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Farming of blue mussels in the Baltic Sea

A review of pilot studies 2007-2016

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Table of contents

Objective

The objective of this review is to summarize results from previous mussel-farming attempts of blue mussels (*Mytilus edulis trossulus*) in different parts of the Baltic Sea during the period 2006-2016, focusing on production and technology. The review is intended as internal reference material for partners of the Baltic Blue Growth project (BSRP 2016-2019), but can also be used for external communication.

Method

The review summarizes results and conclusions from previous mussel-farming projects in the Baltic Sea: Mussel-farming as an environmental measure in the Baltic (Baltic 2020, 2009-2012), Aquabest (EU Baltic Sea Region Programme 2011-2014), Baltic Ecomussel (EU Central Baltic Interreg programme 2012-2014), Bucefalos (EU Life 2012-2015) and preliminary results from Baltic Blue Growth (EU Interreg Baltic Sea Region 2016-), including also results from pre-studies and co-finance/sister projects. Pros-and cons with the tried methods and sites are evaluated, but data on costs are excluded. Development of mussel-farm systems in different parts of the world have usually focused on mussel production for human consumption, but the aim of the Baltic Blue growth project is instead to demonstrate full scale production of mussels as a nutrient catch culture. As a consequence, the farm systems are discussed with optimization of maximum production of mussel biomass as target, while other parameters such as mussel quality and size has been given less attention.

The results from project reports are complemented with results from scientific papers that was recommended and shared by members of the Baltic Blue Growth project team, and updated with recent interviews with practicing Baltic mussel farmers Torbjörn Engman (Finland), Urmas Pau (Estonia) and Tim Staufenberger (Germany). Conclusions have been reviewed and discussed with Orbicon, Izabela Alias, John Bonardelli and Mads van Deurs.

The review does not claim to summarize *all* mussel farm trials done within the defined area and time-period, as quite a few reports are published only in national language and are not easily accessible.

Definition of Baltic Sea

The mussel-farm trials reviewed here have been conducted in the Southwest Baltic Sea and the Baltic Proper, an area stretching from the straits of Little Belt, Great Belt and Öresund in the west to Åland islands and Gulf of Finland in the north/east.

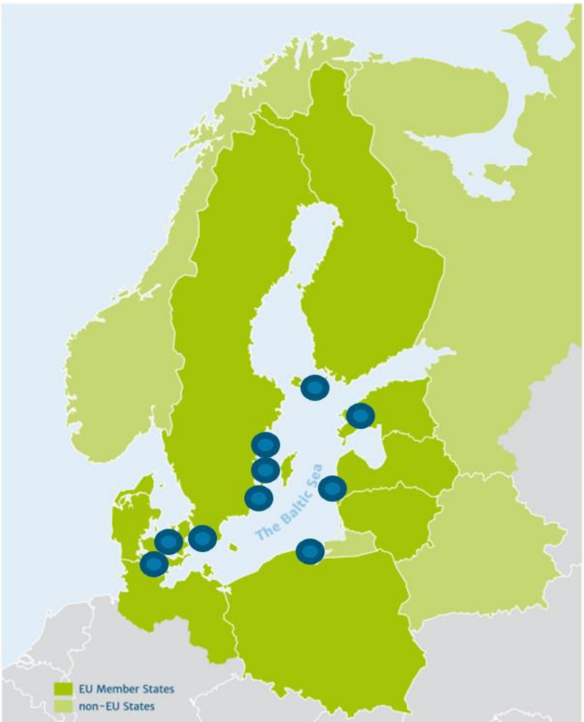


Figure 1: Sites for the mussel-farming trials described in this review

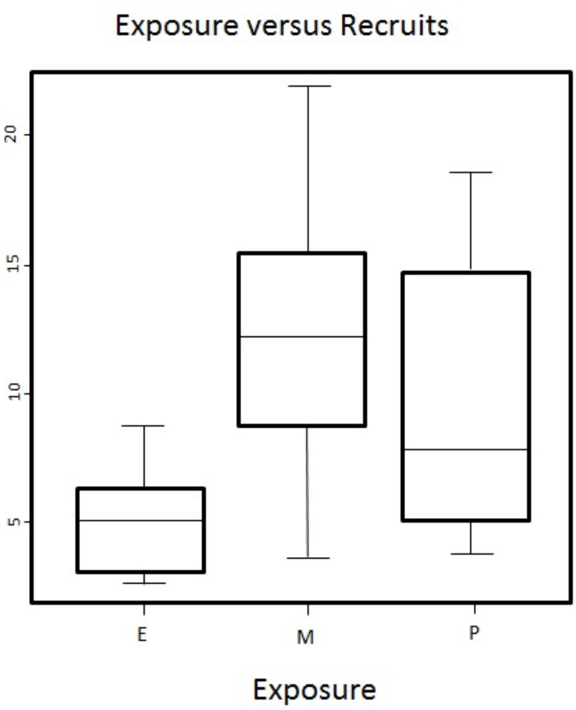
Åland archipelago

Baltic Eco Mussel, National projects

Pre-studies, site selection

The optimal site for mussel-farming within the Åland archipelago was evaluated through a comparison between 76 sites in 2012 (Granholm 2012). Based on studies from other sea-areas, the pre-assumption was that a rapid water exchange is good, while wave-exposure, drift- and pack ice are risk factors. Water exchange provides the planktonic food needed for mussel growth and minimizes negative impact on sediments underneath the mussel farm, while wave exposure can lead to mussel loss, and drift and pack-ice can damage the equipment. Oceanographic data was used to classify the sites into 3 categories: VOK I medium time for water-exchange 0-9 days (outer archipelago), VOKII medium time for water exchange 10-39 days (middle archipelago), and VOKIII water-exchange time more than 40 days (inner archipelago). To find sites with a good balance between water exchange and protection, most of the sites were set in the outer archipelago. Here, decisions about suitability were made based on the knowledge of local people in combination with geographical/geological/biological indicators. Some, but not all, sites had access to data about salinity, chlorophyll, nutrients, currents, water-exchange, blue-mussel occurrence and bottom structure. Administrative and social factors were also considered, such as other water-uses, environmental protection and the interest of local habitants. Most of the sites considered "not suitable" were ruled out because of high exposure to open sea. But some sites with high exposure were left, because it was considered that technical development or a mobile farm-concept could solve this problem in the future.

The pack-ice in some areas could go several meters deep, so if sinkable farms should be used to avoid ice in those areas they would have to be placed at great depths. Considering the main current and wind directions, it was concluded that sites protected from north and south were the best. 26 of the 76 sites could be suitable for mussel farms.



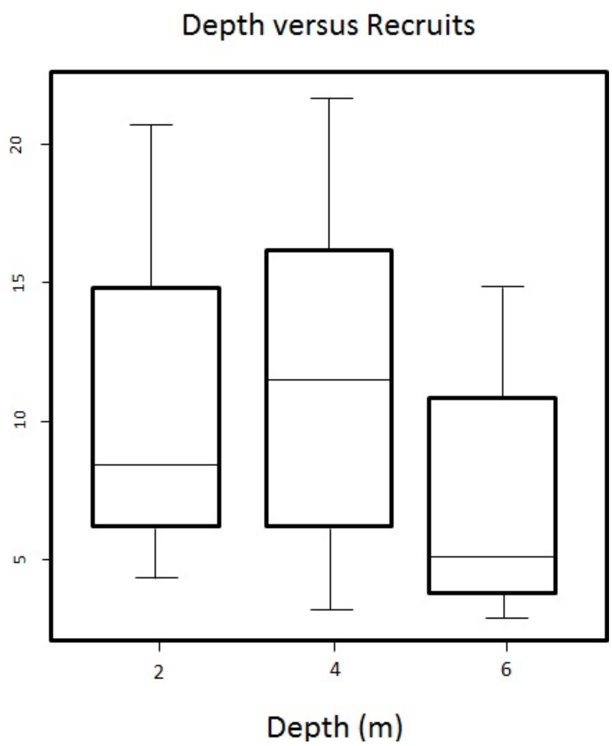


Figure 2: Two-way ANOVA showing how mussel-recruitment is affected by the factors wave-exposure (left figure) and depth (right figure). E=Exposed site, M=Moderately exposed site, P=Protected site). From Diaz and Kraufvelin, 2013

Another pre-study for mussel-farming was made in the nearby area of Hanko in the western Finnish archipelago (Diaz and Kraufvelin, 2013). Nine sites were divided in three levels of wave exposure and equipped with experimental units for repeated tests of mussel recruit density at three depths: 2 m, 4 m and 6 m. The results showed that most mussel-larvae were found at 2-4 m depth. Closer to surface the mussels were fewer, but they had the same size as those found at 2-4m. Around 6m depth the mussel recruits were fewer and also smaller. In regard to wave-exposure, the results showed that mussel-abundance was higher at moderately exposed and sheltered sites compared to more exposed sites. In addition, Diaz and Kraufvelin identified some environmental data that seemed to have a statistical significant effect on size (initial growth) of the mussel recruits: Chl-a concentration, temperature and oxygen showed positive correlation with mussel recruit size. Phosphorous concentration showed negative correlation.

