Development of Bornholm mussel farming

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The purpose of this report is to present the results and effects that have been achieved with the project *Development of Bornholm blue mussel farming*. The project started in July 2021 and was completed in April 2022. The project was a feasibility study, with the purpose of establishing a local pilot farm/s with mussels in the future, to investigate the potential of recycling essential nutrients that have accumulated in the Baltic Sea. Our motivation to carry out this project lies in a desire to combine sustainable food production and the improvement of the marine environment in the Baltic Sea with growth in a local community that has great ambitions regarding the climate and environmental challenges. The project is a preliminary study and the planning of where pilot mussel farms can be placed, which farm technologies should be tested, and how it should be operated and monitored focusing on the environmental effects. In the project we have made an information video (in Danish), and it can be watched via this link.

In this report, the potentials and barriers that are considered relevant regarding Bornholm and mussel farming will initially be presented. Subsequently, the results and effects of the activities carried out in the projects will be presented. Finally, the future opportunities in relation to mussel farming and Bornholm will be outlined.

Picture 1, a still shot from the information video, which can be watched here

1.1 Introduction

Mussel farming has positive effects on several relevant local, national, and international policies concerning sustainable development. The concept of sustainability is often difficult to operationalize as the complexity of the issue under consideration increases. If we look at a single subject e.g. nitrogen emissions, it is simple to set up a model that calculates how much input a given area can withstand. When we look at complex issues, such as the goal of sustainable development in relation to food production, requirements for high water quality, biodiversity,

low impact on the climate, animal welfare, health, etc., then the problem is not quite as easy to operationalize.

In 1987, the Brundtland Commission published the report Our Common Future. The report was the first of its kind focusing on global sustainability and it provided a broad approach to sustainability that included both the social, economic, and environmental aspects. Sustainable development was defined by the Commission as:

> "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs...*" (WCED, 1987: p. 8)

The definition has fostered the thought pattern that is fundamental to our thoughts on sustainability today, but it is not very useful in relation to complex assessments.
A new way of looking at sustainability is The Doughnut Model, which in recent years has been initiated in several large cities, including Copenhagen and Amsterdam. The model is based on the same understanding as UN's 17 Sustainable Development Goals, but it also manages to integrate the goals to an extent taking shortfalls in wellbeing and the carrying capacity of ecosystems into consideration. The model is another concept and it is not operationalized with specific goals. The Doughnut Model describes how society and businesses can contribute to an economic development that is not at the expense of the well-being of the earth (Figure 1). The Doughnut Theory was introduced by Kate Raworth in 2012. The economic theory is named after a doughnut, as the model paints a picture of a doughnut-shaped space where it is possible to meet human needs in a sustainable and socially responsible way. The model consists of two concentric circles: an inner circle that represents welfare such as health, education, nutrition, equality and working conditions, and an outer circle that indicates the limits of the amount of environmental impact and resource consumption the planet can handle. Between the social foundation and the ecological ceiling, we find a long-term, sustainable way of life, visualized with the doughnut. This thus represents the space where the fundamental human wellbeing is met and where there is no over-exploitation of the earth's resources. If we create a world where we over-utilize the earth's resources by creating climate change and pollution, etc., there is an overshoot of the ecological borders - and thus not sustainable development. If, on the other hand, we do not ensure the fundamental human wellbeing, there is a shortfall where people do not experience a just world and will experience distress.

The establishment of local mussel farming on Bornholm, can have an impact on many environmentally and socially important issues. The ideas from The Doughnut Model can be immediately transferred to understand the importance of factors such as the ecological boundaries of nature, environment and climate, but also access to local food, jobs, education, health, etc., which is part of the social foundation of the doughnut's innermost being. circle, i.e. the conditions that must be met to ensure a good life.

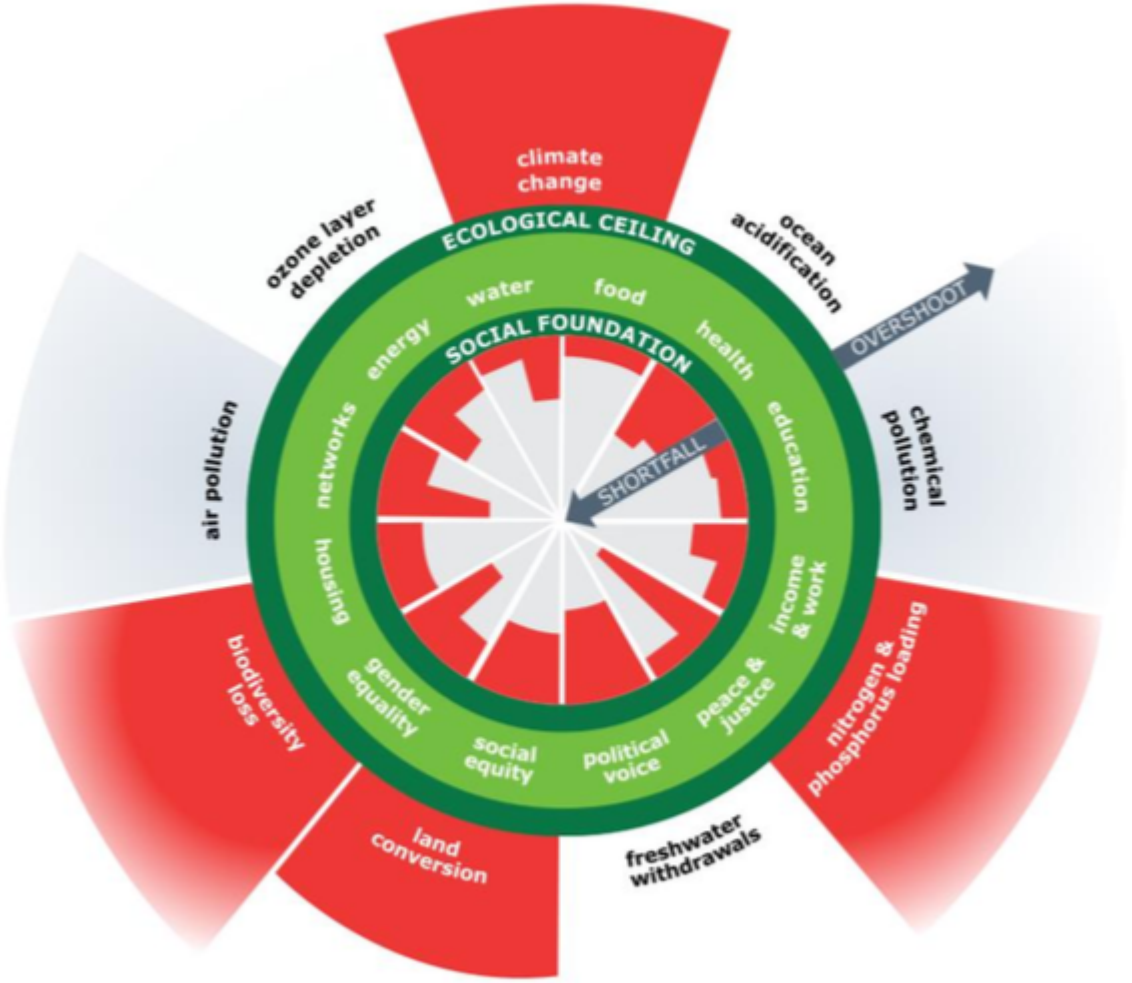


Figure 1, The Doughnut Model describes how society and business can contribute to an economic development that does not happen at the expense of the well-being of the earth.

1.2 Environmental and climate effects

The Baltic Sea is one of the most polluted sea areas in the world (Den Europæiske Revisionsret, 2016), and the poor environmental condition has major negative impacts on the ecosystem (HELCOM, 2021), limiting the ecosystem services which the society depends on. An example of this is that the poor environmental condition contributes to the reduction of fish stocks which has led to a considerable decline in the Bornholm fishery (Den Europæiske Revisionsret, 2016). This has since the 1980s has negatively affected the local community both economically and socially (Hedetoft, 2017).

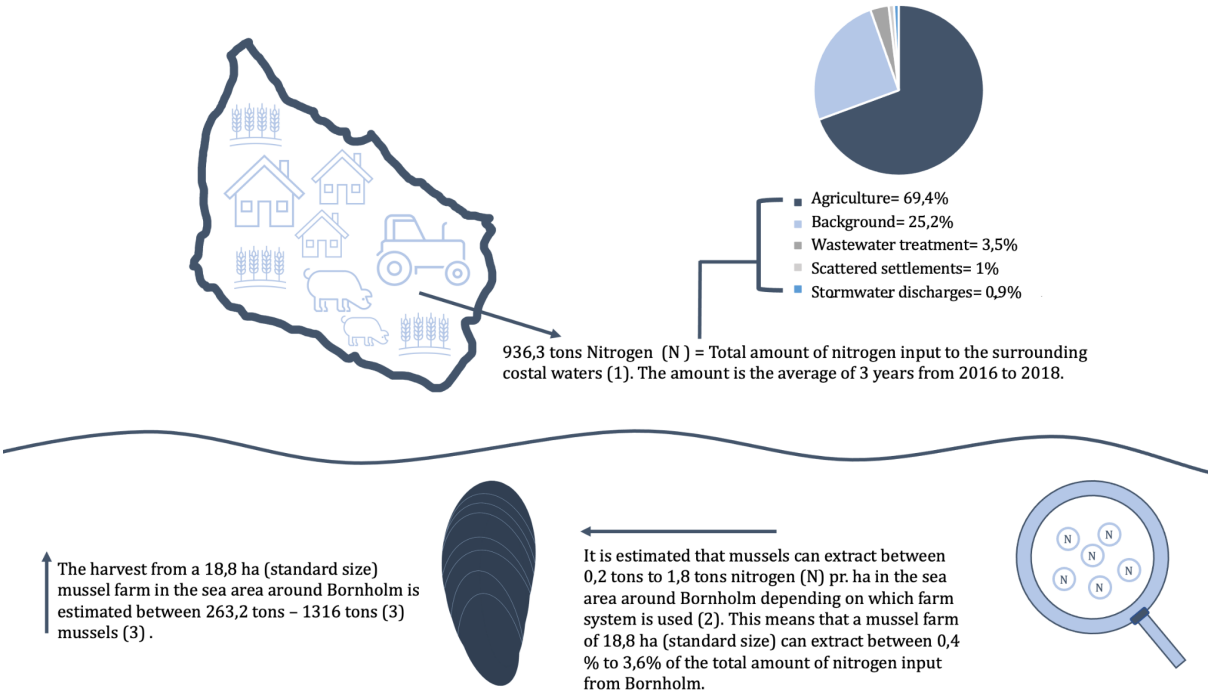
HELCOM[1] recommends, among other things, that the situation in the Baltic Sea should be improved by ensuring sustainable use of marine resources (HELCOM, 2021). One of the biggest

[1] HELCOM or the Helsinki Commission is a Marine Environment Protection Commission for the Baltic Sea Region (HELCOM, 2018).

challenges with the environmental condition of the Baltic Sea is eutrophication[2] caused by the perennial and current massive input of nutrients to the marine environment.

