Baltic Blue Growth: Initiating large scale mussel farming in the Baltic Sea

Summary of key findings

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About

The present report is a summary of the knowledge accumulated as result of the Interreg project Baltic Blue Growth. It was published online and print in October 2019, by Region Östergötland (contact person lena.tasse@regionostergotland.se). All data, methods, results and conclusions are detailed in extensive, topic-specific reports, which can be downloaded from the project's website www.balticbluegrowth.eu and also consulted using the Operational Decision Support System (ODSS) for Baltic Mussel farming at www.sea.ee/bbg-odss.

 Cover photo: Mussel harvest at the mussel farm in St. Anna, Sweden (photo by Lena Tasse, Region Östergötland).

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Mussel farming in the Baltic Sea

Mussel farming has been suggested as a new economic activity for the Baltic Sea Region, with several potentially positive effects on environment, nutrient cycling, food security and employment. Small experimental mussel farms have been present in the area for about a decade, and in recent years several new and larger mussel farms have been initiated.

The Baltic Blue Growth (BBG) project has followed most of the currently active mussel farms and studied the farming technology, potential impact on the environment, nutrient uptake, economic factors, usage as feed, maritime spatial planning and regulatory aspects. BBG had the ambition to move a step ahead as to enable the so far mainly experimental mussel farms to continue as viable businesses supported by public as well as private funding in order to take the next step in installing mussel farming as a normal and accepted activity within the Baltic Sea.

The project has produced a large selection of specialized reports, which can all be downloaded from the Submariner Network website. The present document is a summary of these reports.

1 Background

The Baltic Sea is one of the world's largest brackish water areas, and both marine and fresh-water species can be found in its waters. One of these is the blue mussel (*Mytilus edulis*), a keystone species in the Baltic Sea that grows abundantly in many areas despite the low salinity. The blue mussels of the Baltic are the same kind of mussels that are widely farmed and commercialized in more western parts of Europe (Denmark, Netherlands, Swedish West coast). In the Baltic Sea, the mussels grow more slowly and to a smaller size compared to mussels growing in the Atlantic high-salinity waters.

The Baltic Sea

The drainage basin of the Baltic Sea is inhabited by more than 80 million people, and all water from this area runs into the Baltic Sea. Human activities result in large quantities of nutrients (phosphorous and nitrogen) being released from various sources, such as sewage treatment plants, industrial activities and running off from agricultural land. These excess nutrients end up in the Baltic Sea, leading to intensified eutrophication, one of the main threats to the Baltic Sea. The symptoms of eutrophication include shift in species composition from perennial to ephemeral species, excessive growth of opportunistic benthic and pelagic algae, blue-green algal blooms, increased turbidity, oxygen depletion and disappearance of the biota.

Nutrient influx to the Baltic Sea from land based sources (rivers, sewage plants…) is called ***external load***. These excess nutrients eventually accumulate at the sea floor, in oxygen-depleted sediments. The term ***internal load*** refers to nutrients that are released from these sediments.

The reduction of eutrophication is one of the main goals of the Baltic Sea Action Plan (BSAP, see Figure 1). The BSAP is a joint programme for HELCOM countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden) and the EU to restore the good environmental status of the Baltic marine environment by 2021. To this end, is vital to reduce afflux of new nutrients into the system, using land-based measures such as efficient wastewater treatment, nutrient recycling and manure management. However, these land-based measures can be complemented by sea-based measures, in particular to reduce the amount of nutrients already present in the sea ("historical sins"). Examples of sea-based measures that have been proposed are large-scale dredging, oxygen pumping, aluminium injections or the use of blue-catch crops such as selective fishing, algae or mussel farming. Compared to land-based methods, sea-based methods have been less developed and studied. More than 40 years of land-based measures have resulted in a significant decline of the influx of nutrients to the Baltic Sea, but inputs remain above the maximum allowable levels. Additional efforts are needed, both land-based and sea-based.

The EU strategy of the Baltic Sea Region

The European Union Strategy for the Baltic Sea Region (EUSBSR) was the first Macro-regional Strategy in Europe. The EUSBSR is divided into three objectives, which represent the three key challenges of the Strategy: Saving the sea, Connecting the region and increasing prosperity.

The EUSBSR is implemented in concrete joint projects and processes. Projects and processes named "Flagships of the EUSBSR" demonstrate especially well the progress of the Strategy. However, no new funding or institutions have been founded to support the implementation of the Strategy. Instead, the EUSBSR, as all Macro-regional Strategies, is based on effective and more coordinated use of existing funding sources, and the promotion of synergies and complementarities.

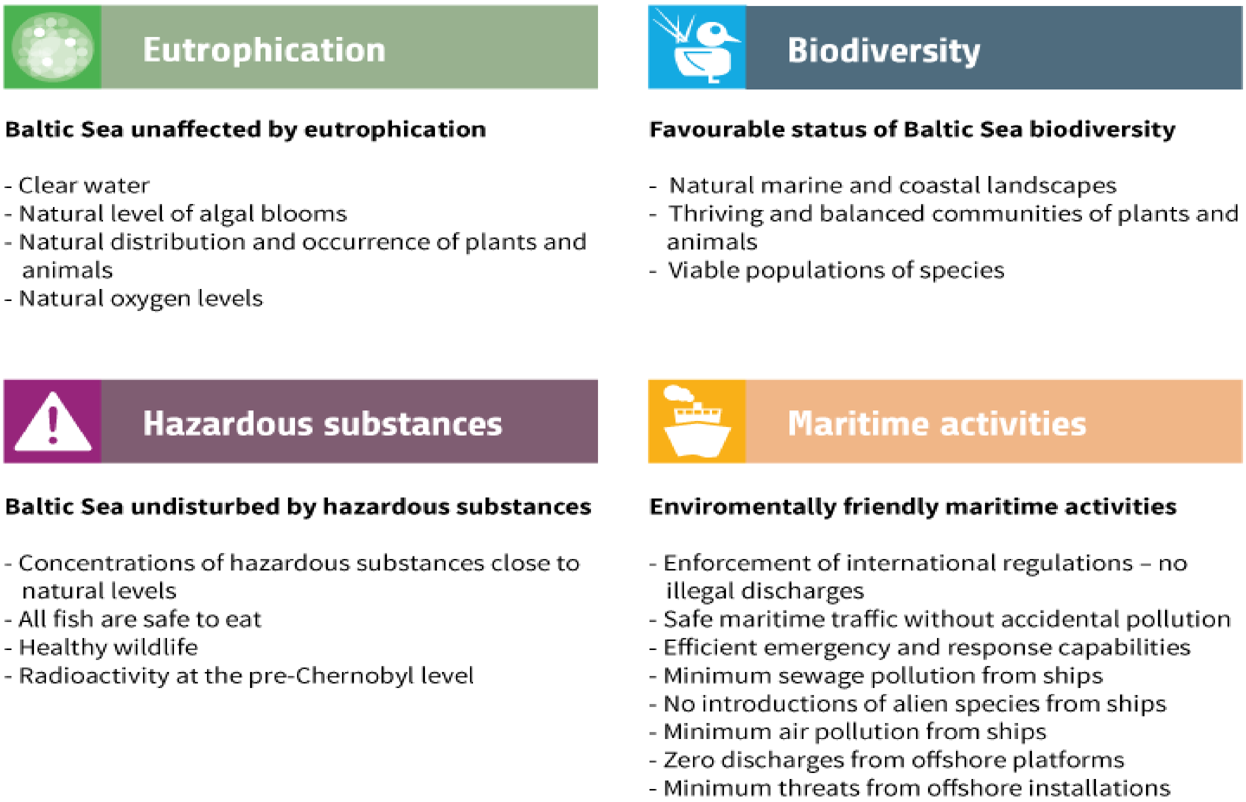


Figure 1. Goals and objectives of the Baltic Sea Action Plan.

The Baltic Blue Growth Project

The Baltic Blue Growth project has studied the possibility to perform large scale mussel farming in the Baltic Sea. Cultivating and harvesting blue mussels in the Baltic Sea can substantially improve the water quality as mussels take up nutrients through their food intake. The harvested mussels can be processed into a mussel meal to be used as an ingredient in animal feed, replacing e.g. imported fish and soybean meal. Mussel farming has the potential to recycle nutrients, provide food and feed and induce blue growth in the Baltic Sea Region.

Mussel farming in the Baltic Sea has so far not gone beyond experimental scale. To build up a commercially viable mussel farming value chain, it is not only necessary to develop suitable farming techniques for Baltic Sea conditions, but also to develop accepted mechanisms to compensate the ecosystem services provided by mussel farming.

To pave the way for full-scale mussel farming, the project partners have studied technical, environmental, legal and regulatory aspects of mussel farming. Based on data and experiences collected at the fully operational mussel farms to be established by Baltic Blue Growth, the project's main outputs are described in this summary report and include:

- Production methods adapted for Baltic Sea environmental and societal conditions,
- Models and functional decision support tools on suitable farming sites and their production potential,
- Business plans and farming manuals for large scale mussel farms,
- A demonstration line for processing mussels into fish and poultry feed,
- A guide on licensing processes for mussel farming in the Baltic Sea Region,
- Recommendations on harmonised maritime spatial planning and ecosystem service compensation measures.

The Baltic Blue Growth project is a Flagship of the EUSBSR under Policy Area "Nutri", and financed by the Interreg Baltic Sea Region Programme 2014-2020. More info about the project can be found at the end of this document.

For a review of other past and ongoing mussel farming initiatives in the Baltic Sea Region, see fact box on page 11.

2 The Mussel Farms

Blue mussel farming is a well-established industry in the EU, with 175,000 tonnes produced annually on the North Atlantic shores mainly in France, Netherlands, Ireland and the United Kingdom. In all farms, specific substrates such as nets or ropes are introduced into the water for naturally occurring mussel larvae to settle upon them. Traditionally, blue mussels have not been farmed in the Baltic Sea, but mussel larvae are present and willingly settle on any substrate introduced into the water at the right time and site. As part of the Baltic Blue Growth project, several new farms were started and others modified/enlarged (1). Detailed technical information of the farms can found in chapter 4.