Kumlinge musselfarm

Aquabest, national project

A small pilot-farm in Kumlinge municipality 2007-2009 using 10 cm thick 8 mm plastic mesh stripes as settling substrate showed production of 2,5 kg/m after 2,5 years (T. Engman 2009). A much larger farm was launched at the chosen site Synderstö in 2010. The farm, still there today, consist of 4 Smartfarm units from Smartfarm A/S. This type of mussel farms were originally designed to collect mussel spat in high saline waters. Mussel larvae settle and grow on the nets before they are harvested for the first time at 3-4 cm size after 1 year (provided enough salinity, food and temperature). Then they are put in a sock or spread out on the sea floor for further outgrowth. In low-saline areas of the Baltic Sea, mussels rarely grow larger than 4 cm. So in theory they could stay on the spat-collection net for their entire life.

The settlement at Synderstö was successful and everything worked out fine technically, even though the winters in 2010-2011 were harsh. Hard winds and ice caused great strain on the units.

Figure 3: Smartfarm units at Kumlinge. Each unit is made up of a 120*4m mesh that hangs down from a black flotation pipe anchored to the bottom.

Results

The farm was harvested after 2,5 years 27-28 nov 2012. The result was 14.4 tonnes of mussels, considerably less than expected (Engman, pers. comm). Based on results from the previous pilot farm, the expectation was to harvest 20-28 tons (Van Deurs, 2013). The approximate difference in harvest per m substrate between the pilot and the larger farm can be seen in Fig 16 (Kumlinge plastic mesh strip vs. Kumlinge rope net). The difference from expectations was partly explained by the fact that a grid used to separate the mussels from water at harvest was too large, so that smaller mussels slipped through the grid and biomass was lost. In conclusion, if the aim is to harvest biomass and nutrients, next time the separation after harvesting should be optimized so there is less loss with the smallest mussels. Besides the circumstance with the grid, some other unexpected problems had to be solved during harvest. The harvesting machine from Smartfarm, specially designed for mechanized harvest of smartunits turned out to be too heavy for the boat crane to load onto the workboat. The alternative solution to tow the self-floating harvester after the workboat didn't work either, because it was too deep-going for the harbor. The problem was finally solved by driving a truck with crane aboard a ferry. The ferry and truck combined was then used as temporal crane-boat.

Present situation

The mussel-farm in Kumlinge has continued and Torbjörn Engman, who runs the farm for the government, checks it twice a month. So far it has survived many storms and extreme ice-winters without damage and without submerging. No repairs have been necessary since the project finished in 2012. Water currents can occasionally pull down the mussel nets under water. Barnacles, green and red algae compete for space, but they have not had problems with eider ducks. There are eider ducks present in the area, but for some reason they don't seem to approach the farm. The medium size of mussels at harvest after 2.5 years is 25 mm. There has been serious interest from a restaurant to buy mussels from the related company Ålandsmusslan AB to serve as human food, but it has not yet been possible to get a license for food production. So far, despite repeated inquiries from the company, authorities have not been clear about how to implement the requirements according to Engman. Åland government started to investigate the prerequisites in 2016 (ÅLR 2016/7828). A microbiological investigation of the proposed farm-area (first step in permit process) showed that the sanitary conditions at the farm-site were very good. Nevertheless, it was stated that a lot more investigative work was needed in order to issue a permit, in particular because of presumed risks for algal- and environmental toxins (Linsén and Abrahamsson, 2016). Another conclusion from these reports was that although mussel-farming for human consumption in Åland is possible, economic conditions to build up the infra-structure needed to support a mussel-farm industry in Åland today is lacking (Linsén 2016).

Vormsi archipelago

Interview with Urmas Pau

This pilot-farm was established in May 2015 by the company Vormsi Arendus OÜ. It is made up by in total 126m coils of trawl net (made from 45 mm mesh) hanging down to 3,5 m depth from a single 50m longline provided by Nordshell A/S. Salinity is only around 5 PSU, but older mussels up to 5 cm size have been reported from the area. In spring 2017 the farm planned to scale up with 2-3 similar units. Water-depth at the site is 9-10 m. The farm can be observed from the coast and present maintenance is limited to visits every 6 weeks.

In the beginning it was difficult to see the small mussels on the rope, but in July 2015 successful settlement was reported. In summer 2016 the mussels had grown up to 20mm length, 10-12 mm width. There were a lot of green algae growing on the substrate from 0-2,5m depth, but at the deepest final meter of substrate there was less algae. In autumn 2016 the surface buoys were stolen, leading to substrate touching bottom. In 2017 they are probably going to submerge the line down to 3 meters depth, to avoid green algae but also to avoid unwanted attention of the farm. So far they have not had problems with storms. The farm is secured by 500 kg anchors. There is seldom ice reported around the farm site. When in operation they plan to harvest the mussels in springtime, because it will be easier based on knowledge about the local weather patterns.

Figure 4: The pilot mussel farm at Vormsi use coils of trawl net as mussel- substrate

If mussel farming is successful, the company plans to establish the whole chain of mussel production and processing themselves. Today they process macro algae for various products including human consumption, but they don't yet have the license to produce mussels for the food or feed market.

St. Anna archipelago

Pre-study – site selection

County Administrative Board of Östergötland, national project

14 small pilot mussel farms were set out in June 2009 along a salinity gradient in the county's three major bays: Bråviken, Slätbaken and Valdemarsviken. In addition, four pilots with five different substrates were set out in the middle archipelago. Before the summer of 2010 three additional pilot

mussel farms were set out to compensate for farms that disappeared during the harsh winter 2009-2010. The substrates were: 80 and 100 mm mesh fishnet, 10 cm plastic mesh stripe seed collector (Figuree 5) and two different ropes. The pilots were maintained by local fishermen, sampled in Sept-Oct 2010 and 2011, and the results were evaluated with regard to site, substrate, mussel nutrient content and toxin content. (Henning and Åslund 2012).

The results from the pilot mussel farms showed that there were several places in the Östergötland archipelago that are suitable for mussel farming. Areas that were shown to be unsuitable for mussel farming were two of the northern bays, due to the impact of freshwater run off. The harvest results varied due to localisation and the method/substrate being used. Spat settlement occurred at least twice during May-Sept. In 2011, spat was reported already in late May and then a second settlement occurred during summer. Best production was found at two sites in the middle archipelago Kråkskär and Höga skäret, where production after 16 months was 1.2 kg and 1.0 kg mussels, respectively, on the best substrate, the sock. The plastic mesh stripe turned out to be the superior substrate at most sites. Filamentous algae stuck to the nets and in the first year, it seemed like mussels had difficulty settling to the slippery plastic material in the ropes and nets. Interestingly this was not a problem the second year. In Sep-Oct 2011, harvest results from the ropes were at some stations comparable to those from socks. From this, it was speculated that mussels could settle better to slippery plastic materials when it had been in water for a while and become roughened.

Figure 5: Left: The fine plastic mesh stripe used as settling substrate after 5 months in Aspöfjärden with mussels up to 7 mm. Right: Few mussels settled to the material in brand new fish nets during the first summer. From Henning and Åslund 2012

Results indicated that mussel production in at least two of the bays will not work due to the low salinity and lack of spawning mussel populations. In one of the bays with a little higher salinity, settlement was good, but the mussels were lost or only small mussels were found. This could have been because of weak attachments of mussels to the substrate, strong currents flushing off larger mussels from the substrate and/or predation. Environmental toxin analyses showed that recorded values in mussels from all the sites were below the legal limits for toxic substances included in the legislations for feed and fertilizer. Environmental monitoring programs had shown levels above limits for Cd in bottom living mussels, but the Cd levels in farmed mussels were half of those found in wild mussels from the same sites.

Conclusions from the pre-study were that farm site was more important than substrate for the mussel production observed. Another conclusion was that the harvest biomass at most sites was similar after 1.5 years to that after 2.5 years. Recommendations from the study were to place mussel farms in the middle archipelago at sites with a good balance between water exchange and shelter, installation of collectors in May at year 1 and harvest in Sep year 2. With regard to substrate, the recommendation was to choose a substrate that is easy to handle and to harvest.

St. Anna musselfarm

Baltic Blue Growth, national project

Based on results from the pre-study an up-scaled mussel farm was launched in the middle archipelago of St. Anna in spring 2016. The farm uses submerged long-line technology and 24 000 m Christmas tree seed collector ropes as substrate. The mussels were allowed to grow out to full size on the collector ropes, no socking was planned. So far, the farm technology has worked fine, but the settling of mussels has suffered some competition from cockles Cerastoderma *sp*. Submerging of the longlines for winter 2016/2017 was considered but not performed. The farm it did not suffer from ice damage first winter, presumably due to the high tension of the long lines (Emilsson pers. comm).