Mussels have been proposed by several research projects and scientific articles, etc. as a tool to mitigate and remove nutrients from marine environments (Bruhn et al., 2020, Timmermann et al., 2016, Petersen et al., 2021, Kotta et al., 2019; Schultz-Zehden et al., 2019; Petersen et al., 2018). Mussels are filter feeders and thereby absorb phytoplankton, and when harvesting the mussels, the total amount of nutrients in the marine environment is reduced.

In addition to removing nutrients from the marine environment, mussels also have several other positive climate and environmental effects. Mussel farming is a regenerative form of food production. All food production affect the earth's ecosystem, but regenerative food production contribute with a greater positive effects regarding restoring robust ecosystems and have very few negative effects.



(1) Miljøministeriet, 2021: p. 58, Table 3.28. (2) Bruhn et al., 2020: p. 19, Table 3.1.1. (3) Bruhn et al., 2020: p. 18, Figure 3.1.1

Figure 2 shows the total nitrogen input to the coastal waters from Bornholm in 2018, and the percentage distribution of the input. It appears that agriculture accounts for the largest share of emissions of almost 70%. The figure also shows that mussels grown on a farm of 18.8 hectares (ha) in the sea area of Bornholm, can absorb between 0.4%-3.6% of the total nitrogen emissions and environmental factors such as temperature, salinity etc. It is estimated that from a longline farm (see section 2.2) of 18.8 ha, between 263.2 tons - 1,316 tons of mussels can be harvested in the sea area of Bornholm.

[2] Eutrophication occurs when too many nutrients are added to a water body, and as a result algae grows and unclear water is formed and sunlight cannot penetrate effectively to the bottom. This creates poor living conditions for benthic plants and animals. Algaes also fall to the bottom when they die, and a decay process takes place, where bacteria that breathe degrade the biomass. As a result of this process, oxygen depletion occurs and the living organisms and marine animals that do not move away from this area die as a result (Withgott & Laposata, 2012).

Mussels also have direct positive climate effects as they absorb CO_2 from the marine environment when they form their shells. This process is called biomineralization. However, the actual CO_2 removal will depend on how and where the mussel shells end up (Filguera et al., 2018). If the mussel shells are recycled in materials for insulation, for example, the CO_2 removal will be large compared to if the shells end up in waste incineration. It is estimated that the total global production of all kinds of mussels and oysters has a CO_2 sequestration per year, which corresponds to the annual emissions from 242,307 cars, each driving an average of 20,000 km (ibid.). However, the concrete climate effect and CO_2 uptake of mussel production has not yet been studied in Denmark (Bruhn et al., 2020).

The climate effects derived from mussel production relate to mussels as food and as feed in livestock production. DCA at Aarhus University estimates that CO_2 emissions per kilo of Danish produced mussels to 0.1 kg CO_2 and imported to 0.2 kg CO_2 (Mogensen et al., 2016). Thus, mussels have the same CO_2 effect as Danish apples and pears and are thus clearly the animal protein source with the lowest climate footprint (ibid.). This is mainly since neither fertilizer, pesticides nor feed are used when farming mussels, as they eat what is already present in the water, and therefore no fertilizer, pesticides or feed must be produced, which has positive effects on climate and environment. Therefore, if we replace other protein sources with a higher intake of mussels, we will reduce our total CO_2 emissions. In addition, we currently import more than half of the fishery and aquaculture products we eat in the EU (European Commission, 2020), and with a higher degree of self-sufficiency we can reduce imports, which will lower our CO_2 emissions regarding transport. Below is a graph of the CO_{2e} emission per. kilos of food. Here it is clear that mussels have a significantly lower CO_{2e} emission than other animal foods.

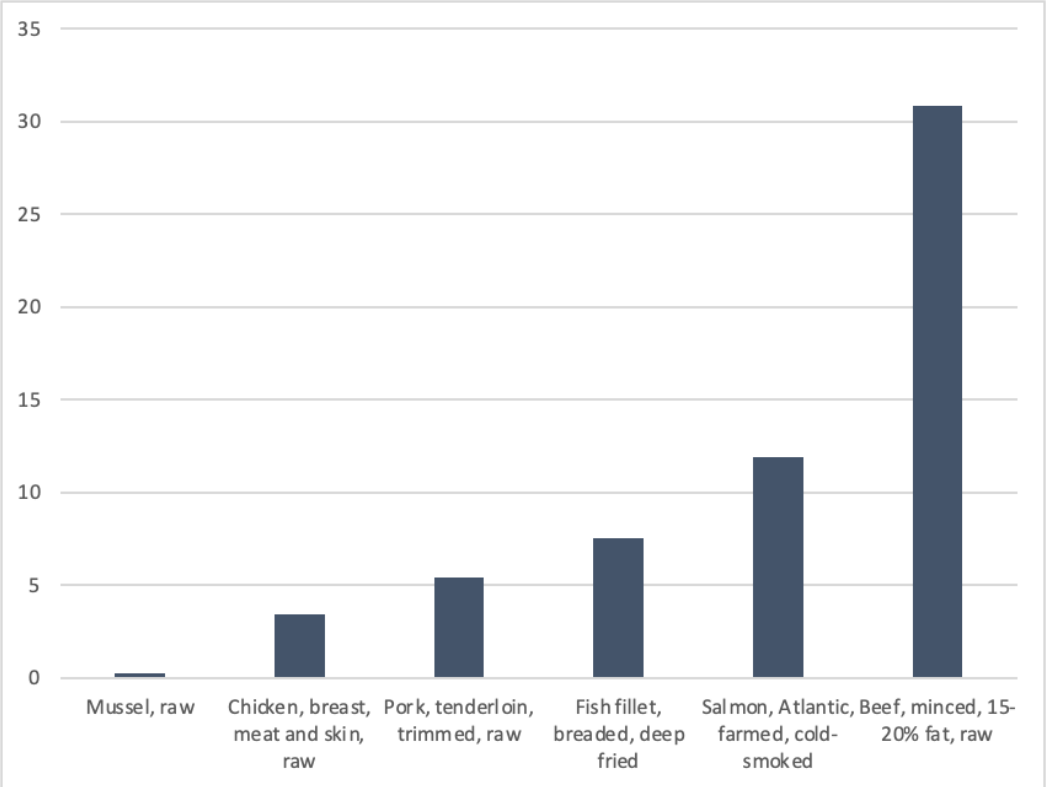


Figure 3, graph of the CO2e footprint of various animal foods. The graph is based on data from the "Den store klimadatabase" which translates to The big climate database.

Mussels can also be converted into a feed product comparable to fishmeal, and can be included in livestock production, as a more climate and environmentally friendly alternative to fishmeal and soy. Thus, parts of Bornholm farms can potentially reduce their need for imported feed.

In relation to the environmental aspect, mussels have several positive impacts on the ecosystem in the marine environments in which it is located. As mentioned, mussels filter water, and by this filtration the mussel purifies the water of particles, which increases visibility in the water (Petersen et al., 2018), which is good for benthic animals and plants. Eelgrass, for example, is easily affected in terms of visibility, and the distribution of eelgrass is used as a quality element to assess the condition of coastal waters (Miljø- og Fødevareministeriet, 2016). When farming mussels, some of the mussels fall from the farm and land on the bottom, and if they are still alive, they will continue to filter the water, and they can also create mussel banks or reefs of mussels. These reefs then become new habitats for benthic animals and plants, which can have a positive impact on the biodiversity in the area (Vismann, 2011). Mussel farming also creates temporary habitats around the farming systems, where, for example, small fish can hide between the longlines or the nets with mussels.

Picture 2, mussels during mussel farming in Horsens Fjord. Mussels, beach crabs, sea anemones and a number of other benthic organisms are seen on the mussels (Photo: Per Dolmer).

All in all, there are many parameters that mussels have a positive impact on in our society, and by using mussels as a provider of these "services" to our society, we can influence the environmental situation in the Baltic Sea in a more positive direction.

1.3 Site-specific barriers

When it comes to farming mussels around Bornholm, there are several challenges that must be considered in the planning and establishment phases. The well-known and most widespread farming systems in Denmark have been developed to be located in bays and fjords, where the impact from wind, weather and current is reduced. This is necessary as the production systems are affected and can easily be damaged by, for example, storms. As there are no bays or fjords around Bornholm, it is necessary to develop new offshore systems that can withstand the sometimes rough weather around the island, as the existing cultivation technology is not considered sufficient (Petersen et al., 2021). This development is already underway in Denmark, and several actors are investigating the possibility of submerging the longlines with mussels, so that they are removed from the wave zone, thus reducing the impact. In Denmark, these systems have not yet been commercialized or tested on open water or offshore to a significant degree,

and there have been no site-specific studies at Bornholm (ibid). In New Zealand, there are positive results with offshore submerged longlines (Buck & Langan, 2017), which gives hope for testing at Bornholm.

Mussels have a growth rate determined by a number of conditions. At low salinity, and especially at low and varying salinity, the mussels spend a lot of energy adapting to the surrounding environment. As can be seen from the map below, there is a low salinity in the sea area around Bornholm, and it varies from 8-10 psu (Figure 4). Studies from 2011 in the western part of the Limfjord (salinity 30 psu) to the southern part of Faxe Bay (salinity 8.5 psu) showed that the growth rate in Faxe Bay was only approx. 40% of the growth rate in the Limfjord, where growth was maximum. The difference in growth is due to a greater need for osmosis regulation at low salinity (Maar et al., 2015). In the sea area around Bornholm the growth of the mussels will be approx. 40% to 60% of the maximum based on the studies (Bruhn et al., 2020).

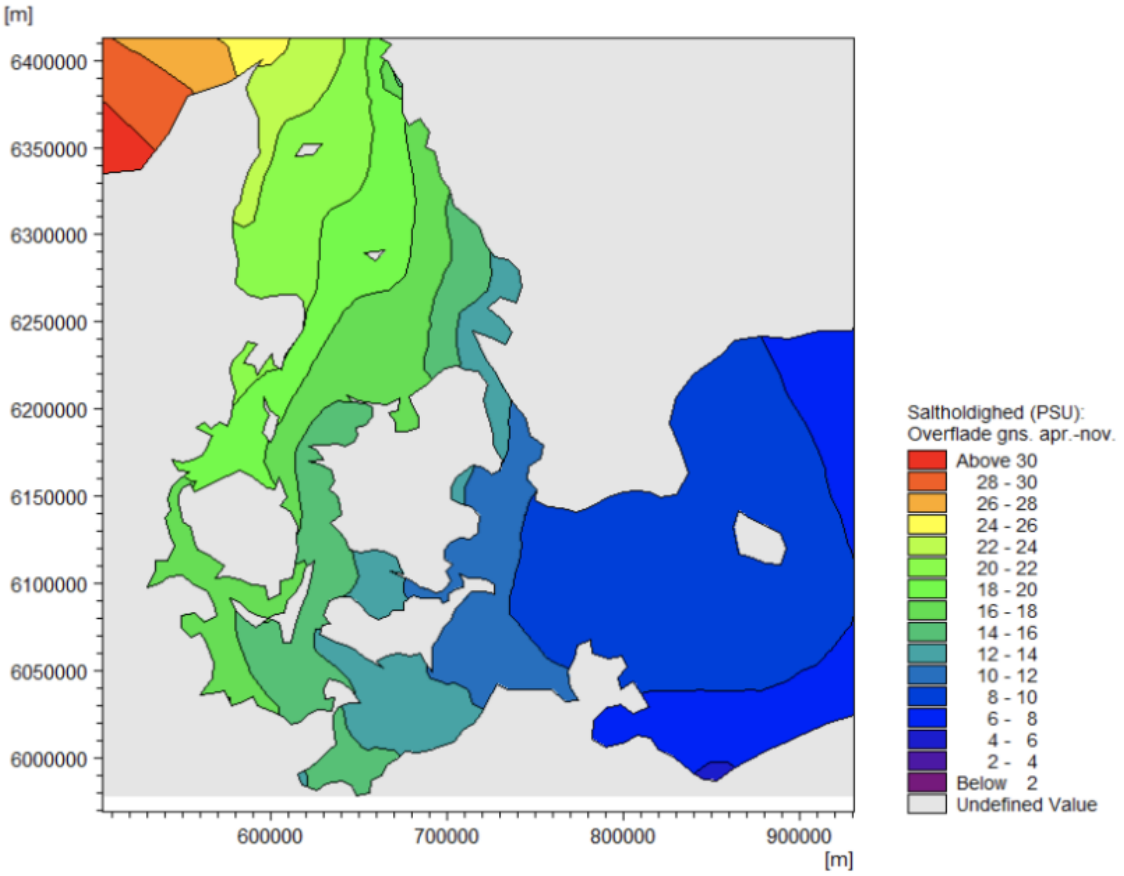


Figure 4, Map of salinity in the Danish waters.