→ ***More information about the farming technology used by the different farms can be found in section 4, and the harvested mussels (quantity, quality) is described in section 5.***

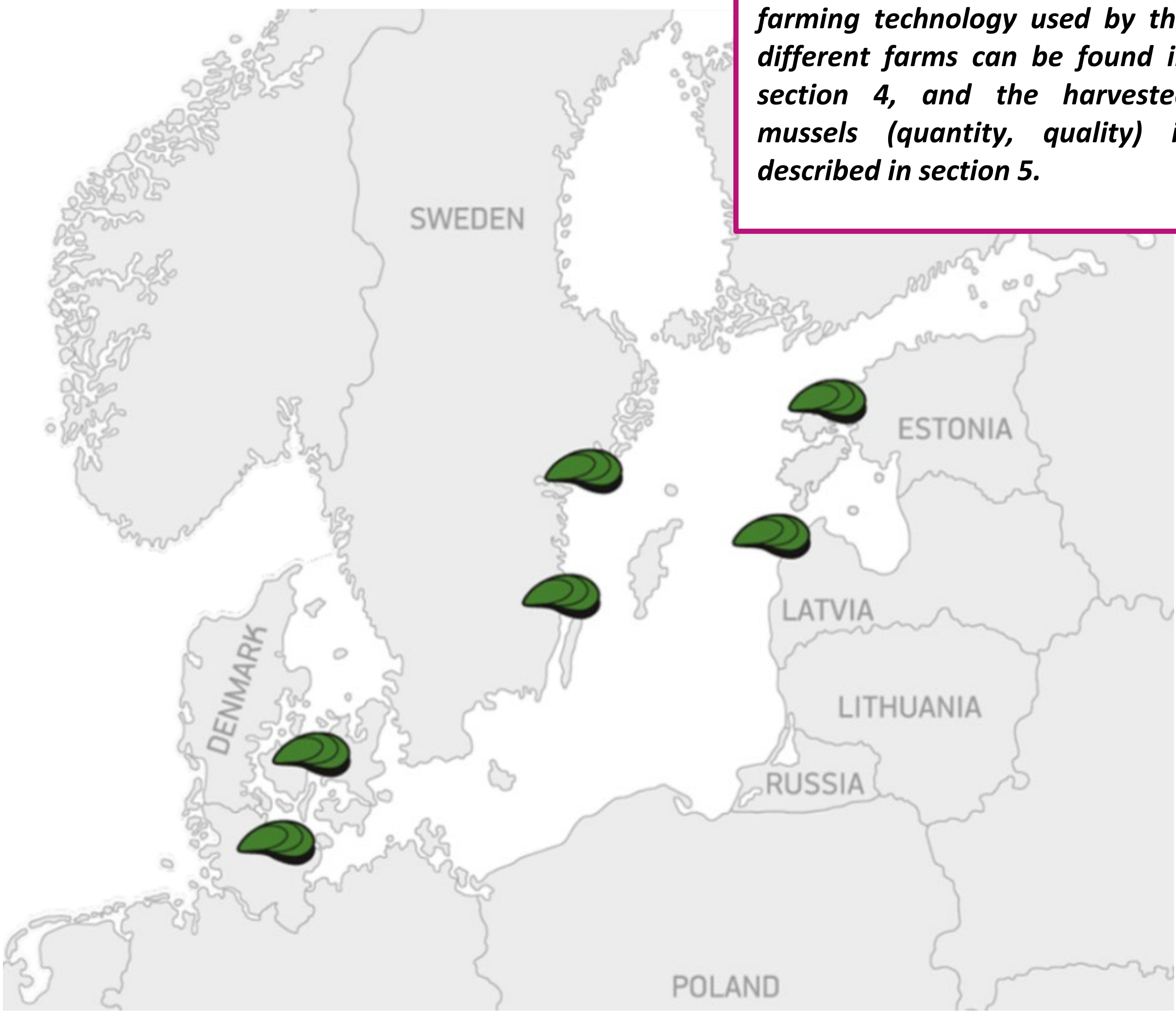


Figure 2. Baltic Blue Growth mussel farms.

St. Anna archipelago, Sweden

This mussel farm was started in spring 2016, and is owned and operated by the East Regional Centre for Aquaculture (www.vattenbrukscentrumost.se), a structure devoted to the promotion and teaching of aquaculture, in particular RAS and blue catch mussel farming. The farm is located in the archipelago of St. Anna, in Östergötland, on a site sheltered from the dominating winds. The mussels are grown on a total of 24 km of fuzzy ropes in a long-line system. The farm is managed by a single person, visiting the site once a week. For the harvest, additional personnel were contracted during a 4 week period. A total of 80 tonnes was harvested in 2018, and used for feed production experiments, biogas and as fertilizer.

Västervik, Sweden

Figure 3. The Västervik farm, built using trawl nets.

The mussel farm is located close to Hasselö, is owned by Västervik municipality and is operated by an NGO (Hasselö island local fishing conservation group). The farm was established in 2012 as part of the project "Aquabest". Approximately 10 tonnes of mussels were harvested from this net-type farm in 2016 and again in 2018. The mussels were used for feed ingredient production tests.

Byxelkrok, Sweden

Figure 4. Byxelkrok farm.

The Byxelkrok farm was established by the Baltic Blue Growth project partner Kalmar municipality, for testing off-shore farming techniques suitable for particularly difficult sites with high waves, strong current and ice drift. The equipment tested was 10 submerged 120×3 m net units, fixed to the sea floor with drill anchors. Despite large efforts, the technology was never successful in the very challenging environment of the Kalmar Sound, and the farm will be transferred to a more sheltered site in the future.

Hagby, Sweden

Figure 5. Hagby farm.

The farm outside Hagby, close to Kalmar, is a net-type farm established in 2014 and purchased by Kalmar municipality in 2016. The farm, a modified SmartFarm, was submerged using ice-safe buoys. A harvest of 9 tonnes brought ashore in 2018 and used for fertilizer.

Musholm, Denmark

Figure 6. The Mushoolm mussel farm.

Musholm A/S (www.musholm.com) is a fish producer in the Great Belt (Denmark) that uses net-type mussel farm units to capture parts of the nutrients released in the water by the fish farming activity. Conditions at the fish farming site are very challenging for mussel farming purposes, with high waves, current and heavy predation by eider. During the Baltic Blue Growth project, a new production technique involving moving the farm units depending on the season was tested. After settling and growing in the Great Belt, the units were towed to Limfjorden for a final growth period before harvest. Several techniques for eider predation control were tested in the Great Belt, including sound, laser and drones. Unfortunately, none of these techniques were very successful. Despite this, 360 tonnes were harvested from 18 units in 2018.

Kieler Meeresfarm, Germany

Figure 7. Kieler Meeresfarm is located close to the town of Kiel and the Kiel canal. Photo: R. Lemke.

The Kiel Bay farm is operated by the private company Kieler Meeresfarm (www.kieler-meeresfarm.de), which sells mussels to locals and restaurants for human consumption. The farm was first deployed in 2010. The company also grows sugar kelp and as part of current expansion plans, will include fish farming in a "zero-emission" strategy within the frame work of an IMTA (Integrated Multi-Trophic Aquaculture).

As contracted operator for the Schleswig-Holstein Ministry of Energy, Agriculture, Environment and Rural Areas, Kieler Meeresfarm has deployed three additional rigs, within the already existing farm area, each with 150 m of Swedish Band substrate. Production methods have been specifically designed for the production of large biomass, as opposed to the mussels produced for human consumption, where large mussels are privileged and total biomass less important. The farm has not encountered any major problems, except some eider predation. In spring 2018, approximately 5 ton of small blue mussels were harvested.

Pavilosta, Latvia

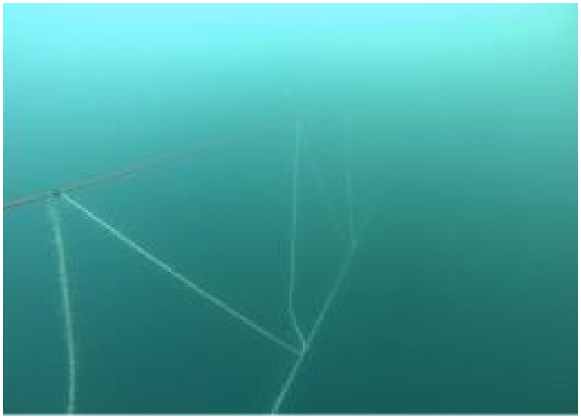


Figure 8. The Pavilosta farm, just immerged.

Built for scientific demonstration purpose and intended for very exposed offshore conditions, this submerged mussel farm is located 7 km from the port of Pavilosta and consists of 5 parallel single fuzzy-rope longlines. The site is exposed to waves, current and icing in the winter season, and located close to trade routes and fishing areas. Despite being submerged, it has repeatedly suffered heavy damage from weather and unauthorized fishing around and above the farm. The farm was not harvested during the project.

Vormsi, Estonia

Figure 9: The Vormsi mussel farm in Estonia.

The mussel farm at Vormsi, in Estonia, is a small test farm operated by Est-Agar (www.estagar.ee), a company producing the gelling agent furcellaran from red seaweed. The farm did not receive any European funds as part of the project, both investment and man-hours were privately funded demonstrating mussel farming investment will in Estonia. The original farm was made up by in total 126 m of trawl net hanging down to 3.5 m depth from single 50 m longlines. After the theft of all buoys, the farm was slightly submerged to avoid attracting attention. Maintenance is run by 1 person, visiting the farm once every 1-2 months. The farm was not harvested during the project.

Other mussel farming initiatives in the Baltic Sea

- Aquabest (EU Baltic Sea Region Programme 2011-2014)
- Baltic 2020 (2009-2012)
- Baltic Eco Mussel (EU Central Baltic Interreg programme 2012-2014)
- Bucefalos (EU Life 2012-2015)
- Life IP Rich Waters (EU Life programme 2014-2020)
- MumiPro (Innovation Fund Denmark)
- Nutritrade (Interreg Central Baltic 2014-2020)
- Optimus (BONUS 2010-2017)

For more information:

“Farming of blue mussels in the Baltic Sea. A review of pilot studies 2007-2016” (20).

3 Environmental impact of mussel farms

Mussel farming is widely perceived as a tool for mitigating eutrophication effects (2). However, potentially detrimental impacts of bio-deposits, amongst other particulate organic matter, of which mussels assemble substantial amounts, remains to date a subject of research. On the other hand, direct positive effects such as increased transparency and higher biodiversity around the farms have been suggested. To study potential impacts, and as a follow-up on previous studies on the subject (3), six of the mussel farms described in section 2 were monitored for key environmental variables during 2017-2018. The results are detailed in the report "Ecological impacts at the small-scale commercial mussel farms in the Baltic Sea" (4).