Kalmar sound

Pre-studies, pilot farms

Aquabest and rural development projects (EU agriculture and rural development fund)

In Kalmar sound there have been several smaller mussel farm projects from 2007-2013 at various sites, including Västervik archipelago. Due to a large natural mussel population, high nutrient levels, good water exchange, shelter from the open sea and eastern/western winds the sound has been considered a suitable area for mussel production. Currents can be high at the narrowest part of the sound, with a medium current of 20 cm/s. Currents of up to 3 knots (140 cm/s) are known from the Öland bridge (https://opendata-download-ocobs.smhi.se/explore Kalmarsund boj 2002-2004). Currents at the various test-sites for mussel-farms in Kalmar sound are supposed to be a bit lower, but were not measured. The first study, a cooperative effort between municipalities and the Kristineberg Marine Science Center, followed 5 smaller longline units (60-200m) with different designs in the middle of Kalmar sound in 2007-2010. They were launched offshore at Oknöskär (spring 2006), in the archipelagos of Svartö and Ljungnäs (summer 2007), close to shore at Revsudden (2007) and offshore at Hagby (2008). The sites were chosen based on recommendations from local people. Tested substrates were Ø5 cm socks (not filled with seed mussels but used as settling substrate) 80*80 mm eel mesh, 100*100 mm double-knitted trawl mesh, 200*200 rope mesh, ladders, Ø14mm PE-rope and Swedish bands (Nielsen, Nielsen and Aronsson 2008). The farm at the most exposed site Öknöskär showed good settlement. Mussels grew to medium size 10.3 mm until Aug year 2. After this, the farm was lost in a storm and could not be further evaluated. The loss could be ascribed to insufficient strength of equipment for exposed conditions. The Revsudden farm showed no mussel growth at all, presumably due to low salinity. It was later shown by a dive inventory that wild mussels were lacking in this area. The harvest from different substrates of the three remaining farms in 2008 and 2010 showed highest biomass, 1.0-4.6 kg/m on the socks (Lindahl, pers comm), followed by the rope net in Hagby 14 kg/m2 (Lindahl 2012). The eel-nets were problematic because they accumulated filamentous drift-algae, and Swedish bands and ladders showed limited settling and got entangled even at the sheltered sites likely because of insufficient dead weights to sink them in higher currents. Perhaps this could have been prevented with more experience on currents and farm design. Environmental toxin analyses showed values below the legal limits for toxic substances included in the legislations for feed and fertilizer (Nilsson, 2009).

Another pre-study in Kalmar sound was done in 2013 within the Aquabest project. 12 settlement-stations were spread out in Kalmar sound and Västervik archipelago in mid-May at selected localities. The settlement stations consisted of four different substrates; ropes, seed collector bands, single knit trawlnets and double knit trawlnets. Ropes and bands were repeated twice at each settlement station. The evaluated result in September was based on nine localities, since three stations had to be excluded for various reasons.

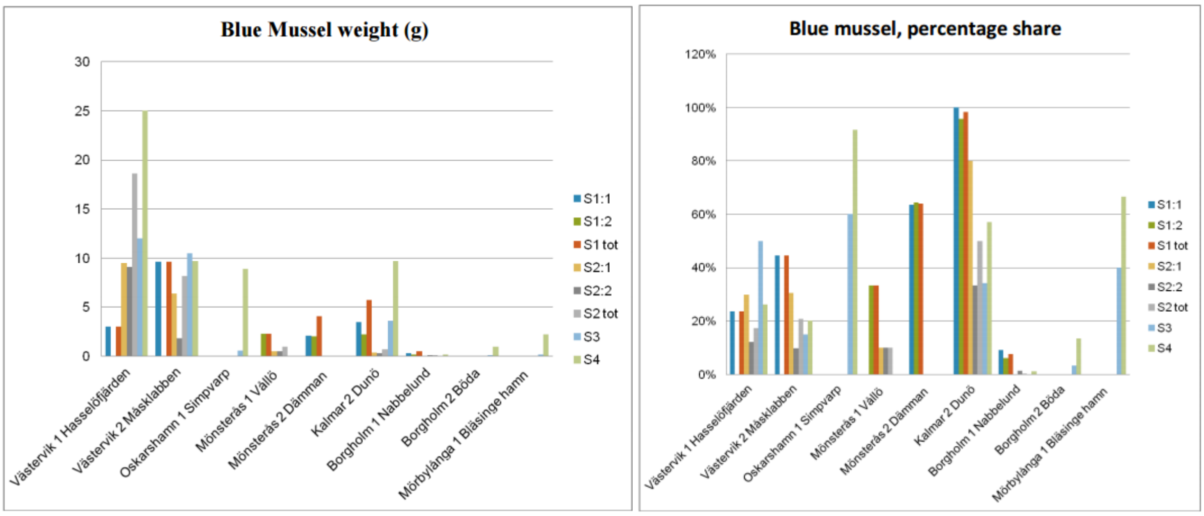


Figure 6: Left: Total weight of blue-mussels, and right: Percentage share of blue-mussels to total biomass, on the test-substrates after they had been left out at sea for 4 months. S1=PP-rope, S2=Swedish band, S3=single knit trawl-net, S4= double knitted trawl-net. From Olofsson et al 2014.

Results from this pre-study showed a trade-off one must consider while choosing between a protected vs a less protected farm site. Some settling stations that were placed in protected areas (Västervik 1, Västervik 2) showed a high biomass from settled mussels, but also high biomass from competing organisms like horn-wrack, algae and barnacles. As seen in the right Figure, there was less inter-species competition at stations that were more exposed (Oskarshamn 1 Simpvarp and Kalmar 2 Dunö). The overall impression was that settling stations in more exposed waters were “cleaner”, with lower total biomass, but on the other hand consisting of close to 100 % blue mussels in some cases. Similar to results from other studies, there was more difference in mussel-settling between different sites than between different substrates. The most successful substrate in this settling study was 150 mm double-knitted trawl net. (Olofsson *et al* 2014).

First large-scale trials in Kalmar sound

Baltic Sea 2020, national projects

10 Smartunits from Smartfarm A/S, similar to those in the picture from Kumlinge (Fig. 3) were installed in June 2009 at Hagby in south Kalmar sound. Also, 4 units were installed in Hållsviken in the archipelago south of Stockholm. The farming nets were 4 m deep and used ø 250 mm PVC-pipes for

floatation. Each net was made of rope of different thicknesses (10, 12 and 14 mm) and with three different mesh sizes (100x100, 125x125 and 150x150. The plan was to harvest the farms in autumn 2011, however thick ice and ice drift caused disturbance, loss of settled mussels, damage and loss of farming equipment in the winters of 2009-2010 and 2010-2011. Results of the settlement of mussel spat was first studied in early June 2010 on farm units which were intact after the ice impact. A high settlement of mussels had occurred and a large number of mussels were growing on the nets. Most of the mussels were smaller than 10 mm, but there were also a small amount of up to 15 mm in length. Medium mussel length at the Hagby-farms was 5 mm after 1 year, 12 mm after 1.5 years and 13 mm after 2 years (recalcutated from Lindahl, 2012). The biomass after 1.5 years (Oct 2010) was 10 kg per m^2 net and there was no noticeable difference between the different mesh sizes. Because the farm was completely destroyed during the second winter, there are no values on biomass from 2011. Conclusions from this first large-scale trial was that future mussel farms at exposed sites in the Baltic must be able to manage ice and ice drift, most probably through lowering the farms below sea surface and having a design appropriate for active management practices. Another conclusion was that there was a lack of available vessels in the area, large and powerful enough to be used for maintenance and repair (and harvest) of the farm. It turned out to be a big step, scaling up from the small-scale test farms which preceded the project to larger scale production.

The most successful mussel farm in the area so far is the farm at Hasselö, Västervik outer archipelago that was harvested in spring 2016. The harvest was approximately 10 tons of mussels, corresponding to a production of 10.4 kg biomass per m^2 substrate after 2 years (Minnhagen, unpublished). This farm site is protected from direct exposure from open sea, but has good water exchange and current. The design is from DSF/Kingfisher consist of 2*120 m PVC-tubes carrying 2*120*4 m double knitted trawl net of 150 cm mesh-size. Harvest was solved by using a work platform with crane, lifting up the farm units section by section with the crane over a container placed on the platform, and rinsing off the mussels from the net with a fire hose. The harvest took around 4 hours per unit to perform with a minimum of 4 workers, not counting the additional work time and personnel needed for transport and packing of the mussels.

