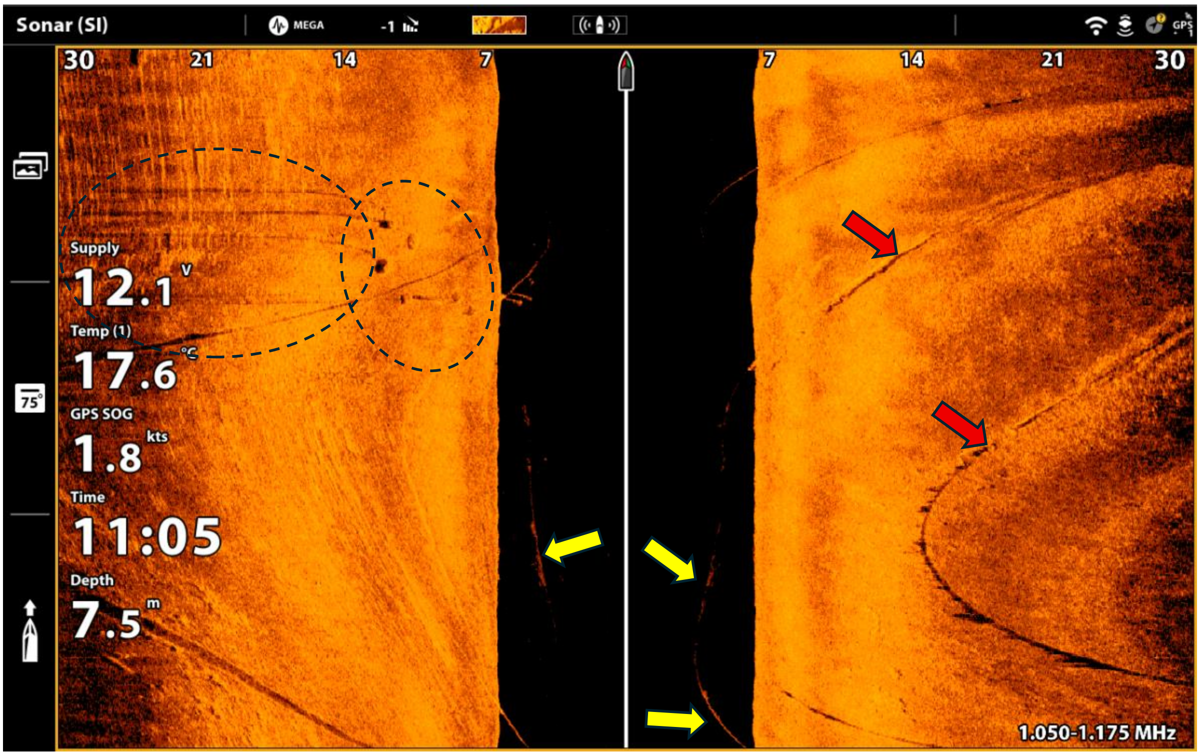


*Figure 7: Sidescan image showing deployed blocks and lines (dashed lines), lines at the seabed (red arrows), and lines in the water column (yellow arrows).*

The sidescan image (Figure 7) shows the 6 deployed blocks at Rotholmene (Location 1). From each block, a line that goes to the surface is visible. There are also several other lines, some of which lie on the bottom, and some float up in the water column. Monitoring using an underwater drone is therefore very risky, as there is a high risk of the drone getting entangled in the lines, which either mark the blocks or the lines that lie on the bottom/in the water column. Since the lines can move with the current, it is difficult and time-consuming to carry out safe monitoring. Safe monitoring of the bio-blocks can therefore only be carried out by removing the lines, which was beyond this project's capabilities.

The four locations all had soft sediments. A certain sinking of the blocks was observed, which reduces the surface area for flora and fauna to settle on. Therefore, it makes the most sense to design blocks with holes and structures in the upper 2/3 of the blocks.

Also, it was concluded that a period of 3-5 months in the winter and spring is a short time to monitor a possible effect on biodiversity. This activity is a result of Amendment 2 (approved spring 2025) in Baltic MUPPETS, which led to a short monitoring period.

It was observed that the bio blocks are still completely intact after five months on the seabed. No crumbling or damage from handling was observed. Therefore, it is concluded that the material and design are suitable for use in the submersion of the mussel net system.

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From the data collected from this deployment it can be concluded that the use of bio blocks during mussel farming has a beneficial effect on biodiversity. However, it cannot be concluded from this trial whether the 3D structures of the blocks have a greater effect on biodiversity than the traditional blocks. Regardless of shape and surface, the concrete constructions contribute to biodiversity by providing new habitats and thereby increasing biodiversity.

## Video documentation of bio block deployment

https://youtu.be/c846hsA0jXo

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## ANNEX 1: MONITORING PLAN

Day 0: After the placement of the concrete blocks, an inspection is carried out with ROV, showing how the blocks are positioned on the bottom.

Day 14: A ROV survey is conducted to assess the presence of organisms using the blocks. All blocks are photographed from both sides of the chain using both video and GoPro camera.

After 2-6-10 months following the placement, monitoring is conducted as on day 14.

Based on the images and video frames, a count of the organisms' occurrence is made. The organisms are classified as the lowest possible taxonomic level, and their utilization of the concrete blocks is classified according to the following classification:

- Fixed on the top side of the block.
- Mobile on the top side of the block.
- Fixed on the upper third of the side of the block.
- Fixed on the middle third of the side of the block.
- Fixed on the lower third of the side of the block.
- Mobile on the upper third of the side of the block.
- Mobile on the middle third of the side of the block.
- Mobile on the lower third of the side of the block.
- Fixed in cavities in the upper third of the side of the block.
- Fixed in cavities in the middle third of the side of the block.
- Fixed in cavities in the lower third of the side of the block.
- Mobile in cavities in the upper third of the side of the block.
- Mobile in cavities in the middle third of the side of the block.
- Mobile in cavities in the lower third of the side of the block.
- Fixed on the bottom up to 30 cm from the block.
- Mobile on the bottom up to 30 cm from the block.

From the image and video material, it is also assessed how much each block has sunk into the sediment.

A final report will be prepared, which analyzes the robustness of the concrete blocks in use and the effect of the concrete blocks in promoting biodiversity. An assessment will be made of whether the use of holes and/or 3D surface has a positive impact on the ecosystem in relation to fish habitat, mobile fauna, and attached organisms, and whether there is any spread of invasive species.

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