Environmental monitoring

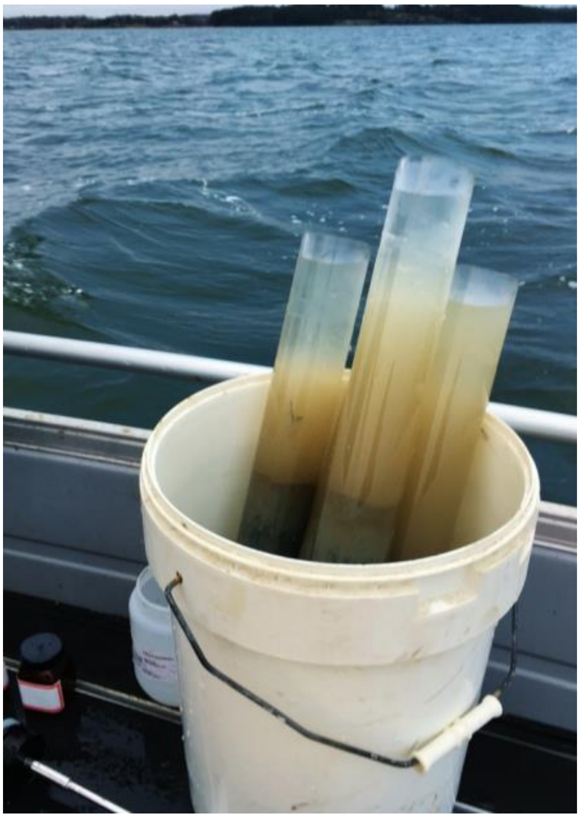


Figure 10. Sediment samples.

All water quality parameters were studied in 2017 and 2018 at two polygons; at a reference site and at the mussel farm according to a formalized monitoring scheme and applied to all BBG mussel farms. The visits to monitoring stations were timed so that the period from June to October, when the mussel farms are most likely to have an impact on water quality or sediments, would be covered by monitoring observations. The water for nutrient analyses was sampled at distinct depths and thereafter analysed in laboratory by standard analytical methods. The water transparency was measured by Secchi disc. The oxygen concentration was measured as continuous profile by CTD except in Sankt Anna where oxygen was measured in the same water samples as nutrients by use of standard analytical method. The chlorophyll a concentration and phytoplankton species composition and biomass were measured in integrated water samples that represent photic layer at respective farm (e.g., 0-10 m). Meso-zooplankton was sampled using a WP-2 net (or smaller) of 100 µm mesh size (except in Sankt Anna farm where substandard procedure was used).

The zoobenthic samples were taken by a grab sampler and sieved through 0.5 mm × 0.5 mm mesh size sieve, phytobenthos samples were sampled by scuba diver collecting sample from area of 30 cm x 30 cm. Surface sediments (0-2 cm) were sampled at the same time as zoobenthos by taking subsample from grab sampler. Total carbon and total nitrogen in sediments were determined by high temperature combustion. Total sediment phosphorus was extracted from sediments with 1M HCl after sediments were heated in oven.

Sedimentation was indirectly observed, measured as species composition and carbon content of the sediments below the six farms. At the Kiel farm, a more ambitious sedimentation study was carried out. Researchers deployed a sedimentation trap beneath the farm and at a reference site, during 14 days, allowing for the direct observation of the deposition of particulate matter during the period, and additional bottom samples were taken to study the organic content of the sediments and the depth of the oxygenated sediment, observed as a colour shift of the sediments.

Table 1.Monitoring plan of the mussel focus farms

Variable	No of polygons	No of stations per polygon	No of horizons	No of visits per year	No of years
Nutrients in water	2	3	3-4	3	2
Water transparency	2	3	1	3	2
Oxygen in water	2	3	3-4	3	2
Chlorophyll *a*	2	3	1	3	2
Phytoplankton	2	1	1	3	2
Zooplankton	2	1	1	3	2
Zoobenthos	2	5	1	1	2
C, N and P in sediments	2	5	1	1	2
Phytobenthos	2	5	1	1	2
CTD casts	2	1-3	n.a.	3	2

The linkage between data collection and environmental impact assessment was achieved by combining traditional sampling of water quality variables e.g. water chemistry, phytoplankton, sediment, phytobenthos, benthic invertebrates and birds (in collaboration with WP3), with a deployment of innovative oceanographic instruments. Oceanographic instruments recorded short term variability of water parameters such as salinity, temperature, flow regime, turbidity, chlorophyll a and dissolved oxygen over longer periods.

A website for mussel farming data and computer models

All environmental data, economic data from the farms as well as the result of computer modelling of nutrient uptake have been stored in a database that can be accessed using the Baltic Blue Growth operational Decision Support System (ODSS). This GIS-enabled tool functions as an umbrella dissemination tool that dynamically links and georeferences a plethora of information sources. It contains raw environmental data, modelling products (5), information on mussel farms, pictures and more. Through its analytical capabilities to synthesize and disseminate up-to-date information and knowledge to different end users, the ODSS is designed to facilitate and improve the quality of decision-making of maritime spatial planners, scientists, policy actors and investors. It can be accessed at www.sea.ee/bbg-odss

The impact of mussel farming on the environment of the Baltic Sea

Mussel farming is potentially associated to detrimental impacts of bio-deposits (dead mussels, faeces) in the sediments underneath the farm. Such deposits can lead to low oxygen levels in the bottom and anoxic conditions, “dead bottoms”. Prior to the BBG project such negative impacts were expected to occur in sheltered areas with limited water exchange. Among the monitored farms, Sankt Anna and Kiel farms are located in relatively sheltered areas, whereas the Pavilosta, Musholm and Hagby

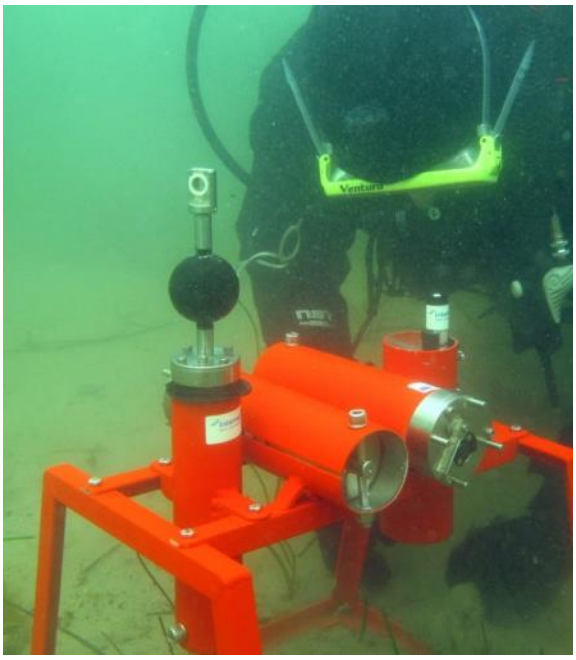


Figure 11. Diver from University of Tartu with oceanographic instruments.

farms are located in exposed sea area. The Sankt Anna and Pavilosta farms are situated in comparatively deep (20 m) sea areas compared to other farm areas (8-10 m). The BBG monitoring demonstrated that regardless of exposure level and water depth, relatively dynamic water exchange was observed at near-bottom water at most of the studied farms. In general, near-bottom water was relatively well oxygenated at all farms both in the mussel farm and reference areas. No systematic difference in total carbon or oxygen levels between the farms and their reference area could be seen.

Direct sedimentation of particulate organic matter was measured only at the Kiel farm. As expected, it was somehow higher underneath the mussel farm units compared to the reference area, due to moderate water exchange and very high production potential of mussels. Nevertheless, the expected associated oxygen depletion did not manifest in changes in its biota. We assume that the higher sediment oxygen consumption was compensated by increased bioturbation transporting oxygen into the sediment, which is triggered by increased feed availability at the sediment surface. The recordings by oceanographic instruments of oxygen at sediment-water interface beneath the Kiel mussel farms demonstrated that oxygen conditions were mostly favourable for biota over the course of the year. Indeed, mussel farming had no negative impact on benthic invertebrates and most mussel farms (Sankt Anna, Hagby, Musholm, Kiel) had an increased richness of benthic invertebrates (number of encountered species) compared to adjacent control areas. No clear differences in benthic invertebrate biomasses due to mussel farming were found and the observed variability was due to natural seasonal and/or inter-annual variability.

Similar to oxygen conditions, nutrient concentrations at all farms and their respective reference areas exhibited natural patterns. As could be expected, no direct influence of mussel farms was detected. Similarly, the species composition and abundance of phytoplankton (as well as its proxy chlorophyll a) did not manifest any clear impact of mussel farms.

To conclude, the systematic monitoring of six Baltic Sea mussel farms in 2017 and 2018 ***did not show any negative environmental impacts*** and thereby in those sites where environmental conditions support a high production potential of mussels, mussel farming can be seen as a sustainable way of removing excess nutrients in the Baltic Sea areas.

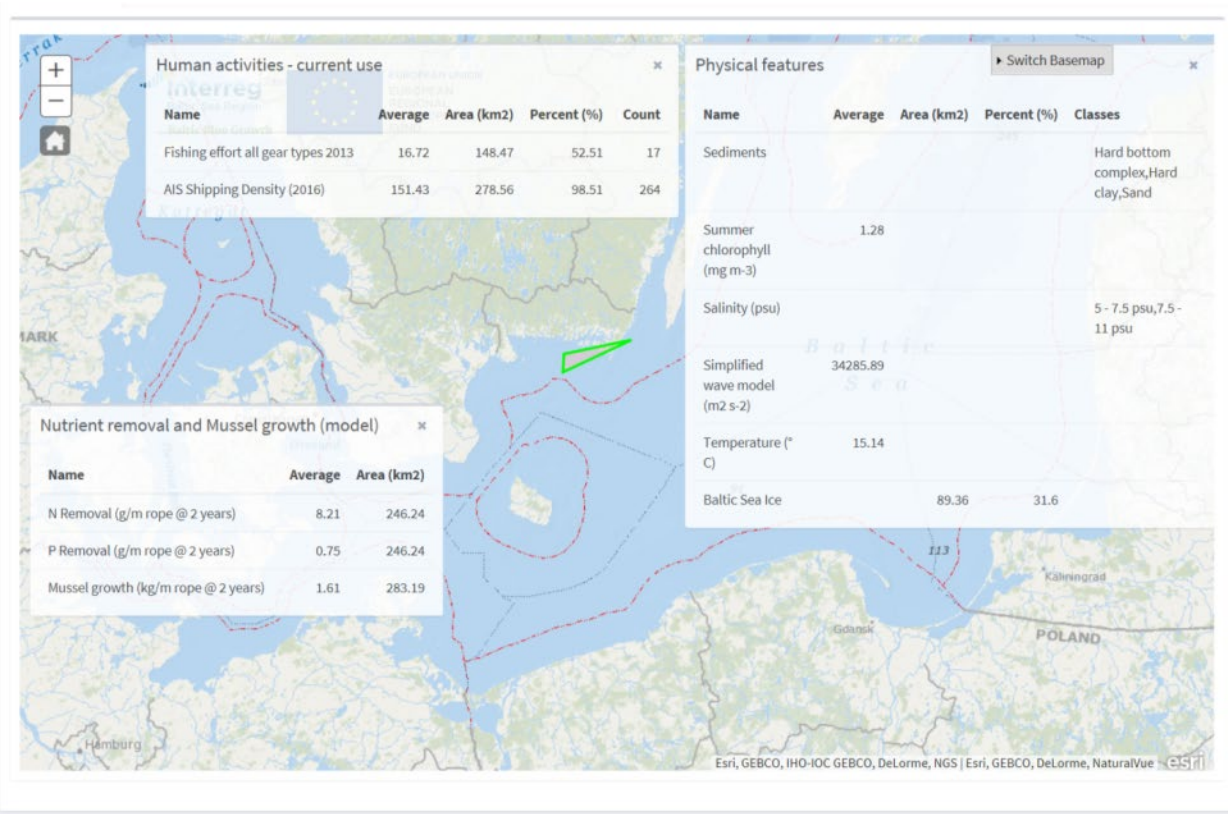


Figure 12. Screen capture from the ODSS.