The Byxelkrok musselfarm

Baltic Blue Growth, national project

Because of ambitions to overcome the technical challenges of Kalmar sound and evaluate the potential of offshore mussel production for the future, it was decided to test a new type of submerged farm from Bohus Havsbruk AB. The farm consists of 10 units with 100*3 m, 200mm mesh size Shelltech rope net, drill anchors and buoys as flotation units. The idea behind the farm is to overcompensate flotation power from start, so that the number of buoys won't need to be adjusted regularly to compensate for the weight of growing mussels. For this concept to work, also anchoring need to be magnified. A site in the northern Kalmar sound south from Byxelkrok was chosen as the test site, because of its suitable water depth, easy access to harbor and the total dominance of blue mussels colonizing all available substrate in the area. There are no oceanographic measurement stations in the area, but during the launching of the farm in 2016 there were unexpected difficulties to set the 110 drill-anchors needed to submerge the farm. It was hard to maneuver the drilling rig from the classic round-bottomed fishing boat used as a work-vessel, due to the great momentum caused by bobbing also from moderate waves. As shown in earlier projects, new combinations of equipment do not always work together as planned. The lack of available larger vessels in the Kalmar sound area left no alternative but to solve the problems stepwise by time-consuming technical adjustments of the boat and equipment. The farm lay exposed to storms and waves throughout the summer and in Aug 2016 it was moved to a more protected site until anchoring could be solved. An inspection after winter 2017 showed that there had been either very little settlement, or high loss of mussels from the farm substrate.

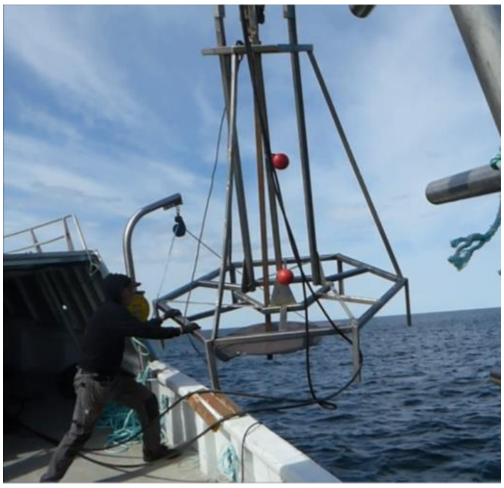


Figure 7: It was hard to maneuver the swinging drill rig from the workboat, a fishing vessel

Kurzeme coast

Baltic Eco Mussel, Baltic Blue Growth

Pilot farming ropes have proven settlement of mussels spat at the open coast of Liepaja, Latvia. The coast is very exposed to the open Baltic Sea. Wave impact limits the growth of benthic organisms severely at 2 – 5 m depth, but the impact decreases by half at 10m depth and further diminishing at 20-30m depth (Seņņikovs et al, 2007). The Latvian Institute of Aquatic Ecology has established a test cultivation farm with 625 m substrate rope located some 5 km off the shore in the open sea submerged. The cultivation units are submerged to 5-7, thus protected from severe wave-action. The site has a depth of approx. 20 m with a stony bottom with patches of sand. A special focus with this open water test farm will be on comparing its costs and benefits to those of already existing farms in sheltered sites. It is expected that the costs of deployment will be comparable to other farms, whereas the maintenance costs will probably be higher.

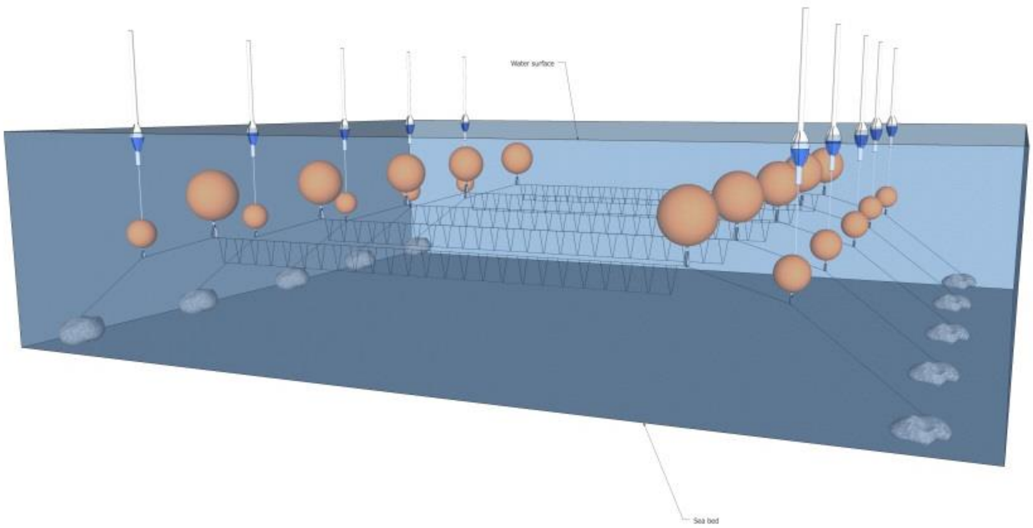


Figure 8: Drawing of the planned offshore farm at the Kurzeme coast in Latvia

Gulf of Gdansk

Sami Alias, I (2014). Doctoral thesis

In 2008-2012, the small scale experimental farming of the mussel *Mytilus trossulus* was carried out in the Gulf of Gdansk. In 2009, farming collectors made of polypropylene rope (Ø 32 mm) were installed at three sites at a depth of up to 12 m (tested a priori for their suitability for culturing). They were submerged about 2 m below the surface to avoid both the destructive effects of maritime traffic as well as human devastation. The experimental construction survived storm and ice winter. Places for conducting the experiment were selected based on the analysis of both hydrological and biological data, i.a benthic communities and taxonomic composition of zooplankton, and primary production. The research revealed that larvae harvesting depends mainly on the availability of favourable substrate at a suitable depth, available food resources and sea currents. As evidenced by the observations of mussel larvae settlement, there is a large number of free-leaving larvae occurring in the pelagic zone throughout the year. It has been found during the experiment that the number of mussels varied with the depth at all the study sites. The maximum abundance occurred at a depth of 3 – 6 m and was statistically significantly higher than the number of mussels occurring in the terminal section of the rearing rope (9 – 10 m). The largest count of juvenile specimens was found in late autumn in the first year of the experiment, and ranged from 74,000 to almost 150 000 ind. m^{-1} of the rope depending on the location of a given study site. At the age of ca. 8 months the largest specimens growing on the culture reached the size of up to 22.00 mm, i.e. more than specimens in the natural population living on the bottom in the same area.

Figure 9: 7m-long rope, covered by mussels, after two years of being submerged

The conducted experiment showed that it is possible to obtain a large number of larvae for further farming directly from the environment and the growth rate is determined mainly by environmental (biotic and abiotic) conditions prevailing in the pelagic zone at different depths. The largest biomass was obtained in cultures after two years of ropes exposure. The maximum biomass values were obtained at a depth ranging from 3 to 6 m. The studies shown that the mussel biomass obtained at the terminal section of the rope was statistically significantly lower at each stage of the experiment compared to rope sections at shallower depths.

After 3 years, mussels shell length reached maximum 40.00 mm.

Kiel fjord

Kieler Meeresfarm

Interview with Tim Staufenberger, EBAMA-project

Kieler Meeresfarm originally started in 2010 as part of the EBAMA-project and, since 2014, is run by a private company, Kieler Meeresfarm. It consists of seven submerged 100m horizontal longlines, separated 7.5 m distance from each other and occupying an area of 0.6 ha. It uses buoys as flotation units, adjusts the number of buoys as mussel biomass increases so that the mussels hang directly below the water surface. The Kiel Fjord has fluctuating salinity from 2.6 -16 PSU and a mean salinity of 14.3 PSU. The current at the site is constant, 1-3 cm/s from northeast to southwest. The longlines have been placed parallel to the main current direction. Different substrates, seed collector bands and socks hang about 0.5 m apart from each other on the longlines. Spat settles on the collector ropes and after about three months, at a size of 1-1.5 cm, the juvenile mussels are socked into 3.5 m long mussel socks. The initial weight of each sock is set at about 0.75 kg/m. After a growing period of about 18 months and a net gain of approximately 10 kg per sock, the mussel yield for a fully established farm with 10 long lines and 2000 mussel socks is approximately 20 t. Meat content of mussels was measured in Nov-May 2010-2011. It was high in November, December and May, low in March and April (Abschlussbericht fur das Projekt EBAMA, 2012). The environmental effect of the farm to the surrounding area has been measured by Schröder et al 2014, who showed that the farm had an effect on Chl-a and secchi depth. Secchi depth values increased with 0,2-0,5 m downstream compared to upstream from the farm. Most problematic is increased sedimentation below the mussel farm. Earlier measurements at the Kiel farm showed increased sedimentation by 50% in January and 400 % in March in comparison to a remote reference point (Peter Krost, pers. comm). Therefore it is crucial that the production site has appropriate water circulation. During the monitoring from 2010 – 2012 in Kiel, no algaetoxins occurred in analysed mussels (monthly measurements in 2010 and during mussel season in 2011 and 2012). The bacterial load (E.coli) was analysed at the same time and appeared to be closely related to water temperature. The microbiological quality of the shellfish water "Kiel Fjord" was proved A (< 230 cfu / gmussel meat) except during summer months where it was proved B (230 – 4600 cfu / gmussel meat). All further analyses of chemical contaminants like heavy metals, organic pollutants or other harmful residues were uncritical (Rössner et al 2013).