In addition to the mentioned challenge, Baltic mussels also have thinner shells and a smaller adductor muscle. These are defense mechanisms that are not activated in mussels in the eastern Baltic due to the absence of crabs and starfish (Reimer & Harms-Ringdahl, 2001). It is not known how this affects the possibility of farming and harvesting mussels, and this is also interesting to investigate further. The slow growth is particularly interesting to study as it means longer harvest cycles. Furthermore, it is also not known how the market will receive significantly smaller mussels than normal. The smaller Baltic mussels, if found unfit for human consumption, can also replace climate and environmentally harmful feed products in livestock production as previously mentioned.

Despite the mentioned uncertainties and challenges of growing mussels around Bornholm, it is still an attractive activity to test. Unlike CO_2 in the atmosphere, it does not help to reduce the amount of nutrients in the Limfjord and expect an improvement in the condition of the Baltic Sea around Bornholm, therefore the challenges of eutrophication must be handled locally. If you therefore succeed in farming and harvesting mussels on Bornholm, you can handle eutrophication locally. Once nutrients have reached a body of water such as the Baltic Sea, only regenerative production of mussels and seaweed, and fishing, can remove nutrients by removing biomass from the water.

However, there are other factors that make Bornholm particularly interesting for the cultivation of mussels. For many years, Bornholm has built up infrastructure, capacity and knowledge within the maritime industries including commercial fishing, landing facilities, processing and storage, etc. but also for recreational and tourism activities at sea. New activities that fit into these frames can be implemented on Bornholm. Furthermore, the island also has a strong gastronomic scene, and it is assessed that there are abilities and opportunities to develop new dining experiences and products with the smaller mussels. As previously mentioned, Bornholm has experienced a large decline in fishing since the beginning of the 80s, and thus also the supply of local fish, and with the latest fishing quotas there is no prospect of this situation changing. New opportunities with alternative food products from the ocean, such as mussels, can therefore be the activity that can replace the traditional value chains and fill the need for local supply of marine foods on Bornholm.

1.4 Political picture

The local community on Bornholm is very special, whether it comes from necessity or passion, there is a great unity and drive on the island, which means that there is short distance between people with key skills, networks and access to initiate development. The short distances (both figurative and literally) between people on the island provide opportunities to work across sectors and industries, and Bornholm has kept pace with development since the collapse of fishing, which makes the island a beacon in food, tourism, green technology, arts, crafts and gastronomy etc. This well-developed and complex ecosystem of companies makes Bornholm an attractive place to try out new initiatives, activities and projects, as more complicated value chains can be more easily commercialized here. Furthermore, the political level on Bornholm has set an ambitious climate and energy policy, which resulted in the Bright Green Island strategy and the 8 Bornholm goals, which show how the island actively contributes to Denmark fulfilling its obligations under the Paris Agreement (Bornholms Regionskommune, 2018). The strategy also tries to activate the local business, and the development of new value chains, which make it a good business to take better care of our nature and climate (ibid). In the strategy, the municipality also acknowledges the poor environmental condition of the Baltic Sea, and writes that they wish to work on reducing the pollution of the Baltic Sea. (Bornholms Regionskommune, 2018 p. 25).

The municipality of Bornholm has also entered a collaboration with Gourmet Bornholm and Bornholms Landbrug & Fødevarer (Bornholm's Agriculture & Food), which has led to Bornholm's Food Strategy (Bornholm Regional Municipality, 2018). The purpose of the strategy is to strengthen the island's food sector with a focus on self-sufficiency, and to expand interest in

locally produced food products. In addition, the desire, with the strategy, is also to create jobs and value on a sustainable foundation.

In addition to a local focus, there are several other political agendas that make mussels a topic that is becoming increasingly relevant to implement as a contribution in several areas of action.

Excess nutrients in the sea
The Minister of the Environment has in a letter to the Danish Parliament stated that in the national plan for 2021-2027 for implementing the Water Framework Directive there will be binding requirements for a major effort regarding nitrogen regulation. The Minister of Environment stated that the baseline scenario assumes that other countries comply with international agreements, including the Baltic Sea Area Action Plan, the fulfillment of other countries' objectives in their river basin management plans and, for the nitrogen deposition from air, compliance with the NEC Directive. In the baseline scenario, the total Danish target load is 36,600 tons of nitrogen, which can, however, be increased if a reduction in the supply of phosphorus is implemented in the catchments where it will have an effect (Miljøministeriet, 2020, p. 1).

Thus, a significant regulation of agriculture has been planned, and it is indicated in some discussions that up to 30% of the agricultural areas must be set aside. The national plan implementing the Water Framework Directive has been sent for consultation, and it appears from the draft that for Bornholm there is a comprehensive need for action of 398.5 tonnes of nitrogen per hectare. year (Miljøministeriet, 2021).

Reduction of greenhouse gasses
As a co-signer of the Paris Agreement, Denmark has committed to reducing its greenhouse gas emissions significantly by 2050, and with the adoption of the Climate Act in 2019, a broad majority of the Danish Parliament committed itself to reducing Denmark's greenhouse gas emissions by 70% in 2030 compared to 1990 levels, as well as achieving climate neutrality by 2050. The Paris Agreement allows for compensatory measures where greenhouse gasses can be bound and where the bound quotas can be sold as climate credits.

Restoring biodiversity
The biodiversity crisis can be attributed both nationally and internationally to the way we utilize the resources from land and water. Another part of the crisis can be attributed to the way we get rid of our waste and waste products. With a circular bioeconomy, we can use waste to produce new products. Excess nutrients from land can thus be used for new biomass production and thus contribute to the improvement of marine habitats and the biodiversity that depends on healthy ecosystems. There is a lot of focus on the protection of biodiversity with limitation of impact, protected areas, and restoration of important structures such as reefs, eelgrass areas, mussel banks, etc.

Bioeconomic growth
With different initiatives, including the Bioeconomy Strategy, the EU has a special focus on economic growth in the bioeconomy, a central growth engine. The strategy is made particularly relevant by the fact that an expected population growth combined with an increased buying capacity in many nations will lead to a marked increase and demand for food and resources. The

development of the bioeconomic and more forms of production is therefore the answer to an expected shortage of resources. It is expected that a large part of the increased bioeconomic growth will take place at sea.

2. Results and effects of the project

In the following part of the report, the results and effects of the projects will be presented. The following part is divided into sections regarding the project's main activities, and we want to provide an insight into how we have approached the activities, as well as what results and effects.

2.1 Location

A previous analysis (Appendix 1) on mussel farming and Bornholm, carried out by the project coordinators, an area has was suggested. The location was appointed on the basis of criteria set out to ensure: 1) That there are optimal living conditions for mussels, and the best possible conditions for improving the environment. 2) That costs regarding the establishment, farming and harvest are as low as possible. 3) That the pilot mussel farms comply with relevant regulations and plans.

Salinity, which as previously mentioned has an influence on the growth of mussels, was deselected as a criteria, as it does not vary around Bornholm. The following criteria were considered relevant:

Natural population of mussels

The mussel starts reproducing when the males and females spawn eggs and sperm in the sea and larvaes are formed. The larvaes swim around for 3-4 weeks and then settle on a solid substrate, such as another mussel, a rock or bands or ropes in a mussel farm. The mussel grows on the solid substrate, and can only move to a limited distance. There must therefore be a natural population of mussels near the farm, as the capture of mussel spat occurs naturally. Thus, there are no costs associated with purchasing spat, etc. If there is a natural population of mussels in the area, it is also evidence of adequate living conditions.

Picture 3, new mussels on a Swedish band[3] in Tejn Harbor, August 2020

Adequate water change and exposure to current and waves

[3] Swedish bands are 5 cm wide white synthetic bands made for recruiting mussel larvaes in the water column.

Mussels have a growth rate determined by several conditions. The amount of food and the transport of food with water movements such as currents are of great importance for the growth of the mussels. This is ensured by sufficient inflow and outflow of water in the selected area. The inflow and outflow of water in the production area is also important to reduce concentrations of mussel feces on the bottom, which can have a negative effect because there is an enrichment of nutrients. On the other hand, currents and waves can also be a challenge with regard to the harvest yield. Waves and currents can also cause damage to the system and will also affect how often it is possible to work on the farm by boat. Both lost biomass yield as well as damage to the farm due to waves and wind are associated with costs.

Area without oxygen depletion
Oxygen depletion is a widespread problem in the Baltic Sea, due to extensive eutrophication. Mussels need oxygen, so it is important that there is no oxygen depletion in the production area. Oxygen depletion can vary from year to year and will therefore be a criteria that must be monitored on an ongoing basis.

Sufficient depth
The depth should be more than 3 meters, and there should be a distance to the bottom to reduce the loss of mussels and reduce the risk of the mussels ingesting and therefore containing sand. In addition, impact on the seabed is also avoided. The recommendation to submerge plants to more than 3 meters is also based on challenges with ice cover or free-flowing ice blocks, which can be a threat to the biomass yield.

Low occurrence predation
Starfish, crabs and eider ducks are the animals that must primarily be kept in mind in connection with a mussel production. Especially around Bornholm, eider ducks can be a challenge, as their main food source is mussels, and there can therefore be loss of biomass and therefore also economic loss. Starfish and crabs are not a challenge around Bornholm, as they do not live in this part of the Baltic Sea due to the low salinity.

Suitable bottom conditions
All mussel farms require anchoring in or on the seabed, which means that it is important to investigate which substrate the seabed consists of. It must therefore be ensured that the anchor does not damage, for example, habitats or vulnerable nature, etc.

Suitable facilities on land
To keep the costs of mussel farming low, it is important that there is a harbor and boat mooring near the farming, thus saving fuel and time consumption during establishment, supervision and harvesting.