4 Mussel production methods

Several different techniques for mussel farming have been tested in the Baltic. So far, most farms have been relatively small experimental-scale farms but with the Baltic Blue Growth project firsts steps were taken towards large-scale commercial farms. Results from this work is summarized in the report "Results from Baltic Blue Growth project's mussel farms and way forward for mussel farming in the Baltic Sea" (1). In total 8 farms were studied as part of the project, all using their own preferred combination of farming techniques, substrates and equipment (Table 2).

Farm design

Basically, farms are either long-line or net-based, with floats in the surface or submerged. Outcome of the project shows that no single method can be designated as best adapted to Baltic conditions. Instead, it was demonstrated that farming is successful when methods are adapted to local conditions and farm managers allowed to gain experience and site-specific knowledge. When this is successful, ***very good biomass harvests can be obtained even in low-salinity areas*** (more about this in section 5).

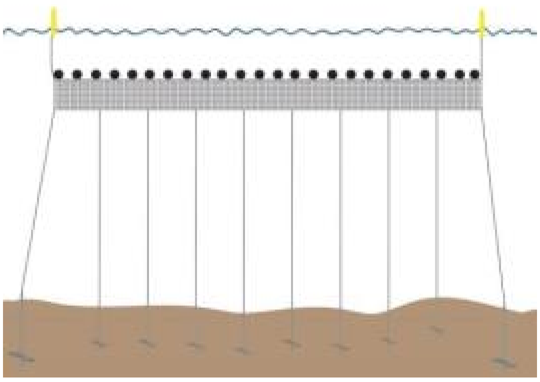


Figure 5. Design of the Byxelkrok farm

Submerged farming

Submerged mussel farming has been suggested as a method to avoid damage due to high waves, strong winds and drifting ice. As part of the Baltic blue Growth project, two farms (Byxelkrok and Pavilosta) were submerged using slightly different techniques described in the report "Technical evaluation of submerged mussel farms in the Baltic sea" (6).

In Byxelkrok, a new design called Shelltech Offshore was tested at a very challenging site, with high currents and large likelihood to encounter drifting ice and severe storms. Shelltech Offshore is a submerged net farm with 120 m×3 m Shelltech rope nets of 200 mm mesh size. Each net is anchored with 9 vertical screw anchors and 2 helix side anchors at the sides. For each net, 400 pieces of Ø30 cm trawl floats are used as flotation in order to over-compensate the weight of growing mussels already from the start, so that no floats would have to be added during the growth cycle due to the increasing weight of growing mussels. The whole farm should stay submerged at 3-6 m depth, no parts in surface. The establishment of the farm encountered several problems due to handling difficulties and after almost 2 years at sea, substantial damage of the farm units was documented. Evaluation concluded that both the design of the farm and methods used were sub-optimal.

In Pavilosta, a submerged farm was established in an equally challenging site, with open sea conditions and located close to the trading routes and fishing areas. The Kurzeme coastal zone of the Baltic Sea belongs to high energy shores where wind and waves are the major hydrodynamic forces influencing the coastal habitats. Sea ice formation occurs in particularly strong winters near the coastline; however, the open sea is usually free of ice. The Pavilosta farm was first submerged to 5-7 m deep, with 5 parallel long-lines concrete anchors and 4 metal floats per line. Unfortunately, significant damage to the farm was observed due to autumn-winter storms and suspected unauthorized fishing activities inside the farm area. It was also noted that similar to the situation in Byxelkrok, the lack of a suitable working vessel made set-up and inspection difficult. The following summer, a new, improved construction was again submerged (Figure 14). To avoid further damage, this new design involved deeper submersion (10 m), thicker ropes, more but smaller plastic floats and more anchors to avoid anchor drift on the sandy bottom. This new farm was submerged in summer 2018. It performed better than the first design, but it still suffered a lot of damage during winter.

Figure 13. Visit at the mussel farm in St. Anna, Sweden, February 2018.

It can be noted that a "partial submersion" technique was used in St. Anna. This long-line farm has floats that are partially submerged and manually adjusted by the farm manager (Mats Emilsson, a very experienced fisherman and archipelago farmer). The buoys are carefully and frequently adjusted to sit low on the water surface to allow ice sliding over them. In a picture (Figure 13) taken by Emilsson in February 2018, some buoys can be seen over the ice and some are under the ice. This design proved very successful, since the ice broke that year with a strong storm with winds directed straight on the farm (which was unharmed by the drifting ice). However, it must be noted that the conditions at the St. Anna farm are very sheltered compared to Byxelkrok and Pavilosta.

Following these trials, it can be concluded that submerged farming can possibly be a solution for Baltic farms, but it is important to carefully consider other possibilities and if possible choose a sheltered site. Furthermore, the farm manager and other personnel must be suitably trained, experience and equipped for the task. A suitable work platform is crucial.

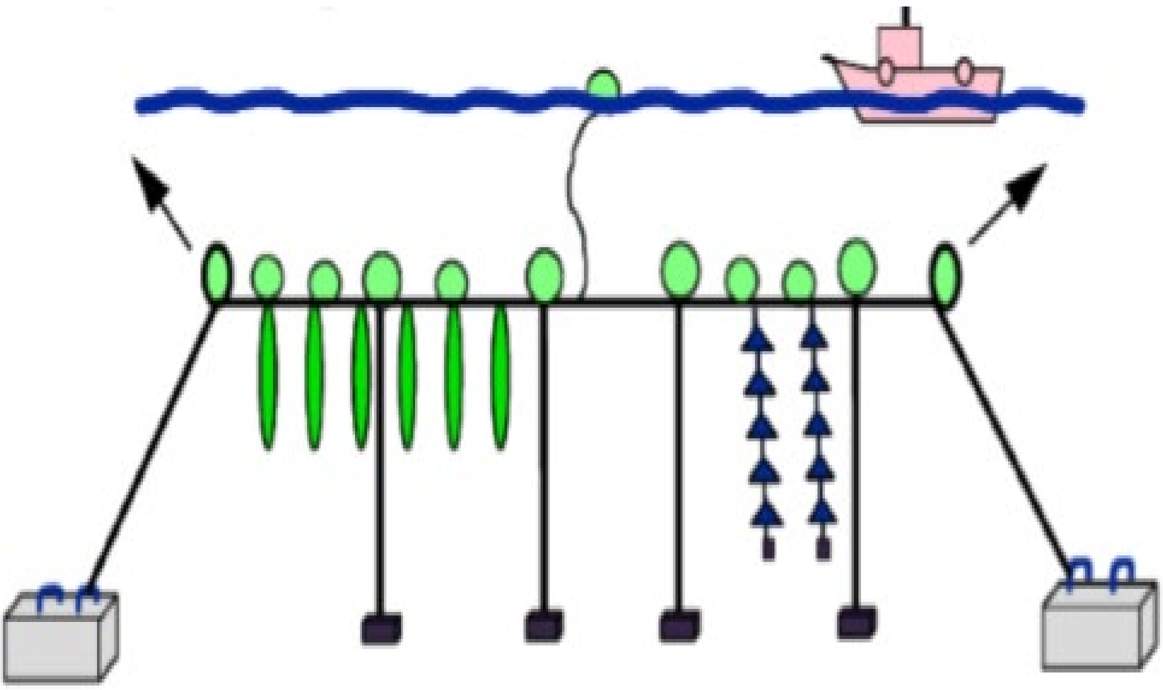


Figure 14. Submerged long line farm system. Sketch by Shellfish solutions A/S.

Substrates

In traditional mussel-producing areas, mussels are grown on a wide variety of different support, depending on conditions on the site, the production methods and historical background. To identify the optimal substrate for Baltic conditions, Baltic Blue Growth partners studied recruitment (how many mussels grew on the substrate) and growth on different types of substrates such as trawl nets with different mesh size, Smartfarm nets, Fuzzy rope, and Swedish bands. This work is described in the report "Recruitment, growth and production of blue mussels in the Baltic Sea" (7). In this study, a set of test substrates were deployed at participating farms using small, dedicated test rigs. Unfortunately, due to experimental difficulties, data from rope and fuzzy rope testing are inconclusive.

Figure 15: Substrate test of different net mesh sizes at Musholm.

At the Musholm and Kiel test site, Swedish Bands appeared to provide the best substrate for settling larvae the first year of this study (2017) but very low on the second year. At the Byxelkrok farm, results on Swedish Bands showed that larvae settling patterns were similar on all substrates, but growth rate and average lengths were lower on Swedish bands than on nets. Furthermore, if the mussels are large and in high biomass on Swedish Bands, they have a high risk of falling off. This is most likely what happened in Kiel in 2018, where most of the larger mussels disappeared from both nets and bands.

In general, there was no difference in the growth rates of mussels on the different mesh sizes of the net substrates at any of the test sites. This was in line with the assumption, that the growth rate is unaffected by differences in mesh size, when densities of mussels do not result in food limitation. Very small mesh sizes can potentially create an almost closed mussel net, that reduces the food availability but this was not observed. With respect to biomass, there were significant differences between nets with different mesh sizes. In the beginning of the production period, the largest amount of biomass was often on the net substrates with the smallest mesh sizes. This tendency often continued as the production period progressed, as the estimated biomass was also greatest on the smaller and mid-range mesh sized substrates (30-100 mm) at the end of the sampling period. Here, the biomass on the small and medium mesh substrates was typically twice as high as the biomass on the net substrate with largest mesh size (300 mm – Smartfarm nets).