The mussels are sold as fresh food to local restaurants and private persons. To qualify as food producers the company follows the EU and German control-program for food-safety. The farmers do weekly sampling themselves during harvest season and deliver mussels to the accredited lab LUFA-ITL GmbH AGROLAB Laborgruppe for analyses of e-coli and salmonella. Furthermore mussels are analysed weekly in the State Laboratory of Schleswig Holstein and the LAVES in Cuxhaven for algal toxins. Heavy metals, DDT and PCB are sampled and analysed every 6 months. In addition, water samples for algal taxonomy are taken once per month through an environmental monitoring program. Farm owner Tim is critical about the relevance of present control programs to guarantee safety for his customers. They pay EUR 500 per week to lab Schleswig Holstein for controlling the mussels in the laboratory, but it takes up to 3 weeks to receive the algal toxin analyses and by then the harvested mussels are already sold and eaten. So in addition, they do self-checks (microscopy of phytoplankton mesh samples) to guarantee the safety for their customers. Secondly, the algal toxins monitored are not likely to occur in the farm-area. Only once during several years of monitoring did the chromatograph detect something, in that case Yessotoxin, far below the safe limit. This was after a period of turbulent weather and water-exchange. Tim believes that safety is important, but that the money for control programs in their case is spent un-wisely.

Figure 10: Left: Kiel Meeresfarm is situated in a densely populated area close to the Kiel-canal. Right: After a few months, the young 2-4 cm mussels are sorted by size-class and socked for further out-growth

Planned studies at the Kiel farm

During spring 2017 Kieler Meeresfarm as contracted operators for the Schleswig-Holstein Ministry of Energy, Agriculture, Environment and Rural Areas has deployed three new 100 m longlines within the approved farm area, each with 150 units of seed collecting substrates. Mussels will be produced for experimental protein extraction and animal fodder production, and information on production and environmental impact will be collected for studies within the Baltic Blue Growth-project.

Öresund

Pre-study

Bucefalos project, national project

Öresund has huge mussel beds.To investigate the potential of future mussel farming, small mussel cultivation units were placed at six locations along the coast of Skåne: Torekov, Domsten, Malmö Skåre, Simrishamn and Tosteberga. The locations were selected as representative of the respective areas. The cultivation units were submerged from April to October 2014 and mussel growth was evaluated. Measurement data from nearby oceanographic stations was used to compare the results with data on salinity, depth, temperature, nutrients, oxygen Chl-a, Secchi depth, exposure to waves and strong currents, as well as access to harbor and work vessel. The locations at the east and south coast of Skåne (Tosteberga, Simrishamn and Skåre) showed good settlement. In southern Öresund (Malmö) the recruitment was believed to be good, but the result showed few settled mussels so it was concluded that the strong current 13 cm/s probably stripped mussels from the units. In both Tosteberga and Malmö, a considerable amount of cockles Cerastoderma *sp*. had settled on the stations. In northern Öresund at Domsten, where current reaches 16 cm/s, recruitment was almost non-existent and in the southern Kattegat (Torekov) recruitment was very low. On these units, predation from starfish probably strongly reduced the amount of mussels. The size of the spat followed the salinity gradient, with larger spat at higher salinity. Settlement success was higher at stations with lower current, like Skåre at 8 cm/s, but also correlated to abundance of mussel larvae. The other parameters tested showed no correlation with the mussel data and they likely had a minor impact during the short time of the experiment. It was concluded that northern Öresund is not suitable for mussel cultivation due to low recruitment of larvae combined with strong currents. There is probably a limit for how strong the current can be for mussel spat to settle. It was speculated that this limit is somewhere between 13-16 m/s. Finally, it was concluded that settlement potential is not the same as farming potential (Hvitlock, 2015).

Figure 11: Mussels colonizing the Öresund bridge (Bucefalos project report, Design of full scale blue mussel cultivation site in Öresund)

The pre-study also included several trials with different models of pilot farms in municipalities Malmö and Lomma from 2010-2014 (Karlsson M, 2016). Lomma is situated just north of Malmö in the Öresund. Two growth sites was used, one in each municipality. Similar to the trials in the Kalmar sound the first farm designs were unsuccessful and it was decided to try a submerged farm model. Two submerged pilot farms, 1 in Malmö and 1 in Lomma, were launched in spring 2012 and harvested 2.5 years later in autumn 2014. Medium biomass of harvested mussels was 17kg/m^2 mesh in Malmö and 20.4kg /m^2 in Lomma. It was observed that the mussels consisted of different size-classes at the two stations (Fig. 12)

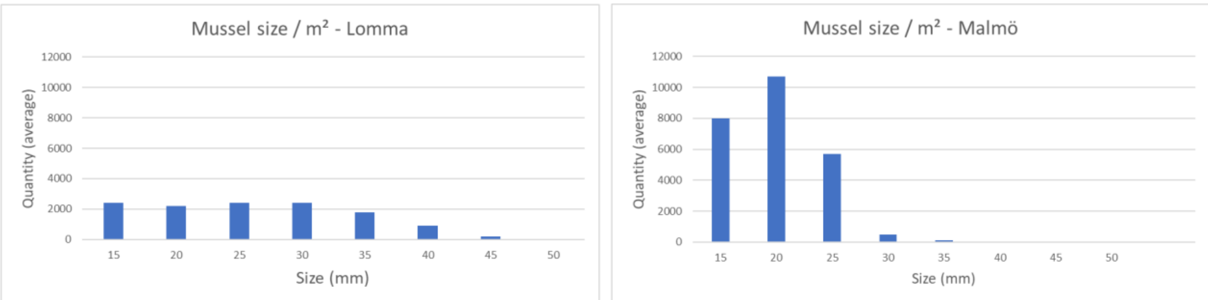


Figure 12: Difference in size-classes after 2.5 years from the submerged pilot farms in Lomma and Malmö, respectively. It is speculated in the report that the larger mussels in Lomma could be due to the stronger currents, in combination with higher nutrient run-off from land in Lomma compared to Malmö, which resulted in more food for the mussels. From: Bucefalos project report Förstudie till blåmusselodling i Öresund, 2015

The Malmö farm

Bucefalos project

This was the first attempt to grow mussels in Malmö at a larger scale. 4 units, 120*4 m were deployed during autumn 2013. Each unit was divided into 3 sections with different test substrates mounted on a frame: Double-knitted trawl net 100mm mesh, Rope net 200 mm mesh, Swedish bands 50 mm. The units, produced by AB DFS, were permanently submerged 2 m below surface, and flotation buoys were adjusted during the experiment to compensate for the growing mussel biomass. Each unit had 4*500 tonnes anchors and heavy chains between the side anchors and anchor lines to moderate wave impact.

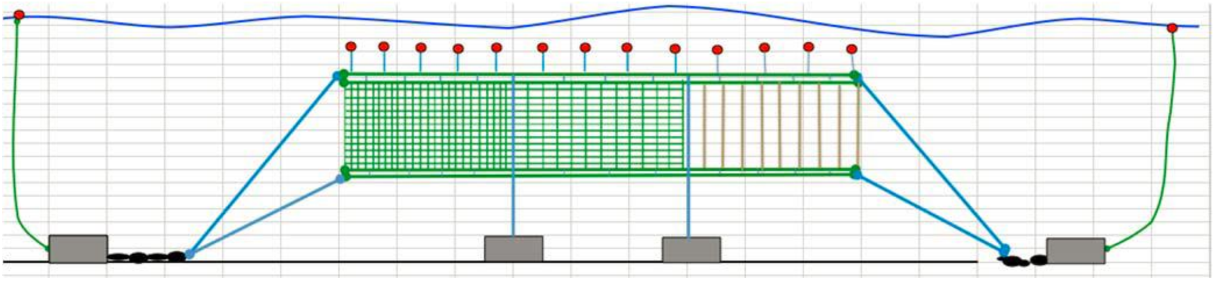


Figure 13: The Malmö farm was specially designed to withstand the tough conditions of Öresund with high current 13 m/s and occasional ice. From the Bucefalos project report Design of full scale blue mussel cultivation site in Öresund (2015)

The farm was harvested in June 2015 after the mussels had grown for 1 year (from recruitment in spring 2014). The harvest was made by divers, fetching the frames with the different substrates. Masses of filamentous drift-algae had got stuck in the trawl nets. The last 2 m of nets had to be cut off and discarded, and from 1 of the 4 units it was not possible to harvest any mussels because of excessive algae. This unit was left until Aug 2015, for the algae to disintegrate by itself. The harvested mussels were socked and put out again. The Swedish bands were not harvested the first year, because there were very few mussels growing on them. In the second year after 24 months, the third unit and the Swedish bands were harvested. The measured mussel production was 23.6kg/m2 on the double-knitted trawl net, 18 kg/m2 on the rope net and 2.35 kg/m on the Swedish bands. The lower yield from Swedish bands was partly because it had smaller area, but is was also speculated if the surface was too slippery for the mussels to attach, and also if the larger movements of the bands as compared to the nets could have led to mussel loss. Swedish band works poorly in strong current (J. Bornardelli, pers. comm).