Low risk of heavy metals, toxic algae and other pollutants
Heavy metals, algae toxins and other undesirable pollutants are all factors that have an impact on food safety in a mussel farm (See section 2.3). The Danish Veterinary and Food Administration has thresholds for the content of heavy metals and environmentally harmful substances, which must be complied with. Algae toxins must not be traceable in the mussel meat, as this can be harmful to health to ingest. In addition, the farm must be located away from local marked zones as well as sewage and wastewater discharges. Harvest time is an important

factor in relation to algae and the presence of toxins in the mussel meat, the risk of algae toxins is something that must be considered. The content of heavy metals, algae toxins and other undesirable pollutants varies from year to year and will therefore be a criteria that must be monitored ongoing.

Low risk of conflicts over the sea area

There are many activities at sea that may conflict with the location of a mussel farm. This can be activities such as shipping, passenger transport, fishing etc. or other aquacultures. The coastal areas on Bornholm are frequently used by both local citizens and tourists, and it is therefore important to include recreational interests such as sailing, swimming, water sports and more. Natura 2000 sites must also be considered when choosing the location. It is also important to assess whether other municipal, national and regional plans will conflict with the location of the pilot mussel farms. The analysis is attached in its full length as Appendix 1. The suggested location based on the analysis is marked on the map in Figure 5, south of Nexø and about 4 km from the coast.

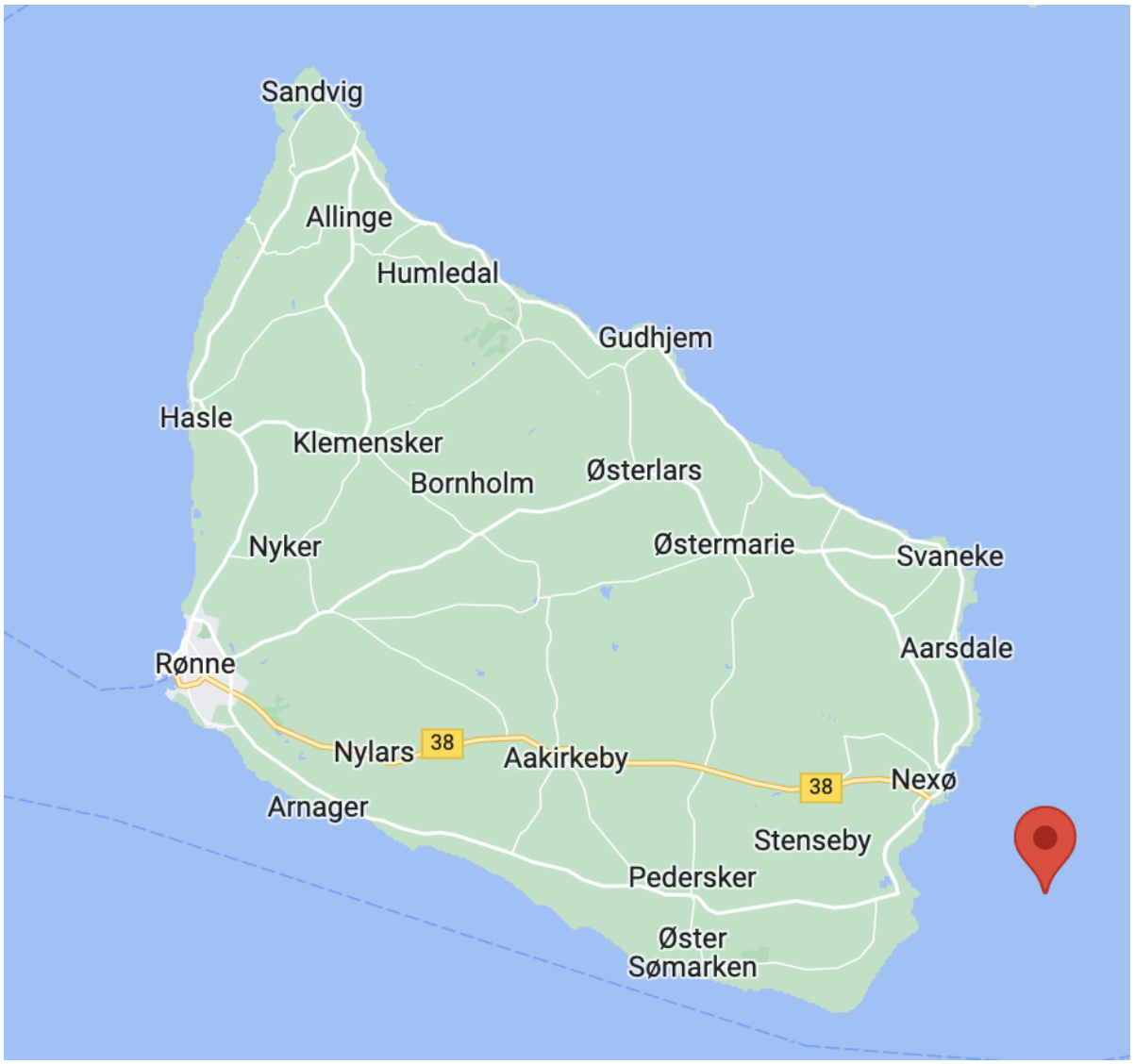


Figure 5, the location south of Nexø and about 4 km from the coast

In this project, the suggested location, and the criteria, have been evaluated by reindeer herder Klaus Hjorth Hansen, longtime fisherman in the area Karsten Holm, and the project's consultant

Per Dolmer. As a result of the evaluation, the location was moved south of the original, as anchoring, fishing and work on the seabed are not recommended in this area due to the dumping of ammunition from World War II.

2.2 Design of the systems

2.2.1 Criteria for choosing the farm system

Blue mussel production on Bornholm has not been tested on a commercial scale yet. This is mainly due to two factors; 1) The low salinity that results in lower growth rates, and a smaller mussel. The small size of mussels has long been seen as a limiting factor in relation to commercial blue mussel production in this part of the Baltic Sea. 2) Blue mussel production in open waters, or "offshore", requires large robust systems that are either not yet fully developed or have not been tested to a sufficient extent in Denmark. These two factors make it risky and therefore there are no systems that are ready to be commercially implemented in the sea around Bornholm. Therefore, it has been central to this project to proceed critically and systematically in the selection process of which system to be tested on Bornholm.
In particular, the following 7 criteria have been of great importance for the selection:

- Robustness: a system located in open water must be able to withstand exposure from waves and currents.
- Anchoring: the anchoring method must match the bottom substrate. This is both important for the anchor not to affect the seabed unnecessarily, as well as to create the best possible anchoring.
- Maintenance and harvesting: work at sea can be challenging and costly, therefore it is important to ensure that it can happen safely in connection with maintenance, bending, and harvesting. It is important to choose a system that encourages safe and fast work during maintenance, as this will have a major impact on the economy and the business potential.
- The look and size of the mussels after harvest: depending on the farm system, the harvest of the mussels can vary in volume, and the size of each blue mussel is also affected. It is therefore important to define what the purpose of the productions is before choosing a design for the production system.
  Production flexibility in relation to being able to adjust the density of mussels in the system and, for example, further cultivate mussels collected from the rock or imported from other localities in the Baltic Sea.
- TRL or technology readiness level describes how mature a technology or a technological solution is and can thus help to assess how easy it will potentially be to implement a farm system. This method can not only be used to assess the farms themselves, but also the following systems that are necessary in connection with for example harvesting and maintenance.
- Economic profitability: low and slow growth means lower earnings, and as this will be the case around Bornholm, economic profitability is a key factor.

2.2.2 Selection of designs

Circle system (not selected)

The project coordinators have theorized this system in collaboration with Klaus Hjorth Hansen from Nexø Vodbinderi. The system is based on an anchoring method that has been used around Bornholm for many years when fishing herrings. The method is called setting net for sway, where the net can move in the direction of the current. That way, a net can stay in the water despite a lot of movement from waves and currents. This method was also used to anchor the aquaculture that was tested in Nexø from 2014 to 2017. Thus, the anchoring method works to handle the rough weather conditions around Bornholm. The system was designed with a ring or circle made of PE and attached to this a net or Swedish bands where the mussels are farmed (See sketch below). In a variation of this system, several rings could be placed inside the outer ring, and in this way, it would be possible to harvest more mussels, but the rings were never sketched.

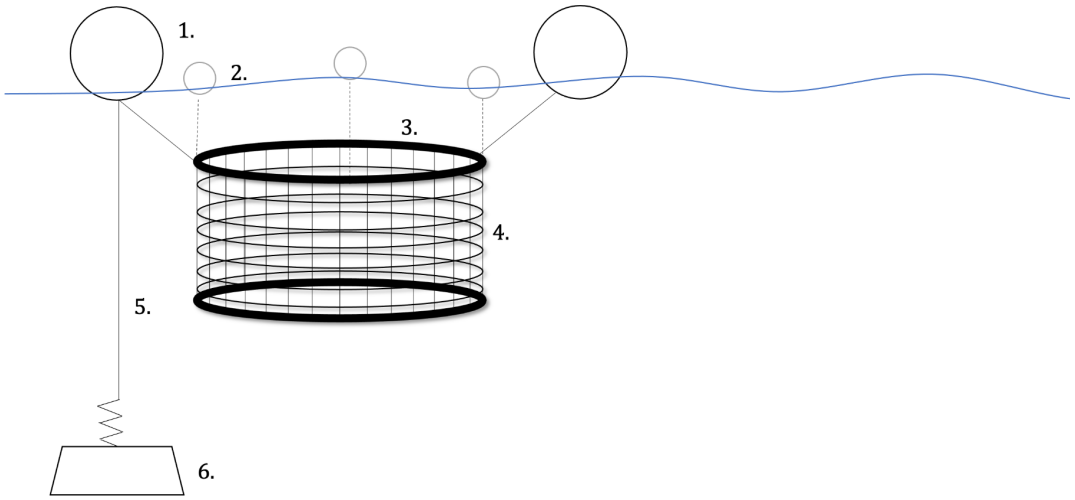


Figure 6, illustration of circle system: 1. marker buoys 2. floating buoys 3. PE tube in circle formation 4. net 5. ropes 6. anchor

The system was not selected, and no further work has been done to develop or test the system. Through networking in SUBMARINER Networks Mussel Group, which is a network of actors working with mussel farming across the Baltic Sea, the project coordinators became aware that the idea for the anchoring method has previously been tested in the Sound, where it worked, but the system's movement, will take up an inappropriately amount of space. This is a problem regarding economic profitability, because a larger production area means higher transport costs and more work time on the water and there is also a risk that the mussel farm will collide with other activities in the area. In addition, harvesting would be a significant challenge as there is no existing technology or know-how. At the same time, submerged PE rings will also present challenges when harvesting, as it is difficult to remove the outer rings after harvest when harvesting the inner rings.