To conclude, all substrates tested proved applicable for mussel production in Baltic waters, which allows the farmer to focus on cost price and how well the substrate performs with respect to weather and handling. From the growth and recruitment study, and from the substrate test study, it was demonstrated that the production potential in different areas of the Baltic Sea does not simply follow variation in salinity and food availability. It very much depends on the site-specific growth environment where e.g. predation on mussel farms can be an obstacle for any mussel growth at all. A thorough screening of a potential mussel farming area with respect to food availability, predation and weather conditions is therefore highly recommended before a new mussel farm is started. Alternatively, new mussel farms should start in a small scale, using some years to test and area, and develop a site-adapted husbandry optimizing the production before scaling up.

Predator control

Mussel farming in the Baltic is subject to predation from fish, starfish and seabirds such as eider. During the Baltic Blue Growth project, predation by eider has by far emerged as the main issue for farmers and several methods to control this predation was tested and is described in the report "Experiences from predator mitigation tool testing" (8). The eider ducks were present on farms in the southern part of the Baltic (Musholm, Kalmar and Kiel) but absent in St. Anna, probably due to diminishing populations in this areas.

Several methods have been proposed to limit predation by eider, but unfortunately so far no entirely satisfactory method for the Baltic Sea has been found. The most efficient way to keep eiders from consuming the mussels before harvest is to place nets all around the farming area. The eiders are talented divers, so the nets must be partially submerged. The birds also fly inside the farm area, if leaving too much room inside the farm makes landing within the farm area possible.

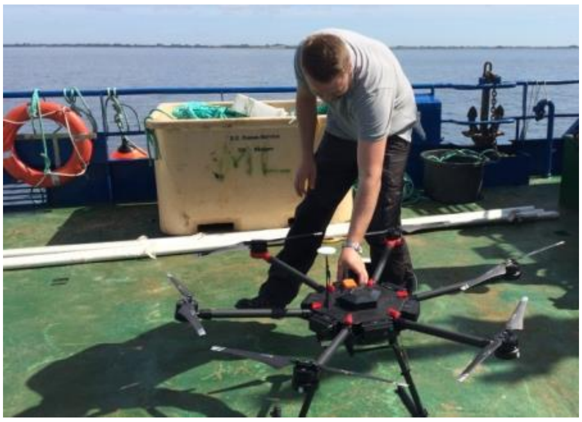


Figure 16. Drone tested for predator control at Musholm.

Hence, the netting must be extensive. This implies a heavy investment, and is resource demanding in start-up establishment and maintenance. Furthermore, the netting will decrease mobility around the farm, making harvest and maintenance more difficult.

Lasers have proven efficient in low-light conditions in, for example, Norwegian fjords but were inefficient when tested at the Danish farm of Musholm. The laser did not prove useful as a mitigation tool, as the eider ducks showed little to no response to disturbance from the light, most likely because there is too much daylight in Denmark, even in winter when predation is the heaviest.

Over the past few years, drones have become increasingly popular and more versatile, securing a fast technological development. Testing two different air-craft drones - one small and one medium sized – at the Musholm farm showed that the small drone had little to no effect on the birds, even when navigated very close to the birds. The bigger drone had an effect on the birds by forcing them to swim away, when flown straight over the mussel lines. However, the same birds returned after intervals of just ten minutes, indicating a minimal and inconsistent effect of the drone on keeping eiders away, especially if not flown constantly. It is possible that eiders register flying drones as predator birds, and since eider ducks have poor flying ability they tend to seek refuge in the water until a threat from the air has disappeared. Mitigation techniques focused on airborne tools may therefore be less efficient than waterborne equipment. By consequence, a **drone boat** was tested and proved most efficient as a mitigation tool for scaring eider ducks away from the production site. Preliminary results indicate the drone boats seem promising as a mitigation tool for eider ducks, but this will need further testing before a complete recommendation can be made.

Figure 17: Harvest of a net farm (Musholm), using a UW harvester.

Harvest technology

Depending on the farm design, harvest methods can be manual (Kiel) or mechanical (St. Anna, Hagby, Musholm). In St. Anna, the working platform was fitted with a conveyer belt to lift up the longline on the platform, a scraper to clean the mussels from the substrate and a crane to lift the big bags containing the harvest (Figure 19). At the Hagby farm, a catamaran platform (Figure 18) was designed and used to lift the net out of the surface and then the mussel were washed off the net using a high-pressure cleaner. Finally, at the Musholm farm a underwater (UW) harvester was deployed Figure 17: Harvest of a net farm (Musholm), using a UW harvester.(Figure 17). All the methods tried needed at minimum two, and were better off with three persons in the work team. The UW harvester was by far the fastest and most efficient, but it represents a large investment and is only cost effective if harvests are large. By consequence, farm design and choice of harvest technique must be concordant.

Table 2. Baltic mussel farms 2016-2019

Location	Size	Substrate type	Depth
Sankt Anna, Sweden (16.836,58.384)	Long line, 16×150 m lines. Total length 24,000 m. Surface area 4 ha.	Fuzzy rope	1-10 m
Byxelkrok, Sweden (57.303, 16.960)	Shelltech net 10×120m units. Total 3600 m^2; 40000 m rope. Surface area 1.2 ha.	Net, mesh size 200 mm	3-6 m
Musholm, Denmark (55.475, 11.090)	Rope net 18-10×120m units. Total 4200 m^2; 49000 m rope. Surface area 8.2 ha.	Net, mesh size 300 mm	0-3 m
Kiel Bay, Germany (10.420,54.552)	Longline, 3×100 m lines. Total 1500 m. Surface area 0.21 ha	Fuzzy rope	0,5-3 m
Pavilosta Coast, Latvia (20.857,56.902)	5 parallel single submerged longlines, total length 625 m.	sisal rope	5-7 m
Vormsi island, Estonia (23.032,59.057)	126 m unit	Nets	0-3,5 m
Västervik farm, Sweden (57.845, 16.757)	2 units 120×4 m. Total substrate 960 m^2	Trawl nets, mesh size 150 mm	0-4 m
Hagby farm, Sweden (56.560, 16.258)	4 units 115×3.15 m. Total 1380 m^2	Nets, different mesh sizes	1,5-5m

Figure 18: Harvest of a net farm (Hagby), using a catamaran platform to lift up the net and wash off mussels using a high pressure cleaner.

Figure 19: Harvest of long-line farm (St. Anna), using a conveyer belt to lift up the longline on a harvest platform and a scraper to clean the mussels from the substrate.

5 Production volumes and quality of the harvested Baltic Sea blue mussels

The production cycle of blue mussels in the Baltic is roughly twice as long as it is in the western part of Europe. Typically, the production units have been put into water in spring and harvested before summer 1.5-2 years later, even though shorter production cycles for high biomass mussel production are being considered. The largest mussels are found in the most saline regions of the Baltic Sea but differences in mussel sizes and production volumes does not clearly depend only on salinity. Other quality factors, such as nutritional value and food and feed safety, were similar for all farms.

Harvest and mussel sizes

Data regarding mussel production (volumes, quantities and quality) is mainly found in the report "Report on fish and poultry trials - food and feed safety aspects of mussels" (9).

Figure 20: 2 year old mussel from St. Anna.

The production cycle in the Baltic is roughly twice as long as in the western part of Europe. Typically, production units are put into water in spring and harvested before summer 1.5-2 years later. Observed harvests for the period 2016-2018 can be seen in Table 3. There was a large variation in the abundance and length frequency distribution of mussels between different regions and sampling times. As expected, the largest mussels were found in the most saline regions of the Baltic Sea. For example, in the Kiel mussel farm, mussels above 60 mm can be found. However, within the Baltic area, the spatial differences in mussel abundance and length, frequency-distribution did not clearly follow the salinity gradient. Here, the most represented length classes in all the mussel farms remained between 0 and 20 mm. The highest abundance of mussels was recorded at the Pavilosta farm, where the maximum count reached higher than 40,000 individuals.

Table 3. Observed harvests 2016-2019 for Baltic Blue Growth mussel farms.

Harvest	Date	Tonnes
St. Anna	2017-12-15	15
St. Anna	2018-05-15	51
St. Anna	2018-09-15	12
Musholm	2016-05-15	12
Hagby	2017-08-15	2,5
Hagby	2018-11-07	6,7
Västervik	2016-05-31	10
Västervik	2018-05-25	11

Unwanted substances

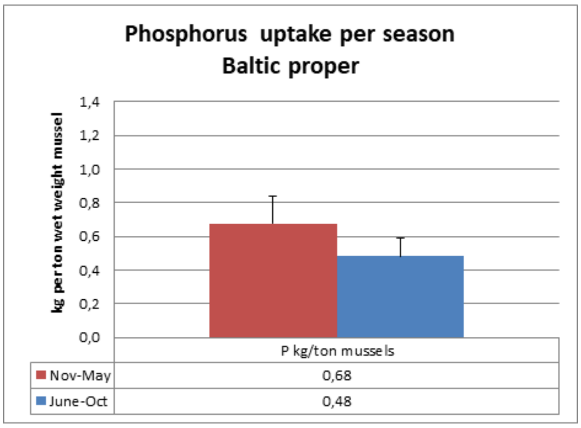
By communication with regional authorities and experts, a list of unwanted substance relevant for mussels grown in the Baltic was established. The list comprises substances such as pollutants, heavy metals, pathogenic bacteria or viruses and algal toxins. During the first phase of the project the list was used to procure analysis for the Baltic Blue Growth project. It was decided that analysis of unwanted substances should be conducted throughout the food chain (see also section 5), in order to identify any accumulation of unwanted substances. Samples were taken at several time points from St. Anna, Västervik and Vormsi farms, and analysed for the presence of bacteria, PAH (polycyclic aromatic hydrocarbons), heavy metals and algal toxins. None of these were over regulation limits, and ***most weren't even detected***.

N/P content of mussels

The nitrogen and phosphorus content in mussel tissues (shells, soft tissue and associated water) was analysed in 121 samples.

In addition to the fact that the mass of mussels harvested per production unit is much higher than expected, we can also note that the difference in nutritional content between mussels from the low salinity Baltic Proper (St. Anna, Byxelkrok) and the high salinity western Baltic (Musholm / Kiel) is less than what has been presented previously. In particular, P content in whole mussels harvested during autumn and winter is similar from high and low salinity sites on both Swedish coasts. N-content was correlated to P-content, as shown in Table 4.

Recent data, pooled from several sources (10), also shows that there is a potential to optimize nutrient uptake by selecting the right harvest period. Average phosphorus content in our mussel samples from the Baltic Proper was 42 % higher November - May, compared to June – October.