Figure 14: Drift algae can get stuck in net farms, and in worst case scenario, weighs them down. From the Bucefalos project report Design of full scale blue mussel cultivation site in Öresund (2015)

The submerged farm units survived ice and storms and production was good with the mesh substrates, but massive mats of drifting algae caused problems. Despite cutting off the 2 deepest meters of the nets, 50 % of the harvested biomass used for socking was algae. The algae also threatened to drag the units down to the bottom, so flotation had to be adjusted more often than would otherwise have been necessary. It was concluded from the study that efforts should be made to avoid sites with accumulation of algae, although drift algae is hard to avoid.

Great Belt

The Musholm farm

In the Great Belt, the partly organic certified aquaculture company Musholm A/S have tested mussel farming since 2012 on 10 SmartFarm units, for the purpose of nutrient mitigation for fish farms. The conditions for mussel farming at the site are challenging, with generally strong currents, variable salinity, rough weather and predation by eider ducks. The number of eider ducks observed in May in the Musholm area during the last 10 years has fluctuated between 300-1000 individuals, with approximately 100 mating couples (Moltke Lyngsgaard et al., 2017).

First production experiments within the Baltic Blue Growth project

Within the Baltic Blue Growth project the farm installed 4 additional units to test the production on trawl nets with mesh size 50 mm, 80 mm and 150 mm in comparison to SmartFarm rope nets with mesh size 300*300. The 2 trawl net test units, carrying 4*3 m2 test nets stretching from the surface to 3 m depth and with different mesh sizes, were put out in late of May 2016 and harvested in Jan 2017. In Sep, Oct and Dec, the production was measured by cutting out test squares from the nets to analyze in the lab. After this, the units were harvested and the experiment terminated. The trawl net units were placed inside an empty fish cage, to see if this could prevent predation by eider ducks. The SmartFarm rope nets were placed at a different location outside the fish cage. On the trawl nets, overall biomass per substrate cm increased during the study period from Sept-Dec. In contrast, the biomass per substrate cm on Smartfarm nets did not increase from Sept-Dec. Average mussel weight increased from Sept to Dec on both the trawl nets and the Smartfarm nets, and so did also the average mussel lengths. However, while mussels grown on the trawl nets increased their average weight per month by 300 % during the study period, the mussels grown on Smartfarm nets only increased their average weight per month by approx. 60 %. Average mussel lengths changed from 1-8 mm in September on both trawl nets and Smartfarm nets, to a broader size distribution in Dec, peaking in the range of 12–19 mm on the trawl nets but only 6-9 mm on the Smartfarm nets. There was no statistical difference between the weight per length of substrate in samples taken from the top and bottom of the nets. The difference in mussel biomass per m substrate varied between different mesh sizes and different months: For Sept, Smartfarm nets (mesh size 300 mm) had the highest biomass indicating the largest settlement of mussel spat. In Nov the highest biomass was found on trawl nets with mesh size 80 mm, while in Dec, the trawl net with mesh size 80 mm had been lost. Then the trawl net with mesh size 150 mm showed the highest biomass. It is important to notice that all values were normalized to biomass per cm substrate for this comparison, and not biomass per area, as is often reported from other studies with net units. (Moltke Lyngsgaard et al., 2017).

Tabel 1: Estimates of the production (biomass) of mussels on all the substrates (mesh size 50 mm, 150 mm and 300 mm) in December upscaled to 100 m long nets with 3 m deep vertical panels

Mesh Size	Estimated biomass production (tons per 100 m unit)
50 mm - trawl	1.95
80 mm - trawl	No data – damaged production units
150 mm - trawl	3.7
300 mm - Smartfarm	0.22

The results from the production study were scaled up to theoretical full scale units in order to compare the production results from this study to production from other Danish mussel farms. The total estimated biomass was only between 0.2 – 3.7 tons per 100 m unit (Tabel 1), which must be considered low in comparison to for example Smartfarm units in other areas such as the inner Horsens Fjord, where (theoretical scaled up) biomass estimates of up to 20-25 tons of mussels per farm unit in after 5 months in Oct/Nov, mean size of mussels 10 mm, have been recorded (LJ Plesner et al, Faglig rapport fra Dansk Akvakultur nr. 2015-12). From Moltke Lyngsgaard et al 2017.

The conclusion from the present study was that the length of the study makes it difficult to make definitive conclusions on what net mesh sizes would be best for optimal mussel production. The overall low biomass on all units could be caused by several factors: Firstly, the small average size of the mussels and the fact that there were almost no mussels >10 mm in length found in Sept indicates that the biomass on all units was primarily represented by mussel recruitment from late summer or early Autumn. In conclusion they may have missed the spring settlement in May. Secondly, predation by eider ducks probably affected the low production outcomes on all the units and mesh sizes in this study. The development of the biomass and average size of mussels on the Smartfarm nets, as compared to the trawl nets, can only be explained by a larger loss of mussels from the Smartfarm in particular of mussels from the larger size-classes. As the trawl-nets were placed inside of an empty fish-cage in an area with lots of human activity, they were more protected from predation by eider ducks than the Smartfarm units. In addition, the natural self-thinning process where larger clumps of mussels fall of the nets due to higher mussel density could be a factor behind loss of larger mussels (J. Bonardelli pers. comm).

Comparative summary of the mussel farming trials

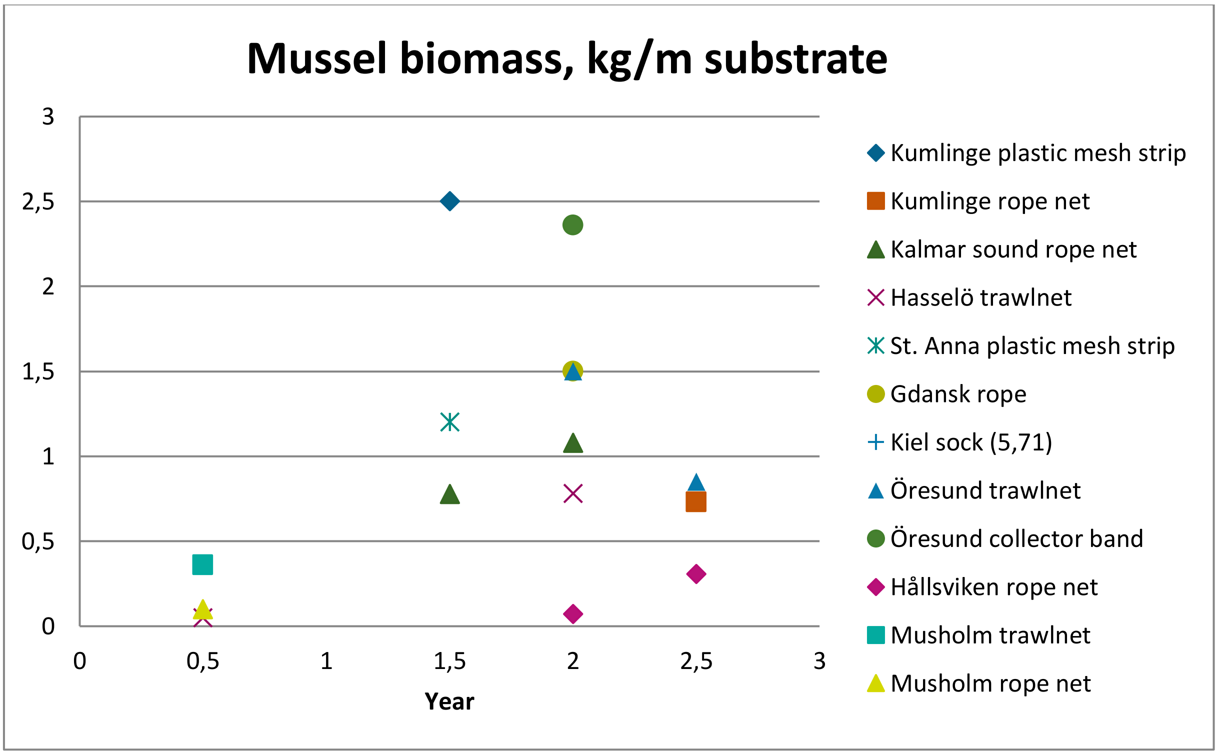


Figure 15: Mussel biomass (wet weight soft tissue plus shell) as a function of time, with the summary of trials from the Baltic Sea. The purpose of this Figuree is to provide an overview of studies that were not originally planned together or using the same methods. The result from Kiel (5.71 kg/m) was cut out from the diagram for visual reasons. In order to compare data from various substrates, data has been normalized to kg/m rope, band or sock. This is a standardized method to compare production statistics in mussel farming (J. Bonardelli pers comm). The practice in Kiel to sock mussels largely increased the production in kg/m substrate. But this result is not really comparable to the other studies, as mussels were first harvested, then socked, and the length of the original seed collectors were not reported. References: Engman 2009, Wennström and Engman 2014, Lindahl 2012, Olofsson et al 2014, result from harvest 2016 of the Västervik farm, Henning and Åslund 2012, Sami Alias 2014, Schröder et al 2014, Bucefalos project 2015, Moltke Lyngsgaard et al 2017