Offshore submerged longline system with Swedish bands, collection and socks (selected)

In Denmark, the most widespread method of farming and harvesting mussels is a longline system. In these systems a longline is held up by buoys and stretched out between two buoys, and from the longline socks or Swedish bands are attached where the mussels grow. This system is relatively simple and well-tested, however, the systems usually work best in fjords or bays, as

longline systems are easily affected by movement of the water. Thus, an ordinary longline system located in open waters, for example at Bornholm, will be easily exposed and damaged when exposed to current and waves. Submerging the longlines is a well-known method in Denmark, and is used to avoid damage caused by ice blocks, but offshore farms have not yet been sufficiently established or tested in Denmark. In New Zealand and in Canada, offshore submerged longlines with green-shelled mussels, which are very similar to the Danish blue mussel, have successfully been tested and commercialized. Below is a sketch of a submerged longline system.

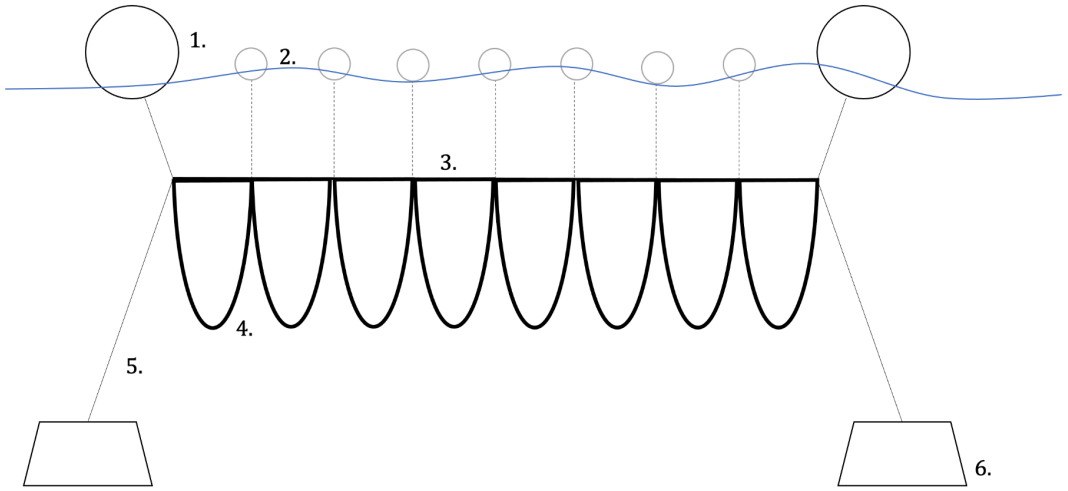


Figure 7, illustration of submerged longline system. 1. marker buoys 2. floating buoys 3. longline 4. seed collector bands also referred to as Swedish bands which are later replaced by socks. 5. ropes 6. anchors

Picture 4, left: mussel farming on longlines in Nørre Fjord. The mussels are produced by amateur fishermen with the purpose of laying the mussels on the seabed to promote biodiversity and improve water quality in the area (Photo: Per Dolmer). Right: mussel farming on nets. The nets are kept afloat on closed PE pipes. The picture is from Venø Sound in the western part of the Limfjord (Photo: Per Dolmer)

Based on the technology readiness level of the longline system and the success of the offshore farms in New Zealand and Canada, we have decided that this system will be most relevant to test at Bornholm. There are several factors that make Bornholm a good fit to try a submerged pilot mussel farm. For example, just off the coast of Bornholm the water depth is sufficient, and therefore the pilot mussel farm does not have to be located far from the coast, which shortens transport time, which reduces costs and use of fuel. When mussels are grown and harvested from longline systems, a technique where you place mussels in socks is often used. With this technique, mussels from the Swedish bands are harvested, and the largest are put in socks, which are then finished growing on the longline. This technique produces larger and more uniform mussels, resulting in a higher price in the market.

The occasionally rough weather and current conditions around the island place great demands on the choice of materials, and can complicate maintenance and harvest. This can have a major impact on the economy of a production, and thus it is important to investigate new solutions to keep expenses down. This could be, for example, by using more monitoring equipment in the form of sensors, drones and cameras, so that the farm systems can be controlled and supervised remotely. We will contact the mussel farmers from New Zealand, regarding the techniques they use. In addition, there are also opportunities in combining offshore wind farms and mussel production, where the foundations of the wind turbines can be used to anchor longlines. This could reduce the costs in the establishment phase, and spare nature, as less space will be used for both activities.

Land-based system (selected)

To eliminate the challenges of working in high seas, we also want to try out a land-based pilot farm, which works by pumping water in from the Baltic Sea through a basin of mussels. After the water has been through the basin with mussels, the feces from the mussels will be collected and removed from the water before being discharged to the Baltic Sea again. By collecting the mussels 'feces, the environmental effects will be increased, as there is both nitrogen and phosphorus in the mussels' feces. With this system, we also see a potential in investigating whether it is then possible to use the residual material from the production for something valuable. For example, it could be used in agriculture or in biogas production, as a form of "sea fertilizer". It is usually stated that ⅓ of the nitrogen in the microalgae eaten by mussels is converted into biomass, ⅓ is released as ammonium into the water, and the last ⅓ ends up at the bottom with the mussels' feces. With the production method used with the collection of feces, the removal of nitrogen from the Baltic Sea can thus be doubled.

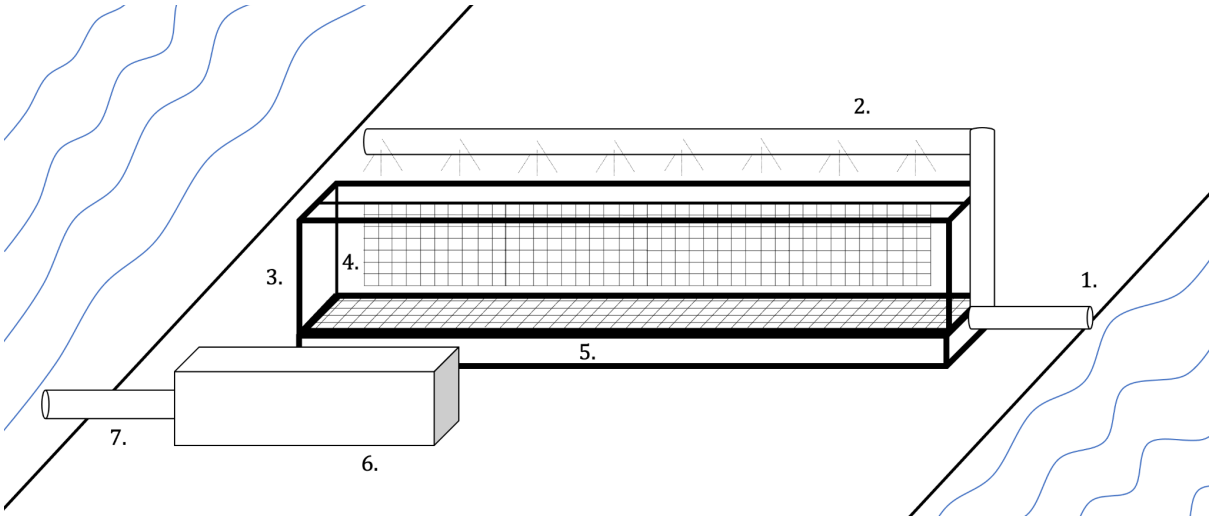


Figure 8, illustration of the land-based system. 1. water intake with pump system 2. distribution of water 3. basin 4. net 5. grate and collection of mussel feces 6. sedimentation tank 7. discharge of filtered water

The land-based system has never been tested before and there will therefore be a great deal of uncertainty associated with both the establishment and the operation. Aquaculture on land is often expensive, and if the value of the product is relatively low, the cost of operation may exceed the potential revenue from sales. This can perhaps be overcome by using renewable energy sources such as wind and solar power, which is relatively cheap and is currently being developed on Bornholm. Furthermore, no feed is needed in the production, and if the water is pumped in and back to the Baltic Sea continuously, there will most likely be no need for cooling, which is a major expense of aquaculture on land.

The cost of production on land may mean that there will be no commercial opportunities for a land-based farm. However, the potentials are seen as being large if successful, as it will increase security when working on the farm, because one does not have to go on open water, which will also lower costs thereby. In addition, the environmental benefit will also be greater as nutrient uptake is increased.

2.3 Permits

Below is an overview of permits that we have dealt with in the project, and which must be obtained depending on the purpose of a mussel farm. A distinction is made between commercial, scientific and recreational purposes.

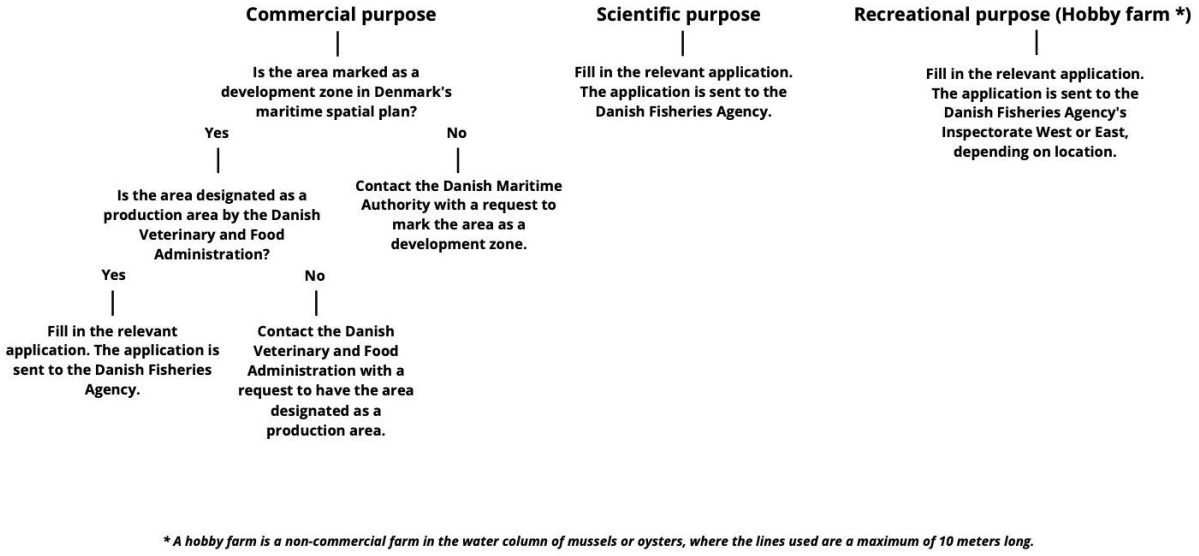


Figure 9, illustration of process for obtaining a permit for mussel farming

The starting point for the project was to obtain a permit for commercial production, as this is the long-term goal. As the area is currently not marked as a development zone, but as a general zone, the first step is to contact the Danish Maritime Authority. The Danish Maritime Authority has in March 2021, under the Ministry of Trade and Industry sent a plan for the national marine area in public hearing. The plan is a tool for spatial planning of marine areas in Denmark, and the purpose is to ensure appropriate coordination between different activities such as transport, energy production, aquaculture and nature protection (Søfartsstyrelsen, 2021). Denmark's spatial plan for the national marine area has been criticized both by political actors, NGOs and

scientists, and in a report published by WWF Baltic Ecoregion Program Denmark received the worst score among all the Baltic Sea countries (WWF, 2022). This is due to several points, including the low degree of protection of marine nature and the fact that it does not help to accelerate a sustainable blue economy (ibid.). The latter is distinguished, among other things, by the fact that there is no focus on the development of regenerative production.