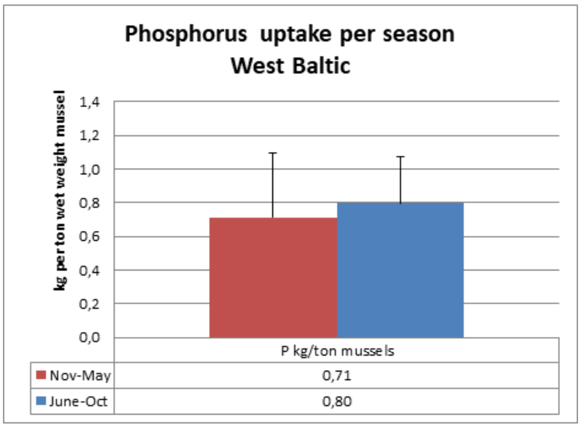


Table 4. Data from analyses of mussel flesh. Parameters followed by the same letter show no statistically significant difference between regions.

Area	Salinity	Meat Dry Matter %	Percent Soft Tissue	Soft Tissue Fat %	N (% soft tissue dry weight)	P (% soft tissue dry weight)
Western Baltic	High	15.1 a	58 a	9.5 a	9.5 a	1.41 a
Central Baltic	Moderate	14.2 a	52 b	10.3 a	10.3 a	1.48 a
Eastern Baltic	Low	13.7 a	41 c	9.7 a	9.7 a	1.33 a

6 Processing mussels

Mussels harvested in the Baltic Sea currently have limited commercial value, due to small sizes and thin shells making the mussels less appreciated for direct human consumption. Instead, processing mussels into mussel pâtés, frozen products or other processed food has been suggested, but this potential usage encounters regulatory challenges and faces high costs. Instead, using the mussels as ingredients for feed has been proposed. Mussel meal can be used as a replacement for imported fish and soya meal, thus creating a closed nutrient loop in the Baltic Sea region. As part of the Baltic Blue Growth project, two processing methods were evaluated and the products tested as ingredients in feed for fish and poultry. A cost benefit analysis was made and is reported in “Cost Benefit Analysis of Mussel Processing“ (11).

Mussel meal

Two production trials for mussel meal were performed (9). The mussel meal of trial 1, was produced at Nofima facility of Trondheim, Norway (12). 2 975 kg mussels were lysed by addition of a proteolytic enzyme (alcalase) and the lysate was spray dried into 90 kg of mussel meal. This mussel meal was a very fine powder. The mussel meal of trial 2, was procured through an associated project lead by Municipality of Borgholm. The meal was processed by Musselfeed, Orust, Sweden. Approximately 2,000 kg mussels were rinsed in fresh water, naturally lysed and dried into about 70 kg of mussel meal, with a rather flaky texture.

Analysis of the two mussel meals was performed by Eurofins, and no bacteria or algae toxins were detected. Some substances showed slightly elevated values, such as PAH (polycyclic aromatic hydrocarbons) and arsenic. However, no limits in either food or feed regulation were exceeded. Sodium and chloride content (i.e. salt from sea water) was rather high in the Nofima meal.

Insects

Insect protein meal is an interesting alternative to mussel, fish or soya meal. Baltic Blue Growth partner SLU showed that if insects are fed mussels, the insects also contain healthy marine fatty acids (13). A suggested process (Figure 22) was tested as part of the Baltic Blue Growth project. In this trial, 200 kg of blue mussels was acquired in June 2018 from Sankt Anna farm, mussels were transported on ice to Uppsala (SLU) and kept on ice for 24 hours until the further transfer to RISE for processing. The processed material was transferred to SLU’s black soldier fly composting facility and fed to black soldier fly (BSF, Figure 21) larvae for several weeks. Larvae were then harvested, frozen and transported to RISE for drying. Following drying, larvae were processed into a meal at SLU. More detailed information regarding processing of mussels and black soldier fly larvae production can be found in the report “Process line-mussels to feed through fly larvae” (14).

Figure 21: Black soldier fly larvae.

Feed trials

Poultry

The mussel meal was tested as poultry feed (9) in collaboration with Ölands Kyckling, which is active in breeding broiler chickens. The company also tests new feed for chickens in association with Swedish Agro. Tests on 200 chickens showed that the feed produced using meal from the first trial (Nofima) was difficult to handle, and had a sticky texture that tainted the beaks and feathers of the chicken. This was most likely due to high salt content (from sea water) and wrong texture of the mussel meal. Despite the sticky texture, the chickens liked the feed and grew well. Recommendations to achieve a better performing meal are to reduce salt content and produce a meal with better texture (larger particle sizes, flakes or pellets).

A second trial using poultry was made, using the meal from trial 2 (Musselfeed). This meal made for a better feed ingredient (less hygroscopic) but was slightly less appreciated by the chickens.

The main conclusion by Swedish Agro and Öland kyckling from the poultry trials is that the mussel meal is an ***interesting raw material*** if texture is perfected and the absence of unwanted substances, in particular dioxins, can be guaranteed. In addition, the raw material needs to be in access year-round, in enough quantities and at a competing price level.

Fish

The aim of the fish trial (9) was to assess the Baltic blue mussel meal (MM) and black soldier fly larvae meal (LM) as feed ingredients in diets for rainbow trout by evaluating the nutrient digestibility, growth performance and fatty acid deposition in the fillets. The mussel meal used in fish trial was identical to the meal used in the first poultry trial described earlier in this report.

The results of the fish trial show that both mussel meal and larvae meal based on Baltic mussels, have high potential for their use in commercial aqua feeds. However, there were some issues due to bitter taste of the pea protein used for the sample feeds. Further efforts should be directed towards development of the feed recipes for farmed fish if these ingredients are to be used.

Analysis showed that the larvae production seems to decrease the levels of most toxins from the starting material, and should be developed further in the context of its potential use for industrial applications.

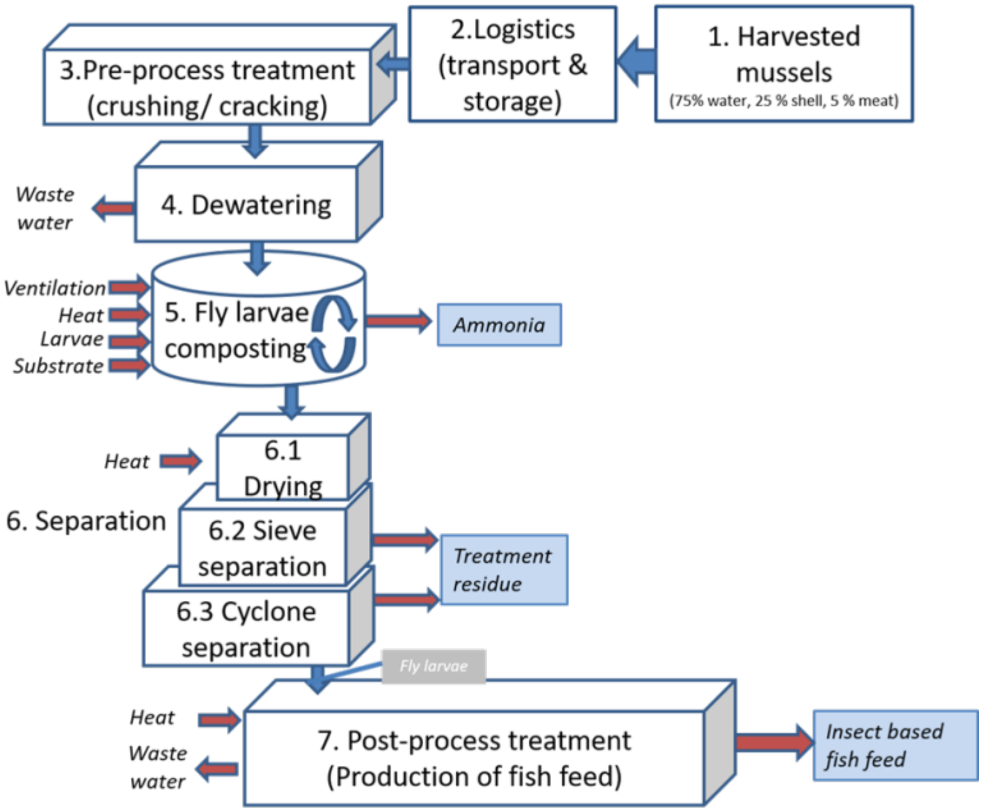


Figure 22. Insect process line flowchart

7 Legislative aspects

To prepare the ground for full-scale mussel farming, legal and regulatory aspects of mussel farming need to be clarified. Regulatory and administrative barriers are often cited by stakeholders as obstacles to developing mussel farms and other types of aquaculture business in the region. Permission processes are long and costly, and in most countries both potential mussel farmers and civil servants are unfamiliar with the rules and regulations in place.

Current legislative status

The BBG project has produced a status description on legislative procedures in the Baltic Sea Region, "Legislation Issues Status Report" (15) covering especially the EU law, and additional law of the concerned Member States. In the report, it is assumed that the mussels are harvested *for mussel meal and fodder purposes only*. If production is targeted on mussels for human consumption or there is the intention to combine mussel production with finfish aquaculture (for instance in an IMTA), additional legal requirements have to be considered.

The legislative framework surrounding mussel farming activities in the Baltic can be grouped in three main sections:

EU Framework Legislation: The EU Water Framework Directive, the Birds Directive, the Habitats Directive, the Aquatic Animal disease Directive and Marine Strategy Directive are relevant to this study. A "directive" is a legislative act that sets out a goal that all EU countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals.

EU directly enforceable law: The EU also provides directly enforceable law, mainly as regulations. The Animal By-products regulation, the Organic Products regulation the EMFF regulation and a few others are relevant to this study. A "regulation" is a binding legislative act. It must be applied in its entirety across the EU.

National law (not primarily EU guided): The already diversified EU legislation is completed by the national law of the Member States. The analysis made within Baltic Blue Growth mainly concerns the German law, where especially the nature conservation law, construction law, waterways legislation, and fisheries law concerns Baltic mussel farming. The most important permissions for Baltic mussel aquaculture premises are the fisheries permission and the river and shipping police permit.

The legislative status report presents a total case study for Germany (Schleswig-Holstein) and provide a general template to register all relevant law (EU, national, if relevant regional level) for other countries. Representatives from Poland, Denmark, Latvia and Sweden also provided information on their respective legal framework, especially regarding the implementation of EU law in the national context.

Licencing manual

In addition to the status report, a licencing procedures manual for full scale mussel farming in the Baltic Sea has been developed (16), based on the status report and on an empirical steering of the licensing process in Germany (Schleswig-Holstein).