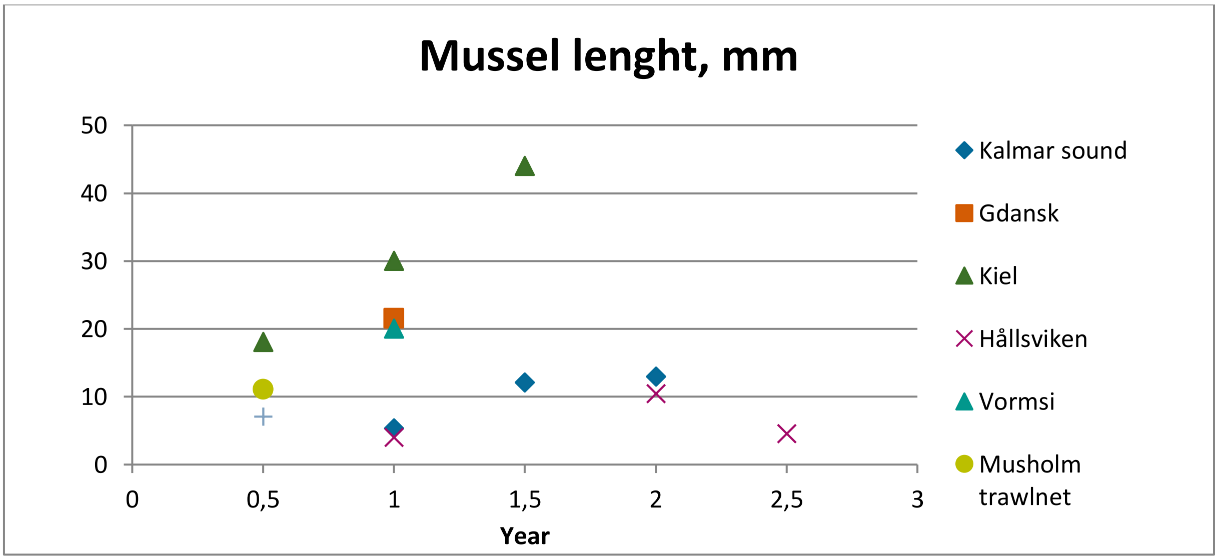


Figure 16: Size of mussels, expressed as average length of mussels from farm samples. The results reflect a combination of factors: 1: the mussel population in each sample averages different size classes, and 2: mussel growth rate and mean size vary greatly from site to site depending on environmental factors, such as salinity, temperature, current and food availability. References: Lindahl 2012, Sami Alias 2014, Schröder *et al* 2014, Urmas Pau pers. comm., Moltke Lyngsgaard *et al* 2017

Discussion and conclusions

Bottle necks for mussel production in the Baltic

Main bottle necks for the Baltic Sea mussel production identified by the pilot studies in this review are the low salinity resulting in slower growth and smaller mussel size, the lack of market for most part of the Baltic Sea and, as result, the lack of infrastructure such as suitable boats and places to process the mussels.

Choosing a site

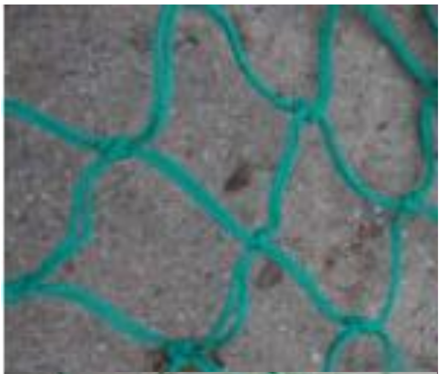
Many studies have concluded that the most important decision is choosing the right site. To place the large scale mussel farm in Åland at Synderstö, Kumlinge turned out to be a good choice. This decision was based on expert recommendations, a pre-study and pilot farming (Engman 2009, Granholm 2012). Kieler Meeresfarms is another example of a good site. Although the Kiel fjord brings about challenges such as limited space, exploitation and shipping, the biological conditions for mussels are superior with moderate steady current and high nutrient levels. Less successful choices have been made for example in the Kalmar sound and Öresund. Even though pilot studies were carried out in both areas, results were inconclusive and the shortcomings in production were largely a result of loss of equipment (Nielsen *et al* 2008, Förstudie till blåmusselodling i Öresund 2015). Many of the early pilots failed because they underestimated the forces of currents, waves and ice. A more exposed site could work if you have good anchoring, enough flotation and no loose lines that could get entwined. In Öresund the trials with submerged farms showed that new designs can be a way forward (Design of full scale blue mussel cultivation site in Öresund (2015). But the problem remains with exposed sites, that even if smart technology can keep the farm still at the site, it is not certain that the mussels will stay on the substrate. A pattern of success at protected vs exposed sites can be seen in the results from settlement studies conducted in Öresund, Kalmar sound, St. Anna and Hanko archipelago (Henning and Åslund 2012, Diaz and Kraufvelin 2013, Olofsson *et al* 2014, Hvitlock 2015,). In the sounds, the most protected sites showed the best settlement, while in the archipelagos, the medium exposed sites showed the best settlement. Although the studies have used different criteria to index sites as "exposed" vs "sheltered", a common recommendation from all studies must be to avoid the most exposed locations to maximize settlement. But settlement is not the same as production. When the submerged pilot farms in Malmö resp. Lomma were harvested after 2,5 years, the site that had highest current (Lomma) turned out to have both the higher biomass and largest medium size of mussels. Current is not the only factor determining exposure, but it is interesting that in this case, the production was better at the site with stronger current (Förstudie till blåmusselodling i Öresund 2015). In the settlement study from Kalmar sound, mussel biomass but also biomass of competing organisms was generally higher at the sheltered sites (Olofsson *et al* 2015). Had the experiment not been terminated after 6 months, it is possible that competition from other organisms would have limited the mussel production at those sites. Apart from finding a moderately exposed site with not too many competing species, it is important to have a reasonably close distance to harbor. It is expensive to spend maybe 2 hours of a workday just going to and from the farm. Also, the water depth in the harbor should be enough to enable the occasional use of bigger boats to harvest and maintain the farm. In other sea areas, an important factor to consider when choosing a mussel farm site is nutrient level (Bergström *et al* 2015). An enigma when it comes to Baltic mussel farming is that sites like the Great Belt, Öresound and Kalmar sound have very high populations of wild blue mussels, but they don't seem to get particularly high production on mussel farms. Perhaps it can be concluded that dominance of blue mussels in the natural environment is *not* a particularly good indicator of a good mussel farm site. The huge mussel banks of the sounds could result from slow and gradual colonization, in a harsh environment where the mussels have had few competitors.

Substrates

From all the studies that have compared different substrates, there is no clear pattern to be observed from the data. Thörring, 2008 concluded from the substrate study in Limfjorden that 1) site had more importance than substrate, and 2) many competing factors such as biofouling, varying strength of byssus threads of the mussels, intraspecies competition (the phenomena when clumps of mussels fall off the substrate because small mussels settle on the older ones and compete for space) can impact on the results. So even after many trials it is difficult to give any straight-forward recommendations about best substrate to use in the Baltic Sea. For complementary information on experience from other sea-areas, the summary table “Overview of global off-bottom mussel culture technologies” is recommended (Bonardelli, 2013 pg. 9). A remark by Bonardelli 2013 is that a very important factor to think about when choosing substrate is how it should be harvested.