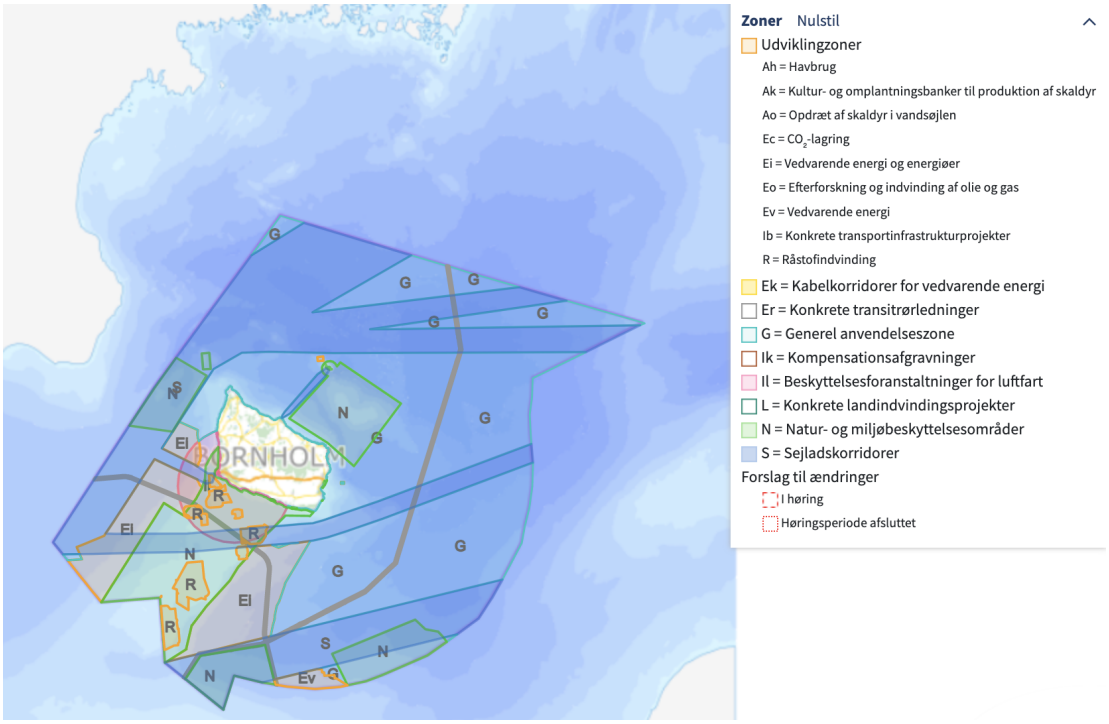


Figure 10, map of the zones in the spatial plan for the marine areas around Bornholm

In the plan, as mentioned, no areas have been marked for mussel production around Bornholm. If the plan is adopted without the addition of areas for mussel farming around Bornholm a commercial mussel farm will not be permitted. A response to the public hearing was therefore made in the project, requesting the designated area for mussel farming. The response can be found in Appendix 2.

As a result of the national budget negotiations, it was decided that the plan for the national marine areas should be politically negotiated and that marine national parks and trawl-free zones should be established (Finansministeriet, 2021). The political negotiations are expected to take place during the spring of 2022, and the adoption of the plan has therefore been postponed to later this year.

The next step in obtaining permits for the establishment of commercial mussel farming is, as illustrated in Figure 9, an application to the Danish Veterinary and Food Administration, as no production areas have yet been marked around Bornholm. As previously mentioned, mussel production is subject to strict requirements for food safety and may only be produced and harvested from areas designated by the Danish Veterinary and Food Administration. If mussels are harvested from production areas, they are required not to contain biological contaminants, contaminants such as heavy metals or algae toxins.

The establishment of a mussel farm presupposes a permit for the farming of mussels in the water column from the Danish Fisheries Agency. With Executive Order no. 1456 of 24 June 2021,

the Ministry of Food, Agriculture and Fisheries has stopped submitting new applications per. July 1, 2021 (Ministeriet for Fødevarer, Landbrug og Fiskeri, 2021A). It is unclear how long this stop will apply. The stop for application will be used to ensure the preparation of the overall planning of mussel farms in Denmark.

As will appear later in section 2.7, in regard to the planning of the next phase after ending this project, it has been decided that pilot mussel farms with scientific purposes must be established. As shown in Figure 9, this presupposes permission from the Danish Fisheries Agency and the relevant application will be submitted during the spring. Based on the above, it can be concluded that it is a lengthy process when areas where there has been no commercial mussel farming before must be approved. Based on the experience of this project, this can be a deterrent, as there is no transparency regarding the time horizon. There has been political concern about the large number of applications for new farms, and whether this will have a negative effect on the environment. The concern relates to areas with existing mussel farming, which are in few and closed sea areas (Ministeriet for Fødevarer, Landbrug og Fiskeri, 2021B).

In the process of obtaining permits for commercial mussel farming around Bornholm, the project has also faced a challenge in relation to incorrect information, which has made the process longer than necessary. This is particularly a result of the fact that there are three different agencies that are involved in the process. A solution to this could either be to centralize in such a way that only one agency must give permission for mussel farming, or that a group or committee is set up across the agencies. Another challenge that we have experienced is that the timeframe is very long. It has been particularly long because of the implementation of the new plan, as well as the previously mentioned stop for applications to the Danish Veterinary and Food Administration. This is problematic, as this may stop new environmentally improving blue mussel projects and productions outside the Limfjord area, where, as previously mentioned, there are particularly many farms and applications to establish more.

The result of this activity is that we will apply to establish pilot mussel farms with a scientific purpose to the Danish Fisheries Agency. In order to establish a commercial production of mussels on Bornholm, a development zone must first be marked in the intended area in the spatial plan for the Danish marine areas, after which the area must be approved by the Danish Veterinary and Food Administration as a production area, which as mentioned is part of a longer process. The Danish Fisheries Agency must afterwards allow the establishment of a mussel farm in the area.

2.4 Communication

The purpose of communication in the project has been to inform local citizens and visitors about the environmental and climate effects that occur in connection with farming mussels. In the project, we also wanted to inform about the poor environmental condition of the Baltic Sea and why there is a need for measures, such as mussel farming, to counteract eutrophication. In addition, the communication of the project has addressed that the smaller size of the Baltic blue mussel does not exclude it as an interesting food. These subjects for the communication are based on the project coordinator's previous studies (Appendix 3) and the past work of *ivandet*,

where it has been concluded that there is a knowledge barrier in relation to mussel farming on Bornholm, as it has not been tested around the island before.
The communication has to a large extent been dialogue-based, with the purpose of including as well as informing citizens and visitors, and meeting potential social barriers around future commercial mussel farming. DTU Aqua assesses in Petersen et al. (2021) that the social barriers associated with implementing mussel farming as a tool against eutrophication specifically address the visual pollution, which can lead to resistance and lack of acceptance. In addition to the visual pollution, there may also be dissatisfaction with waste from the mussel farms that may end up at nearby beaches. However, the two mentioned causes of social barriers are particularly associated with farming mussels on Smart Farm systems. DTU Aqua's primary method of meeting the social barriers is to work on reducing visual pollution, and thus has a focus on technical solutions (Petersen et al., 2021). We believe in the project that involvement and dialogue with the local citizens already in the planning phase before the establishment of the farms, is also a very important method that can help to overcome social barriers. Especially citizens who live in or are in some way connected to the local area (e.g., holiday home owners) can create conflicts due to visual pollution. Involvement of the local community both helps to make the planning process democratic and ensures a broad support for the project, which can make implementation easier (Appendix 3).


Picture 5 & 6, setting up hobby farming in October 2021 in Lagunen, Tejn Harbor.

Hobby farming of mussels has been used as a communication tool in the Tejn Harbor on Bornholm for activities with both school classes and visitors, and in this project has also worked to demonstrate what farming of mussels looks like. On 19th of October 2021, put the mussels in a hobby farm into socks. After a longer processing time, we received permission on 14th of March 2022 to set up hobby farming in Nexø Harbor. The hobby farm in Nexø Harbor will be established when there are mussel larvae in the water again in the spring.


Picture 7 & 8, communication at Gaardens Høstfest on 26th of September 2021

We participated on 26th of September 2021 in Gaardens Høstfest (Harvest Festival), and we experienced great interest and many visitors from the approx. 2500 guests that attended the event. The posters that were used for visual communication and as a starting point for dialogue with the visitors at the event can be found in Appendix 4.

The project coordinators gave a presentation on 27th of September 2021 at Gourmet Bornholm on Gaarden in connection with Sustainable Food Week. The project coordinators' presentation dealt with why mussels are interesting regarding sustainable blue bio-resources of the future, and how mussel production can become a reality on Bornholm. There were approx. 30 participants present. In week 42, we also had events in relation to the project.

To present the project's results, we have together with Madeclear made a video as a popular scientific product that communicates what a blue mussel farm on Bornholm can look like, why it is a good idea and what challenges may be associated with it. The video has over 1,300 views on Facebook, and 112 people have either liked, commented or shared it on LinkedIn. With the video format as a popular scientific product, it has been possible to reach a broad target group, and we have chosen to use both Facebook and LinkedIn to reach as wide an audience as possible.

Based on a workshop evaluating the project, a short version of this report will be written, which will be aimed at the general local citizen. In addition, a version of the project's results and effects will be translated into English to support the project's goal of knowledge sharing through the SUBMARINER Network, which is a collection of actors from the entire Baltic Sea region.

In the future, the interaction between communication and environmental monitoring around the pilot mussel farms will be of great importance. We believe that a special focus on food safety is important, as the mussels, in addition to being food, can help to counteract an environmental problem, the issue of food safety may arise. This can be a complex topic to understand, and will be central to communicate. Furthermore, we want to create a visual understanding of the production through video and perhaps live streaming, which can show the positive environmental effects around the breeding. By having this extended focus on communication also during the production itself, it may also be possible to mediate the transition of our value chains in the food sector that is needed.

2.5 Measurement of growth rate

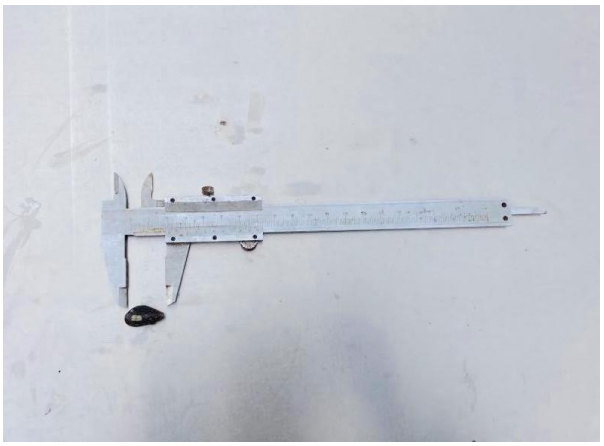
As mentioned earlier in the report, the growth of mussels is an important factor in relation to the possibilities in a production of mussels around Bornholm. How large they become has an impact on their application possibilities, and their growth rate determines the time of harvest, and has an impact regarding economic sustainability. Therefore, in the project we have carried out a pilot experiment of Bornholm blue mussels' growth rate. The experiment has given us insight into the average growth rate of mussel shell length under comparable living conditions, such as those at the chosen location. The experiment ran from 25th of August to 1st of November 2021.