In this area (and the situation is similar in many parts of the Baltic Sea Region), at least four permissions are required for mussel cultivation. Depending on the product and farm location other permissions are required additionally, meaning that the mussel farmer needs to apply for 4-8 different permits. This enormous amount of applications causes substantial costs and results in an even greater amount of bureaucratic work. The licensing guide provides a clear procedure for potential investors as well as for authorities on necessary steps. It was developed by the evaluation of the applicants and authorities' experiences about the permission process. The manual also enables estimation for the permission procedure duration and costs, which are crucial for the farm schedule. Finally, it shall also be regarded as a potential example for other EU Member States that have no aquaculture permission system yet.

A short version of the manual is available at the Baltic Blue Growth website.

Practical Hints

~ for mussel farmers and authorities in the permission process ~

Nobody said it was easy! However, if some hints are considered, the permission procedure shall be less frustrating.

...for Mussel farmers

Accuracy: Save yourself some valuable time and be as accurate as possible in your descriptions. Lacking documents are the main reason for delays in permission procedures. Use easy words to assure easy understanding.

Remove your blinkers: Your business potentially may have an impact on the environment and in particular on conservation objectives of neighbouring protected areas. Study your desired location not only for your required infrastructure. Study the environment and evaluate its capacity for commercial mussel cultivation.

Do door-knocking: Make friends not opponents right from the beginning! Get in touch with locals and be as transparent in your business as you can account for.

Grab the red tape: Permissions are official authorisations and not revoked prohibitions. Most authorities are service agencies. Remember, cooperativeness is two sided. Get in touch with your authorities personally before applying for permissions. Ask for help and there shall be help and guidance.

...for authorities

Translate your officialese: Your official language includes vocabulary that is not easy to understand and that potentially creates a gap between you and the applicant.

Sharing is caring: Mussel farmers must apply for a variety of permissions each consisting of a lot of exemptions and specific conditions. Share your information with the applicants and also other authorities.

Achieve comprehensibility: Be transparent not only in your decisions but also during the procedure as much as you can account for. Transparency allows to gain a deeper insight in your work and thus allows the applicant to switch between perspectives. This may improve the applications information quality you receive, thereby shortening the permission procedure duration.

Figure 23. Practical hints for mussel farmers and authorities. From the Licensing Procedures Manual developed by Dr. Yvonne Rössner.

8 Economics of mussel farming in the Baltic

Currently, mussel farming in the Baltic Sea is performed on a commercial scale only in the westernmost parts, were the relatively higher salinity allows for the production of larger mussels. Out of the participating farms, only Kieleer Meeresfarm and Musholm are financially viable, and their business model is based on the combination of mussel farming with other activities. However, farms for the production of mussels for ecosystem services and/or feed products could be operated on a commercial basis if the ecosystem services were compensated. To demonstrate this, a set of business plans and situation analyses, was drafted for representative Baltic mussel farms.

Mussel farming business plans

Sweden

Mussel aquaculture on the Swedish East coast in the Baltic Sea is based primarily on a two-year production cycle. Based on the case study, yearly harvest at the St. Anna farm is approx. 40 ton wet weight mussels, and this amount could be trippled using the same set-up. Calculated for a farm 3 times the size of the current farm, yearly operational costs including harvest and transport of mussels is around 0,3 EUR/kg. Depending on the level of investment support, potentially from the European Maritime and Fisheries Fund (EMFF), the total production cost for 1-3 cm blue mussels from the Swedish east cost is 0,7-1,1 EUR/kg. Three paths towards a viable business were suggested:

1. No investment support. Payment for the nutrient uptake: 500 EUR/kg P, 50 EUR/kg N
2. 50% investment support. Payment for the nutrient uptake: 360 EUR/kg P, 30 EUR/kg N.
3. 50% investment support. Payment 0.069 EUR/kg for feed mussels. Payment for the nutrient uptake: 350 EUR/kg P and 25 EUR/kg N.

In this ten year scenario, the first year has no income due to the growth cycle of the mussels and revenue in year 2-9 must be at least 26,000-41,000 EUR/year, depending on the level of start-up investment support from EMFF (0-50%). Depending on scenario, there will be a need for payment of nutrient uptake corresponding to 500-350 EUR/kg P and 50-25 EUR/kg N, annually to the operator.

Germany

The Kieler Meeresfarm has produced a business plan as part of their plans to expand their farm into a 9 Ha IMTA facility for mussel, fish and algae breeding on the Kiel Fjord (see Figure 24). The goal is to produce food in the Baltic Sea in a sustainable and environmentally friendly way, as well as to create and secure jobs.

Breeding, harvesting and selling blue mussels is the focus of the business. Approximately 85 long-line-systems will offer mussels a species-appropriate habitat in which they are monitored and from which they can be harvested. The harvest plan behaves analogously to the multi-field economy on land, so that at no time all lines are harvested at the same time. This takes into account the reproduction cycle of the mussels.

Algae cultivation is added as a second component after about 2-3 years. For this purpose, up to a maximum of one quarter of the plant area is expected to be used. Fish farming will then be implemented as a third pillar from the fourth year, rather later.

The biggest cost factor is the installation of the new aquaculture facility, which means higher investment costs right at the beginning of the project, but that will pay off in just a few years. In order to ensure this rapid repayment, all the necessary vehicles, machines and other materials have to be purchased promptly in order to completely install the complete system as quickly as possible.

Financing ecosystems services of Baltic mussels

As shown by the Baltic Blue Growth project, mussel farming provides important ecosystem services such as more transparent waters, reduction of pathogens and removal of excess nutrients. Since mussel farming for other purposes, such as selling the mussels for feed or food, currently is not financially viable in the Baltic Sea, these services needs to be financed by a support mechanism. A review of the situation is available in the report "How to turn Ecosystem Payments to Baltic Mussel Farms into reality?" (17). Indeed, in view of the importance to also tackle the "legacy nutrients" and the ongoing nutrient outflow from non-point sources in order to reduce eutrophication in the Baltic Sea, it can be argued that sea-based measures protecting and promoting marine ecosystems should receive support for providing ecosystem services, just like farmers for their land-based measures. Mussel farming should not be understood as an alternative for other measures, but as a complement required to meet good environmental status in the Baltic Sea.

Currently, no ecosystem payment scheme suitable for compensation to mussel farmers is fully deployed in the EU. The analysis of existing public funding sources identifies the EMFF as the most promising fund for mussel farming so far. However, the national operational programs decide for what measures the funding will be used, so the actual support for mussel farming needs to be decided on a

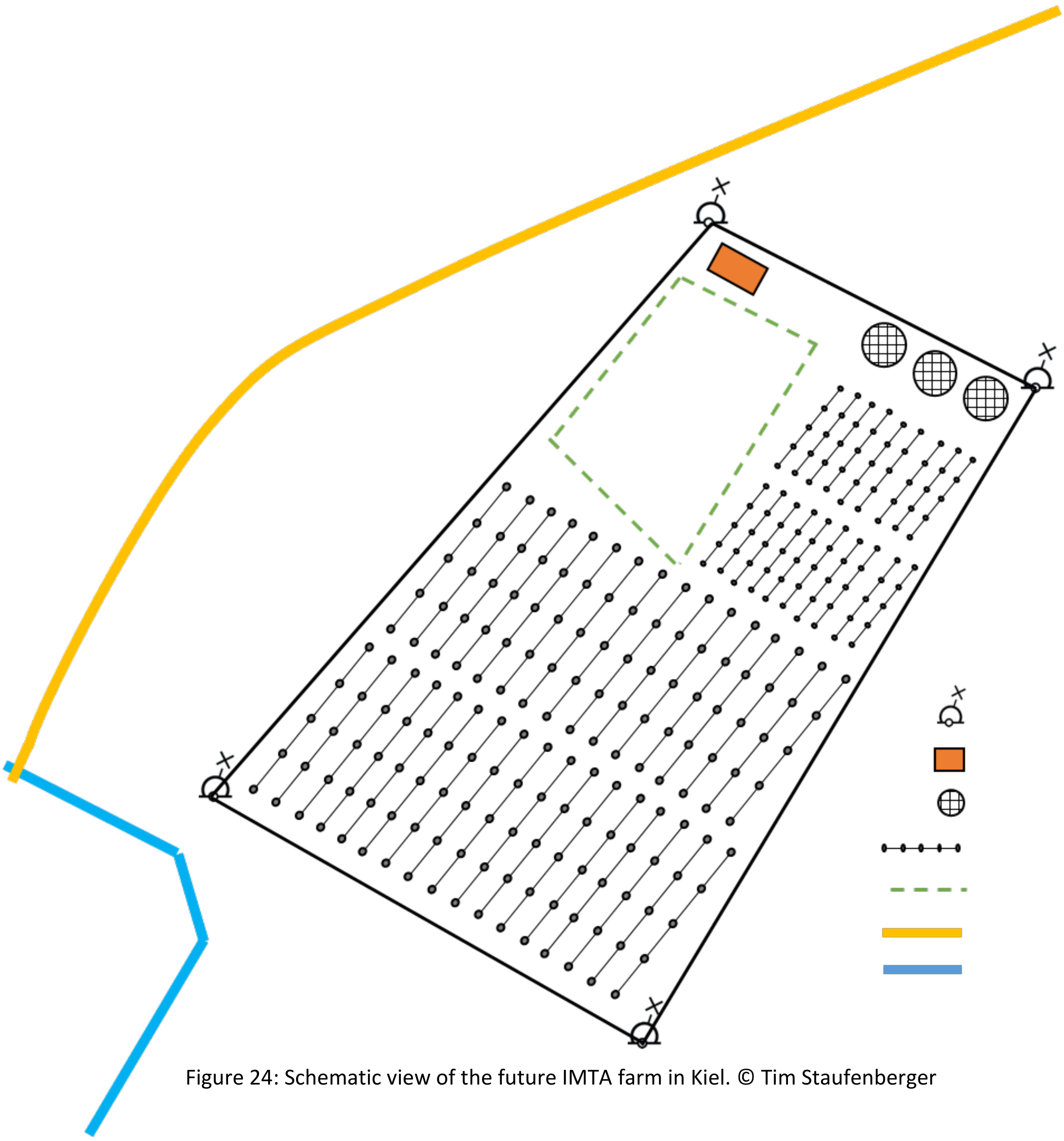


Figure 24: Schematic view of the future IMTA farm in Kiel. © Tim Staufenberger

national/regional level. Moreover for the time being, EMFF funds seem to be directed more towards support towards specific investment and/or training projects; but do not provide for an ongoing payment scheme for the ecosystem services provided.