Tabel 2: Overview of some different substrates used in mussel-farm trials from the Baltic Sea, and their potential capacity to produce mussels based on results from these studies

	Ropes of various material (polyester, polypropene, polyethylene) and thickness have been used for many mussel farm trials in the Baltic Sea. Unfortunately, results have not always been reported in a way that allows comparison between studies. In this limited selection the best production on ropes, 1.5 kg/m after 3 years, was shown in the study in Gdansk. They used single ropes that were mounted from the bottom-up and thus protected from wave-impact. (Henning and Åslund 2012, Sami Alias 2014, Olofsson *et al* 2014, Hvitlock 2015).
	Trials in Kalmar sound and Öresund reported technical difficulties with seed collector bands (or Swedish bands) because the bands were getting entangled in each other (Nielsen *et al* 2008, Design of full scale blue mussel cultivation site in Öresund 2015). Kalmar sound and St. Anna reported bad settling at seed collector bands (Henning and Åslund 2012, Olofsson *et al* 2014). In contrast, in a comparative study of many different substrates by Thörring 2008 in Limfjorden, Swedish bands showed good settling results. Also from the Kiel fjord, Rössner 2013 showed satisfactory settling and growth on seed collector bands. Swedish bands are known to work less good in strong currents, which could explain the lack of success in Kalmar sound (J. Bonardelli pers comm). Also, Baltic Sea blue mussels are known to have weaker byssus threads than mussels in more saline waters, which might have lowered their ability to attach to the collector bands in St. Anna and Kalmar sound. Because of the collector bands smooth surface, they might work better in more saline waters where mussels have strong byssus threads.

	Plastic mesh strips, specially manufactured for mussel farming, showed good performance in the pilot studies in Kumlinge and St. Anna. (Engman 2009, Henning and Åslund 2012).
	Nets made of polypropen-polymer rope. Mesh-sizes from 100-300 mm have been used. Rope nets in general have shown poor production compared to other substrates in the studies covered by this review, when the data is normalized to kg/m rope. (Lindahl 2012, Wennström and Engman 2014, Moltke Lyngsgaard *et al* 2016).
 	Trawl or fish-nets made by single or double knitted polyethylene rope showed good settlement in comparison to thicker ropes in studies from Musholm and Kalmar sound (Olofsson *et al* 2014, Moltke Lyngsgaard *et al* 2016). At Musholm, settlement and production was highest in a mesh with relatively small mesh-size (80 mm) and in Kalmar sound the double-knitted trawl-net showed best results. In the study in St. Anna by Henning and Åslund 2012, trawl nets showed poor settlement compared to ropes in the first year, but better settlement the second year. It was discussed if this was an effect of the plastic substrate getting more rough and easier for the mussels to attach to with age. Studies from both Öresund, St. Anna and Kalmar sound have reported problems with accumulation of algae in nets with a small mesh size (Nielsen et al 2008, Henning and Åslund 2012, Design of full scale blue mussel cultivation site in Öresund 2015,).

Timing of settlement

In the Baltic Sea and elsewhere, the peak of mussel spawning and settlement is determined by the timing of the phytoplankton spring bloom, which in turn depends on the temperature. It can vary from April (Kiel) to May (Great Belt) to June (Kalmarsound) to July (Åland). The timing will be different in different years, and there is often not one peak but several repeated events of mussel settlement during the summer. Purina 2013 wrote referring to an earlier study by Diaz *et al* that the species *Mytilus edulis*, *Mytilus trossulus* and the hybrids M. *edulis x trossulus*, all commonly referred to as "blue mussels" show differences in timing of spawning in experimental studies. *M.edulis* spawning was most often observed from February to May while the spawning time of *M.trossulus* was observed from May to September. In the hybrid *M. trossulus× edulis*, gonads in a spawning state were observed during most of the year. The best way to time the peak of spawning in mussels is to analyze the water for mussel larvae concentration. The substrate should be in the water for 2-3 weeks before settling in order to get the biofilm on the surface. In many cases it works well if the substrates are put out when the water temperature reaches 9-10 ^{o}C (van Deurs, pers. comm.)

Growth with Depth

Most studies from the Baltic Sea report that mussels show a good growth potential at 2-4m depth and that growth in the upper 0-1 meter is reduced, supposedly because of wave exposure in combination with other factors. The settlement study from Hanko reported most recruits at 2-4 m depth and fewer at 6m depth. On the Åland farm, by visual appearance the biomass on the nets increased with depth to the maximum depth of the farm, 4m. The study from Gulf of Gdansk reported that most biomass grew at 3 - 6 m depth (closest to surface in this study) and then markedly decreased with depth down to 10 m. In the Musholm study, there was no statistical difference in biomass between the top (0) or bottom (3m) samples, so that study does not fall into the pattern reported from other sites. In areas of the Baltic Sea where natural populations of mussels dominate, they typically thrive on 3-7 m depth (Weijola 2011). Biological inventories report mussels at depths down to 20 -30m (Kautsky 1982). Many studies have reported that mussels grow faster on mussel farms ropes close to the surface than what they do in their natural bottom habitats, because there is more light and therefore more production of food for the mussels

Harvest method

Mussel harvest from the Baltic Sea have been done with an elevator and stripper from the longline farms, specially designed Smartfarm/Easyfarm harvesters at Åland and Musholm, and other projects with net-farms have used various methods where the substrates have been lifted over containers and the mussels manually flushed or brushed off. Because of limited long term experience, cost evaluation and very different farm designs, it is not possible to recommend any particular harvest method from these reviewed projects. For developing harvesting techniques it is important to think about capacity. Lines can be harvested in a simple way, while the nets requires more advanced and larger machinery that can only be cost-effective if the harvests are big.

If the harvest is a major event, factors like present water level, harbor facilities, crane lifting capacity and alternative back-up solutions (rental equipment and service providers) should be checked in advance.

When to harvest

If harvest should be done within 1, 2 or 3 years growth-cycle, and whether it should be done in the autumn or the spring, has been discussed. Because nutrient uptake and animal feed are the two most predicted niches for future Baltic Sea mussel farmers, the common practice for mussel farmers in food production to harvest continuously will be left out from this discussion. It the purpose is to harvest for nutrient uptake, but with a quality so that the mussels could be processed to animal feed, one have to consider the following factors: Total biomass, meat content, toxic algal blooms and bacteria. At Vormsi, the seasonal weather is also a factor taken into account.

A seven month growth cycle May/June-Nov/Dec has been suggested for the more saline areas of the Baltic Sea (Nguyen 2013). The reason to harvest just before the winter would be to avoid losing mussel biomass and equipment due to ice and winter storms. The data in Figure 16 show that mussels reach approximately the same medium size after 6 months at Musholm as they do after 18 months in the Kalmar Sound. From this pattern, also confirmed by many other studies, a 1 year growth cycle for “western”, and a 2 year growth cycle for “eastern” Baltic mussels could be suggested. Not many studies have followed mussel production in the Baltic Sea for more than 2,5 years, but the trials in Öresund and Hållsviken indicate that there is no gain in biomass or size from leaving the mussels out to grow for more than 2 years, at least not with the methods tested (Figure 15 and Figure 16). Generally if mussels are not socked, there is a risk to loose biomass and large mussels due to the competition and crowding from small mussels (Thörring 2008). The meat content of Baltic mussels is high in Nov, Dec and April/May, and they have their highest meat/shell ratio just before spawning (Kautsky 1982b). In wintertime, they starve and they can lose up to 80% of their meat weight, but with the spring bloom in Mar-Apr they quickly catch up in meat content. After spawning they continue to grow in size and biomass, but in proportion, the mussel will increase shell length and weight more that they will increase their meat weight during the summer and autumn. In an old study from 1972-73, Kautsky showed that 20-25 mm mussels captured in Apr-May had the same meat weight as 30-35 mm mussels captured from standard conditions outside of the reproductive period (Kautsky 1982b). Thus, it can be concluded that even if the harvest could increase in biomass and mussel size until autumn, the nutrient uptake per harvest biomass will be greater in spring. With harvest in spring and then re-settlement of the substrates, a full year of production is gained. So the trade-off between nutrient uptake, time and work-effort between spring vs. autumn harvest in the eastern parts of the Baltic Sea should be evaluated.

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Interreg Baltic Sea Region

EUROPEAN REGIONAL DEVELOPMENT FUND

EUROPEAN UNION

Baltic Blue Growth

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 Center VCO (SE)*
- *Kalmar municipality (SE)*
- *Kurzeme Planning Region (LV)*
- *Latvian Institute of Aquatic Ecology LIAE (LV)*
- *Maritime Institute in Gdańsk (PL)*
- *Ministry of Energy, Agriculture, Environment and Rural Areas (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 Tartu (EE)*
- *Coastal Research and Management (DE)*
- *Orbicon Ltd. (DK)*
- *Musholm Inc (DK)*
- *Coastal Union Germany EUCC (DE)*
- *Swedish Institute of Agricultural and Environmental Engineering JTI (SE)*