The method of the experiment is described below:

- We collected mussels at Hammer Harbor from a buoy from a hobby mussel farm, which had been established the year before.
- The collected mussels were measured and sorted by size: 20 small mussels (> 5 mm - ≤10 mm) 20 between (> 10 mm - <15 mm) and 20 large (≥15 mm - ≤20 mm) were transferred to each their cylindrical net bags by size (diameter: 10 cm, height: 25 cm, mesh: 5 X 5 mm).
- Subsequently, the net bags were placed in the water column at a depth of approx. 0.5 m. Each net bag was attached to a horizontal rope.
- The net bags were cleaned every two weeks to avoid overgrowth, and hence potential starvation of the mussels.
- Collection of the net bags with mussels took place at the beginning of November and the shell length of the mussels was measured.

The conclusion from the experiment is that the growth of the shells was 6.56 mm on average over the period from 25th of August 2021 to 1st of November 2021 in 67 days, which means that the mussels have grown 0.097 mm / day. In particular, the small mussels had grown a lot, and here the average was 7.32 mm, which corresponds to 0.109 mm / day. The overview of the results for the growth is attached in Appendix 5. In Landes et al. (2015) similar experiments were performed, where mussels grew in bags, and their growth for a period in the autumn, at different salinity in the inland Danish waters, was investigated. If we compare with the results in the mentioned publication in relation to the increase in the mussel shell length, in a test area at Nørrefjord with a salinity of 16.1 psu an increase of 0.21 mm / day was observed for large mussels and 0.19 mm / day for little ones (Landes et al., 2015). In our experiment we have observed a lower increase in shell length, but this was also to be expected, due to the lower salinity around Bornholm.

The mussels used in the experiment are from a hobby farm (see section 2.4) which we established in July 2020, and we therefore know that the largest of the mussels were approx. 15 months in November 2021. The average for the large mussels in the experiment was after approx. 15 months in the water of 2.25 cm. If the average daily growth continues, which is uncertain, the large mussels from the experiment will reach a size of 4.5 cm after a little over 11 months. In this result, it has been considered that the growth stops in the winter period when the temperature is below about 5 degrees. The smallest blue mussels sold from the Limfjord for human consumption are 4.5 cm, and this measure has therefore been used in the calculation (Dansk Skaldyrcenter, u.å).



Picture 9 & 10, the mussels are measured and distributed in three net bags according to size.

Picture 11, final measurement of the mussels in November 2021

Through dialogue with marine biologist and senior researcher Josianne Støttrup from DTU Aqua, who has previously carried out a number of research projects on Bornholm at *Bornholms Lakseklækkeri,* we have become interested in investigating how the different layers with varying salinities in the water column affect the mussels' growth rate, which we will test in future pilot mussel farms. This is interesting as the water becomes more saline on deeper water and it affects the growth rate of the mussels positively, and thus may be a helping factor. Furthermore, we will perform several tests in relation to temperature influence, shell versus soft tissue and kg CO_2 per. kg shell, etc.

2.6 Planning of running and monitoring the pilot mussel farms

In the project, a plan for operation and environmental monitoring has been made. It has also been investigated how the future operation of the pilot mussel farms will proceed in collaboration with Klaus Hjorth Hansen. We held a meeting on October 29th 2021 where we made a budget for material expenses for pilot mussel farms. The plan for the establishment, operation and environmental monitoring of the pilot mussel farms is attached in Appendix 6.

The activities for the operation of sea-based pilot mussel farm:

- Collection of spat
- Control of spat recruitment
- Maintenance and cleaning of spat recruitment
- Monitoring and assessment of growth (monthly measurements of length and weight)
- Attachment of buoys according to growth of the mussels
- Inspection, maintenance and repairs
- Socking
- Securing th systems for the winter
- Sampling of water and tissue for harvesting
- Harvest
- Post-harvest cleaning as well as repair and preparation of recyclable materials
- Purchase of missing materials

The activities for the operation of land-based pilot mussel farm:

- Collection of spat (in the sea)
- Control of spat recruitment
- Maintenance and cleaning of spat recruitment
- Placement of recruited spat in the land-based system
- Monitoring and assessment of growth (monthly measurements of length and weight)
- Inspection and maintenance of pump system, vessel and possibly adaptation and development of systems
- Testing the uses of the mussel feces
- Socking
- Sampling of water and tissue for harvesting
- Harvest
- Purchase of missing materials

Picture 12 & 13, buoy from hobby farm and finds of big blue mussel shells in Nexø Harbor

In addition, there is a plan for monitoring the environmental effects, which focuses on the mussels' feces and the impact on the bottom conditions, as this is an area that has received special attention from environmental organizations. It has also been decided that monitoring of species composition near the farm is relevant, as it is an indicator of whether water quality has improved. Measurements of growth for the mussels will also be an important indicator of the amount of nitrogen and phosphorus uptake.

In Denmark we are missing knowledge on the subject of increased biodiversity in relation to mussel farms, and we therefore also want to monitor this during visual inspections. It is also concluded in Bruhn et al. (2020) that effects on biodiversity in areas with mussel farming is an area where knowledge is lacking.

We also want to investigate climate effects both what impact climate change has on mussel farming, and conversely what effects cultivation of mussels can have on the climate, including CO_2 uptake. Climate change has major consequences on the ocean, which is reflected in acidification, temperature changes, changes in precipitation and therefore salinity in the sea (Avdelas, 2021). The economic loss for shellfish productions in Europe caused by ocean acidification is estimated at DKK 6.8 billion annually in 2100 (ibid.). As previously mentioned, we are lacking knowledge on the climate effects of mussel production in Denmark, and we therefore find it interesting to investigate.

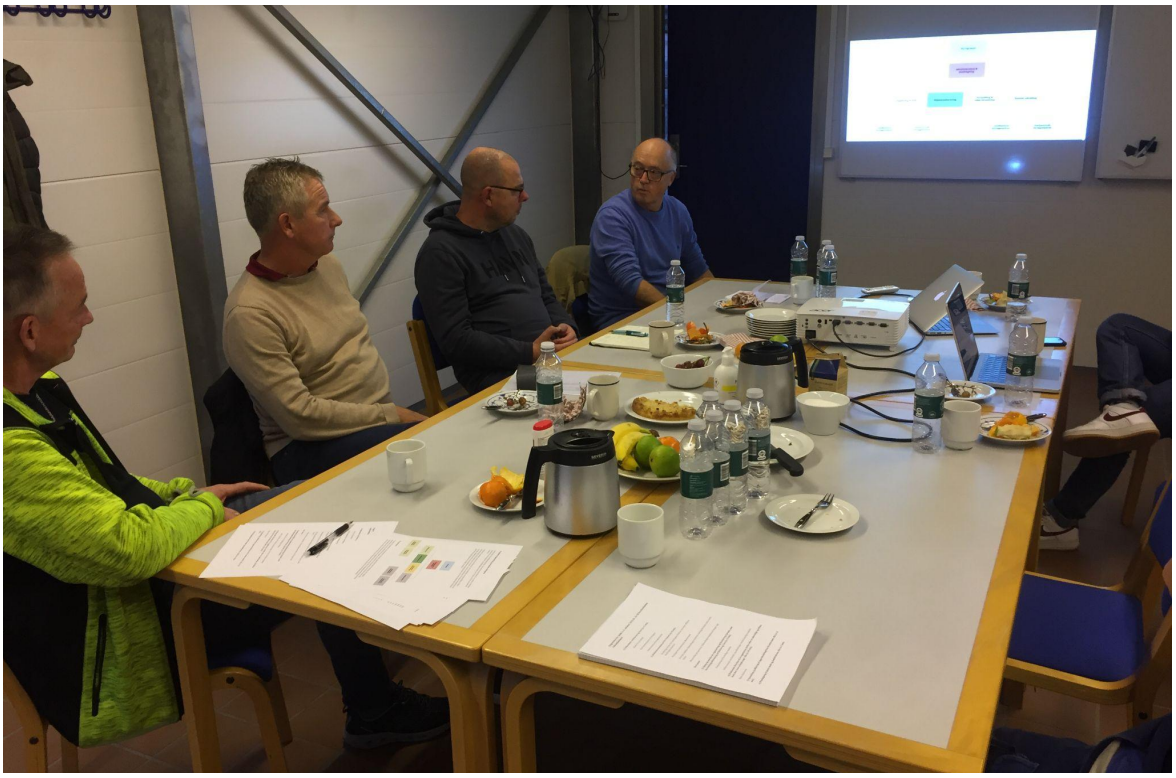
2.7 Establishment of networks and the next phase after completion of this project

The purpose of this activity in the project was to create a network around the development that would lead to the establishment of local pilot mussel farms. In the project, we have wanted, and succeeded in, engaging actors across sectors, and we believe that with a broad composition we have exactly the competencies and experience needed to support the intended development. The European Commission supports the importance of organization at local level and, in the context of the blue transition, recommends promoting and supporting local participatory initiatives and combining the recovery of marine resources with the preservation of the livelihood of the local community (European Commission, 2021).

We have engaged actors with competencies and knowledge within research, communication, environmental monitoring, nature conservation, legislation, bioeconomy, regional and local development, business, food production, tourism and the local maritime industry.
With this project, we also wanted to establish an organization of this network, whether it should be a company or an association.

Marie Miller Birk (ivandet), project coordinators Morten Ledertoug and Clara Mühlhausen and consultant Per Dolmer (Blue Research) arranged a meeting with Klaus Hjorth Hansen (Nexø Vodbinderi), Carsten Andersen (Nexø Havn Udvikling), Gert Jørgensen (Bornholms Lakseklækkeri) and Christian Prip (DN Bornholm) on 4th of October 2021. Here we discussed how the network should be organized so that pilot mussel farms can be established after this project. At the meeting, it was concluded that the network would be strengthened by involving local actors who can represent future buyers of mussel products, and it was suggested that we should work on obtaining cooperation agreements from Bornholms Landbrug og Fødevarer (Bornholm's Agriculture & Food) and Gourmet Bornholm. At the meeting, Christian Prip said that Danmarks Naturfredningsforening Bornholm (the Danish Society for Nature Conservation Bornholm) wants to be part of a follow-up group, and advise on the future project, but can not be included as a partner. At the meeting, it was also concluded that the best way forward for the development of Bornholm mussel production is to establish an association with a network of relevant actors who can apply for funds for financing. The Velux Foundation was presented as an

opportunity at the meeting, as it has a standing application opportunity focusing on the marine environment and there is a strong focus on local communities, communication and sustainable use of marine resources. Based on the meeting, Nexø Vodbinderi, Bornholms Lakseklækkeri and Nexø Havn Udvikling signed a declaration of affiliation to enter into the establishment of pilot mussel farms (Appendix 7).



Picture 14, Meeting on organizing of the network and future financing at Bornholms Lakseklækkeri on 4th of October 2021

We held a meeting with Bornholms Landbrug og Fødevarer (Bornholm's Agriculture & Food) on 16th of November 2021 on how they can be included, and they have subsequently signed a declaration of interest (Appendix 8).