Another possible source for payment could be derived from the polluter pays principle. This may, however, if applied in the wrong way be contra productive for the aim of reducing nutrient emission. Instead, a scheme based on payments by beneficiaries seems more appropriate to safeguard ongoing ecosystem services payments. Different sources such as private foundations, crowdfunding, companies or even sectors or public authorities are discussed. However, this form of payment needs a mechanism to reduce free-riding, to motivate potential payers and to raise awareness for the need of mussel farms providing important ecosystem services. Three different approaches for motivation were suggested:

- Ecolabelling or certificates for mussel farms and mussel products
- Make the beneficiary/user aware of his/her nutrient footprint, by using a nutrient emission calculator
- Suggest that the beneficiary/use pays for ecosystem services

The payment should be based on the effective ecosystem service that mussel cultivation and harvest provide. This is first and foremost filtering the water by feeding on phytoplankton, thereby taking up nutrients. However, it is difficult to determine an exact prize for the ecosystem service. Two approaches seem possible. The first would be to calculate costs and benefits, but monetarising the benefit is difficult and highly complex. The other option is to use the more qualitative and subjective approach of willingness to pay: asking people about their willingness to pay, gives a clear message to the politics on the priorities of the society.

Relevant in this discussion is to what extent mussel farming is competitive compared to other possible measures to combat eutrophication. The comparison made by researchers in the Baltic Blue Growth project shows that the efficiency of mussel farming for nutrient uptake is on a medium level concerning the cost-benefit ratio. Considering that single measures are not enough to reach the goal of GES and that the cost-efficiency of each measure highly depends on local conditions, it is reasonable to argue, that mussel farming could and should be part of a mix of measures.

Even though general principle is clear, a one size fits all scheme does not seem realistic. Rather, local solutions tailored to the specific region or farm need to be developed. But therefore, more specific research on site would be necessary to include specific characteristics.

Table 5. Costs of different nutrient-reduction measures based on N/P uptake.

	Ahlvik et al. 2012		Hasler et al. 2012		Baltic Blue Growth	
	€/kg N	€/KG P	€/Kg N	€/Kg P	€/kg N	€/KG P
Reduced fertilization	2-158	0-463	0.5-8	-	-	-
Catch crops	4-133	433-3,670	0.3-9.7	-	-	-
Livestock reduction	16-512	950-150,000	0-328	0-14,688	-	-
Restoring wetlands	2-332	239-3,105	1.6-93	1.6-1,647	-	-
Constructing phosphorus ponds	-	18-867	-	-	-	-
Improving wastewater treatment	2-642	10-2,772	14.6-13,898	57-537		
Banning phosphorus in detergents	-	22-373	-	-	-	-
Mussel farming	-	-	-	-	15-43	430

The creation of a system for ecosystem services payments to mussel farms is realistic, but that it cannot be left to individual mussel farmers on their own to create it. It requires the joint effort of the entire 'mussel community' at least within a given region to provide the optimal framework for allowing the given first mover mussel farms to continue their operations and expand to more such mussel farms.

Socio-economic aspects

Mussel farming offers great development possibilities for enhancing food and livelihood security of the stakeholders in our coastal regions. In order to understand the possible impact of mussel farming on the coastal regions, researchers from Kurzeme planning region conducted a study on socioeconomic aspects of mussel farming in the Baltic Sea (18). Using data from the Baltic Blue Growth project, and Pavilosta region as a case study, a portrait of the economic and social situation was drafted and alternative development scenarios with a time-scale of 6-10 years were presented.

Precautionary scenario

Slow growth of harvested amount by 1.5 % yearly:

- harvested blue mussel amount – up to 340 tonnes per year;
- new workplaces – two full time employees;
- EUR 4,200–17,000 as tax payments per year;
- Nutrient uptake of 1–3 tonnes of nitrogen per year from the Baltic Sea.

Realistic scenario

Harvested amount increases by 25-35 % yearly, as mussel farming reaches commercial scale:

- harvested mussel amount – 2,200 up to 8,000 tonnes per year (adjusted data);
- 15–53 full-time workplaces;
- EUR 106–400 thousand as tax payments per year;
- Nutrient uptake of nitrogen 17–65 tonnes per year from the Baltic Sea.

The assessment is based on information obtained over the period from 2016 to 2018. Considering that marketing aspects in this field are changing rapidly and social factors are influenced by marketing, a more in-depth research could provide more extensive information on this field.

Based on the conducted analysis, it can be concluded that mussel farming in the Baltic Sea region is at its pre-development stage and there are many ways to go. According to the sector experts, it takes from 15 to 20 years to build a mussel farming industry in the Baltic Sea. Recommendations for advancement of this sector are summarised based on the data presented above and the experience of authors and expert conclusions from the Baltic Blue Growth project meetings and reports:

- Co-operation between mussel farmers ought to be strengthened at local, regional and transnational levels.
- Regulations and licensing processes must be made easier, to avoid unnecessary bureaucracy and time-consuming procedures
- The linkages between fisheries sector and mussel farming should be strengthened.
- Support involvement of young enthusiasts with great ideas in the development of the aquaculture sector, both politically and financially
- Research and development in mussel farming should be continued.
- Improvement is needed in common understanding in monitoring and benchmarking of different farms, techniques and products.
- Mussel farmers need to communicate the value of the product.

9 Mussel farming in maritime spatial planning

Mussel farming has the potential to become an important business activity in the Baltic Sea, which has to be addressed in the maritime spatial planning process. In some cases, mussel farming activities will come into conflicts with other sea uses. Thus, it is important to have a clear, and as far as possible uniformed planning methodology among countries in the maritime spatial planning process.

A method for integrating mussel farms in MSP processes

A proposal for a uniform planning methodology was developed within the Baltic Blue Growth project, and it addresses optimal environmental conditions for mussel growth, role and utilization of national and regional aquaculture development plans, legal regulations and formal procedures, role and power of associations representing the sector, potential conflicts with other marine use and ways to minimize or mitigate them. The proposed approach is presented in the document "Addressing the mussel farms in maritime spatial planning process" (19) and can also be applied to other types of mariculture.

Optimal site selection and use of the Baltic blue mussel farming ODSS

The optimum conditions for mussel growth in mussel farms, considered in the proposed methodology for addressing the mussel farms in MSP processes, can be seen in Table 6.

Table 6. Optimum conditions for mussel growth and farming.

Parameter	Value for optimal mussel growth
Water temperature	20°C
Salinity	26 PSU
Oxygen concentration	>5 ml·dm-3
Chlorophyll-a (phytoplankton)	>3 µg·dm-3
Wave dynamics	low
Current	medium
Marine ice	absence of drifting ice

When choosing suitable locations for new mussel farms, the data in Table 6 is of key importance but other factors must also be considered, such as the presence of hazardous substances or toxic algae that would limit the use of the mussel biomass for food or feed. The location of the farm has also an important economic dimension, as running costs of the farm raises with the distance from the harbour.

In practice, this means that there are not too many areas in the Baltic were the conditions are *optimal* for blue mussel growth. However, data from the Baltic Blue Growth farms shows that high production per meter rope is observed even in locations that are not optimal for growth of this saltwater species, when farm technologies are optimized for production of high biomass and small mussels.

A Baltic scale production model is presented on the Baltic Sea mussel farming Operational Decision Support System platform (see section 3). The ODSS platform also offers a tool called "Plan Your FARM" were one can easily get detailed information on the environmental conditions and maritime activities in an area selected by the tool user. This tool offers interesting possibilities of its use in the planning process, because it allows quick identification of marine areas predestined for the location of mussel farms at the scale of the whole Baltic. However, the Baltic scale production model provides only a regional picture and may not be sufficiently representative of small-scale local conditions. For example, the gridded data may not capture the effects on water quality of local features such as the barrier impacts of peninsulas on the production potential of coastal waters, e.g. Puck Bay, Vistula or Curonian Lagoons. Therefore, further to identification of the site by use of this ODSS tool, the suitability of candidate farm locations should be corroborated by site visits and collections of water samples for salinity and chlorophyll analysis to compare actual site conditions to the input data used for production modelling.

10 Conclusion

The Baltic Blue Growth project has shown that mussels can be farmed successfully farmed in large parts of the Baltic Sea, when farming methods are adapted to the local conditions. The environmental effects from the mussel farms are largely beneficial, and close to zero negative effects were recorded in the participating mussel farms. On the contrary, it was demonstrated that the mussel farms perform important ecosystem services, by filtering the water and trapping excess nutrients. These ecosystem services can be valued in monetary terms and compensation should be paid to the mussel farmer for the provision of these services. Combined by usage of the mussels for food or feed products, mussel farming can drive blue growth in the Baltic Sea Region, by providing private business opportunities, in particular when combined with other types of aquaculture as a nutrient-catch culture. It must be stressed that mussel farming does not compete with, or substitute, any attempts to reduce nutrient inflow from land but can contribute to reduce and recycle already existing nutrients.

To conclude, mussel farms in the Baltic Sea can make a significant contribution to reduce eutrophication by their action to take up nutrients, while also providing a new sustainable resource for food and feed in the region.

Figure 25: Mussel farm rigs being prepared. Photo by Mats Emilsson, East Regional Centre for Aquaculture.

11 Further reading

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About

Baltic Blue Growth is a three-year project financed by the European Regional Development Fund. The objective of the project is to remove nutrients from the Baltic Sea by farming and harvesting blue mussels. The farmed mussels will be used for the production of mussel meal, to be used in the feed industry. 18 partners from 7 countries are participating, with representatives from regional and national authorities, research institutions and private companies. The project is coordinated by Region Östergötland (Sweden) and has a total budget of 4,7 M€.

Partners

- *Region Östergötland (SE)*
- *County Administrative Board of Kalmar County (SE)*
- *East regional Aquaculture Centre VCO (SE)*
- *Kalmar municipality (SE)*
- *Kurzeme Planning Region (LV)*
- *Latvian Institute of Aquatic Ecology (LV)*
- *Maritime Institute in Gdańsk (PL)*
- *Ministry of Energy, Agriculture, Environment, Nature and Digitalization of Schleswig-Holstein (DE)*
- *Municipality of Borgholm (DK)*
- *SUBMARINER Network for Blue Growth EEIG (DE)*
- *Swedish University of Agricultural Sciences (SE)*
- *County Administrative Board of Östergötland (SE)*
- *University of Tartu (EE)*
- *Coastal Research and Management (DE)*
- *Orbicon Ltd. (DK)*
- *Musholm Inc (DK)*
- *Coastal Union Germany EUCC (DE)*
- *RISE Research institutes of Sweden (SE)*

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