Based on the meeting on 4th of October 2021, the project coordinators worked on establishing an association and on the application to the Velux Foundation to finance the next phase. On the 3rd of December, the project coordinators and consultant Per Dolmer held a meeting with representatives from the Velux Foundation; Tanja Nielsen, who is the fund adviser, and Mikkel Klougart, who was the program manager at the time. At the meeting, Tanja Nielsen and Mikkel Klougart recommended broadening the purpose of the future project to include more initiatives that can support the sustainable development of the local blue bioeconomy. In addition, they emphasized that they find the organization as an association very interesting.

After the meeting, the project coordinators held a meeting with Avodan on 23rd of November 2021, which assisted the project in establishing the association. During December, the project coordinators held a series of meetings with relevant actors regarding establishing the board of the association. This resulted in a start-up meeting that was to lead to the founding general meeting and formal establishment of the association. The meeting was held on 12th of January 2022 in Nexø Boldklub with the following participants:

Online participation: Ebbe Mølsted-Møller (Erhvervshus Hovedstaden), Mikkel Bach-Jensen (Gourmet Bornholm) and Miller Birk (ivandet).

Physical attendance: Mette Skøt (project developer in Bornholms Energi og Forsyning, Energiø Bornholm and board of GUDP), Hanne Strøby (Destination Bornholm), Henrik Olsen (experienced with associations and business consulting), Per Dolmer (Blue Research), Gert Jørgensen (Bornholms Lakseklækkeri), Carsten Andersen (Nexø Havn and Nexø Havn Udvikling), Maria Barslund (Chairman Gourmet Bornholm), Christian Prip (Danmarks Naturfredningsforening and FLAG), Klaus Hjorth Hansen (Nexø Vodbinderi), Jacob Dam Nielsen (Plant Breeding Consultant Agriculture and Food, Organic Egg Producer), Pernille Kofod Lydolph (Destination Bornholm) and the project coordinators Morten Ledertoug and Clara Mühlhausen.

At the meeting, the draft application for the Velux Foundation and the articles of association were reviewed. In addition, a plan on the future work was presented and the application to the Velux Foundation.

With the association, we want to create a basis for initiating development projects with a focus on sustainable blue bioeconomy. The basis will be to gather a network of actors who want a positive development of the environmental state of the Baltic Sea, and who together can develop and implement the projects. We want to show how we, in collaboration with nature, can turn the negative development in a more positive direction through regenerative activities.

Picture 15, start-up meeting about establishing an association in Nexø Boldklub on 12 January 2022

With the project, a goal was set to engage a minimum of 10 actors, and this goal has been achieved and has in practice been formed in the establishment of an association, which will continue the work that has started with this project.

On 9th of February 2022, a founding general meeting was held in which the project coordinators, Hanne Strøby, Per Dolmer, Gert Jørgensen, Carsten Andersen, Christian Prip and Ebbe Mølsted-Møller participated. Here, the articles of association were finally adopted, and the following board members were elected: Gert Jørgensen, Christian Prip, Pernille Kofod Lydolph, Per Dolmer, Ebbe Mølsted-Møller and Jacob Dam Nielsen. At a subsequent constituent board meeting, Ebbe Mølsted-Møller was elected chairman, and Per Dolmer was elected deputy chairman.

On 10th of March 2022, the association sent an application to the Velux Foundation regarding financing the association's further work. In the next phase after ending this project, if we receive funding from the Velux Foundation, we want, among other things, to establish pilot mussel farms and develop the association so that it can support a sustainable blue transition on Bornholm.

3. Development potentials

There are five different models for mussel farming on Bornholm, which are fully or partly dependent on political priorities and adaptation of framework conditions.

The national plans for 2021-2027 for implementing the Water Framework Directive
In 2021, the Danish Parliament should have decided on the national water plan for the period 2021-2027, but the plans are still in consultation. The water plan for 2021-2027 will presuppose a reduction in the input of nitrogen to coastal areas. The consultation draft states that the reduction in the input to coastal areas for Bornholm is 398.5 tons of nitrogen per year (Miljøministeriet, 2021), which will require a major effort, including especially from agriculture, which is one of the largest emitters of nitrogen.

Removal of nutrients from land-based fish farming
On Bornholm, work is being done on the development of sites for land-based salmon farming in so-called recycled closed systems (RAS). In a RAS production, there is an intake of salt water, and the fish is produced in large concrete tanks, where the saltwater flows through. All the water in the tanks is replaced approx. twice an hour and cleaned with a mechanical and a biological filter (nitrification), after which oxygen is added and the pH is adjusted. There is an ongoing discharge of water back to the sea. This water is further purified with a denitrification, in which most of the nitrogen in the production water is removed. Without purification, approx. 45 kg N pr. tons of fish produced, but with efficient treatment, the discharge can be reduced to approx. 2.5 kg N per ton fish produced. It is thus a form of production with a very high environmental efficiency. In relation to aquaculture, the environmental efficiency is thus approx. 20 times larger. However, RAS production still emits a small amount of nitrogen, and this amount of nitrogen can be removed with mussel farming.

Farming of mussels for human consumption

There is a growing interest among Danes in limiting the climate impact through food choices. In certain consumer groups, animal protein is thus deselected, as the climate impact from these products is relatively high compared to vegetarian foods. Analyzes of the climate impact of mussel production show, as previously mentioned, that this form of production of animal proteins has a climate impact that is lower than the production of vegetables. Thus, there is a lack of focus on the fact that consumers can eat animal proteins in the form of mussels, and at the same time have a climate impact that is lower than when consuming a diet consisting exclusively of vegetable foods. There is thus an opportunity for a targeted sale of mussels for food with a focus on the product's low climate impact.


Picture 16 & 17, Kieler Meeres Farm (mussel farm) in Kiel, Germany has a small production of mussels sold directly to customers without expensive intermediaries. Left: The mussels are produced on longlines in a labor intensive process . Right: The mussels are sold directly over the quay. Note the sign where the price is stated at 11 euros per kg (Photo from Kieler Meeresfarm).

Industrial production of mussels for animal feed

For the last 5-8 years, there has been a focus on the use of mussels for feed in agricultural production. Mussels have a high protein content and the same amino acid composition as fishmeal, and they are therefore suitable as a feed ingredient. For mussels to be sold as a feed ingredient, the price must be comparable to the price of fishmeal, however with a small extra price up 10-15% due to the value of sustainability in production. The price for fishmeal is approx. $1500 per ton, equivalent to 9400 DKK per ton. The processing of mussels usually gives a low yield of approx. 10-15%, and thus only a very low price can be paid for the mussels (700-1000 DKK / ton mussels). Two factors could promote the industrial production of mussels and the processing of these into feed ingredients:

1. Payment model for mussel production as a mitigation tool for eutrophication

2. Access to cheap energy for processing. The mussel meat and shell must be separated, and the meat must be dried, which presupposes cheap energy. European Proteins is working on the development of a fermentation method in which the mussels are included. The mussels are separated in shell and meat fraction but not dried. The liquid in the mussels replaces the liquid normally added during a fermentation process, thus saving energy for drying. Feed with a high protein content is obtained and the fermentation process ensures a high digestibility.

Mussels grown in areas with low salinity have a thinner shell, and new products may be made where the shells are retained in the product.

Improving water quality and removing microplastics

In recent years, there has been increasing focus on the importance of untreated wastewater in connection with overflows from wastewater treatment plants during heavy rainfall. Aarhus Municipality, in collaboration with WSP and COWI, has carried out an experiment that investigated whether mussels can purify the water of bacteria and microalgae in the Port of Aarhus. The municipality is challenged by poor water quality in connection with rainy events and overflows from wastewater treatment plants that flow into the Aarhus A (Aarhus Stream). As Aarhus Å has an outlet at the bottom of the harbor, overflows lead to high concentrations of bacteria from untreated wastewater in the harbor, where a Harbor Bath has been established and there are various water sports activities. In the experiment, four rafts of 5x5 meters with mussels were placed so that the mussels could filter along a gradient of salinity and food concentration from the bottom of the harbor, where Aarhus Å ends, and where the bacterial concentration is therefore greatest. The outermost measuring station with a mussel frame was located outside Aarhus Havbane outside the harbor, which represents unaffected conditions compared to Aarhus Å (Aarhus Stream). The studies showed that the mussels were able to reduce the bacterial concentration of E. coli and the microalgae concentration. The results showed that mussel farming can be an affordable method of reducing the occurrence of biological bacteria in bathing water for areas that e.g. is affected by overflow from wastewater treatment plants or diffuse discharge of wastewater. In the experiment in the Port of Aarhus, the mussels' capacity to reduce the occurrence of viruses in bathing water was not investigated. To the extent that viruses are bound to particles, these can be taken up by the mussels and either accumulate in the mussels or exported to the bottom with the feces of the mussels.

In recent years, there has been a lot of focus on microplastic in the marine environment. There are several sources of microplastics. Larger pieces of plastic can eventually disintegrate and form microplastics. Micro-rubber from wear on tires makes up more than half of all microplastic emissions, and rainwater therefore becomes the largest source of microplastic pollution. Studies of the microplastic load from Danish wastewater treatment plants show that the retention for microplastics is up to over 99%. Attention should therefore be paid to the microplastic discharge from the rainwater-dependent outlets, as microplastic is discharged directly into the marine environment. Mussels used for the purification of bathing water in connection with the overflow of wastewater treatment plants or for the purification of microplastics should not be used for feed or food. Thus, there can be an important communicative task in telling citizens that mussels used for water purification cannot be used for feed or food, so that mussels as an important source of protein do not get a bad reputation. Likewise, it must be communicated that the mussels are used for energy and fertilizer in a circular economy where important nutrients are brought back to land where they can benefit.

4. Conclusion

Below is an overview of the weaknesses, strengths, threats and opportunities we have presented in the report. This overview provides insight into the strengths a Bornholm mussel production should "highlight" and the future opportunities that exist to improve or strengthen a production in the long run. It also lists the weaknesses that should be addressed and the threats that need to be considered when establishing a commercial production.

Strengths	***Weaknesses***
· There is an existing market for mussels in Denmark · Local infrastructure, capacity and knowledge in the maritime industries from commercial fishing · Strong gastronomic scene · Local political focus on climate and environment · Strong tradition of nature communication · Plans for the establishment of offshore windmill islands · Relieve eutrophication problems · Recycling of nutrients · Sustainable food products with a very low climate footprint · Sustainable feed products · Job creation · Increased supply of local food · Improved water quality · Potential increased biodiversity · Strong local network · Improving bathing water quality and removal of microplastics	· No previous experiences with mussel farming on Bornholm (knowledge barrier and long application process) · Low growth and small size of the mussels for human consumption · Resistance to mussel farming (however only seen in the Limfjord) · Other use of the sea area
Opportunities	***Threats***
Payment for ecosystem services (payment for nutrient and CO_2 uptake) · Technological development and innovation (offshore, submerged systems and combination with offshore wind) · National and EU regulations focusing on improving the state of the Baltic Sea, reducing greenhouse gasses, increasing biodiversity and bio economic growth · Co-create land-based fish farms with mussel production	· Application stop for new application for commercial mussel farming · Site-specific barrier: Low salinity and high exposure · Toxic algaes · Heavy metals in sediment · Predation · Climate change

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